UNIVERSITY OF NEVADA-RENO

NEVADA BUREAU OF MINES AND GEOLOGY

BULLETIN 101

GEOLOGY OF ELKO COUNTY, NEVADA

ROBERT R. COATS
U.S. Geological Survey

Prepared in cooperation with the U.S. Geological Survey

1987

A comprehensive report on the stratigraphy and tectonics of Elko County. A full-color, 1:250,000-scale geologic map is included.

UNIVERSITY OF NEVADA SYSTEM

Board of Regents

Daniel J. Klaich, *Chairman*

Mr. James Eardley
Mr. Joseph M. Foley
Mrs. Dorothy Gallagher
Chris Karamanos
Mrs. Joan Kenney
Mrs. JoAnn Sheerin
Mrs. Carolyn M. Sparks
Mrs. June Whitley

Robert M. Bersi, *Chancellor*

UNIVERSITY OF NEVADA-RENO

Joseph N. Crowley, *President*

MACKAY SCHOOL OF MINES

James Taranik, *Dean*

NEVADA BUREAU OF MINES AND GEOLOGY

John Schilling, *Director/State Geologist*
Larry J. Garside, *Chief Geologist*[1]
Susan L. Tingley, *Deputy to the Director*[1]

INFORMATION SERVICES
Keryl Fleming, *Geologic Computer Specialist*[1]
Ron Hess, *Geologic Information Specialist*
Arlene Kramer, *Sales Manager*
Becky S. Weimer, *Geologic Information Specialist*
David Davis, *student assistant*[1]
Heidi Lohn, *student assistant*[1]

LABORATORY SERVICES
Paul J. Lechler, *Chief Chemist/Geochemist*
Mario Desilets, *Assistant Chemist*
vacant, *student assistant*[1]
John Foss, *Mineral Preparator/Shop Mechanic*

CLERICAL SUPPORT
Dorene E. Camp, *Receptionist*
Ann E. Dalbec, *Business Manager*
Rose Newton, *Account Clerk*[1]

PUBLICATION SUPPORT
Susan L. Tingley, *Publication Manager/Cartographer*
Rayetta Buckley, *Composition/Paste-up Artist*
Larry Jacox, *Geologic Cartographer*
Mati A. Stephens, *Publication Assistant*[1]
Michael Tracy, *Drafting Assistant*[1]
Richard Meeuwig, *Geologic Editor*

BASIC GEOLOGY, GEOCHEMISTRY, & GEOPHYSICS
Harold F. Bonham, Jr., *Geologist*
John Erwin, *Geophysicist Emeritus*[2]
Liang-Chi Hsu, *Geochemist*[1]
Trowbridge Grose, *Geologist/Research Associate*[1,2]
David Weide, *Geologist/Research Associate*[1,2]

ENGINEERING & URBAN GEOLOGY
John W. Bell, *Engineering Geologist*
James G. Rigby, *Engineering Geologist*

MINERAL-RESOURCES GEOLOGY
Larry J. Garside, *Energy-Resources Geologist*
Richard B. Jones, *Metal-Resources Geologist*
Keith G. Papke, *Industrial-Minerals Geologist Emeritus*[2]
Joseph V. Tingley, *Economic Geologist*
Daphne D. LaPointe, *Geologist*[1,2]
Jack Quade, *Geologist*[1,2]
vacant, *Industrial-Minerals Geologist*

COOPERATIVE PROGRAMS
U.S. Bureau of Mines
mineral statistics & activities
Fred V. Carrillo, *State Liaison Officer*[2]
U.S. Geological Survey
Geologic Division
geology and mineral resources
National Cartographic Information Center
National Mapping Division
Eugene S. Faust, *State Resident Cartographer*[1,2,3]
Water Resources Division
Dave Wood, *Hydrologist*[2,3]
Nevada Department of Minerals
oil & geothermal drilling samples, logs, and other data
New Mexico Bureau of Mines and Mineral Resources
Isochron/West—Journal of Isotopic Geochronology

[1]part time
[2]non-state funded
[3]stationed at NBMG

Editing: Dick Meeuwig
Graphics: Susan Tingley and Larry Jacox
Typesetting:
By: Rayetta Buckley
At: Nevada Bureau of Mines and Geology
On: Compugraphic EditWriter 7770
Text: English Times, 10 pt.
Heads: English Times Bold, 12 pt.
Paste-up: Rayetta Buckley

Printing:
First edition, second printing, 1991
Copies: 2000
By: A. Carlisle
1080 Bible Way, Reno, NV
Stock, cover: Gainesborough by Simpson Paper, Sand, 80 lb.
Stock, text: Zellerbach Lustro Offset Enamel Book, Dull, Cream, Basis 80
Ink, cover: Pantone 469
Binding: perfect-bound

For sale by the Nevada Bureau of Mines & Geology, University of Nevada, Reno, NV 89557-0088.

NEVADA BUREAU OF MINES AND GEOLOGY

BULLETIN 101

GEOLOGY OF ELKO COUNTY, NEVADA

ROBERT R. COATS

1987

CONTENTS

ABSTRACT 5

INTRODUCTION 5
- Geography 5
  - Access 6
- Climate 7
- Vegetation 7
- Previous work 7
- Present work 7
- Acknowledgments 8

STRATIGRAPHY OF ELKO COUNTY 8
- Introduction 8
- Stratified rocks, not regionally metamorphosed 8
  - Introduction 8
  - Late Proterozoic Era 9
    - McCoy Creek Group [Ꝑmc] 9
  - Paleozoic Erathem 10
    - Western assemblage 10
      - Ordovician, Silurian, and Devonian Systems 10
        - Mudstone, shale, chert, siltstone, gray quartzite, greenstone, and minor limestone [DOs] 10
        - Limestone [DOsl] 12
      - Devonian System 13
        - Woodruff Formation [Dw] 13
    - Eastern and transitional assemblages 13
      - Cambrian System 13
        - Prospect Mountain Quartzite [Ꞓpm] 13
        - Carbonate rocks and minor quartzite [Ꞓc] 15
        - Carbonate rocks, minor quartzite, and phyllite [Ꞓc] 16
      - Cambrian and Ordovician Systems 17
        - Shale, phyllite, and limestone [OꞒs] 17
      - Ordovician System 17
        - Pogonip Group (Lower and Middle Ordovician) [Op] 17
        - Eureka Quartzite (Middle Ordovician) [Oe] 19
        - Aura Formation [Oa] 20
      - Ordovician and Siluran Systems 20
        - Predominantly dolomitic rocks [SOd] 20
        - Hanson Creek Formation [SOh] 21
      - Silurian and Devonian Systems 22
        - Lone Mountain Dolomite [DSlm,DSd] 22
        - Roberts Mountains Formation [DSrm] 23
      - Devonian System 24
        - Sevy, Simonson, and Nevada Formations [Dd] 24
        - Platy siltstone, limestone, and shale [Dt,Dl] 27
        - Guilmette and Devils Gate Formations [Dgd] 27
      - Ordovician, Silurian, and Devonian Systems 27
        - Dolomitic rocks [Dod] 27
      - Devonian and Mississippian Systems 28
        - Joana Limestone and Pilot Shale [MDjp] 28
      - Mississippian(?) System 28
        - Grossman Formation [MDg] 28
      - Mississippian System 29
        - Tripon Pass Limestone [Mtp] 29
        - Webb Formation [Mw] 29
        - Argillite of Lee Canyon [Ma] 29
        - Banner Formation [Mbn] 29
        - Nelson Formation [Mbn] 30
        - Chainman Shale [Mc] 31
        - Mountain City Formation [Mc] 31
        - Sedimentary clastic and limy rocks [Ms] 31
      - Mississippian and Pennsylvanian Systems 31
        - Introduction 31
        - Diamond Peak and Chainman Formations, undivided [ℙMdc] 31
        - Diamond Peak Formation [ℙMdp] 34
      - Pennsylvanian System 34
        - Moleen and Tomera Formations, undivided [ℙcd] 34
        - Ely Limestone [ℙe] 35
        - Quilici Formation [ℙq] 36
        - Van Duzer Limestone [ℙvd] 36
      - Pennsylvanian and Permian Systems 36
        - Undivided limy rocks [ℙPu] 36
        - Limestone and dolomite [ℙPl] 37
        - Strathearn Formation [ℙPs] 37
        - Carlin sequence (amended) [ℙPcs] 38
      - Permian System 39
        - Pequop Formation [Pp] 39
        - Arcturus Formation [Pp] 40
        - Loray Formation [Pp] 40
        - Unnamed bioclastic limestone [Pbl] 40
        - Park City Group [Ppc] 40
          - Grandeur Formation [Ppcg] 42
          - Murdock Mountain Formation [Pgp] 42
          - Gerster Formation [Pgp] 42
          - Murdock Mountain(?) and Gerster Formations, undivided [Pgp] 42
        - Phosphoria Formation [Pph] 43
          - Meade Peak Phosphatic Shale and Rex Chert Members 43
      - Mississippian, Pennsylvanian, and Permian Systems 43
        - Limestone, shale, chert, orthoquartzite, and quartz siltite [PMl] 43
        - Chellis and Storff Formations [PMl] 44
    - Paleozoic and Mesozoic rocks deposited west of the Antler orogenic belt after the Antler orogeny 45
      - Mississippian and Pennsylvanian Systems 45
        - Schoonover Formation [ℙMs] 45
      - Pennsylvanian System 45
        - Mitchell Creek Formation [ℙmc] 45
      - Pennsylvanian(?) and Permian(?) Systems 45
        - Havallah and Reservation Hill Formations [ℙPhr] 45
      - Permian and Permian(?) Systems 46
        - Sandstone and siltstone of Horse Mountain [Phm] 46
      - Permian System 46
        - Edna Mountain Formation [Pem] 46
      - Permian and Triassic Systems 47
        - Marine conglomerate [ℝPc] 47
        - Sedimentary and volcanic rocks [ℝPs] 47
  - Mesozoic Erathem 48
    - Rocks deposited within and east of the Antler orogenic belt 48
      - Triassic System 48
        - Marine sedimentary rocks [ℝs] 48
      - Triassic and Jurassic Systems 49
        - Nonmarine sedimentary rocks [JℝS] 49
      - Jurassic System 50
        - Frenchie Creek Rhyolite [Jf] 50
      - Cretaceous System 50
        - Newark Canyon Formation [Knc] 50
  - Cenozoic Erathem 50
    - General discussion 50
    - Tertiary(?) and Tertiary rocks 51
      - Volcanic rocks 51
      - Lower Tertiary rocks 51
        - Conglomerate [Tc] 51
        - Sedimentary rocks [Ts_1] 54
        - Cherty limestone [Ts_1] 55
        - Limestone [Ts_1] 55
        - Elko Formation [Ts_1] 55
        - Phenorhyolitic to phenodacitic ignimbrite [Tt_1] 55
        - Latitic rocks [Tl] 57
        - Andesitic to latitic flows and pyroclastic rocks [Ta_1] 57
        - Rhyolitic to dacitic flows and domes [Tr_1] 58
        - Tuff, sedimentary rocks, and lava [Ttsl] 58
      - Middle Tertiary rocks 58
        - Gravel [Tg_2] 58
        - Welded tuff and sedimentary rocks [Tw] 59

CONTENTS (continued)

Indian Well Formation [Tw,Ts_2] 59
Tuffaceous and clastic sedimentary rocks [Ts_2] 59
Phenorhyolitic and phenodacitic tuff, flows, and domes [Tr_2] 59
Phenoandesitic and phenolatitic flows and pyroclastic rocks [Ta_2] 60
Basalt, basaltic tuff, and tuff breccia [Tb_2] 61
Phenorhyolitic to phenodacitic ignimbrite [Tt_2] 61
Upper Tertiary rocks 62
Jarbidge Rhyolite [Tjr] 62
Landslide deposits [Tls] 62
Gravel [Tg_3] 62
Sedimentary and volcanic rocks [Ts_3] 62
Ignimbrite, tuff, and sedimentary rocks [Tts] 63
Basalt [Tb_3] 65
Big Island Formation [Tbi,Tb,Tbc] 65
Pyroxene and hornblende phenoandesite and phenodacite, and pigeonite phenoandesite [Ta_3] 66
Pyroxene phenodacite ignimbrite [Tt_3] 66
Breccia [Tbx] 67
Phenorhyolitic and phenodacitic flows and domes [Tr_3] 67
Porphyritic phenorhyolitic and phenodacitic flows and domes [Tpr] 67
Tertiary and Quaternary Systems 69
Hot-spring travertine and sinter [QThs] 69
Sedimentary rocks [QTs] 69
Older alluvium [QTa] 70
Quaternary System 70
Alluvium [Qa] 70
Glacial moraines and rock glaciers [Qg] 71
Landslide deposits and colluvium [Qls] 71
Pluvial lake deposits [Qp] 72
Plutonic rocks 73
Jurassic and Jurassic(?) plutons [Jgr,Jd] 74
Cretaceous and Cretaceous(?) plutons [Kgr] 75
Cenozoic plutonic rocks 76
Early Tertiary plutons [Tgd] 76
Alaskitic granite [Tgr] 77
Regionally metamorphosed rocks 77
Late Proterozoic(?) schist [Ꝑs] 77
Late Proterozoic Era and Cambrian System 77
Foliated metaquartzite [ЄꝐq] 77
Cambrian and Ordovician Systems 77
Calcite marble [OЄm] 77
Ordovician System 78
Metaquartzite [Oem] 78
Cambrian(?), Ordovician(?), Silurian(?), and Devonian(?) Systems 78
Dolomite marble [DOm,DЄm] 78
Devonian System 78
Graphitic marble [Dm] 78
Metamorphic rocks 78
Proterozoic(?) Eonothem, and Cambrian(?), Ordovician(?), Silurian(?), and Devonian(?) Systems [DꝐm] 78
Mesozoic Erathem 79
Gneiss [Mzgn] 79
Proterozoic and Phanerozoic Eonothems 79
Migmatite [m] 79

TECTONICS 79
Introduction 79
Late Proterozoic and Early Cambrian orogeny 79
Ruby disturbance 80
Tooele arch 80
Early Mississippian orogeny 80
Antler orogeny 80
Early Mississippian to Middle Pennsylvanian uplift and downwarp 83
Humboldt disturbance (Humboldt orogeny of Ketner, 1977) 84
Late Paleozoic to late Mesozoic orogenies 84
Post-Early Triassic deformation 87
Sonoma orogeny 87
Mesozoic orogenic movement in eastern Elko County 88
Origin of convergent directions of thrusting 91
Trail Gulch fault 95
Direction of Mesozoic movement in southwestern Elko County 95
Wells fault 97
Oroflexural bending 98
Cenozoic tectonics 98
Dolly Varden cryptoexplosion structure 98
Joana Limestone 98
Early Cenozoic compressional tectonics 99
Post-Oligocene(?) thrusting 99
Early Tertiary extensional tectonics 100
The Ruby-East Humboldt metamorphic core complex 100
Late Tertiary extensional tectonics 101
Basin-and-range faulting 101
Tilting of the Basin and Range province 102
Oregon-Nevada lineament 102
Quaternary faulting 102
Sagging 103

BIBLIOGRAPHY 103

INDEX OF STRATIGRAPHIC UNITS 112

PLATE (in pocket)
Geologic map of Elko County, Nevada

FIGURES
1. Map of Elko County, showing locations of certain geographic features mentioned in text 4
2. Index to U.S. Geological Survey topographic maps of Elko County that were available April 1979 6
3. Chart illustrating variations in stratigraphic nomenclature used in mapping of Mississippian, Pennsylvanian, Permian, and Triassic rocks of Elko County 32–33
4. Plot of the sums of alkali oxides against silica content, in weight percent, for 71 analyzed volcanic rocks from Elko County and adjacent areas 52
5. Plot of Niggli **k** value against weight percent of silica, normalized to 100% total, for 71 analyzed Tertiary volcanic rocks from Elko County and adjacent areas 53
6. Miocene rhyolitic domes in southwestern Elko County and vicinity 68
7. Triangular diagram plotting quartz/potassium feldspar/plagioclase modal ratios for certain plutonic rocks of Elko County. See table 1 for identification of samples 73
8. One of the earliest maps showing the approximate position of the Antler orogenic belt in Elko County (Roberts and others, 1965, fig. 4) 82
9. Some approximate tectonic boundaries in Elko County 85
10. Sketch map showing directions of movement on late Paleozoic and Mesozoic thrust faults in Elko County. Tip of arrow denotes point of observation 92
11. Time-sequential sketch map illustrating the hypothesis that the presence of Paleozoic eugeosynclinal rocks in northern Elko County is the result of about 75 mi of right-lateral displacement on an east-northeast-trending fault in southern Owyhee and Twin Falls Counties, Idaho 93
12. Time-sequential series of diagrammatic north-south cross sections through Mountain City, Nevada to the Strike Reservoir near Bruneau, Idaho, illustrating the sequence of geologic events proposed to explain the seismic layering shown by Hill and Pakiser (1967, fig. 5) 94

TABLE
1. Modal composition of some plutonic rocks in Elko County and vicinity determined by point counting 74

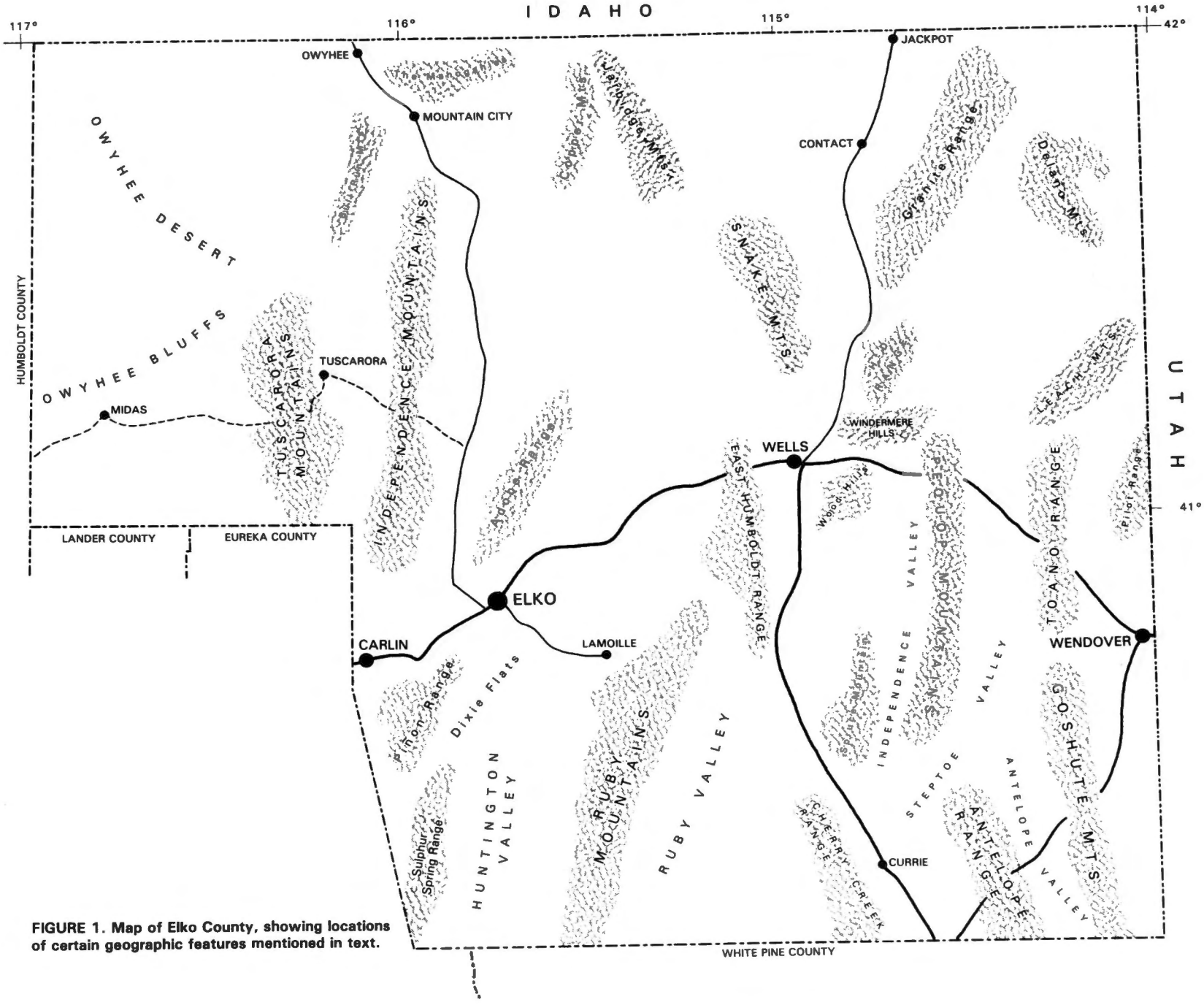


FIGURE 1. Map of Elko County, showing locations of certain geographic features mentioned in text.

ABSTRACT

The known geologic history of Elko County is long and complex. The oldest rocks, more than 600 m.y. old, are of Late Proterozoic age; they have been recognized in the Ruby Mountains and the East Humboldt Range, in the Pilot Range, and near Copper Mountain in the Jarbidge mining district. Rocks of each of the Paleozoic systems are widely distributed in Elko County; because of the great expanse of territory, significant lateral changes in thickness and lithology occur in the rocks of each of these systems. Rocks of Triassic age are the youngest of the great thickness of marine rocks in Elko County; sometime during the Early Triassic the sea withdrew from Elko County for the last time. Continental rocks of Triassic(?), Jurassic(?), and Cretaceous age are distributed sporadically in the county.

The crust of the earth in Elko County has undergone gradual uplift and sinking as well as intense deformation many times during the decipherable geologic history, beginning before the middle of the Early Cambrian, and continuing to the present. One of the most significant tectonic events was movement on the Roberts Mountains thrust, which climaxed during the Early Mississippian and resulted in the movement eastward, from a source west of Elko County, of silicic and volcanic rocks originally deposited on the ocean floor. Similar rocks in southern Idaho have been moved eastward even greater distances; the boundary between the two crustal blocks is believed to be a major east-west-trending wrench, or transcurrent fault, the Owyhee rift, which now is buried beneath the lava plateau of Owyhee and Twin Falls Counties, Idaho. Repeated relative eastward movement of thrust plates during later Paleozoic and Mesozoic time carried younger Paleozoic and Triassic rocks into northern Elko County; some rocks of similar provenance in the southern Idaho block were remobilized and moved southward into northern Elko County.

Plutonic rocks, ranging in age from Jurassic to late Tertiary and mostly of silicic to intermediate composition, are widely distributed in Elko County. The oldest recognized plutons are Jurassic; these Jurassic plutons generally are both smaller and less silicic than the Cretaceous plutons, whose geographic distribution overlaps that of the Jurassic plutons. The Jurassic plutons range in composition from diorite to granodiorite, and the Cretaceous plutons range from granodiorite to granite; smaller masses of more extreme composition may also be present. Cooling ages of the Tertiary plutons are concentrated in the period 40–34 m.y. Most of the Tertiary plutons are porphyritic; the groundmasses of many are cryptocrystalline—one conspicuous exception is the coarse-grained Harrison Pass pluton. Nearly all the Tertiary plutons seem to be granodioritic to quartz monzonitic in composition; however, a dioritic phase is reported from Lone Mountain. A single small Miocene pluton is genetically and spatially associated with the Jarbidge Rhyolite; this pluton is characterized by a highly silicic composition and extraordinary contrasts in both mineralogy and grain size.

Pervasively and, presumably, regionally metamorphosed rocks occur principally in the Ruby and Pequop Mountains and the East Humboldt Range, and in the Wood Hills. In the Wood Hills, metamorphism occurred in two phases: a synkinematic phase during which rocks reached the kyanite-staurolite zone, and a postkinematic phase representing recrystallization that continued after penetrative deformation had ended. Metamorphism in the core of the Ruby Mountains reached the sillimanite zone, and the rocks have been extensively migmatized, apparently during the Jurassic. Potassium-argon ages of metamorphic rocks of the Ruby Mountains, presumably reset, are as young as middle Tertiary, like those of the Harrison Pass pluton.

The oldest well-dated Tertiary sedimentary rocks, of Paleocene to Eocene age, occur in southern Elko County; they generally have coarse clastic textures. Other coarse clastic sedimentary rocks that may be as old are widely distributed in the county. These rocks are succeeded, in the southern part of the county, by fine-grained shale, sandstone, and limestone; at about the same time, in the northern part of the county, voluminous pyroclastic rocks of silicic composition were being erupted. From about 43 to 6 m.y. ago, the geologic record in northern Elko County is dominated by the eruption of volcanic rocks: ignimbrites produced by the eruption of numerous commonly voluminous hot debris-charged clouds; and quieter, less voluminous eruptions of exogenous domes of silicic rock, and flows and pyroclastic deposits produced by eruptions of intermediate and mafic composition. The local distribution of the deposits resulting from many of these eruptions may both reflect their small volume and be the result of their confinement by block faulting, which dissected the land area more or less concomitantly with the eruptions. Occasional pauses in eruptive activity permitted the accumulation of bodies of sedimentary rock, the coarseness of whose fragments suggests the continued presence of mountain ranges of diverse trend.

Since the close of volcanic activity, the forces of erosion, principally glacial and fluvial, have been ascendant; the products of erosion, though temporarily mantling much of the landscape, are being removed from the area by streams of the Humboldt River and Snake River drainage basins, or are coming to rest in the broad playa basins of southern and eastern Elko County.

INTRODUCTION

Geography

Elko County (fig. 1), the northeasternmost and second largest county in Nevada, comprises an area of 17,163 mi². It is the fourth largest county in the United States, after San Bernardino County, California; Coconino County, Arizona; and Nye County, Nevada. It exceeds in area each of the nine smallest of the United States. According to the 1980 census, the population of Elko County was 17,269. Elko, the county seat and its largest town, had a population of 8,758; it is also the largest town in northeastern Nevada. Two other towns, Carlin (pop. 1,232) and Wells (pop. 1,218), are, like Elko, on the main transcontinental lines of transportation. These three towns, together with a

few smaller towns, serve as centers for the local mining and ranching industries.

ACCESS

The county is crossed by two transcontinental railroads, the Southern Pacific Railroad and the Western Pacific Railroad, whose tracks run close together and are nearly parallel west of Wells but diverge eastward to take routes on opposite sides of Great Salt Lake. The Union Pacific Railroad tracks connect Wells with Twin Falls, Idaho, and the Nevada Northern Railroad serves Ely by a connection with the Southern Pacific at Cobre, Nevada.

In addition to the major highways of the federally aided system—Interstate Highway 80, U.S. Highways 40, 50 (alternate), and 93—several State highways connect the principal towns. Many minor roads are improved and maintained by the county, the U.S. Forest Service, and the U.S. Bureau of Land Management. The detailed topographic maps made by the U.S. Geological Survey that cover most of the county (fig. 2) show, in addition to the roads shown on the geologic map (pl. l), a multitude of minor roads and jeep trails that have been broken, improved, and maintained on the independent initiative of local residents, in whom the pioneering Nevada spirit is far from dead.

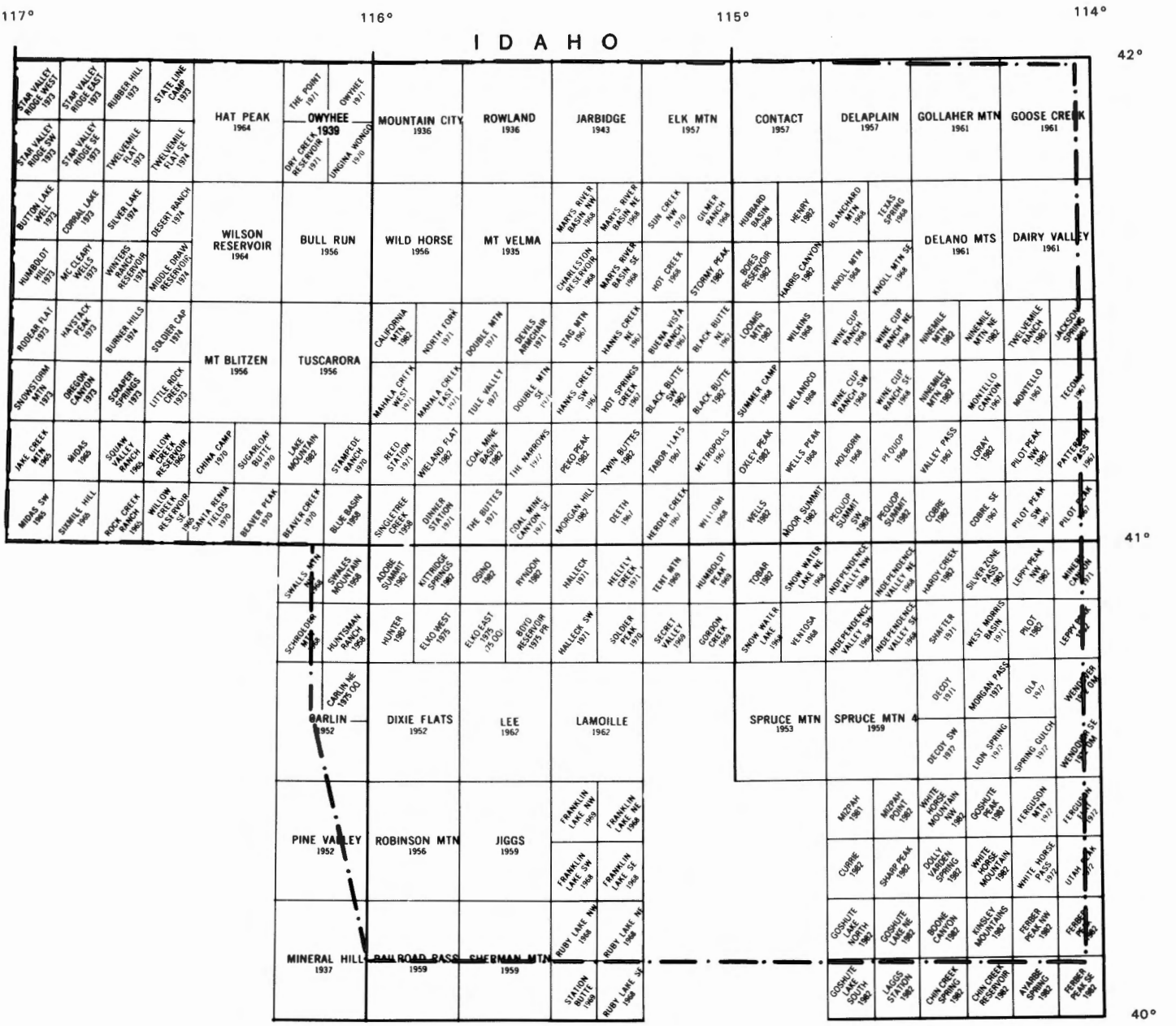


FIGURE 2. Index to U.S. Geological Survey topographic maps of Elko County that were available April 1979.

Elko County is one of the higher parts of Nevada; nearly the entire area is above 5,000 ft, and most of the valleys lie at elevations of more than 6,000 ft. The southern part of the county is characterized by the pattern of north-south-trending mountains and intervening alluviated valleys that is characteristic of most of Nevada; the extreme northwestern part is a plateau, largely underlain by young basalt flows and somewhat older ignimbrites. From the east edge of the Owyhee plateau, eastward to the Utah state line, a strip about 40 mi wide, best characterized as a complexly dissected upland, has many summits ranging from 8,000 to more than 10,000 ft in elevation (pl. 1). The disappearance in this strip of the linear north-south-trending ranges that are so prominent farther south is due not to the absence in this northern belt of the structures that originally outlined them—because these structures are indeed present—but rather to the dominance of fluvial dissection in this area, which lies within the drainage basin of the Snake River and has a lower base level of erosion than the area tributary to the Humboldt River. The intermontane valleys of the central part of the county are mostly drained by tributaries of the Humboldt River, and the Quaternary valley fill is being slowly removed; in the southeastern and extreme southwestern parts of the county, the basins are undrained and slowly aggrading.

Climate

The climate of Nevada was summarized by Brown (1960). In Elko County, summers are short and hot, and winters long and cold; the heat of summer is moderated by the elevation and is most noticeable in the basins at low elevations. The lowest recorded temperatures of winter are due to orographic ponding of cold air—the lowest temperature recorded (−50°F) was at San Jacinto, near Jackpot; the lowest mean temperatures tend to occur in some of the broad lowland areas. The lowest temperatures of summer are probably in the highest mountains but, because of an absence of recording stations, are not well known; the Jarbidge Mountains are one cold spot. Precipitation is strongly orographically controlled—the highest amount, about 20 in., falls on the highest mountains, the Jarbidge, Independence, and Ruby Mountains and the East Humboldt Range. It is not surprising that these are also the places where evidence of Quaternary glaciation is clearest and most extensive. The rain shadows to the east of each of these mountains are places of notably low precipitation. Mean annual temperatures generally range from 45 to 50°F.

Vegetation

The extreme range in elevation of the terrain of Elko County has resulted in the presence of numerous species of grasses, forbs, and shrubs. These plants are of great importance to the rancher; their distribution and means of identification were reviewed by Holmgren (1942). Trees are far more limited in number of species. Distributions of coniferous trees and a few hardwood trees in Elko County are shown on the distribution maps by Little (1971); these species include: white fir, subalpine fir, Utah juniper, Rocky Mountain juniper, Engelmann spruce (found in the East Humboldt Range only), whitebark pine, limber pine, bristlecone pine, singleleaf piñon, Douglasfir, boxelder, black cottonwood, and quaking aspen. Distributions of some minor western hardwoods that occur in Elko County are shown on the maps by Little (1976); these species include: Rocky Mountain maple, thinleaf alder, western and Utah serviceberries, water birch, curlleaf mountain mahogany, redosier dogwood, cliffrose, black hawthorn, narrowleaf cottonwood, common chokecherry, and several species of willow and elder.

The most widespread species of evergreen tree is probably the piñon pine, the nuts of which were formerly harvested regularly by the Indians. The oldest trees in Elko County are probably the ancient bristlecone pines of the southern Ruby Mountains; similar but younger trees of the same species are present as far north as Spruce Mountain. Subalpine fir was formerly logged for mine timbers in the Jarbidge area; white fir may also have been used locally. Alder, cottonwood, willow, aspen, and mountain mahogany have been used locally for fuel, and aspen has also been used for cabin construction; timber of two species of juniper has served for fence and corral construction.

Previous Work

As a perusal of the Bibliography will show, geologic work in Elko County has been continuing, with interruptions, for more than a century, commencing with the Fortieth Parallel Survey by King (1878). It would be superfluous to repeat here all the sources used for this report that are in the Bibliography and in the list on plate 1. The most recent previous general reconnaissance geologic map of Elko County was by Granger and others (1957, pl. 1), a black-and-white map on a planimetric base furnished by the Nevada Highway Department.

Present Work

Roger A. Hope began fieldwork for this report in eastern Elko County in the summer of 1966 and continued through the summer of 1973. A preliminary geologic map at a scale of 1:200,000 for the southeast two-thirds of the county, embodying the results of Hope's fieldwork and a compilation of other maps available to him, was published in 1970 (Hope, 1970). I commenced reconnaissance fieldwork in western Elko County for the county map in the summer of 1970 and continued through the field seasons of 1971 and part of 1972. I reexaminated some critical areas in 1973, 1974, 1975, 1977, 1978, 1979, 1981, and 1982. Hope resigned from the U.S. Geological Survey in 1974 and left a completed map of the southeastern part of the county, abstracted references, and field notes. A preliminary geologic map of the whole county was published at a scale of 1:100,000 by Hope and Coats (1976). The geologic map (pl. 1) accompanying this report shows essentially the same geologic boundaries as that of 1976, with a few minor modifications and considerable generalization in many places to make it more legible at the

reduced scale of 1:250,000. For this report, the geologic map was completely redrafted at publication scale by John E. Carlson, to whose patience and superb draftsmanship the map itself is sufficient testimonial.

Fossils collected during the course of fieldwork are described in a separate open-file report (Coats, 1986). Collection numbers mentioned in this Bulletin refer to that open file report.

Acknowledgments

It is a pleasure to acknowledge here the enormous amount of work done by paleontologists of the U.S. Geological Survey and their consultants on the fossils collected in the course of the mapping for this report, and for earlier studies in Elko County. A total of 29 paleontologists have contributed data; their names are listed here, approximately in the order of decreasing number of collections studied. A dagger precedes the names of those who died before the submission of this manuscript: †J. W. Huddle, R. C. Douglass, Mackenzie Gordon, Jr., B. R. Wardlaw, R. J. Ross, Jr., †Helen Duncan, A. G. Harris, O. L. Karklins, W. J. Sando, A. R. Palmer, I. G. Sohn, E. L. Yochelson, E. B. Leopold, R. E. Grant, J. T. Dutro, Jr., L. A. Wilson, A. J. Rowell, F. F. Krause, W. A. Oliver, Jr., John Pojeta, Jr., John Repetski, M. E. Taylor, †W. H. Hass, C. A. Repenning, W. B. N. Berry, †C. W. Merriam, N. J. Silberling, J. A. Wolfe, and K. E. Lohman. Special mention should be made of two, Mackenzie Gordon, Jr., and R. J. Ross, Jr., who more than once joined me in the work of collecting in the field. Without the contributions of these devoted scientists, completion of this report would have been very difficult if not impossible; my gratitude is inexpressible.

Robert Greene petrographically studied not only rocks from his area [19] but also some other rocks collected by our field party in 1972.

The ages of many of the plutonic- and volcanic-rock units in the county were determined by various geochronologists, whose work is specifically acknowledged in the descriptions of the several rock units. Most of this work was done by E. H. McKee, Zell Peterman, R. F. Marvin, and T. W. Stern.

The people of Elko County were friendly and hospitable to the mapping work of Hope and myself; few but natural obstacles restricted our access.

The contribution of two field assistants who worked with me in mapping the Mountain City 15′ quadrangle, Keith Howard and W. Suharsono, is acknowledged here because their work has not been elsewhere acknowledged. Leland Cress assisted in the mapping in 1970, 1971, and 1972. The compilation of the maps was materially assisted by the precision photography of Norman Prime, Lowell Kohnitz, and Christopher Utter.

The help of my late son, Tom Coats, whose sharp eyes contributed to the completeness of many fossil collections and whose cheerful company lightened many a weary mile of driving, must not go unrecorded.

The manuscript and geologic map were reviewed by Richard Hose, Keith Ketner, Maureen Sherlock, J. Fred Smith, Jr., John H. Stewart, and Charles Thorman, with beneficial results. None of the reviewers is to be held responsible for remaining errors of fact or differences of interpretation.

STRATIGRAPHY OF ELKO COUNTY

Introduction

The stratigraphy of Elko County comprises rocks ranging from Late Proterozoic to the Cenozoic. During the compilation of the previous work and the mapping by R. A. Hope, myself, and our field assistants for this report, it was decided—because many of the units convenient or necessary for mapping comprise rocks belonging to more than one formation, group, series, or system—to combine established units in various ways. The groupings used here differ from one part of the county to another; these groupings are shown in the legend for the geologic map (pl. 1). To facilitate reference to pertinent reports, descriptions of the stratigraphy of rock units in the several areas of the county are accompanied by bracketed numbers that correspond to those in the "Index to Sources of Geologic Mapping" (pl. 1).

Stratified Rocks, Not Regionally Metamorphosed

INTRODUCTION

For the purposes of this report, both the sedimentary rocks and the extrusive igneous or volcanic rocks are discussed together because at many times, particularly in the Tertiary, they are closely associated; thus, rocks of both groups are, in places, included within a single map unit. Late Proterozoic rocks have been recognized in a few places in Elko County; rocks of each of the Paleozoic systems have been mapped extensively in the county. Rocks of Cambrian to Late Devonian age were laid down in a broad, generally longitudinally trending geosyncline that probably occupied most of the area of the county. These rocks have been subdivided (Nolan, 1928, 1943; Nolan and others, 1956; Roberts and others, 1958) into two contrasting assemblages: an eastern or carbonate assemblage, and a western or siliceous and volcanic assemblage. The carbonate assemblage (eastern) comprises limestone, dolomite, quartzite, and shale; the siliceous and volcanic (western) assemblage comprises a more heterogeneous group of rocks in which chert and dark shale are commonest but that also includes quartzite (commonly dark), graywacke, basalt, diabase, some mafic pyroclastic rocks, and minor amounts of limestone.

At the beginning of the Antler orogeny, shortly after the close of the Devonian, the western assemblage was thrust eastward over the eastern assemblage along the Roberts Mountains thrust (Merriam and Anderson, 1942) and subsidiary thrusts. Internal deformation of the upper plate is severe in most exposures in Elko County. Nearly all the western assemblage in Elko County is known or thought to be allochthonous, that is, displaced from its original site of deposition by

movement on the Roberts Mountains thrust or subsidiary thrusts and, in some places, by movement on the Roberts Mountains thrust and by later thrusts of diverse directions of movement. In very few places have datable rocks been found overlapping any of the major thrusts in such a way that clear proof of the time of thrusting can be obtained. Although some thrusting as late as Early Pennsylvanian has been considered by some workers as a part of the Antler orogeny, most thrusting that involves rocks younger than Early Mississippian is here attributed to younger orogenies, chiefly the Sonoma and middle Mesozoic orogenies.

In addition to the eastern and western assemblages, a transitional assemblage having some of the characteristics of each of the other two has been recognized in many places. Locally, rocks assigned to this assemblage interfinger with the eastern assemblage. The transitional assemblage is discussed below with the eastern assemblage, which it resembles most closely and with which it is most closely associated geographically.

In certain areas, particularly the Ruby Mountains,the East Humboldt Range [33, 39, 39A, 45, 49A], the Wood Hills, and the Pequop Mountains [34], the eastern assemblage has been subjected to regional metamorphism, probably beginning in Mesozoic time, and has reached in places a medium to high metamorphic grade. These rocks are discussed separately from probable coeval rocks of the eastern assemblage in the section entitled "Regionally Metamorphosed Rocks."

After the Early Mississippian, the rising welt of the Antler orogenic belt was rapidly eroded, and clastic material of varying degrees of coarseness accumulated during the late Paleozoic, just east of the Antler orogenic belt. Presumably, clastic material also accumulated to the west of the orogenic belt; rocks of this age and origin may be present as allochthons in Elko County. Within the belt itself, detrital materials were mingled with limestone; to the east, in areas more remote from the orogenic belt, rocks poorer in coarse detrital material accumulated to considerable thicknesses.

Silurian rocks of the western assemblage have been recognized in comparatively few places [15, 21, 26, 29, 30]; they are not mapped separately in this report. Devonian rocks of the western assemblage have been recognized in still fewer places. One Devonian formation (the Woodruff Formation) was separately mapped by Smith and Ketner (1975) [43]; their description is used in this report.

The Mesozoic was a time when seas were generally retreating from the area, and most of the sedimentary rocks, except the Early Triassic marine rocks, were continental in origin. Some volcanic rocks foreshadowed the intense intrusive activity of the late Mesozoic.

The Cenozoic was dominated by volcanic activity, particularly in northern Elko County, although extensive areas in the southern part of the county also were covered by volcanic rocks. The Cenozoic rocks are here separated into age groups based on isotopic ages, insofar as these ages are known; the division boundaries coincide with those used by Stewart and Carlson (1974, 1978a, b). Some paleontologic data are also available on the Cenozoic rocks. The Cenozoic rocks are also separated on the basis of lithology.

The Quaternary units, and the Tertiary or Quaternary units, are here separated into groups on a lithologic basis. It has not proved feasible to subdivide either of these groups further by age for the purposes of this report, although such subdivision is shown on some of the detailed maps from which this report was compiled.

LATE PROTEROZOIC ERA

McCoy Creek Group [Pmc]

The McCoy Creek Group was defined and named by Misch and Hazzard (1962) for rocks in an area on the east slope of the Schell Creek Range in White Pine County, Nevada. In the Pilot Range [36], Woodward (1967) described a section of rocks approximately 3,300 ft thick that he correlated with the McCoy Creek Group of Misch and Hazzard (1962); this section includes five units that correspond, unit for unit, with those described by Misch and Hazzard. The lowest exposed unit in the Pilot Range, unit C, is 200 ft of green and gray spotted phyllite; the base is not exposed. The next unit, unit D, is about 535 ft of green slate, green coarse grit, and gray quartzite. The succeeding unit, unit E, is about 645 ft of green and blue-gray slate, gray quartzite containing minor green quartzite, and red quartz conglomerate. Unit F is 570 ft of gray quartzite and minor conglomerate overlain by 170 ft of gray quartzite and quartz conglomerate. Unit G totals 1,350 ft, of which 800 ft consists of green and gray slate and metasiltstone containing subordinate quartzite, and 400 ft of green and gray slate, metasiltstone, and argillite. Intercalated in this unit are two 75-ft-thick layers of laminated black-and-white marble that are quite distinctive in the Proterozoic section. The McCoy Creek Group in the Pilot Range is overlain disconformably by the Prospect Mountain Quartzite. The Pilot Range area has been mapped by Miller (1983).

In the Jarbidge area [6], Coats (1964) described Precambrian(?) rocks that are here regarded as equivalent to the McCoy Creek Group; these rocks are also exposed in the Rowland quadrangle [5] and in the Mount Velma quadrangle [13]. Principal rock types are thin-bedded quartzite and quartz-mica schist. The schists, generally muscovite and chlorite schists, locally biotitic, have also been thermally metamorphosed to andalusite hornfels and biotite-cordierite-staurolite hornfels in some places; in many places the andalusite, cordierite, and staurolite have retrogressed to mica and chlorite. The schist, quartzite, and hornfels rest in thrust contact on Prospect Mountain Quartzite. A depositional contact between the schist and quartzite unit and the overlying Prospect Mountain Quartzite is exposed on the north side of Copper Creek Canyon in the Marys River Basin NW quadrangle and in the Jarbidge quadrangle. The bedding in the quartzite in the Prospect Mountain Quartzite nearly parallels the bedding in the underlying schist and quartzite. The schist, quartzite, and hornfels are here regarded as Late Proterozoic. In the Ruby Mountains, in the Jiggs 15′ quadrangle [48], Willden and Kistler (1969) mapped small areas of schist in Dawley Canyon. According to K. A. Howard (oral commun., 1976), these rocks are probably the equivalent of the McCoy Creek Group.

The characteristics of the schist of Dawley Canyon are described more fully in the section entitled "Regionally Metamorphosed Rocks"; these rocks are highly metamorphosed in comparison with the rocks of the McCoy Creek Group found elsewhere in the county.

PALEOZOIC ERATHEM

Western Assemblage

Ordovician, Silurian, and Devonian Systems

Paleozoic rocks of the western assemblage in Elko County, for the purposes of this report, are largely grouped into a single unit on the geologic map (pl. 1) because of the difficulty of separating them in mapping at the scale adopted. Two Ordovician formations, the Vinini Formation and the Valmy Formation, are apparently the most widespread units in the western assemblage in Elko County. The name "Vinini Formation" was originally applied by Merriam and Anderson (1942) to rocks in the Roberts Mountains. The lower part of the Vinini, which is Early Ordovician, consists of quartzite, limestone, and calcareous sandstone and includes siltstone, shale, and minor amounts of andesitic flows and tuffs. The upper part of the Vinini, which is Middle Ordovician, is chiefly bedded chert and black shale, rich in organic matter. The Valmy Formation was named by Roberts (1949, 1951) in the Battle Mountain area; it differs from the Vinini in its higher proportion of massive quartzite, chert, and volcanic material. The Valmy is of nearly the same age as the Vinini (Roberts and others, 1958, p. 2833).

***Mudstone, Shale, Chert, Siltstone, Gray Quartzite, Greenstone, and Minor Limestone* [DOs].** The western assemblage is represented in the Owyhee 15′ quadrangle [3] by rocks that were originally attributed by Coats (1971) to the Valmy Formation. The rocks here are: micaceous quartz calcarenite and calcareous sandstone, locally in small lenticular masses containing phyllocarid shells; thin-bedded chert with slaty partings, ranging in color from white to dark gray, rarely black to grayish green, locally phosphatic or baritic; hard well-bedded micaceous siltstone and black quartzose phyllite; numerous irregular masses of greenstone, meta-andesite (now quartz-albite-chlorite schist), metagabbro, and diabase in which some of the original textures and some of the primary pyroxene and plagioclase are preserved; and micaceous phyllitic limestone, locally phosphatic. The most conspicuous rock type is gray to black and locally tan quartzite that is generally fine grained with interlocking textures and contains rare detrital tourmaline and zircon and, in the dark quartzite, black carbonaceous material.

In the adjacent Mountain City 15′ quadrangle [4] to the east, the same type of quartzite, which apparently was deposited as two distinct beds now somewhat tectonically dismembered, can be traced eastward from the quadrangle boundary for more than a mile to the contact with overlapping Tertiary volcanic rocks. The quartzite beds and interbedded phyllite and chert reappear near the east half of the Mountain City 15′ quadrangle as a much less distorted and tectonically deformed north-south-trending narrow band that is thrust, on the Roberts Mountain thrust, over the Goodwin Limestone of the Pogonip Group and has been intruded by Cretaceous granodiorite. To the north of this band of undisturbed outcrops, the Valmy and Grossman Formations are represented within imbricate thrust slices that make up most of the mass of Merritt Mountain.

The Valmy reappears again in the Rowland quadrangle [5], where Bushnell (1967, p. 14) mapped three units that he called Paleozoic A1, A2, and A3, which he stated may be either lateral equivalents, parts of the same formation that succeed one another, or completely unrelated. These three units consist of black quartzite, dark shale, minor amounts of coarsely crystalline gray limestone, and light and dark phyllite, schist, and chert. Other rock types besides argillite are dark-gray to black metamorphosed chert(?), greenschist, calc-schist, and altered flows. Some of the altered flows are light-colored, fine-grained rocks, possibly rhyolites; they are rich in quartz and feldspar.

In the eastern part of the Tuscarora 15′ quadrangle [21], Kerr (1962) mapped what he called the Seetoya sequence (part of the western assemblage of this report) and divided it into two members. The lower member consists of predominantly brown to black, thin- to medium-bedded chert that is commonly knobby and locally interbedded with brown laminated quartz siltite; impure dark-gray calcisiltite; mudstone containing flow casts; and dark volcanic rocks, locally pillow basalt. Although the thickness of the lower member could not be determined accurately because of internal folding, it is at least 700 ft. Only one shale bed of Early Silurian age was identified but not separately mapped. The upper member is a poorly bedded, light-olive-gray to medium-gray quartzite of fine- to medium-grained, subrounded quartz grains cemented by silica; it is interbedded with chert in the basal part and, locally, higher.

In the western part of the Tuscarora 15′ quadrangle, northwest of the town of Tuscarora, the western assemblage consists of two distinct lithologies that are not found in contact with each other. In a very narrow horst or fault sliver that can be traced northward for several miles from just west of the town of Tuscarora, black quartzite, chert, shale, and clastic limestone are present. The limestone (field nos. 69NC23, 69NC65A, *in* Coats, 1986) is Devonian, and this is one of the few places in this part of the county where Devonian rocks have been definitely recognized in the western assemblage.

Still farther west, in the Mount Blitzen 15′ quadrangle, L. D. Cress and I mapped chert and dark impure quartzite and shale of the western assemblage; no fossils were found in these rocks, and they are not in contact with any other Paleozoic unit but are overlapped unconformably by Tertiary units. West of the Mount Blitzen 15′ quadrangle, the western assemblage occurs mostly as fault slivers of black chert and shale, that are generally unfossiliferous.

In the Ivanhoe mining district [20] the western assemblage crops out in two very small areas, one of which is largely chert and the other a typical black quartzite that is characteristic of the Valmy Formation.

South and east of the Ivanhoe district [20A, 20B], L. D. Cress and I mapped large areas of black chert and shale that we regarded as part of the western assemblage; this area is nearly continuous with the southern Tuscarora Mountains, between Maggie Creek and the Ivanhoe mining district. In the Tuscarora Mountains, the principal rock types are greenish-gray and green chert with interbedded shale and minor lenses of limestone that are locally replaced by barite. On the east side of the Tuscarora Mountains just west of Maggie Creek [30A], lenses of limestone, partly replaced by dolomite, contain brachiopods that also are Devonian (field no. 70NC21 *in* Coats, 1986).

Western-assemblage rocks were described in the Antelope Peak area [25] by Peterson (1968), who assigned them to the Valmy or Vinini Formation but noted that they might include some Silurian rocks. The rocks consist of interbedded chert, shale, siltstone, conglomerate, limestone, and orthoquartzite, deformed into tight folds and containing many unmapped faults.

In the Snake Mountains the chert, orthoquartzite, and limestone on the north grade southward into chert conglomerate and siltstone. I believe that in the northern Snake Mountains [15], which were mapped by Gardner (1968), the western assemblage consists entirely of Ordovician rocks, whereas to the south it includes both Ordovician and Silurian rocks.

In the HD Range [17] Riva (1970) described three new formations in the Ordovician part of the allochthonous western assemblage, in ascending order: the Valder Formation, the Agort Chert, and the Tiser Limestone; he also described the Silurian Noh Formation as being present in some thrust slices. The Valder Formation consists of lower to middle Lower Ordovician shale and volcanic rocks. The lower member comprises 230 ft of light-gray-weathering black siliceous shale alternating with light-brown and tan shale and contains lenses of greenish-gray andesitic volcanic rocks; it is interbedded with green chert in the upper part. The upper member is overlain unconformably by the Tiser Limestone or the intervening Agort Chert. The Middle Ordovician Tiser Limestone is 90 to 150 ft thick; basally, thin limestone beds alternate with gray graptolitic shale. The succeeding limestone, in beds as much as 1 ft thick, contains stringers and nodules of black chert. The Agort Chert in some places conformably overlies volcanic rock of Valder-type or unfossiliferous sandy limestone. The Agort Chert, 700 ft thick at the type locality, consists of a succession of gray to black chert beds, as much as 1 ft thick, with gray siliceous-shale interbeds; one bed of massive light-colored quartzite is 25 ft thick. The Agort Chert contains graptolites of Middle to Late Ordovician age. The Noh Formation of Silurian age, which has a maximum thickness of 1,100 ft, is present in thrust slices. The basal part of the Noh disconformably overlies the Upper Ordovician Agort Chert, separated by a hiatus that represents the lowermost Silurian. There are three units in the type sections: a lower unit of 140 ft of dark-gray chert and light-gray shale; a middle unit of 400 ft of light-brown-weathering siliceous shale and siltstone; and an upper unit of at least 550 ft of tan- and light-brown-weathering, thin-bedded siltstone, sandstone, and minor shale. In the southern HD Range [27], John Riva (written commun., 1971) mapped a unit of Ordovician limestone, as much as 200 ft thick, that rests conformably on the Valmy Formation in that area. The unit locally contains a quartzite-limestone conglomerate, as much as 24 ft thick. This unit is not separated in mapping everywhere from the rest of the western assemblage.

In the Windermere Hills [26], Oversby (1972) mapped the western assemblage in several thrust plates in six named sequences; facies differences occur between rocks of the same age in different sequences. Although all these rocks are allochthonous, some thrust plates include rocks resembling those of the eastern assemblage. In what Oversby (1972) called thrust sheet 1 (part of his Thousand Spring sequence), the basal part of the section consists, in ascending order, of three formations, all correlative with those named by Riva (1970): the Valder Formation, the Agort Chert, and the Noh Formation. The Valder Formation is about 300 ft of fissile black argillite and minor amounts of tan siltite. The Agort Chert, about 150 ft of dark chert and argillite, contains chert beds, from 20 to 50 ft thick, which alternate with fissile, black, ash-gray-weathering argillite in units of similar thickness. The Noh Formation consists of about 325 ft of platy, flaggy, and blocky tan calcareous quartz siltite that weathers brown and pink. Locally the siltite is green and argillaceous; a 50-ft-thick unit of dark-gray calcisiltite is also present. Graptolites in the Noh suggest a Wenlockian to middle Ludlovian age. In thrust sheets 2 and 4 of his Thousand Spring sequence, Oversby (1972) mapped Devonian rocks of the transitional assemblage. In thrust sheet 2 the Devonian succession consists of a lower 2,000 ft of limestone and minor quartz siltite and arenite, overlain by about 200 ft of moderately well exposed gray arenaceous calcarenite and calcirudite. All the sand grains have a moderate to high sphericity; the presence of a few calcareous graded beds suggests deposition by turbidity currents. Some chert breccia is present near the top, overlain by bedded chert and arenaceous calcarenite. Conodonts in the limestone suggest a Frasnian age. Thrust sheet 4 in the same sequence is also Devonian (Frasnian). The lower 500 ft of thrust sheet 4 is flaggy to slabby quartz siltite, locally calcareous, and minor platy to slabby calcilutite; below is more than 120 ft of medium-bedded to blocky arenite and calcarenite, commonly laminated. These rocks were compared by Oversby (1972) to the allochthonous carbonate formations of possibly earliest Late Devonian age in the Sulphur Spring Range.

The Vinini Formation was named by Merriam and Anderson (1942, p. 1693–1698) for exposures on Vinini Creek on the east side of the Roberts Mountains in Eureka County. Outcrops of the Vinini are generally poor, and hills and slopes are covered with small pieces of chert, shale, siltstone, and mudstone. The predominant rock type is chert which is generally black and weathers black, tan, brown, or gray; the beds are 2 to 6 in. thick, with millimeter-size laminations. The mudstone, which is gray and weathers white to brown, ranges in composition from siliceous to argillaceous. Some calcareous siltstone is also present, some of which contains sponge spicules. The gray clastic rock is made

up of very coarse sand and granule fragments, mostly gray chert, and scattered medium grains of quartz in a chert matrix. The limestone, dark gray, densely to finely crystalline, and weathering light gray to tan gray, is present in 2- to 5-in.-thick lenses in the chert.

In the southwestern part of the Carlin-Piñon Range area [43], the Vinini Formation is poorly exposed in several elongate bands north and south of Willow Creek. Chert, mudstone, shale, and siltstone are the principal rock types; very coarse sandstone to granule conglomerate are minor constituents. The internal structure must be complex because graptolites collected (Smith and Ketner, 1975, p. A11) indicate that Lower, Middle, and Upper Ordovician rocks are present but are not now in stratigraphic order. The thickness cannot be estimated.

In describing the stratigraphy of central Elko County, Ketner (1975b) included Ordovician, Silurian, Devonian, and Mississippian(?) rocks in the western and transitional assemblages. Two major facies are present, partly equivalent in age. The chert, shale, and siltstone facies, which includes Ordovician to Devonian and Mississippian(?) rocks, crops out mainly in the southern Independence Mountains and in the northern Adobe Range [29].

A quartzite facies crops out at Double Mountain, in the hills north of Double Mountain [22], and in the northern Independence Mountains. Chert, shale, and argillite and siltstone predominate south of the latitude of Double Mountain, and quartzite is a prominent constituent north of that line. Here, the western assemblage is composed principally of bedded chert, argillite, shale, siltstone, quartzite, greenstone, and smaller amounts of sandstone and limestone. Lithologically the chert, argillite, and shale are similar in each of the systems included; the chert is graptolitic in many places. Siltstone is common in the Silurian rocks. This siltstone is composed mainly of quartz and smaller amounts of carbonate, microcline, and plagioclase; grains are generally angular, and bedding is distinct. The sandstone, medium to coarse grained, is made up of generally well rounded, frosted quartz grains cemented by carbonates, silica, or iron oxide. Massive, medium- to coarse-grained pure quartz arenite is common in the northern exposures. Limestone, interbedded with chert, argillite, and shale, constitutes less than 1% of the western assemblage in this part of the county. The limestone is commonly Middle Ordovician or Late Devonian; many units are dark-gray, thin-bedded, slightly cherty calcilutite. This limestone was mapped separately by Ketner (1973) in only one place, at the north end of the Adobe Range. Some of the limestone is evidently turbiditic and displays graded bedding. The basal beds in the graded sequences may be bioclastic calcarenite or intraformational conglomerate. The finer grained beds in the graded sequences include calcisiltite, quartz siltstone, impure calcilutite, and silty chert; analysis shows that these beds are siliceous limestone.

On the west slope of Swales Mountain some beds are rich in barite. Thin conglomerate layers contain pebbles of barite, chert, and, in some beds, pebbles of argillite and mudstone; "...barite rosettes seem to have grown before consolidation of the sediment because the blades of the rosettes clearly have distorted the bedding." (Ketner, 1975b, p. 16). Greenstone forms a minor proportion of the western assemblage where visible close to the dated Ordovician beds. Analyses generally suggest a basaltic composition, although alteration has evidently affected the composition of some beds. "Where dating is possible Ordovician beds...consist mainly of bedded chert, argillite, shale, quartzite, greenstone, and limestone. The Silurian beds are dominantly siltstone and the Devonian beds are dominantly chert, argillite, shale, and limestone." (p. 20). These rocks include "...dated beds of Early, Middle, and (probably) Late Ordovician, Silurian (Wenlock), Late Devonian, and possibly Early Mississippian ages." (p. 22). The rocks are correlative with the Vinini and the Valmy Formations, at least partly with the Woodruff Formation (Smith and Ketner, 1975), and possibly with the Webb Formation.

Churkin and Kay (1967) divided the western assemblage in the northern Independence Mountains [12] into three formations—the Snow Canyon Formation, the McAfee Quartzite, and the Jacks Peak Formation—that they considered part of the Valmy Formation, which they raised to group status in their report. This usage has not been adopted here; for the purposes of this report, all these units are combined **[DOs]** on the geologic map (pl. 1).

The Snow Canyon Formation is predominantly thin-bedded, medium-dark-gray to dark-gray chert with argillite partings and thin beds of shale and siltstone. Basaltic lava is the next most abundant rock type, locally with pillow structures; lenses of coarse-grained, very light gray limestone are interbedded with the massive lava flows. Several fine-grained, light-gray quartzite beds, tens of feet thick, are interbedded with the chert. A few beds of fine-grained, medium-gray, thin-bedded to laminated limestone, as much as 20 ft thick, are interbedded with chert of the type Snow Canyon; the limestone splits into slabs and weathers olive gray. The total thickness of the Snow Canyon is about 1,200 ft. In some places the greenstone is vesicular; it may be lithic breccia or tuff in part.

The McAfee Quartzite is mostly fine-grained, white to light-gray quartzite, in beds from 10 to more than 100 ft thick. A few thin beds of graptolitic shale or siltstone are present between the quartzite beds, and some bedded chert is present in the top. The total thickness of the unit is about 1,387 ft.

The Jacks Peak Formation is divided into two units: a lower member of predominantly chert, 200 to 300 ft thick, of predominantly thin-bedded black chert, with dark-gray shale partings; and an upper member 150 to 200 ft thick, consisting of mostly white, fine-grained, very thick bedded, massive quartzite. Barite has been found in the Jacks Peak Formation(?) and was regarded by Churkin and Kay (1967) as a secondary mineralization. My observations in this locality suggest replacement of a limestone lens in the Jacks Peak.

Limestone **[DOsl]**. Ketner (1975b) pointed out, in discussing the stratigraphy of central Elko County, that limestone of the western assemblage in Elko County is principally confined to the Ordovician and Devonian parts of the section, insofar as these rocks can be recognized. This generalization also seems to be true in

the parts of Elko County northeast and west of where Ketner (1975b) worked. The limestone in Ordovician rocks of the western assemblage is generally present as areally small, relatively thin beds interbedded with shale or chert; commonly the limestone is clastic. All these limestone beds are of interest because they offer the possibility of finding fossils that do not commonly occur in the western assemblage. In western Elko County, at the latitude of Lone Mountain and at the north end of the Adobe Range, somewhat larger lenses of limestone occur in Ordovician rocks, and these lenses are here mapped separately (pl. 1); the smaller and thinner lenses are not mapped as individual units. The larger lenses, according to R. J. Ross (oral commun., 1972), who examined them in the field and collected fossils from them, generally resemble those in the carbonate mudmound at Beatty, Nevada. (Ross and Cornwall, 1961, p. 231–232). Collections from the mudmound at the north end of the Coal Mine Basin quadrangle (Ketner, 1973a) are described under field nos. 62NC100 and 65RJ26 (*in* Coats, 1986), and those from the limestone window, which is just north of Lone Mountain in the Reed Station quadrangle, under field no. 71NC160 and collns. D2379-CO, D2380-CO, D2321-CO, and D2322-CO. Smaller masses of calcarenite have been found in thin structural screens of western-assemblage rocks in the western part of the Tuscarora 15′ quadrangle. The best age determination available was made on conodonts from a collection (field no. 69NC63) that J. W. Huddle thought to be late Early Devonian. In the Lake Mountain quadrangle, one limestone that is partly replaced by barite was dated as Late Devonian by Huddle (field no. 70NC13), and another as Late Devonian on the basis of brachiopods by J. T. Dutro, Jr. The brachiopods are partly replaced by barite and occur in a deposit that has been mined for barite.

In the HD Range [17], in his tectonic plate B, Riva (1970, p. 2694) described 120 to 150 ft of buff-, orange-, and pink-weathering limestone in thin platy beds. Lying on lavas referred to by Riva (1970) as oligoclase trachyte and directly in contact with the volcanic rocks is a thin siliceous limestone bed, succeeded by a 5- to 8-ft-thick conglomerate layer of slabs and blocks of limestone in a matrix of detrital shale. The brachiopods and trilobites in the platy limestone beds suggest a time correlation with the upper part of the Pogonip Group. The close association of the limestone here and north of Lone Mountain with greenstone or greenstone tuff suggests that these beds were deposited on top of volcanic seamounts, where they were relatively isolated from terrigenous debris, and that both these units are allochthonous and have been carried eastward and southward for considerable distances—the one in the HD Range for much greater distances. This thrusting is believed to be Mesozoic.

Devonian System

***Woodruff Formation* [Dw].** In the Carlin-Piñon Range area [43], Smith and Ketner (1975) mapped a unit that they had previously (Smith and Ketner, 1968, p. 14–17) named the Woodruff Formation. This unit crops out in the Piñon Range more extensively than any other unit in the upper plate of the Roberts Mountains thrust. The Woodruff Formation contains principally siliceous mudstone and chert, lesser amounts of shale, siltstone, dolomitic siltstone and dolomite, a few lenses of limestone, and very few beds of sandy limestone and calcareous sandstone. The siliceous mudstone, chert, and shale are chiefly dark gray to black and weather the same; the other rock types are mostly tan to light gray and weather the same. No accurate thickness for the formation could be determined; in the southern part of the Carlin-Piñon Range area its thickness is at least 3,000 ft and may total several thousand feet more. Spores of vascular land plants are present locally, but conodonts were used most in dating these rocks. *Tasmanites*, graptolites, radiolarian tests, and rami of *Angustidontus* were also recognized. The Woodruff ranges from Early Devonian to late Late Devonian. The Early Devonian rocks are grayish-brown, tan, and gray siltstone containing phosphatic nodules.

The Middle to early Late Devonian rocks include pale-brown to black siltstone, in 1- to 6-in.-thick beds, as well as dolomitic siltstone, claystone, shale, and chert containing lenses of limestone. The siltstone and claystone are gray to tan, weather tan to buff, and break into platy pieces and irregular fragments. All the strata are thin bedded. Chert, gray to black dolomitic shale, and mudstone are also present; gray to dark-gray limestone and sandy limestone are minor constituents. The Late Devonian rocks, which include beds as young as early Famennian, consist of gray to black carbonaceous shale, dolomitic mudstone, and black chert. In the southern part of the belt of the Woodruff Formation, an estimated 500 to 600 ft of shale underlies 700 to 800 ft of chert as exposed; farther north, the estimated total thickness of the Woodruff is at least 3,000 ft. The youngest beds in the Woodruff are late Late Devonian. The formation to the north consists of siliceous mudstone, chert, and lesser amounts of shale and dolomite. Carbonate rocks, which form a noticeable part of the Woodruff, are largely calcitic dolomite or dolomite but contain a large proportion of noncarbonate clastic fragments.

The Woodruff is, in part, the time equivalent of the Slaven Chert (Gilluly and Gates, 1965). Part of the Woodruff is also equivalent to the Lower Devonian Rabbit Hill Limestone (Merriam, 1963). Other formations equivalent to the Woodruff include the Nevada Formation of previous usage, the Devils Gate Limestone, the lower part of the Pilot Shale, and the upper part of the Roberts Mountains Formation (Evans and Mullens, 1976; Mullens, 1980). The Woodruff Formation is overlain unconformably by the Lower Mississippian Webb Formation and the Lower and Upper Mississippian Chainman Shale.

Eastern and Transitional Assemblages

Cambrian System

***Prospect Mountain Quartzite* [Ꞓpm].** The Prospect Mountain Quartzite occurs in several localities in Elko County, principally in the Pilot Range [36], the Toano Range [35], the Ruby Mountains [45, 48, 49], and in the

Rowland [5], Jarbidge [6], Mount Velma [13], Marys River Basin NW [14], and Bull Run [9] quadrangles.

In the Pilot Range [32] (Blue, 1960), the Prospect Mountain Quartzite is fine to medium grained and highly jointed and fractured; it ranges in color from white or light gray to pink or light maroon where fresh to dark maroon, reddish, or dark reddish brown on weathered surfaces. The quartzite is massive, with some low-angle crossbeds and a few micaceous partings. Because of faulting and the absence of a bottom or top, no complete sections were measured.

In the northern Toano Range [35], Pilger (1972) questionably assigned certain beds to the Prospect Mountain that he thought might include some Precambrian rocks; neither the top nor bottom is exposed, and the beds are mostly medium- to coarse-grained, well-sorted micaceous metaquartz arenite. The beds range from a few inches to more than 3 ft in thickness. Planar and festoon crossbeds are common. Thin beds of biotite-chlorite-muscovite-quartz schist occur throughout, in units from less than ¼ in. to several feet thick. The total thickness must be several thousands of feet, but because of the absence of internal structure, the thickness cannot be measured accurately.

In the Rowland quadrangle [5], Bushnell (1967) described a well-exposed sequence of quartzite that he questionably correlated with the Prospect Mountain Quartzite. The lower part consists of alternating layers, 50 to 200 ft thick, of thin- to thick-bedded, light-colored quartzite with some schist interbeds, and interbedded, laminated to thin-bedded, dark-colored quartzite and schist. The lightest colored quartzite, light gray to brown on fresh surfaces and pale brown to grayish orange pink on weathered surfaces, is composed almost entirely of poorly sorted rounded quartz grains. The thin schist interbeds are grayish brown to grayish olive; these interbeds are chloritic. The lower part of the formation contains a slightly metamorphosed quartz wacke in which angular to subrounded quartz grains are set in a matrix of muscovite and sericite. In all the quartzite beds, zircon is a common accessory mineral. Locally the schist layers dominate and form beds as much as 50 ft thick; cross-beds, ripple marks, mud cracks, and rill marks(?) are present in all the schist layers.

The summit of Copper Mountain, in the Rowland quadrangle, is made up of a bed, about 40 ft thick, of highly magnetitiferous quartzite. Thin beds of quartz-cobble conglomerate are present near the exposed base of the Prospect Mountain Quartzite in Copper Creek, in the Jarbidge quadrangle; and a thin layer of conglomerate containing quartz cobbles and cobbles of rounded masses of actinolite, interpreted as metamorphosed basic igneous rocks, was found at the north end of the Copper Mountain ridge, near the boundary between the Rowland and Jarbidge quadrangles (Bushnell, 1967, p. 10). The minimum thickness of the quartzite in the Rowland quadrangle is estimated at about 3,500 ft (this thickness includes rocks mapped by Coats (1964) as Precambrian quartzite and schist); in the Jarbidge quadrangle, just to the east of the Rowland quadrangle, Coats (1964) estimated a minimum thickness of about 1,500 ft for the Prospect Mountain.

The Prospect Mountain Quartzite was also described by Decker (1962) in the Bull Run quadrangle, principally in the Bull Run Mountains; he reported that it consists chiefly of buff to red-brown, fine- to medium-grained orthoquartzite, with a few thin beds of quartz-pebble conglomerate and schistose rock, generally exposed in dark, massive, well-jointed outcrops. The Prospect Mountain Quartzite has a minimum thickness of 4,200 ft in the Bull Run Mountains, but the base is not exposed. The presence locally of large-scale cross-bedding structures suggests a fluvial environment of deposition. The Prospect Mountain Quartzite is also extensively exposed in the northern Ruby Mountains [45, 48, 49], where it was described by Howard (1966b).

In the northern Ruby Mountains, Howard (1966b) and, in the Lee 15′ quadrangle, Smith and Howard (1977) considered the Prospect Mountain Quartzite to be of Late Proterozoic and Cambrian age. In the Lee 15′ quadrangle it is a brown-weathering metaquartzite containing 80% to 90% quartz and 10% to 20% feldspar, muscovite, and biotite; the rock is generally foliated.

In the Franklin Lake NW quadrangle (just east of the northern part of the Jiggs 15′ quadrangle), Willden and Kistler (1979, p. 226) reported that the basal unit of the Prospect Mountain Quartzite is

> ...characterized by coarse-grained, poorly sorted arkosic quartzite and by micaceous pebble conglomerates in which the pebbles are predominantly light-gray or white, medium- to coarse-grained quartzite. The pebble conglomerate beds may be a few inches to tens of feet thick, but in some places they are missing entirely, and the base of the quartzite is marked only by the arkosic quartzite.
>
> The Prospect Mountain Quartzite above the basal unit is composed largely of pale-yellowish-gray, pink, or light gray, thick-bedded, often cross-bedded, medium- to coarse-grained quartzite. ...Quartzite beds are separated by shale partings or by thin micaceous quartzite layers."

Willden and Kistler estimated a maximum thickness of 4,000 ft for the Prospect Mountain Quartzite in the Ruby Mountains. The age of the quartzite rests on a whole-rock Rb-Sr date of 550 ± 30 m.y., determined by R. W. Kistler (Kistler and Willden, 1969) for a metamorphic event that affected the underlying schist but not the quartzite. Willden and Kistler (1979) also recognized in the Prospect Mountain Quartzite of this area a magnetite-bearing quartzite unit highly reminiscent of the magnetitiferous bed that forms the summit of Copper Mountain in the Rowland quadrangle, nearly on the border of the Jarbidge quadrangle.

Hematite-bearing sandstone from the upper part of the Osgood Mountain Quartzite, a probable correlate of the Prospect Mountain Quartzite in the Osgood Mountains of Humboldt County, Nevada. (Hotz and Willden, 1964, p. 8–9), may represent sediment that resembles the magnetite-bearing quartzite but that accumulated under oxidizing conditions.

In the southern Ruby Mountains, Sharp (1942, p. 651) described 1,400 ft of the Prospect Mountain Quartzite on the Rattlesnake Mountain dome, at the mouth of Brown Creek. The rock is a massive vitreous quartzite containing some schistose beds or partings and sparse conglomeratic layers; it is commonly white, light

gray, or light tan and weathers dark brown. The quartzite is medium grained and contains minor amounts of orthoclase, zircon, apatite, ilmenite, muscovite, pyrite, and hematite or limonite. Thin beds of mica schist containing muscovite, sericite, sillimanite, zircon, and pyrite are scattered sparsely throughout the unit.

The assignment of the Prospect Mountain Quartzite of Elko County to the Cambrian does not negate the conclusion of Stewart (1974) that the Prospect Mountain Quartzite in southern Nevada and southeastern California is of Precambrian (Late Proterozoic) and Early Cambrian age. The base of the Prospect Mountain Quartzite has generally been regarded as time transgressive in the Great Basin.

Carbonate Rocks and Minor Quartzite **[Ꞓc].** Cambrian rocks above the Prospect Mountain Quartzite are combined into a single unit on the geologic map (pl. 1). These rocks were described and subdivided into several formations and members in the Eureka mining district by Nolan and others (1956). The units included are, in ascending order: the Pioche Shale, the Eldorado Dolomite, the Geddes Limestone, the Secret Canyon Shale, the Hamburg Dolomite, the Dunderberg Shale, and the Windfall Formation. In eastern Elko County, Cambrian rocks of the eastern assemblage have been described from the Kinsley Mountains [35], the Toano Range, the southern Pilot Range, the Ruby Mountains, and the Elk Mountains.

Buckley (1967) described the Cambrian rocks of the Kinsley Mountains under three divisions, in ascending order: the Dunderberg Shale, the Windfall Formation, and the lower part of the Notch Peak Dolomite. The Dunderberg Shale, which forms mostly low, brown hills, is generally a dark-gray to brown argillaceous shale that weathers khaki. Several beds of dark-gray limestone, from 5 to 10 ft thick, are interbedded in the lower 200 ft and in the upper 50 ft. Limestone with bird's-eye structures was noted in several thin interbeds in the upper 50 ft. The total thickness of the Dunderberg is probably greater than 500 ft, but the base is not exposed. The Windfall Formation, which overlies the Dunderberg Shale, is about 2,150 ft thick; the upper 950 ft is a thick-bedded to massive limestone, that weathers to irregular plates. Chert is present locally as nodules or irregular stringers. The limestone is typically uniformly light gray, the lower 1,200 ft is also uniform and consists of thin-bedded, dense, fine-grained, dark-gray limestone, in beds as much as 1½ in. thick, separated by argillaceous partings that weather red brown. Minor chert laminae, less than ¼ in. thick, are sporadically distributed. Overlying the Windfall Formation is the Notch Peak Dolomite, more than 1,250 ft thick. The top was not seen; the lower 500 ft is blue-gray, medium-grained massive limestone. Thin-bedded chert is present throughout the lower part of the Notch Peak but rare in the overlying dolomite; the upper 750 ft of the Notch Peak is massive dolomite, including several minor quartzite beds.

In the northern Toano Range [41], Pilger (1972), divided the Cambrian into three formations. The lowest formation, which is correlated with the Pioche Shale, here amounts to 683 ft of brownish-gray, fissile sericitic argillite and metasiltstone; no fossils were found. The middle formation, unnamed here, is divided into two units: a lower (a), and an upper (b). Unit (a) is an argillaceous, ferruginous, and somewhat dolomitic limestone that has been recrystallized to marble owing to thermal metamorphism; argillaceous layers are present throughout. The total thickness of unit (a), ignoring structural complexities, is about 2,775 ft. Unit (b) contains a basal bed of distinctive massive zebra-striped marble with thin, irregular, white and black layers; an equally distinctive oolitic marble occurs several tens of feet above the zebra-striped marble. The highest formation is the Notch Peak Dolomite. Neither the base nor top of the Notch Peak was observed; the maximum thickness of the formation is greater than 1,447 ft. Three distinctive rock types are present: the first is massive, blue-gray, fine- to medium-grained limestone; the second is mottled, blue-gray, laminated cherty dolomitic limestone; and the third is crystalline, light- to dark-gray, massive dolomite containing nodular chert. The chert is mainly in the middle part of the formation; the dolomite occurs throughout, but the upper 400 ft is all dolomite. Fossils were not seen, and the stratigraphic similarity to the Notch Peak Formation in the Silver Island Mountains is the basis for assignment of the rocks to this formation.

In the Pilot Range area [36], O'Neill (1968) described a section of Cambrian rocks above the Prospect Mountain Quartzite. The lowest unit, the Pioche Shale, is more than 150 ft thick but is exposed in a fault block, and no top was seen. Above the Pioche Shale are four units, aggregating approximately 3,000 ft in thickness, for which no names were assigned; O'Neill described these as units 1 through 4, consecutively. The lowest unit has a lower member of more than 235 ft of limestone and an upper member of dolomite, argillaceous dolomite, and limestone, aggregating more than 470 ft in thickness. Unit 2, for which neither the base nor top was seen, consists of more than 225 ft of argillaceous dolomite. Unit 3 is more than 300 ft thick; no base was seen. It consists of limestone and silty limestone. Unit 4, 230 ft thick, is sandy and shaly limestone. Above these units is the Dunderberg Shale, more than 200 ft thick, consisting of shale. Above the Dunderberg is his Johns Wash Formation, aggregating more than 950 ft in thickness. The lower 250 ft, for which no base was seen, consists of shale, argillite, and phyllite; the upper 700 ft, the thickness of which is questionable, consists of dolomite. Above the Johns Wash is his Corset Spring Formation, apparently mostly covered and rather thin. Above the Corset Spring is more than 250 ft of the Notch Peak Formation, which here is limestone. The Johns Wash and the Corset Spring Formations were apparently correlated with formations described in the Wheeler Peak quadrangle (see Whitebread and others, 1962) in east-central Nevada.

In the Ruby Mountains [48], in the Jiggs 15′ quadrangle and in the Franklin Lake NW quadrangle just to the east of it, Willden and Kistler (1969, 1979) described a considerable thickness of Cambrian rocks above the Prospect Mountain Quartzite. The lowest formation is the Pioche Formation, the lower part of which is light- to dark-gray, coarse to recrystallized carbonaceous limestone with a thin, dark phyllite bed at the base. Willden

and Kistler (1979) estimated a thickness of 225 ft for this part of the Pioche. In the upper part of the Pioche Formation is a hornfels member containing some quartzite beds; the total thickness of this member is about 300 ft (Willden and Kistler, 1979). Above the Pioche Formation is an unnamed shaly-limestone member that consists of generally thin bedded, buff to light-gray highly recrystallized silicate rock or marble that grades upward into thick-bedded, buff to light-gray, fairly pure, generally recrystallized limestone. The shaly-limestone member was assigned a Middle Cambrian age by Willden and Kistler (1979); the overlying limestone member yielded late Middle Cambrian fossils. Above the limestone is a hornfels that grades southward into phyllite; the hornfels is generally brown in contrast to the dark-gray overlying unit. The hornfels is thought to be the temporal equivalent of the Hamburg(?) Dolomite; Willden and Kistler (1979) reported the hornfels to be 650 to 800 ft thick. Above the hornfels is a unit of hornfels and limestone, which is regarded as equivalent to the Dunderberg(?) Shale (Late Cambrian) and is about 500 ft thick west of Sherman Mountain. The dark-gray hornfels grades southward into phyllite and contains some interbedded recrystallized limestone. Above the hornfels and limestone is the Late Cambrian Windfall Formation, the lower member of which, correlated with the Catlin Member of the Eureka area, is a gray limestone in beds that range from a few inches to 1 ft in thickness, with thinner interbeds of recrystallized chert and a total thickness of 350 to 500 ft (Willden and Kistler, 1979). Above the gray limestone is the Bullwhacker Member of the Windfall Formation, about 300 ft thick, consisting of alternating light-brown shaly or silty limestone and light-gray limestone in beds more than 2 in. thick.

In the southern Ruby Mountains, Sharp (1942, p. 653) measured 3,100 ft of Middle Cambrian rocks that consist of thin-bedded arenaceous and argillaceous limestone, above which is approximately 3,550 ft of thin-bedded limestone, argillaceous limestone, limy argillite, and arenaceous beds, of Late Cambrian age.

In the Elk Mountains [7], Mathias (1959) described a section of Cambrian fossiliferous rocks that he correlated with the Hamburg Dolomite, the Dunderberg Shale, and the Catlin and Bullwhacker Members of the Windfall Formation. Of the lowest unit, which he regarded as equivalent to the Hamburg Dolomite, approximately 320 ft or more is exposed. The lower part is a light-gray, unfossiliferous, regularly bedded limestone, in ¾- to 2-in.-thick beds; the upper part is mainly dense, dark-gray siliceous limestone, in beds 1 to 7 in. thick, containing a few thin beds of gray chert. Above the Hamburg Dolomite, Mathias described a unit, no more than 215 feet thick, that he correlated with the Dunderberg Shale. The lower 200 ft is entirely yellow-brown fissile shale that weathers to small angular flakes; at the top is a 15-ft-thick bed of interbedded shale and limestone. The gray limestone in the top 15 ft is in beds ½ to 1 in. thick, interbedded with shale beds of the same thickness. The only fossiliferous part of the section occurs in the Windfall Formation. Its lower member was correlated by Mathias with the Catlin Member of the Eureka section. The lower part of this member is approximately 150 ft thick. At the base are 2- to 3-ft-thick beds of massive, blue, finely crystalline limestone separated by shale partings. The upper part of the member, which is about 30 ft thick, is thin-bedded, flaggy, gray limestone with interbedded tan shaly layers. The upper member is massive, fine-grained, yellow to gray quartzite, of which approximately 90 ft is exposed. The base of this quartzite is not exposed. Above(?) this quartzite is about 390 ft of flaggy limestone and siltstone, weathering brilliant orange red, that contains trilobites and brachiopods. This limestone and siltstone grades into a 280-ft-thick upper member of very thin bedded, laminated, light- to medium-gray siliceous limestone that weathers to flat angular plates; this upper member is unfossiliferous. Michael Taylor (oral commun., 1976) examined this section and reported that the entire Cambrian section could be regarded as temporally equivalent to the Windfall. The Cambrian limestone is overlain by a quartzite that is questionably correlated with the Eureka.

***Carbonate Rocks, Minor Quartzite, and Phyllite* [Ꞓc].** Along the upper part of the North Fork of the Humboldt River [11], a small area of Cambrian rocks was discovered and described by Widmier (1960) and Hawkins (1961). They divided these rocks into four units informally designated A, the lowest, through D, the highest. Exposures are very poor; the total thickness of these units was estimated by Hawkins at more than 3,000 ft. The principal rock types are light-gray silicified limestone, quartz siltite, and massive, dark-blue to black, thin-bedded chert. Unit D, about 3,000 ft thick, is silty shale and calcisiltite that includes thin-bedded, blue calcisiltite interbedded with thin-bedded, laminated, buff argillite. On the basis of specimens of *Eurekia* and *Olenoides*(?), unit D was assigned to the Windfall Formation. All of these units are here regarded as Cambrian.

In the Bull Run quadrangle [9], Decker (1962) described two Cambrian formations, the Edgemont Formation and the overlying Porter Peak Limestone. The Edgemont Formation, an argillaceous unit recognized in the field by its blue-gray to brown color, is generally schistose to slaty; the lower part of the formation is sandy, and the upper part calcareous. The computed total thickness of the formation is about 700 ft, and the lower contact is gradational into the Prospect Mountain Quartzite. On the basis of one trilobite specimen identified at the generic level, the Edgemont Formation was tentatively assigned to the Lower Cambrian. The Porter Peak Limestone is generally composed of a limestone characterized by cream- to buff-gray-weathering, massive subrounded structure, and weathered sandpapery texture crisscrossed by fine calcite veinlets. The upper 2,000 ft of the Porter Peak Limestone is too massive to determine the attitude of the bedding; its color on fresh rock surfaces is blue gray. The lower third of the formation is more complex in lithology. Part of the formation is a black and tan dolomitic limestone containing light-colored sandy limestone beds, ½ to 2 in. thick, intercalated with dark-gray to black dolomitic limestone. The lowest part of the formation is composed of two limestone conglomerate members separated by a set of gray siltstone and black

shaly limestone, 150 ft thick. Both limestone conglomerate members are thought to represent local intraformational conglomerate. The total thickness of the Porter Peak Limestone is estimated from map measurements at about 3,200 ft.

In the Rowland quadrangle [5], Bushnell (1965, 1967) described a unit that he called the "Paleozoic Schist and Limestone." The unit is unfossiliferous and is here somewhat doubtfully correlated with Cambrian rocks of the transitional assemblage. It ranges in composition from massive, recrystallized, partly silicified, light-gray limestone to low-grade calc-schist; minor rock types are low-grade mica schist, altered argillaceous sandstone, and thick-bedded recrystallized limestone. Thicknesses were not given, apparently because dips and strikes of the bedding are extremely difficult to determine; several hundred, perhaps a thousand, feet might be estimated, but this value is very approximate.

Cambrian and Ordovician Systems

***Shale, Phyllite, and Limestone* [O€s].** Cambrian and Ordovician rocks of the transitional assemblage include units that have been described in two areas, the west side of the Snake Mountains [15] and the Rowland quadrangle [5]. In the Snake Mountains, Gardner (1968) described approximately 500 ft of siliceous and carbonaceous shale and siltstone, with thin interbeds of carbonaceous limestone. This shale is slightly phyllitic near a thrust fault, which separates it from the eastern assemblages. In the Rowland quadrangle [5], Bushnell (1967) described a thick sequence of highly deformed, thinly interbedded limestone and argillaceous rocks that he called the Tennessee Mountain Formation. Argillaceous rocks are predominant in this formation in the southern exposures, and thin-bedded limestone is predominant in the northern exposures.

The limestone consists typically of thin beds of medium-gray, very fine grained limestone and silty limestone separated by very thin phyllite laminae. On weathered surfaces the limestone is light gray, the silty limestone yellowish gray or light brown, and the phyllite light gray to greenish gray. Locally, the phyllite laminae are torn and broken into more or less rectangular pieces. Phyllite beds, from 10 to 50 ft thick, are locally interbedded with the limestones; the phyllite ranges in color from yellowish gray to green or grayish green. Cleavage has obliterated the bedding in the phyllite; because of this deformation, estimates of the thickness of the formation are likely to be in considerable error, although a conservative estimate was thought by Bushnell (1967) to be about 5,000 ft of phyllite and 5,000 ft of limestone, or a total thickness of about 10,000 ft. Two fossil collections were made in the southeast corner of the Mountain City 15′ quadrangle from the Tennessee Mountain Formation (field nos. 62NC40, 62NC41). Both of these collections contained spicules and acrotretid brachiopods; A. R. Palmer dated one collection as probably Cambrian or Early Ordovician.

Bushnell (1967) also described another formation, a Paleozoic limestone that lies north of an intrusive body which separates it from the typical Tennessee Mountain. This formation is a thin-bedded to very thin bedded, very fine grained limestone with silty or cherty partings; the fresh surface of the limestone is typically pale yellowish brown or grayish orange pink. This formation resembles, according to Bushnell, certain parts of the Tennessee Mountain Formation and may be an offset part of it; the differences may be due to a greater degree of silicification in the Paleozoic limestone. In 1969, a sample (field no. 69NC126) was collected from this unit in the Rowland quadrangle, and the conodonts from it were reported on by J. W. Huddle, who stated that the fauna was probably Ordovician. On this basis, the Paleozoic limestone unit of Bushnell (1967) is mapped (pl. 1) as part of the Tennessee Mountain Formation.

Ordovician System

***Pogonip Group (Lower and Middle Ordovician)* [Op].** The Pogonip Limestone, as originally defined by King (1876, 1878), embraced all the strata between the Prospect Mountain Quartzite and the Eureka Quartzite. Later, Merriam and Anderson (1942) raised the Pogonip to a group and restricted it to the strata lying between the top of the Upper Cambrian Dunderberg Shale, which is present in the Eureka mining district and the base of the Eureka Quartzite. More recently, Nolan and others (1956), in their report on the Eureka district, redefined the Pogonip Group to include, in ascending order: the Goodwin Limestone, the Ninemile Formation, and the Antelope Valley Limestone; the latter two are new units. As now defined, the group includes rocks ranging from Early Ordovician to Middle Ordovician.

In regional extent, the Pogonip has been recognized from southeastern California to much of eastern Nevada and western Utah and, locally, southern Idaho. In Elko County, rocks assigned to the Pogonip Group occur in the Kinsley Mountains [55], in the Toano Range and the Goshute Mountains [35, 41], in the Pilot Range [36], at Spruce Mountain [46], in the Pequop Mountains [47], in the Windermere Hills [26], at Antelope Peak and in the Snake Mountains [15, 25], in the southern Ruby Mountains [49], in the Piñon Range [43], in the Jarbidge Wilderness [14], in the Mountain City 15′ quadrangle [4], and in the Wild Horse 15′ quadrangle [11A].

In the Kinsley Mountains [55], Buckley (1967) divided the Pogonip Group, which has a total thickness there of more than 4,500 ft, into two informal members; neither the base nor top was seen. The lower member, more than 1,800 ft thick, consists of massive limestone and dolomite, and thin-bedded argillaceous limestone and shaly limestone; the top of this member was placed at the top of the highest massive dolomite bed. The upper member, more than 2,700 ft thick, is a thin- to thick-bedded argillaceous limestone. Intraformational limestone conglomerate is common in 1- to 2-ft-thick beds. Minor bedded chert is present throughout; it generally ranges in color from light brown through light gray to buff.

In the Toano Range and the Goshute Mountains [49], H. J. Bissell (written commun., 1973) measured a total thickness of 4,290 ft of the Pogonip overlying the Notch Peak Formation of Cambrian age and underlying the Eureka Quartzite. He recognized the following units, in

ascending order: the Garden City Formation, with five unnamed members, 3,100 ft thick; the Kanosh Shale, 275 ft thick; the Lehman Formation, 680 ft thick; the Swan Peak Quartzite, 55 ft thick; and the Crystal Peak Dolomite, 180 ft thick. (The U.S. Geological Survey does not include the Garden City, Swan Peak, or Crystal Peak in the Pogonip Group.)

The units commonly recognized in western Utah and eastern Elko County as parts of the Pogonip Group, which have been assigned names different from those used in the Eureka area, are, in ascending order: the Garden City Formation, the Kanosh Shale, the Lehman Formation, the Swan Peak Quartzite, and the Crystal Peak Dolomite. All these units are here mapped (pl. 1) with the Pogonip for the purposes of this report, but it should be recognized that where the Crystal Peak Dolomite is absent or thin, the Swan Peak Quartzite may have been mapped with the Eureka Quartzite. In western Elko County, the Pogonip is poorly fossiliferous, and the subdivisions recognized correspond to those of the Eureka area; on the geologic map (pl. 1), all these units are mapped with the Pogonip.

In the northern Toano Range [35], Pilger (1972) indicated that the Pogonip is present in several thrust plates and is intensely faulted. The basal Pogonip is a highly argillaceous, nodular, gray, fine- to medium-grained crystalline limestone that includes a brown to black, cherty, thick-bedded, nodular, gray limestone. The Kanosh Shale has a thin cherty dolomite at the base and a thin quartz arenite above; the upper half of quartz arenite is cross-bedded. Above the quartz arenite is a bluish-brown crystalline dolomite, a shaly yellow-gray nodular limestone, a thin cherty limestone, and an argillaceous gray limestone with minor argillite partings. Above the Kanosh is the Lehman Formation, which consists of blue-gray, crystalline, fine-grained, thin- to medium-bedded, yellowish-orange-weathering argillaceous limestone; the Lehman is highly fossiliferous and contains planispiral gastropods and the ostracode *Leperditia*, which are characteristic. The total thickness of the Lehman is about 650 ft; the top of the formation is brecciated. Overlying the Lehman is the Swan Peak Quartzite, which is overlain by the Crystal Peak Dolomite, which consists of 50 ft of cherty gray dolomite; above the Crystal Peak Dolomite is the Eureka Quartzite.

In the Pilot Range [36], O'Neill (1968) divided the 3,935 ft of the Pogonip into five formations: the Garden City Formation, which he divided into two members totaling more than 2,515 ft in thickness; the Kanosh Shale, 215 ft thick; the Lehman Formation, 840 ft thick; the Swan Peak Quartzite, as much as 45 ft thick; and the Crystal Peak Dolomite, 320 ft thick, upon which rests the Eureka Quartzite.

In the Spruce Mountain 15′ quadrangle [46], Hope (1972) recognized about 2,500 ft of the Pogonip Group, mostly thin-bedded to massive gray limestone with shaly partings; at the top is a very fine grained, granular, dark-gray dolomite about 50 ft thick. Hope (1972) distinguished one unit in mapping—the Kanosh Shale, which consists of about 200 ft of medium-gray, highly siliceous pyritic shale with thin interbeds of gray silty limestone.

In the Pequop Mountains [34], Thorman (1970) recognized in the most complete section of the Pogonip a total thickness of 1,855 ft, but the base is faulted. The lowest unit he recognized was the Wah Wah or Juab Limestone, 585 ft thick, overlain by: the Kanosh Shale, 580 ft thick; the Lehman Formation, 510 ft thick; and the Crystal Peak Dolomite, 180 ft thick. The contact of the Crystal Peak Dolomite with the overlying Eureka Quartzite is gradational through a 5-ft interval of sandy dolomite and quartz sandstone.

In the Windermere Hills, in an area northeast of Wells and south of the area mapped by Oversby (1972), R. A. Hope (written commun., 1970) mapped a thickness of 3,475 ft of rocks assigned to the Pogonip. The lowest unit of these rocks is the equivalent of the Garden City, to which he assigned a thickness of more than 800 ft, succeeded, in ascending order, by 400 ft of the Kanosh Shale, 200 ft of quartzite that resembles the Eureka, and 1,075 ft of strata assigned to the Lehman Formation. Overlying the Lehman are rocks that he considered the Fish Haven Dolomite.

In the Antelope Peak area [25], Peterson (1968) mapped 250 ft of the Pogonip, but the base is not exposed. The rock consists of massive limestone that is somewhat dolomitic, medium to dark gray, and brown to gray weathering, with irregular patches that give it a muddy look, according to R. A. Hope. The limestone is very fine grained and thin bedded; fossil hash is common.

In the northern Snake Mountains [15], Gardner (1968) mapped at least 479 ft of the Pogonip(?) consisting of dolomitic limestone overlying thin-bedded limestone.

In the extreme southern part of the Ruby Mountains, R. A. Hope measured 2,600 ft of limestone in the lower part of the Pogonip, succeeded by 100 ft of Kanosh Shale equivalent and then by 300 ft of limestone, for a total thickness of 3,000 ft. Sharp (1942) reported in the same area 3,650 ft of gray, massive cherty limestone, platy argillaceous limestone, and shale, with limy quartzite at the top.

In the Ruby Mountains [48], in the Jiggs 15′ quadrangle, Willden and Kistler (1969) reported three units in the Pogonip: a lower unit of gray, thin- to medium-bedded shaly limestone, a middle unit of medium- to thick-bedded cherty limestone with some beds of intraformational conglomerate, and an upper unit of sandy dolomite and limy sandy siltstone overlain by platy limestone. The Pogonip is succeeded unconformably by the Lone Mountain Dolomite.

In the Piñon Range [43], Smith and Ketner (1975) mapped beds that represent only the top 350 ft of the Pogonip Group; the base is not exposed. In general appearance and faunally, the Pogonip here resembles the Antelope Valley Limestone in the Eureka district (Nolan and others, 1956), which there is the uppermost formation of the Pogonip Group; here, however, the Pogonip is dolomite rather than limestone. The fauna present probably represents the *Anomalorthis* zone at the top of the Antelope Valley Limestone. The beds of the dolomite range from 1 to 12 in. in thickness; the rock is gray. Thin interbeds of cherty shale occur in the upper part; the cherty shale weathers yellow to brown,

and poorly preserved fossils are abundant. The recrystallization and silicification, which are widespread, are probably due to a nearby intrusion. The dolomite may be primary or secondary.

In the Jarbidge Wilderness part of the Marys River Basin NE quadrangle [14], Coats and others (1977) mapped massive limestone beds, probably of the Pogonip Group, that are about 1,400 ft thick. The base is not exposed, and the upper contact is a thrust fault. The limestone was dated on the basis of several moderately large gastropods collected by R. C. Greene (field no. G1398); Ellis Yochelson examined these fossils and assigned them to the lower part of the Antelope Valley Limestone.

In the Mountain City 15′ quadrangle, a few hundred feet of massive, light-colored limestone is present; the rock is extensively silicified, possibly owing to a nearby granitic intrusion. The several fossil collections from these beds contained linguloid, acrotretid, and orthoid brachiopods as well as some conodonts and several species of trilobites (field nos. 57NC21, 62NC124, 65RJ25). R. J. Ross, Jr. concluded that these rocks are Early Ordovician and are the same age as the lower part of the Goodwin Limestone (the Goodwin is the lowest of three formations in the Pogonip Group in the Eureka mining district).

Near the point where Trail Gulch leaves the mountains in the northwest corner of the Wild Horse 15′ quadrangle, a small fault sliver of intraformational conglomerate, made up entirely of limestone fragments, yielded a conodont fauna that Anita Harris stated is earliest Ordovician in age (field no. 73NC16) and thus temporally equivalent to the middle part of the Pogonip.

Eureka Quartzite (Middle Ordovician) **[Oe]**. The Eureka Quartzite was named by Hague (1883) for exposures in the Eureka mining district. Later Kirk (1933) designated Lone Mountain, about 18 mi northwest of Eureka, as the type locality. The Eureka Quartzite has been mapped in the following areas in Elko County: the Kinsley Mountains [55], the Toano Range and the Goshute Mountains [35, 41], the Pilot Range [32, 36], Spruce Mountain [46], the Wood Hills and Pequop Mountains [34, 40, 47], the Windermere Hills [8, 25], the Snake Mountains [15, 25], the Piñon Mountains [43], the Elk Mountains [7], and Wheeler Mountain [21]; it may also occur in the Bull Run Mountains [9]. Kirk (1933) considered the Eureka Quartzite to be essentially a continental deposit because of the widespread occurrence of cross-beds, ripple marks, and sun cracks. The formation is almost everywhere completely unfossiliferous except where it contains limestone or other similar rock types.

In the Kinsley Mountains [55], Buckley (1967) mapped about 200 ft of the Eureka Quartzite; neither the base nor top was seen. Here, as in most places, the Eureka is a remarkably uniform, vitreous, white, massive quartzite that weathers pink; bedding is almost invisible. The quartz grains are well rounded, well sorted, and average ¼ in. in diameter; the cement is secondary silica.

In the Toano Range and in the Goshute Mountains [41], H. J. Bissell (written commun., 1972) mapped a thickness of 0 to 20 ft of the Eureka northwest of White Horse Pass. In the northern Toano Range [35], Pilger (1972) mapped the Eureka Quartzite, where it rests on the Pogonip Group and is overlain by the Fish Haven Dolomite; here the Eureka Quartzite is a massive, medium- to coarse-grained quartz arenite that is white at the base to bluish gray at the top. It is present in klippen; its measured thickness is 428 ft. R. A. Hope measured a thickness of 425 ft of the Eureka Quartzite in the central part of the Toano Range and 950 ft in the northern part.

In the Pilot Range [32], in the Lucin mining district, Blue (1960) measured a thickness of 150 to 175 ft of the Eureka Quartzite. O'Neill (1968), in the Pilot Range, measured a thickness of 260 ft of the Eureka Quartzite.

At Spruce Mountain [46], Hope (1972) measured a thickness of 8 ft of the Eureka Quartzite. In the Windermere Hills, northeast of Wells, Hope (1972) mapped a thickness of 725 ft of the Eureka Quartzite between the Pogonip Group and the Fish Haven Dolomite.

In the Snake Mountains, in the Antelope Peak area [25], Peterson (1968) mapped a thickness of 900 ft of the Eureka Quartzite between the Pogonip Group and the Hanson Creek Formation, which here is dolomitic and limy. The Eureka consists of pink, white, and gray to black orthoquartzite that weathers grayish orange pink to pale reddish brown. Some cross-bedding is present in the lower 150 ft; 99% of the grains are medium to coarse sand size; the grains are subrounded to well rounded and cemented by quartz.

In the Wood Hills and in the Pequop Mountains [34] (Thorman, 1970), the Eureka Quartzite is a prominent light-gray-weathering cliff-former. The rock is white, vitreous, and medium grained; a maximum thickness of 325 ft was measured. A disconformity beneath the overlying Fish Haven Dolomite is believed to exist but was not observed.

In the northern Ruby Mountains, Howard (1971) mapped a white, vitreous, massive metaquartzite that he correlated with the Eureka; it disappears south of the latitude of Lamoille, apparently because of a regional disconformity. In the Elko County part of the southern Ruby Mountains [49], Sharp (1942) noted the absence of the Eureka Quartzite as well as an angular discordance between the Pogonip, of which the uppermost beds are missing, and the overlying Silurian Lone Mountain Dolomite; he interpreted this discordance as an unconformity at the Ordovician-Silurian contact. Willden and Kistler (1967) placed this unconformity at the base of the Lone Mountain Dolomite and believed that the Eureka was once present but has been eroded. Hose and Blake (1976, p. 9), however, cited the evidence of places in the southern Ruby Mountains, White Pine County, Nevada, where the bedding in the Eureka almost exactly parallels that in the highest underlying beds of the Pogonip, although they did not specify which part of the Pogonip these highest underlying beds represent. Hose and Blake (1976, p. 9) described the gradational contact between the Eureka Quartzite and the Fish Haven (or Ely Springs) Dolomite; this evidence, together with the evidence of angular discordance of Eureka or post-Eureka beds on the Pogonip in the part

of the Ruby Mountains mapped by Willden and Kistler (1979), suggests an unconformity that is post-Pogonip and pre-Eureka, and further suggests that the variations in thickness in the Eureka that have been recorded by many workers in this part of Nevada are due to wedge-outs of the Eureka against higher parts of the terrane developed by erosion of the pre-Eureka rocks that were deformed by the Ordovician tectonism described by Willden and Kistler (1967). Willden and Kistler (1979, p. 233) cited places where the base of the Lone Mountain Dolomite apparently overlies rubble of nearly white quartzite. I suggest that more than one tectonic pulse may have occurred in parts of Elko County, particularly in the southern Ruby Mountains, and that the unconformity most conspicuous at one place may be less obvious a few miles away.

In the northern Snake Mountains [15], Gardner (1968) mapped a total of 1,212 ft of the Eureka Quartzite. Here, the lowest 503 ft is orthoquartzite, overlain by 539 ft of limestone and dolomitic limestone, followed by 170 ft of more orthoquartzite. It may be that the lower orthoquartzite may be attributed to the Swan Peak Quartzite and that the intermediate limestone and dolomitic limestone may correspond to the Crystal Peak Dolomite of some authors. Thus, only the uppermost portion of 170 ft should be regarded as the true Eureka Quartzite.

In the Piñon Range [43], Smith and Ketner (1975) mapped a thickness of 70 ft of the Eureka Quartzite, which there is obscurely thin bedded to thick bedded, white, and cliff forming. The quartz grains are fine to medium sand size and well sorted. The contact of the Eureka Quartzite with the overlying Hanson Creek Formation generally is sharp; in one valley, Smith and Ketner (1975) reported that this contact appears to be gradational from quartzite into dolomite through a thickness of about 2 ft.

In the Elk Mountains [7], Mathias (1959) mapped a thickness of approximately 250 ft of the Eureka Quartzite, which is characterized by two distinct lithologies. The lowest approximately 100 ft of the Eureka in this area consists of cross-laminated, yellowish-white and mottled reddish-brown to red quartzite; the upper part is pure white and fine grained. The constituent grains are subrounded, range from $^1/_{64}$ to $^1/_{32}$ in. in diameter, and are cemented by secondary silica.

In the Wheeler Mountain area [21], Kerr (1962) reported the presence of the Eureka Quartzite in two different sequences. In one, the Smith Creek sequence, the Eureka Quartzite is about 1,027 ft thick, divided into a lower and an upper member by an intervening middle member of fossiliferous limestone. This is one of the few places where the Eureka Quartzite contains any interbedded limestone that is fossiliferous. The lowest member of the Eureka here is about 420 ft thick, of which the lowest 170 ft is cross-bedded. The quartzite is generally medium or light gray to olive gray, and commonly weathers grayish orange; the quartz grains are cemented by quartz. The middle, limy member of the Eureka in the Smith Creek sequence contains a fauna including *Receptaculites* sp., *Rafinesquinas* sp., and orthid brachiopods resembling *Orthambonites* sp. Approximately 500 ft more of the Eureka Quartzite is present above the limy member in the middle of the Smith Creek sequence. In the other sequence, called the Burns Creek sequence, the Eureka is 557 ft thick and includes a dolomite member in the lower part, but not basally. Here, the base is conformable with the underlying Pogonip Group, and contains 25 ft of light- to medium-gray, ledge-forming quartz sandstone, overlain by 90 ft of mainly light-olive-gray, medium-gray-weathering shaly dolomite, with argillaceous interbeds weathering medium reddish orange. The upper member of the Eureka in the Burns Creek sequence is 440 ft thick; it is composed of pale-yellowish-brown vitreous quartzite, with fine- to medium-grained, subrounded quartz sand grains cemented by silica and a little iron oxide.

***Aura Formation* [Oa].** The Aura Formation (Decker, 1962) is separately mapped here (pl. 1) because it differs in lithology from equivalent rocks of the eastern assemblage. The total thickness of the Aura Formation is approximately 3,800 ft [9]. The lower part of the formation consists of brown to black phyllite and chert alternating with blue-gray limestone, that ranges from ¼-in.-thick laminations to massive 300-ft-thick limestone beds. The middle part of the formation locally contains a buff, medium-grained, vitreous quartzite member, nearly 500 ft thick, that Decker considered possibly correlative with the Eureka Quartzite. Decker thought that this member was lenticular because it was not seen in exposures to the east; it appeared to me, however, on examining the area, that it may have been faulted out. Above the quartzite, brown to black laminated phyllite reappears interbedded with calcareous layers. The Aura Formation is here assigned to the transitional assemblage because its lithology seems to differ from that typical of the eastern assemblage. No paleontologic evidence for the age of the Aura Formation was found.

Ordovician and Silurian Systems

***Predominantly Dolomitic Rocks* [SOd].** A unit of Ordovician and Silurian dolomite that includes the Laketown, Fish Haven, and Ely Springs Dolomites, which are probably the lateral equivalent of the Hanson Creek Formation, in many places also includes rocks that are here mapped (pl. 1) as the Laketown Dolomite. The Fish Haven Dolomite was originally named by Richardson (1913) for exposures in southeastern Idaho; it is dated as Late Ordovician. In general, in western Utah, the Fish Haven disconformably underlies the Laketown Dolomite and in some places overlies the Eureka Quartzite. The name "Ely Springs Dolomite" was originally applied by Westgate and Knopf (1932) to an Ordovician dolomite in the Pioche mining district of eastern Nevada. The Ely Springs Dolomite is a dolomite or dolomitic limestone, commonly dark gray, weathering smoky brown, in beds as much as 5 ft thick. Some beds are laminated; in many places they are cherty. The total thickness of the Ely Springs in the Pioche district is about 675 ft. It overlies, apparently conformably, the Eureka Quartzite, which elsewhere is conformably overlain by dolomite containing Silurian fossils. The Ely Springs Dolomite is now regarded as Late Ordovician in

Nevada. Ross and others (1980, p. C2) reported that a Silurian age has been accepted for an upper member of the Ely Springs and Fish Haven Dolomites. According to Sheehan (1971), however, in the central and northern part of eastern Nevada the entire Ely Springs Dolomite is Late Ordovician.

Above the Ely Springs and Fish Haven Dolomites is a Middle Silurian (Niagaran) dolomite that was named the Laketown Dolomite by Richardson (1913) in the type area; it is a massive, light-gray dolomite, about 1,000 ft thick. All of these dolomites, the Fish Haven, Ely Springs, and Laketown, are combined on the geologic map (pl. 1).

In the southeastern part of the county, in the Kinsley Mountains [55], a unit called the Hanson Creek Dolomite by Buckley (1967) is here regarded as the Fish Haven Dolomite; it consists of dark-brown to medium-gray, massive dolomite, locally massively bedded. Only about 200 ft of this dolomite is exposed above the Ordovician Eureka Quartzite, and the top has been eroded away. The contact with the underlying Eureka Quartzite is gradational, and some quartzite and dolomite are interbedded. Fossils are absent and, because the formation is present in a klippe, the total thickness may have been greater than that measured.

In the Goshute Mountains [41], H. J. Bissell (written commun., 1970) mapped 320 ft of Fish Haven Dolomite, which he considered Ordovician, overlain by about 750 ft of the Laketown Dolomite. In the Toano Range to the north, R. A. Hope, for the purposes of this report, combined the Fish Haven and Laketown Dolomite into a single map unit. The Fish Haven Dolomite, here of Ordovician age, is 375 ft thick in the northern part of the Toano Range and 700 ft thick in the southern part; how much of this change in thickness is due to later tectonism is not altogether clear. The Fish Haven is medium- to dark-gray dolomite, very fine grained to sublithographic, massive, with thin lighter gray streaks and fossil-hash beds. No chert was noted; some silicified fossils(?) were observed, as well as some crinoid-brachiopod hash and a few cup corals. The overlying Silurian Laketown Dolomite, which, as mapped here (pl. 1), may include some of the Devonian Sevy Dolomite, is light gray, locally sugary, and 1,500 ft thick.

On the east edge of the county, in the Pilot Range, Blue (1960) mapped both the Fish Haven Dolomite and the overlying Laketown Dolomite. The Fish Haven Dolomite here is 370 to 395 ft thick, and the Laketown ranges from 1,055 to 1,070 ft in thickness. The Fish Haven Dolomite is a massive, cliff-forming, medium-gray- to black-weathering, fine- to medium-grained calcareous dolomite. The lower unit of the Fish Haven, approximately 275 ft thick, is typically a massive-appearing unit. The upper unit consists of about 100 ft of thick-bedded cherty, medium- and dark-gray arenaceous dolomite. It is slope forming and appears from a distance to be banded; the bands are rarely more than 20 ft thick. Chert nodules and stringers are present in both the lower and upper units. A few well-preserved fossils were found in the Fish Haven Dolomite. The Laketown Dolomite, of Silurian age, is chiefly fine- to very fine grained calcareous dolomite and dolomite; the beds range in thickness from several feet to more than 20 ft and are light to medium gray as seen from a distance. The lower zone in the Laketown is about 250 ft thick and is light gray; the middle zone, approximately 400 ft thick, is dark gray to black; and the upper zone, ranging from 365 to 415 ft in thickness, is light to medium gray. The lower two zones are thin bedded, have rough, weathered surfaces, and contain chert nodules and stringers; the chert is dark gray to black on fresh surfaces and weathers brown.

In the southern Pilot Range [36], O'Neill (1968) described both the Fish Haven and Laketown Dolomites. The Ordovician Fish Haven Dolomite there is approximately 440 ft thick, consisting largely of cherty dolomite and some shaly dolomite. Overlying the Fish Haven is about 540 ft of the Laketown Dolomite; the contact is not exposed.

In the Pequop Mountains [34], Thorman (1970) distinguished several separate thrust slices that consist of different stratigraphic sequences. Two of these slices include units within which, for the purposes of mapping (pl. 1), rocks ranging in age from Ordovician to Devonian are combined; these units are discussed in the next section of this report. In one thrust plate in the Pequop Mountains, the Ordovician Fish Haven Dolomite and the Silurian Laketown Dolomite are combined for the purposes of mapping; in another plate only the Fish Haven is present, and the overlying Laketown is missing. In Thorman's (1970) structural plate IID, the total thickness of the Fish Haven in the Pequop Mountains is 570 ft; it consists of four units of light-to dark-gray, medium-bedded dolomite that alternates light and dark. The lower 80 ft of the Fish Haven is dark-gray dolomite containing black chert. Overlying the Fish Haven Dolomite is the Laketown Dolomite, which totals 1,110 ft in thickness, according to Thorman (1970). The lower member of the Laketown is 390 ft thick and contains medium-bedded dolomite with thin-bedded shaly dolomite at the base. The middle member is a dolomite that is thick bedded and dark gray; the upper member, 580 ft thick, is medium-bedded light-gray dolomite. In structural plate IIE of Thorman's (1970) classification, only the Fish Haven Dolomite is present.

***Hanson Creek Formation* [SOh].** The Hanson Creek Formation was named and defined by Merriam (1940, p. 10–13). The type section is on the north fork of Pete Hanson Creek on Roberts Creek Mountain, northwest of Eureka, in Eureka County, Nevada. In the type section the total thickness of the Hanson Creek is about 560 ft, consisting mostly of dolomitic limestone and limestone. Mullens and Poole (1972) showed that the uppermost few feet of the Hanson Creek in parts of Eureka County should be regarded as Early Silurian.

In the Snake Mountains area [15, 25], Gardner (1968) and Peterson (1968) mapped the Hanson Creek Formation. In the area mapped by Gardner, the Hanson Creek was estimated to be 1,075 ft thick, and consists of limestone. In the area mapped by Peterson, the total thickness of the Hanson Creek Formation is about 1,000 ft. The basal 275 ft is a massive, fossiliferous, dark-gray dolomite, finely crystalline and sandy near the base; the fossils suggest an age of late Middle Ordovician. Above this dolomite are, in ascending

order: 45 ft of massive, light-gray, coarsely crystalline limestone; 60 ft of dolomite; and 225 ft of light- to medium-gray, thin-bedded limestone that grades into massive limestone near the top (the uppermost 35 ft). The top of the Hanson Creek was considered to be Late Ordovician. The formation has a gradational boundary with the Roberts Mountains Formation, which is more massive and resistant in this area than farther west.

In the Piñon Range [43], Smith and Ketner (1975) described the Hanson Creek Formation, which they estimated to be about 130 ft thick. It is a thin- to thick-bedded, fine-grained dolomite containing a few limestone beds, which are commonly dark gray to black. The bedding is distinct in some areas but more commonly is obscure. It was assigned a Middle and Late Ordovician age on the basis of corals and brachiopods which are abundant locally but poorly preserved. The total thickness of the Hanson Creek here is somewhat more than a quarter of its thickness at the type locality, and Smith and Ketner (1975) suggested that, like the Eureka Quartzite, the Hanson Creek thinned out originally against the Tooele arch.

In the Wheeler Mountain (Seetoya Peak) area [21], Kerr (1962) reported the Hanson Creek Formation in two different thrust slices. In one thrust slice, a total thickness of 724 ft was measured, about the lowest 300 ft of which is bedded, medium-gray calcisiltite partly replaced by beds and nodules of black chert. The middle segment, about 40 ft thick, is ridge-forming, medium-dark-gray quartz-silty dolomite; the uppermost segment, at least 365 ft thick, is dominantly dark-gray calcisiltite in beds 1 to 2 in. thick. In the second thrust slice, which originally lay farther north (the Burns Creek sequence of Kerr, 1962), the Hanson Creek Formation comprises about 535 ft of generally thin bedded, medium-gray calcisiltite.

Leland Cress and I also mapped the Hanson Creek Formation in the California Mountain quadrangle [12A], northeast of the area mapped by Kerr. The lithologies are similar, but noteworthy is a 15-ft-thick bed of oolitic limestone near the top of the Hanson Creek. Most of the fossils collected from the Hanson Creek (field nos. 69NC94, 69NC95, 70CS34, 70NC42, 70NC43, 70NC138; colln. D2383CO) were trilobites. The formation appears to underlie conformably the Roberts Mountains Formation; no fossils were collected from either formation near their depositional contact.

Most of the Hanson Creek Formation in Elko County has been dated as Middle and Late Ordovician on the basis of its marine fauna. Since the uppermost part is unfossiliferous, it is not known whether the formation in Elko County includes beds of Early Silurian age although it has been assumed to do so.

Silurian and Devonian Systems

Lone Mountain Dolomite **[DSlm,DSd]**. The Lone Mountain Dolomite was named the Lone Mountain Formation by Hague (1883, p. 262–263). As originally defined, it embraced deposits of both Ordovician and Silurian age. Merriam (1940, p. 10, 13–14) applied the name Roberts Mountains Formation to the middle part of this sequence and restricted the name Lone Mountain Formation to dolomite rocks overlying the Roberts Mountains Formation. He considered the Roberts Mountains to be Early Silurian and the restricted Lone Mountain to be Late Silurian. Current ideas on the relation between the Lone Mountain Dolomite and the Roberts Mountains Formation were illustrated by Berry and Murphy (1975, p. 5, fig. 2), who showed the lower part of the Lone Mountain to be coeval with most of the Roberts Mountains Formation. At present, the Lone Mountain Dolomite is generally regarded as a reefal deposit and the Roberts Mountains as an off-reef–slope deposit. In the southern Ruby Mountains area [49], the Lone Mountain Dolomite is the only Silurian rock present; the Ordovician formations above the Pogonip have probably been removed by erosion or were not deposited.

In the central Ruby Mountains, Willden and Kistler (1979) reported that the Lone Mountain Dolomite consists of two members separated by an unconformity; the lower member rests unconformably on rocks ranging in age from Late Cambrian to Middle and Late Ordovician. A layer of conglomerate containing clasts of quartzite, limestone, and dolomite is present locally at the base of the lower member. The lower member above the conglomerate consists of: platy, fine- to medium-grained, locally porcelaneous dolomite as much as 100 ft thick; dark-gray to black, generally medium grained, medium- to thick-bedded, fossiliferous dolomite, ranging in thickness from 40 to 100 ft; and medium- to thick-bedded, finely laminated to massive, saccharoidal, light-gray, sublithographic to coarsely crystalline dolomite. A layer of dolomite conglomerate locally marks the base of the upper member; it grades upward by interfingering with light-gray cherty dolomite, which is overlain by about 200 ft of medium-gray, fossiliferous limy dolomite. The remaining 700 to 1,000 ft to the top of the Lone Mountain consists of light-brownish-gray, thick-bedded to massive saccharoidal dolomite interlayered with white to pale-bluish-gray sublithographic dolomite. The maximum preserved total thickness of the Lone Mountain Dolomite in the central Ruby Mountains is about 2,700 ft, and the minimum about 200 ft; it grades upward into rocks formerly designated the Nevada Formation. Willden and Kistler (1979) considered the entire Lone Mountain Dolomite in the central Ruby Mountains to be Silurian because of the absence of Devonian fossils.

In the southern Ruby Mountains [49], Sharp (1942) described a thickness of 1,350 ft of the Lone Mountain Formation. At the base is 100 ft of dark-gray, nearly black, medium-grained to dense flaggy dolomite, which weathers light gray, and contains irregular intergrowths of white, coarsely crystalline dolomite and brachiopods in the upper part. The overlying strata consist of light-gray, medium- to coarse-grained crystalline limestone containing corals, crinoid stems, and scattered gray chert nodules. The Lone Mountain, at least locally, probably rests unconformably on the Ordovician Pogonip Group.

In southwestern Elko County [43], Smith and Ketner (1975, 1978) mapped partial stratigraphic sections of the Lone Mountain Dolomite that aggregate as much as 775

ft in thickness. The base of the formation is not exposed, but the top is, and the formation is generally divided into three units. The lowest unit, about 610 ft thick, is brownish gray to yellowish gray; the dolomite beds are generally about 2 ft thick and some show thin laminations. A 10-ft-thick sedimentary-breccia zone occurs about 540 ft above the base of the section. The middle unit consists of alternating brown and gray beds of dolomite, 2 to 12 ft thick. Both the brown and gray beds are vuggy; very small amounts of quartz grains are present near the top. The upper unit also consists of alternating brown and gray beds of dolomite 2 to 3 ft thick. The brown beds have a petroliferous odor and contain many crinoidal columnal fragments; both the brown and gray beds are vuggy.

In the Jiggs 15′ quadrangle [48], Willden and Kistler (1969) described a thin sequence of the Lone Mountain Dolomite as "Generally medium- to thick-bedded sugary-textured, light-gray dolomite. Some beds are finely laminated and others are massive."

In the Spruce Mountain 15′ quadrangle [46], Hope (1972) combined several of the Silurian and Devonian dolomitic units into a single map unit. He described this unit as light-gray, thoroughly brecciated dolomite interbedded with light-gray, very fine grained dolomite and dark-gray, very fine grained dolomite and minor shale. The total thickness of the unit is about 1,000 ft. The basal 200 ft contains small black chert nodules and Silurian pentamerous brachiopods. The Lone Mountain Dolomite is considered to be Silurian and Devonian in the area of this report.

Roberts Mountains Formation **[DSrm]**. The Roberts Mountains Formation was defined by Merriam (1940) as a carbonate unit that overlies the Hanson Creek Formation and underlies light-gray dolomite of the Lone Mountain Dolomite, restricted. The type section of the Roberts Mountains Formation is on the west side of Roberts Creek Mountain, about 30 mi northwest of Eureka, Nevada, where the total thickness is 1,900 ft. The formation was also discussed by Nolan and others (1956, p. 36–37), who considered it to be Silurian (Niagaran) as defined by Merriam (1940). In the Carlin-Piñon Range area, Smith and Ketner (1975, p. A33) regarded the 150 ft of the Roberts Mountains Formation exposed there as earliest Devonian. Thicknesses in other areas of Elko County are much greater, and Silurian fossils are common. The Roberts Mountains Formation is considered to be Silurian and Devonian in the area of this report.

Mullens (1980) has recently reviewed exhaustively the stratigraphy and petrology of, and has given some additional fossil data on, the Roberts Mountains Formation in Nevada. The principal subdivision of regional extent used by Mullens (1980, p. 7) is a basal unit of chert, limestone, and dolomite; this unit is erratic in thickness and locally absent but may be as much as 100 ft thick. In Elko County, the Roberts Mountains Formation was observed in Thomas Jose Canyon (Seetoya Mountain area) [21] by Kerr (1962), in the Antelope Peak area [25] by Peterson (1968), and in the Snake Mountains area [15] by Gardner (1968). According to Mullens (1980, p. 7): "typically, the cherty unit contains about half chert and half carbonate rock in alternating beds 2.5–50 cm [1–20 in.] thick... The chert content, however, ranges from 25% to 100%... Most chert is black or brown and weathers black or brown..." He added (p. 8): "...the cherty unit conformably overlies both transitional shaly limestone and coarse-grained carbonate rock deposited eastward, and shelf rocks of the geosyncline... The cherty unit seemingly conformably underlies laminated limestone typical of the bulk of the Roberts Mountains Formation."

The laminated limestone generally weathers to platy fragments and locally contains medium- to coarse-grained limestone in thin lenticular beds, as well as thin beds of chert and small chert nodules; the coarser grained beds and chert nowhere make up more than 2% of the unit. The laminated limestone, where fresh, is black to dark gray and weathers medium gray at first, then tan, pale red, and reddish brown. The average composition of all unaltered laminated limestone is about 70% total carbonate (45% calcite and 25% dolomite) and 30% insoluble residue.

Graptolites (Mullens, 1980, p. 25) indicate that the Roberts Mountains Formation contains Silurian beds of Llandoverian, Wenlockian, Ludlovian, and Pridolian age and Early Devonian beds of Gedinnian and Siegenian ages.

In the Pequop Mountains [34], Thorman (1970) described, from one of the thrust plates in that area, 595 ft of the Roberts Mountains Formation, consisting of light-gray cherty limestone, with 45 ft of argillaceous soft-weathering dolomite at the top. No fossils were found.

In the Snake Mountains [15], Gardner (1968) mapped a thickness of the Roberts Mountains Formation of more than 436 ft; no top was seen. The rock is largely platy and silty limestone, with thin interbeds of calcareous silty shale; some chert occurs near the base of the formation. The rock ranges in color from yellowish brown to dark gray to medium gray where fresh, and from olive gray to medium gray and light gray where weathered. The chert unit near the base consists of thin beds of chert interbedded with micrite, overlying about 5 ft of massive, light-gray dolomitic micrite containing pelmatozoan columnals.

In the Antelope Peak area [25], Peterson (1968) described approximately 1,500 ft of the Roberts Mountains Formation, which generally forms a smooth scree slope except for a basal cliff. The lowest 25 ft is massive, light-gray dolomitic limestone overlain by 25 ft of black, thin-bedded chert intercalated with ¼-in.-thick laminae of dark-gray limestone. Above the chert is 950 ft of very thin bedded, light-gray to light-brown limestone; the lower 15 ft contains *Monograptus*, is nearly homogeneous in lithology, and includes a few cherty zones several feet thick. Above the limestone is about 500 ft of thin- to medium-bedded, fossiliferous, light-gray limestone overlain by Devonian limestone of similar appearance that cannot be distinguished lithologically. According to J. F. Smith, Jr. (written commun., 1980), the massive dolomitic limestone below the lowest black chert should probably be excluded from the Roberts Mountains Formation and included with the Hanson Creek Formation.

In western Elko County, the Roberts Mountains Formation occurs near the crest of Lone Mountain, in the Singletree Creek quadrangle [30], in the eastern part of the Tuscarora 15′ quadrangle [21], and in the two quadrangles just east of the Tuscarora 15′ quadrangle—the California Mountain [21A] and Mahala Creek West [30A] 7.5′ quadrangles.

In the Sulphur Spring Range in the extreme southwest corner of the county [55A], C. A. Nelson and D. C. Carlisle (written commun., 1972) mapped the Roberts Mountains Formation between the Hanson Creek Formation and the Lone Mountain Dolomite. They reported that it consists of thin-bedded, platy silty limestone, gray limy siltstone, and minor medium-grained clastic limestone. Berry and Murphy (1975), mapping in the type area of the Roberts Mountains Formation, recognized that typical lithologies of the Roberts Mountains Formation extend upward into the lowermost Devonian (*Monograptus uniformis* zone). In the Simpson Park Range section in Eureka County, Nevada, Berry and Murphy (1975, p. 20) report that the Silurian part of the Roberts Mountains Formation is 1,255 ft thick and that the Devonian part is probably between 350 and 400 ft thick.

In the Wheeler Mountain (Seetoya Peak) area [21], Kerr (1962) recognized two formations, the lower of which he called the Happy Camp Formation; it lies conformably on the Hanson Creek Formation. The lower member of the Happy Camp, about 108 ft thick, consists of light- to medium-gray calcisiltite and very light gray calcilutite; the basal part is locally dolomitized. The upper member of the Happy Camp, from 20 to 65 ft thick, consists of alternating thin-bedded black chert and gray calcisiltite. The Happy Camp is overlain disconformably by a second formation that Kerr named the Taylor Canyon Formation, a calcareous argillaceous quartz siltite. Strata above the siltite have been truncated by a thrust fault; however, a maximum thickness of 1,150 ft of the Taylor Canyon is preserved. The upper part of the Happy Camp Formation and the Taylor Canyon Formation, taken together, are regarded as equivalent to the Roberts Mountains Formation; this correlation is based on the ubiquity throughout the section of various species of *Monograptus* that closely resemble those in the Roberts Mountains Formation.

To the north of the Wheeler Mountain area [10A], the Roberts Mountains Formation continues and occupies almost the whole width of the range, but here it also lies below overthrusts of western-assemblage rocks. The Roberts Mountains is a fairly uniform, thin-bedded, gray calcisiltite, somewhat siliceous in composition. The presence of *Monograptus* and continuity with the Taylor Canyon Formation of Kerr (1962) establish correlation.

In the Carlin-Piñon Range area [43], Smith and Ketner (1975, p. A32) described a small outcrop area of the Roberts Mountains Formation amounting to less than a quarter of a square mile. The thickness of the exposed part is between 200 and 500 ft; the rocks are platy and consist of 70% dolomite, 10% quartz, and the rest organic matter. Graptolites are abundant and are Early Devonian (Gedinnian); these fossils are equivalent in age to those in part of the Lone Mountain Dolomite. It is worth noting that elsewhere in Elko County most of the Roberts Mountains Formation is Silurian but part of it is Devonian; here, apparently only the Devonian part is exposed. The Roberts Mountains Formation in this area is allochthonous.

At Lone Mountain [30], Ketner (1975b) reported that the Roberts Mountains Formation is a thin- to medium-bedded, carbonaceous, blue-gray limestone. At Lone Mountain, the Roberts Mountains Formation is overlain conformably by Devonian rocks formerly designated the Nevada Formation. A section of the Roberts Mountains Formation and overlying unnamed Devonian rocks at Bootstrap Hill [28] was published by Evans and Mullens (1976). The lowermost 590 ft of this section consists of the Roberts Mountains Formation; neither the base of the formation nor the cherty zone commonly found above the base is exposed here. The rock consists of "...mixed silty dolomitic laminated limestone and coarse-grained limestone in the ratio 4:1. Beds of black chert 1–2 in. (2.5–5 cm) thick occur within the laminated limestone. The beds of laminated and thick-bedded coarse-grained limestone range in thickness from a few inches (several centimeters) to 60 ft (18 m). The thickest zones of coarse-grained limestone are about 30 ft (9 m) thick. Many of the coarse-grained beds have scour surfaces, bioclastic debris (corals, stromatoporoids, brachiopods, and algae), angular fragments of coarse-grained pelletal limestone, and graded bedding." (Evans and Mullens, 1976, p. 119, 121). Above the laminated limestone is 900 ft of "...is mainly coarse-grained limestone; it includes less than 5% laminated limestone identical to the characteristic lithology of the underlying Roberts Mountains Formation. The thickest zone of the laminated limestone occurs in the lowermost 100 ft (30 m) of the Devonian limestone and is 10 feet (3 m) thick." (p. 122). It is presumably this lowermost 100 ft that Merriam and McKee (1976, p. 16) favored including in the Roberts Mountains Formation "...because it is similar to the upper part of that formation at many places in central Nevada." According to Merriam and McKee (1976, p. 16): "An alternative nomenclature, in line with other studies of the Silurian and Lower Devonian in central Nevada, would term the lower part of the unnamed unit of Evans and Mullens (the top of our Roberts Mountains Formation) the Windmill Limestone...and the upper part the Rabbit Hill Limestone." In any event, Evans' and Mullens' map does not distinguish the Roberts Mountains Formation from the overlying unnamed Devonian formation. The reader should realize, then, that the Roberts Mountains Formation at Bootstrap Hill, as mapped here, includes rocks higher in the Devonian than is commonly the case elsewhere, where the lithologic boundary between platy-fracturing and massive limestone is used as the formational boundary.

Devonian System

***Sevy, Simonson, and Nevada Formations* [Dd].** The Devonian sequence includes three well-known formations: the Sevy Dolomite, the Simonson Dolomite, and the Nevada Formation. The Sevy Dolomite was named and defined by Nolan (1930) from exposures in the Gold

Hill mining district of western Utah. It is a remarkably homogeneous, typically well-bedded, light-gray dolomite, in layers 6 to 12 in. thick, that weathers very light gray and is extremely dense. The basal bed is conglomeratic in the Gold Hill area. The total thickness of the Sevy is approximately 450 ft; Nolan observed no diagnostic fossils. The Sevy grades into the overlying Simonson Dolomite, which here contains Middle Devonian fossils.

Osmond (1954) recognized the Sevy Dolomite as far west as east-central Nevada and at that time thought that the lower part might be Late Silurian. The Sevy rests unconformably (Osmond, 1962) on the Lone Mountain or Laketown Dolomite over most of its regional extent; it is lithologically equivalent to the lower part of the Nevada Formation of former usage at Eureka, Nevada. Osmond (1962) divided the Sevy into three members, in ascending order: a dolomite member, which reaches a maximum thickness of more than 1,300 ft in eastern Nevada; a cherty argillaceous member, probably present only in the extreme southwestern part of Elko County; and a sandy member, apparently also extending only into the southwestern part of the county. The sandy member is overlain by coarsely crystalline dolomite of the Simonson Dolomite. Osmond (1962) considered the Sevy Dolomite to be entirely Devonian. The Sevy Dolomite is presently regarded by the U.S. Geological Survey as Early and Middle Devonian.

In the southern Wood Hills, Anctil (1961) and Willson (1961) described the Sevy Dolomite as a massive bench-forming formation of light- to medium-gray units, most of which are devoid of textural and structural variations and are very fine grained. High in the Sevy Dolomite but several hundred feet below the upper, sandy member is a blue-gray, medium-grained dolomitic limestone, approximately 200 ft thick. The upper member is a fine-grained rock composed of 60% to 70% quartz, with a dolomitic matrix. It is light gray on a fresh surface; cross-lamination is common. The thickness of the upper member is unknown.

In the Goshute Mountains [41], Bissell (1964) mapped 485 ft of the Sevy Dolomite. In the Pequop Mountains [34], Thorman (1970) described the Sevy Dolomite as about 85 ft thick and composed of fine- to medium-grained dolomite that strongly resembles units in the Laketown Dolomite. The sandy upper beds of the Sevy grade into the Simonson, and placement of the contact is a matter of individual judgment.

The Simonson Dolomite was originally described by Nolan (1930) from the Gold Hill mining district in western Utah. It is characteristically a medium- to dark-gray dolomitic rock in which individual grains of dolomite are sufficiently large to be distinguished by the unaided eye. The beds range from 1 to 2 ft in thickness; a fine lamination is generally present but may be extremely irregular in detail. Two nonresistant layers of dolomite conglomerate occur within the formation; a third conglomerate, which is everywhere resistant, has been chosen to mark the uppermost unit of the Simonson Dolomite. The thickness of the Simonson in the Gold Hill mining district is about 1,000 ft; it is overlain by the Guilmette Formation at Gold Hill. In many places in Elko County, the Simonson differs little from the Sevy Dolomite except in color and local, fine brown laminations.

In the Windermere Hills [26], Oversby (1972) recognized a considerable thickness of what he called the Nevada Formation, which R. A. Hope preferred to regard as the Simonson Dolomite. The total thickness here is more than 1,700 ft; the base is not exposed. The rock is a gray calcareous dolostone, medium bedded, commonly mottled and laminated, containing euhedral dolomite and authigenic quartz in a calcite cement; dolomite makes up approximately 60% to 75% of the rock. Beds of light- and dark-gray blocky dolomite alternate at about 10-ft intervals except in the upper 120 ft, where they alternate at about 1-ft intervals; finely laminated, thin (approximately 1 ft thick) very fine grained dolomite interbeds also occur in the upper part. The dolomite is finely laminated and tan. All of the rocks contain sedimentary structures such as those described by Osmond (1954) for the lower and upper members of the Simonson, in which light- and dark-gray dolomite beds alternate regularly. A 6-ft-thick white orthoquartzite bed is present about 1,500 ft below the top of the Simonson. The Simonson here is regarded as Middle Devonian.

In the southern Snake Mountains, R. A. Hope mapped the Simonson Dolomite, the base of which is not exposed, and reported that it is a typical laminated dolomite.

In the southern Wood Hills, Anctil (1961) and Willson (1961) described the Simonson Dolomite as overlying the sandy member of the Sevy. However, R. A. Hope (written commun., 1973) considered the sandy member to be the basal part of the Simonson. Thorman (1970), mapping in the Wood Hills [34], described the Simonson as consisting of alternating light and dark beds of laminated dolomite; the lamination is characteristic. Crossbeds, from a few feet to 200 ft thick, form the basal beds.

In the Pequop Mountains [34], Thorman (1970) described the Sevy and Simonson Dolomites. The Sevy, which is about 85 ft thick, is fine- to medium-grained dolomite that strongly resembles units in the Laketown Dolomite. In his subplate IID, the Simonson Dolomite includes a basal sandy dolomite member and is about 1,170 ft thick (Thorman, 1970); elsewhere, in subplate IIH the Simonson is about 970 ft thick (Thorman, 1970). The Simonson consists of alternating light and dark beds of laminated dolomite; the lamination is distinctive. Basal beds of the Simonson consist of cross-bedded sandy dolomite in three subplates and range from a few feet to more than 200 ft in thickness. The upper half of the Simonson contains interbedded limestone similar to that of the Guilmette Formation.

In the Goshute Mountains [41], H. J. Bissel (written commun., 1965) estimated the Simonson Dolomite to be 485 ft thick.

In the Toano Range north of Silver Zone Pass, R. A. Hope (unpub. data, 1973) mapped the Simonson Dolomite, which he found was medium- to dark-gray laminated dolomite containing abundant *Amphipora* (a stromatoporoid resembling spaghetti) and sections of elongate brachiopods. He thought that this dolomite was probably the upper part of the Simonson. No Sevy

Dolomite was recognized by Hope, but if present, it probably was mapped with the Laketown or Fish Haven Dolomites.

In the Pequop Mountains [31], Thorman (1970) mapped several thrust plates in which the stratigraphic sections differ somewhat. In subplate IID, the Simonson Dolomite is mostly laminated light and dark dolomite and totals 1,170 ft in thickness (Thorman, 1970). Basal beds are cross-bedded sandy dolomite, ranging from a few feet to as much as 200 ft in thickness. The Simonson rests on the Laketown Dolomite and is overlain by the Guilmette Formation. Although Thorman did not recognize the Sevy Dolomite, Osmond (1962), in his study of the Sevy, thought that it might be as much as 375 ft thick. Budge (1972) and Sheehan (1971) believed that in subplate IID there were some Late Silurian faunal assemblages near the base of what they considered the Simonson. This relation suggests that the lithologic boundaries do not coincide with the chronologic ones here, whereas they do coincide in the area farther east. In subplate IIH, Thorman (1970) recognized 85 ft of Sevy and 970 ft of Simonson Dolomite; these units rest on the Lone Mountain Dolomite. The Sevy is fine- to medium-grained dolomite that strongly resembles some units in the Laketown. Basal beds of the Simonson are cross-bedded sandy dolomite in three of the subplates. The upper half of the Simonson Dolomite contains interbedded limestone, like the Guilmette.

In the southern Pilot Range, O'Neill (1968) measured 365 ft of the Simonson, although this thickness represents only a partial section. The Simonson here rests on the Laketown Dolomite and is overlain by dolomite of the Guilmette Formation. The Simonson is divided into two members. The lower member is medium crystalline, with alternating bands of light- and dark-gray dolomite; these bands average 2 ft in thickness. The total thickness of the lower member is at least 75 ft. The upper member, more than 290 ft thick, consists of medium-gray, fine- to medium-crystalline, finely laminated, calcareous dolomite with local bright-red argillaceous partings and zones of fossil hash, interbedded with light- to medium-gray, medium-crystalline, locally laminated dolomite with irregular bedding planes. The upper member forms a bench-and-bluff topography.

In the Leppy Range (the western, or Elko County, part of the Silver Island Mountains [42]), Schaeffer and Anderson (1960) mapped a total thickness of 1,270 ft of the Simonson Dolomite, resting on the Laketown Dolomite and overlain by what they termed the Guilmette Dolomite. The lower member, 336 ft thick, consists of alternating light- and dark-gray dolomite. The upper member, 934 ft thick, consists of alternating light- and dark-gray dolomite with interbedded limestone and dolomite like that in the Pilot Range. The age of the Simonson in the Leppy Range is thought to be Middle Devonian.

In the Spruce Mountain 15′ quadrangle [46], Hope (1972) mapped about 500 ft of the Simonson Dolomite, which he described as a laminated, medium- and dark-gray, very fine grained dolomite. Several beds of dolomite containing quartz sand are present near the base, and the upper 200 ft contains interbedded limestone. The Simonson here rests on undifferentiated dolomite that is at least partly Laketown and may contain some Sevy. In some places, this undifferentiated dolomite also contains some Simonson, which, where altered, is difficult to distinguish from the underlying Laketown and Sevy Dolomites.

The Nevada Formation was originally named the Nevada Limestone and described by King (1876). The name was redefined by Hague (1883), who described the Nevada Limestone in the Eureka area, near the type area, as gray, saccharoidal, and indistinctly bedded in the lower horizons, passing upward into strata that are distinctly bedded, brown to reddish brown and gray, commonly finely striped, and variegated in appearance. The formation is mainly limestone and dolomite, although intercalated beds of shale and quartzite also occur. Merriam (1940) restricted the Nevada Formation to the lower 2,448 ft of Devonian strata as exposed at Lone Mountain (west of Eureka); the upper part of the original Nevada Formation was named the Devils Gate Formation. Nolan and others (1956) subdivided the Nevada Formation in the vicinity of Eureka into the following members, in ascending order: Beacon Peak Dolomite, Oxyoke Canyon Sandstone, Sentinel Mountain Dolomite, Woodpecker Limestone, and Bay State Dolomite Members.

Hose and others (1981) raised every named member within the Nevada Formation to formation rank, and, as a consequence, the U.S. Geological Survey considers the name Nevada Formation to be obsolete. Although abandoned, the name is retained in this report merely to reflect the stratigraphic nomenclature employed in the publications being cited, it has not yet been feasible to subdivide rocks previously assigned to the Nevada Formation in Elko County as was done by Hose and others (1981) in Eureka County.

In the Ruby Mountains, in the Jiggs 15′ quadrangle [48], Willden and Kistler (1969) described the Nevada Formation from the Cedar Mountain klippe on the west side of the range as consisting of dark-gray to gray, laminated and mottled dolomite.

In the Franklin Lake NW quadrangle, according to Willden and Kistler (1979, p. 238), the Nevada Formation is about 1,200 ft thick and "...consists mainly of alternating beds of light-, medium-, and dark-gray, fine- to medium-grained dolomite. The beds generally are thin but some are laminated and some coral-stromatoporoid reefs occur, particularly in the upper part." The Nevada Formation grades downward into the Lone Mountain Dolomite and is overlain conformably by the Devils Gate Limestone.

The Nevada Formation crops out on Lone Mountain [30], where it consists largely of limestone. According to Ketner (1975b), the prevailing appearance is that of a fine- to coarse-grained, thick-bedded calcarenite; some quartzose zones are present near the middle of the unit. The formation was mapped by Lovejoy (1959) as part of his McClellan Creek sequence.

At Swales Mountain [37] the Nevada Formation is a parautochthonous unit, resting on a thrust. According to Ketner (1975b), the upper part, as well as some beds lower down, consist of thick-bedded, dark-gray calcarenite; some interbeds of black chert are also present.

"Lower parts are predominantly thin bedded or massive fine grained dark silty and argillaceous limestone that weathers yellow." (Ketner, 1975b, p. 57)

The Nevada Formation in the Swales Mountain and Lone Mountain areas [30, 30A, 30B, 37] was considered by Ketner (1974) to be probable Middle Devonian. Although Ketner (1975b, p. 64) considered the Nevada Formation at Lone Mountain to be part of the eastern assemblage, at Swales Mountain the rocks assigned to this formation may be part of the transitional assemblage.

Platy Siltstone, Limestone, and Shale **[Dt, Dl].** In the Lone Mountain area [30], Lovejoy (1959) mapped two thrust plates, one **[Dt]** containing limestone, calcareous siltstone, and shale of Devonian age, and the other **[Dl]** limestone of questionable Devonian age; the first unit is here mapped (pl. 1) as belonging to the transitional assemblage. Ketner (1975b, p. 66) summarized the lithology of this unit in the upper plate as limestone, argillaceous limestone, "...and graded sequences of quartz-sandy limestone, siltstone, shale, and bedded black chert. In some areas much of the upper plate is soft, brown to black calcareous flaky shale. It is poorly bedded and breaks down to form soft soil." Lovejoy (1959) collected fossils from this unit that were assigned by E. C. Stumm to the Upper Devonian.

In the Snake Mountains [15], Gardner (1968) mapped about 300 ft of rocks that are here assigned to the transitional assemblage in three small areas on the west flank of the range. These rocks contain Middle Devonian corals and early Late Devonian conodonts. The lithologies include dark carbonaceous limestone apparently overlain by a light-gray, siliceous platy siltstone.

Guilmette and Devils Gate Formations **[Dgd].** The Guilmette Formation was named by Nolan (1930) for exposures in the Gold Hill quadrangle, western Utah. At Ferguson Mountain [54], Berge (1960) described the Guilmette as present in an unknown thickness of dark-gray to black crystalline limestone that occurs as a cliff-forming unit. In the White Horse Mountain area [53A], Messin (1973) described the Guilmette Formation as light- to dark-bluish-gray, generally medium-gray, thin- to thick-bedded, cliff-forming, dense, medium-grained dolomite and limestone. The dolomitic facies is indicated by brown-weathering or spotted surfaces; a silty facies is also present. The total thickness of the Guilmette is 1,000 to 1,300 ft. The Guilmette is folded into a broad recumbent anticlinal fold, trending north-south and dipping east. The upper contact is brecciated; Misch (1957) suggested that this contact is an overthrust or high-angle fault.

In the Spruce Mountain area [46], Hope (1972) described the Guilmette Formation as thick-bedded, medium-gray, fine-grained limestone more than 1,500 ft thick.

In the Wood Hills and the Pequop Mountains [31], Thorman (1970) described the Guilmette Formation and considered it Middle and Late Devonian. Several tectonic subplates occur in the Wood Hills, and the stratigraphic sequence differs in each subplate. The Guilmette consists of four limestone units, totaling 1,840 ft in thickness (Thorman, 1970). The middle and upper parts of these units form a characteristic bench-and-bluff topography. The Guilmette is considered Middle and Late Devonian in Elko County. It rests conformably on the Simonson Dolomite and is unconformably overlain by the Joana Limestone. A similar lithology is present in the Guilmette of the western miogeosynclinal succession of Thorman (1970) and in the eastern tectonic plates.

In the Piñon Range, Smith and Ketner (1975) described the Devils Gate Limestone, which rests on the Nevada Formation of former usage and is approximately 800 ft thick. The rock consists of thin- to thick-bedded interbedded limestone and dolomite. The limestone is blue gray to white; the dolomite is black to white. A stromatoporoid that resembles spaghetti (*Amphipora*) is common. In the Sulphur Spring Range, in the extreme southwest corner of the county, C. A. Nelson and Donald Carlisle (written commun., 1976) described the Devils Gate Limestone, which rests on rocks they called the Telegraph Canyon Dolomite, as gray to gray-blue, well-bedded to massive stromatoporoid and "spaghetti" limestone.

In the Windermere Hills [26], Oversby (1972) mapped approximately 300 ft of thick-bedded, cliff-forming limestones. The rock is predominantly dark-gray to black, light-gray-weathering calcilutite and calcisiltite interbedded with dark-gray calcareous dolomite units, more than 10 ft thick, lower in the section. The dolomite is locally associated with platy black calcilutite. All of the limestone contains argillaceous and bituminous material, as well as small amounts of sand-size authigenic and clastic quartz. In the Railroad mining district (Ketner and Smith, 1963), much of the dolomite is probably secondary and due to hydrothermal recrystallization of the limestone. Both the dolomite and limestone are altered to marble and skarn. The Devils Gate in Elko County is possibly late Middle and probably early Late Devonian; the formation may include younger beds. The upper contact of the Devils Gate is a major unconformity; the Devils Gate is overlain by clastic rocks of Early Mississippian age.

In the Ruby Mountains [49], Sharp (1942, p. 664–667) described the Devils Gate Limestone as aggregating a total thickness of 1,200 ft, separated on the basis of lithology into two members—a lower member, 900 ft thick, and an upper member, 300 ft thick. The lower member is dark-gray to black, dense to crystalline, flaky to massive limestone with a few thin beds of dense, light-colored limy dolomite at the base. Some oolitic beds are present near the middle of the lower member. The upper member consists of red- to brown-weathering, platy, arenaceous and argillaceous limestone. Lenses of chert-pebble conglomerate near the base are distinctive. The contact with the lower member is gradational.

Ordovician, Silurian, and Devonian Systems

Dolomitic Rocks **[Dod].** In the East Humboldt Range [39], Snelson (1957) described a unit in which presumed Ordovician, Silurian, and Devonian rocks are combined; it may include rocks as young as the Simonson Dolomite, which is of Middle Devonian age in Elko

County. This combined unit consists mostly of fine- and coarse-grained dolomite; all of the unit may actually be Devonian.

In the Wood Hills [34], Thorman (1970) described rocks that here are mapped (pl. 1) as a single unit of Ordovician, Silurian, and Devonian age. These rocks include those that elsewhere would be called the Fish Haven Dolomite (Ordovician), the Laketown Dolomite (Silurian), and the Sevy Dolomite (Devonian); the base is not exposed. The Fish Haven here is predominantly light- to dark-gray, medium-bedded dolomite. The Sevy Dolomite here is 375 ft thick, according to Osmond (1954, p. 2041). (For descriptions of individual units, see previous sections.)

Devonian and Mississippian Systems

***Joana Limestone and Pilot Shale* [MDjp].** Spencer (1917) divided the White Pine Shale of former usage into three units: the Pilot Shale, the Joana Limestone, and the Chainman Shale. For the purposes of this report, the Pilot Shale and Joana Limestone are combined into one unit on the map (pl. 1). The Pilot is Late Devonian and Early Mississippian and the Joana is Early Mississippian. This unit occurs principally in the southeastern part of the county, specifically in the Leppy Range [4A], the Pequop Mountains [34], the Spruce Mountains [46], the Windermere Hills [26], and the Cherry Creek Mountains [8].

Willden and Kistler (1979) mapped the Pilot Shale, which they called the Pilot Formation, along the crest and east side of the Ruby Mountains, in the Franklin Lake NW quadrangle [49]. It is about 300 ft thick and, according to Willden and Kistler (1979, p. 239), "...consists mainly of dark-gray to black, thin-bedded and platy, shaly and sandy limestone that weathers to a distinctive tan or yellowish-gray color. Thin, black, carbonaceous shale beds that also weather tan are interlayered with the limestone through most of the section and such shale is predominant near the top of the formation." The contact with the overlying Joana Limestone is gradational. The Joana Limestone is also exposed in several blocks in the same area (Willden and Kistler, 1979, p. 240). "The Joana is consistently a cliff-forming unit although it is generally thin bedded. It consists of alternating beds of medium- to dark-gray limestone and dark-gray to nearly black chert. The limestone beds are about 3 to 8 inches thick and chert beds are generally 1 to 2 inches thick.... The Joana is about 250 ft thick." It is Early Mississippian (Kinderhookian).

In the Wood Hills [31], Thorman (1970) recognized two distinct miogeosynclinal successions—an eastern and a western. In the eastern miogeosynclinal succession, the Joana Limestone is present in a faulted succession, at least 125 ft thick, that is considered Kinderhookian; the rock consists of fine- to coarse-grained limestone, in part crinoidal. In both successions, the Joana Limestone lies disconformably on the Guilmette. The Joana here is divided into three members: (1) a basal member of 65 ft of medium- to coarse-grained encrinite; (2) an intermediate member of 280 ft of interbedded platy buff siltstone, black chert, and platy fine-grained limestone, and (3) an upper member of approximately 1,400 ft of platy to thin-bedded, fine-grained, partly argillaceous limestone. The upper member is probably equivalent to the Tripon Pass Limestone.

In the Ferguson Mountain area [54], Berge (1960) mapped a thickness of 15 to 20 ft of the Joana Limestone, which is present as a thin ledge of crystalline, medium- to dark-gray lithographic limestone.

In the Ruby Mountains, Sharp (1942, p. 667–669) mapped a limestone sequence that he assigned to the Mississippian(?). This sequence, here regarded as equivalent to the Joana Limestone, is mapped (pl. 1) as part of the Joana Limestone and Pilot Shale, undivided. The unit is a 300-ft-thick, cliff-forming, light- to dark-gray, dense crystalline limestone, locally containing nodular layers of black chert.

In the Cherry Creek Mountains [8], R. A. Hope (1973, written commun., 1973) observed a gradational contact between the Guilmette Formation and the overlying Pilot Shale, which here consists of dark-gray-brown-weathering calcareous siltstone and thin-bedded platy and crossbedded sandstone. Toward the top the Pilot becomes a more irregularly bedded muddy limestone, containing beds of mud clasts. The Pilot grades upward into the cliff-forming Joana Limestone. The Joana becomes thicker bedded upward, in beds 4 to 12 ft thick; it consists of medium-dark-gray, fine- to medium-grained bioclastic limestone containing abundant horn corals and some brachiopods and snails.

On the west side of Spruce Mountain [46], Hope (1972) described a small outcrop of the Pilot Shale, which here is light-gray-weathering platy calcisiltite and olive-green shale. The Joana Limestone in this area is a thick-bedded, medium-gray, fine-grained bioclastic limestone containing abundant large crinoid-stem sections, and a thin-bedded limestone containing dark-gray to black chert stringers, mainly in the upper part of the unit. The maximum exposed thickness of the Joana is about 100 ft; the top is in thrust contact with the upper part of the Diamond Peak Formation.

Mississippian(?) System

***Grossman Formation* [MDg].** The Grossman Formation was originally described by Coats (1969, p. A22) in the Owyhee 15′ quadrangle, near the boundary between the Owyhee [3] and Mountain City [4] 15′ quadrangles. The Grossman is clastic and ranges in composition from coarse conglomerate to siltstone and phyllite. The clasts in the conglomerate, which are tectonically flattened, consist of gray quartzite, black chert, phyllite, and magnetitiferous siltstone. The fresh rock is generally medium gray to greenish gray, and in the coarser grained sandstone a distinct salt-and-pepper appearance results from the contrast between the dark chert and the lighter colored quartzite. The absence of bedding and of a demonstrable top to the formation, which generally has fault boundaries, makes its thickness difficult to determine; it may, however, be as much as 2,000 ft thick. The formation locally rests unconformably on the Valmy Formation and is locally overlain unconformably by the Banner Formation.

The age of the Grossman Formation is uncertain; because it is post-Valmy and pre-Banner, the formation must be Late Ordovician or younger and Late Mississippian or older. Coats (1969) considered it to be Devonian or Mississippian. However, this age assignment seems to be negated by the absence of any post-Antler rocks of Devonian age in the Carlin-Piñon Range area, where the Roberts Mountains thrust has been most precisely dated (Smith and Ketner, 1968). Its clasticity and obvious derivation from the Valmy now suggest that the formation postdates the beginning of the Antler orogeny (latest Devonian to Osagian) in the area where it was deposited; its age is, therefore, here revised to Early Mississippian.

In the Fish Creek Reservoir area of south-central Idaho, Skipp and Hall (1975) described the Copper Basin Formation. They assigned it an Early and Late Mississippian age, but pointed out that it might possibly be latest Devonian at its base, and earliest Pennsylvanian at its top. Nilsen (1977, p. 284), who subdivided the Copper Basin Formation into several units, suggested that movement on the Muldoon Canyon thrust, which cuts one of his subplates, took place "...between Early and Late or in early Late Mississippian time, thus closing the basin." The lithology in parts of the Copper Basin Formation, as described by Skipp and Hall (1975), is nearly identical to that of the Grossman Formation, and the tectonic relations are consistent with deposition of the Grossman (or the Copper Basin Formation of Skipp and Hall, 1975) by erosion resulting from the Antler orogeny, beginning during the Early Mississippian and terminating by deformation and erosion before the latest Early or early Late Mississippian Banner Formation was deposited unconformably on it. The Grossman is, therefore, questionably correlated with the lower part of the Copper Basin Formation.

Mississippian System

***Tripon Pass Limestone* [Mtp].** In the Windermere Hills [26], Oversby (1972, 1973) mapped about 1,500 ft of clastic-limestone beds of Kinderhookian age; the lithology includes calcisiltite, calcarenite, and calcirudite, interbedded with minor black argillite, quartz siltite, and quartz-chert arenite. The Tripon Pass lies disconformably on the Guilmette Formation. The clasts in the calcirudite are as large as 1 ft in diameter, although 2-in.-diameter clasts are common. Some of the calcirudite beds are crudely graded and have sole marks, suggesting turbidity currents. The formation is a time equivalent to the Joana Limestone but differs from it lithologically.

In the Swales Mountain quadrangle [37], Evans and Ketner (1971) mapped an unnamed Kinderhookian limestone turbidite, informally called the Camp Creek sequence, that here is at least 850 ft thick, consisting mostly of brown quartz-sandy limestone, grading upward into gray shaly limestone. Ketner (1975b) later correlated this sequence with the Tripon Pass Limestone, a correlation accepted here. Ketner (1970) discussed the tectonic significance of this limestone turbidite. Lithologic features of the turbidite indicate a northeastern provenance; he believed that the sequence was deposited by currents flowing from the edge of the miogeosyncline. The absence of debris from the western assemblage, however, suggests that the sequence was deposited before the emergence of the eugeosynclinal rocks, although the instability suggested by the turbidite lithology was considered by Ketner (1970) to reflect an early Antler orogenic episode. These rocks are temporally correlative with the Early Mississippian Webb Formation of the Carlin-Piñon Range area, which is known to postdate the earliest and maximum movement on the Roberts Mountains thrust in that area (Smith and Ketner, 1968).

Limestone of similar age but dissimilar lithology is mapped (pl. 1) with this unit in the Peko Hills, to the east of the North Fork of the Humboldt River (K. B. Ketner, oral commun., 1976).

***Webb Formation* [Mw].** In the Carlin-Piñon Range area [43], Smith and Ketner (1968; 1975, p. A35–A37) described a unit that they named the Webb Formation. The oldest Mississippian formation in the area, the Webb is 735 ft thick at its type section; its maximum thickness is about 800 ft. The Webb principally consists of gray mudstone and claystone that weathers gray brown; some strata also weather black. All the strata are thin bedded, and a few are faintly laminated; thin layers of sandstone are as coarse as medium sand, rarely coarser. Chert and quartz grains are common. Limestone, in lenses from 1 to 30 ft thick and from a few feet to about 1½ mi long, is also present. Claystone nodules, some baritic, occur near the top of the formation. The Webb Formation is Early Mississippian (upper Kinderhookian), probably equivalent at least in part to the Joana Limestone (Nolan and others, 1956, p. 54–56) and possibly also to the lowest part of the Chainman Shale in the south half of the Carlin-Piñon Range area. The Chainman Shale also overlies the Webb Formation in part.

***Argillite of Lee Canyon* [Ma].** In the Carlin-Piñon Range area [43], Smith and Ketner (1975, p. A38–A40) mapped a unit that they referred to as the argillite of Lee Canyon, consisting of black siliceous argillite and minor black chert, possibly totaling as much as 5,000 ft in thickness. Also present are a few beds of conglomerate, as much as 700 ft long and a few feet thick, composed of chert pebbles and granules. The formation was probably thermally metamorphosed by the intrusion of Tertiary igneous rocks. The argillite of Lee Canyon is here provisionally considered to be Early Mississippian, probably equivalent in part to the Webb Formation and to the lower part of the Chainman Shale. Part of the Chainman also overlies the argillite of Lee Canyon.

***Banner Formation* [Mbn].** This formation name was first published as Banner Limestone by Granger and others (1957, p. 116), who credited the name to T. B. Nolan (unpub. data, 1932). Coats (1969) changed the name to Banner Formation because of the varied lithology. The type locality of the Banner Formation is near the west edge of the Mountain City 15′ quadrangle [4]. The formation crops out in the Mountain City and Owyhee 15′ quadrangles in a narrow belt trending nearly east-west, and also occurs in small areas in the eastern part of the Mountain City 15′ quadrangle, on the north edge of the Rowland quadrangle [5], in small patches in

the northeast corner of the Mount Velma quadrangle [13], and in small areas in the California Mountain quadrangle [12A]. The thickness of the Banner Formation varies widely; the maximum thickness exposed where outcrops are reasonably good is about 600 ft. The basal part of the Banner is a conglomerate composed mostly of subangular to subrounded quartzite boulders, as seen in some underground workings; on the surface, a few rounded quartzite boulders, which appear to be derived from a light-colored quartzite of the Valmy, have been noted. Above this conglomerate is light-brown sandstone, consisting of fine to medium, subangular to subrounded quartz grains; above is tan-weathering siliceous siltstone, about 160 ft in total thickness, which is succeeded by at least 260 ft of limestone that is arenaceous in the lowest 100 ft and grades upward into soft, massive, bluish-gray limestone. The Banner Formation rests with a marked angular unconformity on the Valmy Formation, and with a less marked unconformity on the Grossman Formation. The Banner grades upward and perhaps also laterally into the Nelson Formation, the lowest part of which is a peperite, consisting of volcanic fragments erupted into limy mud that is locally fossiliferous; the contact is commonly drawn at the lowest occurrence of volcanic material. The Banner was considered to be Pennsylvanian or Permian and, later, Late Mississippian (Granger and others, 1957, p. 116; Coats, 1969, p. A24). As indicated by fossil collections (field no. 58NC56, collns. 1766-PC, 19526-PC, 19527-PC, 19528-PC, 21588-PC, 22813-PC, 22499-PC, 24780-PC), the Banner is now considered to be possibly Osagean or probably Meramecian (latest Early or early Late Mississippian).

In the extreme northeast corner of the Mount Velma quadrangle, the Banner Formation occurs as two small erosional outliers of calcareous conglomerate that rest unconformably on the top of a thrust plate of the Valmy Formation (field no. 56NC56). The Banner also occurs in a small plate, 200 ft across and perhaps as much as 100 ft thick, resting tectonically on the Valmy Formation in the southwestern part of the California Mountain quadrangle. Here, it appears to be the upper part of a fault sliver that has been downfaulted along the front of the Independence Mountains.

In the Rowland quadrangle, Bushnell (1967, p. 13, 14) described what he called the Diamond A Formation and tentatively suggested that it can be correlated with the Banner. Although this correlation was based only on lithologic similarity, the Diamond A is included in the Banner on the geologic map (pl. 1). The Diamond A Formation, as described by Bushnell (1967, p. 12) from exposures on the north side of Bear Paw Mountain and along the Bruneau River, comprises a basal chert-quartzite-pebble conglomerate and beds of limestone with shale members. It rests on various formations from place to place; at Rowland it seems to rest on a black quartzite that is probably part of the Valmy Formation. The total thickness of the Diamond A Formation in two different sections ranges from 600 to 1,500 ft; both sections seem to be somewhat metamorphosed. In some places in one section, the limestone is interbedded with black hornfels, which probably represents black shale and may be the equivalent of some of the uppermost part of the Banner in the Owyhee quadrangle. In other places, shearing has occurred along the contact, and the conglomerate is converted to a medium-gray phyllite containing sheared and stretched pebbles. Although these rocks may properly be assignable to the Grossman Formation, they were mapped by Bushnell (1967) as part of the Diamond A. No recognizable fossils have been found in the Diamond A Formation.

Nelson Formation **[Mbn]**. The Nelson Formation was originally called the Nelson Amphibolite by Granger and others (1957, p. 116), who credited the name to T. B. Nolan (unpub. data, 1932). It crops out in an east-west-trending belt of largely volcanic rocks, adjacent to and north of the outcrop of the Banner Formation on the north side of Mill Creek in the Mountain City 15′ quadrangle and to the west in the Owyhee 15′ quadrangle as far as the Paleozoic rocks can be traced. Its thickness ranges widely at the type locality, in S/2 S2,T45N,R53E. The Nelson is approximately 600 ft thick, perhaps somewhat thinner, near the Owyhee-Mountain City 15′ quadrangle boundary and is much thicker near the headwaters of the East Fork of Fawn Creek, in the Owyhee 15′ quadrangle [3], where the discontinuous outcrops suggest a thickness of 2,500 ft; some duplication of the section due to thrust faulting may be present there. The greater part of the formation in this area consists of flows and tuff breccia of andesitic and basaltic composition, and includes minor sills of diabase and one lens of rhyolitic tuff. Because of metamorphism in the Mountain City 15′ quadrangle, the Nelson, in the western part of the quadrangle, is a greenschist composed of tremolite-actinolite, chlorite, epidote, calcite, ilmenite, and andesine, in part altered to albite. The grade of metamorphism is greatest near the east end of this belt of exposure, near where the Owyhee River crosses the belt of exposures of the Nelson; here the rocks are closest to the quartz monzonite contact. Westward the amphibole becomes lighter in color; the feldspar is more albitic, and the rock contains chlorite. Locally the rock appears to be a metadiabase, probably a metamorphosed sill, although exposures are inadequate to permit determination of the contact relations.

The Nelson Formation is also exposed in several belts in the eastern part of the Mountain City 15′ quadrangle, from the ridge separating the drainages of Merritt Creek from those of McDonald Creek, northward almost to the northeast corner of the quadrangle. Absence of fossil evidence leaves some uncertainty whether this rock is really the Nelson or possibly some other volcanic formation. Because the Nelson Formation grades downward into the Banner, the Nelson has been assigned a Late Mississippian age (Coats, 1969). Although the Nelson Formation does not appear above the Banner in the Rowland quadrangle, the rocks above the limestone are apparently greenish-gray to olive-gray or light-olive-gray shale. This coloration suggests that the shale may contain mafic volcanic detritus, which would be expected if this shale is the lateral equivalent of volcanic rocks of the Nelson Formation. The Banner and the Nelson, taken together, are surely equivalent to the Goughs Canyon Formation of Hotz and Willden (1964).

Chainman Shale **[Mc]**. The Chainman Shale was originally named and described by Spencer (1917) in the Ely area. In the Wood Hills and the Pequop Mountains [34], Thorman (1970) described the Chainman as consisting of shale, siltstone, sandstone, and conglomerate. A distinct difference exists between the northern Pequop section, which consists largely of black shale, and the Wood Hills and southern Pequop Mountains sections, which are largely siltstone. The various rock types alternate, and the grain size coarsens toward the top. In Thorman's (1970) tectonic subplate IID, a maximum thickness of 2,790 ft of the Chainman was measured; the base is a fault. The Chainman in this area is Meramecian and Chesterian.

In the Ferguson Mountain area [54], Berge (1960) described the Chainman Shale, which he considered to be entirely Late Mississippian (Meramecian). Here, the total thickness of the Chainman is 350 ft; it comprises a sequence of light-brown quartzite, sandstone, and silty cherty limestone, overlain unconformably by the Ely Limestone.

In the HD Range [17], Riva (1970) described the Chainman Shale, the thickness of which could not be measured accurately because of intense deformation. The rock is light-gray-weathering brittle black shale; it may be parautochthonous but is considered to be allochthonous to the south in the Windermere Hills and in the Pequop Mountains. In the White Horse Mountain area [53A], Messin (1973) described the Chainman Shale as a very thin unit of light-bluish-gray to dark-gray fissile shale; the Scotty Wash Quartzite may also be present.

Mountain City Formation **[Mc]**. The Mountain City Formation was originally named by Granger and others (1957, p. 116), who credited the name to T. B. Nolan (unpub. data, 1932). The type locality is the long-inactive gold mine on the crest of the hill north of Mill Creek in the Mountain City 15′ quadrangle. The Mountain City Formation, as pointed out by J. H. Stewart (oral commun., 1971), has a stratigraphic relation and lithology which suggest that it is temporally correlative with the Chainman Shale of Mississippian age. Accordingly, the Mountain City is herein considered to be Mississippian and is mapped (pl. 1) with the Chainman Shale. The Mountain City Formation west of the Owyhee River consists largely of fine-grained, dark-gray to black siliceous schist that has a poorly defined schistosity, commonly parallel to the bedding. Small amounts of sericite and calcite are present, as well as a few thin limy beds, as much as 2 ft thick. Although the total thickness of the unit is unknown, the minimal original thickness is probably at least 4,000 ft, possibly as much as 10,000 ft. The Mountain City Formation rests conformably on the Nelson Formation. East of the granodiorite of Mountain City, the Mountain City Formation on the northeast side of Merritt Mountain is largely a calcareous schist, much richer in limestone than that to the north of Mill Creek, although these differences reflect differing depositional environments of the rocks in the different thrust plates.

Sedimentary Clastic and Limy Rocks **[Ms]**. The sedimentary clastic and limy rocks make up a sequence, only a few hundred feet thick, that rests unconformably on the Valmy Formation in the lower part of Schoonover Creek (Churkin and Kay, 1967, p. 663). These rocks were regarded by Churkin and Kay as the lowest part of Fagan's (1962) Schoonover Formation. Their stratigraphic usage is not adopted. The rocks consist largely of a basal conglomerate of white quartzite and black chert boulders and pebbles. The basal boulder conglomerate is 20 to 30 ft thick and, according to Churkin and Kay, grades upward into several hundred feet of chert-quartzite-pebble conglomerate, chert arenite, and very fine grained quartzitic sandstone and quartzose siltstone. In a limy bed near the base of the unit, Keith Ketner and I collected some fossils (field no. 66NC68, colln. 22498-PC). Mackenzie Gordon, Jr. believed the rocks to be Late Mississippian (Chesterian), based on the presence of a productid in the collection.

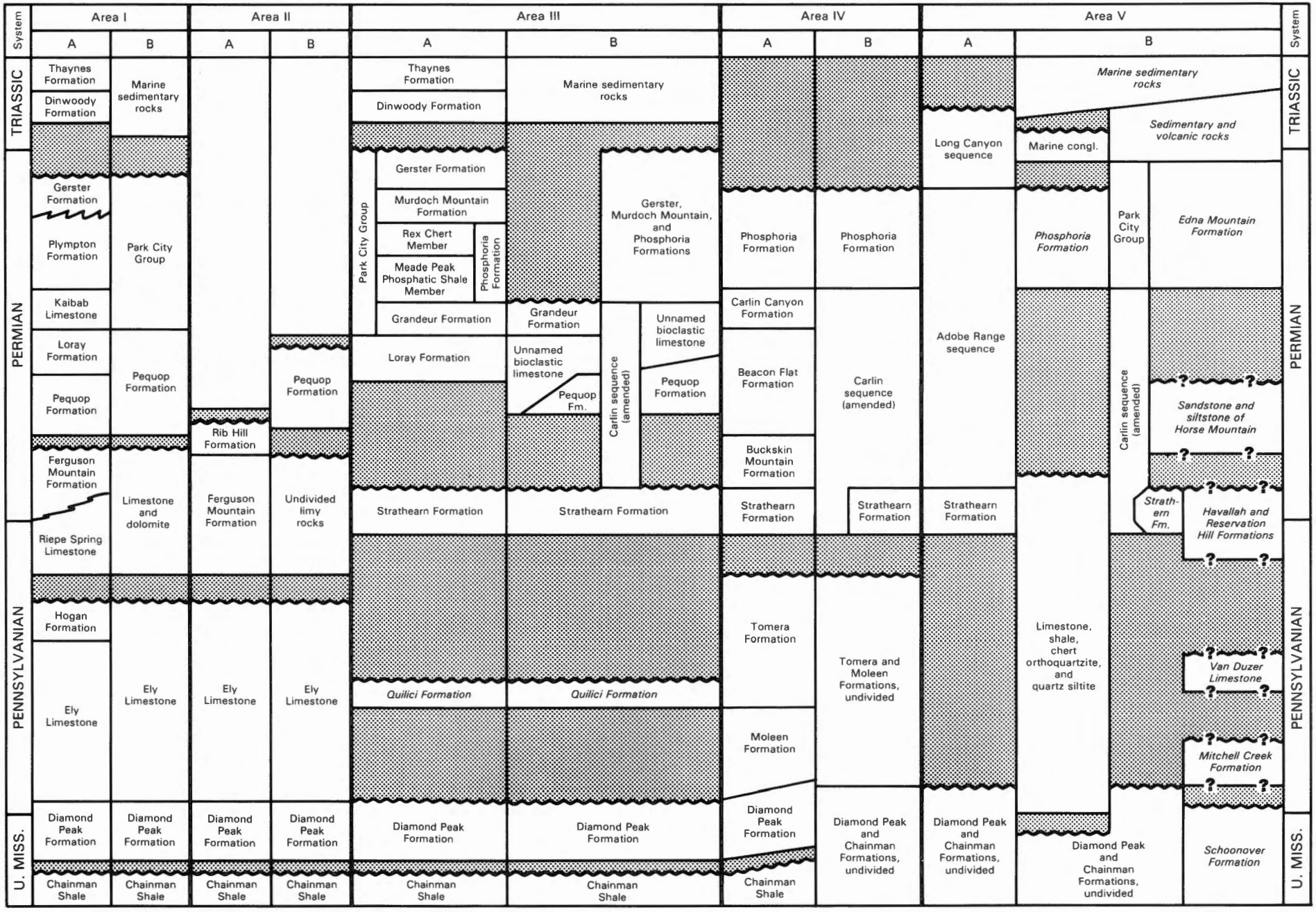
Mississippian and Pennsylvanian Systems

Introduction. In Elko County, earth unrest, which intensified with the onset of the Antler orogeny, had far-reaching effects and resulted in facies gradients in late Paleozoic rocks that are quite abrupt in comparison with those of the early Paleozoic. The complexities due to the late Paleozoic or Mesozoic orogeny, as well as the depositional-facies differences, make it difficult to assign consistent map units throughout the county. For this reason, I present a chart (fig. 3) illustrating variations in stratigraphic nomenclature between different geographic areas in Elko County.

Diamond Peak and Chainman Formations, Undivided **[IPMdc]**. In some areas [31, 43] both the Chainman and Diamond Peak Formations are combined in a single map unit, whereas in other areas [29, parts of 43, 54] they are mapped separately. In some areas [3, 5, 21] the Chainman Shale is mapped separately, and in other areas [8, 11A, 13, 26, 27, 36, 39A, 42, 45A, 46] the Diamond Peak Formation is mapped separately (pl. 1). It must be understood that because these two formations interfinger, the assignment of some areas to either one formation or the other may, in part, reflect the judgment of individual workers.

The Diamond Peak and Chainman Formations, undivided, were mapped in the Leppy Range [42] by Schaeffer and Anderson (1960), whose practice of combining the two units in that area is followed here, as well as in other places where the undifferentiated unit was used by the original mapper. The Chainman Shale was originally described by Spencer (1917, p. 26–27) in the Ely mining district. It was regarded as the upper shale member of the White Pine Shale of former usage in the Hamilton mining district (Brew, 1971). The Diamond Peak Quartzite was originally described by Hague (1883, p. 266–270) in the Eureka area. In that area it consists mostly of quartzite, although some conglomerate, shale, and limestone are also present. Lenticularity and interlensing generally characterize the relation between the Chainman Shale and the Diamond Peak Formation, thus they are not separated in the Leppy Range.

In the Leppy Range, the Diamond Peak and Chainman Formations, undivided, can generally be divided into five major rock units, in ascending order: (1) a lower clastic unit, (2) a carbonate unit containing a


System
Area I
Area II
Area III
Area IV
Area V
A
B
TRIASSIC
PERMIAN
PENNSYLVANIAN
U. MISS.
Thaynes Formation
Dinwoody Formation
Marine sedimentary rocks
Gerster Formation
Plympton Formation
Park City Group
Kaibab Limestone
Loray Formation
Pequop Formation
Ferguson Mountain Formation
Limestone and dolomite
Riepe Spring Limestone
Hogan Formation
Ely Limestone
Diamond Peak Formation
Chainman Shale
Rib Hill Formation
Undivided limy rocks
Park City Group
Murdoch Mountain Formation
Rex Chert Member
Meade Peak Phosphatic Shale Member
Phosphoria Formation
Grandeur Formation
Unnamed bioclastic limestone
Pequop Fm.
Carlin sequence (amended)
Gerster, Murdoch Mountain, and Phosphoria Formations
Strathearn Formation
Quilici Formation
Long Canyon sequence
Adobe Range sequence
Carlin Canyon Formation
Beacon Flat Formation
Buckskin Mountain Formation
Tomera Formation
Moleen Formation
Tomera and Moleen Formations, undivided
Diamond Peak and Chainman Formations, undivided
Marine congl.
Sedimentary and volcanic rocks
Edna Mountain Formation
Sandstone and siltstone of Horse Mountain
Strath-ern Fm.
Havallah and Reservation Hill Formations
Van Duzer Limestone
Mitchell Creek Formation
Schoonover Formation
Limestone, shale, chert orthoquartzite, and quartz siltite

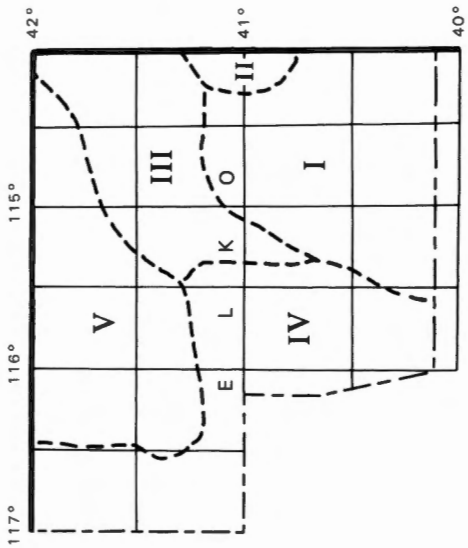


FIGURE 3. Chart illustrating variations in stratigraphic nomenclature used in mapping of Mississippian, Pennsylvanian, Permian, and Triassic rocks of Elko County. The index map shows the approximate areas, I-V, to which the columns in the chart apply. Part A of each column indicates the commonly recognized units that correspond most closely to the units used in the mapping. Part B of each column indicates the units used in the mapping. Space devoted to each unit in the column is not necessarily a reflection of duration of time or stratigraphic thickness. Apposition of units is not intended to indicate precise time equivalence. Italic names indicate units allochthonous at least in part. Shading indicates gaps due to erosion, nondeposition, or faulting. Mention of a stratigraphic name does not imply acceptance by the U.S. Geological Survey.

locally prolific gastropod fauna, (3) a predominantly shale unit, (4) locally, a second carbonate unit, and (5) a conglomeratic unit that is correlative with the Diamond Peak. In the lower clastic unit, the dark-gray quartzite near the base weathers orange tan; the fissile black claystone of the shale unit weathers purple, black, maroon, tan, and light red; and the siltsone weathers light gray to light orange brown. The conglomeratic unit, which weathers reddish tan to medium gray, contains angular to subrounded pebbles of chert and quartzite, ranging from ½ to 2 in. in diameter, that are orange, green, light gray, red, and black. The quartzite and the chert clasts resemble the quartzite and chert of the Valmy Formation. The thickness of the Diamond Peak and Chainman Formations, undivided, is 1,141 ft in the central Silver Island Mountains. The unit rests with angular unconformity on the Guilmette Formation, the Pilot Shale, and the Joana Limestone and grades upward into the Ely Limestone.

In the southern Pilot Range [36], O'Neill (1968) described a unit of the Diamond Peak and Chainman Formations, undivided; at the bottom is about 180 ft of the Chainman Shale, which consists of alternating medium-gray, thin-bedded argillaceous limestone and thin-bedded tan sandstone. Neither the base nor top of this unit is exposed in the southern Pilot Range. The Diamond Peak part of the unit, which was called quartzite by O'Neill, comprises more than 425 ft of pebble conglomerate with interbedded medium-gray, coarse-grained quartzite. The conglomerate is yellow white to gray and weathers very dark orange brown; the quartz pebbles, as much as 1¾ in. long, are subanglular to subrounded. The upper contact is placed at the top of the thick sequence of pebble conglomerate, which is the base of the first bioclastic limestone and the base of the Ely Limestone.

In the Spruce Mountain district [46], Hope (1972) mapped the Chainman and Diamond Peak Formations together. The typical lithology is a chert- and quartzite-pebble conglomerate, crossbedded calcarenite containing some silicified siltstone, and greenish-gray shale, with limestone beds near the top. The total thickness of the unit is more than 2,500 ft.

In the Wheeler Mountain (Seetoya Peak) area [21], Kerr (1962) described a unit of about 700 ft of late Paleozoic or Mesozoic siltstone that lies unconformably on lower Paleozoic rocks. The base of the formation is marked by medium-grained graywacke containing a few black shale and chert pebbles. Most of the section is platy, black, argillaceous quartz siltite interbedded with some fine- to medium-grained graywacke. The unit rests on both of the structural plates made up of rocks of the eastern assemblage, and is overlain by a thrust that carries the western assemblage. Kerr named this unit the "Waterpipe Canyon Formation," but it is herein designated the Chainman and Diamond Peak Formations, undivided.

In the Carlin-Piñon Range area [43], Smith and Ketner (1975, p. A40–A51) described a unit of the Diamond Peak and Chainman Formations, undivided, of Early and Late Mississippian age. They discussed at some length the origins of the names of the various units and pointed out that the two formations constitute essentially a single major sequence, as noted by previous workers (Nolan and others, 1956, p. 56–59; Sadlick, 1960, p. 82; Stewart, 1962). According to Nolan and others (1956, p. 57, 60–61) the Chainman generally lies below the Diamond Peak, although the two formations also intertongue. In one area [43] where Smith and Ketner (1975) combined the two formations into a single unit, the sequence ranges from Early to Late Mississippian.

The predominantly finer grained clastic rocks in the lower part of the sequence in the Carlin-Piñon Range area [43] are here mapped as the Chainman Shale, although some conglomerate is also included. Some sections of the Chainman are sandstone. The shale in the Chainman is mostly soft, and commonly carbonaceous. The gray siltstone weathers white in some places. The sandstone in the Chainman, locally quartzitic, is mostly gray or tan and brown and weathers tan and brown. The sandstone beds are lenticular and thin. "The Chainman Shale and Diamond Peak Formation compose a flysch-like and molasselike sequence of clastic rocks in which is recorded the depositional history of material derived from the region of continuing uplift in the Antler orogenic belt." (Smith and Ketner, 1975, p. A40). The sandstone is mostly made up of chert and quartz grains

in a matrix of chert, clay, and some micaceous material; the percentages of quartz and chert in the clasts range widely. Plant fragments are present as carbonaceous coatings on the bedding surfaces.

Limestone, sandy limestone, and calcareous sandstone crop out locally throughout the formation but make up only approximately 1% of the total thickness of the formation. The limy beds are gray or tan, no more than 1 ft thick, and commonly fossiliferous. Pebbly mudstone is present in many places, especially near the base. Flute markings and prod casts are present. Most of the clasts could have been derived from sources fairly close to the depositional site. Some turbidite deposits are recognizable; currents generally appear to have moved toward the southeast. The conglomerate in the Chainman Shale is present as lenticular beds containing angular to well-rounded cobbles, pebbles, and boulders, chiefly of quartzite, chert, and sandstone, in a sandstone matrix. Some limestone-clast conglomerate is commonly well bedded. Some of the shale, similar to typical Chainman, contains veins of solid bituminous material.

In the Mountain City 15′ quadrangle [4], some rocks are mapped (pl. 1) as part of the Diamond Peak and Chainman Formations, undivided, but are more like the Diamond Peak in lithology. These rocks are massive, medium-grained, dark quartz-chert sandstone; and crop out northeast of Merritt Mountain and in the extreme southeast corner of the quadrangle. Several fossil localities were found near Merritt Mountain and were reported on by Mackenzie Gordon, Jr. (field nos. 62NC306, 62NC348, 62NC360, 62NC361 *in* Coats, 1986).

***Diamond Peak Formation* [IPMdp].** In the Carlin-Piñon Range area (Smith and Ketner, 1975, p. A40–A51), the Diamond Peak Formation is generally considered to be a coarse clastic unit that, however, contains much shale, siltstone, and some limestone; it includes, as mapped, the Tonka Formation (Dott, 1955, p. 2222–2223). The Diamond Peak has many prominent outcrops; the conglomerate forms the most conspicuous beds, though not everywhere the volumetrically dominant one. The units are generally lenticular, and the bedding is indistinct, except where sandstone layers are present in the conglomerate. Most of the conglomerate clasts are made up of chert, quartzite, and sandstone, and range from pebbles to boulders in size. The chert clasts are mostly gray, tan, green, and black. A few clasts of gray limestone are also present, probably derived locally from the Devils Gate Limestone. The percentage of fine-grained rocks increases toward the south. In the northern part of the Carlin-Piñon Range, 4,700 ft of the Diamond Peak Formation is exposed. A distinctive and unusual sequence of fossiliferous, tan and yellow shale, locally calcareous, occurs in the Diamond Peak; the maximum thickness of this shaly unit is 650 ft. The Diamond Peak Formation is Early and Late Mississippian and very Early Pennsylvanian.

In the HD Range [17], Riva (1970) described a thin unit of the Diamond Peak Formation, which here is apparently entirely Mississippian, but no fossils were found. It lies unconformably on western-assemblage rocks in Riva's (1970) tectonic plate A and so both the Diamond Peak and the western assemblage are allochthonous in this area. The greatest thickness of section measured was 205 ft; the lower 80 ft includes 10 ft of chert conglomerate, mostly made up of black chert fragments, minor amounts of shale fragments, and quartzite and pebbly conglomerate in massive, generally lenticular beds with shaly partings.

In the Wood Hills and the northern Pequop Mountains [34], Thorman (1970) described the Diamond Peak Formation as composed of a chert-pebble conglomerate, sandstone, siltstone, and subordinate limestone. It intertongues with the underlying Chainman Shale and the overlying Ely Limestone; the Diamond Peak is that part of the section containing abundant conglomerate and sandstone. The limestone in the Diamond Peak is generally fine grained, and that in the Ely is medium to coarse grained. The Diamond Peak is 1,350 ft thick in the Wood Hills and 1,190 ft thick in the Pequop Mountains.

In the southern Pequop Mountains area [40], Robinson (1961) described the Diamond Peak Formation, which he divided into two members. The lower member consists of interbedded protoquartzite, small- to medium-pebble conglomerate, and some siliceous shale or argillite. In the protoquartzite the quartz grains are fine to medium grained; the pebbles are angular to subangular, mostly gray, greenish-gray, or black chert; some quartzite fragments occur in the conglomerate. The shale near the top of the member is micaceous. The protoquartzite beds are commonly cross-laminated. The upper member contains, in the lower three-quarters, various types of limestone and, in the upper quarter, siliceous shale, protoquartzite, and fine-pebble conglomerate, similar to those rock types in the lower member. The thickness of the lower member is 656 ft and of the upper member 775 ft.

In the Ruby Mountains [49], Sharp (1942, p. 669–670) described the Diamond Peak Formation, which here consists chiefly of siliceous chert-quartzite-pebble conglomerate, quartzite, and massive limestone, 4,000 to 10,000 ft thick. It is exposed chiefly on the west base of the range between Cass House Creek and Sherman Creek. The limestone is grayish brown and crystalline and contains irregular light-brown chert nodules and layers. Coarse oolitic limestone and dense, black, flaggy to platy argillaceous limestone are less abundant. This unit is here regarded as part of the Diamond Peak Formation, although it was mapped by Sharp (1942) as undifferentiated Carboniferous.

Pennsylvanian System

***Moleen and Tomera Formations, Undivided* [IPcd].** In the Carlin-Piñon Range area [43], Smith and Ketner (1975) described the Moleen and Tomera Formations, undivided. The Moleen and Tomera were first defined by Dott (1955, p. 2234–2248). The Moleen Formation ranges from about 1,200 to about 1,600 ft in thickness. It is largely a ledge-forming limestone in various shades of gray; the beds are 1 to 4 ft thick, although some are thinner. The limestone is detrital; some of the beds are silty or sandy, and contain conglomerate lenses of green, gray, or brown chert pebbles. A few pods of

chert, in layers as much as 10 ft long, are also present; the chert resembles that of the Ely Limestone. Dott (1955, p. 2243) considered the Moleen to be Early and early Middle Pennsylvanian; it is here regarded as equivalent to the lower part of the Ely Limestone. The distinction between the Moleen and the Tomera Formations is based on three factors: (1) the Moleen includes conspicuous beds of limestone containing nodules, pods, and layers of chert; (2) the Tomera contains more clastic fragments of chert and quartz that form thick beds of conglomerate in places; and (3) the Tomera contains better developed coquinite and more whole fossils. Smith and Ketner (1975) mapped the Moleen and Tomera Formations separately in some areas and as a single unit in other areas. For the purposes of this report, the Moleen and Tomera are combined in the carbonate and detrital rocks unit **[ℙcd]** on the geologic map (pl. 1). Where Smith and Ketner (1975) mapped the two together, the lower part is more conglomeratic than normal. Dott (1955) considered the Tomera to be Middle Pennsylvanian in age and equivalent to the upper part of the Ely Limestone.

Ely Limestone **[ℙe]**. The Ely Limestone was originally defined by Lawson (1906); his definition was later modified by Spencer (1917), Pennebaker (1932), and Steele (1960). The Ely Limestone is Early and Middle Pennsylvanian (late Morrowan to late Atokan or Derryan) in Elko County. According to R. K. Hose (written commun., 1950), some Mississippian rock is present in the Ely in east-central Nevada and western Utah. The top of the Ely becomes younger northward from the latitude of Ely. According to Steele (1960), the Ely generally consists of medium- to coarse-grained bioclastic limestone.

In the Wood Hills-Pequop Mountains area [34], Thorman (1970) described the Ely Limestone in several of his thrust plates. In subplate IID, the Ely Limestone is about 1,500 ft thick (Thorman, 1970) and Diamond Peak-like conglomerate is present in the lower 600 ft, which is not unexpected because the Ely and the Diamond Peak are approximately coeval. The Ely is overlain conformably by the Hogan Formation of Robinson (1961), or disconformably by the Ferguson Mountain Formation of Berge (1960). The Hogan Formation is not separately mapped here (pl. 1) but is everywhere included in the Ely Limestone for the purposes of this report. The Hogan consists of a thin-bedded limestone to calcareous shale unit. It is 750 ft thick in the Pequop Mountains just south of the area mapped by Thorman, and from 0 to 500 ft thick in the northern Pequop Mountains, where it is unconformably overlain by the Ferguson Mountain Formation. The Hogan Formation is Desmoinesian (Middle Pennsylvanian) in the type area. At the north end of the Pequop Mountains in Thorman's plate IIH, the Ely Limestone varies in thickness (Thorman, 1970), probably because of Late Pennsylvanian erosion; it contains clastic units at a few localities. Thorman (1970) pointed out that the Pennsylvanian rocks of the Ely might be part of the Carlin sequence of Roberts and others (1965, p. 1932).

At White Horse Mountain [53A], Messin (1973) measured about 500 ft of the Ely Limestone, which is present as a light-medium-gray, thick-bedded limestone containing gray and brown chert in nodules or continuous beds. Intense fracturing of the limestone may be a merely local characteristic. The upper part of the Ely is missing in this area.

In the Leppy Range [42], Schaeffer and Anderson (1960) described the Ely Limestone, or the Ely Formation, as they referred to it (they used the name "Ely" to refer to the predominantly calcareous unit, regarded by them as a formation rather than a group). In the Silver Island Mountains, Schaeffer and Anderson (1960) used the term "Ely Formation and Oquirrh [lower part] Formation, undifferentiated." The clastic content of the formation in the western Silver Island Mountains (the Leppy Range in Nevada) does not justify extension of the name "Oquirrh" (Schaeffer and Anderson, 1960, p. 89) from its type area in the Oquirrh Mountains, Utah. In the Leppy Range the Ely Limestone can be divided into a lower member, 1,275 ft thick, and an upper member, 466 ft thick. "The lower member consists mainly of fine- to medium-crystalline, medium- to dark-gray limestone which weathers light to medium gray and contains bedded and nodular chert throughout." (Schaeffer and Anderson, 1960, p. 89) The upper member is three-fourths calcareous siltstone and one-fourth argillaceous limestone. The calcareous siltstone is thin bedded, reddish brown to red gray, and weathers buffish pink; chert nodules are common. The argillaceous limestone is light to dark gray, fine to coarse crystalline, and medium bedded. The limestone and the siltstone are interbedded. The Ely rests conformably on the what Schaeffer and Anderson (1960) called the Diamond Peak Conglomerate and is overlain unconformably by the Strathearn Formation; the contact with the Strathearn is placed at the base of a brownish-gray chert-pebble conglomerate with a silty, pink to brown matrix.

In the Pilot Range [36], O'Neill (1968) mapped a 1,040-ft-thick unit that he called the Ely Limestone and lower Oquirrh (undifferentiated). He divided it into two members. The lower member, 505 ft thick, consists of dark-gray to black locally bioclastic limestone; of this 505 ft, the lower 127 ft is medium to coarsely crystalline and highly fossiliferous. The upper or argillaceous member, at least 535 ft thick, is alternating medium-gray, fine- to medium-crystalline limestone and yellow-brown- to pink-weathering argillaceous limestone and calcareous siltstone. Siltstone and chert nodules occur throughout the limestone. The base of the unit is placed at the top of the highest conglomerate bed of the Diamond Peak.

In the central Pequop Mountains [40], Robinson (1961) divided the Ely Limestone into five informally designated members. Member 1, the lowest member, is approximately 500 ft thick and is gradational with the underlying Diamond Peak Formation; the member "...consists of interbedded bioclastic, argillaceous, silty-sandy, and siliceous-cherty limestone, with subordinate units of calcareous, quartzitic siltstone to orthoquartzite, and chert-small-pebble conglomerate to conglomeratic limestone." (Robinson, 1961, p. 100) Chert, rare in the lower beds, is present as nodules and beds in the upper beds. Member 2 is a 50-ft-thick conglomeratic sequence with subordinate interbeds of sandy and pebbly

limestone. Clasts in the conglomerate are subrounded to angular granules and small pebbles of varicolored chert and quartzite. Member 3 about 527 ft thick, resembles member 1 and is mainly composed of micritic limestone, argillaceous limestone, silty and fine-sandy limestone, and bioclastic limestone. Minor interbeds of shaly siltstone to orthoquartzite are also present; these interbeds range from thin and platy to massive. Chert is present as 1- to 3-in.-thick beds, nodules, and lenses. Member 4 is 250 ft thick; it differs from the normal Ely Limestone in its composition of interbedded micritic limestone, dolomitic limestone, calcareous dolomite, gypsiferous limestone, hard siliceous fossiliferous limestone, silt, and fine-sand detritus. The bedding is thin to massive; chert is rare or absent. Member 5 is a cliff-former and consists of medium- to thick-bedded, very fine- to fine-grained limestone, argillaceous limestone, and silty to fine-sandy limestone. Chert nodules make up as much as 5% of this unit. The five members of the Ely total 1,510 ft in thickness and are composed of rocks of Morrowan (Early Pennsylvanian) and Atokan (Middle Pennsylvanian) age.

At Ferguson Mountain [54], Berge (1960) found that the Ely Limestone is 1,411 ft thick and consists predominantly of limestone in alternating resistant, thick-bedded, cliff-forming units and thin-bedded, platy, slope-forming units. The rock is light to medium olive gray. Chert and fossils are common to abundant. Berge reported an unconformity in the middle of the Ely extending from the Desmoinesian to the Missourian.

At Spruce Mountain [46], Hope (1972) divided the Ely Limestone into two members. The lower member, about 900 ft thick, is massive to thick-bedded, medium-gray, fine-grained limestone containing abundant large concentrically layered chert nodules. The upper member, about 1,700 ft thick, consists of thin- to thick-bedded, medium-gray, fine-grained limestone commonly containing small spheroidal black chert nodules.

In the Ruby Mountains [49], Sharp (1942, p. 670) included the Ely in the undifferentiated Carboniferous; it consists "...of gray to light-brownish gray, flaggy to massive, fine- to medium-grained limestone locally argillaceous and containing considerable gray chert as nodules and irregular bedding lenses." Less abundant, nearly black, dense carbonaceous limestone is also present. The limestone weathers light gray or muddy tan. It crops out at the east base of the range just south of Harrison Pass and is separated from other Paleozoic rocks by a fault.

Quilici Formation **[ℙq]**. Riva (1970) applied the name "Quilici Formation" to rocks in the HD Range [17]. This formation unconformably overlies the western assemblage. The Quilici is approximately 350 ft thick and is largely made up of ledge-forming limestone, with a basal chert conglomerate that is about 120 ft thick at the formation type locality. The upper 230 ft of the formation is a ledge-forming limestone alternating with thinner red-weathering siltstone and sandstone in lenticular beds of chert conglomerate. It is unconformably overlain by the Permian Buckskin Mountain Formation (Fails, 1960). The Quilici is dated principally by Desmoinesian (Middle Pennsylvanian) fusulinids. It probably correlates temporally with the Tomera Formation and with the Hogan Formation (Robinson, 1961) in the central Pequop Mountains. It differs from the Tomera in its content of coarse clastic material. The name appears to be a valid one and is adopted here. The type locality is in the HD Range, on the south side of Blood Gulch.

Van Duzer Limestone **[ℙvd]**. The Van Duzer Limestone was named by Decker (1962) for exposures in Van Duzer Creek, a conspicuous stream flowing eastward from the Bull Run Mountains in the southern part of the Owyhee 15′ quadrangle. The Van Duzer crops out in the Bull Run quadrangle [9] and in the Owyhee 15′ quadrangle [3]. The Van Duzer Limestone consists of thin-bedded to massive, nearly white to blue-gray nearly pure calcareous limestone with paper-thin laminations of shaly limestone. The amount of limestone everywhere exceeds the amount of shaly interbeds. According to Decker (1962), the total thickness is more than 7,200 ft.

Decker (1962) assigned the Van Duzer Limestone a Devonian(?) age. Two collections of fossils from the same locality on Trail Creek (field nos. 71NC94, 74NC78) contained bryozoans, brachiopods, and conodonts. Mackenzie Gordon, Jr. and B. R. Wardlaw dated the megafossils as Middle Pennsylvanian to Early Permian; Anita Harris dated the conodonts from the second collection as Morrowan to Desmoinesian. Because these two age determinations overlap in the Desmoinesian, the Van Duzer Limestone is here assigned an age of Desmoinesian (Middle Pennsylvanian). However, the great thickness of the limestone suggests that it may include much rock both younger and older.

In the northern part of the Rowland quadrangle [5], Bushnell (1967, p. 16) mapped a unit that he called Paleozoic limestone and argillite. He divided it into a lower(?) argillaceous member and an upper(?) laminated limestone member. The lower(?) member consists of very thick beds of argillaceous rocks and minor amounts of interbedded limestone. These rocks have been converted to argillite by thermal metamorphism due to a nearby granitic intrusion. Fresh surfaces of the argillite are dark gray to grayish black, and weathered surfaces are light olive gray to greenish gray. Argillaceous beds in the lower(?) member are interbedded with crystalline, micaceous, light- to dark-colored laminated limestone. The upper(?) member is largely thinly laminated to laminated, medium-light- to medium-dark-gray, very fine grained limestone. In overall lithology and appearance, Bushnell's (1967) Paleozoic limestone and argillite unit resembles the Van Duzer Limestone and therefore is mapped (pl. 1) with the Van Duzer **[ℙvd]**.

Pennsylvanian and Permian Systems

Undivided Limy Rocks **[ℙPu]**. In the Leppy Range [42], Schaeffer and Anderson (1960) described a sequence of calcareous rocks that are here mapped (pl. 1) as a single unit. Included in this unit are the Strathearn Formation, the Rib Hill Formation, the Ferguson Springs Formation (now known as the Ferguson Mountain Formation), and the Pequop Formation. The Strathearn Formation was named by Dott (1955, p. 2248) for exposures in the South Fork of the

Humboldt River near Carlin, Nevada. The name "Rib Hill" was first published by Pennebaker (1932). The Ferguson Springs Formation was named by Steele (1960) for exposures near Ferguson Springs in the southeastern part of Elko County. The name "Ferguson Mountain" has priority over the name "Ferguson Springs." The Pequop Formation was named by Steele (1960) for exposures in the Pequop Mountains in Elko County.

The lowest part of the undivided limy rocks in the Leppy Range includes 287 ft of brown-weathering, brown-gray, chert-pebble conglomerate with a pink silty limestone matrix, interbedded with limestone, siltstone, and dolomite. The conglomerate beds are not notably lenticular. Above this part of the unit is about 2,550 ft of fossiliferous medium- to dark-gray limestone, interbedded with gray, brown, and tan siltstone that is locally fossiliferous; red-, orange-, and maroon-weathering sandstone; and a few beds of fine-grained, light-gray dolomite. The lowest part of this unit (the conglomeratic 287 ft), according to Schaeffer and Anderson (1960, p. 97), corresponds to the Strathearn Formation or conglomerate of the Sunflower Formation (Coash, 1967); it rests with angular unconformity on the Ely Limestone in the Leppy Range. Fossil collections in the Elko County portion of the Leppy Range indicate that the unit ranges in age over at least the interval from Early Pennsylvanian to middle Wolfcampian to middle Leonardian (Early Permian). The upper 2,550 ft corresponds to the Riepetown, Ferguson Mountain, and Pequop Formations.

In the Pilot Range [36], O'Neill (1968) described an undifferentiated sequence of limy rocks that are equivalent to the Strathearn Formation, the upper part of the Oquirrh Formation, the Riepetown Sandstone, the Ferguson Mountain Formation, and the Pequop Formation. The undivided limy rocks in the Pilot Range are poorly exposed and the thickness could not be measured. The unit consists of thin- to thick-bedded, somewhat argillaceous, bioclastic, medium-grained, dark-gray limestone and minor interbeds of dark-brown-weathering siltstone.

Limestone and Dolomite **[ℙPl]**. The limestone and dolomite unit (pl. 1) includes the Rib Hill Formation (Riepetown Sandstone), the Riepe Spring Limestone, the Ferguson Mountain Formation (Berge, 1960) [41], and an unnamed limestone (Riva, 1970). In the HD Range [17], Riva (1970) described a thick, Upper Pennsylvanian limestone formation with a basal conglomerate that rests with angular unconformity on rocks of the western assemblage. In the Spruce Mountains [46], Hope (1972) mapped a unit of undivided Pennsylvanian and Permian rocks that includes the Riepe Spring Limestone below and the Rib Hill Formation (Riepetown Sandstone) above. The Riepe Spring in the Spruce Mountains is thick-bedded to massive, medium-gray, fine-grained limestone. Nodular chert is common in the lower part and very rare in the upper part; chert-pebble conglomerate is common to the north and rare at the south end of Spruce Mountains. The unit is about 1,400 ft thick. The Rib Hill Formation in this area consists of tan-weathering platy siltstone and thin-bedded limestone, and ranges from 600 to 1,500 ft in thickness.

In the Wood Hills and the Pequop Mountains [34], Thorman (1970) described the Ferguson Mountain Formation as a sandy, partly cherty, fusulinid-bearing limestone; the maximum measured thickness is 275 ft. In the Wood Hills it rests disconformably on the Ely Limestone, and in the Pequop Mountains it disconformably overlies the Hogan Formation, which in this report is mapped (pl. 1) with the Ely Limestone **[ℙe]**. The Ferguson Mountain Formation is Wolfcampian (Early Permian) in the Pequop Mountains and in the Wood Hills. The Ferguson Mountain Formation was originally described by Berge (1960) as a 1,986-ft-thick sequence at Ferguson Mountain on the east margin of the county [54]; it consists predominantly of dark- to light-gray limestone, in alternating beds of massive, cliff-forming and platy, slope-forming limestone. The bedding ranges from massive to laminated. Chert is common throughout. Early Permian fossils, especially fusulinids, are abundant and represent all of the Wolfcampian and part of the overlying Leonardian.

In the Kinsley mining district [55], Buckley (1967) described a 1,250 ft thick section (base not exposed) of the Ferguson Mountain Formation, which consists mostly of massive, light-brown- to gray-weathering, medium-grained, argillaceous limestone. Chert is present as beds, nodules, and stringers. Fusulinids, corals, and bryozoans are common. The Ferguson Mountain Formation is Early Permian and ranges from late Wolfcampian to early Leonardian; it is equivalent in age to the Riepe Spring Limestone or the Rib Hill Formation (Riepetown Sandstone) and the lower part of the Arcturus Formation in the Ely mining district.

Strathearn Formation **[ℙPs]**. In the Carlin-Piñon Range area [43], Smith and Ketner (1975) mapped the Strathearn Formation, some areas of which were separately mapped for this report, whereas other areas are here included in the Carlin sequence of Roberts and Thomasson (1964) (amended). The Strathearn Formation of Late Pennsylvanian and Early Permian age, was named by Dott (1955, p. 2248) for the old ranch headquarters of the Strathearn Cattle Co. in the N/2 S8,T33N,R54E; the type section was designated "...at the west side of the head of the lower canyon of the South Fork of the Humboldt River." In the type area, the Strathearn is 1,200 to 1,500 ft thick, and north of Carlin Canyon it is more than 2,000 ft thick. The Strathearn consists generally of clastic rock, much of which is calcareous; gray limestone in thin- to thick-bedded units is characteristic of the formation. Such rocks are scarcer in the overlying part of the Permian formations. There are platy, silty, and sandy beds in the Strathearn like those in the overlying strata. Well-rounded chert and quartzite pebbles and cobbles are common; chert clasts are black, gray, green, and red.

In the Mount Velma quadrangle [13], Coash (1967, p. 7) described a sequence of rocks that he named the Sunflower Formation. In this report the Sunflower Formation is mapped (pl. 1) as the Strathearn, which it resembles closely both in age and in lithology. J. H. Stewart (written commun., 1980) suggested that the Sunflower is lithologically correlative with the Antler Peak Limestone. However, the Antler Peak Limestone is not conglomeratic, and the Battle Formation underlying the Antler Peak in its type area is younger than any

rocks in the Sunflower. The total thickness measured by Coash is more than 4,000 ft. He divided the formation into three members: a conglomerate at the base, a limestone in the middle, and a sandstone at the top. The formation rests on the Tennessee Mountain Formation (Cambrian and Ordovician; Bushnell, 1967) and is overlain by Tertiary rocks or by older rocks in thrust contact.

The lower member of the Sunflower consists of well-sorted quartzite and chert-pebble conglomerate, quartzite, and sandstone; the conglomerate has a sandy matrix. The maximum measured thickness is 1,985 ft. The rocks characteristically weather brownish gray or grayish red, and the bedding is generally well defined.

The middle member of the Sunflower has a total measured thickness of 530 ft (Coash, 1967) of largely quartzose calcarenite in the Mount Velma quadrangle; it is 1,100 ft thick in the Rowland quadrangle (Bushnell, 1967). The limestone is medium dark gray, weathers dusky yellow, and grades into the underlying conglomerate member.

The upper member of the Sunflower lies conformably on the middle member. In the Mount Velma quadrangle this upper member comprises about 1,400 ft of fine-grained sandstone, micaceous siltstone, and thin beds of silty limestone; the beds are generally calcareous. One 30-ft-thick bed of pale-red volcanic ash is present near the base of this member. In his mapping of the Rowland quadrangle, Bushnell (1967) did not distinguish the sandstone member.

Massive limestone correlated with the Sunflower or the Strathearn is also present in the southeastern part of the Mountain City 15′ quadrangle and in the northwest corner of the Marys River Basin NW quadrangle. The thickness is several hundred feet, but both the bottom and top are thrust faults (field nos. 60NC14, 60NC19). This limestone also occurs on the south side of the Humboldt River canyon, in the Osino quadrangle (field nos. 79NC55, 79NC56).

R. D. Hoare (Coash, 1967, p. 11–12) reported that fossils collected from the middle member include both Pennsylvanian and Permian forms, including some that are exclusively Permian; he considered the limestone to be earliest Permian (Wolfcampian). Several U.S. Geological Survey workers and I collected fossils that are also Pennsylvanian and Permian (field nos. 62NC8, 62NC308, 309, 310, 64G28, 64G28A, 64G29, 64NC165, 71NC78, 72CR49), and the formation as a whole is correlated with the Strathearn Formation of Late Pennsylvanian and Early Permian age. The lithologic sequence of the Strathearn Formation in its type area differs from that of the Sunflower, although the time-span is approximately the same.

Carlin Sequence (Amended) **[IPPcs]**. Roberts and Thomasson (1964) included the following formations, in ascending order, in their Carlin sequence: (1) the Tonka Formation (Early Mississippian to Pennsylvanian; Dott, 1955), which consists of conglomerate, sandstone, shale, and graywacke, totaling about 2,500 ft in thickness; (2) the Moleen Formation (Early and Middle Pennsylvanian; Dott, 1955); (3) the Tomera Formation (Middle Pennsylvanian; Dott, 1955), in which the Moleen and Tomera comprise at least 3,200 ft of limestone, fine conglomerate, and sandstone; (4) the Strathearn Formation (Late Pennsylvanian and Early Permian), which consists of limestone and fine conglomerate; and (5) the Buckskin Mountain Formation (Early Permian; Fails, 1960), comprising 6,200 ft of sandstone and limestone.

The Tonka Formation was considered by Smith and Ketner (1975) as a synonym of the Diamond Peak Formation; accordingly, the name Diamond Peak is used in this report instead of the name Tonka because it has priority. The Diamond Peak has commonly been separately mapped in the Elko-Carlin area, as in most of Elko County and locally is mapped (pl. 1) with the Chainman Shale. The Moleen and Tomera Formations, undivided, are also separately mapped (pl. 1) in the Elko-Carlin area. As a consequence, I have excluded the Tonka, Moleen, and Tomera Formations from the Carlin sequence as employed in this report; I have included the Beacon Flat, Carlin Canyon, and Phosphoria Formations within the Carlin sequence above the Buckskin Mountain Formation because they form a conformable stratigraphic sequence. As a consequence of this modified usage, I will use the term "Carlin sequence (amended)" within this report to distinguish my usage from that of Roberts and Thomasson (1964). The Strathearn Formation generally is also separately mapped (pl. 1) in this report, although parts of it may be locally included in Carlin sequence (amended).

The Buckskin Mountain Formation was named by Fails (1960) for Buckskin Mountain, 3 mi south of the type locality north of Carlin Canyon. The rock "...consists predominantly of light-yellow-buff and tan quartzose calcisiltites with...numerous thin interbeds of gray-brown, clean calcisiltite. Minor beds of gray, fine- to coarse-grained calcarenite occur, and a few beds of brown chert are also present." (Fails, 1960, p. 1693) The Buckskin Mountain in the type locality is approximately 1,200 ft thick. The Buckskin Mountain was believed by Fails to be wholly Wolfcampian (Early Permian).

The Buckskin Mountain is conformably overlain by the Beacon Flat Formation, named by Fails (1960, p. 1697–1699) for Beacon Flat, an area of low relief north of Carlin Canyon. The formation, estimated to be about 2,800 ft thick, consists of a lower member about 560 ft thick, and an upper member about 1,140 ft thick, with a covered intervening interval of 1,100 ft. The lower member is composed of silty calcisiltite and calcilutite interbedded with gray and tan calcarenite and gray chert beds and nodules in the lower part. These calcisiltites and calcilutites are overlain by a thin limestone-pebble conglomerate, an interbedded, fine-grained calcarenite, and massive gray, chert beds. The upper member is composed of thick-bedded, gray, fine-to coarse-grained calcarenite containing gray chert beds and nodules. The lowermost 140 ft of the member consists of massive, light-gray calcisiltite with gray chert interbeds; light-gray, fine-grained quartzose calcarenite with brown chert interbeds makes up the topmost 65 ft. The upper member is irregularly dolomitized. The Beacon Flat is considered to be Wolfcampian and Leonardian (Early Permian) and the boundary probably occurs within the lower member.

The Carlin Canyon Formation was named by Fails (1960, p. 1699–1703) for rocks north of Carlin Canyon that conformably overlie the Beacon Flat Formation. The Carlin Canyon is composed largely of yellow-tan quartzose calcisiltite containing massive brown chert and thin beds of dense, clean, grayish-brown calcisiltite.

On the west flank of the HD Range [17], Riva (1970) described two distinct units that he believed belong to the Buckskin Mountain Formation. The lower unit is 400 to 700 ft of tan-, pink-, and purple-weathering silt and shale in thin platy beds; thin platy limestone beds occur in the lowermost 300 ft. The upper unit, possibly 600 ft thick, is uniform, medium-grained, light-brown sandstone. The maximum thickness of the formation in this area is 1,200 ft. On the east flank of the HD Range, in the same thrust plate, Riva mapped a formation that consists of 700 ft of tan and olive-gray siltstone and shale containing many thin limestone beds and a smaller proportion of pink-and purple-weathering beds. This formation also occurs on the southeast margin of the HD Range, where it consists of massive limestone, platy siltstone, and carbonaceous limestone. It is here mapped (pl. 1) as part of the Carlin sequence (amended).

In the Windermere Hills [26], Oversby (1972) described several formations: the Strathearn Formation, the Buckskin Mountain Formation (Fails, 1960), and the Carlin Canyon Formation (Fails, 1960). The Strathearn unconformably overlies the western and transitional assemblages; it consists of limestone in beds 1 to 10 ft thick, and quartz siltite in 10-ft-thick beds that alternate with the limestone beds. The limestone consists of dark-gray, light-gray-weathering, medium-bedded bioclastic calcarenite and calcirudite. The bioclastic material is primarily crinoid fragments mixed with quartz siltite and sandstone and scattered subangular granules of brown and gray chert. Quartz-chert arenite and rudite, and quartz siltite, occur in lenses as much as 80 ft thick. The clastic rocks commonly occur in graded beds. The Strathearn is apparently early Wolfcampian (Early Permian) in this area.

The Buckskin Mountain Formation is apparently conformable on the Strathearn. The Buckskin Mountain is about 1,500 ft thick and forms rounded hills and ridges. The predominant rock type is a brown-gray quartz siltite, that is platy, flaggy, slaggy, and commonly calcareous, and weathers shades of brown and red; it also contains lenses of medium-bedded to blocky and slabby quartz-chert arenite, as much as 80 ft thick. Subangular to subrounded clasts of brown, black, tan, and green chert containing a few pale-tan and gray orthoquartzite clasts are also present. Some of the rudite beds are graded. Also present are medium-bedded, commonly bioclastic calcisiltite and calcarenite, in beds as much as 10 ft thick. The Buckskin Mountain ranges in age from Wolfcampian to Leonardian (Early Permian).

The Carlin Canyon Formation overlies the Buckskin Mountain Formation, apparently conformably according to Oversby (1972), although the Beacon Flat Formation of the Carlin area is absent. The Carlin Canyon Formation is about 1,500 ft thick. The lower part consists of buff calcareous quartz siltite containing medium-bedded calcilutite, calcisiltite, and calcarenite; it is locally dolomitic and commonly cherty. The limestone may grade laterally into dark-brown to black, medium-bedded, blocky and slabby chert; quartz-chert arenite and rudite are present in lenses as much as 100 ft thick. The upper 300 ft of the formation is dominated by bedded chert that is commonly purplish, with irregular and knobby bedding surfaces. The brachiopods in this chert suggest a lower Guadalupian (Early Permian) age.

In the O'Neil Pass area [16], Bezzerides (1967) described 800 to 900 ft of what he called the Phosphoria Formation, which includes a dark siltstone, chert, and phosphorite beds. The Phosphoria in that area is mapped (pl. 1) as part of the Carlin sequence (amended).

In the southern part of the Carlin-Piñon Range area [43], Smith and Ketner (1975, p. A63–A74) described a unit that spans the entire Late Pennsylvanian and Early to Late Permian interval. The rocks are characteristically thin-bedded siltstone, sandstone, and calcareous debris, weathering to form yellow, tan, and reddish-tan platy fragments. The carbonate rocks range in composition from limestone to dolomite. In the southern part of the county, the unit includes, in some places, the Strathearn Formation and coeval rocks. This unit includes the equivalent of the units of Fails (1960). Smith and Ketner (1975) chose to combine Fails' units into a single map unit because his units could not be differentiated in much of their map area.

Permian System

***Pequop Formation* [Pp].** The Pequop Formation was named by Steele (1959b, p. 1105; 1960, p. 106) for a thick sequence of thin-bedded, fusulinid-bearing limestone measured 1½ mi north of the Jasper Railroad tunnel in the central Pequop Mountains. Steele (1960, p. 106) stated: "At the type locality the formation is composed of purplish-gray, irregularly bedded, platy silty limestones with interbedded fusiline coquinas. The lower contact is placed at the base of a red silt member which overlies the Wolfcampian-age massive limestones of the Ferguson Springs [Ferguson Mountain] Formation. The upper boundary is placed at the base of the Loray Formation...of Lower Guadalupian age." The formation as defined by Steele (1960) is 1,570 ft thick at its type locality; the basal reddish-tan silt member ranges from 8 to 130 ft in thickness.

In the area of the Wood Hills and the Pequop Mountains [34], Thorman (1970) described a sequence of rocks that he ascribed to the Pequop Formation. This sequence is composed of thin-bedded to platy silty limestone containing some fusulinids. Robinson (1961, p. 105) mapped 3,087 ft of the Pequop Formation in the central Pequop Mountains.

In the Spruce Mountain area [46], Hope (1972) divided the Pequop Formation into two members. The lower member, about 1,200 ft thick, is composed of medium-to thick-bedded, medium-gray, fine-grained limestone interbedded with platy siltstone. Chert nodules are locally abundant. Many fusulinid and crinoid columnals are present, but gastropods are rare. The upper member, more than 4,000 ft thick, is composed of thick-bedded to massive, medium- to fine-

grained limestone containing abundant pentagonal to circular crinoid columnals, many gastropods, and rare fusulinids.

In the Ferguson Mountain area [54], Berge (1960) described a considerable thickness of the Pequop Formation, which constitutes the upper (Early Permian) part of the Leonardian Series. The total thickness is about 682 ft of interbedded, characteristically yellow-brown calcareous quartzite and silty limestone. Quartzite and calcareous quartzite predominate and commonly weather to platy fragments.

The Pequop Formation includes the Arcturus Formation in the extreme southeastern part of Elko County and the Loray Formation in the southern part of the county; thus, the Pequop Formation, as mapped for this report, is nearly equivalent to the Arcturus Group (Bissell, 1964).

In the Medicine Range [50], Collinson (1966) described two units of the Arcturus Group, which he mapped separately, the Pequop Formation and the Loray Formation. The Pequop Formation, which has a total thickness of 3,830 ft, is divided into three members—A, B, and C—in ascending order: member A consists of 790 ft of dark-gray massive, ledge-forming fusulinid-bearing limestone; member B comprises 2,070 ft of slope-forming calcareous siltstone and silty limestone; and member C consists of 970 ft of dark-gray limestone with interbedded calcareous siltstone. The terrigenous material is quartz silt and very fine sand, and the limestone is micrite and biomicrite. All of these units are included within the Pequop Formation on the geologic map (pl. 1).

Arcturus Formation **[Pp]**. Lawson (1906, p. 294) assigned the name "Arcturus Limestone" to an argillaceous and sandy limestone above the Ely Limestone near Ely, Nevada. The status of the Arcturus Limestone has been somewhat uncertain since Spencer (1917, p. 26) used the name "Arcturus Formation" for the rocks immediately above the Ely Limestone at the Arcturus Mine. Wilson and Langenheim (1962, p. 496–502) defined the Arcturus Formation in the Ely mining district as a unit above the Riepetown (Rib Hill) Sandstone and below the Kaibab Formation. Bissell (1964, p. 585) proposed to raise the Arcturus Formation to group rank and included in it, in ascending order: the Riepe Spring Limestone, the Riepetown (Rib Hill) Sandstone, the Pequop Formation, and the Loray Formation.

In the Kinsley Mountains [55] of southeastern Elko County, Buckley (1967) found less than 500 ft of the Arcturus Formation exposed. The rock consists of a fine- to medium-grained sandstone that weathers white to purple or reddish brown; where fresh, it is generally olive brown. Although no fossils were found, the age of the Arcturus is bracketed in the middle to late Leonardian (Early Permian) by dates on the overlying and underlying rocks. The Arcturus Formation overlies the Ferguson Mountain Formation (Berge, 1960).

Loray Formation **[Pp]**. Above the Pequop Formation is a unit mapped by Collinson (1968) as the Loray Formation, which is included with the Pequop in the geologic map (pl. 1). The name "Loray Formation" was proposed by Steele (1960, p. 106) "...for a sequence of yellow-tan, gypsiferous silts and thin bioclastic limestones exposed at the head of Loray Wash in a Southern Pacific Railroad cut on the southwest side of Montello Valley."

In the Medicine Range the Loray Formation is recognized as a slope-forming unit below the Kaibab Formation. The Loray is composed of a thin-bedded to thinly laminated silty dolomite and siltstone; sporadic beds of algal and shelly limestone crop out in the lower half of the formation. The Loray conformably overlies the Pequop and is conformably overlain by the Kaibab Formation. The Loray Formation is mapped (pl. 1) with the Pequop or Arcturus Formations and, elsewhere, with the Park City Group.

Unnamed Bioclastic Limestone **[Pbl]**. In the central Leach Mountains, west of Montello, Hope (1970) mapped a section, about 300 ft thick, of thick-bedded to massive, medium-gray, medium-grained, mostly bryalgal and crinoidal bioclastic limestone; these rocks are interbedded with platy, fine-grained, light-gray siltstone and limestone. Thick beds of milky to light-gray chert are common. The unit conformably overlies the Pequop and underlies the Grandeur Formation. According to B. R. Wardlaw, the fossil evidence (field nos. 344, P8, P10, 73A28, L98, 78, 76, 187, P14, 73A29, 347) suggests a Leonardian age (Early Permian).

Park City Group **[Ppc]**. The Park City Formation was defined by Boutwell (1907, p. 443–446) as the beds overlying the Weber Quartzite of Pennsylvanian age and underlying the Woodside Shale of Triassic age in Big Cottonwood Canyon, near Salt Lake City, Utah. This unit was later subdivided by McKelvey and others (1956). At the type locality, Park City, the formation consists of an unnamed lower member composed principally of carbonate rock, and an upper member, the Franson; the members are separated by the Meade Peak Phosphatic Shale Member. Cheney and others (1956) named the lower member of the Park City Formation the Grandeur Member. Hose and Repenning (1959) raised the Park City to group rank in the Confusion Range, where it includes, in ascending order: the Kaibab Limestone, the Plympton Formation, and the Gerster Limestone. They considered the group to be correlative with the Park City Formation in other areas. The usage of Hose and Repenning (1959) is adopted here for rocks in the southeastern part of Elko County that are lithologically similar to those in the Confusion Range.

In the northeastern part of the county, all of the Gerster and part of the Phosphoria are mapped (pl. 1) as a single unit **[Pgp]** , which rests on and may grade into the Phosphoria Formation. The Phosphoria consists of in descending order: the Meade Peak Phosphatic Shale Member, the Rex Chert Member, and an unnamed dolomite member of the Phosphoria Formation; presumably, in such places, the Gerster and Phosphoria Formations, undivided, are mostly the Gerster. The Grandeur Formation, which is equivalent to the Kaibab Limestone of the Park City Group, has been mapped, separately **[Ppcg]** in some places in the northeastern part of the county. In parts of eastern Elko County, the Park City Group has been included entirely within the Pequop Formation.

In the Currie area [51], Nelson (1956) described rocks that he also ascribed to the Park City Group. The lowest

exposed Paleozoic formation in the Currie area is the Kaibab(?) Limestone, consisting of at least 200 ft of pale-gray limestone and some chert; the limestone weathers pale brownish gray. Conformably overlying the Kaibab(?) is a sequence of beds that Nelson regarded as the Phosphoria Formation; these beds are here reassigned to the Plympton and Gerster Formations of the Park City Group. The lowest unit, considered to be the Plympton Formation, comprises about 90 ft of shale, siltstone, and some yellowish-brown and black chert and oolitic phosphate rock. This unit is exposed only in the center of Phalan Butte.

At Spruce Mountain [46], Hope (1972) described the Kaibab and Plympton Formations. The Kaibab Limestone overlies the Loray Formation, here a tan-weathering platy siltstone and silty limestone. The Kaibab Limestone is a light-gray, medium- to thick-bedded, cherty limestone, about 400 ft thick. The Plympton Formation is a light-gray fine-grained cherty dolomite, more than 500 ft thick, that rests on the Kaibab.

At Ferguson Mountain [54], Berge (1960) recognized the Park City Group as containing the Kaibab Limestone and the conformably overlying Plympton Formation. The Kaibab consists of about 420 ft of yellowish-gray, finely crystalline limestone. Massive units are predominant; these units weather to rounded cliffs containing abundant chert in the lower part. The Plympton contains 238 ft of predominantly light-gray, coarse-grained, crystalline dolomite that forms massive cliffs.

Small amounts of calcareous rocks occur in the Divide Peak area in the Double Mountain quadrangle. These rocks are largely limestone and limy siltstone, only a small thickness of which is exposed. They were originally thought by Coats and Gordon (1972) to be part of the Phosphoria, but because of their calcareous lithology it seems more appropriate to assign them to the Park City Group **[Ppc]**.

In the Medicine Range [50], Collinson (1968) described a section of the Park City Group which includes the three formations included in it by Hose and Repenning (1959): Kaibab, Plympton, and Gerster. The Kaibab is 280 ft thick, the Plympton is 510 ft thick, and the Gerster is 1,210 ft thick. The Kaibab Limestone conformably overlies the Loray Formation, the Plympton Formation conformably overlies the Kaibab and underlies the Gerster, and the Gerster Formation is unconformably overlain by 520 ft of Early Triassic marine rocks that were referred to by Collinson (1968) as the Thaynes Formation. The Kaibab is a 280-ft-thick prominent cliff-former composed of massive light-gray dolomite, with isolated beds of medium-dark-gray limestone near the base; some light-gray chert nodules occur in the upper part of the formation. The Plympton, 510 ft thick, is divided into four lithologic units. The lowest unit, 75 ft thick, consists of saddle-forming silty chert. The second unit, 115 ft thick, is a light-gray calcareous dolomite resembling Kaibab dolomite but finer grained. The third unit, 190 ft thick, is predominantly chert with thin interbeds of fine-grained phosphatic dolomite. The uppermost unit, 125 ft thick, consists of interbedded dolomite and chert. The Gerster Formation, which is 1,210 ft thick, consists (Collinson, 1968, p. 31) of "...micrite, dolomitic, silty, yellowish gray, thin to medium bedded, and siltstone, calcareous; overlain by packed biomicrite and unsorted biosparite, light gray to yellowish gray medium to thick bedded with 10–60% of chert nodules (which are) light brownish gray to moderate brown."

Generally, the Kaibab, according to B. R. Wardlaw and J. W. Collinson (written commun., 1977), in the study area is 245 to 270 ft thick. The upper part of the Kaibab is commonly dolomitized. "The limestones of the Kaibab," they report, "are commonly brachiopod-bryozoan-crinoidal wackestone and packstone." The limestone in the lower parts of the section grades upward into medium-crystalline dolomitic limestone and dolomite; considerable nodular chert is present in the dolomitic part. In places in eastern Nevada, the Kaibab overlies the Loray Formation (Steele, 1960), which rests on the Arcturus Formation.

Hose and Repenning (1959, p. 2181–2182) divided the Plympton Formation in its type area in the Confusion Range, Utah, into five lithologic units, in ascending order: (1) a basal unit, "hackly, medium- to dark-gray bedded chert", 20 to 25 ft thick; (2) "very finely crystalline yellowish-gray dolomite," 110 to 115 ft thick; (3) "medium-light-gray to light-olive-gray" chert interbedded with "yellowish-gray dolomite," 115 ft thick; (4) "finely crystalline yellowish-gray dolomite containing abundant siliceous material, about 125 ft thick; and (5) "dolomite, chert, carbonate breccia, sandstone, siltstone, and gypsum," in decreasing order of abundance, about 310 ft thick. The lithologic sequence described at the type locality, according to B. R. Wardlaw and J. W. Collinson (written commun., 1977), is generally recognizable over the regional extent of the formation. Although the total thicknesses are comparable, the Plympton, which is less competent than the underlying and overlying carbonate rocks of the Kaibab and Gerster Limestones, is much more susceptible to internal deformation. As B. R. Wardlaw and J. W. Collinson (written commun., 1977) reported, the two lithologic units that compose the basal third of the Plympton Formation are distinctive enough to be recognized regionally. The basal unit (unit 1 of Hose and Repenning, 1959) is a dark-gray and brown phosphatic chert and mudstone. Hodgkinson (1961, p. 180) noted the occurrence of phosphate rock in this unit and was the first to suggest that it might represent a tongue of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation. Yochelson and Fraser (1973, p. 22) described thin beds of pelletal phosphate within the unit in the southern Pequop Mountains. A resistant unit of massive, fine-grained dolomite (unit 2 of Hose and Repenning, 1959) overlies the basal unit; this unit closely resembles the upper part of the Kaibab Limestone lithologically but is thinner and more completely dolomitized. The thicknesses range from 110 ft in the Confusion Range to 83 ft at Gold Hill, Utah. It consists mostly of silty light-gray crystalline dolomite, interbedded with dark-gray microcrystalline dolomite; chert nodules are common near the top of the unit. In the upper two-thirds of the Plympton Formation the specific units are definable only in general terms, according to B. R. Wardlaw and J. W. Collinson (written commun.,

1977), because of the lack of a resistant marker unit. The middle part of the formation is predominantly bedded chert and dolomite. Much of the bedded chert is massive. Locally in the dolomite the elongate chert nodules do not join to form nodular chert beds. As noted by Hose and Repenning (1959, p. 2182), unit 5 of the Plympton Formation contains a great variety of rock types. Chert-granule conglomerate has been reported from many sections—for example, in the Confusion Range, the Medicine Range, the southern Pequop Mountains, and at Gold Hill; Wardlaw and Collinson (1977) reported it at Spruce Mountain. The chert clasts, as they suggested, may have been derived by erosion from the Lower Permian or Mississippian conglomerates that were originally derived from the Antler orogenic belt to the east. I suggest that the Pennsylvanian conglomerate may also have been involved as source beds. Wardlaw and Collinson (1977) reported limestone beds of Gerster-like lithology, containing brachiopods of the Gerster fauna, in the uppermost unit of the Plympton Formation in the central Butte Mountains, the Medicine Range, the Cherry Creek Mountains, at Spruce Mountain, and at Gold Hill; the presence of these beds suggested to them an intertonguing between the Plympton and Gerster Formations.

The Grandeur Member of the Park City Formation was named by McKelvey and others (1959, p. 12) for exposures near Grandeur Peak in the Wasatch Range of Utah. In most of the western phosphate field, this member is, though dominantly carbonate rock, a characteristically heterogeneous unit. Wardlaw and others (1979a, p. 12), who recently studied the Phosphoria Formation and related rocks in northeastern Nevada and northwestern Utah, concluded that the Kaibab Limestone of northeastern and east-central Nevada and adjacent Utah, the Grandeur Formation of northwestern Utah, and the Grandeur Member of the Park City Formation in northeastern Utah are all temporally equivalent. For the purposes of this report, R. A. Hope chose to map this unit as the Grandeur Formation in northeastern Elko County. In the Leach Mountains section, according to Wardlaw and others (1979a, fig. 10), it consists largely of cherty dolomite.

Grandeur Formation **[Ppcg]**. In northeastern Elko County, the Grandeur Formation is separately mapped (pl. 1); elsewhere, it is not differentiated from the Park City Group. The Grandeur was originally defined as the basal member of the Park City Formation by J. S. Williams (*in* McKelvey and others, 1959, p. 36–37), who described it as consisting of carbonate rock, cherty carbonate rock, and carbonate-rich sandstone and siltstone. The type section is near the mouth of Mill Creek Canyon in Salt Lake County, Utah.

In the central Leach Mountains, west of Montello, R. A. Hope (unpub. data, 1973) measured several thousand feet of the Grandeur Formation, here consisting mostly of very fine grained, medium- to thick-bedded, chalk-white-weathering dolomite containing some bryozoans, algae, crinoid stems, and brachiopods in the lower part. Some beds contain abundant, generally dark-gray chert nodules; a few beds of chert-granule conglomerate are also present. The nodular limestone and chert beds are more common in the upper part of the Grandeur Formation. Near the base there is some interbedded bioclastic limestone as the Grandeur grades into the underlying bioclastic limestone. The Grandeur is overlain by a siltstone and chert correlated with the Meade Peak Phosphatic Shale and Rex Chert Members of the Phosphoria Formation.

Murdock Mountain Formation **[Pgp]**. The Murdock Mountain Formation was named by Wardlaw and others (1979b) for a sequence of dolomitic chert, dolomite, fine-grained sandstone, and siltstone. The type section is on the east flank of Murdock Mountain in the N/2 S36,T39N,R67E in the Loray quadrangle. "The formation conformably overlies the Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation and is conformably overlain by the Gerster Limestone. [It] is laterally equivalent to the Plympton Formation... and to the Rex Chert Member of the Phosphoria Formation." (Wardlaw and others, 1979b, p. 5) It is believed to be equivalent to the unnamed dolomitic member at the top of the Phosphoria Formation, which was recognized by T. M. Cheney (written commun., 1958) and by R. A. Hope (written commun., 1972). The formation is 1,260 ft thick in its type area. The Murdock Mountain Formation is mapped (pl. 1) with the Gerster and Phosphoria Formations, undivided **[Pgp]**, in the northeastern part of the county.

Gerster Formation **[Pgp]**. The Gerster Formation was named by Nolan (1930) for a thin-bedded sandy and shaly limestone in the Gold Hill mining district, Utah. Regionally the basal part of the Gerster is characterized by a 45- to 90-ft-thick massive ledge of cherty, light-gray bioclastic limestone. The upper part of the formation consists of a substantial thickness of 1½- to 9-ft-thick beds of cherty, yellow-gray bioclastic limestone, interbedded with siltstone (Wardlaw and Collinson, 1977; Wardlaw and others, 1979a). Wardlaw and others (1979a, p. 11) pointed out that the Gerster forms the upper unit of the Park City Group throughout its regional extent. "The Gerster Limestone is a cherty bioclastic limestone containing minor beds of chert, dolomite, and siltstone. Crinoid and bryozoan fragments and, commonly, silicified whole brachiopods make up much of the rock."

Murdock Mountain and Gerster Formations, Undivided **[Pgp]**. In the Leach Mountains and vicinity, Hope (1970) mapped a unit he referred to as the Phosphoria Formation and Gerster Formation, undifferentiated. The Gerster in the Leach Mountains area was shown overlying the Phosphoria Formation. These relations suggest that his usage of Gerster includes the Murdock Mountain and the Gerster of this report. In their columnar sections depicting the Phosphoria and Park City in the Leach Mountains, Wardlaw and others (1979a, figs. 9, 10) showed the Gerster as including two tongues of the Murdock Mountain Formation. This combined unit, referred to by them as the Phosphoria and Gerster Formations, undifferentiated, was mapped by R. A. Hope in T38–44N,R65–70E. According to Wardlaw and others (1979a, p. 11): "In the upper part of the Gerster in the Leach Mountains is a thick interval of alternating limestone and secondary chert replacing limestone, which could be interpreted as another tongue

of the Murdock Mountain Formation but is here kept in the Gerster. In the middle of this interval is a platy limestone that may be equivalent to the Retort Phosphatic Shale [Tongue] of the Phosphoria Formation." At the base of their Leach Mountains section of the Murdock Mountain Formation, Wardlaw and others (1979b, fig. 10) showed about 430 ft of cherty dolomite, phosphate, limestone, and shale that may well have been mapped by R. A. Hope with the immediately underlying Meade Peak Phosphatic Shale Tongue of the Phosphoria.

***Phosphoria Formation* [Pph].** The Phosphoria Formation was originally defined by Richards and Mansfield (1912, p. 683–689) from Phosphoria Gulch in southeastern Idaho. It was later redefined by McKelvey and others (1956, p. 2844–2852) to include only the chert-mudstone-phosphorite facies. In northeastern Elko County, the Meade Peak Phosphatic Shale Member and the Rex Chert Member are mapped (pl. 1) with an underlying dolomite, which is probably equivalent to the Grandeur Member of the Park City Formation in Utah or to the Kaibab Limestone of the Park City Group in southeastern Elko County.

Meade Peak Phosphatic Shale and Rex Chert Members. The thickest section of the Phosphoria Formation in Elko County was measured in Montello Canyon in the Leach Mountains, west of Montello, by T. M. Cheney (written commun., 1958), who furnished the following information:

> At the base of the map unit considered here is a dolomite about 160–200 ft thick, consisting of interbedded massive light-gray dolomite containing silicified brachiopods and other fossil fragments, and a massive light-gray dolomite with abundant chert nodules. Glauconitic cherty sand is present in the lower part of the dolomite unit. Thin phosphorite stringers occur in the upper part of the unit, which contains a fauna similar to that of the Kaibab Formation. The lower contact is gradational with the sandstone unit below. [This dolomite is probably the Grandeur Formation.] Above the dolomite conformably is the Meade Peak Phosphatic Shale Member of the Phosphoria Formation, which is here about 650 ft thick. Some of the shale is cherty, and a 80- to 100-ft-thick unit of chert and dolomite is present 80 ft above the base of the shale. A conglomerate 1–10 ft thick, composed of green chert, quartzite, and pebbles of other rock is present at the top of the chert and dolomite. The lower 80 ft of the shale is the most phosphatic; the main phosphorite beds include one that is 3 ft thick at the base and one 7–10 ft thick about in the middle of the unit. Conformably overlying the Meade Peak is a unit about 980 ft thick, predominantly chert but with light-gray dolomite making up about one-half of the upper half of the unit. Some chert is also present in the lower half of the unit. The chert is mostly black, thin bedded, or nodular, generally without visible spicules. The dolomite is light gray and massive with some silicified fossil fragments. [This 980-ft-thick unit probably includes the Murdock Mountain Formation.]

Overlying the Plympton Formation is about 1,100 ft of beds termed by Nelson (1956) the "lower Rex Chert(?)," which is probably equivalent to the Rex Chert Member of the Phosphoria and which here consists of varyingly interbedded and intermixed shale, limestone, chert, and sandstone. More than 50 ft above the base of the member is the base of a 50-ft-thick bed of pale-gray limestone, pebble sharpstone conglomerate, and near the top of the member is a dull-red, medium-grained well-cemented quartzite. Above the lower part of the Rex Chert(?) Member is a unit, about 500 ft thick, of light-to medium-gray, medium-grained, massive, highly fossiliferous limestone containing nodules and lenses of milk-white chert.

In the Snake Mountains [15], Gardner (1968) measured a total thickness of 700 to 800 ft of the Phosphoria Formation, consisting of bedded chert, siltstone, phosphatic shale, and limestone. From his description, these rocks are believed to correspond to the Meade Peak Phosphatic Shale and Rex Chert Members of the Phosphoria Formation. Small amounts of rocks that are age equivalents of part of the Phosphoria Formation also occur in the extreme northwestern part of the Wild Horse 15′ quadrangle and in the western part of the Elk Mountain 15′ quadrangle in the study area adjacent to the Jarbidge Wilderness. In these areas, the formation consists mostly of dark shale and siltstone. The Phosphoria in the Wild Horse 15′ quadrangle is closely folded and appears to be the upper plate of a thrust that has moved eastward, although exposures are not good enough to determine the exact position of the thrust. Some Pennsylvanian rocks may be included in the Phosphoria Formation as mapped here (pl. 1). In all probability, the Phosphoria in the Wild Horse 15′ quadrangle is parautochthonous.

Mississippian, Pennsylvanian, and Permian Systems

***Limestone, Shale, Chert, Orthoquartzite, and Quartz Siltite* [PMl].** The rocks here mapped (pl. 1) as the unit of limestone, shale, chert, orthoquartzite, and quartz siltite are distributed in a latitudinal band, 30 minutes wide, across northern Elko County. This unit includes rocks lithologically equivalent to those mapped in other nearby areas as the Oquirrh Formation and the Ely Limestone, but the varying lithology suggests that these names should not be used until further work has been done. These rocks are regarded as being generally autochthonous to parautochthonous, although in many areas, particularly in the Mount Velma, Marys River Basin NW, and Marys River Basin NE quadrangles, they are cut by imbricate thrusts to such an extent that the original relations of the various sedimentary facies have not yet been deciphered. The rocks are not highly fossiliferous, but conodonts and, in the eastern part of the map area, fusulinids have been found.

The unit of limestone, shale, chert, orthoquartzite, and quartz siltite includes rocks that were mapped by Coash (1967) as the Hammond Canyon and Poorman Peak Formations. The Hammond Canyon Formation (Coash, 1967, p. 12) is composed of thin-bedded limestone interbedded with cherty limestone and siltstone; I also observed one bed of metaquartz siltite near the Gold Creek stock. The Hammond Canyon was questionably assigned a Permian age by Coash (1967, p. 11). The Poorman Peak Formation (Coash, 1967, p. 14) is composed of generally dark crinoidal limestone, shale, and chert; Coash estimated a thickness of more than 3,800 ft in a highly-faulted section. The Poorman Peak contains fossils of Late Pennsylvanian or Permian age in one place and of Late Mississippian(?) age in another; it was questionably assigned to the Permian by Coash (1967, p. 14).

Pervasive faulting in the Mount Velma and neighboring quadrangles makes inadvisable any attempt to divide this unit into named formations at the present

time. The unit of limestone, shale, chert, orthoquartzite, and quartz siltite includes beds ranging in age from Late Mississippian (Chesterian) to Early Permian (Wolfcampian) (see Coats, 1986). These ages overlap those of the Strathearn or the Sunflower Formation as well as those of the Chainman and Diamond Peak Formations, both of which are present in this area; however, the contacts of the unit here described with those formations are, so far as has been observed, uniformly faulted.

The rocks of this unit are moderately well exposed in the northwest corner of the Marys River Basin NE quadrangle. In the Marys River Basin NW quadrangle, a section is exposed that includes the Mississippian–Pennsylvanian System boundary (field nos. 69NC113–69NC117). This section in Major Gulch, in the northwestern part of the quadrangle, may be as much as 4,300 ft thick. Although the total section may be considerably thicker, the structure is much disturbed by intrusive stocks and possible bedding-plane thrusts, and in Major Gulch the entire section is overturned. The lowest recognizable unit exposed is about 500 ft of dark bedded chert. The rocks stratigraphically above this are medium-gray, light-gray-weathering shale and limestone in beds as much as 20 ft thick; the limestone beds are calcisiltite to calcarenite. Megafossils are rare although conodonts were recovered from many beds.

In the Marys River Basin NE and Marys River Basin SE quadrangles, three distinct facies are present in the rocks mapped in this unit (Coats and others, 1977). Some of the contacts between these facies are definitely thrust faults, and others may be, but it is uncertain whether the rocks may be regarded as parautochthonous, at least with respect to each other. The three facies recognized are a limestone-shale facies, a calcareous-siltstone facies, and a quartz arenite facies. The limestone-shale facies has the widest distribution, and the fossils from it cover the greatest timespan. The limestone forms beds from a few inches to 6 ft thick, with thinner interbeds of shale. Most of the limestone is micritic to calcarenitic; the calcarenite is commonly quartzose. Brachiopods and fusulinids are sparse; most of the fossils identified are conodonts, ranging in age from Late Mississippian (Chesterian) to Late Pennsylvanian and possibly Early Permian. The calcareous-siltstone facies is principally a massive to thin-bedded, pale-gray calcareous siltstone. Fossils, though rare (field nos. 72NC137, 72NC138), suggest a Late Pennsylvanian or Early Permian age for these rocks. Because many of the limestone-shale facies collections fall within this age range, it may be that the contacts between the two facies are tectonic. The quartz arenite facies is composed of massive, white- to maroon-weathering, medium-grained quartz arenite or orthoquartzite. The quartz arenite facies in the valley of Camp Creek is principally pearly-gray, fine-grained, quartz-cemented quartzite to siltstone. It is largely massive and unbedded but with a few conglomerate beds as much as 1 ft thick; the conglomerate is composed of angular to rounded fragments, generally less than 1 in. across, of dark-gray quartzite and chert in a pale-gray quartzite matrix. The quartz arenite facies is typically a cliff-forming unit.

In the O'Neil Pass area [16], Bezzerides (1967) reported a thickness of 900 ft of the Oquirrh(?) Formation, best exposed on the northeast side of Cold Spring Mountain. This unit is predominantly a gray, massive to platy limestone that occurs in rough-surfaced outcrops, and is highly silicified in places. The interbedded mudstone is tan to brown and weathers to red and yellow chips. The base is not exposed, and the top is erosional. The unit is here included within the limestone, shale, chert, orthoquartzite, and quartz siltite unit **[PMl]**.

In the HD Range [17], Riva (1970) described a section measured on a ridge immediately east of and parallel to Miller Canyon on Blanchard Mountain. Riva (1970) measured four lithologic units, totaling 1,870 ft in thickness, of Early Permian (Wolfcampian) age, in ascending order, 1 through 4. Unit 1 is 600 ft thick and is a thin- to medium-bedded, light- to dark-gray or black sandstone, silicified siltstone, and shale, weathering light brown to dark gray, with sporadic limestone beds. Unit 2 is 210 ft thick and is composed of dark-gray limestone, the lower part of which is sandy and cross-bedded; the upper part is more regularly bedded and less sandy. Unit 3 is 750 ft thick and is fine-grained, medium- to thick-bedded, red-weathering quartzite and minor limestone; the basal 200 ft is an alternating black-and-white quartzite that includes one 20-ft- and one 30-ft-thick limestone bed in the lower part. Unit 4 is 310 ft thick and is thin-bedded, brittle, silicified black siltstone. In the Contact mining district [7A], Gibbons (1973) measured a total thickness of 2,200 ft of quartzite, shale, and limestone that he regarded as probably correlative with Riva's (1970) Miller Canyon section just described. Gibbons separated the Paleozoic rocks of his study area into two sequences. The lower sequence, totaling 1,570 ft in thickness, consists of, in ascending order: dark-gray argillite, medium-grained quartzite, and massive, blue-gray silty limestone; an interbedded chert and limestone unit and fine-grained quartzite; and a unit of interbedded chert and quartzite. The upper sequence is divided into two units, the lower of which is about 600 ft of blue-gray argillaceous shale and the upper about 300 ft of coarse-grained quartzite.

Chellis and Storff Formations **[PMl]**. Two formations named (Decker, 1962) the Chellis and Storff Formations underlie the Van Duzer **[ℙvd]** ; the Chellis Formation lies structurally and, possibly, stratigraphically beneath the Storff. The Chellis consists of blue-gray, finely crystalline, laminated to massive limestone with numerous calcite seams and some argillaceous and dolomitic beds; a few 1-in.-thick, dark-gray chert beds were also noted. The total thickness, computed from its mapped width, is approximately 1,900 ft. The Storff Formation consists of phyllite and low-rank slate, with interbedded argillaceous limestone. The rock is intensely folded and contorted. The computed thickness is about 3,900 ft, according to Decker. As the Storff Formation is traced eastward, it becomes predominantly carbonate, like the Van Duzer, and the contact becomes difficult to map. No fossils have yet been found in either the Chellis or the Storff, and so the Silurian age assigned to these formations by Decker is based entirely on lithologic correlations with more distant formations of known Silurian age. Mullens (1980, p. 30), who

examined the outcrops of the Chellis and Storff Formations (1962) on the south side of Pennsylvania Hill, "...could not verify a direct correlation of these rocks with the Roberts Mountains Formation." Since these formations lie beneath the Van Duzer and cannot be directly related to any known pre-Pennsylvanian rocks, they are mapped (pl. 1) with the Upper Mississippian to Lower Permian limestone, shale, chert, orthoquartzite, and quartz siltite unit **[PMl]**.

Paleozoic and Mesozoic Rocks Deposited West of the Antler Orogenic Belt After the Antler Orogeny

Mississippian and Pennsylvanian Systems

Schoonover Formation **[PMs]**. The Schoonover Formation was named by Fagan (1962), who mapped it in the western part of the Wild Horse 15′ quadrangle and in the eastern part of the Bull Run quadrangle [11]. The type locality of the Schoonover is near Schoonover Creek and the area northwest of it in the Bull Run quadrangle; this name is adopted here. The Schoonover is largely of eugeosynclinal origin, and is approximately 9,000 ft thick; Fagan divided it into eight named and two unnamed members. It rests tectonically on quartzite of the Valmy Formation. The lowermost part of the Schoonover Formation, a nearshore clastic facies of Mississippian rocks of Churkin and Kay (1967), together with the overlapping unconformable Edna Mountain Formation, have been thrust from the west during post-Permian time. The upper part of the Schoonover includes four principal rock types: argillaceous lutite, bedded chert, arenite and conglomerate, and andesitic lava. The bedded chert probably represents pelagic accumulations of siliceous organic debris, mostly radiolarians. The calcareous quartzose siltite and quartz silty limestone found in certain members are generally dark gray to black; the limestone weathers a lighter color. The limestone is very fine grained to medium grained. Both the quartzose siltite and the limestone are commonly medium bedded; most of the beds contain fine internal laminae that on some weathered surfaces show intrastratal contortions and cross-laminae. The direction of current flow indicated by convolutions and cross-laminae is within 10° of due east (Fagan, 1962).

The arenite of the Schoonover is a poorly sorted mixture of mud, silt, and sand-size material; the arenite is largely composed of quartz grains, which are generally subangular (Fagan, 1962). Chert and feldspar grains, on the average, are a little larger and smaller, respectively, than the quartz grains; the chert grains occur only as sand-size and larger particles and commonly contain radiolarian remains. Few organic remains are found in the arenite. Graded bedding is common in the arenite, particularly in the coarser beds. Some conglomerate is also present, much of which has graded bedding and poor sorting, so that the term "turbidite" may well be applied; some of the conglomerate beds are as much as 10 ft thick. A few units of pebbly mudstone have also been observed.

Elizabeth Miller and others (written commun., April 5, 1980) have presented evidence that only the lowermost 1,000 ft of the Schoonover Formation containing the fossil assemblage described from Schoonover Creek (field no. 66NC68) was deposited unconformably on the Valmy Formation of the Independence Mountains, itself allochthonous. A deep-water sedimentary-rock assemblage consisting of the uppermost 8,000 ft of the Schoonover, so well described by Fagan (1962, p. 597), is thrust over the Chesterian shallow-water portion of the Schoonover. This upper portion is also thrust from the northwest over Valmy and late Paleozoic carbonate rocks.

Fagan (1962) considered the Schoonover Formation, on the basis of fossils he collected, to be Mississippian; these fossils included brachiopods, bryozoans, coelenterates, and echinoderm columnals. Elizabeth Miller and others present dates, on the basis of radiolaria in chert dated by D. L. Jones, "...ranging from Early Mississippian (and possibly latest Devonian) to Pennsylvanian in age." I made a single fossil collection (field no. 66NC5) from a clastic limestone lens near the top of the Schoonover on a northward-flowing tributary to Trail Creek in the Wild Horse 15′ quadrangle. J. W. Huddle suggested a Late or latest Mississippian age, based on the conodonts. Helen Duncan did not find that the age of bryozoan material disagreed with the age of the conodonts. The Schoonover is assigned a late Mississippian (Chesterian) and Pennsylvanian age on the basis of its radiolarians.

J. H. Stewart (oral commun., 1978) suggested a probable thrust relation of the deep-water sedimentary facies of the Schoonover with its shallow-water facies containing a shelly fossil fauna. Elizabeth Miller and others (written commun., 1980) have suggested that the deep-water part of the original Schoonover Formation may be the equivalent of the Havallah Formation and that the thrust beneath this sequence, which they have termed the "Schoonover thrust," may be part of the Golconda thrust.

Pennsylvanian System

Mitchell Creek Formation **[Pmc]**. The Mitchell Creek Formation, named by Coats (1971), comprises a minimum of 500 ft of sedimentary rocks and perhaps several thousand feet of volcanic rocks. The volcanic rocks are chiefly metabasalt and meta-andesite flows and tuff, now greenschist; the sedimentary rocks include minor amounts of calcarenite, locally crinoidal, grading into calcareous quartzite, which is also sideritic; phosphatic quartzite and black chert also occur. The base is not exposed; the formation is unconformably overlain by Tertiary volcanic rocks. The type section is on the northside of Mitchell Creek, in the Owyhee 15′ quadrangle [3].

On the basis of a few fossil collections, the Mitchell Creek Formation was assigned an Early(?) Pennsylvanian age. The high content of volcanic material suggests that it, like the Nelson Formation, is allochthonous in this area.

Pennsylvanian(?) and Permian(?) Systems

Havallah and Reservation Hill Formations **[PPhr]**. The Havallah and Reservation Hill Formations include two lithologically dissimilar units that occur only in

northern Elko County. The lowest unit, dated on the basis of a single fossil conodont in the Burner Hills [1], is questionably assigned to the Havallah. In the Burner Hills, the Paleozoic rocks form a sequence composed largely of flyschlike, dark, poorly sorted sandstone, rich in chert fragments, containing minor greenstone and very sparse limestone lenses. One limestone lens yielded a *Gondolella* sp. (field no. 72NC172), reported by J. W. Huddle as probably Early Pennsylvanian. The second unit, the Reservation Hill Formation, occurs only in the Owyhee and Mountain City 15′ quadrangles [3, 4] and in the area adjacent to the Jarbidge Wilderness on the east, in the Elk Mountain 15′ quadrangle [14].

The type locality of the Havallah Formation is in the Tobin Range (Muller and others, 1951), where it "...contains abundant sandstone and quartzite plus some limestone and calcareous shale, as well as chert and shale" (Roberts and others, 1958, p. 2848). The Havallah in the Burner Hills resembles the published description of the type Havallah Formation fairly well, although the mafic volcanic rocks in the Burner Hills were not seen in its type area; possibly the volcanic rock in the Burner Hills is to be attributed to the Pumpernickel Formation, a formation underlying the Havallah, which differs from the Havallah Formation in the presence of volcanic rock.

In the Owyhee 15′ quadrangle [3], Coats (1969, 1971) described the Reservation Hill Formation, a unit of uncertain age but assigned to the post-Antler orogenic sequence. The Reservation Hill Formation differs lithologically in many respects from the Havallah, both that of the type area and of the rocks of the Burner Hills assigned to the Havallah. Its inclusion in a single map unit is purely a matter of convenience, pending the acquisition of good paleontologic or isotopic data on its age. The Reservation Hill Formation was named by Coats (1969, p. A26–A27). The principal rock type is a fine-grained dolomitic sandstone or siltstone, pale gray on fresh fracture, that weathers creamy white to pale reddish brown (10R–6/4); the latter color is quite distinctive. The formation includes thick uninterrupted sequences in which siltstone beds, 1½ in. thick, alternate rhythmically with thinner phyllite beds. Microscopically, the principal constituents of this rock type are quartz, orthoclase, oligoclase, and dolomite; diopside, tremolite, and, locally, coarsely prismatic wollastonite have formed as a result of metamorphism. A less common rock type ranges from metagraywacke, through micaceous and tremolitic quartzite, to graphitic phyllite. Metachert, biotitic where impure, and pure quartzite are rare. At least one meta-andesite is present, which locally attains a thickness of as much as 200 ft; it is metamorphosed to actinolite-epidote-plagioclase schist or to hornblende-plagioclase schist. One bed of metarhyolite tuff, about 2 ft thick, was observed; others may also be present. Lenses of gray, siliceous dolomitic limestone, as much as 50 ft thick, make up a small part of the formation. No identifiable fossils have been found.

A fairly extensive exposure of rocks correlated, solely on lithologic grounds, with the Reservation Hill Formation is present in the Elk Mountain 15′ quadrangle, in an area adjacent to the Jarbidge Wilderness [14] (Coats and others, 1977, p. 12–13). The lithology observed in this area is much more limited than in the Owyhee and Mountain City 15′ quadrangles, and consists mainly of interbedded dolomitic siltstone and phyllite.

The nearest lithologic and temporal correlatives of the Reservation Hill Formation are found in Idaho. The Reservation Hill Formation is more similar lithologically to the Wood River Formation in the Fish Creek Reservoir area, in south-central Idaho, than it is to any other late Paleozoic formation in northern Nevada. According to Skipp and Hall (1975, p. 683), rocks of the Wood River in the Fish Creek Reservoir area are stratigraphically higher than any in the type locality of that formation, and are presumed to be Early Permian (Leonardian?). They consist of thin-bedded gray siltstone; brown-weathering dolomitic siltstone; gray, soft argillite; some light-brown, fine-grained quartzite; and minor fine-grained impure limestone and grayish-orange dolomite. The lithologic resemblances seem to confirm the correlation and the age assignment of the Reservation Hill Formation as Pennsylvanian(?) and Permian(?), but it would be premature to regard this correlation as established.

Permian and Permian(?) Systems

Sandstone and Siltstone of Horse Mountain **[Phm]**. Horse Mountain is a meridionally elongate ridge, the crest of which is on the east edge of the Little Rock Creek quadrangle (S13,24,T40N,R48E). Most of the ridge crest is made up of the sandstone and siltstone of Horse Mountain, a unit that has a maximum exposed thickness of about 800 ft. The lower contact is not exposed but the formation is presumed to rest unconformably on rocks of the western assemblage; the upper boundary is an erosional surface. The sandstone beds are as much as 3 or 4 ft thick, but are commonly much thinner. The sandstone is medium to dark gray and weathers dark brown. The siltstone interbeds are thinner and range from a dark, siliceous, brown-weathering siltstone to a light-brown white-weathering siltstone.

Several hundred feet of dark-gray, well-indurated, fine-grained sandstone assigned to this unit are present in a fault-bounded window on the western side of the Elk Mountain 15′ quadrangle, part of the study area of the Jarbidge Wilderness. The base of the unit is not exposed. The unit is overlain by dark shale that is correlated with the Meade Peak Phosphatic Shale Member of the Phosphoria Formation. It is unclear whether the contact surface is an unconformity or a fault. Mackenzie Gordon, Jr., William McCaslin, and I collected fossils from this area in 1974 (field nos. 74G4 through 74G6). The age of the unit is Early Permian and Permian(?); it probably correlates with the Rib Hill Sandstone of the Ely mining district (field nos. 70NC91, 70NC92), although it differs considerably from the Rib Hill lithologically.

Permian System

Edna Mountain Formation **[Pem]**. The type locality of the Edna Mountain Formation is on the west slope of

Edna Mountain in the Golconda quadrangle, Humboldt County, Nevada. (Roberts, 1951). The type Edna Mountain is gray to buff calcareous sandstone and shale, with interbedded chert-pebble conglomerate and thin limestone. The maximum thickness is about 250 ft on Edna Mountain.

Rocks resembling the lithology of the Edna Mountain in its type area occur in several areas of Elko County; all of these occurrences are believed to be allochthonous. In each occurrence, the Edna Mountain Formation rests unconformably or in thrust contact on rocks of the western assemblage. In the Divide Peak area [22], the thickness is not readily determinable because of faulting and the absence of marker beds (Coats and Gordon, 1972), although the total thicknesses may be about the same as at Edna Mountain. In the Divide Peak area, the rocks include chert-quartz conglomerate and gray, buff-weathering sandstone and siltstone that contain a mold fauna. Some of the siltstone in the Divide Peak weathers a highly characteristic pale purplish red. The typical sandstone is a chert arenite that grades into a granule conglomerate. In some places as much as 5% of the clasts may be phyllite.

The Edna Mountain Formation has also been recognized elsewhere in Elko County. Small plates of coarse arenite and conglomerate, resting unconformably on Mississippian and Ordovician rocks of the western assemblage, were recognized in the Tuscarora 15′ quadrangle. These rocks were considered by Churkin and Kay (1967) as the basal (Chesterian) part of their Schoonover Formation, although they contain fossils dated by Mackenzie Gordon, Jr. as being possibly as young as Permian. The total thickness is no more than 250 ft. An even smaller patch of conglomerate occurs at about the same latitude on the east side of the Independence Mountains in the California Mountain quadrangle, in an exposure too small to show on the geologic map. According to Mackenzie Gordon, Jr., the fossils from this area are intermediate between those from the typical Edna Mountain farther east, in the Divide Peak area, and those of the Phosphoria Formation (Park City Group) at Divide Peak (field no. 70NC38). Greenish chert-quartz conglomerate and coarse arenite that resembles the Edna Mountain were mapped by Leland Cress and myself (unpub. data, 1971) on the southwest ridge of the mountain southwest of Beaver Peak in the Beaver Peak quadrangle; no fossils were found. In the Hubbard Basin quadrangle, in a tan-weathering siltstone, a single fossil was collected that was identified by Mackenzie Gordon, Jr., and B. R. Wardlaw (colln. 2538-PC) as resembling a species in the Lower Permian Edna Mountain. Another thrust plate of tan-weathering siltstone carries a mold fauna that was collected from an east-west-trending hill in the Summer Camp quadrangle, just west of the Union Pacific Railroad. All of these minor occurrences are believed to be allochthonous.

In the Snake Mountains [25], Peterson (1968) mapped thin-bedded, yellow-brown-weathering sandstone, approximately 2,000 ft thick, that is fossiliferous in many places. The sandstone clasts are subangular to subrounded, medium size, and composed of chert and quartz. About 12% of the rock is matrix, and 5% of the rock consists of muscovite and limestone fragments; the cement is siliceous. The fossils are molds and casts of silicified bryozoans and brachiopods. These rocks are somewhat questionably assigned to the Edna Mountain Formation.

Permian and Triassic Systems

***Marine Conglomerate* [℞Pc].** Rocks described as Marine Conglomerate (pl. 1) occur in the Marys River Basin NE quadrangle, just south of the Jarbidge Wilderness [14], and in the Wild Horse quadrangle. In the Marys River Basin NE quadrangle, small masses of cobble conglomerate, with a limy fossiliferous matrix, rest unconformably on upper Paleozoic sedimentary rocks, or on rocks of the western asssemblage. Some rocks of the Mississippian, Pennsylvanian, and Permian unit **[PMl]** have been thrust over this conglomerate. Although such fossils as could be obtained have been indeterminate, geologic relations compel the conclusion that these rocks are Permian or Triassic. Some conglomerate was mapped in the nearby Triassic marine rocks by Bezzerides (1967), a circumstance that furnishes some support for this age assignment.

***Sedimentary and Volcanic Rocks* [℞Ps].** The only rocks that furnish good paleontologic grounds for their ascription to both the Permian and Triassic systems are present in the northern Adobe Range [29], where they have been described by Ketner (1975b) as the Long Canyon and Adobe Range sequences. These rocks extend in a narrow belt from Coal Canyon northeastward to Long Canyon. The rocks of this unit are mainly platy silty limestone containing lesser amounts of shale. The unit is brown or dark gray but weathers greenish gray; some limestone lenses are dark, and weathers chocolate brown. The upper part of the formation also contains dark silty limestone, as well as shale that weathers gray green, although these upper beds are less platy and contain more chocolate-brown beds and lenses. Volcanic rocks, intermediate in composition, are common in both the Permian and Triassic parts. The unit lies concordantly on older Permian rocks but is overlain unconformably by Tertiary volcanic and sedimentary rocks and lava flows. The Permian part of the formation does not differ markedly from the Triassic part; the two systems are differentiated only on the basis of the fossils in some limestone beds. The intermediate volcanic rock forms resistant beds, a few feet thick; nearly all the beds are concordant with the bedding of the enclosing sedimentary rocks, and the concordant contacts are undeformed. The thickness of the unit is estimated at more than 2,000 ft. Fossils in the limestone beds in the lower part of the unit were regarded as post-Wolfcampian (Permian) by Mackenzie Gordon, Jr. (written commun., 1978), who questionably correlated them with the faunas of the Gerster Formation, although the lithology of this unit differs considerably from that of the Gerster. N. J. Silberling identified Triassic fossils from chocolate-brown limestone lenses in the shale in the upper part of the unit; he stated that the collection represents an early but not earliest late Early Triassic age.

MESOZOIC ERATHEM

Rocks Deposited Within and East of the Antler Orogenic Belt

Triassic System

Marine Sedimentary Rocks [Ꞧs]. The most complete coverage to date of the marine sedimentary rocks of Triassic age in Elko County was that by Clark (1957, 1960). Although more recent work has outlined the areas of outcrop and refined the stratigraphy in many places, few extensive new areas of Triassic rocks have been recognized in Elko County since Clark's (1957, 1960) work. Snelson (1957), however, mapped a considerable area of Lower Triassic marine sedimentary rocks in the southern East Humboldt Range [39]. The principal areas of Triassic rocks assigned to this unit (pl. 1) are in the Currie, Pequop, and Spruce Mountain areas [46, 47, 51, 52, 53], the Medicine Range [50], the Trout Creek area in the northeast corner of the county [8], the Jim Thomas Canyon (now Montello Canyon) area in the Leach Mountains west of Montello [8], the Windermere Hills [26], and the Dinner Springs area north of Montello [8]. Triassic rocks of slightly different facies are present in the O'Neil Pass area [16], the Jarbidge Wilderness [14], and the Mount Velma area [13]. At the north end of the Adobe Range [29], Ketner (1975b) recognized Permian and Triassic rocks that differ lithologically from any of the others in the county (see the preceding section).

In the southern part of the Mount Velma quadrangle [13], Coash (1967) described a sequence consisting largely of massive siltstone, between several hundred and several thousand feet thick. The rock is pale green where fresh but weathers in a few years to a light yellowish tan. Coash suggested that at least some of these beds are tuff, probably water-laid. In 1971, R. D. Kraetsch (oral commun., 1971) of the Standard Oil Co. of California found small, poorly preserved ammonites in a red-weathering sideritic limestone bed in the Mount Velma quadrangle. Concerning these fossils, N. J. Silberling (oral commun., 1971) was able to say only that they could be Early Triassic.

In the East Humboldt Range [39] (Snelson, 1957), the lowest part of the Triassic sequence consists of several hundred feet of grayish-brown limestone overlain by ridge-forming, medium-dark-gray, terebratulid-bearing limestone with intercalated shale. Overlying the ridge-forming limestone is a succession of poorly exposed shale, siltstone, and limestone.

In the Snake Mountains [15], Gardner (1968) mapped a sequence of marine sedimentary rocks that he assigned to the Dinwoody Formation and the conformably overlying Thaynes Formation. The Dinwoody Formation was described as siltstone and silty shale with thin limestone beds; the total thickness is about 2,400 ft. The Thaynes Formation consists of about 600 ft of limestone containing thin siltstone and silty shale. These formations are not differentiated on the geologic map.

In the Ferguson Mountain area [54], Berge (1960) mapped the Thaynes, which there consists of approximately 240 ft of dark-brown crystalline limestone; the characteristic *Meekoceras* sp. zone is overlain by yellowish, variegated shaly limestone. The Thaynes rests disconformably on the Ferguson Mountain Formation or, where missing, on the Kaibab Limestone.

In the Currie area [51], Nelson (1956) described marine sedimentary rocks that consist of about 2,200 ft of limestone, limy shale, and limy sandstone. The base, not exposed, must lie between cherty limestone of the Permian Phosphoria(?) Formation and *Meekoceras*-bearing limestone of the Triassic Dinwoody(?) Formation; the top was placed at the base of the Nugget(?) Sandstone (part of the Triassic and Jurassic nonmarine sandstone of this report). In the Currie area, the Dinwoody(?) is poorly exposed and consists of a 560-ft-thick sequence of greenish-gray to olive-drab calcareous siltstone and shale with a 10- to 50-ft-thick unit of dark-gray, medium-grained, medium-bedded, iron-impregnated, fossiliferous limestone about 50 ft above the base. This limestone weathers very dark reddish brown, and its description suggests that it is a lithologic correlative of the fossiliferous Triassic beds described by Coash (1967) in the Mount Velma quadrangle.

Nelson (1956) measured the total thickness of the Thaynes(?) Formation in the Currie area as approximately 1,560 ft. He divided it into three members. The lower member contains medium-gray, medium-grained, dark-gray-weathering, massive limestone overlain by fossiliferous, light-olive-gray arenaceous limestone and a poorly exposed sequence of pale-yellowish-brown to green and gray calcareous shale and siltstone interbedded with limestone. The middle member, 376 ft thick, is a resistant medium-gray, medium-grained, medium-bedded limestone. The upper member comprises 263 ft of interbedded siltstone, limestone, dolomite, and shale, pale greenish brown, yellow, and gray. The upper part of the upper member is fossiliferous, light gray, fine grained, and contains the pelecypod *Aviculopecten* cf. *A. utahensis* Meek. The Thaynes(?) is overlain by the nonmarine Timothy(?) Sandstone.

In the southern Pequop Mountains [52], Snelson (1955) included two units in his marine Triassic sedimentary rocks: the Dinwoody(?) and the overlying Thaynes(?). The Dinwoody(?) includes about 400 ft of olive-drab to greenish-gray shale, with the *Meekoceras*-bearing limestone near the base. The *Meekoceras*-bearing limestone, a red-brown-weathering limestone, occurs about 16 ft above Permian rock. Above the Dinwoody(?) is about 2,900 ft of rocks that were mapped by Snelson (1955) as the Thaynes(?). The lower 2,450 ft of this unit consists of interbedded olive-drab to greenish-gray shale and gray, fine- to medium-grained, crystalline limestone; the upper 450 ft is argillaceous limestone and siltstone, and shale. In the Currie area, Scott (1954) mapped the Thaynes(?) Formation as gray, yellowish-gray, and brownish-gray limestone and greenish-gray shale. The *Meekoceras* zone occurs 81 ft above the base, which is unconformable on Permian rocks. The total thickness of the Thaynes(?) is 2,200 ft.

In the Windermere Hills [26], Oversby (1972) mapped the Dinwoody and Thaynes Formations. The name Dinwoody Formation was originally applied to the upper shaly part of what was then called the Embar Formation. The Dinwoody was named for exposures in

Dinwoody Canyon in the Wind River Ranges, Wyoming; the name, originally suggested by Eliot Blackwelder, was first published by Condit (1916). The formation at its type locality is about 200 ft thick and consists of pale-green to white clay and shaly limestone. In the Windermere Hills the Dinwoody Formation appears to conformably overlie the Carlin Canyon Formation. A minimum thickness of 300 ft of green silty argillite and argillaceous calcisiltite in the Dinwoody was measured in the Windermere Hills. The argillite occurs in 4- to 6-in.-thick beds, with thinner beds of calcisiltite. The calcisiltite is dark brownish gray and weathers to pale-gray or buff platy and flaggy fragments. The age suggested by Silberling is possibly Smithian (Early Triassic).

The Thaynes was originally named by Boutwell (1907). He described it in the Park City area, Utah, as a sequence of two calcareous parts separated by a red shale member; both calcareous parts are made up of limestone, calcareous sandstone, and shale. Most of the limestone is in the lower part, although each rock type occurs throughout. The total thickness of the Thaynes in the Park City mining district is about 1,190 ft. In the Windermere Hills, the Thaynes conformably overlies the Dinwoody and consists of at least 350 ft of relatively resistant limestone that forms rubbly cliffs; the top of the formation was not seen. Dark-gray calcisiltite and calcilutite predominate. A zone of collapse breccia near the base may suggest the former presence of evaporites. The fossils, though not diagnostic, are believed to be Triassic.

Clark (1957, p. 2201) described a section of the Triassic on the north side of Dinner Springs Canyon (now called Long Canyon) in the Dairy Valley 15′ quadrangle [8]. Clark divided this section into three units: (1) a lower shaly unit; (2) a limestone unit containing the *Meekoceras* zone; and (3) an upper shale and limestone unit. The lower unit consists of brown-weathering, shaly limestone interbedded with slightly thicker limestone beds that contain pelecypods and conodonts. The layer of rocks containing fossils of the *Meekoceras* zone is about 30 ft thick and consists of two limestone beds separated by a shaly interval. At this locality the *Meekoceras* zone is 412 ft above the highest Permian rocks. R. A. Hope (unpub. data, 1973) divided Clark's unit into two parts: a lower part consisting of platy, dark-gray- to light-gray-weathering, laminated silty limestone containing some pelecypods; and an upper part consisting of tan-, brown-, and orange-weathering platy siltstone and crossbedded sandy limestone. The *Meekoceras*-bearing limestone in the lower part was noted to weather chocolate brown and to include orange oxidized parts; the fresh limestone is medium gray, fairly coarse grained, and massive.

Bonham (1961) described a section of marine Triassic sedimentary rocks from Jim Thomas Canyon (now called Montello Canyon) in the Leach Mountains [8]. The section here consists of interbedded shale, sandy limestone, and limestone. The lower part of the section is olive-green to greenish-gray shale and brown shaly limestone. The upper part consists of massive, well-bedded, gray- to brownish-gray-weathering limestone and minor shale. Clark (1957) measured a thickness of 2,200 ft of Triassic rocks. The Triassic rocks paraconformably overlie the Gerster Formation of Permian age.

In the Medicine Range [50], Collinson (1966, 1968) described a sequence of Lower Triassic marine sedimentary rocks, 520 ft thick, that he identified as the Thaynes Formation. The Thaynes Formation here consists of two members that were measured in three partial sections. The lower member, A, is interbedded calcareous sandstone, sandy limestone, and lensing chert-pebble conglomerate. The conglomerate is generally graded from cobbles to coarse sand. At the base of the member the conglomerate grades into a cross-stratified, medium-bedded calcareous sandstone. A graded bed of conglomerate, about 20 ft thick, occurs near the top of the member. The upper member consists of interbedded limestone and calcareous siltstone, which is not well exposed. The *Meekoceras*-bearing beds, which are common in many places near the base of the Thaynes Formation, are absent in the Medicine Range. Collinson (1966, 1968) supposed that these beds that are present in the Medicine Range are somewhat higher in the section than the *Meekoceras*-bearing limestone beds to the east.

Triassic and Jurassic Systems

***Nonmarine Sedimentary Rocks* [JTs].** Three almost exclusively clastic formations, each questionably identified, are included in the unit of nonmarine sedimentary rocks on the geologic map (pl. 1). The lowest of these formations is the Timothy(?) Sandstone; above the Timothy(?) is the Chinle(?) Formation, which is overlain unconformably by the Nugget(?) Sandstone. All of these formations are unfossiliferous.

In the Currie area [51], Nelson (1956) described what he called the Timothy(?) Formation, which overlies the marine Thaynes(?) Formation. The Timothy(?) reaches a maximum thickness of 200 ft and wedges out to the north; it consists of friable, medium- to coarse-grained quartz sandstone. The Timothy(?) disconformably underlies rocks that were mapped by Nelson as the Shinarump(?) Conglomerate. The U.S. Geological Survey no longer considers the Shinarump a separate formation but includes it as a member of the Chinle Formation. In Elko County, the Shinarump Conglomerate Member is the lowest member in the Chinle Formation.

In the Currie area [51], Scott (1954) described the Shinarump(?) Conglomerate Member as consisting of 42 ft of pale-yellowish-brown, massive pebble conglomerate containing subrounded pebbles of quartz, quartzite, and chert in a matrix of very fine grained quartz-sandstone and clay. Petrified-wood fragments are numerous. Nelson (1956) described the Shinarump(?) as 42 ft of well-cemented, yellowish-brown sharpstone and roundstone chert-pebble conglomerate containing gray, green, and dull-red pebbles. Large amounts of silicified wood are also present. The Shinarump(?) is overlain conformably by the upper part of the Chinle(?) Formation. Scott (1954) described the upper part of the Chinle(?) as consisting largely of olive-green fissile shale and medium- to dark-gray shale; grayish-red, thin-bedded, micaceous siltstone and shale; and pale-yellowish-brown, very fine grained sandstone containing some pale-yellowish-brown limestone and pale-

yellowish-gray, medium-bedded, medium-grained sandstone. Nelson (1956) described the same unit as consisting of more than 500 ft of light-gray to olive-green and deep-red shale and siltstone interbedded with very fine grained sandstone; a few beds of pale-grayish-brown limestone are 1 to 20 ft thick. The Chinle is gypsiferous at the top; it is overlain by the Nugget(?) Sandstone.

The Nugget Sandstone was named by Veatch (1907) for Nugget Station on the Oregon Shortline Railroad in southwestern Wyoming. In the type area, the Nugget is about 1,900 ft thick and shows two distinct members: a lower brightly colored red-bed member, 600 ft thick, and an upper light-colored sandstone member. Boutwell (1907) restricted the Nugget Sandstone to about 500 ft of white sandstone in the Park City mining district, Utah, a sandstone that represents only the lower part of the upper member of the Nugget Sandstone of Veatch (1907). The Nugget(?) Sandstone in the Currie area apparently unconformably overlies the Chinle(?). The Nugget(?) contains, in the Currie area, about 2,800 ft of white, yellow, pink, and red, fine- to medium-grained sandstone, in part crossbedded. The sandstone contains numerous raindrop, rill, and oscillatory-ripple-mark impressions. Sirkin (1970) reported that the Nugget(?) is mainly a quartz sandstone containing about 2% feldspar and 2% chert grains. Load casts and slump structures are present; some lebensspuren in the form of filled burrows(?) are also present.

Because these three formations, the Timothy(?), the Chinle(?), and the Nugget(?), are doubtfully identified and represent considerable extensions from their respective type areas, they are here mapped (pl. 1) as nonmarine sedimentary rocks and are assigned to the Triassic and Jurassic Systems.

Jurassic System

***Frenchie Creek Rhyolite* [Jf].** The Frenchie Creek Rhyolite is exposed in two places. One small outcrop in the southern part of the Robinson Mountain 15′ quadrangle [43] was described by Smith and Ketner (1976). The unit here includes rocks ranging in composition from andesite to rhyolite. Smith and Ketner (1976, p. B6) stated: "Nearly all the flows are somewhat sericitized and chloritized, and some are so much altered that the original composition is most uncertain. Most of these rocks must have been vitrophyric, and many now have a devitrified glassy matrix." Another outcrop of somewhat similar rocks, present in a small exposure along the Humboldt River a short distance east of Elko, appears to be a hornblende-biotite dacite. To the south and east, substantial areas of dacitic and andesitic rocks, generally propylitized or kaolinized, which locally intrude Paleozoic sedimentary rocks, are mapped (pl. 1) with this unit.

Cretaceous System

***Newark Canyon Formation* [Knc].** Nolan and others (1956, p. 68–70) used the name "Newark Canyon Formation" for a group of Cretaceous nonmarine sedimentary rocks in the Eureka area. Some small exposures believed by Smith and Ketner (1976) to belong to the Newark Canyon occur in the Piñon Range; the rocks include dark-gray shale and mudstone, sandstone, and limestone. "The shale is thin bedded, almost papery in places, and carbonaceous, and seems to form the thickest part of the sequence... The limestone is dark to light gray and most commonly is found in beds [½ to ¾ in.] thick. ...A few grayish-tan calcareous beds are as much as [½ in.] thick... The sandstone is gray and consists of angular to rounded, fine- to medium-size grains..." (Smith and Ketner, 1976, p. B12) Poorly exposed conglomeratic sandstone and some limestone in two other small areas are here mapped (pl. 1) with the Newark Canyon Formation.

Fouch and others (1979) suggested that part of the Newark Canyon Formation in the Piñon Range near Carlin may range in age from Early Cretaceous to Paleocene.

CENOZOIC ERATHEM

General Discussion

The stratified Cenozoic rocks of Elko County are here divided temporally into five sequences, informally called lower Tertiary rocks, middle-Tertiary rocks, upper Tertiary rocks, Tertiary and Quaternary rocks, and Quaternary rocks. The subdivisions of the Tertiary rocks are based largely on isotopic ages of the volcanic rocks. Identifiable fossils are rather scarce. The lower Tertiary volcanic rocks range in age from 42.5 to approximately 34 m.y. and thus include the late Eocene and part of the Oligocene. The middle Tertiary rocks in Elko County range in age from 34 to about 17 m.y., and the late Tertiary rocks from about 17 to 6 m.y. The middle Tertiary rocks thus include parts of the Oligocene and Miocene, and the late Tertiary rocks are all Miocene.

In describing the volcanic rocks of Elko County, certain terms, long in more or less common use, have proved so useful that they are listed here for the benefit of those unfamiliar with them.

The prefix "pheno" is used for volcanic rocks the chemical composition of which has not been determined precisely but which are named from the phenocryst minerals. "Thus, a pheno-andesite is a rock containing phenocrysts of plagioclase in a groundmass the mineral composition of which cannot be determined; even if the rock, had it been crystallized completely and recognizably, would have become a dacite." (Streckeisen, 1967, p. 178)

The other usage is that suggested by Cross and others (1906) for expressing the ratio by volume of phenocrysts to groundmass in porphyritic rocks, using the terms perpatic, dopatic, sempatic, dosemic, and persemic for rocks in which the ratios of groundmass to phenocrysts fall in the ranges 7:1, 7:1-5:3, 5:3-3:5, 3:5-1:7, and 1:7-0, respectively. Should the groundmass be glassy rather than microcrystalline or cryptocrystalline, the suffix "hyaline" may be used instead of "patic."

The term "ignimbrite," as originally suggested by Marshall (1932) and later adopted by Fisher (1966), is used here for all rocks emplaced by pyroclastic flow, generally as a more or less concentrated dispersion of

rock, crystal, and glass fragments in heated gas, at temperatures such that the volcanic glass was generally plastic. Because the size classification suggested by Fisher (1966) as a modification of that proposed by Wentworth and Williams (1932) is used here, and because many of these deposits resulting from pyroclastic flow are too coarse or variable in fragment size to be properly termed "tuff," the more inclusive term is preferred here to that of "ash-flow tuff" (Williams and McBirney, 1979, p. 152).

Tertiary(?) and Tertiary Rocks

Volcanic Rocks

The chemistry of the Tertiary volcanic rocks of Elko County can best be summarized graphically. Figure 4 shows the plot of total alkali oxides against silica content, in weight percent, for 71 analyzed volcanic rocks, mostly from Elko County. The boundaries in the diagram serve to represent the quantitative distribution of these rocks with respect to the parameters used; these boundaries are modified from Cox and others (1979, fig. 2.2). An additional field, that of rhyodacite, is introduced, the boundaries of which fall on either side of the boundary between rhyolite and dacite. An additional dashed line divides the basalt field into two parts, alkalic basalt and tholeiitic basalt; this line is from Macdonald and Katsura (1964, p. 87).

Moore (1962) plotted the Niggli **k** value for many volcanic-rock provinces in the western United States against the weight percentage of SiO_2 for the same rocks and contoured the **k** values for 50% and 60% SiO_2. Figure 5 shows a similar plot for 71 analyzed rocks from Elko County; a trendline drawn by eye to bisect the field gives **k** values at 50% and 60% SiO_2 of 0.155 and 0.346, respectively. The plot of total alkali oxides against silica content (fig. 4) shows a continuity of trend and a small scatter that suggest a certain unity of origin. In the intermediate range of silica content, some of the rocks are borderline trachyandesite, but most fall well into the andesite field. A few rocks with very high silica content appear to be enriched in phenocrystic quartz.

Lower Tertiary Rocks

***Conglomerate* [Tc].** In many places the lowest Tertiary rocks that rest unconformably on Paleozoic or Mesozoic rocks are a conglomerate, composed largely of cobbles, pebbles, and sporadic boulders of Paleozoic rocks, chiefly chert and quartzite, and locally of granitic rocks. Van Houten (1956) suggested that reddish-brown conglomerate in northwestern Utah and east-central Nevada may be equivalent to conglomerate in the Paleocene and lower Eocene Wasatch Formation of north-central Utah. Evidence for a Paleocene rather than Eocene age is generally absent in the parts of Elko County that were studied for this report (but see Fouch and others, 1979).

In the Lone Mountain area [30], Lovejoy (1959) described a conglomerate that locally grades upward into breccia. The conglomerate is massive, commonly limonite stained, and composed largely of fragments of chert, with a siliceous or tuffaceous matrix. The chert fragments range in shape from angular to well rounded; some are as large as one foot in diameter. The thickest lens of conglomerate is estimated to be a few hundred feet thick. No fossils have been found. Similar conglomerate occurs in the western part of the Mahala Creek West quadrangle, overlying rocks of the western facies. Its maximum thickness is probably about 300 ft, but local variations of thickness are quite apparent. The conglomerate grades southward into rock with a tuffaceous matrix that locally is montmorillonitic, as in the exposures along State Highway 11 near the summit between the drainage of Pie Creek and that of Maggie Creek. Similar conglomerate also occurs south and west of this point along the base of the Tertiary section in the Lake Mountain and Reed Station quadrangles. In some places in the Reed Station quadrangle, the presence of barite cobbles in the conglomerate where it overlaps lenses of barite in Paleozoic rocks of the western assemblage is evidence for a pre-Tertiary age of the barite deposits. Small amounts of red, iron-stained conglomerate occur in a small outcrop in the North Fork quadrangle (Coats and Gordon, 1972).

Fairly extensive outcrops of conglomerate in the Mount Velma quadrangle were described as prevolcanic gravel by Coash (1967, p. 15), who noted that they vary a great deal in thickness and lithology, and are as much as 75 ft thick. The cobbles and boulders are chiefly quartzite, and the largest boulder I saw was about 2 ft in diameter. The gravel in the Mount Velma quadrangle has a red clay matrix in many places. The matrix was sampled but proved not to be particularly rich in alumina; thus, the climate probably was not favorable for lateritic weathering. In a few places, conglomerate beds overlie tuff; one such place is near the mouth of Taylor Canyon, and another is in the northern part of the basin of Berry Creek, in the Mount Blitzen 15′ quadrangle. Elsewhere, the gravel assigned to this unit is very coarse and shows no signs of strong oxidation during weathering. In the southern part of the Mount Blitzen 15′ quadrangle and in the northern part of the Sugarloaf Butte quadrangle [20B], very coarse gravel containing angular quartzitic boulders, as much as 4 ft in maximum dimension, occurs without any signs of weathering of the bedrock. This gravel probably accumulated near the foot of some steep scarp because it now occurs along a fault scarp that cuts underlying Paleozoic rocks of the western assemblage. It is by no means certain that all of the conglomerate and gravel in Elko County that rest on Paleozoic rocks and are overlain by Tertiary rocks are necessarily Tertiary because in many places the critical evidence is absent. Such gravel occurs in the Marys River Basin SE quadrangle along the road from Charleston to O'Neill Basin; it was reported in several places in the Independence Mountains by Churkin and Kay (1967). The presence of gravel or conglomerate with a montmorillonitic matrix in a few places suggests the occurrence of air-fall tuff that was subsequently mobilized as mudflows and was capable of picking up and transporting boulders from the land surface to form poorly sorted conglomeratic deposit with a clayey matrix.

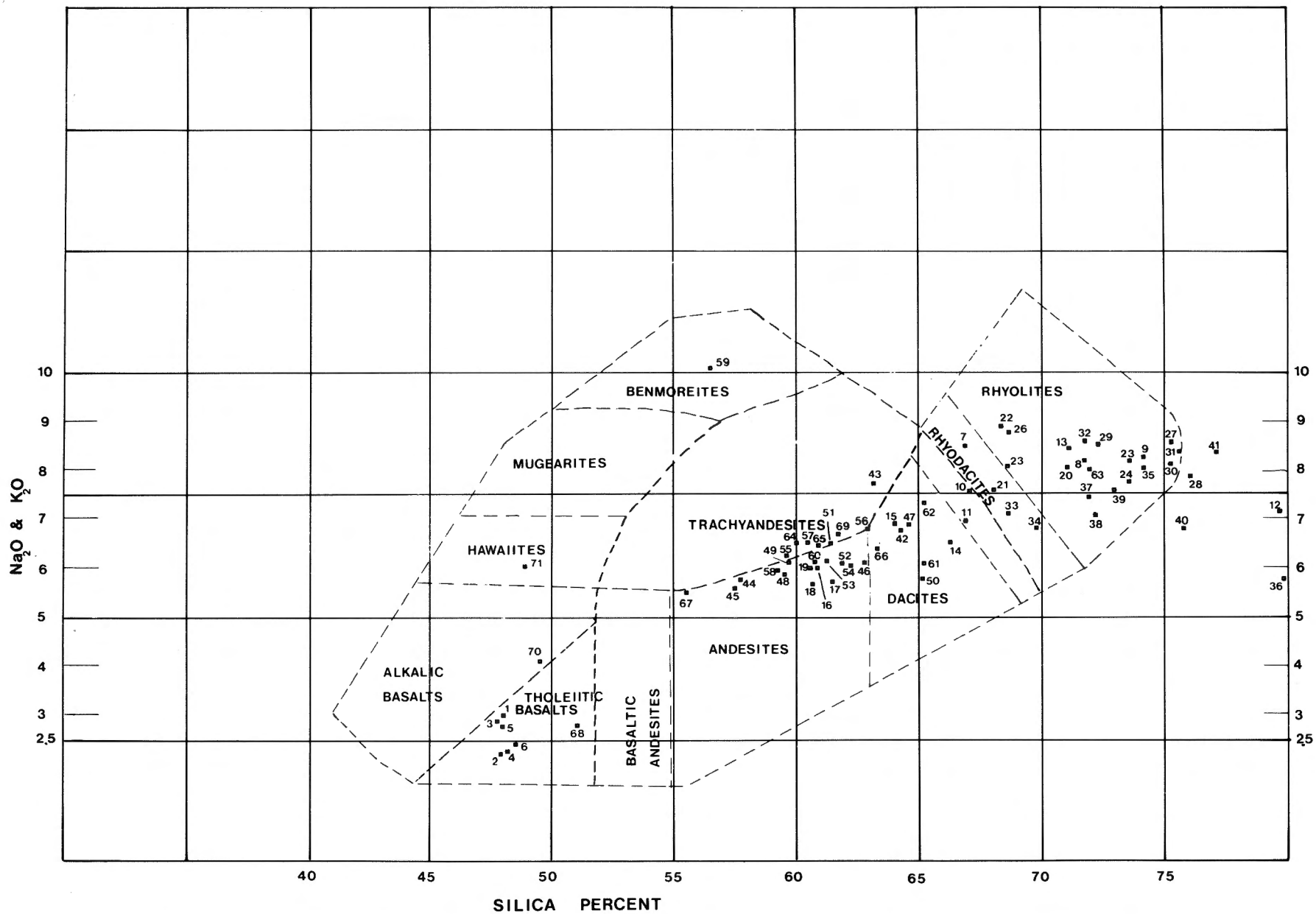


FIGURE 4. Plot of sums of alkali oxides against silica content, in weight percent, for 71 analyzed Tertiary volcanic rocks from Elko County and adjacent areas.

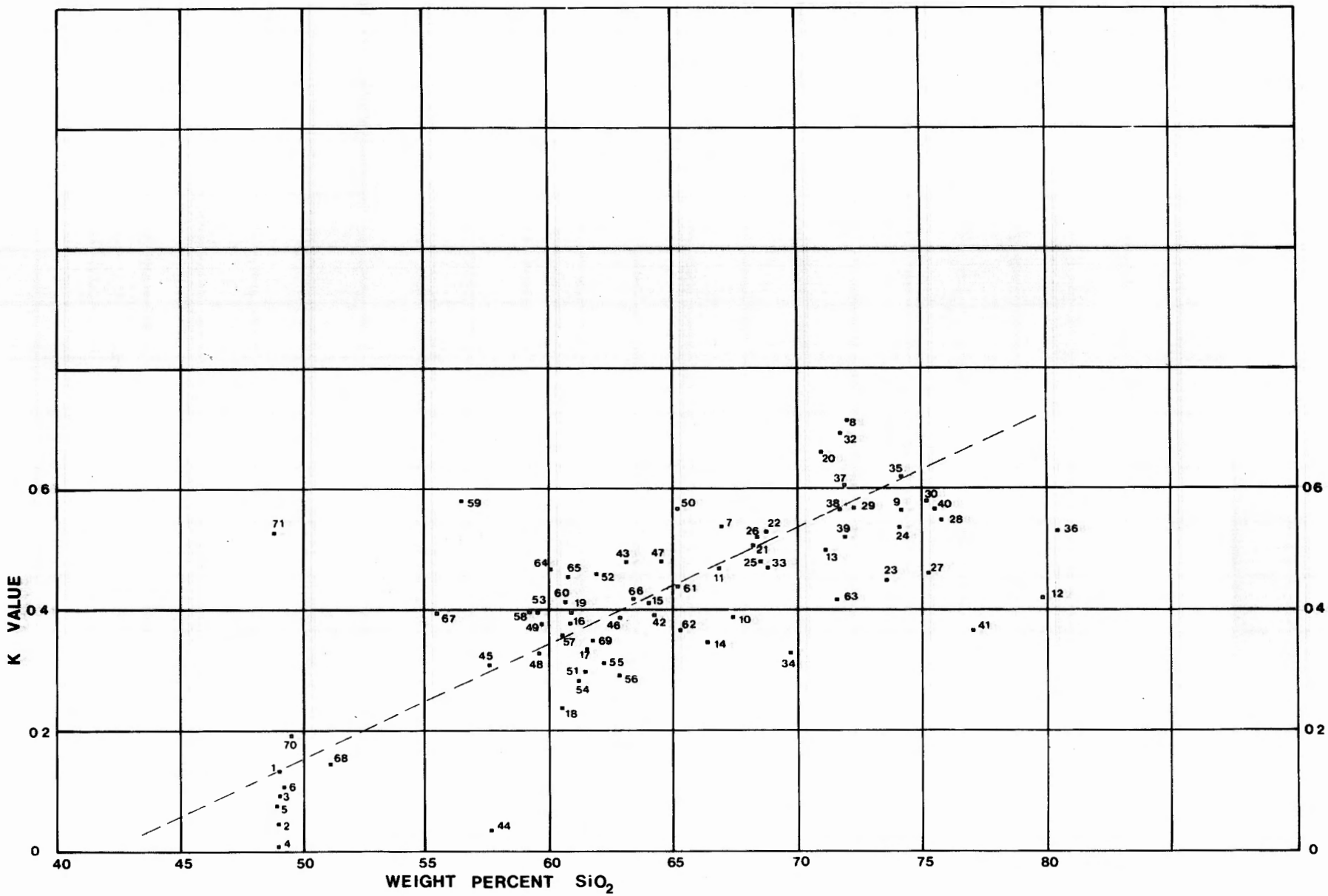


FIGURE 5. Plot of Niggli k value against weight percent of silica normalized to 100% total, for 71 analyzed Tertiary volcanic rocks from Elko County and adjacent areas.

The early Tertiary conglomerate includes two areas of rock that are much younger than those which have previously been described. Conglomerate in the southern part of the Jarbidge quadrangle [6] was named the Meadow Fork Formation by Coats (1964); although he assigned a late(?) Eocene age, the age of the Meadow Fork has not yet been precisely determined because of an absence of datable material. It rests conformably on the 39.9-m.y.-old Dead Horse Tuff, and thus is presumably among the younger units of early Tertiary conglomerate.

Unconsolidated material, perhaps more properly termed boulder gravel than conglomerate, is present in the Mountain City 15′ quadrangle [4] in the vicinity of Mustang Butte and to the west; this material was dated radiometrically by E. H. McKee (McKee and others, 1976, sample 20) at 38.0 ± 1.1 m.y. on biotite from a very thin hornblende-biotite phenodacite ignimbrite interbedded with coarse boulder gravel. The Meadow Fork Formation and the gravel near Mustang Butte probably represent coarse material that accumulated as a result of the same extensional tectonic event; probably they are correlative and will prove to be very late or latest Eocene.

In the Carlin-Piñon Range area, the earliest Tertiary rocks are nonvolcanic. Smith and Ketner (1976, p. B14–B15) described the earliest Tertiary unit in this area as a limestone and limestone-clast conglomerate:

> This unit...consists principally of tan dense limestone and some gray limestone, and...conglomerate composed mostly of limestone pebbles to boulders that can be identified as derived from Paleozoic rocks in the immediate vicinity. Fine-grained sandstone and siltstone, which are poorly exposed and are red locally, make up a small part of the unit... In the northeast part of the [Carlin-Piñon Range] area, the basal beds of this unit are conglomerate [wherever seen]. Clasts in the conglomerate are mostly limestone and less chert, although some beds contain many chert grains and pebbles. The matrix is limestone. Limestone clasts are rounded to angular, and the largest one observed is 1.2 m (3.5 ft) across. Most boulders obviously were derived from nearby Permian limestone....
>
> The northeasternmost exposures of this unit in secs. 15 and 16, T. 33 N., R. 55 E. consist mostly of conglomerate derived from the Diamond Peak Formation and look much like the Diamond Peak.

In the Carlin-Piñon Range area [43], Smith and Ketner (1976, p. B16) also described a sequence of conglomerate, sandstone, siltstone, and limestone that is exposed in several widely scattered areas:

> ...this unit of varied lithology characteristically has a red weathered surface or red soil on it in many places....
>
> Conglomerate makes up a prominent part of this rock unit... Clasts in the conglomerate are mostly limestone, range from pebbles to boulders, and are angular to rounded; pebbles tend to be fairly well rounded, and cobbles and boulders tend to be subangular to angular. All clasts appear to have been derived from Paleozoic rocks in the mapped area, and many from beds exposed nearby. Sorting ranges from poor to good. The matrix is mainly quartz sand and is both calcareous and noncalcareous.

Fouch and others (1979, fig. 2) indicated that two of the units assigned by Smith and Ketner (1976, p. B14–B16) to the Eocene(?) and Eocene Series—the limestone and limestone-clast conglomerate, and the younger unit of conglomerate, sandstone, siltstone, and limestone—contain Paleocene and possible Late Cretaceous fossils. The distribution of these fossils with respect to the two units mapped by Smith and Ketner (1976) is not known. The age assignment by Fouch and others (1979) may be compatible with that of Smith and Ketner (1976), because the second of these two units furnished snails and clams that D. W. Taylor assigned to the Cretaceous or lower Tertiary.

Smith and Ketner (1976, p. B16) described finer clastic beds of this formation as follows:

> The sandstone is fine grained to coarse grained, poorly to well sorted, and evenly and well bedded to indistinctly bedded, and consists mostly of quartz and chert grains. These beds are tan, brown, and gray and weather brown and grayish brown. Poorly exposed siltstone seems to be interbedded with the sandstone....
>
> Limestone in the unit is brown and gray and weathers mostly tan, brown, and red. Some beds are dense and fairly pure limestone, and others are clayey, sandy, or pebbly.

In the extreme northwestern part of the Wieland Flat quadrangle, a sequence of several thousand feet of volcanic cobble conglomerate, restricted in areal distribution, rests on early Tertiary ignimbrite, like that found along McClelland Creek, and is overlain by early Tertiary latitic volcanic rock. The presence of these rocks suggests local faulting and the rapid filling of a restricted basin by a stream of high gradient. The volcanic rocks that make up the cobbles resemble those of the early Tertiary andesitic and latitic flows and pyroclastic rocks.

Sedimentary Rocks **[Ts_1].** Somewhat arbitrarily, the unit of sedimentary rocks is here (pl. 1) restricted to include rocks that, where clastic, are relatively fine grained and have a relatively small pyroclastic content. Cherty limestone, limestone, and the Elko Formation constitute significant fractions in many places. Much of the limestone is pale buff,and weathers white, although very pale gray limestone has been recognized in some places. As noted by Smith and Ketner (1976), rocks free from pyroclastic material accumulated in some places while tuff was being deposited elsewhere.

The early Tertiary sedimentary rocks include units of limestone (locally cherty), conglomerate, sandstone, claystone, siltstone, shale (including carbonaceous shale and oil shale), and tuff. In northwestern Elko County, minor amounts of limestone, generally pale tan or buff but locally gray, occur; these rocks are commonly ostracodal but identifiable ostracodes have not been recovered.

In the North Fork quadrangle, the lower Tertiary sedimentary rocks overlie Tertiary gravel. The unit also includes the Elko Formation in the North Fork quadrangle and in areas on both sides of the Humboldt River near Elko, and in the Carlin and Pine Valley quadrangles (Smith and Ketner, 1976) [43]. It includes also three unnamed Eocene formations studied by D. I. Axelrod (written commun., 1966) in the Bull Run quadrangle, in which there are several fossil-leaf localities. The Elko Formation is also traceable along the hills on the west side of the North Fork of the Humboldt River to a point in the North Fork quadrangle a few miles north of the North Fork of the Humboldt River, although it is not as thick there as in the Elko area. In Long Canyon (Ketner, 1973) the Elko Formation overlies a conglomerate that is here mapped (pl. 1) as part of

the lower Tertiary conglomerate. In the Mount Velma quadrangle two quite distinct units are included in the lower Tertiary sedimentary rocks. One unit is a fairly coarse volcanic sandstone, of which a few hundred feet is exposed in the southwestern part of the Mount Velma quadrangle and which appears to be somewhat younger than the conglomerate. The other unit is a coarse gravel that is poorly consolidated but appears to have been folded; it is very poorly exposed because of the lack of consolidation, but the fragments in it are all of Paleozoic or plutonic rocks. This second unit is present in the western part of the Mount Velma quadrangle south of Penrod Creek.

On the northwest side of the Medicine Range [50], Collinson (1968) described lakebeds consisting of calcareous sandstone and interbedded limestone. Some of the limestone beds contain well-rounded chert pebbles and stromatolites; large silicified logs belonging to the long-ranging genus *Cupressinoxylon* occur in one friable crossbedded sandstone. Collinson (1968) correlated these lakebeds with the Eocene Sheep Pass Formation and with Eocene(?) lakebeds 60 mi to the east in the Gold Hill mining district, Utah.

In the Carlin-Piñon Range area, the lower(?) and lower Tertiary rocks include three units described by Smith and Ketner (1976): a cherty limestone unit, a limestone unit, and the Elko Formation.

Cherty Limestone **[Ts_1]**. In the northeastern part of the Carlin-Piñon Range area (Smith and Ketner, 1976, p. B17) is a unit of limestone containing abundant opaline chert. The limestone is mostly gray and dense and weathers about the same color. Bedding is indistinct. It contains black, brown, tan, and some almost white chert that is commonly opaline. The total thickness of this cherty limestone is probably more than 1,000 ft. The cherty limestone is considered to be Eocene and rests on Eocene(?) units.

Limestone **[Ts_1]**. The limestone unit covers an area of about one square mile at the eastern edge of the Carlin-Piñon Range area (Smith and Ketner, 1976, p. B18). It is dense, sugary, gray to light tan and white, and thick bedded. Some beds are algal. Some fine- to coarse-grained calcareous sandstone and sandy limestone are locally interbedded with the limestone. The unit is at least 1,000 ft thick and may be as much as 2,000 ft thick.

Elko Formation **[Ts_1]**. The Elko Formation is composed of claystone, siltstone, shale, some limestone, and tuff. The tuff, the lowest tuffaceous member, which appears in the middle of the formation, is a biotitic rhyolite tuff that furnished a K-Ar age of 38.6 ± 1.2 m.y. Although the thickness of the formation cannot be estimated precisely, its maximum thickness is probably more than 2,500 ft. The Elko Formation is late Eocene and Oligocene(?). Solomon and others (1979) described the Elko Formation in great detail.

Phenorhyolitic to Phenodacitic Ignimbrite **[Tt_1]**. The most widespread early Tertiary unit and the earliest volcanic unit of any consequence is the phenorhyolitic to phenodacitic ignimbrite. Two different rock types are included in this unit (pl. 1). One rock type, extremely rich in phenocrysts of hornblende, augite, hypersthene, and plagioclase, commonly contains many xenoliths of chert of the Valmy Formation or some other black, hard cherty rock. The other rock type includes rocks that in many places are densely welded, somewhat poorer in phenocrysts, and richer in glass, now largely devitrified. The phenorhyolitic to phenodacitic ignimbrite includes the oldest dated volcanic rocks in northern Elko County.

Crystal-rich ignimbrite occurs in four major areas. The first, the northernmost occurrence, is in the northern part of the Mount Velma quadrangle, the second in the southern part of the Mount Velma quadrangle and the northern part of the adjacent quadrangles to the south, and the third along State Highway 11 between the Elko–Mountain City highway and the Mount Blitzen quadrangle. The fourth is in the Bull Run quadrangle.

The occurrence in the northern part of the Mount Velma quadrangle is in the drainages of Thompson Creek and Williams Creek; the area was mapped by Coash (1967) as "younger volcanics." The sequence is largely composed of crystal tuff and crystal-vitric tuff, rich in hornblende and biotite, both of which have been substantially altered, generally to chlorite; the other conspicuous minerals are plagioclase and minor quartz. Glass originally present has generally been recrystallized to fine-grained quartz and feldspar or to zeolites. Similar volcanic rocks are present in the valley of the west fork of Beaver Creek, where they were mapped as "older volcanic rocks" by Coash (1967). These rocks also form a steeply dipping sequence of largely crystal-vitric tuff, light in color and probably dacitic in composition. The thickness of the sequence can only be guessed at because of the probable presence of numerous strike faults. Other exposures include those of a unit, nearly continuous with the previously mentioned units, that occurs in the Mahala Creek West and Reed Station quadrangles on both sides of State Highway 11, as well as south of State Highway 11 in the Stampede Ranch, Lake Mountain, Sugarloaf Butte, China Camp, and Mount Blitzen 15′ quadrangles. Somewhat similar tuff containing a larger component of well-bedded sequences seems to make up the wall rock of veins in part of the Tuscarora mining district, although it is poorly exposed there; the age of this tuff is unknown at this time.

The second major area of crystal ignimbrites extends into the southern part of the Jarbidge Wilderness and into the adjacent parts of quadrangles east of the Mount Velma quadrangle, where the crystal-rich ignimbrite has an upper part that in many places is unconformable on the lower part and contains more fresh glass and less hornblende than that part of the unit which occurs around Island Mountain and Little Island Mountain in the Mount Velma quadrangle.

In the third area of early Tertiary ignimbrite, in the headwaters of McClelland Creek, on either side of State Highway 11 and westward, the composition differs slightly from that of the ignimbrite in the upper part of Beaver Creek. Plagioclase is commonly andesine rather than oligoclase, and biotite is more nearly ubiquitous, although both hypersthene and augite are also present in many of the rocks. In addition to the ignimbrite, some flows of phenoandesite, ranging in composition

from hornblende-biotite phenoandesite to biotite-hornblende-pyroxene phenoandesite and phenorhyodacite, are present, as well as welded tuff of phenorhyodacitic composition.

A fourth area of these ignimbrites is in the Bull Run quadrangle, where D. I. Axelrod (written commun., 1964) described, from the base of the Tertiary sequence, volcanic rocks exposed in the vicinity of Frost Creek; these have a wide range of composition, and for convenience they are here mapped (pl. 1) with the phenorhyolitic to phenodacitic ignimbrite. The most silicic member is a biotite phenorhyolite welded tuff composed of crystals and crystal fragments of quartz, sanidine, plagioclase, and biotite, with a matrix of devitrified glass, shards, and pumice fragments. This member is widely exposed from Doby George Creek to Maggie Summit in the Bull Run quadrangle, eastward into the Wild Horse 15′ quadrangle and the southern part of the Mount Velma quadrangle, and possibly even farther. The other members of this unit, as described by Axelrod, though not as well exposed or as widespread, include a glassy ignimbrite containing phenocrysts of biotite; the plagioclase ranges in composition from oligoclase to andesine-labradorite. Many of these rocks should properly be referred to as welded lapilli tuff because they contain lapilli, as much as 3 in. long after flattening, that impart a spotted appearance to the rock. Axelrod considered these rocks to be latitic in composition; many of them are markedly porphyritic. The mafic minerals of the latite are generally biotite or hornblende and some augite. Some of these rocks may be flows. Some rhyolite flows also are probably present—for example, at the base of the scarp southeast of Wilson Peak in the Bull Run quadrangle and in smaller areas on Lime Mountain and along Deep Creek. Andesite is also present in the Bull Run Mountains south of Wilson Peak; local patches were mapped on the north and northwest margins of the Bull Run Basin. These rocks are typically greenish gray to nearly black. Somewhat similar rocks occur in the northern part of the Bull Run Basin, underlying rhyolitic and latitic welded tuff. Some of the andesite contains phenocrysts of augite or diopside as well as plagioclase, which may be as calcic as bytownite or as sodic as oligoclase. D. I. Axelrod (written commun., 1964), included biotite from the biotite latite welded tuff in the lower part of the section in Frost Creek dated by Geochron Laboratories, Inc., which indicated an age of 42.5 ± 2.1 m.y.

In the Mountain City 15′ quadrangle, early Tertiary pyroclastic rocks of a slightly different facies are generally richer in glass, much of which is well preserved. In the extreme northern part of the Mountain City 15′ quadrangle, the oldest of this welded tuff, which rests on Cretaceous granite, is characterized by a high proportion of glass and the presence of plagioclase, biotite, hornblende, hypersthene, and augite. This welded tuff is overlain by a series of units of welded tuff that are generally characterized by the presence of plagioclase and biotite. Some units also contain sanidine and quartz, and some contain hornblende as well as biotite; the plagioclase is intermediate to sodic in composition, generally oligoclase to andesine. These rocks are overlain by one remarkable unit that contains such a high percentage of biotite that it is as fissile as a biotite schist. This mica-rich welded phenodacitic tuff was dated by John Obradovich (written commun., 1965, sample DKA1074) at 43.5 ± 2.2 m.y. This is one of the oldest Tertiary rocks that has been dated in northern Nevada.

One of the older units in the extreme northern part of Elko County is a phenorhyodacite that contains hypersthene, augite, hornblende, and biotite. What appears to be the same unit has been dated from two different collections; the dates agree within the error limits of their determinations. One collection furnished a biotite dated by E. H. McKee (McKee and others, 1976, sample 13) at 42.4 ± 1.5 m.y.; the other collection was dated by McKee (McKee and others, 1976, sample 24) at 41.8 ± 1.5 m.y. Both these rocks are very similar in lithology; some rocks of similar lithology occur on Haystack Creek in the Mountain City 15′ quadrangle. Nearly everywhere the rocks rest on prevolcanic rocks, except that in one place the welded tuff rests on air-fall tuff, presumably of about the same age. In two or three places in the Mountain City 15′ quadrangle (for example, near Rabbit Draw), a thin biotite phenorhyolite pumiceous welded tuff that characteristically contains dark smoky quartz generally rests on Paleozoic rock or on Cretaceous granite; biotite from one unit of this welded tuff was dated by E. H. McKee (McKee and others, 1976, sample 12) at 40.0 ± 1.2 m.y.

One conspicuous and highly significant unit in this sequence is a tuff that has been referred to as the pumiceous lapilli tuff of Packer Ranch, named after the Packer Ranch in the southern Independence Valley. This tuff is well exposed near and to the northwest of the saddle on State Highway 18 between Independence Valley and the drainage of Willow Creek. Here the unit is twofold; both parts appear to be the product of Katmaian eruptions because they contain very coarse lumps of pumice and a few cognate xenoliths of glassy volcanic rock, and are completely unsorted. One part is apparently a biotite phenorhyolite tuff, and the other a hornblende-biotite phenodacite tuff. Biotite from the biotite phenorhyodacite pumice, which was collected near the saddle mentioned above, was dated by E. H. McKee (McKee and others, 1976, sample 37) at 41.0 ± 1.2 m.y. Another tuff, a biotite phenodacite ignimbrite that probably is part of this same unit, is exposed only in a small outcrop in a streambank some distance away; biotite from this tuff was dated by E. H. McKee (McKee and others, 1976, sample 32) at 39.3 ± 1.2 m.y. The error bars of these dates overlap, and so they probably refer to the same unit, although this conclusion may be somewhat uncertain because of the later cover which surrounds the rocks that furnished the second date.

One of the most widespread units belonging to the early Tertiary ignimbrite is a very thick mass that has been called the ignimbrite of Tuscarora; it is exposed in the vicinity of Mount Blitzen northward in the Mount Blitzen 15′ quadrangle to and beyond the South Fork of the Owyhee River. It was apparently deposited as a single cooling unit and is very thick—at least 1,000 ft. More than one eruption may be represented, but there are very few markers or indications of any interruption

to the eruptive process. These rocks commonly contain quartz, plagioclase, sanidine, biotite, and hornblende; some perrierite is present, and accessory apatite is common, as well as a few hypersthene phenocrysts. This unit, as mapped here (pl. 1), includes rocks mapped by Evans and Ketner (1971) as "...chiefly latite... that...includes...tuffaceous sedimentary rocks." Some part of this unit of Evans and Ketner probably corresponds to the unit of andesitic to latitic flows and pyroclastic rocks (see next section).

Latitic Rocks **[Tl]**. The unit of latitic rock (pl. 1) resembles ordinary basalt in the field but is characterized by rather higher silica and potash contents than would be expected from the rock's appearance. These rocks are black, dense to aphanitic, and in many places very hard; they are composed chiefly of plagioclase, augite with or without hypersthene, and olivine. The plagioclase ranges from sodic labradorite to sodic andesine in composition. These rocks range fairly widely in lithology. Some have a glassy groundmass; in others the groundmass is crystalline and consists of potassium feldspar as well as fine plagioclase. Many are vesicular and evidently flowed out across the surface that unconformably transects the earlier Tertiary tuff of the area in which they occur. Most of these rocks are mapped in the Reed Station, Stampede Ranch, Lake Mountain, and Sugarloaf Butte quadrangles. E. H. McKee (McKee and others, 1976, sample 39) dated a whole-rock sample of these rocks from the south end of the Independence Valley at 35.4 ± 1.0 m.y.

Andesitic to Latitic Flows and Pyroclastic Rocks **[Ta_1]**. Near Tuscarora, many rocks of the Tuscarora mining district are andesite, as noted by Nolan (1936, p. 19–21), who recognized that andesite flows, mapped here (pl. 1) as part of the andesitic to latitic flows and pyroclastic rocks, and andesitic intrusive rocks should properly be considered part of the early Tertiary phenoandesitic rocks. Although the phenoandesitic rocks are difficult to distinguish in the Tuscarora mining district itself because of a pervasive alteration that has destroyed most of the primary minerals, in descending order of importance they probably include biotite-pyroxene phenoandesite, hornblende-biotite-pyroxene phenoandesite, and biotite phenoandesite.

Southwest of Tuscarora, at the south end of the Independence Valley, several units or sequences of phenoandesitic rock are considered to be early Tertiary(?). Many of these rocks have not been dated radiometrically. One such undated sequence occurs in a low range of hills immediately west of the Packer Ranch, where the andesite is characterized by two pyroxenes and sparse hornblende.

Early Tertiary phenoandesite also occurs in the Owyhee and Mountain City 15′ quadrangles. In the northern part of the Owyhee 15′ quadrangle, these rocks were mapped by Coats (1971) as the andesite of Summit Creek, which is largely a pyroxene phenoandesite and a pyroxene-hornblende-biotite phenoandesite that also includes biotite-pyroxene phenodacite vitrophyre. Some vents were evidently present; the vent breccia may mark a source area for some of this phenoandesite. Phenoandesite also occurs to a limited extent in the southern part of the Mountain City 15′ quadrangle, in the valley of Allegheny Creek. In the southern part of the Mountain City 15′ quadrangle, tuff that apparently conformably lies beneath the phenoandesite of Summit Creek is here mapped with it (pl. 1).

Phenoandesite—apparently earlier than the Tertiary tuff—is present at the base of the early Tertiary tuff in the Jarbidge Wilderness; and in the Charleston Reservoir, the Stag Mountain, and the three Marys River Basin quadrangles. The rock is a pyroxene-biotite phenoandesite and pyroxene phenoandesite and, to some extent, also basalt. Some phenobasalt is here mapped (pl. 1) with these rocks. The age of the phenoandesite is uncertain because much of it occurs in areas where it is neither overlain nor underlain by any dated extrusive rocks. Most of the phenobasaltic or phenoandesitic rocks show a considerable degree of alteration. In the Mountain City 15′ quadrangle, they occur in three areas, southwest and southeast of the town of Mountain City, up California Creek, and in the northern part of the quadrangle in the western tributaries to Cottonwood Creek. These rocks form a sequence of dark-gray to black aphanitic rocks that are apparently pyroxene phenoandesite or augite phenoandesite welded tuff. The mafic minerals are almost uniformly destroyed by alteration, but the plagioclase suggests an andesitic composition. These rocks are closely associated with uranium deposits in at least three places: on the hill along the north side of the mouth of Russel Gulch across the Owyhee River from Mountain City; in the hills immediately southeast of Mountain City; and on the north side of California Creek about 3 mi east of Mountain City. No precise age is available on them, but in some places they are younger than the early Tertiary phenorhyolitic ignimbrite.

In the headwaters of Yankee Bill Creek, near the center of the Mountain City 15′ quadrangle, a poorly exposed sequence of phenoandesite closely resembles that of Russel Gulch, with which it may be correlative. The rock is largely welded tuff, and in much of it the only phenocrysts preserved are andesine. Where the mafic phenocrysts are preserved, they are commonly augite and hypersthene; hornblende is quite rare, and quartz is very sparse. A few flows of hornblende-biotite-hypersthene phenodacite and biotite-hornblende-pyroxene phenoandesite welded tuff are present; one bed of biotite-hornblende-pyroxene phenorhyodacite was also noted. Thus, the total range in composition of these rocks is greater than that of the andesite of Russel Gulch. In parts of the basin of California Creek, these rocks are also associated with uranium deposits that apparently accumulated chiefly along the contact with the underlying granitic rocks, and presumably represent uranium that was leached from the glassy parts of the welded tuff.

Along the east flank of the Independence Mountains and south of Independence Valley is a sequence of volcanic rocks of varying composition that, though only slightly younger than the early Tertiary tuff of this area, rests on the tuff with marked uncomformity in most places; the younger volcanic rocks are very well exposed around the headwaters of Pie Creek in the Reed Station

quadrangle and in the Mahala Creek West quadrangle to the north. These rocks are largely pyroclastic, although flows are also present, with typical pilotaxitic structure. The rocks range in composition from pyroxene phenoandesite, through hornblende-biotite phenoandesite tuff, hypersthene-biotite-hornblende phenoandesite welded tuff, biotite phenoandesite tuff, and biotite phenorhyodacite ignimbrite, to biotite phenorhyolite welded tuff characterized by quartz and sanidine. The pyroxene phenoandesite flow rocks are characterized by augite, hypersthene, and, commonly, hornblende. One of these rocks, a biotite-hornblende rhyodacite ignimbrite, was dated by E. H. McKee (McKee and others, 1976, sample 40) at 40.7 ± 1.2 m.y.

The mafic to silicic volcanic rocks of Smith and Ketner (1976, p. B23), here mapped (pl. 1) with the unit of andesitic to latitic flows and pyroclastic rocks of early Tertiary age, occur in three isolated exposures in the Carlin-Piñon Range area (Smith and Ketner, 1976, p. B23). Temporal correlation with this unit may be somewhat doubtful because only the upper limit of its age has been determined. In the Carlin-Piñon Range area, some volcaniclastic sandstone is interbedded with the flows. The flows range in composition from andesite and quartz latite to black basalt; the andesite and quartz latite are somewhat altered.

Rhyolitic to Dacitic Flows and Domes **[Tr_1]**. The unit of early Tertiary rhyolitic to dacitic flows and domes (which may also include some ignimbrite) is only sparsely distributed; it occurs mostly in southwestern Elko County, in the western part of the Mount Blitzen 15′ quadrangle and in the quadrangles to the west of it.

A conspicuous, if not widespread, member of the unit is phenorhyodacite that has formed a volcanic dome that makes up Walker Mountain, in the Mount Blitzen 15′ quadrangle. The rock is generally porphyritic and dosemic; the groundmass ranges from glassy to aphanitic. The principal phenocrysts are sanidine, sodic oligoclase, quartz, biotite, and, less commonly, small amounts of hornblende, as well as very common perrierite(?) or chevkinite(?); augite has also been recognized. Biotite from this rock was dated by E. H. McKee (McKee and others, 1976, sample 35) at 35.4 ± 1.1 m.y. The phenorhyodacite of Walker Mountain rests on the ignimbrite and phenoandesite of early Tertiary age that underlie a large part of the Mount Blitzen 15′ quadrangle and that are hydrothermally altered in the vicinity of the Walker Mountain. The absence of this alteration in the rhyodacite dome confirms the relative ages measured by the K-Ar method.

An ignimbrite mapped (pl. 1) with this unit **[Tr_1]** in the vicinity of the Burner Hills as well as in the valley of Rock Creek is best described as a biotite phenorhyodacite ignimbrite, characterized by the presence of quartz, sanidine, and plagioclase; the plagioclase is andesine to oligoclase. The mafic minerals are principally biotite, minor hornblende, and, quite commonly, a trace of perrierite. Another unit, which here is included in the early Tertiary phenorhyolites, but somewhat doubtfully because of the absence of any age determination on the biotite in it, is typically exposed in the vicinity of Wolf Creek north of the hills that lie north of Rock Creek and west of Deep Creek. This second unit is generally dopatic, as the proportion of phenocrysts is very small; phenocrysts are of quartz, sanidine, plagioclase, small amounts of biotite, and, in some rocks, perrierite. Some of the rocks are ignimbrite, and others appear to be flows. Because the exposures are not good enough and the contacts have not been studied, these two types cannot always be distinguished; microscopically some show the typical shard structure of an ignimbrite, whereas others do not.

The Ottawanah Rhyolite occurs in the Owyhee [3] and Mountain City [4] 15′ quadrangles, and in the Hat Creek quadrangle [2] to the west of Owyhee; it also occurs sparsely in the block of 15′ quadrangles to the south of the Mount Velma quadrangle. As defined by Coats (1971), the Ottawanah consists of two units of different ages and includes rhyolitic domes and welded tuff. The typical tuff is older than the domes. The abundant phenocrysts in these tuffs are principally plagioclase, quartz, hornblende, and biotite in some rocks, or plagioclase, sanidine, quartz, hornblende, and biotite in others. One sanidine sample and one biotite sample from two localities gave an age of 39.6 ± 2 m.y. by K-Ar analysis (John Obradovich, written commun., 1965, samples DKA1073 and DKA1070, respectively). Another welded tuff, which has a maximum thickness of about 400 ft, is well exposed in the lower part of Reed Creek in the Owyhee quadrangle. It is younger, about 33.4 m.y. old. The oldest rhyolite tuff unconformably overlies the andesite of Summit Creek and is overlain unconformably by the volcanic and sedimentary rocks of Jones Creek or by younger formations.

Tuff, Sedimentary Rocks, and Lava **[Ttsl]**. A sequence of pebble and cobble gravel and bentonitic tuff and pumiceous tuff occurs in the Mount Blitzen 15′ quadrangle, west of the Falcon Mine north of Rock Creek, and south of Rock Creek in the valleys of the South Fork of Rock Creek and of Toejam Creek, a tributary to Rock Creek. These rocks have been referred to as the tuff and gravel of Toejam Creek. Two lines of evidence for the age of this sequence are available. Lignitic mudstone furnished a pollen flora that was dated by E. B. Leopold (field no. 71NC290) as pre-Miocene or Miocene. A K-Ar age of 33.6 ± 1.6 m.y. was determined by E. H. McKee (McKee and others, 1976, sample 34) on biotite extracted from rhyolite pumice in a pyroclastic flow interbedded with gravels that are thought to be part of the same formation, although the area is disjunct from that of the outcrop that furnished the pollen.

Middle Tertiary Rocks

Gravel **[Tg_2]**. Just northeast of the Peck Ranch (now abandoned) in the valley of Allegheny Creek, in the southern part of the Mountain City 15′ quadrangle, are three hills of cobble gravel. The gravel is unconsolidated, and bedding cannot be discerned. It is composed almost exclusively of tan silicified rock, much resembling the silicified Van Duzer Limestone that is present just above the Lime Creek thrust in the western part of the Mountain City 15′ quadrangle. A few cobbles of early(?) Tertiary lavas are also present. No base is exposed; middle Tertiary tuffaceous sedimentary rocks

that have furnished an Arikareean fauna overlie the gravel. If the dip approximates that on the upper Tertiary rocks to the south, the maximum thickness exposed is about 3,000 ft.

***Welded Tuff and Sedimentary Rocks* [Tw].** In the southern part of the Mount Velma quadrangle and in the Marys River Basin NW and NE quadrangles to the east in the southern part of the Jarbidge Wilderness, the unit of welded tuff and sedimentary rocks (pl. 1) consists largely of hornblende-biotite phenodacite welded tuff. The rocks rest unconformably on the lower Tertiary crystal-rich ignimbrite that is common in this area. Farther to the south, rocks that occupy the same stratigraphic position are largely pyroxene andesite, but those rocks are here mapped (pl. 1) with this unit for convenience. No dates are yet available on this unit.

Poorly exposed welded tuff, air-fall tuff, and, possibly, small flows are commonly found in Harris Gulch just east of Mountain City. These rocks, which are biotite phenorhyolite and biotite-hornblende phenorhyodacite, and tuff of similar mineralogy, are of interest because the type of hydrothermal alteration that they show in the vicinity of Mountain City suggests that they were present when the Mountain City ore deposits were formed. This relation sets a minimum date on the time of formation of the silver-rich ore deposits in the immediate vicinity of Mountain City. Sanidine from these rocks was dated by J. C. Von Essen (McKee and others, 1976, sample 15) at 30.1 ± 1 m.y. A general coincidence in trend between the volcanic rocks of Harris Gulch, which fill a narrow graben, and the silver-bearing veins suggests that the volcanic rocks and the veins may be genetically related.

In the Mountain City district, a poorly exposed bentonitic tuff, arkosic and carbonaceous near the base and containing small amounts of lignite, overlies a quartz monzonite or granodiorite of Cretaceous age on Pixley Creek, a tributary of the South Fork of California Creek in S34(projected),T46N,R54E. These rocks were described by Garside (1973, p. 42). The lignite in this deposit yielded a substantial amount of fossil pollen, which was dated by E. R. Leopold (field no. 62NC91, colln. D-3985) as Oligocene(?).

***Indian Well Formation* [Tw, Ts_2].** The Indian Well Formation was named by Smith and Ketner (1976, p. B23) for exposures in the Carlin-Piñon Range area. They defined four units: three units of sedimentary rocks of lacustrine and fluvial origin, and one unit of ignimbrite or ash-flow tuff. The sedimentary rock units are here mapped (pl. 1) with welded tuff, tuffaceous sedimentary rocks, vitric ash and tuff, and lava [Tw]. The fourth and highest unit, the ignimbrite, is mapped separately as part of the tuffaceous rocks of middle Tertiary age [Ts_2].

According to Smith and Ketner (1976, p. B26), the sedimentary sequence of the Indian Well Formation may be divided into two parts. Approximately the lowest 1,000 to 1,200 ft consists of fluviatile deposits, predominantly sandstone and minor conglomerate, siltstone, and mudstone. Many of the beds are tuffaceous, and many of the conglomerate clasts are pebble- and cobble-size pieces of ignimbrite derived from the formation itself. Near the base is a siltstone containing quartz or chert clasts. Above the lower part of the sequence, the fluviatile deposits are still dominant and consist mainly of tuffaceous sandstone, although some lacustrine tuff beds also occur. Thin-bedded lacustrine limestone, commonly silty, is interbedded with the sandstone throughout this part of the section.

Part of the Indian Well Formation is chiefly ignimbrite, ranging in composition from rhyolite to dacite. The tuff ranges in consolidation from nonwelded to densely welded. Although the exact thickness of the Indian Well could not be determined, its maximum thickness may be about 2,000 ft. The ignimbrite spread over an irregular surface, and the top of the unit has been eroded. The nonwelded and slightly welded tuff commonly ranges in color from white to light gray and locally pink; this tuff is in many places pumiceous. More densely welded tuff occurs in a variety of colors: light and dark gray, pinkish gray, brown, purple, black, and green. The tuff ranges in composition from vitric to crystal vitric. The phenocrysts are quartz, potassium feldspar (largely sanidine), and plagioclase; biotite flakes are common. Some of the welded tuff is vitrophyric. In places, tuffaceous sediment is interbedded with the ignimbrite. The age of the Indian Well Formation, as determined by R. F. Marvin and others using K-Ar methods, ranges from 37.6 ± 1.3 to 33.2 ± 0.7 m.y. on biotite from near the base of a lapilli tuff. R. F. Marvin and S. W. Dobson obtained a K-Ar age of 38.5 ± 1.3 m.y. on biotite from the Indian Well Formation in Eureka County (written commun., 1980).

***Tuffaceous and Clastic Sedimentary Rocks* [Ts_2].** At the south edge of the Mountain City 15′ quadrangle, in the valley of Allegheny Creek, is a sequence of tuff and associated sedimentary rocks that are light cream to pale green, locally biotitic, and contain small lenses of fine gravel and tuffaceous gravel. Some of these gravel lenses contain a vertebrate fauna of Arikareean or early Miocene age, according to C. A. Repenning (oral commun., 1965; 1966, p. A117).

***Phenorhyolitic and Phenodacitic Tuff, Flows, and Domes* [Tr_2].** Only a few members are assigned to the unit of phenorhyolitic and phenodacitic tuff, flows, and domes (pl. 1), and their assignment is somewhat questionable because their ages have not been directly determined. One of these members makes up a volcanic dome and certain associated layers of welded pumiceous tuff that are distributed around Huber Hills in the southwestern part of the Mountain City 15′ quadrangle. The rocks are pale-pinkish-gray dopatic biotite phenorhyodacite or phenodacite. The plagioclase, which is quite rare, is generally andesine or oligoclase; the biotite in the dome is brown and has been marginally, in some places heavily, resorbed. The rocks are vesicular, and the areas around the vesicles commonly are bleached; the vesicles are lined with tridymite owing to gas-phase transportation. The welded tuff contains many flattened pumice fragments that have been converted to sanidine and tridymite aggregates.

Another member is a phenorhyolite, which occurs in two places: principally near the head of Telephone Creek in the Mountain City 15′ quadrangle [4], and in a very small area northeast of the Wild Horse Reservoir in the Wild Horse 15′ quadrangle [11A]. The primary

composition of the unaltered phases of these rock masses comprises a range of minerals. The phenocrysts may be plagioclase alone or quartz, sanidine, and plagioclase, commonly with sparse green biotite. The rock found near the head of Telephone Creek is more remarkable, however, for the presence of topaz in vesicles surrounded by bleached zones. The topaz crystals are very small, generally millimeter size, and quite scarce, and so the rock does not seem likely to be sought after by mineral collectors or to be a goal for those searching for gemstones. The color of the topaz where it has not been exposed to light is somewhat yellowish, rather reminiscent of the topaz of Topaz Mountain in Utah, and like the topaz of that locality, it bleaches colorless on exposure to light. Fluorite, cassiterite(?), and rutile are very rare accessories.

Phenoandesitic and Phenolatitic Flows and Pyroclastic Rocks **[Ta_2]**. Several areas of the unit of phenoandesitic and phenolatitic flows and pyroclastic rocks (pl. 1) of middle Tertiary age are in Elko County. One area is in the Owyhee and Mountain City 15′ quadrangles and was mapped in the Owyhee 15′ quadrangle by Coats (1971) as the volcanic and sedimentary rocks of Jones Creek. These rocks, which have a maximum thickness of about 1,000 ft, consist of flows and tuff breccia of pyroxene andesite and hornblende andesite; the hornblende andesite is less common. The rocks are dark gray to medium gray and commonly porphyritic. Gray air-fall tuff is locally present, and some vent-filling breccia has also been observed.

Another area of the unit is in the vicinity of the Cornucopia mining district (Coats, 1967), where it makes up the wall rock of many of the veins and is the oldest Tertiary rock in the district. The rock is principally a pyroxene phenoandesite or hornblende-pyroxene phenoandesite; the pyroxene is typically augite but hypersthene is also present, and some hornblende and biotite phenoandesite welded tuffs are also present in the sequence. Most of the rock is somewhat hydrothermally altered—the biotite to chlorite, the plagioclase to calcite, and the hornblende to chlorite and magnetite. Some of the pyroxene is altered to nontronite, and where the rocks are intensely propylitized, the plagioclase may be altered to albite. The more highly altered rocks are bleached and partly replaced by calcite, pyrite, and sericite. These pyroxene phenoandesites and some hornblende phenoandesites, as well as correlative tuff breccias, are present for a considerable distance to the southwest along the north side of the hills between the drainage of the Owyhee River and that of Rock Creek, as far as the road between the Rock Creek valley and the Burner Hills.

In the valley of Rock Creek west of the Mount Blitzen 15′ quadrangle and in the Little Rock Creek quadrangle are a few areas where a largely glassy air-fall tuff carrying small amounts of biotite is present beneath a phenoandesite that has been correlated with the phenoandesite of Cornucopia; the tuff is here mapped (pl. 1) for convenience with the unit of phenoandesitic and phenolatitic flows and pyroclastic rocks. In the vicinity of Adobe Summit northwest of Elko in the Adobe Summit quadrangle, many hills are capped by masses of phenoandesite that include hypersthene phenoandesite and hornblende-pyroxene phenoandesite containing both augite and hypersthene; the hornblende generally shows strong resorption in these undoubted volcanic flows. The phenoandesite rests unconformably on pumiceous phenorhyolitic tuff that is perceptibly baked and reddened near the contact. The andesites near Adobe Summit are correlated with the andesite, south of Elko, for which Soloman and others (1979) reported ages of 30.9 ± 1 and 35.2 ± 1.1 m.y.

Some of the phenoandesites grade into basaltic phenoandesite and some may, on analysis, turn out to be dacite. One of these units includes the phenoandesite in the vicinity of the McKnight Ranch, the tuff of which furnished one of the few fossil localities in this part of Elko County. The McKnight Ranch, though generally unoccupied and unlabeled on the Wells sheet (scale 1:250,000), is known to be the ranchhouse shown in S26,T29N,R46E, in the valley of the North Fork of the Humboldt River. Merriam (1914) described a small collection of fossil-mammal remains gathered by C. W. West and J. C. Jones at the McKnight Ranch. Jones reported to Merriam (1914) that the bones were obtained from a massive lenticular yellow siltstone, at least 50 ft thick, overlying andesite or basalt. These rocks dip about 20°SW. I reexamined this site, but found no more bones. The description given by Merriam (1914), which he obtained from J. C. Jones, was merely "near the ranch of George McKnight."

The fossils identified from the McKnight locality are generally thought to be Barstovian (Miocene) (C. A. Repenning, oral commun., 1977). The sequence of which they are part consists largely of phenoandesitic flows, tuff, and breccia, mostly pyroxene phenoandesite. This sequence is overlain unconformably by at least two other sequences of phenoandesite, one of which has been dated by interbedding with Jarbidge Rhyolite as about 15 m.y. old, an age suggesting that the McKnight locality may be early Barstovian rather than late Barstovian, as some workers have supposed. The phenoandesite at the McKnight Ranch also is unconformably overlain by sedimentary rocks of the Humboldt Formation (restricted), which are widespread in King's (1876) Bone Valley (the North Fork of Beaver Creek), although the McKnight Ranch locality is certainly not the same as King's (1876) Bone Valley site, as some workers have thought.

R. A. Hope collected hornblende-hypersthene phenoandesite, part of a sequence that may include more siliceous rocks and other types of phenoandesite, near Stag Mountain, an irregular mountain mass crossed by the road from Deeth to Charleston, in the Hanks Creek SW and Hot Springs Creek quadrangles. Farther west, basaltic phenoandesite caps some hills in the vicinity of Adobe Summit and, still farther west, north of Beacon Flat. This phenoandesite is also found as several masses on the summit of the Elko Hills (Solomon and others, 1979).

On the north side of the head of Rock Creek, on the divide between Rock Creek and the northward-flowing streams, is a sequence of phenoandesite flows and tuff breccias that are unconformable on the ignimbrite of Mount Blitzen and probably belong to the middle Tertiary rocks. The extrusive rocks included in the pheno-

andesite of Pole Creek include biotite phenoandesite, porphyritic hornblende-biotite phenoandesite containing green hornblende, and other phenoandesites with biotite, hornblende, augite, and hypersthene; andesine is the common plagioclase. The source of these volcanic rocks is thought to be a subcircular vent, almost half a mile in diameter, on the ridge between the North Fork of Rock Creek and the head of Red Cow Creek, near the west edge of the Mount Blitzen 15′ quadrangle. The vent filling is a biotite phenoandesite; several recognizably distinct bodies of rock that fill the vent range somewhat in plagioclase composition, but all are characterized by biotite and accessory magnetite and apatite.

West of the Mount Blitzen 15′ quadrangle, in the Little Rock Creek, Soldier Cap, and Scraper Springs quadrangles, a series of fault blocks expose dark- to medium-dark-gray to grayish-red generally somewhat weathered pyroxene and hornblende-pyroxene phenoandesite. These rocks have been somewhat tentatively correlated with the phenoandesite of Cornucopia (Coats, 1967), although outcrops are discontinuous and no isotopic age on the rock is yet available. The rocks of this unit form the country rock of a massive zunyite replacement deposit (Coats and others, 1979).

Another sequence of flows in the Mountain City 15′ quadrangle consists of a basal unit of thin and very locally distributed hornblende phenoandesite, overlain by a more widely distributed pyroxene phenoandesite characterized by both augite and hypersthene. Both units are seemingly related to the present topography, but this appearance may be illusory and due to exhumation after these two andesite units were deposited. The absence of boulders of the late Tertiary rocks in the sediment that includes boulders derived from the two andesite units suggests that both of these units are considerably older than the late Tertiary rhyolite or even the middle Tertiary Seventy Six Basalt, which occurs in the southern part of the Mountain City 15′ quadrangle. The two andesites described above, which are well exposed around Rocky Gulch in the southern part of the Mountain City 15′ quadrangle, are thought to be somewhat younger than another unit in the middle Tertiary andesite in the Owyhee 15′ quadrangle [3], which was described by Coats (1971) as the volcanic and sedimentary rocks of Jones Creek. This unit, as much as 1,000 ft thick, consists of flows and tuff breccia of pyroxene phenoandesite and hornblende phenoandesite; the pyroxene phenoandesite is more common. The rocks are medium to dark gray and commonly porphyritic. In a few places, gray air-fall tuff is present. Many of these rocks have been opalized, bleached, and stained. Some vent-filling breccia was recognized.

Basalt, Basaltic Tuff, and Tuff Breccia **[Tb_2].** This unit includes alkali olivine basalt, minor intrusive rocks, basaltic tuff, tuff breccia (in some places such as in the Owyhee 15′ quadrangle), and underlying gravel as much as 200 ft thick. The thickness of the tuff, which in many places is cindery and palagonitic, varies considerably from place to place because apparently small cinder cones were built at the time of its eruption. The unit of basalt, basaltic tuff, and tuff breccia (pl. 1) includes several flows of basalt originally mapped under different names, the most common of which is the "Seventy Six Basalt" (Coats, 1964, p. M8). The Seventy Six Basalt is generally a dark-gray to black porphyritic rock containing phenocrysts of plagioclase, some as much as 6 in. long but mostly smaller (as small as ½ in.). The phenocrysts comprise a maximum of 33% of the rock to a minimum of less than 1%. The plagioclase is about An_{68}, as determined by index of refraction. The basalt is subophitic; the pyroxene is generally purplish titanaugite. The basalt also contains olivine, magnetite, ilmenite, apatite, and, locally, patches of mesostasis made up of biotite and orthoclase. In some places the groundmass is glassy, and the clinopyroxene is in rude sheaves and clusters of fibers containing chains of magnetite crystals. Some of the olivine is altered to chlorite, serpentine, antigorite, and nontronite.

In the Owyhee 15′ quadrangle, the unit called the basalt of Panguipah Spring by Coats (1971) is probably the same age as the Seventy Six Basalt; it is underlain in parts of the Owyhee 15′ quadrangle by tuff and a considerable thickness of gravel. The general distribution of the Seventy Six Basalt is limited to the northern two tiers of quadrangles near the Idaho state line between the Jarbidge quadrangle and the Owyhee 15′ quadrangle, and it has not been found much farther south than the Mount Velma quadrangle. In the Mountain City 15′ quadrangle, this unit contains considerable amounts of pyroclastic rocks, some of which include bipolar breadcrust bombs. The unit generally rests on a surface of unconformity that cuts across the early Tertiary rocks, or on pre-Tertiary rocks. The only date available on the Seventy Six Basalt is 22.9 ± 3 m.y. determined by J. C. Von Essen (*in* McKee and others, 1976, sample 16) on some plagioclase phenocrysts that weathered out of a basaltic tuff in the Mountain City 15′ quadrangle. In a few places in the Mountain City 15′ quadrangle, basalt correlated with this unit is so rich in mafic minerals that it approximates ankaramite; such material has been found in a small exposure, perhaps an erosional remnant of larger mass, about 1 mi north of the town of Mountain City.

Phenorhyolitic to Phenodacitic Ignimbrite **[Tt_2].** In the Mount Velma quadrangle, just south of Elia Ranch, and as far east as the Charleston Reservoir and Marys River Basin NW quadrangles, the lower Tertiary tuff is overlain unconformably by a sequence of ignimbrites that are generally phenodacitic to phenorhyodacitic in composition, with phenocryst combinations ranging from hornblende and biotite plus sanidine, plagioclase, and quartz to plagioclase, with or without quartz, and hornblende plus hypersthene and, in many samples, augite. Most of these rocks are nearly flat lying or show a gentle sag-basin type of deformation. The total thickness of the sequence may be as much as 300 to 400 ft.

A sequence of tuffs and ignimbrites occurs in the Willow Creek Reservoir quadrangle and in the hills to the north, at least as far as the valley of Rock Creek. These tuffs and ignimbrites are mostly pale pinkish gray, sempatic, and consist of biotite phenorhyolite or related rock that contains phenocrysts of quartz, sanidine, and biotite. Individual units, which may be as much as 200 ft thick, are well exposed in the valley of Willow Creek near the damsite for the Willow Creek

Reservoir and westward in the valley of Willow Creek, where they dip steeply east. The total thickness suggested by the width of exposures and consistent eastward dip is several thousand feet; however, some repetition by strike faulting probably has occurred. These rocks were dated by E. H. McKee (written commun., 1973) at 32.1 m.y. and thus fall within the middle Tertiary rocks. They rest on a sequence of sedimentary rocks that includes much coarse, poorly consolidated gravel containing minor amounts of tuff and are succeeded by phenoandesites.

Upper Tertiary Rocks

Jarbidge Rhyolite **[Tjr]**. The Jarbidge Rhyolite is one of the most distinctive and widespread volcanic units in northern Elko County. It was originally described in detail by Schrader (1923, p. 17) and was named by Coats (1964, p. M10). The rhyolite includes flows, tuff, and welded tuff of rhyolitic composition; small amounts of coaly material are locally interbedded. A few dikes and small necks of vitrophyre are also present. The flows appear to far outweigh in volume and areal extent the welded tuff and tuff, but because of pervasive crystallization and hydrothermal alteration in much of the area, the welded tuff is difficult to differentiate from the flows, at least on the basis of the number of thin sections examined. The ash-fall tuff is more common than the welded tuff, but well-bedded, fine-grained ash-fall tuff is rare. The rhyolite ranges from pale bluish gray to yellow gray and oxidizes to shades of brown and red; locally, greenish and purplish tints are visible, and the fresh glassy rocks are black to dark gray. The rocks are characterized by large amounts of quartz phenocrysts (up to 5 mm in diameter) that are mostly rounded or corroded but are in part euhedral; by sanidine crystals that are slightly smaller and less numerous; and by somewhat rarer phenocrysts of oligoclase-andesine. The rarely recognizable clinopyroxene is pigeonitic, and bastite pseudomorphs after orthopyroxene(?) are common. Biotite and hornblende are recognizable, but they or the pseudomorphs after them are extremely rare. Accessories include zircon, apatite, ilmenite, magnetite, and pale-pink garnet. A single occurrence of apparently secondary topaz was found in the Jarbidge quadrangle. Locally the Jarbidge Rhyolite has been altered propylitically, with the formation of epidote and chlorite, but more commonly, in the Jarbidge mining district, the groundmass plagioclase and sanidine phenocrysts have been replaced by adularia and, locally, by clay minerals. The thickness of the Jarbidge Rhyolite has not been precisely determined because it is sliced by numerous high-angle faults and easily mappable marker beds have not been found. Its thickness is certainly at least 2,000 ft, but probably not much more. Most of the dips in the Jarbidge Rhyolite, where they can be measured on the interbedded tuffs, are low.

The age of the Jarbidge Rhyolite is based on two K-Ar determinations, one of which was on a sample collected by D. I. Axelrod from Meadow Creek in the Rowland quadrangle, and determined by Geochron Laboratories, Inc. as 16.8 ± 0.5 m.y. Another sample, which I collected from a basal vitrophyre of the Jarbidge Rhyolite just northeast of the Wild Horse Reservoir, was dated by Evernden and others (1964) at 15.4 m.y. This second sample was not from the same outcrop area as that collected by Axelrod; the age difference here may be real; and the total spread in ages for the unit may be greater than that indicated.

The Jarbidge Rhyolite is quite widespread; it has been recognized in the eastern and southern parts of the Mountain City 15′ quadrangle [4], in the western part of the Rowland quadrangle [5], in the northern part of the Wild Horse 15′ quadrangle [11A] (where some masses are continuous into the Mountain City 15′ quadrangle), in the Jarbidge quadrangle [6], in the Marys River Basin SE quadrangle [14], in the Elk Mountains [7, 8] to the east of the Jarbidge quadrangle, and extensively in the quadrangles south of the Marys River Basin SE quadrangle [14A, 14B, 23, 24]. Isolated occurrences of what appears to be the same unit are present in the quadrangles east of U.S. Highway 98 and north of Interstate Highway 80 [8], as well as at the extreme north end of the East Humboldt Range and in Secret Pass, between the East Humboldt Range and the Ruby Mountains [39A]. It also is widespread east of the North Fork of the Humboldt River [1] in the North Fork and Mahala Creek East quadrangles, and in the Devils Armchair quadrangle to the east. The westernmost exposures were mapped in the Bull Run quadrangle [10].

Landslide Deposits **[Tls]**. Tertiary landslide deposits, consisting of poorly sorted debris, have been recognized in only a few places, although many more may be present. Two general criteria were used for assigning a Tertiary age to the landslide deposits: (1) their presence at high levels on divides well above present stream channels, and (2) their stratigraphic position beneath rocks known to be Tertiary. Landslide deposits of the first kind occur in a few places in the Mountain City 15′ quadrangle [4]; landslide deposits of the second kind occur near the Wildcat Guard Station just south of the Jarbidge Wilderness [14].

Gravel **[Tg_3]**. Gravel of late Tertiary age is here mapped (pl. 1) in a few places. One conspicuous unit occurs in the Jarbidge quadrangle [6], where it was named the Slide Creek Gravel (Coats, 1964, p. M12). It rests unconformably on the Jarbidge Rhyolite and is overlain unconformably by the Jenny Creek Tuff. The gravel is poorly sorted and unconsolidated and contains boulders as much as 4 ft in diameter, some of which are rounded and some of which are subangular. The gravel is not deformed except by faulting.

Sedimentary and Volcanic Rocks **[Ts_3]**. The unit of upper Tertiary sedimentary and volcanic rocks (pl. 1) includes a large part but not all of the rocks that have been called Humboldt Formation for many years. The name "Humboldt Group" was originally applied to upper Tertiary continental deposits in western Utah and eastern Nevada by the members of the Fortieth Parallel Survey (King, 1878, p. 434–443). In some places on the maps of the Fortieth Parallel Survey (King, 1876, 1878), this unit was referred to as the Humboldt Pliocene or the Humboldt Group. Most of the Humboldt Formation that was included in these designations is here included in the upper Tertiary sedimentary and volcanic

rocks. Sharp (1939b) designated Tertiary basin deposits in northeastern Nevada, particularly those west of the Ruby Mountains, as the Humboldt Formation and considered it Miocene.

Smith and Ketner (1976, p. B32) stratigraphically restricted the Humboldt Formation as follows:

> ...an upper Miocene sequence of beds that contains much vitric ash and tuffaceous rocks, ...designating a section along the east side of Huntington Creek...the Lee [15′] quadrangle as the reference section; by this designation, the Humboldt Formation includes the middle member and at least part of the upper member of the Miocene Humboldt Formation as used by Sharp (1939b, p. 143–145). In accord with this definition of the restricted Humboldt Formation, the upper part of the Raine Ranch Formation and the Carlin Formation of Regnier (1960) are included in the Humboldt, although these two units are separated by a slight unconformity (Regnier, 1960, p. 1199).
>
> Beds constituting the Humboldt Formation (restricted) are of both fluviatile and lacustrine origin and consist of ash and tuff, conglomerate, sandstone, siltstone and claystone, and thin beds of limestone. The most common rock colors are light gray to almost white, and so most exposures are very light; locally siltstone and sandstone beds have a pinkish-orange cast and form pinkish bands along the slopes.

The maximum thickness in the general area was thought to be about 2,000 ft (Smith and Ketner, 1976, p. B35).

In the lower half of the reference section, ash and tuff are most conspicuous, and in the upper half, siltstone, sandstone, and conglomerate. As many observers have noted, gray to silvery-gray vitric ash, which may weather gray, tan, or brown, forms striking outcrops in many places. The siltstone, sandstone, and conglomerate beds vary locally in lithology. In the area just west of the Ruby Mountains, the lowest conglomerate beds are rich in Paleozoic limestone clasts; the higher beds are richer in clasts of crystalline rocks, a feature that reflects, as Smith and Ketner (1976) pointed out, progressive erosion of the Paleozoic limestone to uncover the crystalline rocks of the Ruby Mountains. The sandstone grains range in size from very fine to granule. The grains are mostly rounded to angular quartz, lesser muscovite, and some chert and biotite. Siltstone and claystone are most abundant in the upper half of the formation. The beds are commonly light gray to almost white; some beds have been altered to montmorillonite. The limestone commonly occurs in beds from 2 to 12 in. thick; it is white to cream or tan and slightly sandy in some beds, and may be dense to porous.

D. I. Axelrod (written commun., Nov. 1979) reported a small leaf flora of Clarendonian age from just west of Thurston Spring in the Windermere Hills in the SW/4 S1,T39N,R64E of the Wine Cup Ranch SW quadrangle; according to him, the leaves occur in an opalized shale. The boundaries between this unit and the older Tertiary rocks to the east, which were identified solely on the basis of lithology, were drawn photogeologically on conspicuous unconformities in the section. These boundaries may well be subject to substantial revision when K-Ar ages become available. The whole section is rich in volcanic material, and fossils are very scarce. The latest radiometric date obtained was a fission-track age of 9.5 ± 1.9 m.y. determined on zircons by C. W. Naeser. Both the fossil and K-Ar ages suggest a late to very late Miocene age for the Humboldt Formation. Because the Humboldt Formation (restricted) is overlain by the Palisade Canyon Rhyolite, this stratigraphic relationship suggests that the Humboldt had been deposited over a total timespan of at least 5 m.y., from about 15 to 10 m.y. ago.

In the western part of the Mountain City 15′ quadrangle [3] and the eastern part of the Owyhee 15′ quadrangle [2], a somewhat different unit was mapped—the sedimentary rock of McCall Creek. The rock is a poorly sorted, coarsely tuffaceous boulder gravel, apparently a mudflow from an ash eruption that was remobilized and that picked up a large amount of very coarse debris during its flow; some of the boulders are as much as several tens of cubic yards in volume. Weathering out of the tuff components in this unit has left a material that superficially resembles a very coarse boulder gravel; only in artificial cuts is the tuffaceous matrix visible.

Another unit, which is included here **[Ts_3]**, is present in California Basin in the Mountain City 15′ quadrangle; it consists of rather poorly exposed green to white rhyolitic tuffs, that are characterized by the presence of large amounts of petrified wood, including logs as much as 3 ft in diameter and several feet long. Most of the wood is black to white, and some has been mined as a source of ornamental material.

In the Rowland quadrangle, Bushnell (1967, p. 23) mapped a unit that he referred to as the Young America Gravel. The Young America Gravel rests unconformably on the Jarbidge Rhyolite or on older rocks. The gravel is composed of angular to subrounded fragments, ranging in size from less than 1 in. to 3 ft in diameter, largely of quartzite and Jarbidge Rhyolite. Bushnell (1967) noted that the gravel filled a trough which has a steep east side, probably a fault scarp. Traced southward, the Young America Gravel interfingers with sedimentary rocks of the Humboldt Formation (restricted) or with tuff and sedimentary rocks of the Idavada Volcanics; it is difficult to draw any sharp boundary between these units. It is overlain locally by the Cougar Point Welded Tuff.

Ignimbrite, Tuff, and Sedimentary Rocks **[Tts]**. The unit of ignimbrite, tuff, and sedimentary rocks (pl. 1) includes the Idavada Volcanics of Malde and Powers (1962), generally also the Cougar Point Welded Tuff, and locally the Jenny Creek Tuff and the Pole Creek and Robinson Creek Dacites (in the Jarbidge quadrangle [6]). The Jenny Creek Tuff (Coats, 1964, p. M13) is an air-fall unit that accumulated before the eruption of the ignimbrite of the Cougar Point Welded Tuff; it is locally interbedded with units of welded tuff, some only 3 ft thick. The Jenny Creek probably interfingers with and grades into the Cougar Point by an increasing content of welded tuff and decreasing contents of air-fall tuff and sedimentary tuff.

Beneath the Jenny Creek Tuff, two welded phenodacite vitrophyric pyroclastic flows, each less than 20 ft thick, have been sampled, one from the southwest side of the Mountain City 15′ quadrangle and the other farther south in the northwestern part of the Wild Horse 15′ quadrangle. Both these units contain small amounts of plagioclase, apparently about An_{23}, as well as orthoclase; one flow contains ferroaugite. One of these pyroclastic flows was dated at 15 ± 0.8 m.y., and the other at 16.2 ± 0.8 m.y., both on plagioclase.

These ages average slightly, but not significantly younger than those on the middle Miocene Jarbidge Rhyolite. One source vent for this tuff is a small neck, a few hundred feet across, exposed in the valley of Trail Creek in the southwestern part of the Mountain City 15′ quadrangle.

The Jenny Creek Tuff everywhere rests on Miocene volcanic rocks, approximately 16 to 15.5 m.y. old, or on still older rocks, and is generally overlain by the Cougar Point Welded Tuff. The oldest age obtained on the Cougar Point Welded Tuff in the Owyhee 15′ quadrangle is 12.2 m.y. Since the Cougar Point in Nevada is generally overlain, commonly with slight unconformity, by the Big Island Formation, which ranges in age from 10.6 ± 1.0 to 8.2 ± 0.6 m.y., the age of most of the Jenny Creek Tuff in Elko County probably falls in the timespan 15.8–12.2 m.y., although the results of Armstrong and others (1980) suggest progressively decreasing ages eastward for the Cougar Point and, presumably, also for the Jenny Creek.

Fossils were collected from the Jenny Creek Tuff. Two paleobotanical collections (field nos. 59NC38, 59NC45E *in* Coats, 1986) were collected from almost identical rocks near the base of a sequence, several hundred feet thick, of the Jenny Creek Tuff in the Owyhee 15′ quadrangle. One of these collections (field no. 59NC38), was assigned paleobotanical colln. Dl594, and the other paleobotanical colln. D3279; they were reported on in some detail by E. B. Leopold, who concluded that materials from both collections are late Miocene or early Pliocene. A sample of diatomite from the Jenny Creek Tuff in the eastern part of the Jarbidge quadrangle was reported on by K. E. Lohmann (field no. 55NC304), who concluded that the rocks are possibly late Miocene or early Pliocene. The dates indicated by the fossils are consistent with the late Miocene age now assigned to the Jenny Creek Tuff.

The Cougar Point Welded Tuff is reddish brown or yellow brown to brownish gray where crystalline, but black to gray or orange red (depending on the degree of oxidation) where glassy. The Cougar Point is made up of several units. The more massive and resistant units are generally cryptocrystalline and form crudely columnar cliffs, as much as 150 ft high; such cliffs may be made up of several flow units. The glassier facies are more closely fractured, commonly perlitic, and commonly obscured by slope wash. Many units have a vitrophyric basal facies that grades upward into dense felsophyric rock.

The Cougar Point Welded Tuff is a phenorhyolitic to phenorhyodacitic ignimbrite, purplish gray to dark brown, or black where glassy, and ranges from a vitrophyric to a friable felsophyric welded tuff; apatite, zircon, and magnetite are accessories. In some of the compact vitrophyres, fayalite and ferroaugite accompany sanidine or anorthoclase(?) and plagioclase; quartz and sanidine are common but not ubiquitous. The plagioclase ranges from An_{25} to An_{80}, with frequency maxima at about An_{27} and An_{45}. The pyroxene ranges from ferroaugite to ferropigeonite and may include hypersthene as well; hornblende is less common, and biotite is extremely rare. The relative proportions and compositions of the various primary minerals vary from unit to unit. In the thicker welded tuff, recrystallization of the glassy phase to sanidine and tridymite is complete. Much of the welded tuff contains gas cavities; the ellipsoidal cavities may be either nearly equidimensional, flattened and slightly elongate, or considerably elongate, but only slightly flattened. The flattening is generally in the plane of the textural layering, and the elongate gas cavities display a marked parallelism. In some places, the thicker welded tuffs exhibit laminar flowage features in the form of sharp anticlinal folds, which commonly trend northeast in the Jarbidge quadrangle but in other directions elsewhere (see Coats, 1976, for a discussion of dike feeders and primary deformation). The next younger beds generally pass undisturbed above the crest of these folds, and in some places the folds may be seen to die out downward within the thickness of a single flow. The anticlinal folds are not bordered by synclinal flexures of corresponding shape.

The Cougar Point Welded Tuff is widely distributed along the north boundary of Elko County and extends some considerable distance farther south into the county. Most of the welded tuff in the Cougar Point gradually wedges out to the south, and its place is taken by air-fall tuff and by sedimentary rocks that are here mapped (pl. 1) with the unit of sedimentary and volcanic rocks **[Ts_3]**.

In a few places, an angular unconformity exists within the Cougar Point. One such place is on Cat Creek, just north of the Idaho state line, in the Mountain City 15′ quadrangle, where the lower part of the Cougar Point dips downvalley (about 15°NNW). Here, the welded tuff is overlain by white air-fall tuff, the dip of which flattens northward, succeeded by brown tuffs, reworked by eolian activity, and overlain in turn by welded tuff. A similar succession of eolian deposits succeeded by welded tuff can be seen in the Owyhee 15′ quadrangle, just north of the point where the road to the Sheep Creek Reservoir leaves the Owyhee–White Rock road. A K-Ar age on samples of sanidine (field no. 62NC51; sample DKA1069) from near the base of the welded-tuff section on the cliffs of Yellow Rock, east of the Owyhee River in the Owyhee 15′ quadrangle, was determined by John Obradovich (oral commun., 1965) as 12.2 ± 0.8 m.y. In some places in Owyhee County, Idaho, ages ranging from 14.2 ± 0.4 to 9.6 ± 2.0 m.y. (Armstrong and others, 1980) were obtained on the Cougar Point Welded Tuff.

In the Cougar Point Welded Tuff, phenocrysts most commonly make up less than 2% of the rock but may make up as much as 10%. They include quartz, sanidine, plagioclase, pigeonite; and accessory zircon, magnetite, and apatite. Hornblende phenocrysts occur in less than 10% of the rocks sectioned, and biotite occurs in about 1%; one ignimbrite that is a biotitic rhyolite vitrophyre, however, was mapped as part of the Cougar Point unit just east of the Willow Creek Reservoir in the southwestern part of the Willow Creek Reservoir quadrangle. The relative proportions of the various primary minerals vary from unit to unit. Plagioclase ranges from An_{25} to An_{80}, with frequency maxima at about An_{27} and An_{45}; pyroxene is almost uniformly pigeonitic, with 2V ranging from 0° to 37°; augite was

identified in about 2% of the sections, and hypersthene in 1%. In the thicker flows, recrystallization of the glassy phase to sanidine and tridymite is complete. The maximum thickness of the Cougar Point Welded Tuff exposed in the Jarbidge quadrangle is about 1,250 ft in the canyon of the East Fork of the Jarbidge River, just west of Cougar Point.

The Robinson Creek Dacite, named by Coats (1964, p. M15), is an extremely localized unit that includes one dike and several small intrusive domes of gray vitrophyric perlite, probably of dacitic composition. It is exposed along Jack Creek and Robinson Creek in the Jarbidge quadrangle and seems to intrude the Jenny Creek Tuff. The greatest exposed thickness of the Robinson Creek is about 200 ft; the maximum length of individual bodies is about ¾ mi. The Robinson Creek was assigned a Pliocene age by Coats (1964). As it is overlain by the Miocene Cougar Point, it is here reassigned to the Miocene.

The Pole Creek Dacite was named by Coats (1964, p. M12) for a few protrusions of medium-gray to black vitrophyre that occur near the east border of the Jarbidge quadrangle. The Pole Creek was assigned a late Miocene age by Coats and others (1977). It is slightly older than the Robinson Creek Dacite and differs from it in some petrographic characteristics. The maximum thickness of the Pole Creek is about 900 ft; the maximum length of individual bodies is about 1½ mi. (according to Malde and Powers (1962) the thickness of the Idavada Volcanics may exceed 1,500 ft). The Cougar Point welded tuff is equivalent to part of the Idavada. Armstrong and others (1975, p. 236) reported an age of 9.7 m.y. for the type Idavada and of 8.5 to 8.4 m.y. for the volcanic rocks near Goose Creek farther east. All these rocks are similar petrographically, and these variations in age as the rocks crop out farther and farther east suggest an actual progression in the dates of eruption toward the east, as proposed originally by Stearns (1926) and later confirmed by Armstrong and others (1975).

The nature of the source vents of the Cougar Point Welded Tuff is generally not well known. Armstrong and others (1975, p. 246) pointed out that the siliceous volcanic rocks of the Yellowstone and Island Park area are clearly associated with large calderas but that no calderas are known farther west; they suggest that the vents are concealed beneath younger deposits. The Cougar Point Welded Tuff has not yet been traceable from an exposed ignimbrite to its vent, although in several places internal structures suggest that the vents that supplied the ignimbrite were very limited in area, probably short and relatively stubby dikes. One such dike was described in the northeastern part of the Mountain City 15′ quadrangle (Coats, 1976); other similar dikes are visible and apparently fed the ignimbrite just south of Contact at Table Top Mountain and at Soldier Cap in the Soldier Cap quadrangle northeast of Midas, where there is a tabular mesa of Cougar Point Welded Tuff that apparently has a dikelike extension at one end. Trends of these dikes are not consistent from one area to another and presumably reflect the existence of local, older fractures.

Basalt **[Tb_3].** Two areas of basalt that are not included in the Big Island Formation (see next section) are here mapped (pl. 1) as the unit of late Tertiary basalt flows. One area is in the Sheep Creek Range in southwestern Elko County, in the Midas area and in the Ivanhoe quicksilver mining district; the other area is at the opposite side of the county, adjacent to the Utah state line, in the Dairy Valley quadrangle. The basalt near Midas is, according to Robert Greene (written commun., 1973), somewhat altered, dark gray to olive green to brownish gray, microcrystalline, and contains very sparse plagioclase phenocrysts. The groundmass is largely plagioclase microlites, augite, magnetite, and small amounts of glass or altered glass; some specimens contain calcite, clays, and other alteration products.

A much younger basalt was mapped by Zoback and Thompson (1978); according to them, it flowed out on the floor of the Midas trough. Described as an olivine-rich basalt, it was dated by E. H. McKee (*in* Zoback and Thompson, 1978) at 6.3 ± 2.3 m.y.

In the Dairy Valley 15′ quadrangle, the basalt contains sparse plagioclase microphenocrysts and generally has a fluidal diktytaxitic texture with sparse olivine, purplish-brown ophitic augite, magnetite, and plagioclase microlites. Chlorophaeite and calcite fill some of the diktytaxitic cavities in the basalt; elsewhere, the interstitial glass is charged with magnetite.

The ages of these basalts are poorly known and they may cover a wide timespan. The basalt in the Sheep Creek Range, south of the Midas area, is correlated with a basalt flow in Lander County that was dated by E. H. McKee (McKee and Silberman, 1970, loc. 23, table 1) at 14.8 m.y. The basalt flows in the Dairy Valley 15′ quadrangle underlie some rhyolite domes that are doubtfully correlated with rhyolite from a rhyolite dome exposed east of Goose Creek on the Idaho-Utah boundary, for which Armstrong and others (1975, p. 240) reported a date of 12.8 ± 0.4 m.y. These rocks may be of the same age as the rhyolite domes in the Dairy Valley 15′ quadrangle that overlie the basalt, and so these dates may be consistent with an age of about 15 m.y. for these basalt flows.

Big Island Formation **[Tbi,Tb,Tbc].** One of the most widespread and youngest of the basaltic volcanic units of northern Elko County was named the Banbury Volcanics by Stearns (1935, p.435) for its type locality, a thick exposure near Banbury Hot Springs, Twin Falls County, Idaho. Coats (in press) has summarized the reasons for substituting the name "Big Island Formation" for rocks previously assigned to the Banbury in northern Elko County. The unit is widespread in northern Elko County and adjacent Idaho (Coats, 1964, 1971). The Big Island Formation (Coats, in press) consists of three units: a lower unit, as much as 600 ft thick, of boulder gravel with fragments locally as coarse as 1½ ft in diameter, succeeded conformably by about 20 ft of rhyolitic tuff; and succeeded by as much as 100 ft of olivine tholeiite. The type locality of the Big Island Formation is the west wall of the canyon of the Jarbidge River, opposite the Big Island Mesa and west-northwest of the confluence of that river with Buck Creek in the Dishpan quadrangle, Idaho.

The boulder gravel, which is as much as 600 ft thick in the Jarbidge quadrangle, consists of unconsolidated gravel to boulder gravel. Clasts vary from about 1/8 in. to as much as 1½ ft in diameter. They are generally derived from older volcanic rocks of the Cougar Point Welded Tuff or the Jarbidge Rhyolite. In the Hat Peak 15′ quadrangle the gravel contains fragments of chert and other resistant rocks that are largely derived from Paleozoic units. The gravel member is overlain by rhyolitic tuff which is 20 ft thick.

The basalt, the upper unit of the Big Island Formation, as described by Mark and others (1975), is an olivine tholeiite; most of the basalt exposed at the type section is quite fresh. The ages on basalt determined by E. H. McKee (*in* Mark and others, 1975, p. 1672) range from 10.6 to 7.9 m.y. The basalt has a small compositional range, it is holocrystalline, or almost so, commonly diktytaxitic, generally contains olivine (Fo_{90}) phenocrysts as much as 1/8 in. in diameter, and has an ophitic groundmass. The pyroxene is a pale-brown augite with a 2V of about 60°. The plagioclase crystals are zoned from about An_{77} to An_{22}. Groundmass olivine is interstitial to the ophitic pyroxene and about 0.1 mm in size. Opaque iron oxides—probably magnetite, ilmenite, and apatite—are also interstitial. Some of the rocks contain clots of early-formed plagioclase and olivine, the prevalence of which may result in slightly higher amounts of MgO, CaO, and Al_2O_3.

In several places in the Owyhee desert, dikes of basalt were formed, and in places where the extrusion of basalt continued for an unusually long time, small hills were built up, but none of these hills rise much more than 300 ft above the general land surface. These hills are either small shield volcanoes or small cinder cones which have been preserved for a long time because of the permeability of the material; they are the youngest volcanic features on the basaltic plateau.

Pyroxene and Hornblende Phenoandesite and Phenodacite, and Pigeonite Phenoandesite **[Ta_3]**. In the Mount Velma quadrangle and from there southward to The Narrows and Peko Peak quadrangles, a distinctive type of andesite occurs, in part interbedded with flows of the Jarbidge Rhyolite. This andesite is peculiar because it contains internal evidence of a hybrid origin, including partially resorbed xenoliths of granite and resorbed crystals of potassium feldspar and quartz, and plagioclase showing spongy textures and sharp discontinuities in An content. These features suggest that the phenoandesite magma has partially assimilated granitic rocks. The most distinctive peculiarity of this andesite is the presence of nearly uniaxial pigeonite; such uniaxial pigeonite is elsewhere exceedingly rare. The spongy crystals of plagioclase are not uncommon elsewhere; some were described by Macdonald and Katsura (1965) from the andesite of Lassen Peak, California.

Several local members are included in the unit of pyroxene and hornblende phenoandesite and phenodacite, and pigeonite phenoandesite. In the Owyhee 15′ quadrangle [3], Coats (1971) described a unit called the volcanic and sedimentary rocks of McCall Creek. The sedimentary rocks are here separately mapped (pl. 1) for the purposes of this report as part of the upper Tertiary sedimentary rocks **[Ts_3]**. The rocks consist of poorly sorted, tuffaceous coarse-boulder gravel with a tuffaceous matrix. This member is apparently a mudflow containing a relatively small proportion of volcanic constituents and large to very large boulders, which consist mostly of quartzite. The gravel is overlain by flows of hornblende phenoandesite, pyroxene phenoandesite, and by tuff breccia containing volcanic bombs. The gravel overlies a hornblende-biotite-hypersthene phenodacite, probably a welded tuff, which is vitrophyric near its base and contains a large proportion of phenocrysts.

In the Jarbidge quadrangle and the Jarbidge Wilderness area [6, 14], Coats (1964, p. M11–M12) mapped a unit as the Gods Pocket Dacite. Most of the dacite is a pale-gray, dense, stony-textured aphanitic rock with locally black vitrophyric phases. It contains relatively large phenocrysts of andesine and smaller amounts of sanidine; quartz and pigeonite phenocrysts are smaller and sparser, and augite and hypersthene are quite rare. Accessory minerals include magnetite, apatite, and zircon. At the base of this unit is a bed, 30 to 50 ft thick, of pale-gray, unconsolidated vitric tuff, probably an air-fall tuff that preceded the eruption and that is not present everywhere. The source of the dacite is unknown but was thought to be a vent beneath Gods Pocket Peak. The total thickness remaining is about 930 ft, but the original top is not preserved. The Gods Pocket lies above the middle Miocene Jarbidge Rhyolite and below the late Miocene Cougar Point Welded Tuff, and was assigned late Miocene age by Coats and others (1977).

On both sides of the North Fork of the Humboldt River, in the Tule Valley, Double Mountain SE, The Narrows, and Peko Peak quadrangles, are small masses of hornblende and pyroxene phenoandesite, apparently the remnants of small andesitic cones. In some places these phenoandesites are interbedded with tuff breccia, and the cones rest unconformably on the phenoandesite of the McKnight Ranch and are, therefore, younger; no more precise dating has yet been done. The cones have been sufficiently destroyed by erosion to suggest that the phenoandesite probably falls into the class of the late Tertiary andesitic rocks.

Pyroxene Phenodacite Ignimbrite **[Tt_3]**. The unit of pyroxene phenodacite ignimbrite (pl. 1) occurs in several parts of northwestern Elko County. One area is near the headwaters of Milligan Creek [19]. The rocks of this area were described by R. C. Green (written commun., 1973) as consisting of an upper, devitrified part and a lower, vitric part. The lower part is a grayish-black to black, dense, vitric welded tuff containing abundant phenocrysts, mostly of clinopyroxene, including both augite and pigeonite. The plagioclase is oligoclase, and the silica content of the rock, estimated from the refractive index of fused beads, is about 69%. The upper part is a pale-brown devitrified tuff with planar partings; gas cavities are common, and the phenocryst content of this part is noticeably lower than that of the lower part. The unit as a whole attains a thickness of only about 20 ft but covers a large area.

In the Wilson Reservoir area, the pyroxene phenodacite ignimbrite unit includes material containing both air-fall tuff and welded tuff; the welded tuff is generally in the lower part of the section. In the Owyhee-Mountain City areas [3, 4], this unit includes several

layers of highly vitric and generally thin, densely welded tuff, as well as some layers of welded lapilli tuffs. The coarse-grained welded lapilli tuff forms bodies, small in surface area, that apparently accumulated on steep slopes; these rocks were isotopically dated at from 16.8 to 15.3 m.y. by R. H. Marvin and others (samples D1543P through D1549P). The rocks are marked by the presence of clinopyroxene, plagioclase, and anorthoclase; in some places, the plagioclase is apparently mantled by anorthoclase. The dating was on a plagioclase that contained some anorthoclase.

***Breccia* [Tbx].** Some bodies of breccia, ranging widely in age and mode of origin, are here included for convenience in the breccia map unit on the geologic map (pl. 1). Breccia extensive enough to map is rare in Elko County. In the Dairy Valley 15′ quadrangle, Olsen (1960) described a rhyolitic breccia, in part intrusive, that involves Paleozoic sedimentary rocks that have been fragmented and intruded by a subvolcanic intrusive body that is continuous with a flow and, in part, with the main intrusive body itself, which was rigid enough to fracture in some places during the later stages of intrusion. Silicification is also widespread.

A mass of brecciated Joana Limestone, east of the north end of the Dolly Varden Mountains, is here considered a cryptoexplosion breccia. One explanation for its origin is that the breccia is part of an astrobleme that formed during Pequop time; the Joana Limestone of the breccia has been displaced upward about 8,000 ft with respect to the surrounding younger Paleozoic rocks. Such drastic upward displacement is common in the central part of large astroblemes. The absence of any shatter cones in the surrounding older rocks, however, argues against this explanation. Further evidence for this origin of the breccia is presented in section entitled "Tectonics."

Small areas of fault breccia, in part Tertiary, but also in part Mesozoic, were mapped in the Owyhee 15′ quadrangle [3]. A large mass of tectonic breccia, evidently formed along the sole of a thrust, was mapped by Willden and Kistler (1969) in the Jiggs 15′ quadrangle [48]. Because the age of this rock body is not entirely clear, it is here mapped (pl. 1) without age designation **[bx]**.

***Phenorhyolitic and Phenodacitic Flows and Domes* [Tr_3].** Regnier (1960) and Smith and Ketner (1976, p. B39) described the Palisade Canyon Rhyolite, which has a maximum thickness of about 800 ft and is mostly brown or reddish brown except the for glassy phases, which are black to dark blue. The phenocrysts include sanidine, quartz, biotite, and pigeonite, according to Regnier (1960, p. 1198). The Palisade Canyon is underlain by the Humboldt Formation (restricted). Armstrong (1970, p. 212–213) reported a whole-rock radiometric age of 15 ± 1 m.y. on the rock.

***Porphyritic Phenorhyolitic and Phenodacitic Flows and Domes* [Tpr].** The unit of porphyritic phenorhyolitic and phenodacitic flows and domes (pl. 1) comprises silicic rocks that were emplaced on or near the existing surface. In the Texas Spring quadrangle, there is a composite dome consisting of flows and welded tuff of silicic rhyolite and containing much quartz, sanidine, plagioclase, minor biotite and hornblende, and some apatite. Some of these volcanic rocks were described by Redfern (1977), who reported abnormally high U/Pb and low K/Rb ratios. Much of this composite dome, part of which was mapped by Redfern, shows consistently high radioactivity (about twice background); it is the only significant mass of biotitic rhyolite younger than the Idavada Volcanics that has been mapped so far in Elko County. The first of these extrusions in southwestern Elko County was apparently recognized by W. A. Oesterling (written commun., 1960). Flow structures in some of these rocks in Lander County, Nevada, were shown on a map (U.S. Geological Survey, 1969) that appears to have been made by photogeologic methods.

The petrography of the Lander County occurrences, in which cassiterite is found locally, was described by Fries (1942, p. 282–283), who remarked that the rocks of this unit contain masses of flow breccia, lithophysal structures, and zones in which the matrix is black glass. Fries also commented on the marked irregularity of the primary flow layering. The phenocrysts that he recorded include quartz, oligoclase, and potassium feldspar, comprising 25% to 35% of the rock; accessory minerals include magnetite, zircon, hematite, apatite, and sphene. Minerals most common in the lithophysal cavities include quartz, chalcedony, and less abundant specularite, topaz, pseudobrookite, and fluorite; sanidine, garnet, tridymite, cristobalite, opal, and, possibly, cassiterite occur in cavities in a few places.

Fries (1942, p. 243) quoted from Knopf (1917, p. 128) the following partial chemical analysis of the rhyolite: 76.25% SiO_2, 5.18% K_2O, 4.05% Na_2O, and 0.44% CaO.

R. C. Greene (written commun., 1972), who studied some of the rhyolite domes in Elko County, noted that they are distinguished by their high percentage of feldspar and, especially, of quartz phenocrysts. He was able to observe trace amounts of augite, magnetite, and fine opaque oxides. Greene estimated from the refractive index of fused beads that the silica content ranges from 73% to 74%.

In the extreme northern part of the Hat Peak 15′ quadrangle [2], a multiple-source mass of porphyritic fayalite-ferroaugite rhyolite, about 8 mi in diameter, occupies a sag basin in the Idavada Volcanics. Coats (1968c) described this mass as a lekolith having a nearly flat top and a lower surface determined by the shape of the basin.

The Circle Creek Rhyolite has a vitric groundmass; phenocrysts include quartz, sanidine (Or_{52-57}), oligoclase ($An_{21-30.5}$), ferroaugite, fayalite, apatite, zircon, magnetite, and ilmenite. Secondary oxidation has formed hematite, pseudobrookite, and rutile in submicroscopic amounts. Spherulitic crystallization and chalcedony nodules are common in the felsophyre. The Circle Creek Rhyolite had been considered early Pliocene by Coats (1968c, p. 74). More recently, John Obradovich obtained an isotopic age of 11.6 ± 0.5 m.y. on a sample of sanidine from the rhyolite. This date is considered middle Miocene by Palmer (1983, p. 504).

As indicated in figure 6, volcanic domes that belong to this unit, which probably are nearly coeval, are distributed in Elko, Lander, Eureka, and Humboldt

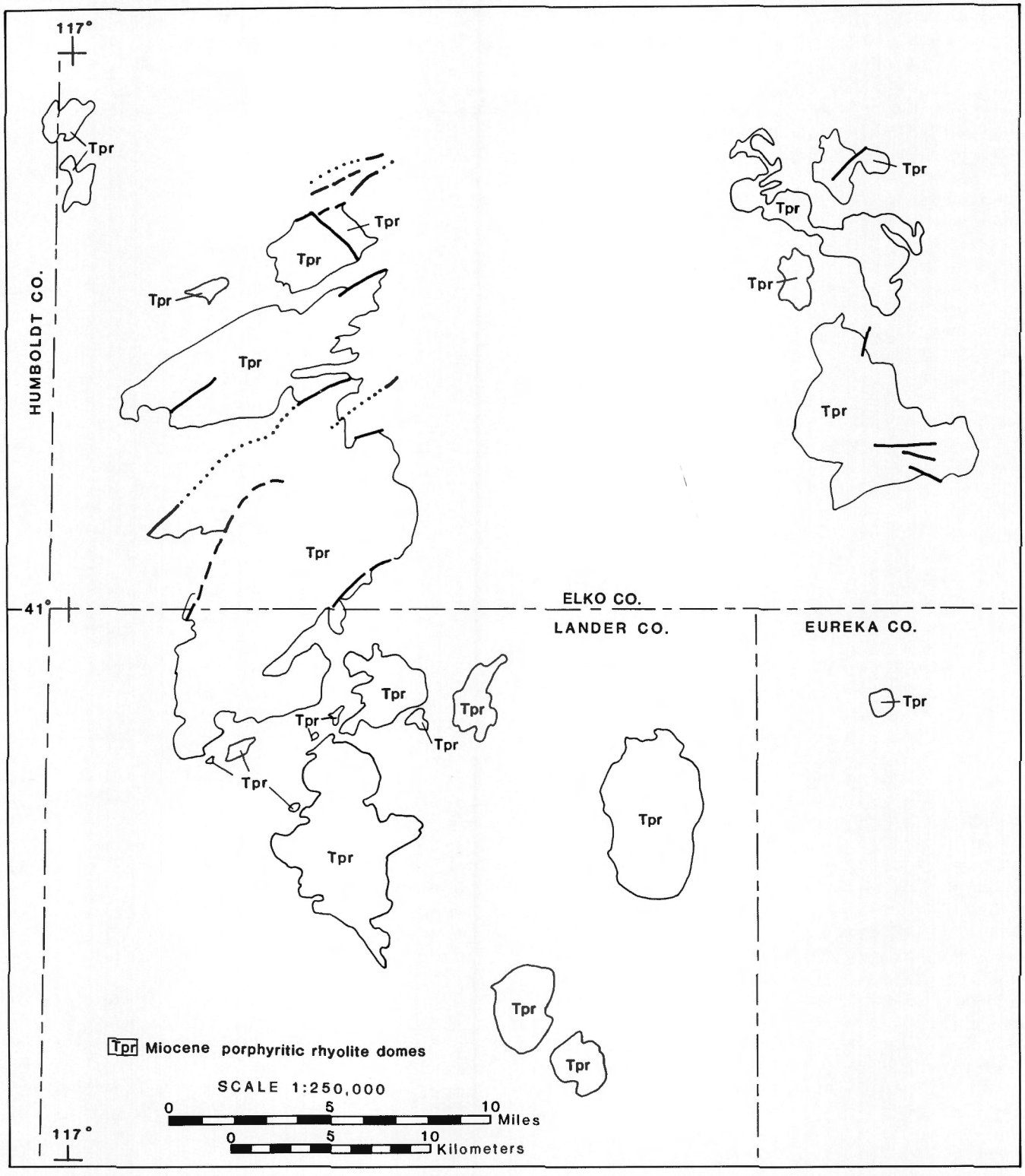


FIGURE 6. Miocene rhyolitic domes in southwestern Elko County and vicinity. Distribution of these domes may reflect the boundary of a sag basin, the northernmost limit of which is the Midas trough. The wide distribution and mode of origin of these domes were first suggested by W. A. Oesterling of the Southern Pacific Railroad (written commun., 1960). Tpr, porphyritic rhyolite and rhyodacite.

Counties in an incomplete ellipse that is open to the north. The suggestion that emplacement of these bodies may have been controlled by a volcano-tectonic depression, with displacement along marginal faults increasing southward, is reasonable, though not the only possible explanation. Although the domes generally are nearly identical petrographically and the concentration of lithophysae and volatile materials that are probably related to the tin deposition, is greater in the domes along the west margin of the horseshoe, insufficient analytical work has been done to determine whether all these domes are, in fact, comagmatic or even coeval. In the Ivanhoe mining district on the east margin, alteration related to mercury deposition has affected some of the domes (Nelson and Roberts, 1943). Gold mineralization has been reported from some of these domes.

Although several other rhyolitic masses resemble the Jarbidge Rhyolite very closely, most of these masses are here mapped (pl. 1) as the porphyritic phenorhyolitic and phenodacitic flows and domes **[Tpr]**. One group of these extrusions that is quite widespread south and west of Wendover, Utah, in Elko County was described as a tridymite rhyolite by Armstrong (1970) and dated on sanidine at 11.6 ± 0.4 m.y., an age differing significantly from that of the typical Jarbidge Rhyolite. It differs petrographically from the Jarbidge in its content of not only ferroan clinopyroxene but also ferroan olivine, probably hortonolite or fayalite.

The rhyolite of Coldspring Mountain, which occurs in the Mountain City 15′ quadrangle, makes up several prominent mountain peaks: Coldspring Mountain, Rough Mountain, and Jenneman Peak. This rhyolite differs substantially from the Jarbidge Rhyolite; in addition to quartz, plagioclase, and sanidine phenocrysts, it contains a hornblende that is pleochroic from dark brown to dark green and, in many thin sections, biotite as well; nearly every section shows small amounts of perrierite. Sanidine from one of these masses was dated by the U.S. Geological Survey (McKee and others, 1976, sample 17) at 14.6 ± 0.9 m.y.

The unit of porphyritic phenorhyolitic and phenodacitic flows and domes (pl. 1) includes an extensive series of rhyolitic volcanic rocks in southwestern Elko County, in the Midas mining district (R. C. Green, written commun., 1973). The rocks are generally resistant and crop out extensively on scarps and canyon walls; they are especially well exposed on the Owyhee Bluff, which is on the north side of the Midas depression. The maximum thickness of the unit is probably more than 2,000 ft; the rocks are mostly rhyolite, rhyodacite, and minor dacite. The rocks are aphanitic and have a groundmass that varies from gray through pale reddish gray to pale brown, with light brownish gray predominating; local vitrophyres are uniformly black or streaked with pale red. The rhyolite contains 5–25% sanidine and plagioclase phenocrysts, and 0.5% quartz phenocrysts. Much of the rhyolite contains very small amounts of hornblende or iron-rich olivine; some contains traces of biotite or augite. The mafic minerals generally are peripherally oxidized. The refractive indices of fused beads range from 1.485 to 1.492, corresponding to 76% to 73% SiO_2. The rhyodacite contains 2–10% sanidine, less than 5% plagioclase, and 0–2% quartz phenocrysts; some units contain small amounts of altered mafic minerals. The few rhyodacite samples have refractive indices of fused beads ranging from 1.492 to 1.501, corresponding to 73% to 70% SiO_2.

Tertiary and Quaternary Systems

Hot-Spring Travertine and Sinter [QThs]

Spring deposits in Elko County are mostly those of present or former hot springs; the present hot springs range widely in temperature. One of the hottest springs occurs in the Sulphur Hot Springs thermal area (Olmsted and others, 1975); the springs are located in S11,T31N,R59E. The sinter here is largely opaline silica, which is unusual among the spring deposits of Elko County. Other spring deposits, particularly those 2 to 3 mi northwest of Wells, Nevada, northwest of the Spanish Ranch in the Independence Valley, north of Tuscarora [10A], and just east of the Deep Creek Reservoir [9A], are largely travertine, chiefly calcite. Similar masses of travertine were deposited by springs that are no longer flowing, such as the masses just north of the mouth of Jarritt Creek on the east side of the Independence Valley [10A]. Not all these occurrences have been examined in detail.

Many springs, even many hot springs, have not laid down appreciable deposits of any kind. Where such springs have risen through soft unconsolidated material, the mound near the source may consist largely of organic matter from local vegetation or of fine silt that has been brought into suspension by the rising spring water and locally includes mineral matter that has been deposited with the other constituents. Other springs have deposited iron oxide, but the masses large enough to be shown on the geologic map (pl. 1) are generally of either siliceous sinter or calcareous travertine. A mound of travertine, evidently deposited in a pluvial Ruby Lake, is present in the Ruby Lake NE quadrangle, on the floor of Ruby Wash, 6,100 ft S55°E of Rock House Well. The mound rises about 25 ft above the detrital floor of the wash. Horizontal layers of calcitic crust with calcite crystals grown downward into open space suggest that the mound, which has a maximum elevation of 6,293 ft, was formed beneath standing water.

A much larger crateriform mound in the Boyd Reservoir quadrangle, in the northeast corner of S5,T34N,R57E, is made up of horizontally layered glassy rhyolitic ash, probably part of the Humboldt Formation, in which a still-preserved open spring tube, several feet in diameter, is lined with ash and cemented with opaline sinter. The outer surface of the cone is strewn with water-worn pebbles, apparently created by lacustrine erosion of the opalized ash. The cone is benched at about the 5,460-ft level, which may be representative of a stillstand in the retreat of the lake responsible for the erosion.

Sedimentary Rocks [QTs]

The unit of sedimentary rocks (pl. 1) includes the Hay Ranch Formation which was named by Regnier (1960, p. 1199) for exposures on the Hay Ranch in Pine Valley.

The formation was regarded by Smith and Ketner (1976) as consisting of typical basin-fill deposits. The rock contains coarse fanglomerate, with boulders as large as 6 ft in diameter, that interfingers with and grades basinward from sandstone and siltstone to clay and limestone beds that are lacustrine in origin. The clastic units are largely tuffaceous; vitric ash and tuff, commonly zeolitic, are interlayered with the other beds. A minor amount of tuffaceous limestone that also occurs in the unit is generally massive, hard, and very light colored or white. The total thickness of the Hay Ranch Formation is at least 1,300 ft.

On the basis of lithologic resemblance, an ash bed near the top of the Hay Ranch was correlated by R. E. Wilcox and H. A. Powers (*in* Smith and Ketner, 1976, p. B40) with the Pearlette family of ash beds in Kansas; the oldest sample of the ash gave a zircon fission-track age of about 1.9 ± 1 m.y. Beds correlative with the Hay Ranch, but much thinner or less dissected, are here (pl. 1) included in the Quaternary alluvium in many places. These beds are unresistant and do not crop out extensively enough to map, and outcrops are commonly obscured by Quaternary alluvial-fan materials. One place where conspicuous exposures may be seen in roadcuts is on State Highway 54, a few miles west of the Elko–Mountain City highway, where interbedded tuff and gravel have been conspicuously faulted. Another place that is doubtfully included but that has not been mapped with this formation is just north of the settlement of North Fork, on the old Elko–Mountain City highway, where flat-lying ostracode-rich limestone is exposed in roadcuts. Some of the light-colored exposures along the Wells–Jackpot highway may also belong here, although they are not separately mapped here.

Older Alluvium [QTa]

The older alluvium consists of boulder, gravel, and sand deposits on high-level stream terraces and on alluvial fans, which have been visibly dissected in many places. In some places the alluvial fans grade into the underlying uppermost Tertiary sedimentary rocks and, in other places, into alluvium of the present valleys; the distinction is most easily made where the older alluvium is currently being dissected. In some places, this unit is very thin, and the boundaries with the Tertiary rocks are difficult to determine. Along the west side of the Ruby Mountains, where alluvial fans of considerable extent and thickness have been dissected, this unit is thicker. Similar fans are present on both sides of the Independence Mountains and in the Chellis Valley in the Bull Run quadrangle.

Stream terraces covered with boulder gravel have been recognized along the Owyhee River in the Owyhee and Mountain City 15′ quadrangles [3, 4], and on the South Fork of the Owyhee River in the Mount Blitzen 15′ quadrangle. Exceptionally coarse boulder gravel caps several stream terraces along the South Fork of the Owyhee River, in the northeast corner of the Mount Blitzen 15′ quadrangle. The best developed terraces are both east and west of the mouth of Cottonwood Canyon, a deeply incised, youthful valley. Well-developed bodies of coarse boulder gravel are present about 160, 320, and 560 ft above the present level of the South Fork of the Owyhee River. The largest boulders in these terraces exceed 2 ft in maximum dimension, much larger than any that can be carried by the present stream. These boulders are almost entirely composed of Ordovician quartzite of the western assemblage, like that underlying the high peaks of the Independence Mountains to the east. To account for their presence, it seems necessary to suppose successive periods of elevation of the Tuscarora Mountains block, across which the antecedent South Fork was flowing in late Tertiary and Quaternary time. The volumes of water moving at the high velocities necessary to transport these boulders are most readily accounted for by the following supposition: during the Pleistocene, the upper course of Jack Creek in the Independence Mountains was dammed from time to time by glacial ice that came from canyons of more southerly tributaries in the Independence Mountains. Floods resulting from breaching of the dams at different times transported glacial boulders down the South Fork of the Owyhee River, and the Tuscarora Mountains have progressively risen along a fault at their east front, now largely buried by the alluvium ponded in the Independence Valley. The highest and thickest of these boulder gravel deposits thus probably corresponds to an early Pleistocene glaciation, and the lower terraces to successively younger glaciations. All of these high-level boulder gravel deposits, however, are too small to show on the geologic map.

West of the Tuscarora Mountains, in the Mount Blitzen 15′ quadrangle, the high-level gravel that forms interstream ridges is underlain by coarser and less well sorted material containing many boulders as large as many feet in diameter but quite monolithologic. These deposits, which are all derived from the rhyodacite of Walker Mountain, were apparently produced by a landslide that furnished material for a mudflow that filled former valleys and subsequently became a ridge topping. For the purposes of this report, this unit is here mapped (pl. 1) with the high-level stream gravel that overlies it. In some places, the high-level gravel has been cut by normal faults that commonly dropped those segments that are farthest from the mountains, particularly west of and in the western part of the Mount Blitzen 15′ quadrangle. In other words, the sense of the displacement is the same as that of the faults that are responsible for uplift of the mountains. As indicated on the geologic map (pl. 1), the wider bodies of alluvium occur in the wide valleys, most of which are tectonic basins, such as the valleys of the Marys River and of Beaver Creek north of the North Fork of the Humboldt River, the lower part of the North Fork of the Humboldt River, and the valley of the South Fork of the Humboldt River.

Quaternary System

Alluvium [Qa]

In the areas of greater relief, most of the bodies of alluvium (pl. 1) consist of relatively thin, coarse, poorly sorted, unconsolidated gravel and sand along the present streams, a few feet above the normal high water

mark. A large part of this alluvium is probably Holocene rather than Pleistocene, although some probable Pleistocene alluvial material is here mapped (pl. 1) with this unit in many areas. In many of the mountainous areas, these relatively wide bodies of alluvium may also result from obstruction of the streams by landslides. Generally, most of the material in the alluvium is locally derived and reflects the composition of the bedrock in the vicinity and upstream. Some broad gravel aprons are also included in this unit on the geologic map (pl. 1). Few identifiable fossils have been collected, although Smith and Ketner (1976, p. 42) reported a fossil mammoth tooth, found in a gravel pit in the Elko East quadrangle, that Edward Lewis identified as late Pleistocene, probably Sangamonian or Wisconsinan.

Glacial Moraines and Rock Glaciers [Qg]

Blackwelder (1931) was the first geologist to recognize glaciation of two different stages in the Ruby Mountains, especially at the mouth of Lamoille Canyon, and he thought that there might be a third, even older, stage. The two more conspicuous morainal systems he referred to as the Tahoe and Tioga "Stages" which he recognized in the Sierra Nevada. The Tahoe, now designated a glaciation, is the older and is characterized by the largest glaciers and the longest moraines. Blackwelder (1934) also noted moraines that he believed to be the products of two glaciations on the east side of the Independence Mountains.

Sharp (1938) mapped in detail the Pleistocene glacial moraines of the Ruby Mountains and East Humboldt Range, including those originally described by Blackwelder (1931), and distinguished two substages, the older of which he called the Lamoille substage and the younger the Angel Lake substage. In the Jarbidge quadrangle [6], Coats (1964) recognized glacial moraines of at least three distinct stages, the youngest two of which probably correspond to the Lamoille and Angel Lake substages recognized by Sharp (1938) in the Ruby Mountains. Two earlier glacial deposits, now much eroded, may represent more than one glacial advance. In addition to these deposits, the very recent glacial erosion at the heads of some cirques in the Jarbidge Mountains suggests the neoglaciation of the Sierra Nevada. The older of the two principal stages recognized has left deposits that lie in valleys whose heads have lost the typical cirque form and are now mantled with talus; much of the outwash rests on surfaces above stream level that have been dissected by the present streams. Postglacial valleys may separate terminal parts of the moraines from their source areas.

Glacial cirques and moraines were also observed by Bushnell (1967, p. 25) on the north and east sides of Copper Mountain in the Rowland quadrangle [5]. The cirque floors are about 9,000 ft high on the east side of Copper Mountain but generally somewhat lower and not consistent in elevation on the north side; the moraines extend from ½ to ¾ mi beyond the cirques. Bushnell (1967) saw no evidence for two glacial stages in this area.

In the Mountain City 15′ quadrangle [4], evidence of glaciation was seen only around the two highest mountains: Bald Mountain, which is on the border between the Mountain City [4] and Owyhee [3] 15′ quadrangles; and Merritt Mountain, where glacial moraines were found as much as one mile below the valley heads, although the cirque form was nearly destroyed. These glacial remains probably date back to Sharp's (1938) Lamoille substage rather than his Angel Lake substage.

Evidence of glaciation was also observed in the Bull Run quadrangle [9] by Decker (1962, p. 33), in California Gulch and Sheridan Gulch in the Bull Run Mountains, and in Chicken Creek and Mill Creek in the Independence Mountains. Some evidence of probable pre-Tahoe glaciation has been found on the east side of the Independence Mountains, in the Wild Horse quadrangle [11A] and the California Mountain quadrangle to the south [12A]. The southernmost glacial moraine recognized in mapping was on Stump Creek, near the south edge of the California Mountain quadrangle, where a small ridge that appears to be morainal occurs in the valley just east of the point where Stump Creek leaves the mountain front. This deposit must have been laid down by a glacier arising from the slopes of California Mountain at an elevation not higher than 8,400 ft. Although no well-defined cirquelike floors remain in the valley of the North Fork of Stump Creek, the general shape of the head of this valley suggests the presence of an old cirque. The other place where evidence of possible pre-Tahoe glaciation was found in the California Mountain quadrangle is in the valley of a small creek just north of Pratt Creek, at an elevation of about 6,500 ft, where ridges that appear to be morainal have been nearly buried by the material of alluvial fans coming off the mountain. These ridges must have been deposited by a glacier generated at an elevation not higher than 9,200 ft on a broad open nose to the east of McAfee Peak.

The rock glaciers in the Jarbidge Mountains [6] were described by Coats (1964, p. M19). These are mostly lobate, as defined by Wahrhaftig and Cox (1959, p. 389). One tongue-shaped rock glacier that lies near the head of a cirque is about 1,500 ft long by 700 ft in maximum width. The rock glaciers described in the Jarbidge Mountains are certainly not presently active; however, some are known to contain interstitial ice even at the height of summer, although no evidence of motion during the last 30 years has been recorded. Rock glaciers were also recognized on the east flank of the Independence Mountains (R. R. Coats, unpub. data, 1971) in the headwaters of the valleys of Peterson, McAfee, Walker, and Pratt Creeks, although they are less well developed here than in the Jarbidge Mountains. This may reflect differences in bedrock, because the presence of easily erodible material, as well as material that furnishes very coarse blocks, seems to favor the formation of rock glaciers.

Landslide Deposits and Colluvium [Qls]

Landslide deposits are also widespread, but most are too small to show on a 1:250,000 scale map. They generally occur in areas of resistant jointed formations, such as the Jarbidge Rhyolite and the Cougar Point Welded Tuff, that overlie weak, commonly clayey units, such as the Danger Point and Jenny Creek Tuffs. In a

few places, glacially oversteepened slopes in locally weakened argillized zones give way to landslides. In detailed mapping, two ages of landslides were distinguished in a few places. The younger landslides have a rougher topography, retain more undrained depressions, and commonly are closely confined to present valleys. The older landslides are more highly dissected, retain fewer undrained depressions, and commonly cap ridges where the underlying rock is easily eroded. Thus, the older landslides have caused an inversion of relief. This recognition of two distinct ages of landslides points to two distinct periods of formation, separated by a period of relatively little landsliding. In at least one place in the Jarbidge quadrangle, the presence of glacial till resting on an older landslide deposit suggests that slides were more prevalent during the period of high rainfall coincident with the glaciation and perhaps began before the glaciation had reached its maximum.

The largest landslide in Elko County is from the west face of Spruce Mountain, thought by Wheeler and McNair (1950) to be a thrust, and by Hazzard and Moran (1952) to be a dissected and faulted alluvial fan. Its landslide origin was later demonstrated by Hope (1972).

Colluvial deposits have been commonly mapped in the more detailed mapping that has been done over parts of the county, particularly where they are extensive enough to obscure the bedrock structures and boundaries. In generalizing for the geologic map (pl. 1), many of these areas of colluvium have been omitted. Most of these areas are on slopes steeper than 10°; on the gentler slopes they generally grade into areas of alluvial-fan deposits and alluvium. The influence of the direction of insolation is marked in detailed mapping; the north-facing slopes, which retain moisture better, are more heavily forested and densely vegetated, and the colluvial deposits are much thicker.

In Elko County, solifluction deposits have been observed only on steep slopes on the east face of the Independence Mountains. Solifluction benches are generally regarded as survivals of colder periods; their presence in this area suggests that they may have formed during the period of glaciation and have survived into the present because of relatively feeble erosion on the surfaces where they occur. The actual thickness of the material that was in motion is small, measurable in yards.

Pluvial Lake Deposits [Qp]

The extreme west margin of one of the most famous of all pluvial lakes of the United States, Lake Bonneville, extends into Elko County (Gilbert, 1890). The deposits laid down during the highest stand of Lake Bonneville were referred to as the Bonneville Formation by Morrison (1965) and Morrison and Frye (1965, p. 275), who divided it into two members, a lower member consisting of white marl and an upper member consisting of sand and gravel. The lower member, which is largely composed of ostracode shells and the remains of calcareous algae, is particularly conspicuous in the area around the west shore of Lake Bonneville, both south and north of Wendover, Utah. The gravel derived from the upper member generally covers exposures of the lower member. Older deposits of Lake Bonneville are not exposed, so far as is known, in Elko County, although they may be present in the subsurface.

Five other pluvial lakes have been recognized by various workers in eastern Elko County; the earliest report summarizing the distribution of these lakes was by Meinzer (1922), who presented a small-scale map showing their approximate locations. More precise locations and areas were shown by Snyder and others (1964); the most precise outline of these lakes was given by Hubbs and Miller (1948). Only one of these lakes, referred to by Hubbs and Miller as pluvial Lake Diamond, the north tip of which extends a few miles into the extreme southwest corner of Elko County, drained into Pleistocene Lake Lahontan during part of its existence (Hubbs and Miller, 1948, p. 34, 35); the others were undrained.

The deposits in the bottom of most of the pluvial lakes have not been dissected and are so poorly exposed that very little can be said about them. In a few of these deposits the beaches and bars are still preserved. Some of the deposits in pluvial Lake Franklin and pluvial Clover Lake on both sides of Spruce Mountain [46] were partly mapped by Hope (1972). Because most of the pluvial lakes in southern Elko County had no outlet, their levels fluctuated rather rapidly and they did not leave as well defined shorelines as did Lake Bonneville. One exception is pluvial Lake Diamond, which drained through Railroad Pass into the South Fork of the Humboldt River and gave rise to bench terraces along the west shoreline that are quite well marked, as indicated by Hubbs and Miller (1948, p. 34). In many places on the geologic map (pl. 1), Quaternary alluvium transects or overlies the beaches and bars of the pluvial lakes. The long distances over which these beaches are preserved where they transect the fans along the mountain front indicate the considerable antiquity of many of these fans and suggest that the fans themselves were developed largely during the pluvial periods.

Mifflin and Wheat (1979) recently reviewed the pluvial lakes of Nevada, with special emphasis on those of the Lahontan drainage. Their map (Mifflin and Wheat, 1979, pl. 1) shows the highest shorelines of the lakes of Lahontan (Wisconsinan) age. The outlines of these lakes generally correspond with those shown on the geologic map (pl. 1), except for the lake shown in Steptoe Valley. Mifflin and Wheat (1979, p. 15) conceded that a much older (pre-Rye Patch?) lake may have existed in this valley but that, by Rye Patch (Illinoian) time, Goshute and Steptoe Valleys were integrated by a channel cut near Currie. They suggested that groundwater discharge is probably responsible for the extensive lacustrine-like deposits and apparent shoreline features in the valley. There is, however, a topographic feature on the west side of the valley, southwest of Currie, that resembles a shore cliff that appears to be as well preserved as the shore cliffs of Lahonton or Bonneville age and does not appear to be related to groundwater discharge. In any event, no distinction is made on the geologic map (pl. 1) between Wisconsinan (Lahontan) and pre-Wisconsinan lakes. Another place where a marked discrepancy appears between Mifflin and

Wheat's (1979) map and the geologic map (pl. 1) is in the Twelve Mile Ranch quadrangle, north of the Twelve Mile Ranch. Reexamination of aerial photographs indicates that the highest shoreline in this area is about 5,240 ft elevation which would indicate a significant extension of Lake Bonneville to the west. No shoreline features were recognized west of Twelve Mile Ranch, and lakebeds of mappable extent must largely be concealed by later Quaternary alluvium, although they could probably be mapped at a larger scale.

In the Owyhee desert, in the extreme northwestern part of Elko County [1], very small playa lakes have formed in the initial irregularities on the upper surface of and at the margins of different flows of the Big Island Formation. Some of these lakes have surficial drainage, and most are floored with fine clayey sediment, probably originally windborne; most are probably covered for brief periods nearly every spring by thin sheets of standing water.

The sediment of the larger pluvial lakes, as mapped here (pl. 1), includes both lake-bottom deposits, characterized by fine grain sizes, and lake-margin deposits, such as beaches and bars. All of these deposits were described in great detail by Gilbert (1890).

Plutonic Rocks

The plutonic rocks of Elko County are predominantly Jurassic and Cretaceous, and range in age from 150 to 80 m.y. Tertiary plutons are predominantly about 38 m.y. old (late Eocene), except for one alaskitic pluton that shows a great range in grain size, and is certainly Miocene. Modal compositions of the plutonic-rock samples examined for this study, most of which are Cretaceous, are plotted in figure 7. In general, the Cretaceous and Tertiary plutons of Elko County would be classified modally granitic and granodiorite according to the classification of Streckeisen and others (1973). It should be noted that most of the so-called "granites" of this classification in Elko County would correspond to adamellite or quartz monzonite, as the term has been used by past workers in the Sierra Nevada (P. C. Bateman, oral commun., 1980). Statistically, the small

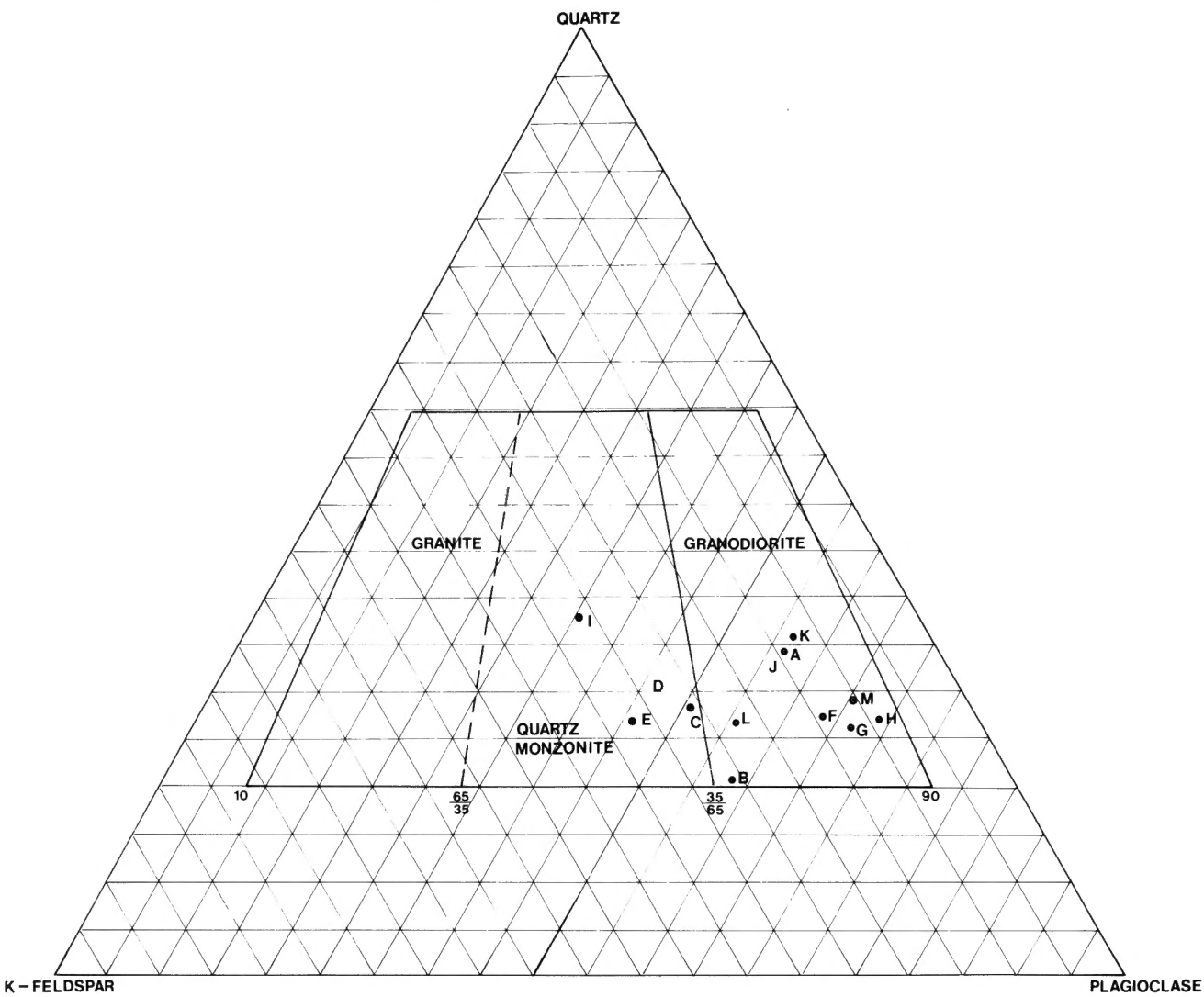


FIGURE 7. Triangular diagram plotting quartz/potassium feldspar/plagioclase modal ratios for certain plutonic rocks of Elko County. See table 1 for identification of samples.

number of samples makes comparisons hazardous, although the general distributions of some compositions resemble those of the Lower Cretaceous Shaver sequence of the Sierra Nevada, according to P. C. Bateman. It should also be noted that the modal studies did not include many of the smaller Jurassic plutons of northern Elko County, which are known to be poorer in potassium feldspar and would plot much closer to the plagioclase corner of the diagram (fig. 7). The Jurassic and Cretaceous plutons of Elko County probably do not differ substantially from those of the Sierra Nevada; the Tertiary plutons, except for the Harrison Pass pluton, are not so deeply eroded and, therefore, differ texturally from the older plutons. If the granite field is divided to separate out quartz monzonite, as is commonly done in the United States, many of these granites would be quartz monzonite, and none would be granite in the strict sense. Table 1 lists the details of the composition of these samples.

JURASSIC AND JURASSIC(?) PLUTONS [Jgr,Jd]

Most of the bodies of plutonic rocks of known Jurassic age are in northern Elko County, although some are also present in the Ruby Mountains, in the Silver Zone Pass area in the Toano Range, and in the Delker Hills.

In the Bull Run quadrangle [9], Decker (1962) mapped a series of small stocks along an easterly trend, from the mouth of White Rock Creek to the head of Trail Creek. The largest of these stocks are the White Rock stock and the Columbia stock, each of which covers an area of about 1 mi^2. The White Rock stock consists of hornblende diorite with a minor amount of quartz. The brown hornblende, which makes up about 40% of the rock, has been partially altered to chlorite and sphene. Stocks farther to the east are progressively richer in potassium feldspar and quartz, the stock at the head of Trail Creek is a granodiorite. Decker thought that this progressive change could be interpreted as produced by a temporal sequence of closely related intrusive bodies.

The first pluton dated from this sequence is the Columbia pluton, a hornblende-biotite-quartz diorite, that E. H. McKee (*in* Coats and McKee, 1972, table 1) dated at 149.7 ± 5 m.y. It is characterized by a textural feature not seen in any of the known Cretaceous plutons—the presence of biotite poikilitically including the other mafic minerals as well as plagioclase. Not all samples of the Jurassic plutons show this textural peculiarity; it is noteworthy that greater compositional variation seems to be more characteristic of the Jurassic plutons than of the Cretaceous or Tertiary plutons.

The Gold Creek pluton, in the Mount Velma quadrangle [13] (Coash, 1967), ranges in composition from hornblende-biotite-quartz diorite to quartz monzonite; the more mafic phases of this pluton also contain poikilitic biotite. E. H. McKee (*in* Coats and McKee, 1972, table 1) dated this pluton at 149.7 ± 5 m.y. (Late Jurassic) on biotite.

Another small pluton, similar in texture, is the Enright Hill pluton in the Mountain City 15′ quadrangle [4]. Biotite extracted from a sample of this pluton was dated by E. H. McKee (written commun., 1979) at 110.9 ± 1 m.y. (late Early Cretaceous). One phase of the Enright Hill pluton is a quartz diorite containing minor potassium feldspar, in part with small axial angles suggesting sanidine, and nearly colorless pyroxene, perhaps diopside, forming cores to the hornblende crystals, as well as brown biotite, zircon, and apatite. This unusual petrography suggests a Jurassic age, but because of its Cretaceous isotopic age, it is questionably assigned a Jurassic age; the age discrepancy is attributed to reheating.

Another pluton, exposed as several disjunct outcrops in the valleys of Beaver Creek and Seventy Six Creek, in the northeastern part of the Mount Velma quadrangle, ranges from diorite to granodiorite in composition and is also characterized by the presence of poikilitic biotite in some phases. Another phase of the stock on Seventy Six Creek is characterized by diopside jacketed by hornblende, by reddish-brown poikilitic biotite, and by apatite and magnetite. Similar biotite characterizes a small stock, barely exposed in an erosional window

TABLE 1. Modal composition of some plutonic rocks in Elko County and vicinity determined by point counting.

Field no.	Quadrangle	Nevada (E zone) coordinates		Index on triangular diagram (fig. 7)	Pluton	Total points	Total percent				Reduced percent		
		East (ft)	North (ft)				K-feldspar	Plagioclase	Quartz	Mafic and accessory minerals	K-feldspar	Plagioclase	Quartz
65NC80	Rowland 15′	500,400	2,570,100	A	Coffeepot	[1]1,000	13.8	47.6	31.7	6.9	14.8	51.1	34.1
65NC5	Elk Mountain 15′	638,400	2,600,400	B	Elk Mountain	[3]900	22.0	44.7	17.2	16.3	26.2	53.3	20.5
57NC89	Mountain City 15′	391,500	2,588,500	C	Mountain City	[2]1,538	23.1	41.1	25.0	10.8	25.9	46.1	28.0
				D	Mountain City	[2]1,747	26.9	36.7	27.1	9.9	29.8	40.1	30.0
65NC146	Mountain City 15′	389,700	2,581,300	E	Mountain City	[1]1,000	29.4	37.3	24.1	9.3	32.4	41.1	26.5
58NC47	Owyhee 15′	379,150	2,617,700	F	Skull Creek	[1]700	12.7	51.7	24.0	11.6	14.4	58.4	27.2
54NC316	Jarbidge 15′	524,100	2,591,300	G	Coffeepot	[1]800	10.8	52.6	22.2	14.4	12.6	61.5	25.9
60NC175	Owyhee 15′	381,000	2,612,500	H	Skull Creek	[1]850	8.0	53.8	22.7	15.5	9.5	63.6	26.9
62NC142	Franklin Lake SW	526,500	2,026,500	I	Harrison Pass	[1]765	30.5	29.3	36.2	4.0	31.8	30.5	37.7
63NC20	Rowland 15′	507,100	2,618,700	J	Bearpaw Mountain	[1]811	16.3	47.8	31.3	4.6	17.1	50.1	32.8
63NC106	Patterson	929,250	2,349,200	K	Patterson Pass	[1]765	11.1	45.2	31.5	12.2	12.6	51.5	35.9
63NC40	Mountain City 15′	449,400	2,612,600	L	McDonald Creek	[1]800	19.4	43.1	22.2	15.3	22.9	50.9	26.2
66NC100	Black Leg Creek	429,150	2,641,400	M	Cottonwood Creek	[2]759	9.5	53.6	25.4	11.5	10.75	60.5	28.75

[1]Point count on stained slab by James Elliott.
[2]Point count on thin section by Robert R. Coats.
[3]Point count on stained slab by Alden Loomis.

through Tertiary volcanic rocks in the northeastern part of the Jarbidge Wilderness area (Coats and others, 1977).

The Contact pluton, for which a single K-Ar age of 150 m.y. (Late Jurassic) was determined on biotite (Coats and others, 1965), apparently ranges in composition from quartz monzonite to granodiorite (Gibbons, 1973). According to Gibbons, the "aplitic dikes" mentioned by Schrader (1912) are narrow zones of potassium-feldspathic alteration. A somewhat gneissose phase of the Contact pluton, sampled by R. A. Hope, is characterized by andesine (An_{41}), diopside (here poikilitically intergrown with hornblende), and biotite, (pleochroic from olive brown to light brown), with accessory apatite, sphene, and allanite; the allanite is yellow and metamict. This phase must be regarded as a gneissose quartz diorite. A more common phase of the Contact pluton is characterized by both plagioclase and orthoclase, as well as by minor quartz. The mafic minerals are hornblende and biotite, and the accessories are magnetite, sphene, apatite, zircon, and allanite; the allanite is yellow green with a low double refraction. Metamictization of allanite has evidently not gone to completion in this rock.

The small pluton in the Ninemile Mountain quadrangle was mapped by R. A. Hope as a diorite. On this basis, it is regarded as Jurassic(?).

In the northern Toano Range, two plutons were mapped by Pilger (1972, p. 22–30). The southerly pluton, termed the Silver Zone Pass pluton, was dated at 150 m.y. (Late Jurassic) by Coats and others (1965). Armstrong and Suppe (1973) reported an age of 127 m.y. (Early Cretaceous) on biotite from this pluton. It is assigned a Jurassic(?) age. The rocks were described carefully by Pilger (1972), who reported that the pluton is dominantly a granodiorite but ranges in composition from quartz diorite to quartz monzonite. Most samples contain biotite or hornblende or both; opaque minerals, apatite, sphene, and zircon are minor accessories. The plagioclase ranges from An_{45} to An_{2}. Zoning of the cores is oscillatory, and the rims are normally microcline or orthoclase, rarely perthitic. The northerly pluton, termed the Toano Springs pluton, which intrudes the Prospect Mountain Quartzite on its south and east margins, is very coarse grained and contains abundant aplitic and pegmatitic dikes. The rock is somewhat foliated owing to synkinematic or postkinematic deformation. The Toano Springs pluton is also a granodiorite but varies more widely in composition than the Silver Zone Pass pluton. R. H. Pilger, Jr. (written commun., 1972), suggested that the rocks he mapped as the Prospect Mountain Quartzite include the McCoy Creek Group, and that the Toano Springs pluton might be Precambrian. R. A. Hope, who examined the outcrop, evidently accepted the original emplacement of the pluton as Jurassic. The Toano Springs pluton may be somewhat older than the Silver Zone Pass pluton; alternatively, it may have been affected to a greater degree by Cretaceous deformation.

In southeastern Elko County [53A], Messin (1973) mapped the White Horse pluton, hornblende from which gave an age of 156 m.y. (Armstrong, 1964). The rocks range in composition from quartz-poor granodiorite to quartz-rich granite. About 80% consists of pinkish-gray, medium-grained, seriate-porphyritic quartz monzonite. The phenocrysts consist of pink microcline or perthite; biotite and hornblende are the principal mafic minerals. Diopside is present near the contact with calcareous intruded rocks.

In the Jiggs 15′ quadrangle [48], Willden and Kistler (1969) mapped two bodies of Late Jurassic plutonic rocks, one of which they described as a pegmatitic muscovite granite that forms "...subhorizontal sheet-like bodies that range in composition from alaskite to biotite granodiorite." Strong cataclasis is locally present. An age of 150 m.y. on the granite was reported by Armstrong and Suppe (1973); R. W. Kistler (written commun., 1978) reported a whole-rock Rb-Sr age of 151 m.y.

CRETACEOUS AND CRETACEOUS(?) PLUTONS [Kgr]

Cretaceous and Cretaceous(?) plutonic rocks are here mapped (pl. 1) in several parts of Elko County. A wide latitudinal band of such rocks is present in the northernmost tier of 15′ quadrangles; sporadic plutons occur farther south. The larger plutons have a range of composition, but generally are somewhat more silicic than the Jurassic plutons, although there is considerable overlap in composition.

In the Dolly Varden area [53], Snow (1964) mapped a sill-like body of hydrothermally altered diorite, the age of which was not determined, and a stock called the Melrose stock that has an outcrop area of about 12 mi^2. The stock consists of medium- to coarse-grained quartz monzonite and porphyritic quartz monzonite, as well as small areas of leucogranodiorite, augite monzonite, and fine-grained granite. Biotitic parts of the quartz monzonite are areally the most extensive; hornblende quartz monzonite is less extensive. The potassium feldspar includes microcline phenocrysts, as well as orthoclase and perthite. Biotite, the most common mafic mineral, is present both as primary biotite and as secondary biotite deuterically replacing hornblende. Plagioclase (An_{32} to An_{36}) is present as phenocrysts and in the matrix. Accessories include magnetite, sphene, and zircon; hematite, epidote, and corundum(?) are minor constituents. In addition, an extensive suite of aplite, lamprophyre, microgranite, and pegmatite dikes was carefully described by Snow. Porphyritic dikes, similar in composition to the Melrose stock, are also present, as well as an extensive sequence of dikes that have an even finer grained groundmass and are more extensively altered. R. L. Armstrong (*in* Snow, 1964) dated a sample of biotite from the porphyritic quartz monzonite at 125 m.y. by K-Ar methods. Armstrong and Hansen (1966) later revised this date to 134 m.y. (Early Cretaceous).

In the Jiggs 15′ quadrangle [48], Willden and Kistler (1969) mapped a small pluton of two-mica granite, described as a medium-grained muscovite-biotite granite with accessory garnet: "The dominant mica phase in the core of the pluton is muscovite and in the border rocks is biotite. Pegmatites associated with this granitic rock type

occur as discrete tabular dikes with sharp contacts. Rb-Sr whole-rock age determinations [Armstrong and Suppe, 1973] indicate an Early Cretaceous [103 m.y.] age for a similar pluton in Dawley Canyon, just east of the Jiggs [15′] quadrangle."

In the Owyhee 15′ quadrangle, at least two major plutons are present, the Skull Creek and Mountain City plutons (Coats and McKee, 1972). Coats (1971) regarded the pluton of Sikikareh Mountain as only an outlier of the Mountain City pluton, separated from the main mass by overlapping Tertiary volcanic rocks. These plutons are principally composed of biotite or hornblende-biotite granodiorite to quartz monzonite, locally containing perthitic orthoclase phenocrysts. Microcline-microperthite alaskite is present along many of the contacts. The Skull Creek pluton was dated at 81 ± 4 m.y. (Late Cretaceous) by a K-Ar determination on biotite, and the Mountain City pluton at 90 ± 4.5 m.y., also by a K-Ar determination on biotite (Coats and others, 1965, p. D13).

In the extreme southern part of the Owyhee 15′ quadrangle and in the northern part of the Bull Run quadrangle, the small Silver Creek pluton of biotite granite (Decker, 1962) contains marginal phases of greisen that have furnished a muscovite which was analyzed by Lois Schlocker and dated by E. H. McKee at 92.1 ± 3 m.y. (written commun., 1980); it is here assigned an early Late Cretaceous age.

A facies of the Mountain City pluton, collected near the forks of Dip Creek in the Mountain City 15′ quadrangle, about 1½ mi west of the summit of Merritt Mountain, has as its principal constituents quartz, microcline, and plagioclase. The rock is characterized by the presence of biotite and hornblende, with accessory sphene, apatite, brown allanite, and magnetite; small amounts of secondary muscovite, epidote, quartz, and chlorite are also present.

In the Mountain City 15′ quadrangle [4], two additional distinct plutons of some size are the McDonald Creek (Hicks Mountain) and Cottonwood Creek plutons; both are partly overlapped by Tertiary volcanic rocks. Both plutons are biotite granodiorite; aplitic phases were not separately mapped for this report. Biotite from the McDonald Creek (Hicks Mountain) pluton gave a K-Ar age on biotite of 88 ± 4.4 m.y. (Coats and others, 1965); two K-Ar determinations on biotite from the Cottonwood Creek pluton gave Late Cretaceous ages of 86.0 ± 3 and 89.2 ± 3 m.y. (Coats and McKee, 1972).

Two major plutons of Cretaceous age crop out in the Rowland quadrangle [5], where they were described by Bushnell (1967, p. 19). The southern pluton, the Coffeepot pluton, was classified as a hornblende-biotite or biotite-quartz monzonite, or adamellite. The potassium feldspar is microcline; accessory minerals include epidote, clinozoisite, sphene, and zircon. In the Jarbidge quadrangle [6], where the eastern part of the Coffeepot pluton crops out, the rock is a fine- to medium-grained biotite-quartz monzonite containing lesser amounts of biotite granodiorite (Coats, 1964). In both quadrangles, a minor contact phase is hornblende-biotite quartz-diorite. A Pb-α age of 120 ± 10 m.y. (Early Cretaceous) was reported for this stock by Coats and others (1965).

In the northern part of the Rowland quadrangle, the Deep Creek stock was reported by Bushnell (1967) to be transitional between a granite and an adamellite or a quartz monzonite. The rock consists of biotite, hornblende, orthoclase, quartz, and plagioclase; magnetite and clinozoisite are minor accessory minerals. Some evidence of postcrystallization deformation was found by Bushnell (1967) and Coats and others (1965). The K-Ar age for this stock (also called the Bearpaw Mountain stock) is 73 ± 3.7 m.y. (Late Cretaceous) (Coats and others, 1965).

A small stock of granodiorite, locally including quartz monzonite, that crops out in the Elk Mountains [7] was described by Higgs (1960) and Fifer (1960). Fifer described the granodiorite as pinkish gray, medium grained, and equigranular. The potassium feldspar is perthitic orthoclase. Biotite is the chief accessory; sphene, magnetite, hornblende, apatite, and pyrite are also present. Numerous aplite dikes intrude the stock. Higgs described a biotite-hornblende granodiorite, grading locally into a quartz monzonite by increase in the abundance of orthoclase phenocrysts; accessories include sphene, apatite, and zircon. A sample of zircon from this intrusive body in the NE/4 SW/4 S9,T46N,R61E was assigned a U-Pb age of 100 ± 10 m.y. (late Early Cretaceous) by T. W. Stern (written commun., 1966).

At Indian Spring in the Delano Mountains [18A], Slack (1974) described a stock that ranges in composition from trondhjemite and granodiorite to albite granite, and in texture from coarsely porphyritic to fine grained equigranular. "Most of the stock is heterogeneously textured quartz monzonite porphyry" (Slack, 1974, p. 271). Biotite is the principal(?) mafic mineral. K-Ar age determinations on biotite by J. F. Sutter (*in* Slack, 1974, table 1) were 134.2 ± 1.5 and 136.0 ± 2.0 m.y.; Slack regarded this age as a minimum.

CENOZOIC PLUTONIC ROCKS

Early Tertiary Plutons [Tgd]

Six plutons in Elko County are of known early Tertiary age: the Mount Neva pluton, the Lone Mountain pluton, the Swales Mountain pluton, the Railroad mining district stock, the Harrison Pass pluton, and the Kinsley pluton. Four of these bodies, the Mount Neva, Swales Mountain, and Lone Mountain plutons, and the Railroad District stock (Smith and Ketner, 1976, p. B29) are definitely epizonal as shown by their textures, whereas the Harrison Pass pluton, according to R. W. Kistler (oral commun., 1977), probably crystallized at a greater depth than many plutons of the Sierra Nevada, as shown by its coarse texture and the general absence of a fine-grained groundmass.

The Mount Neva pluton ranges in composition from hornblende-biotite granodiorite to granodiorite porphyry; most of the quartz and all of the potassium feldspar are confined to the granophyric groundmass. Much of the hornblende is uralitic, but no vestiges of pyroxene have been found. Chloritization of the hornblende is common, whereas the biotite with a K-Ar age of 38.4 ± 1.5 m.y. (late Eocene), determined by E. H.

McKee (*in* Coats and McKee, 1972, table 1), remains quite notably fresh.

The Lone Mountain pluton (Lovejoy, 1959) includes: an intrusive body which has a crescent-shaped outcrop pattern (referred to by Lovejoy as a ring dike), composed of quartz monzonite porphyry characterized by biotite, hornblende, and, possibly, cummingtonite; a composite stock of biotite-quartz latite; altered diorite that is later than the biotite-quartz latite; and quartz monzonite, characterized by biotite with fringes of stilpnomelane and by brown hornblende that occurs on the east flank of Lone Mountain. The Lone Mountain pluton is about 38 m.y. old (K. B. Ketner, written commun., 1970).

The Swales Mountain pluton, which includes phases of biotite-quartz monzonite porphyry and biotite-hornblende monzonite porphyry, ranges in composition from quartz monzonite to diorite (Evans and Ketner, 1971). The quartz monzonite porphyry was dated by Coats and others (1965) at 40 ± 10 m.y. on the basis of a Pb-α age on zircon, and at 38 ± 2 m.y. by K-Ar methods on biotite. Potassium feldspar from the quartz monzonite porphyry was dated at 38.7 ± 1.3 m.y. and biotite at 38 ± 1.3 m.y., by R. F. Marvin (*in* Evans and Ketner, 1971, table 1). The Swales Mountain pluton does not differ significantly in age from the Mount Neva and Lone Mountain plutons.

In the Carlin-Piñon Range area [43], Smith and Ketner (1976) described an intrusive stock in the Railroad mining district near the center of their study area. The outer shell of the stock is medium-grained granite, quartz monzonite, monzonite, and quartz diorite; the core is essentially rhyolite porphyry. K-Ar ages of 35.4 ± 1.1 m.y. on feldspar and 36.8 ± 1.1 m.y. on biotite from the granitic outer shell of the stock were determined by R. F. Marvin and others, and 35.5 ± 0.7 m.y. on biotite from the biotite adamellite and 36 ± 1.4 m.y. on the whole-rock rhyolite porphyry were determined by R. L. Armstrong (*in* J. F. Smith, Jr., written commun., 1980). Ketner and Smith (1963, p. B11) described the rock as follows:

> Typically, the granite, monzonite, and quartz diorite in the outer shell of the stock is hypautomorphic granular to porphyritic and fine to medium grained. Many of the larger plagioclase grains are zoned progressively outwards but also show uncommon reversals. Biotite is the only mafic mineral.....
>
> The rhyolite composing the core, the northeast margin of the stock, and a faulted body on the east side of the district is typically porphyritic and consists of euhedral phenocrysts of quartz, sanidine, and, less commonly, plagioclase, 1 to 6 mm in diameter. The matrix consists mainly of potassium feldspar and quartz grains from 0.01 to 0.1 mm in diameter. [Ferromagnesian] minerals are scarce. The rhyolite is interpreted as intrusive because of its sharp contact with the granitic shell.

The Harrison Pass pluton (Willden and Kistler, 1969) is early Oligocene, based largely on K-Ar dates on biotite (Coats and others, 1965; R. W., Kistler, oral commun., 1977). The rock ranges in composition from biotite granodiorite to quartz monzonite and is characterized by large phenocrysts of microcline. The Harrison Pass pluton is notably larger in area, and more uniform in composition and texture than the Mount Neva, Lone Mountain, and Swales Mountain plutons.

Buckley (1967) described the Kinsley stock [55] as a medium-grained hypautomorphic hornblende-biotite-quartz monzonite. An age of 33–40 m.y. for the stock was determined by Armstrong (1964).

Alaskitic Granite [Tgr]

Near the extreme west edge of the Wild Horse 15′ quadrangle is a small stock of alaskitic granite that intrudes the Jarbidge Rhyolite and, therefore, must be Tertiary. The granitic rock is near the west edge of the body of the Jarbidge Rhyolite and probably is nearly coeval with the rhyolite. The granitic rock apparently is completely devoid of any mafic phases and is characterized by wide variations in the size of the quartz and feldspar crystals from less than a millimeter to a centimeter. The rock contains quartz, sanidine, and sodic plagioclase as the principal constituents. Much of the rock is slightly miarolitic; the cavities are lined with tridymite and glass. The texture and the presence of tridymite in such a coarse-grained rock suggest abrupt quenching by loss of volatile materials before solidification was completed. From the coarseness and size of the quartz and potassium-feldspar crystals, I infer a high water content for the original magma. Minor breccia dikes cut the Jarbidge Rhyolite in the vicinity, apparently from this explosive degassing.

Regionally Metamorphosed Rocks

LATE PROTEROZOIC(?) SCHIST [Ꝑs]

Rocks for which good stratigraphic evidence of a Precambrian age is available occur in a small area of the Ruby Mountains, east of Green Creek (Kistler and Willden, 1969). Here, the Prospect Mountain Quartzite of Cambrian age rests with reported angular discordance on Precambrian quartzite and sillimanite-bearing mica schist. Kistler and Willden reported that Rb-Sr whole-rock analyses of schist, gneiss, and quartzite from the Precambrian rocks indicate that they were metamorphosed 550 ± 30 m.y. ago.

LATE PROTEROZOIC ERA AND CAMBRIAN SYSTEM

Foliated Metaquartzite [ꝐPq]

In many places in the Ruby Mountains [45A], Howard and others (1979) mapped a unit that consists largely of brown-weathering foliated metaquartzite. The quartzite contains 20% feldspar and mica, and, locally, sillimanite, as well as minor schist and calc-silicate rock. In part, this unit may consist of the Prospect Mountain Quartzite, but it also may include rocks older than the Prospect Mountain. The unit as mapped here (pl. 1) is intruded by pegmatitic granite.

CAMBRIAN AND ORDOVICIAN SYSTEMS

Calcite Marble [O€m]

Howard (1966b) described a unit of metamorphic rocks that underlies Verdi Peak in the Ruby Mountains

and that makes up most exposures in the central part of the northern Ruby Range [45A]. The most abundant rock in the unit is marble, containing only a small percentage of impurities; the formation also contains a quartzite and a dolomite member, according to Howard (1966b). The purest marble is 80% to 95% calcite; the remaining constituents are chiefly diopside, potassium feldspar, biotite-phlogopite, plagioclase, and quartz. The marble is fine grained and light gray in the lower amphibolite-facies zone.

The most abundant terrigenous rock described by Howard (1966b) from the amphibolite facies is mylonitic quartz paragneiss. In the sillimanite zone the marble is medium grained and, in some places, shows alternating light- and dark-gray layers; light-gray gneissoid biotitic marble also is common. In the sillimanite zone the formation includes fine-grained phlogopite-graphite paragneiss, biotite-sillimanite schist, and minor biotite-muscovite-sillimanite schist. A distinctive member at or near the base of this unit is a white- to rusty-brown-weathering dolomite marble, interbedded with calcite marble (Howard, 1971). Howard (1966b) considered the protolith of the metamorphic unit to have been the Cambrian limestone and shale above the Prospect Mountain Quartzite, and the Ordovician Pogonip Group.

ORDOVICIAN SYSTEM

Metaquartzite [Oem]

In the Ruby Mountains, Howard (1966b) mapped a metaquartzite that he believed had been derived from the Eureka Quartzite. The maximum thickness of this unit in the Ruby Mountains is more than 200 ft; it thins southward from the northern Ruby Mountains, probably because of a post-Eureka unconformity. The rock is a massive, white vitreous quartzite containing minor tremolite and very rare feldspar and muscovite; minor graphite is locally present.

In the Wood Hills [35], Thorman (1970) recognized a weakly to moderately schistose metaquartzite as having been derived from the Eureka Quartzite; he was able to distinguish in this metaquartzite synkinematic diopside, tremolite, and muscovite from postkinematic diopside and tremolite.

CAMBRIAN(?), ORDOVICIAN(?), SILURIAN(?), AND DEVONIAN(?) SYSTEMS

Dolomite Marble [DOm,DЄm]

In the Wood Hills [35] and the Pequop Mountains, Thorman (1970) recognized a unit of dominantly dolomite marble containing minor calcite marble, tectonitic in texture and medium to coarse grained, with alternating light-gray and white members ranging from a few feet to more than 70 ft in thickness. Some members of nonlayered tremolite-bearing dolomitic marble are also present; dark-gray recrystallized chert occurs in medium-dark-gray dolomite marble overlying the Eureka Quartzite.

In the Wood Hills, Thorman also recognized a unit that he believed had been derived from the Simonson Dolomite of Devonian age. This unit consists of quartzose dolomite marble, locally grading into quartzite. The rock is medium grained, layered, and weathers reddish brown; calc-silicate rocks are commonly present along contacts between the quartzite and marble beds. The unit commonly consists of two quartzose beds, each as much as 100 ft thick, separated by a few hundred feet of dolomite marble. This unit (the Simonson equivalent) has not been separated in mapping the Wood Hills area. In places, Thorman (written commun., 1980) was able to recognize each stratigraphic unit from the Cambrian Dunderberg Shale to the Devonian Guilmette Formation, not only in the Wood Hills but in the East Humboldt Range in the Snow Water series of Snelson (1957). A unit of dolomite marble described by Howard (1966b) and Howard and others (1979) in the northern Ruby Mountains and southern East Humboldt Range has also been mapped as dolomite marble (pl. 1).

DEVONIAN SYSTEM

Graphitic Marble [Dm]

On the northwest flank of the Ruby Mountains, Howard (1966b) mapped a unit of graphitic dolomitic marble to which he gave the local name "Snell Creek Marble." Besides graphite, other noncarbonate minerals include white mica, tremolite, hornblende, idocrase, and hematite. In a few places, calcite megacrysts appear to be derived from crinoidal-stem fragments. The maximum thickness of the unit is about 200 ft. Howard (1971) correlated the marble with part or most of the Devonian Guilmette Formation and Devils Gate Limestone.

Metamorphic Rocks

PROTEROZOIC(?) EONOTHEM, AND CAMBRIAN(?), ORDOVICIAN(?), SILURIAN(?), AND DEVONIAN(?) SYSTEMS [DPm]

In the East Humboldt Range [39], Snelson (1957) mapped an extensive metamorphic succession that he subdivided tentatively into two units and named them the Angel Lake and Snow Water units. The two units differ lithologically and are "...at least in part, in thrust contact with one another." The lower, or Angel Lake unit, includes granitic to dioritic gneiss, biotite schist, quartzitic schist, schistose quartzite, pegmatite, lime silicate granulite, lime silicate marble, and pure marble. The upper or Snow Water unit consists "...predominantly of marble, lime silicate marble, banded lime silicate granulite, schist, pegmatite, and white quartzite." This succession is, at least in part, in thrust contact with the underlying Angel Lake unit and contains both cataclastic and noncataclastic rocks with mylonite at and near the thrust plane.

Comparison with Howard's (1966b) mapping in the Ruby Mountains suggests that the Angel Lake unit includes rocks correlative with the Precambrian schist of

the Ruby Mountains and, possibly, some of the overlying Paleozoic rocks, as well as mixed rocks that are partly of intrusive origin. The Snow Water unit is probably largely early Paleozoic. Most of the metamorphism observed by Snelson (1957, p. 14) is synkinematic; some rocks are polymetamorphic because of mylonitization along thrust planes.

MESOZOIC ERATHEM

Gneiss [Mzgn]

The rocks in the gneiss (pl. 1) unit crop out in the central Ruby Mountains [49A] (Howard and others, 1979). They include biotite granodiorite gneiss, which occupies the core of the Lamoille Canyon nappe; muscovite-biotite-garnet gneiss, which forms a sill in the upper limb of the Lamoille Canyon nappe; and biotite-quartz monzonite gneiss at Secret Peak. All these rocks are, compositionally, granite (Streckeisen, 1967) and consist partly of metasedimentary and partly of orogenic igneous or metaigneous rocks.

PROTEROZOIC AND PHANEROZOIC EONOTHEMS

Migmatite [m]

The migmatite unit (pl. 1) includes Jurassic and Tertiary granite and the Tertiary Harrison Pass Granodiorite (discussed as the Harrison Pass pluton in the section entitled "Plutonic Rocks," and relicts of quartzite of Precambrian and Cambrian age (discussed in this section). Intimate admixture of these various rock types precludes showing them separately at the scale of the geologic map.

TECTONICS

Introduction

In reviewing the tectonic history of Elko County, it should be remembered that the great extent of the area under consideration—approximately 2° of latitude by 3° of longitude. Several events that left a conspicuous record in one part of the county had little visible effect in another. As in every extensive area with a long history, the younger deposits both put a lower limit to the age of earlier events and obscure the evidence of these events in many places. In Elko County, the older tectonic events affected chiefly the Paleozoic rocks; the Mesozoic sedimentary rocks are extremely limited in their distribution, and so dating of the events that occurred just before the beginning of the Mesozoic is very uncertain. In the latitudinal belt that extends for more than 70 mi, from Mountain City to Contact, dating of the plutons (Coats and others, 1965; Coats and McKee, 1972) supplies some constraints on orogenic dating.

As indicated earlier, one of the most striking features of the topographic relief in Elko County is the contrast between the northerly-southerly trending fault-block mountains with their intervening basins in the south two-thirds of the county, and the broad, east-trending belt of generally elevated country without pronounced fault-block-range topography in the north third of the county. The structural basis for this physiographic contrast is largely attributable to differences in tectonic style between the areas. One of these tectonic events is very young—the relatively early diminution in basin-and-range tectonics in the northern part of the county, in comparison with the southern part. The other event, chiefly Mesozoic, in part possibly late Paleozoic, is expressed chiefly by the prevalence in the northern part of the county of east-west-trending orientations of the bedded rocks and, where schistosity is present, of schistosity of similar trends. The event is also expressed by the prevalence of southward-directed thrusts that can generally be dated only as younger than the youngest consolidated sedimentary rocks that the thrusts cut, generally of late Paleozoic or early Early Triassic age, and older than the Jurassic and Cretaceous plutons that cut them.

The easterly trends in the Mountain City area were first recognized by Nolan (1943, p. 177), who compared these trends with the easterly strikes described by B. S. Butler (Butler and others, 1920, p. 498) in the Raft River Mountains, Utah. The work of Compton (1972, 1975) and Compton and others (1977) in the Raft River Mountains has, however, demonstrated a complex history that differs from that in the Mountain City area. In the Raft River Mountains the youngest folding is that which created the broad domal uplift that outlines the present range; this folding affects "...the late Miocene sedimentary and volcanic rocks...so that its age must be Pliocene or early Pleistocene" (Compton, 1975, p. 5). It was preceded by a set of broad folds that have a generally northerly trend, which were formed concurrently with a west-dipping thrust. Some eastward thrusting, and southeastward thrusting attended with metamorphism, are as young as Miocene. These structures deform older thrusts and folds that suggest a tectonic transport from south to north, in exactly the reverse sense of the probable early Mesozoic deformation in northern Elko County.

Late Proterozoic and Early Cambrian Orogony

Evidence for tectonism between deposition of the Late Proterozoic McCoy Creek Group (Misch and Hazzard, 1962) and the overlying Early Cambrian Prospect Mountain Quartzite is sparse in Elko County because of the previously described disconformity between the McCoy Creek Group and the Lower Cambrian Prospect Mountain Quartzite in the Egan and Snake Ranges in Nevada, and in the Deep Creek Range of Utah.

In the Schell Creek and southern Snake Ranges, Misch and Hazzard (1962) described a weak regional metamorphism, thought by them to be Mesozoic, extending upward through the Lower Cambrian Pioche Shale. In the Ruby Mountains, Kistler and Willden (1969) reported a strong angular unconformity between

the Precambrian schist, metamorphosed in the sillimanite zone about 550 m.y. ago, and the overlying Prospect Mountain Quartzite, metamorphosed only to biotite grade. In the Jarbidge, Rowland, and Mount Velma quadrangles, Coats (1964) recognized only a slight disconformity between quartz-mica schist assigned to the McCoy Creek Group and overlying quartzite assigned to the Prospect Mountain Quartzite. The differences in metamorphic grade are slight and are confused by later thermal metamorphism attributed to the Cretaceous Coffeepot stock (Bushnell, 1965, 1967).

In the Mount Velma quadrangle, small amounts of yellowish and reddish phyllite resting on the Prospect Mountain Quartzite (not separately shown on pl. 1) may be correlative with the Pioche Shale and, by reason of their very low grade metamorphism, suggest that a post-Early Cambrian orogenic episode affected these rocks, if only to a slight degree.

Ruby Disturbance

In the central Ruby Mountains, Willden and Kistler (1967) postulated the presence of an angular unconformity between the Pogonip Group, here of Early and Middle Ordovician age, and the Lone Mountain Dolomite of Silurian age. In the southern Ruby Mountains, according to Willden and Kistler (1967), the Eureka Quartzite and the overlying Ely Springs Dolomite of Middle and Late Ordovician age are locally preserved but separated by an unconformity from the overlying Lone Mountain Dolomite. Hose and Blake (1976, p. 9) explained these relations by a disconformity at the base of the Eureka, which lenses out in the southern Ruby Mountains.

Willden and Kistler (1967) suggested that the post-Pogonip and pre-Lone Mountain unconformity, as described by them, gives evidence for the extent of tectonic activity at that time; they called this activity the "Ruby disturbance". I accept their term here, and I offer some scanty evidence that helps to further the interpretation that the Ruby disturbance may have substantially affected both the northern part of Elko County and part of Eureka County.

In the Rowland quadrangle, Bushnell (1967) recognized the Tennessee Mountain Formation, a formation of Cambrian or Ordovician age, which is unconformably overlain by rocks equivalent to the Strathearn Formation. The western part of the belt of the Tennessee Mountain Formation is phyllitic and of higher metamorphic grade than the allochthonous Ordovician rocks of the Valmy Formation that are present nearby. The metamorphism of the Tennessee Mountain Formation, which does not affect the overlying Strathearn Formation, may be attributable to the Late Ordovician Ruby disturbance. The significance for this area of this contrast in metamorphic grade is rendered somewhat doubtful by the fact that the Tennessee Mountain Formation is probably allochthonous or parautochthonous and was brought into the Rowland quadrangle in a major thrust plate. The extent of movement on this thrust plate is impossible to estimate. There seems to be widespread evidence of two unconformities (local disconformities) in this part of Nevada during the early Paleozoic: one at the base of the Eureka Quartzite, and the other at the top of the Ely Springs Dolomite or the Hanson Creek Formation (Langenheim and Larson, 1973, chart 2). Modest changes in the thickness of formations above and below these unconformities (or disconformities) do not suggest intense tectonism at either time except in the Ruby Mountains. The local extent of this intense disturbance may be reflected in the nearly complete elimination of the Eureka and Ely Springs in the central and southern Ruby Mountains.

Tooele Arch

During Middle Ordovician time, an emergent element or ridge developed in western Utah and extended westward across Elko County as far as Cortez, Eureka County. This element was called the Tooele arch by Webb (1958) and renamed the Cortez-Uintah axis by Roberts and others (1965). It has not been recognized west of Cortez because of tectonic overlap by western-assemblage rocks, which were thrust eastward during the Antler orogeny.

Early Mississippian Orogeny

Tectonic disturbances to which an Early Mississippian age can reasonably be attributed are few, partly because of the scarcity of disturbed and overlapping rocks of suitable age.

In the Mountain City area, Coats (1969) described the Grossman Formation, which was originally considered to be Devonian or Mississippian. Its composition, largely clasts derived from the Valmy Formation and possibly from other formations of the western assemblage, suggests that its coarse clastic content reflects a deformation accompanying the Antler orogeny, which is not earlier than latest Devonian in this area (Smith and Ketner, 1977, p. C3). Furthermore, stronger deformation of the Grossman Formation than of the Banner Formation, of Osagean or Meramecian (latest Early or early Late Mississippian) age, suggests not only that the Grossman itself is Early Mississippian but also that the orogenic episode that deformed it is also Early Mississippian. A similar episode of deformation was recognized by Nilsen (1977, p. 284) in the Copper Basin area of south-central Idaho.

Antler Orogeny

Probably the most significant tectonic feature in Elko County is the Roberts Mountains thrust. The Roberts Mountains thrust, originally described in the Roberts Mountains, Eureka County, by Merriam and Anderson (1942), was the principal event, or sequence of events, of what has been called the Antler orogeny (Roberts, 1964). The Roberts Mountains thrust, as defined by Smith and Ketner (1977), brought lower Paleozoic siliceous and volcanic rocks over lower Paleozoic carbonate rocks; they considered the displacement to have occurred during late Late Devonian to early Early Mississippian time. As Smith and Ketner (1977) pointed out, it is by no means certain that every thrust fault displaying these structural relations is coeval, and it is

uncertain that the Roberts Mountains thrust fault, as developed in Elko County, is precisely contemporaneous with the fault in its type area in the Roberts Mountains.

Ketner (1977, p. 363) dated the Antler orogeny as Early Pennsylvanian. One striking aspect of the dating of the Antler orogeny by Smith and Ketner (1968) is the overlap of the thrust in the northern Carlin-Piñon Range area by the Webb Formation, which is composed of relatively fine grained rocks; this relation implies that the subaerial terrain immediately after thrusting was one of subdued relief. The occurrence of foraminifers of latest Kinderhookian age in rocks correlated with the Webb Formation in the Fish Creek Mountains and the Antelope Range, as reported by R. K. Hose (oral commun., 1979) and Hose and others (1979), suggests possible changes in the date of the Roberts Mountains thrust in Elko County. In Elko County, the presence of the Roberts Mountains thrust has been inferred in many places and by various workers where Early Paleozoic rocks of the western assemblage have been observed, and especially where these rocks have been found in fault contact with underlying carbonate rocks, regardless of their age. One of the earliest maps indicating the position of this thrust in northern Elko County was that by Roberts and others (1965, fig. 4), reproduced here as figure 8. The more restrictive definition adopted in this report, which limits the term to those thrust segments in which western-assemblage rocks have been thrust over Paleozoic rocks of the eastern assemblage no younger than earliest Mississippian, results in a drastic reinterpretation of the course of the Roberts Mountains thrust in northern Elko County.

Smith and Ketner (1968, 1977) demonstrated a Late Devonian or early Early Mississippian age for the Roberts Mountains thrust and genetically associated structures in the Carlin-Piñon Range area. Smith and Ketner (1977, fig. 2) showed three windows of the lower plate as well as structures assumed to be similar in age, in the upper plate. These thrusts are confined to a north-south-trending belt in the Piñon Range.

North of the Humboldt River, the Roberts Mountains thrust next crops out in the Swales Mountain quadrangle, where the lower plate includes a Lower Mississippian (Kinderhookian) limestone turbidite (Ketner, 1970). Evans and Ketner (1971), who mapped this area, were in some doubt whether this thrust, somewhat younger than that in the Adobe Range, could properly be regarded as part of the Roberts Mountains thrust; earlier, Ketner and others (1968) had regarded this thrust as part of the Roberts Mountains thrust. It is accepted here, and the possible timespan of thrusting must extend from the latest Devonian or earliest Mississippian through the Kinderhookian (Early Mississippian).

North of Swales Mountain [30] Lovejoy (1959) mapped Ordovician and Silurian rocks of the western assemblage thrust over Devonian limestone of the eastern assemblage. In the Blue Basin quadrangle [30], Ketner (1974) mapped Devonian rocks of the western assemblage, including chert, metaquartzite, sandstone, limestone, greenstone, and barite. The absence of any involvement of post-Devonian rocks in the thrust suggests that this thrust also may be part of the Roberts Mountains thrust.

The tectonics of northern Elko County has been recently reviewed by Coats and Riva (1983). They discuss one of the most conspicuous and persistent features described in the geologic sketches that have been published in the past 25 years—the great eastward bulge in the Antler orogenic belt, first suggested, as nearly as I can determine, by Roberts and others (1965) (fig. 8). These authors, and many later writers, have used a line approximating that of Roberts and others (1965, fig. 4) and have likewise referred to it as denoting the leading edge of the Roberts Mountains thrust plate, generally understood as marking the easternmost position in which early Paleozoic rocks of the western assemblage were found resting in tectonic contact on early Paleozoic rocks of the eastern assemblage. In some places, the mere presence of the western assemblage has been taken as evidence that a thrust plate of these rocks moved into the area at the time of the Antler orogeny. Three explanations have been offered for this bulge: the first, tacitly favored by the earlier writers, is that of a simple bulge in the position of the leading edge of the thrust, which is assumed to have traveled farther eastward in northern than in southern Elko County. A second explanation, first proposed by Stewart and Poole (1974), is that of an "oroflexural feature," deforming the originally more nearly rectilineal course of the Antler orogenic belt. A third explanation (Thorman, 1970; Thorman and Ketner, 1979) is that of right-lateral displacement on a west-northwest-trending strike-slip fault, the "Wells fault," said by Thorman (1970) to pass through Pequop Summit in the Pequop Mountains and extended by some writers great distances to the southeast and northwest. The principal thesis in the discussion of Paleozoic and Mesozoic tectonism in northern Elko County is that none of these explanations is capable of explaining the field data accumulated as a result of many years of detailed mapping in the eastward-trending "overthrust belt" of northern Elko County.

The northwesternmost known occurrence of the Roberts Mountains thrust in Elko County and the most critical one for a reconstruction of the tectonic history, is in S6,T45N,R55E (Coats and others, 1984), nearly in the center of the southeast quarter of the Mountain City 15′ quadrangle, where its approximate position can be traced along a wooded slope for about 3,700 ft. Although exposures are poor, the thrust seems to dip northwest at an angle slightly steeper than the valley slope. The trend of the thrust is nearly northeastward; it terminates on the southwest against a northwest-trending high-angle fault. This high-angle fault trends about N40°W, a small sliver of the thrust is displaced to the northwest with respect to the main outcrop. If the displaced sliver represents drag, reflecting movement on the high-angle fault, then the displacement is a right-lateral shift, and the scanty distribution to the west of possibly displaced exposures of the lower plate suggests total shift on the high-angle fault of a few miles at most. The upper plate, composed of the Valmy Formation, trends generally northeast, parallel to the Roberts Mountains thrust, just to the northwest of its mapped position. These rocks form part of a belt of the Valmy in which the rocks have the same trend as the mapped trend of the thrust, although the Valmy continues

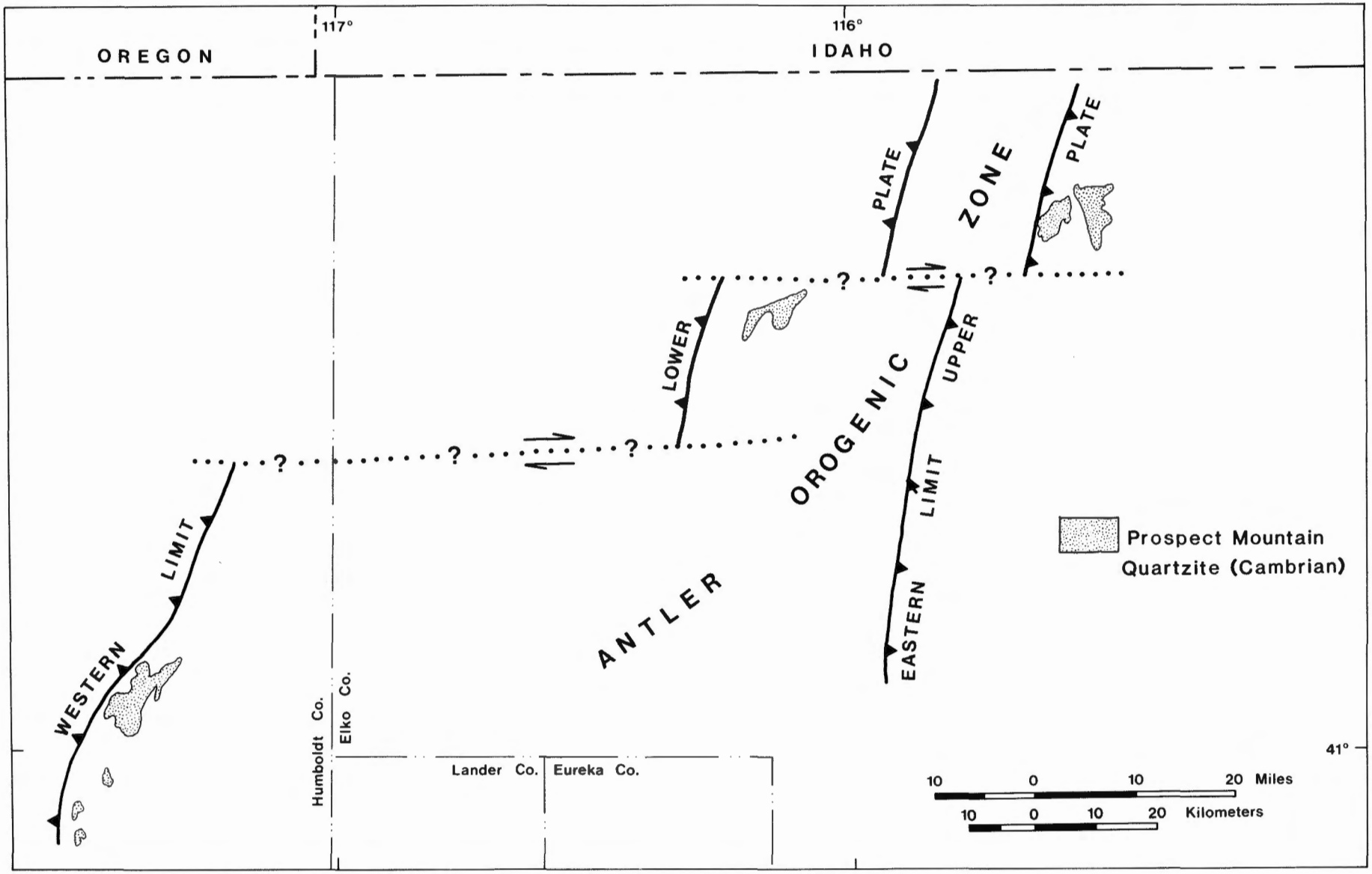


FIGURE 8. One of the earliest maps showing the approximate position of the Antler orogenic belt in Elko County (Roberts and others, 1965, fig. 4).

northward, beyond the place where the thrust is overlapped by Tertiary rocks, for about 9,500 ft on a trend that swings on a long-radius arc to nearly due north. The lower plate, which here consists of the Goodwin Limestone of the Pogonip Group, forms most of the surface for a strip extending southeastward from the thrust for a distance of about 1½ mi, although the width of outcrop gives a deceptive impression of the thickness because the limestone beds of the Goodwin have been thrown into a succession of tight folds occupying the whole distance without any noticeable diminution in the intensity of folding and with fold axes generally paralleling the trend of the thrust, where exposed. Although the original thickness of the Goodwin Limestone here is unknown, a thickness of about 1,000 ft may be inferred from the work of Nolan and others (1956) in the Eureka mining district.

The most probable explanation for the kind, orientation, and type of folding in this area is that the deformation is due to the Roberts Mountains thrust; the Goodwin may have been sheared away from the underlying Cambrian rocks along a subsidiary bedding-plane thrust. It might be argued, from the considerable lateral extent of this deformation, that a deeper level of the Roberts Mountains thrust is visible here. The next formation of the eastern (or transitional) assemblage, going eastward, is the Tennessee Mountain Formation of Cambrian or Ordovician age, separated from exposures of the Goodwin by overlapping Tertiary rocks. Although the Tennessee Mountain Formation is believed to be part of the upper plate of a north-dipping southward-moving thrust that is post-Early Permian, it is not clear how far it may have moved, and the degree of deformation within the Tennessee Mountain, which is much more intense in the western than in the eastern part of its belt of exposures (Bushnell, 1967), cannot readily be used to estimate its distance from the Roberts Mountains thrust. The trend of folds in both the Valmy and the Goodwin, near the mapped part of the Roberts Mountains thrust, might be interpreted as indicating postthrust drag in a right-lateral sense along the northwest-trending high-angle fault mentioned previously. The extent of right-lateral shift is difficult to estimate because of the near-absence of exposures of the Goodwin to the south as far as the Independence Mountains, although this shift is probably no more than 15 or 20 mi.

In the Mount Velma quadrangle, just north of Cornwall Mountain, black chert of the Valmy Formation rests in thrust contact on the Cambrian Prospect Mountain Quartzite. This thrust might be regarded as a part of the Roberts Mountains thrust. An alternative hypothesis, that major thrusting in the northern part of the Mount Velma quadrangle is early Mesozoic, seems more attractive because only a few hundred feet from the thrust that brings the Valmy over the Prospect Mountain, the Strathearn Formation of Late Pennsylvanian and Early Permian age is thrust over the Valmy, and a short distance farther east, the Valmy is thrust over the Strathearn.

One critical area for tectonic interpretation is in the Snake Mountains [15], where Gardner (1968) mapped two major thrusts and inferred the presence of another at depth. The two exposed thrusts mapped by Gardner are: the Stormy Mountain thrust above and the Currant Creek thrust below. The Stormy Mountain thrust separates the western assemblage from the eastern assemblage; the Currant Creek thrust separates the eastern assemblage from the underlying transitional assemblage. The inferred thrust was thought by Gardner to underlie the transitional assemblage. All of these thrusts, including the inferred lowermost, belong to a closely related structural group (Gardner, 1968, p. 146). Regional facies differences in the rocks of the several thrust plates suggest that movement was from the west, the northwest, or, less likely, the north (Gardner, 1968, p. 147). Folds in the western-, eastern-, and transitional-assemblage rocks have rotational senses and axial trends and plunges requiring that movement was southeastward. Gardner considered all these thrusts as related to the Roberts Mountains thrust, and movement on them as part of the Antler orogeny. However, John Riva (*in* Coats and Riva, 1976; John Riva, written commun., 1976) noted that the uppermost thrust, the Stormy Mountain thrust, cuts not only the western assemblage but also Pennsylvanian and Permian rocks that rest depositionally on them. Therefore, at least the uppermost of the thrusts mapped or inferred by Gardner in the Snake Mountains is later than the Roberts Mountains thrust and is not a product of the Antler orogeny. The axial trends in the lower plates suggest that the same is true of the two lower thrusts.

The evidence from the least disturbed areas, which lie along a north-south trend from the Piñon Range to Mountain City, suggests that the Roberts Mountains thrust, over this part of its total extent, has a similar trend. The western assemblage east of Cornwall Pass [19] was probably displaced substantially eastward on the Roberts Mountains thrust but owes its present position and structural association with late Paleozoic rocks to late Paleozoic or early Mesozoic rethrusting in more southerly directions than those characteristic of the Antler orogeny (Evans and Theodore, 1978), or to a right-lateral shift on a major southeast-trending high-angle fault.

Early Mississippian to Middle Pennsylvanian Uplift and Downwarp

After emplacement of the upper plate of the Roberts Mountain thrust, a north-south-trending linear uplift and parallel downwarp on the east formed along the leading edge of the plate (Poole, 1974). Some coarse gravel from the uplifted upper plate was deposited during the earliest Mississippian, as pointed out by Smith and Ketner (1977, p. C10). The time of deposition of the principal flood of coarse sediment, which implies a similar date for the major uplift in the source area, came about the middle of the Early Mississippian, later than the cessation of movement on the Roberts Mountains thrust in some areas; coarse gravel and very coarse boulder gravel continued to be deposited at intervals throughout Early Pennsylvanian time. The trough in which these rocks, the Chainman Shale and Diamond Peak Formation, were deposited had a generally northward extension and very little divergence in trend, contrary to some hypotheses, as far north as the Mountain

City 15′ quadrangle. In the southeastern part of the Mountain City quadrangle, rocks that are temporally correlative with the Diamond Peak, according to a fossil identification by Mackenzie Gordon, Jr. (field no. G2NC306, 348) are overlapped tectonically by southward-directed thrusts. Ketner (1977), in his review of the Pennsylvanian and Permian, called attention to the fact that some parts of the Diamond Peak, in the area just north of Elko, are actually red beds. Similar red beds were observed in the western part of the Mount Velma quadrangle (R. R. Coats and L. D. Cress, unpub. data, 1972), where they are virtually unfossiliferous; the presence of a few small pieces of crinoid stems suggests that these beds were deposited in marine waters and were the products of erosion in an oxidizing environment. Farther north in the Mountain City 15′ quadrangle, rocks correlated with the Diamond Peak are impure, dark sandstone and shale deposited in a reducing environment.

Humboldt Disturbance (Humboldt orogeny of Ketner, 1977)

Ketner (1977) named and indicated the geographic extent of a tectonic episode, the Humboldt orogeny. The time limits of the Humboldt orogeny, as set by Ketner (1977), are from late Middle Pennsylvanian to early Late Pennsylvanian. The disturbance is defined on the basis of an unconformity; the youngest beds below the distinguishing unconformity are early Desmoinesian, and the oldest beds in the sequence resting on the unconformity are Missourian. According to Ketner (1977), generally little or no angular discordance is noticeable between beds above and below the regional unconformity, although locally, as in Carlin Canyon, the contact is discordant. This unconformity in Carlin Canyon was apparently first described by Dott (1955), who showed that the Strathearn Formation of Late Pennsylvanian and Early Permian age is unconformable on middle Mississippian strata. Beds temporally correlative with the Strathearn are present farther north in Elko County. Just north of the 41st parallel, in the Tuscarora Mountains, they are apparently autochthonous; farther north, beds of similar age and lithology are allochthonous or parautochthonous. Autochthonous beds of this age in Elko County north of lat 41°30′N are limestone and shale in large part and, unlike the Strathearn, lack coarse clastic materials. The Strathearn Formation also occurs in the Snake Mountains [15] (Gardner, 1968) and the in Windermere Hills [26] (Oversby, 1972); and is apparently allochthonous in each of these areas. The same is true of the Permian Edna Mountain Formation in Elko County, as in the Divide Peak area (Coats and Gordon, 1972), and in the Beaver Peak quadrangle. The thinness of the coarse clastic parts of these units suggests that no great amount of material was available for erosion. In summary, the evidence in Elko County does not suggest a major orogeny, comparable to the Antler, during Pennsylvanian time; I suggest that the term "Humboldt disturbance" rather than "orogeny" would be more appropriate here.

In the Carlin-Piñon Range area, Smith and Ketner (1977) observed a few northwest-trending folds that are probably Pennsylvanian, as well as two thrust faults also attributed to a Pennsylvanian deformation. Movement on the probable Pennsylvanian thrusts was generally eastward. Some thrusts in northern Elko County also may be attributable to this deformation, although the sense of the movement on many thrusts is southward. The southward thrust in the Owyhee 15′ quadrangle [3] that was formerly (Coats, 1971) called the Roberts Mountains thrust (now the Lime Creek thrust) must be post-Desmoinesian because it has emplaced the Valmy Formation on the Van Duzer Limestone, which is now known to be at least in part Desmoinesian. Thrust movement of post-Early Pennsylvanian age was well dated in the northern Adobe Range by Ketner (1973), and the direction of movement appears to be similar to that of Kerr's (1962) Seetoya thrust, that is, south-southeastward. In the southern part of the Reed Station quadrangle, bedding orientations in the upper plate of western-assemblage rocks, which are thrust southward over a plate of western assemblage rocks that include Ordovician limestone, suggest that the western-assemblage of the upper plate forms part of the same thrust sequence mapped by Kerr.

Late Paleozoic to Late Mesozoic Orogenies

The time distribution of orogenic pulses in Elko County during the later Paleozoic and the Mesozoic is determinable only with difficulty. The youngest known Triassic rocks are limited to the Early Triassic; stratified Jurassic and Cretaceous rocks are restricted the southwestern part of the county (Smith and Ketner, 1976), except for continental rocks near Currie. Jurassic and Cretaceous granitic rocks, though widespread in the county, are not as well distributed geographically as one might wish for tectonic dating.

In southern Elko County, as well as in parts of White Pine County, Nevada, and in northwestern Utah, two contrasting tectonic styles are prevalent in the deformed Precambrian, Paleozoic, and Mesozoic rocks. One style characterizes the suprastructure, the other the infrastructure. The suprastructure is predominantly characterized by low-angle overthrusts, generally slight metamorphism, and crosscutting plutons. The infrastructure is characterized by intense isoclinal and recumbent folds, strong penetrative deformation, high-grade metamorphism, and plutons with gneissic structures (Howard, 1966b, 1980; Howard and Armstrong, 1968; Snoke, 1974, 1980). Most of the following discussion of the tectonics in northern Elko County is devoted to the suprastructure; the infrastructure is well exposed in the Ruby Mountains and East Humboldt Range [39, 39A, 45, 45A, 48, 49]. These ranges are dealt with separately as the Ruby-East Humboldt metamorphic core complex.

In northern Elko County, dating of the various thrusts is difficult because of the absence of well-dated overlapping rocks except in the Tertiary. In part, the sole pertinent evidence is whether the thrusts were intruded by, or were deformed by, datable plutonic-rock bodies. The inferred direction of thrusting in this area of tight imbrication, as outlined in figure 9, depends largely on the orientation of trends of the folded rocks in the upper or lower plate. Such folds, however, are in

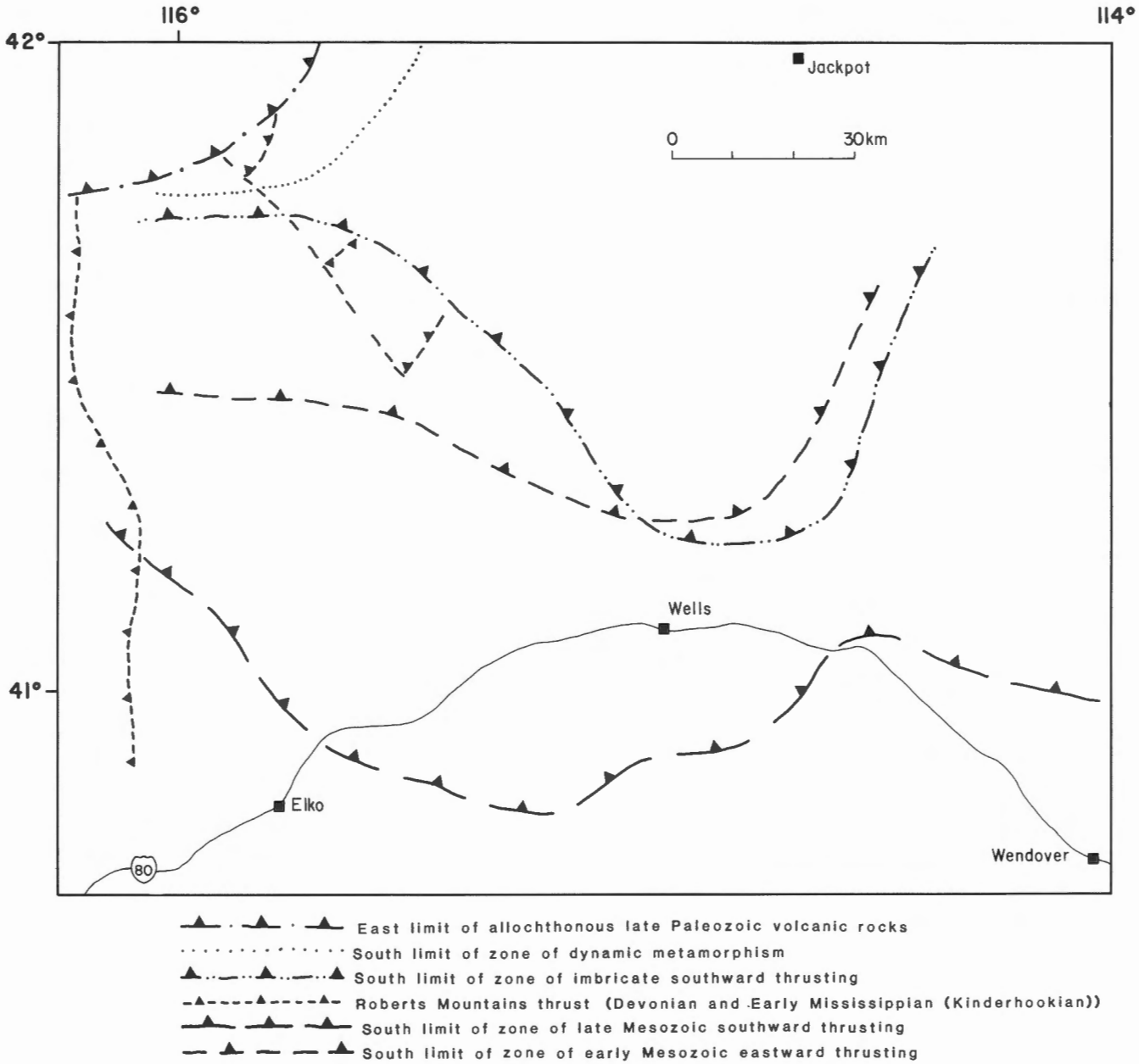


FIGURE 9. Some approximate tectonic boundaries in Elko County. Boundaries indicated are in part generalized boundaries of thrust plates, each composite, but all the members of which are regarded as moving in the same general direction within a limited period. Other boundaries shown are approximate limits of blocks of the crust undergoing a similar intensity of deformation as well as having a similar predominant direction of movement. The oldest thrust shown is the Roberts Mountains thrust, of Devonian and Early Mississippian (Kinderhookian) age; its boundary marks the west limit of rocks of the eastern and transitional assemblages. It is cut by a right-lateral strike-slip fault, the Haystack Mountain fault, northeast of which an outlier of western-assemblage rocks is present as far south as the southern part of the Mount Velma quadrangle. This strike-slip fault disappears to the northwest beneath late Paleozoic rocks, Mesozoic granitic intrusive bodies, and Tertiary volcanic rocks. Dot-dashed line in northwestern part of map indicates southern limit of thrust plates containing a substantial component of mafic volcanic rocks of submarine origin, such as the Nelson Formation, the Mitchell Creek Formation, and the slate of Sikikareh Mountain (Coats, 1962). The southern limit of the zone of dynamic metamorphism (dotted line) is less precise but probably has a northeastward trend through the Mountain City, Rowland, and Jarbidge 15′ quadrangles. The southern limit of the zone of imbricate southward thrusting is still less definite because it depends on the scale of mapping used in the maps from which the geologic map (pl. 1) was compiled and on the degree to which individual units were subdivided in mapping. The southern limit of the zone of early Mesozoic eastward thrusting is based on present distribution of Early Permian rocks, such as those of the Edna Mountain Formation and the Carlin sequence (amended). The southern limit of the zone of late Mesozoic southward thrusting is drawn along a line where generalized trends of the rocks change from northward to eastward. Admittedly, many outliers of this thrust zone are to be found still farther south.

many areas extremely difficult to find, and in some places the dating of folds is ambiguous because of successive episodes of thrusting from several different directions. The following description of thrusting begins in southwestern Elko County and progresses northward and then eastward.

Just north of the Elko-Eureka County line, in the Tuscarora Mountains, the summit of Beaver Peak is made up of a erosional outlier, only a few hundred feet thick, of late Paleozoic rocks, the basal part of which is a calcareous conglomerate consisting of typical Strathearn lithology and typical Strathearn fossils. The lower part of the outlier is a nearly flat lying conglomerate, whereas the upper part is a cherty limestone that dips about 30°E. This rather startling discordance, with deformation increasing upward, is thought to reflect the former presence of a thrust in Paleozoic rocks of the western assemblage that formerly passed some short distance above the top of what is now Beaver Peak.

Just to the west of Beaver Peak is a nearly flat-lying erosional outlier of rocks that are lithologically correlated with the Edna Mountain Formation, that rest unconformably on the lower Paleozoic western assemblage, and that appear to resemble closely the Edna Mountain Formation in the vicinity of Divide Peak some distance to the northeast (Coats and Gordon, 1972). No fossils have yet been found in these rocks, which are here ascribed on a lithologic basis to the Edna Mountain Formation. Although the Strathearn is probably autochthonous, or nearly so, in this area, the deformation of the rocks beneath the western assemblage may in part be ascribable to a late Middle to early Late Pennsylvanian deformation, possibly part of the Humboldt orogeny of Ketner (1977).

In several places, more than one plate of the western assemblage has evidently been emplaced by thrusting; in addition, some of these rocks were evidently emplaced by thrusting from several different directions. One such place is just to the north of Lone Mountain in the Reed Station quadrangle [30B]. The lower plate here contains a limestone reef or mound of the type described by Ross (1977). Immediately above it is a plate of the western assemblage made up largely of shale and chert, that, judging from the orientation of its fold axes, has been thrust southward. Although the date of this southward thrusting in the Reed Station quadrangle is not apparent, in the area farther northwest [21], where Kerr (1962) mapped, the western assemblage was clearly thrust from the north-northwest. Thrusting of these rocks across the Water Pipe Canyon Formation (Kerr, 1962), which seems to be a facies of the Mississippian Chainman Shale, indicates south-southeastward thrusting during post-Mississippian time.

A similar direction of thrusting probably accounts for some of the deformation in the western assemblage that is visible on the east flank of the Independence Mountains in the area of Pratt and Foreman Creeks, where the bedding stands vertically and trends nearly east-west, in considerable contrast to the bedding of the high peaks, McAfee Peak and Jacks Peak, where the massive McAfee Peak Quartzite (Churkin and Kay, 1967) dips gently west. These west-dipping rocks of the western assemblage bear on their surfaces the unconformably overlapping lower or shallow-water facies of the sedimentary clastic and limy rocks of Chesterian age [11]. Overlapping these sedimentary clastic and limy rocks of Chesterian age in the southern part of the area mapped by Churkin and Kay is a small patch of rock in which Churkin and Kay found fossils that Mackenzie Gordon, Jr., thought might be Mississippian to Permian in age. Examined in the field, these rocks seemed to me to be lithologically identical with those in the Edna Mountain Formation, which is present on the east flank of the Independence Mountains and across the valley of the North Fork of the Humboldt River in the Divide Peak area (Coats and Gordon, 1972). The date of the southward thrusting that emplaced the plate beneath that carried the Edna Mountain and the Schoonover Formations is suggested by the presence, along the east flank of the Independence Mountains, of the Banner Formation (field no. 66NC7, 70CS, 337, 339). It is significant that the Banner here is not overlain by the mafic volcanic rocks of the Nelson Formation, as in the Mountain City and Owyhee 15′ quadrangles, so it may be autochthonous.

In the Mountain City and Owyhee 15′ quadrangles, the Banner Formation rests on the western assemblage, which is highly deformed in this area and apparently has undergone more than one period of intense deformation before the Banner was deposited on the erosional surface. One of these earlier deformations may very well have been part of the Antler orogeny; these post-Antler(?) rocks form part of the Grossman Formation (Coats, 1969), which is unconformably overlain by the Banner. However, because both of these formations rest unconformably on the Valmy Formation, all three formations may have been transported into this area from considerably north of their present position. It is noteworthy that in the Owyhee 15′ quadrangle the Valmy has been thrust southward, as shown by mullion structures on the Lime Creek thrust, formerly (Coats, 1971) called the Roberts Mountains thrust. The Valmy in this area is probably a dismembered or broken formation as the result of having been thrust repeatedly in several different directions; it contains two well-defined beds of light- to dark-gray quartzite that have been broken into discontinuous lenses in the Owyhee 15′ quadrangle (Coats, 1971) and in the southwestern part of the Mountain City 15′ quadrangle (Coats, 1968a). Rare minor folds in this part of the Valmy plunge steeply north and suggest movement in a right-lateral sense.

Resting in thrust contact on the Mountain City Formation is a unit that was named the Reservation Hill Formation by Coats (1969). The Reservation Hill, for the purposes of this report, is here mapped with the Havallah Formation **[PIPhr]**, although it shows considerable lithological contrast with the Havallah, and may have been deposited in a different tectonic environment. The Reservation Hill consists largely of fine siltstone and shale, and includes some interbedded lenses of limestone and one substantial flow of andesitic lava. The thrust surface of the Mountain City thrust, on which the Reservation Hill Formation has been thrust over the Mountain City, shows clear mullion structures that dip gently north. The same thrust reappears in the central part of the Mountain City 15′ quadrangle, north of the Mountain City granodiorite pluton, where the

upper and lower plates show a somewhat similar relation. In the eastern part of the Mountain City 15′ quadrangle, several imbricate thrust plates are present, all of which apparently moved southward; some imbricate sets are separated from others by north-trending tear faults. In several of these sets there is repetition of the Mississippian Banner Formation and the overlying Nelson Formation, as well as of the Reservation Hill Formation. To the east of these late Paleozoic rocks, the Paleozoic rocks generally disappear under the Tertiary volcanic rocks, which occupy a considerable part of the western part of the Rowland quadrangle.

In the southeastern part of the Mountain City 15′ quadrangle, the southern part of the Rowland quadrangle, and the extreme northern part of the Mount Velma quadrangle, the Strathearn equivalent, called the Sunflower Formation by Bushnell (1967) and Coash (1967), stands vertically or is overturned southward and rests depositionally on what was named the "Tennessee Mountain Formation" by Bushnell (1967). The Tennessee Mountain Formation is apparently part of the transitional assemblage. In the southwestern part of the Rowland quadrangle and the southeastern part of the Mountain City 15′ quadrangle, the Tennessee Mountain is a shaly limestone in which some fossils of Cambrian or Ordovician age have been collected (field nos. 62NC40, 44).

The thrust plate that includes the Strathearn equivalent and the Tennessee Mountain Formation is separated on the west from rocks that are equivalent to the Diamond Peak Formation (though rather finer grained than most of the Diamond Peak in this area) by a tear fault, and on the south from limestone, that ranges in age from Mississippian to Permian, by a north-dipping thrust fault that is poorly exposed in the Mount Velma quadrangle. However, near the common corner of the Wild Horse, Mountain City, Mount Velma, and Rowland 15′ quadrangles, this southward-directed thrust that apparently brought in from the west rather tightly folded rocks which are lithologically and temporally equivalent, at least in part, to the Phosphoria Formation (field nos. 60NC10, 11). Farther east in the Mount Velma quadrangle, the Phosphoria has not been recognized, although the Strathearn reappears several times in thrust contact with the late Paleozoic limy rocks and with the early Paleozoic western assemblage.

In the northeastern part of the Mount Velma quadrangle and the northwestern part of the Marys River Basin NW quadrangle, the late Paleozoic rocks are preserved by a Tertiary normal fault that drops late Paleozoic rocks on the east against Precambrian schist and the Cambrian Prospect Mountain Formation on the west. The late Paleozoic rocks in this area range from latest Mississippian to Early Pennsylvanian (field nos. 69NC113, 117, 119); they trend nearly east-west and their dips range from rather steep northward to nearly vertical. It is evident, however, that these rocks (the late Paleozoic limestone and shale of this report) are overturned because the north-dipping Mississippian rocks are in the northernmost part of the exposure, where they have been overridden by a thrust plate of chert and shale of the Valmy on which rests a small remnant of flat-lying (Osagian or Meramecian) limestone and conglomerate of the Banner. At the north end of the exposure of the late Paleozoic rocks, conglomerate and limestone of the Strathearn reappear in a thrust plate that overrides the Valmy. To the east, relations are obscured by Tertiary volcanic rocks up to the area of the Jarbidge Wilderness in the Marys River Basin NW and Marys River Basin NE quadrangles. Here complex imbricate thrusting has brought the western assemblage over east-trending sandstone and shale, probably Triassic, which are vertical or overturned to the south by the southward thrusting and now dip steeply north. This thrust is apparently younger than that exposed to the east in the valley of Camp Creek in the Jarbidge Wilderness, in the Marys River Basin NE quadrangle (Coats and others, 1977), although the exact relation between these two thrusts cannot be determined. In the valley of Camp Creek, late Paleozoic limestone and shale rest in thrust contact on the Pogonip Limestone.

POST-EARLY TRIASSIC DEFORMATION

Lower Triassic marine rocks are widespread in eastern Elko County, from the Currie area northward almost to the Idaho state line and westward as far as O'Neill Pass; they generally rest either with slight unconformity on late Paleozoic rocks or with more pronounced unconformity on older rocks. This seems to be the limit of distribution of autochthonous Early Triassic rocks, although marine Lower Triassic rocks are also present a short distance north of the Carlin-Piñon Range area (Ketner, 1975). These rocks, according to N. J. Silberling (*in* F. Ketner, 1975b, p. 117), are early, but not earliest, late Early Triassic and rest apparently conformably on Late Permian rocks. This Permian and Triassic sequence, as well as some underlying late Paleozoic rocks of the northern Adobe Range, may be allochthonous. The amount of shift of the hypothetical thrust may be considerable, on the basis of the presence of intermediate volcanic rocks in both the Permian and Triassic sections, which suggests that these rocks are probably inner-arc-basin deposits and have been thrust eastward a considerable distance.

The Early Triassic rocks in the Mount Velma quadrangle, which are not as precisely dated, show ambiguous relations to the older rocks in some places. In a few places where the evidence is fairly clear, they seem to lie in thrust contact on the western assemblage or on conglomerate, probably the Diamond Peak Formation, that may also have been thrust in from the north, as the Triassic rocks are believed to have been.

SONOMA OROGENY

The Sonoma orogeny was defined by Silberling and Roberts (1962) as a tectonic event in late Early or Late Permian time; it was followed by folding and thrusting that commenced during the late Early Jurassic and persisted into the Cretaceous. The Jurassic and Cretaceous part of the orogeny has sometimes been correlated with the Nevadan orogeny. Silberling (1973) revised the earlier estimate of the age of the Sonoma orogeny to latest Permian and Early Triassic. The timing of the Golconda thrust, the most conspicuous manifestation

of the Sonoma orogeny in north-central Nevada, is bracketed between the age of the overlying Koipato Group, formerly thought to be Permian but now considered entirely Triassic, and the youngest formation under the thrust, the Edna Mountain Formation of late Early Permian age. Allochthonous rocks of the Edna Mountain Formation have been recognized in Elko County at several places; these occurrences were best documented in the Divide Peak area by Coats and Gordon (1972), who preferred to consider that the thrust sheets bearing the Edna Mountain Formation were emplaced during the Triassic.

The somewhat tentative Early Triassic date for thrusting of the Edna Mountain Formation into the Divide Peak area (Coats and Gordon, 1972) is supported by the work of Elizabeth Miller, her students at Stanford, and D. L. Jones of the U.S. Geological Survey (Miller and others, 1981), who subdivided the Schoonover Formation (Fagan, 1962) into two units, separated by a major thrust. The tectonically lower unit is a thin, shallow-water clastic facies carrying the fauna described for the sedimentary clastic and limy rocks of Chesterian age (field no. 66NC68), which rests on the Valmy and is overlapped by the Edna Mountain Formation. The tectonically higher unit is a much thicker deep-water chert, volcanic, clastic, and limestone facies, well described by Fagan, that is thrust across the shallow-water facies and the underlying Valmy. Miller and others suggested that this deep-water facies is correlative with the Havallah sequence of central Nevada and moved into its present position during the Sonoma orogeny. The general trends in the Schoonover Formation, as pointed out by Fagan (1962) suggest that the whole unit was compressed by forces directed southeastward. Farther to the west, in the Bull Run quadrangle [9], the sequence that includes the deep-water facies of the Schoonover is intruded by an undeformed pluton about 150 m.y. old (Coats and McKee, 1972). Therefore, the thrust plates in the Divide Peak area and in the northern Independence Mountains postdate the Early Permian Edna Mountain and predate the Jurassic intrusive body; it seems reasonable to attribute them both to the Sonoma orogeny, as Miller and others (1981) have suggested for the deep-water facies of the Schoonover.

The timing of southward-directed thrusting in the Owyhee 15′, Mountain City 15′, Rowland, Jarbidge, Mount Velma, Marys River Basin NW, and Marys River Basin NE quadrangles is similarly problematical. The latest Paleozoic sedimentary formation involved is the Reservation Hill Formation, to which a Pennsylvanian(?) and Permian(?) age was assigned by Coats (1969); the formation is intruded by middle Cretaceous granitic rocks. The age of southward-directed thrusting, therefore, must lie in the interval Permian to middle Cretaceous. Some of this thrusting may be old enough to be assigned to the Sonoma orogeny, although there is no compelling reason for such an assignment.

MESOZOIC OROGENIC MOVEMENT IN EASTERN ELKO COUNTY

In eastern Elko County, the absence of Cretaceous sedimentary rocks makes difficult the proof of any earlier orogeny. In southwestern Elko County, Ketner and Smith (1974) and Smith and Ketner (1977) were able to date one period of folding as Late Jurassic or Early Cretaceous.

In the HD Range, Riva (1962b, 1970; Coats and Riva, 1983) recognized no fewer than six major and, possibly, three minor thrusts resting on a basement of the Mississippian Chainman Shale or a late Paleozoic clastic sequence, intruded by the Contact pluton (pl. 1). The Chainman Shale itself is known to be part of a thrust plate in the northern Pequop Mountains, 50 mi southeast of the HD Range (Thorman, 1970). In both tectonic style and stratigraphic makeup, the northern part of the HD Range differs distinctly from the southern part, and so these two areas are here discussed separately.

In the northern HD range (Riva, 1970), the lowest plate, A, contains postorogenic clastic deposits of the Diamond Peak Formation lying unconformably on Ordovician and Silurian rocks of the western assemblage. This plate appears in several windows throughout the length of the range and is thrust over the Chainman Shale (pl. 1). East-southeastward thrusting of plate A is shown by folds of northerly-southerly trend overturned to the east-southeast. The two plates above, B and C, show large east-west-trending folds overturned to the south and, locally, the southeast; in the northern part of the range, drag folds indicate movement to the southeast. Plate C is an extensive but thin plate that has undergone considerable deformation during its translation; some segments apparently were rotated and moved independently. The larger folds of plate C are superimposed on older folds, generally north-south trending, believed to be Antler in age, probably developed at the site from which plate C moved. Plate D, the fourth from the bottom, consists entirely of the western assemblage and differs markedly in composition from plate B, which is made up of a transitional carbonate-siliceous-volcanic assemblage, and from plate C, which lacks the siliceous (chert) component. Plate D is entirely restricted to the north end of the HD Range, where it forms a succession of imbricate slices with drag folds, mullion structures, and slickensides on the lower plate that indicate south-southeastward movement. Plate E, the highest in the north-central HD Range, contains both the western assemblage (shale, volcanic rocks, chert, and siltstone) and a thick late Paleozoic overlap sequence that in part resembles that of the Elko-Carlin Canyon area (Dott, 1955; Fails, 1960), 60 mi to the southwest. Large overturned folds at the base of this plate indicate movement to the southeast. Another plate, referred to as the unnamed plate by Riva (1970) overlies plates A through C in the central HD Range and continues southward, where it lies across the highest thrust plates in the southern part of the Range. This plate, hereinafter referred to as plate H, was apparently emplaced last and came from the west-northwest rather than the north-northwest, as did the lower plates; it is discussed in greater detail in the next paragraph

In the southern HD Range, a major thrust plate, F, forms the backbone of the range and is thrust over plate A, the same plate recognized in the northern HD Range and tectonically the lowest known plate in the range. Plate F occurs as a succession of relatively undeformed

east-dipping monoclinal segments, consisting of the early Paleozoic western assemblage similar to the Valmy Formation of north-central Nevada (Roberts and others, 1958), and as a thick postorogenic overlap sequence, formed by the Strathearn, Buckskin Mountain (including a 500-ft-thick conglomeratic lens), and Beacon Flat Formations. The Beacon Flat is practically identical to that described by Fails (1960) in the Elko-Carlin Canyon area of western Elko County. Plate F is thrust over by two smaller plates, G and H. Plate G, which consists largely of the western assemblage with a small overlap sequence, is intensely deformed; drag folds locally indicate movement to the east-southeast. Plate G also carries a small segment of another plate consisting of a highly deformed western assemblage hitherto seen only in plates C and D in the northern HD Range. Plate H, though mostly restricted to the northern part of the southern HD Range, also extends into the central part, where it overlies rocks of plates A, B, and C. Plate H consists of a rather undeformed thick (at least 3,500 ft) postorogenic sequence that can be largely, though not entirely, related to that described by Fails (1960) in the Elko-Carlin Canyon area; it also consists deformed segments of western-assemblage rocks—largely chert of the Valmy Formation. Drag folds in the western assemblage at the base of the thrust plate and broader folds in the overlap sequence suggest movement in an east-southeasterly direction.

In the north-central HD Range [17], swarms of dikes radiating from the 150- to 160-m.y.-old Contact pluton (Coats and others, 1965) cut plates A through E; none, however, were observed cutting plates F through H in the south-central part of the range. This relation may indicate that the thrust plates in the north-central HD Range were emplaced before those in the southern part of the range, possibly during the Triassic or Early Jurassic, assuming that the dikes could as easily penetrate the southern part of the range as the northern part. This hypothesis is supported by a stratigraphy both in the western and overlap assemblages that differs significantly from that of plates in the southern HD Range, and by a direction of thrusting that was south-southeastward rather than east-southeastward. The thrust plates in the southern HD Range are believed to have been emplaced during a later, possibly Cretaceous, tectonic phase and to have moved in from the west-northwest. The stratigraphy of both the western assemblage and that of the postorogenic overlap assemblage also shows, with some exceptions, a remarkable similarity to that of correlative units in north-central Nevada, especially in the Elko-Carlin Canyon area.

In the Windermere Hills northeast of Wells [26] (pl. 1), Oversby (1969, 1972, 1973) mapped in detail a tectonic succession composed of two major and three minor thrust sequences comparable to those mapped in the southern HD Range to the northeast, the Snake Mountains to the west-northwest, and the Pequop Mountains to the southeast. The lowest thrust sequence, the Black Mountain sequence, lies tectonically on the Chainman Shale and thus repeats the relation already noted in the HD Range, which is seen also in the southern Snake Mountains. This sequence consists entirely of middle Paleozoic carbonate rocks (the Nevada Formation of former usage, the Guilmette Formation, and the Tripon Pass Limestone) capped by thick postorogenic Antler clastic deposits (the Diamond Peak Formation), and could be considered parautochthonous rather than allochthonous because it still lies well within the miogeosynclinal domain. Thrust over the Black Mountain sequence is the Thousand Spring sequence, a major tectonic unit formed by rethrusted segments of western-assemblage eugeosynclinal rocks and Upper Devonian limestone of the transitional assemblage, all topped by an overlap succession consisting of the Strathearn, Buckskin Mountain, and Carlin Canyon Formations of late Paleozoic age, and the Dinwoody and Thaynes Formations of Triassic age. Oversby (1972, p. 2680–81) identified Ordovician and Silurian units that were distinguished by Riva (1970) in the north-central HD Range among western-assemblage rocks of the Windermere Hills; Riva (1970) has since recognized similar units in much of the Snake Mountains to the west-northwest. It should be noted here that carbonate rocks of the transitional assemblage resemble the Devonian limestone mapped by Evans and Ketner (1971) on Swales Mountain, 60 mi to the west and north of Carlin Canyon. The overlap succession resembles that of Carlin Canyon (Fails, 1960), except that the Beacon Flat Formation (Fails, 1960) is absent between the Buckskin Mountain and Carlin Canyon Formations; this succession is also practically identical to that described by Bezzerides (1967) and Gardner (1968) from the northern Snake Mountains and resembles that of plates F and H in the southern HD Range, except that the Beacon Flat Formation is widely exposed there, whereas chert of the Carlin Canyon Formation and the Triassic limestone are absent.

The three minor thrust sequences in the Windermere Hills top are interspersed among segments of the major thrust sequences. These minor thrust sequences consist of segments of eugeosynclinal rocks or postorogenic sedimentary deposits that could not be definitely referred to the Thousand Spring sequence. In general, no outcrops of the western assemblage occur east of U.S. Highway 93 in the Windermere Hills; as a result the western Windermere Hills and the HD Range must be regarded as the easternmost major occurrence of lower Paleozoic rocks of the western assemblage in Nevada. Both the allochthonous early Paleozoic rocks of these numerous thrust plates in the HD Range and in the Windermere Hills and the late Paleozoic rocks of the Carlin sequence (amended) are thought to be far traveled and probably twice displaced in different directions, before they reached their present positions.

To the east, just north of the Jackson Mine and almost at the Utah state line, R. J. Roberts (oral commun., 1979) recognized black chert, apparently part of the Valmy Formation, resting in thrust contact on the Devonian Guilmette Formation or the Devils Gate Limestone. This black chert is overlain by conglomerate of the Diamond Peak Formation, but it is uncertain whether this conglomerate is in thrust contact with the chert and the Devonian rocks, or overlaps the chert and is thrust with it over the Devonian rocks.

A short distance to the south, in the Jackson Springs quadrangle, just west of the Utah state line and north-

east of Montello, Nevada, conglomerate of the Diamond Peak Formation is present as a thrust plate on the Guilmette and Devils Gate Formations, undivided. The thrust, which dips about 4°N, is characterized by thrust breccia in both the lower and upper plates and mullion structures (with a relief of several feet) that trend nearly north.

Just south and southeast of the Gamble Ranch, north of Montello and a few miles southwest of the Jackson Mine, light-gray and green chert of uncertain age is in thrust contact with the Pequop Formation, in narrow outcrops in the valley bottom and eastward at a higher level. Mullion structures and minor irregularities on the thrust surfaces suggest that the thrust movement was southerly. Internal structures in the chert, such as minor-fold axes, suggest that deformation was accomplished during movement from the west; these folds are cut off by the southward thrusting.

In July 1979, R. J. Roberts and I discovered, at the north end of the Pequop Mountains, a small klippe of white to dark-gray quartzite, resembling closely the quartzite of the Valmy Formation. The quartzite in the klippe is intensely brecciated, as is the tectonically underlying formation, which is here mapped (pl. 1) as the Pequop Formation. In the valley to the east, outcrops of black chert, resembling chert of the Valmy Formation, suggest disjunct fragments of the klippe.

The Snake Mountains form a broad 40-mi-long northwest-trending mountainous complex west of the HD Range and the Windermere Hills. Bezzerides (1967) and Gardner (1968) mapped the north-central part of the Snake Mountains, and Peterson (1968) mapped the Antelope Peak area in the south-central part; in general, their work was broadly coordinated, and their results differ only in details.

The main conclusions reached by Gardner, Peterson, and, perhaps, Bezzerides are as follows: (1) A major thrust sequence, named the "Currant Creek thrust sequence," lies tectonically on poorly exposed Devonian carbonate rocks of the transitional assemblage on the west edge of the Snake Mountains; this thrust sequence consists of Ordovician, Silurian, and Devonian carbonate rocks of the eastern assemblage. (2) The Currant Creek thrust sequence, in turn, is overridden by a major thrust plate formed of the Stormy Mountain thrust sequence composed, in Gardner's (1968) definition, only of undivided Ordovician and Silurian rocks of the western assemblage. (3) A thick postorogenic clastic sequence, composed of the Strathearn, Buckskin Mountain, and Phosphoria Formations of late Paleozoic age, and of the Dinwoody and Thaynes Formations of Triassic age, was interpreted by Gardner (1968) as overlapping both eastern-assemblage carbonate rocks of the Currant Creek thrust sequence and the western assemblage of the Stormy Mountain thrust sequence.

The interpretation that late Paleozoic to early Mesozoic rocks of the overlap assemblage lie indiscriminately on two separate thrust plates also means that the thrust sequences in question had been moved into their present positions during the Antler orogeny and thus the structural history of the Snake Mountains is much older and unrelated to that of the HD Range and the Windermere Hills. To arrive at a better understanding of this problem, Riva (1970) visited the Hot Creek area at the northwest end of the Snake Mountains, where Gardner had mapped the only occurrence of postorogenic clastics deposits overlapping both the Stormy Mountain and the Currant Creek thrust sequences. After a careful study, Riva (1970) concluded that the overlap assemblage covers only the western assemblage of the Stormy Mountain thrust sequence and is separated by a thrust from the tectonically underlying Currant Creek thrust sequence. This means that the overlap assemblage is strictly allochthonous and was moved into its present position, together with the unconformably underlying western assemblage, not during the Antler orogeny but in one of the Mesozoic orogenic movements that emplaced the thrust plates in the Windermere Hills and in the HD Range. The stratigraphy of the Stormy Mountain thrust sequence is remarkably similar to that of the Thousand Spring sequence of the Windermere Hills [26] (Oversby, 1972), and these two sequences may well be considered or interpreted as large segments of a once-continuous thrust plate.

Gardner (1968) and Peterson (1968) assigned the western-assemblage rocks of the Stormy Mountain thrust sequence to a single broad stratigraphic unit, the Valmy Formation, and estimated its thickness to be more than 10,000 ft. Gardner and Peterson made no attempt to distinguish Ordovician from Silurian rocks, although the lithologies differ markedly and fossils (chiefly graptolites) are abundant. The thickness reported for the Valmy is clearly excessive and is probably due to superposition of various thrust segments. Riva (1970) readily recognized at least three such thrust segments in an exploratory tour through the western-assemblage rocks mapped by Peterson (1968) on the east flank of Antelope Peak; he also recognized the Diamond Peak Formation and the Chainman Shale, both apparently belonging to other distinct thrust sequences. Detailed mapping is still needed here to arrive at a reasonable understanding of the stratigraphy and structure of the western assemblage in the Snake Mountains.

On the east side of the southern Snake Mountains, a brief survey by Riva (1970) readily showed that the geology is essentially that of a deformed thrust slice of Ordovician shale, chert, and associated volcanic rocks together with siltstone of the Silurian Noh Formation (Riva, 1970), all bearing abundant graptolites. This thrust slice, the lowest in the range, is truncated by one slice composed of quartzite of the Diamond Peak Formation and by another slice consisting of highly deformed Late Permian chert of the Carlin Canyon Formation (Fails, 1960). The fact that the visible basement for all these slices is the Chainman Shale repeats a relation already observed in the south-central HD Range by Riva (1970) and in the Windermere Hills by Oversby (1972). Typical chert of the Carlin Canyon Formation was also extensively mapped by Oversby (1972) in one of the thrust slices forming the Thousand Spring sequence on the east flank of the Windermere Hills (Black Mountain). Riva (1970) noted that the Carlin Canyon Formation forms a highly deformed thrust slice at the northeast end of the Snake Mountains near the head of Jakes Creek, where the thrust cuts overlap assemblage rocks of the Stormy Mountain thrust sequence. These

relations demonstrate that at least some members of this family of thrusts are post-Permian.

On the west side of the southern Snake Mountains, another massive thrust sequence is exposed that is composed of Devonian limestone and the Mississippian Diamond Peak Formation, which is quite similar to the Black Mountain sequence of Oversby (1972) in the eastern Windermere Hills. R. A. Hope observed this sequence in thrust contact on a basement of undated siliceous shale that could well be the Chainman Shale. The Black Mountain sequence (Oversby, 1972) lies tectonically on the Chainman Shale in the Windermere Hills. A study of Gardner's (1968) and Peterson's (1968) geologic maps of the north-central Snake Mountains strongly suggests that this thrust sequence that resembles the Black Mountain sequence (Oversby, 1972) is the southward continuation of the Currant Creek thrust sequence but contains the middle to upper Paleozoic strata missing in the Currant Creek thrust sequence in the Snake Mountains. The clastic deposits of the Diamond Peak at the top of this thrust sequence that resembles the Black Mountain sequence certainly indicate that its emplacement postdates the Antler orogeny and that, like the tectonically overlying Stormy Mountain thrust sequence, it can only be related to a Mesozoic orogeny.

At the north end of the Snake Mountains, near O'Neill Pass, Bezzerides (1967) mapped a dike cutting the Triassic Dinwoody Formation, thought to be part of the upper plate of the Stormy Mountain thrust, and surmised that this dike is genetically related to the emplacement of the Contact pluton of Late Jurassic age (Coats and others, 1965). If this hypothesis should be confirmed by radiometric dating, both major thrust sequences in the Snake Mountains must have been emplaced during the Late Triassic or Early Jurassic; the same reasoning will, by analogy, have to be applied to the complex thrust sequences in the Windermere Hills because they are the forward extension of the major thrust plates in the Snake Mountains.

Gardner (1968) concluded from detailed studies of drag folds and from the orientation of major folds in the eastern- and western-assemblage rocks that thrusting in the Snake Mountains was from the northwest. Peterson (1968) reached the same conclusion on the basis of the orientation of major folds and on a review of the regional geology. This direction of thrusting agrees with that determined by Oversby (1972) in the Windermere Hills and that determined by John Riva (written commun., 1970) in the HD Range for the upper plates.

The geology of the HD Range, Windermere Hills, and Snake Mountains is remarkably similar: an extensive sequence composed of Ordovician to Early Triassic miogeosynclinal rocks (the upper plate) is thrust over a basement of metamorphosed and allochthonous lower Paleozoic to middle-Mesozoic rocks (apparently the lower plate). In the Wood Hills and the Pequop Mountains, drag folds overturned to the southeast indicate that thrusting was from the northwest, whereas slickensided surfaces and transverse fractures along the Secret Creek thrust in the northern Ruby Mountains suggest an easterly direction of movement of the upper plate. The time of thrusting of the upper plate is post-Early Triassic, but whether it is Late Triassic, Jurassic, Cretaceous, or Tertiary is purely a matter of conjecture.

M. B. Himes (oral commun., 1978) reported that a low-angle overthrust cuts the Indian Springs pluton in the area mapped by Slack (1974), who reported K-Ar ages of 134.2 ± 1.5 and 136.0 ± 2 m.y. for the pluton. This observation must be regarded as significant because it offers the best evidence to date for the presence of Cretaceous or later thrust faults in northeastern Elko County.

Origin of Convergent Directions of Thrusting

The directions of movement on late Paleozoic and Mesozoic thrusts in north-central Nevada have been summarized and are shown in a sketch map in figure 10. How can the presence of two contrasting trends in the translation vectors of thrust plates over this wide expanse of northern Nevada be explained? The area involved is approximately 2° of longitude by 1° of latitude. Eastward-directed thrusting has been recognized at least since 1960. The problem that seems to defy easy solution is to account for the presence in the same area of thrust plates of overlapping time spans and of orthogonally or nearly orthogonally convergent directions and senses of motion.

As indicated in the subsection entitled "Antler Orogeny," the northwesternmost exposure of the Roberts Mountains thrust in Nevada is just south of Merritt Mountain, in the Mountain City 15′ quadrangle, a few miles east of Mountain City. What is apparently the southwesternmost exposure of the same thrust in Idaho occurs in a set of exposures just east of Hollister, in Twin Falls County, Idaho (Coats, 1980). There, gray quartzite, closely resembling quartzite of the Valmy Formation, and chert, locally including mafic volcanic-rock fragments, are thrust over Ordovician dolomitic limestone. This locality was discovered by Youngquist and Haegele (1956), who regarded the quartzite as the Eureka Quartzite. The abrupt eastward shift of nearly 75 mi from the Mountain City area to the west flank of the Cassia Mountains must take place within a narrow zone, concealed beneath overlapping southward-directed schuppen and Tertiary volcanic rocks. The most reasonable explanation for this shift is the presence of a right-lateral tear fault, here called the Owyhee rift, with a minimum displacement of about 75 mi. Figure 11 illustrates the hypothetical relations of the Owyhee rift to the Roberts Mountains thrust.

Figure 11A diagrammatically illustrates the structural relations of the upper plate to the lower plate of the Roberts Mountains thrust in what is now northern Nevada and southwestern Idaho during the Kinderhookian, immediately after the major episode of movement on the Roberts Mountains thrust. Figure 11B illustrates the hypothesized relations of these plates and the positions of the thrust during the Early Triassic. (Compare the Kinderhookian position of the Roberts Mountains thrust in Idaho, as shown by Dover (1980), with the present inferred position shown by Roberts and Thomasson (1964, fig. 122.1). Initiation of the tear fault must be post-Antler, that is, post-Kinderhookian.

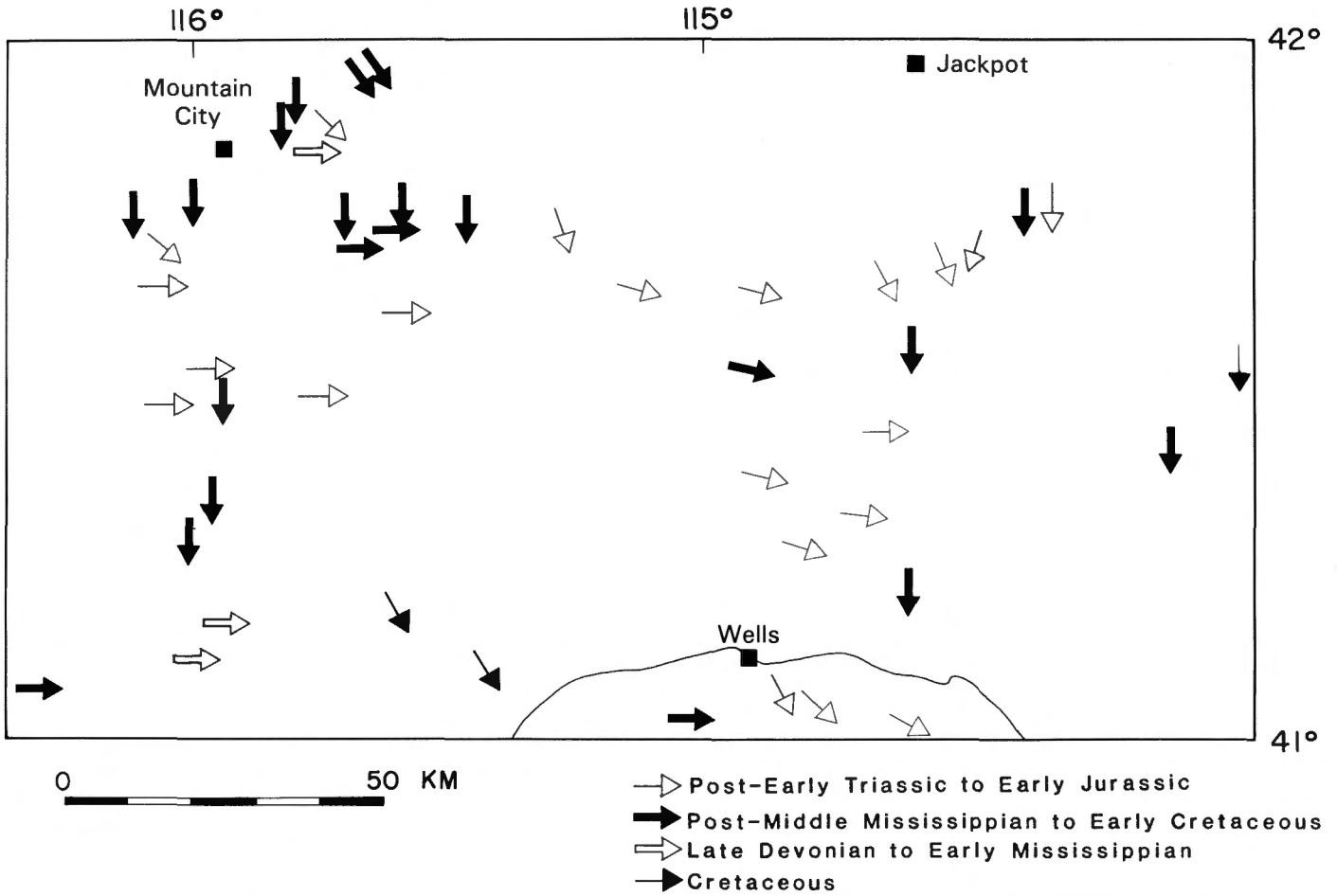


FIGURE 10. Sketch map showing directions of movement on late Paleozoic and Mesozoic thrusts in Elko County. Tip of arrow denotes point of observation.

Eastward displacement of the Mississippian, Pennsylvanian, Permian, and Lower Triassic clastic and volcanic rocks that accumulated west of the longitude of Mountain City and were translated eastward by right-lateral movement on this tear fault to positions north of the central part of Elko County would probably have resulted in the accumulation of a thick pile of sedimentary and mafic volcanic rocks of late Paleozoic and earliest Mesozoic age in southern Idaho. Parts of this pile of lower and upper Paleozoic and Lower Triassic clastic and volcanic rocks were tectonically transported southward into northeastern Elko County and interfingered with similar thrust plates of rocks of similar age that moved eastward. At that time, most of northern Elko County was a part of the craton in which a relatively thin sequence of sedimentary rocks had been accumulating since the early Paleozoic. It may be that accumulation of the sedimentary and volcanic rocks north of the Owyhee rift and their southward displacement by gravity sliding resulted in the construction of a substantial mountain mass, into which the roots of the granodioritic batholiths of northern Elko County intruded; their prevailing latitudinal trend would have been conditioned by the trend of structures resulting from the southward compression.

What may well be confirmatory evidence for the presence of a strike-slip fault, the Owyhee rift, and possibly also for the eastward displacement of marginal-basin material and subjacent oceanic-floor deposits was presented by Hill and Pakiser (1967). Their profile (Hill and Pakiser, 1967, fig. 5), which shows the results of seismic exploration between Eureka, Nevada, and Boise, Idaho, through Mountain City, Nevada, indicates, as a preferred explanation, an abrupt increase northward in the thickness of the intermediate (mafic) layer (6.7 km/s) at about 30 km (18 mi) north of Mountain City (fig. 12A). The thickness of this mafic layer increases from about 10 km (6 mi) to about 30 km (18 mi); the thickness of the silicic layer (6.0 km/s) coincidentally decreases from about 20 km (12 mi), the normal thickness in the Basin and Range province, to a thickness too small for illustration. The surficial layer, here interpreted as being largely Phanerozoic sedimentary and silicic volcanic rocks, thickens northward near the latitude of Mountain City. One favored interpretation (figs. 12B–D) is that continental granitic crust and its west margin have been transported about 75 mi eastward and that the place of the continental crust beneath the Owyhee plateau, north of Mountain City, was taken by a greatly thickened mafic layer, with a thickness

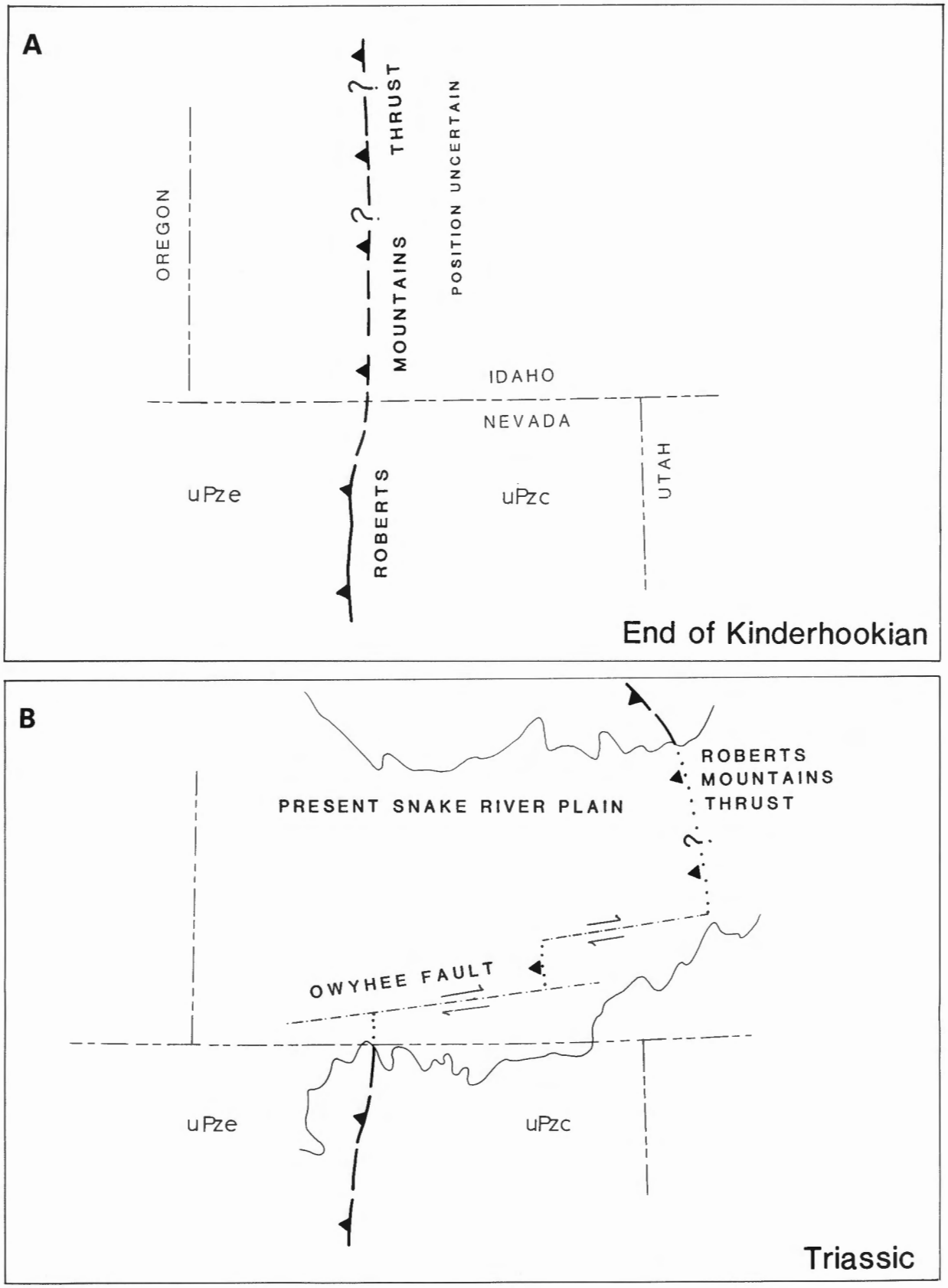


FIGURE 11. Time-sequential sketch map illustrating the hypothesis that the presence of Paleozoic eugeosynclinal rocks in northern Elko County is the result of about 75 mi of right-lateral displacement on an east-northeast-trending fault in southern Owyhee and Twin Falls Counties, Idaho. A—Conditions at end of Kinderhookian post-Roberts Mountains thrusting. B—Conditions at close of the Triassic, after completion of shift on postulated strike-slip fault. uPze—undifferentiated Paleozoic eugeosynclinal rocks; uPzc—undifferentiated Paleozoic rocks of eastern assemblage.

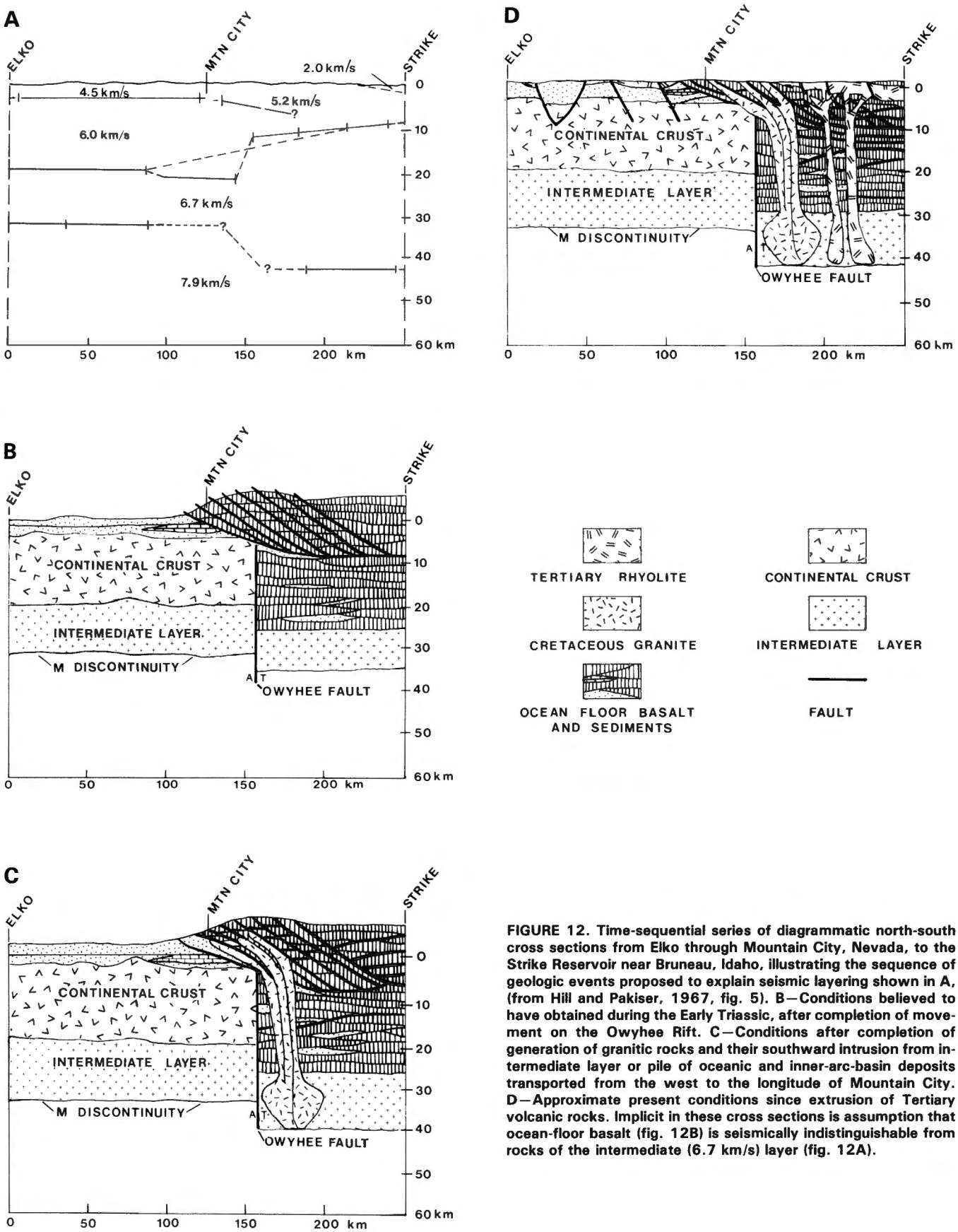


FIGURE 12. Time-sequential series of diagrammatic north-south cross sections from Elko through Mountain City, Nevada, to the Strike Reservoir near Bruneau, Idaho, illustrating the sequence of geologic events proposed to explain seismic layering shown in A, (from Hill and Pakiser, 1967, fig. 5). B—Conditions believed to have obtained during the Early Triassic, after completion of movement on the Owyhee Rift. C—Conditions after completion of generation of granitic rocks and their southward intrusion from intermediate layer or pile of oceanic and inner-arc-basin deposits transported from the west to the longitude of Mountain City. D—Approximate present conditions since extrusion of Tertiary volcanic rocks. Implicit in these cross sections is assumption that ocean-floor basalt (fig. 12B) is seismically indistinguishable from rocks of the intermediate (6.7 km/s) layer (fig. 12A).

more appropriate to ocean floor or even to the roots of a volcanic arc.

Slivers and slices of late Paleozoic volcanic rocks interbedded with marine sedimentary rocks are confined largely to the extreme northwestern area of that part of Elko County occupied by Paleozoic rocks [3, 4], as exemplified by the Nelson Formation (Mississippian) and the Reservation Hill Formation (Pennsylvanian? and Permian?) (Coats, 1969), the slate of Sikikareh Mountain (Paleozoic), and the Mitchell Creek Formation (Pennsylvanian) (Coats, 1969). Minor amounts of intermediate volcanic rocks occur in the Permian and Triassic rocks (Ketner, 1975b); mafic volcanic rocks are also present in late Paleozoic formations exposed farther south, such as the Mississippian Schoonover Formation. The Schoonover is allochthonous, as recognized by Fagan (1962); and most of the Schoonover forms part of the higher allochthonous plate (Miller and others, 1981). To suppose that the Long Canyon sequence of Ketner (1975b) was deposited far to the west of its present position would imply that the rocks on which it rests depositionally, including rocks as old as the Mississippian Chainman Shale, are also part of the same plate and have traveled equally far. Although this hypothesis is not impossible, it involves the supposition that Mississippian clastic materials shed from the Antler orogenic welt must have been carried westward as well as eastward by erosion. No physical evidence, however, is known to me to support this supposition with regard to the late Paleozoic and Triassic rocks of the northern Adobe Range. Such sediment would have accumulated in the Pumpernickel-Havallah trough (Roberts, 1968, fig. 6). The absence of coarse equivalents of the Chainman Shale and Diamond Peak Formation in the Pumpernickel-Havallah trough may be explained by tectonic or erosional denudation during post-Mississippian time; it does not seem likely that the Antler orogenic welt would have shed clastic materials as coarse as those of the Diamond Peak on only one flank.

What may be corroborative evidence for the allochthonous provenance of the Upper Permian rocks (the Adobe Range sequence of Ketner, 1975b) and, from depositional relations, of the Mississippian rocks on which they rest and the Lower Triassic rocks that rest on them may be inferred from the astonishingly restricted distribution of *Atomodesma*, a characteristic bivalve in these Permian rocks (Kauffman and Runnegar, 1975, fig. 3). No occurrences of *Atomodesma* were mentioned by Kauffman and Runnegar in any Upper Permian rocks of the midcontinental United States, in spite of the broad range of sedimentary environments available. In addition to Nevada, occurrences of *Atomodesma* were recorded by Kauffman and Runnegar only in southwestern Alaska and New Zealand.

If the Diamond Peak and overlying Paleozoic rocks of the Adobe Range are, indeed, allochthonous, the best remaining exposure of the thrust surface, here termed the "Ryndon fault," may be visible just west of Ryndon, Nevada, at the east portal of the Southern Pacific Railway tunnel. Here, conglomerate of the Diamond Peak Formation rests on a low-angle, west-dipping fault surface, the mullion structures of which suggest eastward or westward translation for the upper plate. The lower plate is an altered hornblende-biotite dacite, which is here assigned to the Jurassic Frenchie Creek Rhyolite (Muffler, 1964). Whether these volcanic rocks, which differ markedly in lithology and degree of alteration from nearby Tertiary volcanic rocks, are also allochthonous cannot be determined from the exposures examined. Should they be early Tertiary, then major eastward or westward thrusting in this area is post-early Tertiary.

Trail Gulch Fault

In the western part of the Rowland quadrangle [4], Bushnell (1967) mapped a major high-angle fault, striking N30°E, that he considered (Bushnell, 1967, p. 30–31) to be right lateral. He offered cogent evidence for this interpretation, which may account for many features of the distribution of formations in the Rowland quadrangle. One formation that is conspicuously missing on the west side of the fault, however, is Bushnell's (1967) Paleozoic formation D, here regarded as the equivalent of the Van Duzer Limestone. The nearest place to the west in the Mountain City 15′ quadrangle where the Van Duzer has been recognized, somewhat doubtfully, is in the southeast quarter of the quadrangle, just north of the junction of the California Creek road with the Haystack Creek road. The nearest exposure of the Banner Formation, here regarded as equivalent to the Diamond A Formation (Bushnell, 1967), is in S17,T46N,R55E. Offsets of these formations could be regarded as suggesting a left-lateral slip. The tectonic sequences northwest of the Trail Gulch fault in the Rowland quadrangle may be oroflexurally deflected in the left-lateral sense, as shown by the local differences in thrust-fault trends from those in the northern part of the Mountain City 15′ quadrangle. It is also apparent, however, that different sequences of formations are imbricated in the two quadrangles, and so this explanation of the trends of the thrust plates may not be valid. The time of movement and the relation to the plutons are also uncertain. Nothing in Bushnell's (1967) careful mapping requires that the Trail Gulch fault be later than the intrusive bodies; I prefer to regard the fault as pre-pluton, probably pre-Late Jurassic.

DIRECTION OF MESOZOIC MOVEMENT IN SOUTHWESTERN ELKO COUNTY

An interesting and as yet unsolved problem concerns the direction of vergence of the Mesozoic folds in southwestern Elko County [43], as reported by Smith and Ketner (1977, p. C11–12):

> Middle Mesozoic deformation in and near the report area [Carlin-Piñon Range] is far more pervasive and intense than anyone has previously reported, and the style of this deformation is quite different from that of earlier tectonic events. The middle Mesozoic deformation is characterized by strong, large-scale and small-scale folds mostly trending nearly north or northeast, with overturns commonly to the west and northwest, accompanied by relative westward movement of small thrust plates. Some folds of this age trend northwest, however, and may have been folded earlier and then folded again during the Mesozoic deformation. Permian and lower Mesozoic rocks

elsewhere in northern Nevada are also strongly folded, and the axes of those folds generally parallel the principal Jurassic-Cretaceous folds in the Carlin-Piñon Range area.

Initial uplift, probably in Triassic time, was followed in Jurassic time by granitic intrusions and a great outburst of volcanic activity. This activity was followed by climactic folding and thrust faulting. From evidence in this area, the time of most intense folding can only be designated as being younger than early Late Permian time as represented by undivided Permian rocks and being older than early Late Cretaceous time as represented by the Newark Canyon Formation. One of the principal folds, a syncline in the north-central part of the area, continues northeastward into the Adobe Range where it folded Triassic rocks; it is probably also represented in the Cortez Mountains just west of the mapped area (Muffler, 1964) where Upper Jurassic rocks are involved (Ketner and Smith, 1974). On this basis the time of folding is very Late Jurassic or Early Cretaceous.

Smith and Ketner (1977, p. C12) also pointed out that the anticline north of the Humboldt River is exceptional for this area because it is partially overturned to the southeast, and that in this respect it resembles the northern part of the Adobe syncline, part of which is overturned to the east and south. They suggested "possibly a significant change in structural type takes place near the Humboldt River."

Smith and Ketner (1977, p. C12) described four thrust plates in their report area and presented the following evidence for a westward direction of movement of the thrusts:

Evidence for considering thrust movement to have been generally westward directed is gained largely from relations at two of the thrust plates. Rocks composing the Lee plate are Mississippian argillite of Lee Canyon, with overlying small patches of Chainman Shale. The lithology of the argillite suggests that it was deposited east of this area; thus it must have been thrust westward to its present position. In addition, the westward-overturned part of the Piñon Range crestal anticline in the lower plate of the thrust is just east of the outcrop of this plate. Mississippian strata just west of the Willow thrust plate and evidently in the lower plate of the Willow thrust are also overturned to the west.

Whereas the evidence for westward movement of thrusts and for westward vergence of folds in southern Elko County, as recounted by Smith and Ketner (1977), is derived from the suprastructure, Howard (*in* Smith and Howard, 1977) suggested westward overturning for one of the nappes in the metamorphic rocks in the Lee 15′ quadrangle. In the Ruby Mountains as a whole, Howard (1966a, b; 1980) observed relations that seen equivocal: a structurally lower nappe is overturned westward, and higher nappes have no constant direction of overturning. Howard (1980, p. 345) suggested: "The infrastructure core, which had high temperatures and abundant granitic material, had low strength that allowed large-scale rock flow. Its deformation was probably driven by thermal and gravitational instabilities; the opposing overturns of the nappes argue against lateral compression." To me, this explanation seems as reasonable as any other for the extraordinary disharmonies in style of deformation between suprastructure and infrastructure.

In the northern Ruby Mountains, Snoke (1980, p. 287) reported that "...major map-scale folds are overturned westward opposite the common direction of overturning in the infrastructure." Similar observations in the East Humboldt Range were made by Snelson (1957). In the Wood Hills [34], Thorman's (1970) careful mapping showed that the folds in his structural plate I generally have a northward vergence. Thorman (1970, p. 2439) dated the metamorphism of this plate I as the earliest orogenic event, succeeded by relative movement toward the northwest, at first small-scale, and then by large-scale northwestward overfolding. The southeastward movement of structural plate II was postmetamorphic. Both structural episodes were assigned by Thorman (1970, p. 2439) to the "...Late(?) Jurassic to Early(?) Cretaceous and possibly Late Cretaceous orogeny." Thorman thus accepted the orogeny that was assigned to the middle Mesozoic by Misch (1960) and Misch and Hazzard (1962).

Snelson (1955), Nelson (1956), and G. D. Fraser (written commun., 1973) observed, in the Currie area, north-northeast-trending folds, overturned to the west-northwest, affecting rocks as young as the Jurassic(?) Nugget Sandstone. Nelson also indicated that much younger Tertiary rocks have been slightly folded along the same axes.

In the Lee 15′ quadrangle [44], Smith and Howard (1977) suggested that much of the major deformation of Precambrian or early Paleozoic rocks, which is characterized by the recumbent nappe in the northeastern part of the quadrangle (a gneiss-cored, tight recumbent anticline that formed during metamorphism and that faces southeastward), is probably best dated by the Jurassic whole-rock Rb-Sr age reported for pegmatitic granite just south of the quadrangle. Armstrong (1964) divided the Mesozoic orogeny into two distinct episodes: the Nevadan orogeny during the Jurassic, when regional metamorphism occurred in eastern Nevada and west of the Sevier orogenic belt in western Utah, and the Sevier orogeny during the Cretaceous. Little evidence of a distinct Sevier orogeny has been found in Elko County. Thorman (1970) rejected the idea of the Wood Hills thrust as an Abscherungszone because it postdates the regional metamorphism and cuts across structures within Thorman's plate I; the same relation is evident between the Snow Water and Angel Lake units in the East Humboldt Range (C. H. Thorman and Sigmund Snelson, written commun., 1979). Thorman and Snelson were not able to confirm the steep metamorphic gradient that Armstrong and Hansen (1966) postulated.

Hose and Danes (1973) offered an explanation for the development of late Mesozoic to early Cenozoic structures in the eastern Great Basin. They divided the tectonic regimes of the eastern Great Basin into an eastern and a western regime on the basis of structural differences. These two regimes are separated approximately by a line that extends from the east edge of the Raft River Mountains, Utah, to the southeast edge of the Snake Range; this line is the east boundary of Misch's (1960) northeastern Nevada structural province. Hose and Danes (1973) considered that in the western regime, or the western terrane of Misch's northeastern Nevada structural province, the rocks may be divided into two different types, the autochthonous and allochthonous units. (The terms "autochthon" and "allochthon" were used by Hose and Danes somewhat differently from the way they are generally used by most geologists working

in this part of Nevada). Hose and Danes (1973) stated that the autochthonous rocks are nearly all metamorphosed to some extent. They regarded as two essential differences between the structures of the western regime and those of the eastern regime the presence of younger-on-older low-angle faults in the western regime and the presence of autochthonous (in Hose and Danes' sense) rocks in many of the ranges.

The presence of younger-on-older thrusts is not particularly characteristic of any one section in Elko County; such relations also occur in many places in western Elko County, especially where a great extent of a given thrust is not exposed in any one range and the rocks have been seriously deformed in several different orogenies. Younger rocks may be thrust over older rocks, or older over younger. Thus, this criterion of Hose and Danes is not one that can be widely used.

A perceptible degree of metamorphism seems to be characteristic of the lower plate of many of the mountain ranges in southeastern Elko County; strongly metamorphosed Paleozoic rocks have been described in the Ruby Mountains, the East Humboldt Range, the Wood Hills, and the Pequop Mountain, as well as in several of the ranges farther south in White Pine County. On the other hand, many of the rocks that are so strongly metamorphosed resemble rocks in the upper plate that have undergone very little metamorphism; and, as Thorman (1970) pointed out, the rocks change within a distance of 1,000 ft or so, from strongly to very weakly metamorphosed. Therefore, this criterion of the degree of metamorphism, though valid and readily applicable in some places (for example, in the Ruby Mountains and in the East Humboldt Range), seems to break down in the Pequop Mountains.

Wells Fault

Thorman (1970) and Thorman and Ketner (1979) postulated the existence of a major throughgoing right-lateral tear fault, which Thorman named the Wells fault. Thorman (1970, p. 2441) described the zone in which the Wells fault transects the Pequop Mountains as follows:

> The main fault crosses the Pequop Mountains, just north of Pequop Pass, beneath a thick cover of Chainman shales and sandstones. It reaches the surface south of the pass and alternates between a low-angle thrust (Rocky Canyon thrust) and high-angle reverse faults (Meyers Canyon, No-Name Canyon, and Highway faults), so that it resembles stairs leading up to the south... Right-slip movement along the Wells fault is indicated by the juxtaposition of markedly different Paleozoic facies in the Pequop Mountains. Subplate IIH contains a western miogeosynclinal facies, while the underlying and adjacent subplates (IID, IIE, IIF) contain typical eastern miogeosynclinal facies....

The critical point, however, is the presence or absence of the Wells fault, shown by Thorman (1970, fig. 15) as just north of this Highway fault; the Wells fault is not shown, however, on Thorman's (1970, fig. 2) more detailed map of the Pequop Mountains.

A comparison of the map patterns in the area to the north of the Wells fault with those in the area to the south suggests that the nearly orthogonal attitudes of the sets of strikes on the two sides of the Wells fault, as well as the facies contrasts, so carefully reported by Thorman (1970), are better explained by the hypothesis that the Wells fault is not a major transcurrent fault but a thrust-fault zone, separating a region of eastward compression on the south from a region of southward compression on the north. This hypothesis regards the north end of the Pequop Mountains as the south margin of the southward-moving thrust plate, similar to those in the HD Range described by Riva (1970).

Further evidence against southeastward extension of the Wells fault, as mapped by Thorman, through Silver Zone Pass was furnished by the mapping of Pilger (1972). The Wells fault, as nearly as can be determined from Thorman (1970, fig. 15), would pass either through the Silver Zone Pass pluton of Jurassic age or through the post-Pioche Shale undifferentiated Cambrian rocks that lie north of the pluton. The same Middle and Upper Cambrian formations mapped by Pilger north of the pluton occur nearly on strike and south of it; the same is true of the later Paleozoic rocks. R. H. Pilger, Jr. (oral commun., May 1979), reported that there are no substantial facies differences in these rocks from one side of the pluton to the other. The general trends of strikes are similar both north and south of the pluton, except that local folding, with axes parallel to the plutonic contact, occurs near the contact. Such folding, of course, could be explained as the result of forceful intrusion. In short, there is no evidence for any major transcurrent northwestward-trending tear fault in the northern Toano Range. Sheehan (1979) pointed out that a right-slip fault is not needed to explain the regional distribution of Silurian rocks if the Roberts Mountains Formation was deposited along an east-west-trending shelf margin in northern Nevada.

Stevens (1979, p. 431) pointed out that the Wells fault of Thorman "...apparently fails to offset the zone of Leonardian massive rugose corals, at least not 65 km [40 mi]..., suggesting that offset of this fault is not of the magnitude envisaged by Thorman."

R. K. Hose (oral commun., July 1979) pointed out that facies trends in late Paleozoic rocks of the Confusion Range in western Utah are not substantially offset from those of the Silver Island Mountains northeast of Wendover. This relation suggests that no substantial right-lateral translation took place between these two areas during Mesozoic time.

The Wells fault has been projected westward for considerable distances by subsequent writers (e.g., Johnson and Sandberg, 1977, fig. 1; Sandberg and Poole, 1977, fig. 1) to account for facies differences that, in my view, are better explained, however well substantiated sedimentologically, as boundaries between relatively superficial thrust plates of Mesozoic age. No physical evidence for any such right-lateral northwest-trending throughgoing wrench fault has been seen in the Independence Mountains on the projected extension of the Wells fault.

The eastward offset of the Roberts Mountains thrust, mentioned by Thorman (1968) as part of this evidence for the major right-lateral shift attributed to the Wells fault, is negated by the fact that the Roberts Mountains thrust crops out in the Mountain City 15′ quadrangle, nearly due northof its position in the Carlin-Robinson

Mountain area (Smith and Ketner, 1977), in the Swales Mountain area (Evans and Ketner, 1971), and in the Lone Mountain area (Lovejoy, 1959). I conclude that there is no evidence for any deep-seated northwest-trending right- or left-lateral transverse fault between the Mount Velma quadrangle and southwestern Elko County.

Oroflexural Bending

The concept of an oroflexural feature that may occur in northeastern Nevada (Steward and Poole, 1974, p. 32) is not accepted here to account for the distribution of the western assemblage in northern Elko County east of the Mountain City 15′ quadrangle because of the tectonic involvement of lower Paleozoic rocks of this assemblage with late Paleozoic and Triassic autochthonous and parautochthonous rocks in northeastern Elko County. These relations are especially clear in the southeastern part of the Mountain City 15′ quadrangle, where the steeply dipping north-south-trending Valmy Formation is thrust over Pogonip Group carbonate rocks along a north-northeast-trending thrust, the Roberts Mountains thrust. The upper plate of the Roberts Mountains thrust lies tectonically below a pile of imbricate thrust sheets, dipping moderately northand generally trending east, that involves rocks ranging from the Valmy through the Grossman, Banner, Nelson, and Reservation Hill Formations, as well as the Chainman Shale (formerly called the Mountain City Formation). The gradual sweeping change in the trend of structures called for by the concept of oroflexural bending is not present in northern Elko County.

Stevens (1979, p. 431) rejected the hypothesis of oroflexural bending as an explanation for "...various sedimentary and structural trends that swing from more or less north-south to almost east-west in northeastern Nevada..., because of discordances between the trends of the east-trending Ferguson trough and the Antler belt, as well as between the Oquirrh-Uinta uplift and the Antler belt, that suggest these two east-trending tectonic features cannot be regarded as having a common origin with the Antler belt."

Mullens (1980, p. 40), after an exhaustive study of the Roberts Mountains Formation, interpreted the facies changes in that formation, such as the eastward trend in the reef line from Carlin to Wells, as representing "...the original pattern of deposition caused by a curve in the basin of deposition." He also specifically rejected Steward and Poole's (1974, p. 45, fig. 12) attribution of the eastward trend to later oroclinal folding.

Cenozoic Tectonics

DOLLY VARDEN CRYTOEXPLOSION STRUCTURE

Snow (1964) recognized, in his mapping of the Dolly Varden Mountains, an area near the north tip of the mountains, on the east flank, characterized by many scattered outcrops of well-cemented breccia, the fragments of which are derived entirely from the Joana Limestone of Mississippian age. The outcrops, however, are isolated from each other by remnants of a sheet of alluvial-fan gravel; the remnants are distributed over an area that has an extent of 7,000 ft in a northwesterly by about 5,000 ft in a northeasterly direction.

Northeast of the area of breccia shown by Snow on his map, the Joana Limestone crops out locally, is unbrecciated, and dips steeply northeast. The nearest other outcrops of recognizable Paleozoic rocks close to the area of breccia mapped by Snow are those of the Pequop Formation of Permian age; contact between brecciated Joana and the Pequop are not visible. Strata younger than the Joana and older than the Pequop do not crop out in the Dolly Varden Mountains. The missing interval of rocks is well represented in the Spruce Mountain quadrangle, where a stratigraphic section was measured by Hope (1972). The Spruce Mountain section is as follows:

Unit	Thickness (ft)	Composition
Pequop Formation	600–1,500	Platy siltstone and thin-bedded limestone.
Riepe Spring Limestone	About 1,400	Thick-bedded to massive fine-grained limestone containing nodular chert.
Ely Limestone	About 2,600	Thin-bedded to massive fine-grained limestone and chert.
Diamond Peak and Chainman Formations, undivided	More than 2,500	Shale, siltstone, calcarenite, conglomerate.

Joana Limestone

Assuming that the original thicknesses of these formations were once present at the north end of the Dolly Varden Mountains and are still present below the Pequop, then the Joana Limestone has been somehow raised more than 8,000 ft above its normal stratigraphic position. The Joana Limestone in the Dolly Varden Mountains was described by Snow as consisting of large masses of breccia containing fragments of cherty limestone breccia and cemented by white to light-gray coarsely crystalline calcite. Black and tan chert nodules in the limestone exhibit cataclastic textures. Jasperoid dikes that cut the breccia are also brecciated. Both G. G. Snow and R. A. Hope collected fossils from the breccia. Snow's collections were determined and assigned to the Joana Limestone by J. E. Welsh (in Snow, 1964, p. 12). R. A. Hope (written commun., 1967) noted that the fragments in the breccia range from less than a millimeter to more than 3 ft in diameter and are unoriented, with some suggestion of a "jigsaw puzzle" pattern. R. A. Hope's fossil collection (field no. B85, colln. 24689-PC) from the breccia was reported by W. J. Sando to be assignable to a stratigraphic level in the Joana. The origin of the breccia is problematic. The hypothesis that the breccia might represent the central uplifted core of an astrobleme seemed best to account for the breccia (Wilshire and others, 1971; Howard and others, 1972), but careful search in the fine-grained limestone of the nearest exposures of limestone in the

Pequop Formation failed to disclose a single indisputable shatter cone, such as might be expected in an impact structure of the size implied by the wide distribution of breccia (Dietz, 1969). The absence of shatter cones suggests that the purely descriptive term "cryptoexplosion structure" (Dietz, 1959) might be better employed.

Rudolph Kopf (written commun., 1984) suggested that certain characteristics of the Dolly Varden breccia, particularly the evidence of multiple episodes of brecciation, are difficult to account for by any hypothesis that depends on a single catastrophic event such as employed in the cryptoexplosion and astrobleme hypotheses. He suggests that it might be best explained as a hydrotectonic pressure-relief tube rooted in a regional low-angle fault and in which the tube is reactivated by renewed or anomalously rapid shear displacement of that fault (Kopf, 1982). Such a mechanism would require a major overthrust fault beneath the Dolly Varden Mountains, for which there is no direct evidence. The direction of vergence in most of the higher mountain ranges to the west is also westward, making less likely a gravity slide as the explanation for the displacement of the Dolly Varden block. Gravity collapse of the breccia, perhaps facilitated by post-impact hydrothermal solution, may explain multiple episodes of brecciation. If this area of brecciation is due to an igneous intrusion, accompanied by more or less explosive activity, it may well be early Tertiary. Such explosive activity may account for the breccia dikes mapped by Snow (1964) to the south and west, and for a widespread thin sheet of calcitic breccia at the base of the ignimbrite on the west face of the north tip of the mountains. The jasperoid dikes mentioned by Snow (1964) may reflect hydrothermal activity associated with the hypothetical cryptointrusion. That the cryptoexplosion(?) breccia may have been the site of mineralization should be borne in mind in exploration programs because bodies of breccia marking the sites of astroblemes are also sites of epigenetic mineralization, according to Robertson (1977).

EARLY CENOZOIC COMPRESSIONAL TECTONICS

In the Mount Velma quadrangle [5], Coash (1967) mapped, in a unit here mapped (pl. 1) as part of the early Tertiary phenorhyolitic to phenodacitic ignimbrite [Tt_1], a syncline that is characterized by an extremely steep axial plunge as well as steep limbs. No corresponding anticlines occur adjacent to the syncline, and although this syncline could be due to compressional tectonics directed from the north-northwest, it may be taphrogenic, that is, caused by collapse of the ignimbrite into a graben that opened, possible concomitantly with their deposition or shortly thereafter.

In the Carlin-Piñon Range area [43], Smith and Ketner (1977, p. C12–C13) described the early Oligocene deformation and summarized the age relations of tectonism as follows:

> The Elko Formation and other units of early Tertiary age were folded rather strongly in early Oligocene time. Dips of about 45° are fairly common, and in one place the Elko Formation is folded in a partially overturned syncline. Because of the positions, sizes, and forms of these folds, it seems unlikely either that they could be drag folds caused by normal faults or that they are due to differential compaction. They must be the result of compressional forces that mark the final compressional deformation in the area. These folds are almost exactly the same age as the exposed igneous intrusive bodies: 36.8 ± 1.1 m.y. and 35.4 ± 1.1 m.y. ages were determined on biotite and feldspar respectively from the stock west of Bullion (R. F. Marvin, H. H. Mehnert, and J. C. Mensik, written commun., 1965)...

The date and duration of this deformation were determined from K-Ar ages on the youngest formation affected and the oldest unaffected. The youngest age, on biotite from tuff in the upper part of the Elko Formation, is 38.6 ± 0.8 m.y., and the two oldest ages, one on sanidine and the other on biotite, on the Indian Well Formation are 33.2 ± 0.7 and 34.9 ± 0.7 m.y., respectively. Thus, the interval suggested is about 4 m.y.

In the Jiggs 15′ quadrangle [48] Willden and Kistler (1969) mapped a klippe of lower Paleozoic rock, consisting of dark chert and shale and closely associated with a breccia of quartzite, hornfels, and carbonate-rock clasts, that rests on the Harrison Pass pluton. The Harrison Pass pluton, according to R. W. Kistler (written commun., 1978), has an age of 38 m.y., the same as that for tuff in the Elko Formation. Thus, the latest impression of regional extent may have a date of about 38 m.y. In southern Elko County, however, this klippe may be a gravity glide fault, as I interpret the Cedar Mountain klippe to be (see next section).

In the southern part of the Mount Velma quadrangle and in the Reed Station and Mahalla Creek West quadrangles, fairly thick sequences of crystal-rich welded tuff of early Tertiary age have been deformed by antithetic normal faulting. The repetitive exposures thus created give an impression of great thickness that is apparently erroneous; in the absence of detailed work and good marker beds, however, it has not been possible to ascertain the actual thickness of these beds. In all of these places they are overlain by rocks that, in the absence of any ages on the minerals which have been separated from them, have been provisionally dated as Oligocene; this dating is subject to correction once K-Ar ages become available. There is no certain evidence here of pre-Oligocene thrusting or folding.

POST OLIGOCENE(?) THRUSTING

The concept of post-Oligocene thrusting in Elko County had its most persuasive advocate in Ronald Willden (Willden and others, 1967). He and his associates published a map showing three klippen in the Ruby Mountains, for which a post-Oligocene movement date was advocated: from south to north, the Overland Pass klippe, the Mitchell Creek klippe, and the Cedar Mountain klippe. The Cedar Mountain klippe was designated the type locality of the Cedar Mountain thrust.

Willden and others (1967, p. 1352) postulated a thrust klippe at Overland Pass as the most reasonable explanation of the facies contrast between the allochthonous Devonian and Mississippian rocks of the klippe and the autochthonous Devonian and Mississippian rocks north of the high-angle faults that form the north boundary of the klippe. This postulated basal thrust at Overland Pass was not observed, however, by Hose and Blake (1976, pl. 1), and the facies contrast does not exist, according to R. K. Hose (oral commun., 1978).

The evidence for the age of the Mitchell Creek klippe, the next one to the north, is the presence of thermal metamorphism in Cambrian rocks of the lower plate and its absence in the upper plate. This discrepancy in degree of metamorphism may, indeed, be best explained by postmetamorphic movement of the Mitchell Creek klippe; the presence of the Diamond Peak Formation, not part of the normal stratigraphic sequence in the Ruby Mountains, suggests tectonic transport, probably from the west. The critical evidence for dating rests on the differing degree of metamorphism reported for the Diamond Peak in the upper plate, and the Cambrian shale and limestone in the lower plate. Two possible explanations for such a difference, other than a Tertiary age for the thrust, are suggested. One is that the Cambrian rocks have been affected by the Ruby disturbance (Willden and Kistler, 1967) but the Diamond Peak has not; the other is that Jurassic intrusions, such as those farther north in the Ruby Mountains (Willden and Kistler, 1969), may also be present in the subsurface this far south. The Mitchell Creek klippe is here regarded as a part of the Late Jurassic and Early Cretaceous tectonic episode, and is thought to have moved into this area from the west, although the amount of shift may be relatively small because Smith and Ketner (1975) indicated that the Diamond Peak is autochthonous in the Carlin-Piñon Range area.

The Cedar Mountain klippe (Willden and others, 1967) is a displaced block of unmetamorphosed Devonian carbonate rocks resting on a fault surface that is underlain by a brecciated phase of the Oligocene Harrison Pass pluton. That the tectonic emplacement of this klippe occurred during post-Oligocene time is undoubted, but the direction of movement has not been ascertained. Field examination of the klippe in 1978 revealed internal structures suggestive of westward displacement, rather than eastward displacement, as suggested by Willden and others (1967). These structures include subsidiary east-dipping thrusts within the klippe and calcite-filled gash fractures having a Z-shaped cross section looking southward, in which the flatter limbs of the Z nearly parallel the underlying main thrust and the steep limb stands nearly vertical. The fractures on the steeper limb are wider than the flatter ones. The Cedar Mountain klippe is here regarded as a gigantic gravity slide that moved westward from the crest of the Ruby Mountains during post-Oligocene time. Devonian rocks, such as those in the klippe, are present along the east side of the range [45A] and may have extended much farther northward during the late Tertiary (Crittenden and others, 1978).

Perhaps the most telling argument against the post-Oligocene episode of westward-moving thrusts suggested by Willden and others (1967), however, is the general absence to the west of any post-Oligocene compressional feature. The detailed study by Smith and Ketner (1977) recorded no such tectonic event in an area just to the west of the southern Ruby Mountains, where early Tertiary volcanic rocks are widespread and would be expected to show evidence of deformation of the age hypothesized.

Similar arguments would negate the post-15-m.y. thrusting suggested by Snoke (1980) as an explanation for exposures in Secret Pass, between the Ruby Mountains and the East Humboldt Range, where late Paleozoic sedimentary rocks tectonically overlie rhyolite correlated with the Jarbidge Rhyolite of this report. This occurrence is also regarded as a gravity slide.

In northern Lincoln County, Nevada, an example of overriding by older rocks of post-middle Oligocene rocks was confirmed by Tschanz (1960). Tschanz left open the possibility that some of the displacements are due to compressional tectonism but regarded some as definitely the result of gravity sliding.

Kellogg (1960) determined that large-scale exotic blocks moved valleyward from the Schell Creek Range in White Pine County, Nevada, during early Oligocene time and that such movement continued into the Miocene. This occurrence also is probably an example of gravity gliding.

EARLY TERTIARY EXTENSIONAL TECTONICS

One place where extensional tectonics evidently dates from the early Cenozoic is in the Jarbidge quadrangle (Coats, 1964), where both the Dead Horse Tuff of late Eocene age and the overlying Meadow Fork Formation, a very thick clastic formation, apparently accumulated in a fault trough that is sharply bounded to the north. The assumed bounding faults are not exposed but are covered by younger formations. Somewhat similar but geometrically opposite relations are evident in the northern part of the Mountain City 15′ quadrangle, where very coarse gravel containing minor interbedded welded tuff dated at 38 m.y. is faulted against late Paleozoic rocks.

The Ruby-East Humboldt Metamorphic-Core Complex

Howard (1966a, 1966b, 1980) and Snoke (1980) have arrived at very similar interpretations of the structure of the Ruby Mountains and their northern continuation, the East Humboldt Range. They agree in recognizing in these mountain ranges an example of a metamorphic core complex, the essential features of which have been outlined by Coney (1980). These features, as exemplified in the many areas cited by Coney (1980), share three essential elements: (1) a metamorphic-plutonic basement terrane, (2) an unmetamorphosed cover terrane, separated by (3) a decollement or dislocation surface. A part of the Wood Hills, described by Thorman (1970) also is probably part of the core complex. In the Ruby Mountains, the cores of some of the folds in the metamorphic-plutonic basement terrane are gneisses with Precambrian Pb-Pb ages (Snoke, 1980, p. 299). Snoke suggests that the gneisses may represent anatexites remobilized from a Precambrian terrane during Mesozoic(?) regional metamorphism. Howard (1966a, 1966b, 1980) recognized that pelitic Paleozoic rocks in the basement were commonly metamorphosed to the sillimanite grade.

The oldest identifiable formation in the metamorphic-plutonic basement terrane is the Prospect Mountain Quartzite that may include (Howard, 1980) impure metaquartzite and quartz-mica schist. This is overlain by impure calcite marble and calc-silicate rock and a

distinctive brown-weathering dolomite marble (Howard, 1971, 1980, p. 339; Snoke, 1980, p. 293) that apparently lies near the base of the miogeosynclinal carbonate sequence. Still higher is a unit consisting largely of blue-gray calcite marble, white metaquartzite, and fine-grained metadolomite. These rocks are overlain by white metaquartzite, correlated with the Eureka Quartzite, above which is a thick dolomite marble, believed (Snoke, 1980) to be equivalent to the Ordovician, Silurian, and Devonian formations (Howard, 1980) common in the miogeosyncline. Overlying the metadolomite and apparently gradational with it is a calcite marble, commonly with subordinate dolomite (Snoke, 1980, p. 299). This is believed to correlate with the Devonian Guilmette Formation. All of the rocks of the metamorphic-plutonic basement terrane are permeated extensively by Jurassic Cretaceous granitic rocks, commonly granite to trondhjemite. Mafic to felsic gneiss, commonly of igneous origin (Snoke, 1980), is common in the plutonic and metamorphic terrane.

The cover terrane includes unmetamorphosed Paleozoic rocks, Tertiary sedimentary rocks, and Tertiary volcanic rocks. The unmetamorphosed Paleozoic rocks include the Diamond Peak Formation (Snoke, 1980, p. 299), commonly a yellow-to orange-colored grit and pebble conglomerate, sandstone, and gray micritic limestone. Some poorly exposed detrital rocks that may be equivalent (Snoke, 1980, p. 30) to the Chainman Shale are included with it. The Diamond Peak grades upward into the Ely Limestone, a massive, slabby, medium-grained limestone. This is overlain by Permian rocks, which include elements of the Ferguson Mountain and Pequop Formations. These consist mostly of massive silty gray limestone and calcareous sandstone (Snoke, 1980, p. 300).

Several small klippen of Tertiary rocks (Snoke, 1980, p. 300) rest on upper Paleozoic and metamorphic rocks. The Tertiary sedimentary rocks range from lavender to pale green and from siltstone to conglomerate. The finer grained rocks are commonly tuffaceous; conglomeratic rocks contain clasts including reworked Tertiary sedimentary rocks, volcanic rocks, various unmetamorphosed Paleozoic units, and scarce metamorphic rock fragments, including some that contain the conspicuous lineation characteristic of the Abscherungzone, thus indicating that part of the metamorphic complex was exposed during the deposition of these Tertiary rocks. Volcanic rocks are a subordinate component but include a dense black vitrophyre with quartz, sanidine, and green hedenbergitic pyroxene phenocrysts; the sanidine phenocrysts were dated by K-Ar methods at 15.0 m.y. The volcanic rocks are probably correlative with the Jarbidge Rhyolite.

The oldest fold system in the basement terrane displays a penetrative foliation parallel to the axial plane of the folds, with an elongation that consistently trends west-northwest throughout the northern Ruby Mountains. The deeper part of the metamorphic infrastructure is a migmatitic zone pervaded by Jurassic pegmatitic two-mica granite. The structurally higher transition zone underwent extreme tectonic flattening and thinning as the mobile infrastructure rose buoyantly against the more mobile suprastructure (Howard, 1980, p. 345). Flow and stretching to the west-northwest resulted in the regionally consistent direction of lineation in the transition zone. The metamorphism in the northern Ruby Mountains was probably Jurassic, but farther to the south the thermal effect of the Oligocene Harrison Pass pluton reset many of the K-Ar ages to a figure nearer the age of the pluton. The unmetamorphosed rocks of the suprastructure are attenuated into fault-bounded slivers that generally emplace younger rocks on older (Snoke, 1980, p. 301).

Subsequent to the earliest synmetamorphic fold system, a later synmetamorphic or late metamorphic fold system, and a post-metamorphic fold system, both with various trends and vergences, were developed.

Snoke (1980, p. 318) summarized the character of the low-angle faults of the Secret Creek area (separating the northern Ruby Mountains from the East Humboldt Range):

1. The unmetamorphosed rocks of the upper plate are commonly brecciated and complexly faulted, but no mesoscopic folds were observed.
2. Bedding within the upper plate commonly is steep and intersects the basal fault surface at a high angle.
3. The fault surface has been gently folded on a northwest-trending axis.
4. Older-over-younger faults occur as well as younger-over-older...
5. The basal detachment fault is invariably delineated by tectonic slices of low-grade metasedimentary rocks.
6. High-angle normal faults related to the evolution of the present-day basin-and-range topography truncate the low-angle faults.
7. Hydrothermal silicification is a common phenomenon along fault planes within the upper plate.
8. The metamorphic rocks of the lower plate are commonly retrograded or locally brecciated....
9. No rock units of the lower plate are found structurally above the nonmetamorphic strata.
10. Tertiary sedimentary and volcanic rocks (Miocene) are involved in the low-angle fault complex....

LATE TERTIARY EXTENSIONAL TECTONICS

Basin-and-Range Faulting

Extensional tectonics of late Tertiary age have given rise to what is commonly called basin-and-range topography or basin-range structure. The tectonic processes that created the basin-and-range topography of the Great Basin were summarized succinctly by Nolan (1943, p. 178):

> The dominant process in the structural history of the Great Basin in middle and late Tertiary time was the block faulting that produced the characteristic basin-and-range topography of the province ...most geologists now working in the region seem to agree that at least the greater number of the [Great Basin ranges] are bounded on either one or both sides by a fault or fault zone, that the faults are normal rather than reverse, and that the faulting has occurred from late Oligocene to the present time, although some of the scarps may be fault-line scarps rather than primary scarps.

The ensuing 35 years of work have not altered these conclusions to any great degree, and they are still generally valid.

The faults that are responsible for the basin-and-range topography in Elko County generally trend northwest to northeast, although most trend approximately north-south. Within the mountain ranges, minor cross faults are also present, most of which are difficult to date because dated sequences of beds affected by and overlapping the faults are absent. Differences in the age of faulting, however, can be discerned in favorable circumstances. In the Jarbidge Mountains, the Jarbidge Rhyolite, about 16.8 m.y. old, is cut by normal faults trending north-northeast and north-northwest. The faulted terrane was eroded to a surface of low relief and overlapped by the unfaulted Cougar Point Welded Tuff, which has not been dated in this area but has furnished an age date of 12.2 m.y. from a welded tuff in the Owyhee 15′ quadrangle that is low in the sequence, according to John Obradovich (sample DKA1069). In the Hat Peak area, Coats (1968c) observed tensional fractures trending north-south to north-northeast that cut the 12.2-m.y.-old Circle Creek Rhyolite and that are occupied locally by 10-m.y.-old basalt of the Big Island Formation. Both of these units are cut by normal faults trending about N70°E. In the Jarbidge quadrangle, faults of similar trend downthrown to the northare contemporaneous with extrusion of the Big Island Formation (Coats, in press) and thus are about 10 m.y. old. Somewhat similar faults developed on the west side of the Piñon Range, as indicated by Smith and Ketner (1977); may also be contemporaneous. North-northeast-, north-northwest-, and east-northeast-trending normal faults that postdate the Circle Creek Rhyolite were mapped by Coats (1968c) in the Hat Peak 15′ quadrangle and, to some extent, even farther east. Faults of these three systems, which appear to be approximately contemporaneous, occur in the extreme southwestern part of Elko County, in the Midas mining district, and to the southeast of it in the Ivanhoe mining district. Extensional tectonic features are evident, to some extent, even in the area covered by the basalt of the Big Island Formation, where a few faults are present that trend east-northeast. As Coats (1964) showed, in some places these faults were contemporaneous with extrusion of the Big Island Formation and, therefore, could be dated at about 10 m.y. The coincidence of their trend with the south boundary of the Snake River plateau in this area suggests a connection between these faults and the tectonics of the Snake River plateau.

Tilting of the Basin and Range Province

Stewart and Johannesen (1979) published a map showing the direction of tilt of the basins and ranges in the Basin and Range province of the western United States. In some parts of Nevada, as Steward (1980) recognized, and as Louderback (1904) recognized long ago, Tertiary volcanic flows or ignimbrites (Mackin, 1960) furnish the most reliable evidence for the direction of tilt. However, the widespread Oligocene ignimbrites of central Nevada cap few, if any, ranges in Elko County, and so a study must fall back on comparing the asymmetry of the slopes of range fronts or stream gradients—a method subject to errors, as Louderback recognized.

One tilted fault-block mountain in western Elko County, not indicated on the map by Steward and Johnannesen, is the Owyhee Bluffs near Midas [19], which represent the southeast-facing scarp of a fault-block mountain, tilted gently north-northwest and trending at right angles to some of the fault indicated by Stewart and Johannesen. Mackin (1960), as Osmond (1960) acknowledged, also recognized the structural significance of the widespread ignimbrite of the central Basin and Range province. Osmond (1960, p. 261) favored more or less random tilting due to province-wide uplift, rather than tension over large deep anticlines. Moore (1960) related the curvature direction of bounding faults to the facing direction.

Oregon-Nevada Lineament

Extending from north-central Nevada into central Oregon is a feature that Stewart and others (1975) have suggested is a deep-seated fracture zone with a probable complex history of strike-slip and tensional movement of probable middle Miocene age. This lineament, if present, is expressed as an area in which middle Miocene rhyolitic extrusive rocks are thicker and more prevalent than elsewhere in southern Elko County; however, not only are rhyolitic rocks involved but probably also basaltic rocks. Zoback and Thompson (1978) pointed out that the northwestern section of the Oregon-Nevada lineament is cut by the Midas trough (D. R. Shaw, oral commun., 1972; Rowan and Wetlaufer, 1973), a lineament that probably predates, though perhaps not by very much, the youngest volcanic rock in Elko County, a basalt that yielded a whole-rock K-Ar age of 6.3 ± 2.3 m.y. (Zoback and Thompson, 1978). Thus, the northeast-trending fault system, which is responsible for the south-facing Owyhee Bluffs, is dated between 15 and 6 m.y. Although this dating is highly significant locally, it must be pointed out that most of the ranges in the Great Basin are not oriented parallel to this trough. More probably, the orientation of the Midas trough is related tectonically to the faults that have been described along the south margin of the Snake River plateau in the Jarbidge quadrangle [6] and farther west to the Hat Peak 15′ quadrangle [2] area, which were dated at about 10 m.y. High-angle faults of similar trend were mapped in Lander County, Nevada, (Steward and McKee, 1977) and still farther south-southeastward in Eureka County, Nevada, (Roberts and others, 1967). These short structures may be late effects of right-lateral movement on the Oregon-Nevada lineament. The Owyhee Bluffs may also owe their displacement, as suggested earlier, to volcanic activity.

QUATERNARY FAULTING

Quaternary faults have been described in a few places in Elko County, including some that cut Quaternary alluvium in the southern part of the Independence Valley (Coats, 1968b). R. E. Wallace (oral commun., 1978) suggested that these faults may be as much as 200,000 years old, an age that is consistent with the degree of degradation of the scarps and with the absence of any sign of offset in the youngest alluvial valleys or

of any historical fault activity in the Tuscarora mining district. These Quaternary faults trend both northeast and north-south. Faults of similar age have been mapped on the west side of the valley of Maggie Creek [1, 30A] and southeast of Wells.

Slemmons (1967, p. 96) has classified the Pliocene and Quaternary faults that he found mappable by photogeologic methods into four types, defined as follows:

> Type A: Faults with known historic surface offsets [not present in Elko County].
>
> Type B: Prehistoric faults with fresh scarps in alluvium. Many of these are barely prehistoric, and some may be less that 100 years old but without observation or reporting. These rarely offset Pleistocene glacial or pluvial deposits.
>
> Type C: Faults in fresh-appearing, constructional alluvial deposits, but showing some dissection generally. These predate the youngest glacial or pluvial deposits, and are considered to be mainly older than Tioga Glaciation (late Wisconsin) or late Wisconsin pluvial stages. They are generally from 10,000 to about 100,000 years old.
>
> Type D: Faults in older, deeply dissected alluvium, with lighter shades of color due to deeper and more intense weathering. This stage of faulting is generally pre-Wisconsin glacial, or approximately post-Sangamon and may be up to a few hundred thousand years in age.

Slemmons (1967, p. 97) suggested that types B and C "...tend to develop in north-south zones. These zones commonly have chevron or *en echelon* patterns suggesting both right-lateral displacement and dip-slip displacement along north-south mountain and valley blocks."

Slemmons also suggested that right-slip motion is principally observed on faults that have trends between north and northwest, and left-slip motion on faults that trend from north to northeast. His small-scale (1:10,000,000?) maps suggest one set of left-slip faults in Elko County in the Midas trough and another conspicuous right-slip fault along the west wide of the southern Ruby Mountains. Zoback and Thompson (1978), however, described offsets of a Miocene dike along the Midas trough as due to right-lateral movement on a transform fault. It is difficult for me to conceive how the transform-fault hypothesis can explain simultaneous offsets opposite in sense on different faults that appear to be complementary, such as those mapped by Slemmons (1967, fig. 8). The locations of the spreading centers offset by the transform faults are also unclear.

Most of the faults shown on the geologic map (pl. 1) as cutting the Quaternary and Tertiary or Quaternary deposits would, in Slemmons' classification, be types B and C, as nearly as can be determined from his small-scale maps.

Quaternary faulting was also recognized by Sharp (1939a, 1940) along both flanks of the Ruby Mountains, and by Snelson (1957) on the flanks of the East Humboldt Range. Range-front faults, which from their geomorphic expression must be very young, were mapped by Snow (1964) along the west front of the Dolly Varden Mountains.

Sagging

"Sagging" is the term suggested by Radbruch-Hall and others (1976, 1977) as an appropriate translation of the German term "Sackung", defined as a large-scale gravitational spreading of steep-sided ridges characterized by linear fissures, trenches, and uphill-facing scarps on the tops and sides of ridges. Sagging appears to arise where a nearly horizontal, rigid, competent rock body overlies a weak, incompetent one with a steep topographic slope transecting the contact between the two bodies. Because sagging is surficial in origin, it is desirable to distinguish it from the Quaternary faulting that reflects deep-seated tectonics.

In Elko County, sagging has been recognized in two places, both characterized by glacially oversteepened slopes and gently dipping competent rocks overlying less competent ones. One place is in the Jarbidge Wilderness at the head of Marys River, southeast of Marys River Peak (Coats and others, 1977). Here, the Jarbidge Rhyolite is the competent formation; it overlies the ignimbrite of Wildcat Peak. The other occurrence is in the Bull Run quadrangle, on the southwest side of Chicken Creek cirque in the Independence Mountains. Here, the competent layer is massive quartzite of the Valmy Formation (the Valmy Group of Churkin and Kay, 1967), and the underling incompetent layer consists of shale of the same formation.

BIBLIOGRAPHY

Anctil, R. J. (1961) Geology and mineral resources of T. 36 N., R. 63 and 64 E. MDBM, Elko County, Nevada: unpub. report to Southern Pacific Land Co.

_____ (1962) Geology and mineral resources of T. 36 N., R. 45 and 46 E., MDBM, Elko and Lander Counties, Nevada: unpub. report to Southern Pacific Land Co.

Armstrong, R. L. (1964) Geochronology and geology of the eastern Great Basin in Nevada and Utah: Ph.D. thesis, Yale University, New Haven, Connecticut, 290 p.

_____ (1970) Geochronology of Tertiary igneous rocks, eastern Basin and Range Province, western Utah, eastern Nevada, and vicinity, U.S.A.: Geochimica et Cosmochimica Acta, v. 34, no. 2, p. 203-232.

Armstrong, R. L., and Hansen, E. (1966) Cordilleran infrastructure in the eastern Great Basin: American Journal of Science, v. 264, no. 2, p. 112-127.

Armstrong, R. L., Harakal, J. E., and Neill, W. M. (1980) K-Ar dating of Snake River Plain (Idaho) volcanic rock—new results: Isochron/West, no. 27, p. 5-10.

Armstrong, R. L., Leeman, W. P., and Malde, H. E. (1975) K-Ar dating, Quaternary and Neogene volcanic rocks of the Snake River Plain, Idaho: American Journal of Science, v. 275, no. 3, p. 225-251.

Armstrong, R. L., and Suppe, J. (1973) Potassium-argon geochronometry of Mesozoic igneous rocks in Nevada, Utah, and southern California: Geological Society of America Bulletin, v. 84, no. 4, p. 1375-1392.

Axelrod, D. I. (1964) The Miocene Trapper Creek flora of southern Idaho: University of California Publications in Geological Sciences, v. 51, 148 p.

_____ (1966) The Eocene Copper Basin flora of northeastern Nevada: University of California Publications in Geological Sciences, v. 59, 125 p.

Berge, J. S. (1960) Stratigraphy of the Ferguson Mountain area, Elko County, Nevada: Brigham Young University Research Studies, Geology Series, v. 7, no. 5, 63 p.

Berry, W. B. N., and Murphy, M. A. (1975) Silurian and Devonian graptolites of central Nevada: University of California Publications in Geological Sciences, v. 110, 109 p.

Bezzerides, T. L. (1967) Triassic stratigraphy and geology of the O'Neil Pass area, Elko County, Nevada: M.S. thesis, University of Oregon, Eugene, 74 p.

Bissell, H. J. (1964) Ely, Arcturus, and Park City Groups (Pennsylvanian-Permian) in eastern Nevada and western Utah: American Association of Petroleum Geologists Bulletin, v. 48, no. 5, p. 565–636.

Blackwelder, E. (1931) Pleistocene glaciation in the Sierra Nevada and basin ranges: Geological Society of America Bulletin, v. 42, no. 4, p. 865–922.

_____ (1934) Supplementary notes on Pleistocene glaciation in the Great Basin: Washington Academy of Sciences Journal, v. 24, no. 5, p. 217–222.

Blue, D. M. (1960) Geology and ore deposits of the Lucin mining district, Box Elder County, Utah, and Elko County, Nevada: M.S. thesis, University of Utah, Salt Lake City, 125 p.

Boardman, R. S., and McKinney, F. K. (1976) Skeletal architecture and preserved organs of four-sided zooids in convergent genera of Paleozoic Trepostomata (Bryozoa): Journal of Paleontology, v. 50, no. 1, p. 25–78.

Bonham, H. F., Jr. (1961) Geology and mineral resources of Sections 5 and 7, T. 39 N., R. 68 E., Elko County, Nevada: unpub. report to Southern Pacific Railway Co.

Boutwell, J. M. (1907) Stratigraphy and structure of the Park City mining district, Utah: Utah Journal of Geology, v. 15, p. 434–458.

Brew, D. A. (1961) Lithologic character of the Diamond Peak Formation (Mississippian) at the type locality, Eureka and White Pine Counties, Nevada, art. 190 *of* Short papers in the geologic and hydrologic sciences: U.S. Geological Survey Professional Paper 424-C, p. C110–C112.

_____ (1971) Mississippian stratigraphy of the Diamond Peak area, Eureka County, Nevada: U.S. Geological Survey Professional Paper 661, 84 p.

Brown, Merle (1960) The climate of Nevada, in U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Climates of the states, volume II, Western States: Port Washington, New York, Water Information Center Inc., p. 779–793.

Buckley, C. P. (1967) Structure and stratigraphy of the Kingsley Mountains, Elko and White Pine Counties, Nevada: M.S. thesis, San Jose State University, San Jose, California, 50 p.

Budge, D. R. (1972) Paleontology and stratigraphic significance of Late Ordovician and Silurian corals from the eastern Great Basin: Ph.D. thesis, University of California, Berkeley, 859 p.

Bushnell, K. O. (1965) Geology of the Rowland quadrangle, Nevada: Ph.D. thesis, Yale University, New Haven, Connecticut, 152 p.

_____ (1967) Geology of the Rowland quadrangle, Elko County, Nevada: Nevada Bureau of Mines Bulletin 67, 38 p.

Butler, B. S., Loughlin, G. F., Heikes, V. C., and others (1920) The ore deposits of Utah: U.S. Geological Survey Professional Paper 111, 672 p.

Carey, S. W. (1958) The tectonic approach to continental drift, *in* Continental drift; a symposium: Hobart, University of Tasmania, Geology Department, p. 177–355.

Cheney, T. M., Gere, W. C., and Wallace, J. H. (1956) Permian phosphate deposits in northeast Nevada and adjacent parts of Idaho and Utah [abs.]: Geological Society of America Bulletin, v. 67, no. 12, pt. 2, p. 1763–1764.

Churkin, M., Jr., and Kay, M. (1967) Graptolite-bearing Ordovician siliceous and volcanic rocks, northern Independence Range, Nevada: Geological Society of America Bulletin, v. 78, no. 5, p. 651–668.

Clark, D. L. (1957) Marine Triassic stratigraphy in eastern Great Basin: American Association of Petroleum Geologists Bulletin, v. 41, no. 10, p. 2192–2222.

_____ (1960) Triassic biostratigraphy of eastern Nevada, *in* Boettcher, J. W., and Sloan, W. W., Jr., eds., Geology of east-central Nevada: Intermountain Association of Petroleum Geologists, 11th Annual Field Conference, Guidebook, p. 122–125.

Cloud, P. E., Jr., and Boucot, A. J. (1971) Dzieduszyckia in Nevada, *in* Paleozoic perspectives: A paleontological tribute to G. Arthur Cooper: Smithsonian Contributions to Paleobiology 3, p. 175–180.

Coash, J. R. (1967) Geology of the Mount Velma quadrangle, Elko County, Nevada: Nevada Bureau of Mines Bulletin 68, 21 p.

Coats, R. R. (1964) Geology of the Jarbidge quadrangle, Nevada-Idaho: U.S. Geological Survey Bulletin 1141-M, 24 p.

_____ (1967) Economic significance of revised age relations of rocks in the Cornucopia mining district, Elko County, Nevada: U.S. Geological Survey Circular 549, 4 p.

_____ (1968a) Preliminary geologic map of the southwestern part of the Mountain City quadrangle, Elko County, Nevada: U.S. Geological Survey Open-file Map, scale 1:20,000.

_____ (1968b) Recent fault scarps in Independence Valley near Tuscarora, Elko County, Nevada, *in* Geological Survey research 1968: U.S. Geological Survey Professional Paper 600-B, p. B140–B143.

_____ (1968c) The Circle Creek Rhyolite, a volcanic complex in northern Elko County, Nevada, *in* Coats , R. R., Hay, R. L., and Anderson, C. A., eds., Studies in volcanology: A memoir in honor of Howel Williams: Geological Society of America Memoir 116, p. 69–106.

_____ (1968d) Geologic map and schematic cross sections of the Circle Creek rhyolite lekoloth, Elko County, Nevada: U.S. Geological Survey Open-file Map.

_____ (1969) Upper Paleozoic formations of the Mountain City area, Elko County, Nevada, *in* Cohee, G. V., Bates, R. G., and Wright, B. W., eds., Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1967: U.S. Geological Survey Bulletin 1274-A, p. A22–A27.

_____ (1971) Geologic map of the Owyhee quadrangle, Nevada-Idaho: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-665, 2 p., scale 1:48,000.

_____ (1976) Pyroclastic dike feeders of welded tuffs and primary surficial deformation in welded tuffs on the south margin of the Owyhee Plateau, Elko County, Nevada [abs.]: Geological Society of America Abstracts with Programs, v. 8, no. 5, p. 578.

_____ (1980) The Roberts Mountains thrust in central Twin Falls County, Idaho [abs.]: Geological Society of America Abstracts with Programs, v. 12, no. 6, p. 270.

_____ (1986) Invertebrate and paleobotanical fossils collected in Elko County, Nevada: Nevada Bureau of Mines and Geology Open-file Report 86-1, 397 p.

_____ (in press) The Big Island Formation, a Miocene formation in northern Elko County, Nevada, and adjacent Idaho; including a consideration of the composition and petrographic character of its basaltic part: U.S. Geological Survey Bulletin 1605-A.

Coats, R. R., Consul, J., and Neil, S. T. (1979) Massive zunyite rock from western Elko County, Nevada: U.S. Geological Survey Open-file Report 79-764, 10 p.

Coats, R. R., and Gordon, M., Jr. (1972) Tectonic implications of the presence of the Edna Mountain Formation in northern Elko County, Nevada, in Geological Survey research 1972: U.S. Geological Survey Professional Paper 800-C, p. C85–C94.

Coats, R. R., Greene, R. C., Cress, L. D., and Marks, L. Y. (1977) Mineral resources of the Jarbidge Wilderness and adjacent areas, Elko County, *with a section on* An aeromagnetic interpretation, by W. E. Davis: U.S. Geological Survey Bulletin 1439, 14 p.

Coats, R. R., Howard, K. A., Greene, R. C. (1984) Geologic map of the southeast quarter of the Mountain City quadrangle, Elko County, Nevada: U.S. Geological Survey Open-file Report 84-644, 7 p.

Coats, R. R., Marvin, R. F., and Stern, T. W. (1965) Reconnaissance of mineral ages of plutons in Elko County, Nevada, and vicinity, *in* Geological Survey research 1965: U.S. Geological Survey Professional Paper 525-D, p. D11–D15.

Coats, R. R., and McKee, E. H. (1972) Ages of plutons and types of mineralization, northwestern Elko County, Nevada, *in* Geological Survey research 1972: U.S. Geological Survey Professional Paper 800-C, p. C165–C168.

Coats, R. R., and Riva, J. F. (1976) Eastward obduction of early Paleozoic eugeosynclinal sediments, and early Mesozoic transverse thrusting resulting from southward movement of a compressed Paleozoic sedimentary pile, northeastern Great Basin, Nevada, U.S.A. [abs.]: International Geological Congress, 25th, Sydney, Australia, 1976, Abstracts, v. 1, p. 80.

_____ (1983) Overlapping overthrust belts of late Paleozoic and Mesozoic ages, northern Elko County, Nevada: *in* Miller, D. M., Todd, V. R., and Howard, K. A., eds., Tectonic and stratigraphic studies in the eastern Great Basin: Geological Society of America Memoir 157, p. 305–327.

Collinson, J. W. (1966) Permian and Triassic biostratigraphy of the Medicine Range, Elko County, Nevada: Ph.D. thesis, Stanford University, Stanford, California, 156 p.

_____ (1968) Permian and Triassic biostratigraphy of the Medicine Range, northeastern Nevada: Earth Science Bulletin, v. 1, no. 4, p. 25-44.

Compton, R. R. (1972) Geologic map of the Yost quadrangle, Box Elder County, Utah, and Cassia County, Idaho: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-672, 7 p., scale 1:31,680, 2 sheets.

_____ (1975) Geologic map of the Park Valley quadrangle, Box Elder County, Utah, and Cassia County, Idaho: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-873, 6 p., scale 1:31,680.

Compton, R. R., Todd, V. R., Zartman, R. E., and Naeser, C. W. (1977) Oligocene and Miocene metamorphism, folding, and low-angle faulting in northwestern Utah: Geological Society of America Bulletin, v. 88, no. 9, p. 1237-1250.

Condit, D. D. (1916) Relations of the Embar and Chugwater Formations in central Wyoming: U.S. Geological Survey Professional Paper 98, p. 263-270.

Cox, K. G., Bell, J. D., and Pankhurst, R. J. (1979) The interpretation of igneous rocks: London, George Allen & Unwin, 450 p.

Crittenden, Max, Jr., Coney, P. J., and Davis, G., conveners (1978) Tectonic significance of metamorphic core complexes in the North American Cordillera: Geology, v. 6, no. 2, p. 79-80.

Cross, W., Iddings, J. P., Pirsson, L., and Washington, H. S. (1906) The texture of igneous rocks: Journal of Geology, v. 14, no. 8, p. 692-707.

Cuffey, R. J. (1967) Bryozoan *Tabulipora carbonaria* in Wreford Megacyclothem (Lower Permian) of Kansas: Bryozoa article 1: University of Kansas Paleontological Contributions, no. 43, 96 p.

Decker, R. W. (1962) Geology of the Bull Run quadrangle, Elko County, Nevada: Nevada Bureau of Mines Bulletin 60, 65 p.

Dietz, R. S. (1959) Shatter cones in cryptoexplosion structures (meteorite impact?): Journal of Geology, v. 767, no. 5, p. 496-505.

_____ (1969) Shatter-coned astroblemes [abs.], *in* Abstracts for 1968: Geological Society of America Special Paper 121, p. 75.

Dott, R. H., Jr. (1955) Pennsylvanian stratigraphy of Elko and northern Diamond Ranges, northeastern Nevada: American Association of Petroleum Geologists Bulletin, v. 39, no. 11, p. 2211-2305.

Dover, J. H. (1980) Status of the Antler orogeny in central Idaho—clarifications and constraints from the Pioneer Mountains, *in* Fouch, T. D., and Magathan, E. R., eds., Paleozoic paleogeography of the west-central United States: Rocky Mountains Paleogeography Symposium 1: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, p. 371-386.

Dunaeva, N. N. (1964) [New trepostomate bryozoans from the Lower Carboniferous deposits of the Donets basin, U.S.S.R.]: Akademiya Nauk S.S.S.R. Paleontologicheskiy Zhurnal, no. 2, p. 39-44 [in Russian].

Dunn, D. L. (1965) Late Mississippian conodonts from the Bird Spring Formation in Nevada: Journal of Paleontology, v. 39, no. 6, p. 1145-1150.

Evans, J. G., and Cress, L. D. (1972) Preliminary geologic map of the Schroeder Mountain quadrangle, Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-324, scale 1:24,000.

Evans, J. G., and Ketner, K. B. (1971) Geologic map of the Swales Mountain quadrangle and part of the Adobe Summit quadrangle, Elko County, Nevada: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-667, scale 1:24,000.

Evans, J. G., and Mullens, T. E. (1976) Bootstrap window, Elko and Eureka Counties, Nevada: U.S. Geological Survey Journal of Research, v. 4, no. 1, p. 119-125.

Evans, J. G., and Theodore, T. G. (1978) Deformations of the Roberts Mountains allochthon in north-central Nevada: U.S. Geological Survey Professional Paper 1060, 18 p.

Evernden, J. F., Savage, D. E., Curtis, G. H., and James, G. T. (1964) Potassium-argon dates and the Cenozoic mammalian chronology of North America: American Journal of Science, v. 262, no. 2, p. 145-198.

Fagan, J. J. (1962) Carboniferous cherts, turbidites, and volcanic rocks in northern Independence Range, Nevada: Geological Society of America Bulletin, v. 73, no. 5, p. 595-611.

Fails, T. G., Jr. (1960) Permian stratigraphy at Carlin Canyon, Nevada: American Association of Petroleum Geologists Bulletin, v. 44, no. 10, p. 1692-1703.

Fifer, H. C., Jr. (1960) Geology of portion of the Jarbidge I quadrangle, Elko County, Nevada: M.S. thesis, University of Oregon, Eugene, 48 p.

Fisher, R. V. (1966) Rocks composed of volcanic fragments and their classification: Earth Science Review, v. 1, no. 4, p. 287-298.

Fouch, T. D., Hanley, J. H., and Forester, R. M. (1979) Preliminary correlation of Cretaceous and Paleogene lacustrine and related nonmarine sedimentary and volcanic rocks in parts of the eastern Great Basin of Nevada and Utah, *in* Newman, G. W., and Goode, H. D., eds., 1979 Basin and Range symposium and Great Basin field conference: Rocky Mountain Association of Geologists, p. 305-312.

Fraser, G. D., Ketner, K. B., and Smith, M. C. (1968) Geologic map of the Spruce Mountain 4 quadrangle, Elko County, Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-1846, scale 1:24,000.

Fries, Carl, Jr. (1942) Tin deposits of northern Lander County, Nevada: U.S. Geological Survey Bulletin 931-L, p. 279-294.

Fritz, M. A. (1942) A late Paleozoic stenoporoid from British Columbia: Royal Canadian Institute Transactions, v. 24, pt. 1, no. 51, p. 167-169.

Gardner, D. H. (1968) Structure and stratigraphy of the northern part of the Snake Mountains, Elko County, Nevada: Ph.D thesis, University of Oregon, Eugene, 264 p.

Garside, L. J. (1973) Radioactive mineral occurrences in Nevada: Nevada Bureau of Mines and Geology Bulletin 81, 121 p.

Gibbons, J. A. (1973) The geology of part of the Contact mining district, Elko County, Nevada: M.S. thesis, University of Nevada-Reno, 181 p.

Gilbert, G. K. (1890) Lake Bonneville: U.S. Geological Survey Monograph 1, 438 p.

Gilluly, J., and Gates, O. (1965) Tectonic and igneous geology of the northern Shoshone Range, Nevada: U.S. Geological Survey Professional Paper 465, 153 p.

Granger, A. E., Bell, M. M., Simmons, G. C., and Lee, F. (1957) Geology and mineral resources of Elko County, Nevada: Nevada Bureau of Mines and Geology Bulletin 54, 190 p.

Hague, Arnold (1883) Abstract of report on the geology of the Eureka district, Nevada: U.S. Geological Survey Annual Report 3, p. 237-290.

Hass, W. H. (1953) Conodonts of the Barnett Formation of Texas: U.S. Geological Survey Professional Paper 243-F, p. 69-94.

Hawkins, W. H. (1961) Paleozoic south lower North Fork Canyon, northern Independence Range, Elko County, Nevada: M.A. thesis, Columbia University, New York, 52 p.

Hazzard, J. C., and Moran, W. R. (1952) Reported late Tertiary thrusting in northeastern Nevada: American Association of Petroleum Geologists Bulletin, v. 36, no. 5, p. 844-856.

Higgs, N. B. (1960) Geology of the southeastern part of the Jarbidge I quadrangle: M.S. thesis, University of Oregon, Eugene, 100 p.

Hill, D. P., and Pakiser, L. C. (1967) Seismic-refraction study of crustal structure between the Nevada Test Site and Boise, Idaho: Geological Society of America Bulletin, v. 78, no. 6, p. 685-704.

Hintze, L. F. (1951) Lower Ordovician detailed stratigraphic sections for western Utah: Utah Geological and Mineralogical Survey Bulletin 39, 100 p.

Hoare, R. D. (1966) New name for *Cornwallia* Hoare, 1964, and a new species of *Bayhaium* from northern Nevada: Journal of Paleontology, v. 40, no. 1, p. 148-150.

Hodgkinson, K. A. (1961) Permian stratigraphy of northeastern Nevada and northwestern Utah: Brigham Young University Geology Studies, v. 8, p. 167-196.

Holmgren, Arthur (1942) Handbook of the vascular plants of northeastern Nevada: Logan, Utah, Utah State University, 214 p.

Hope, R. A. (1970) Preliminary geologic map of Elko County, Nevada: U.S. Geological Survey Open-file Map, scale 1:200,000.

_____ (1972) Geologic map of the Spruce Mountain quadrangle, Elko County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-942, 3 p., scale 1:62,500.

Hope, R. A., and Coats, R. R. (1976) Preliminary geologic map of Elko County, Nevada: U.S. Geological Survey Open-file Map 76-779, scale 1:100,000.

Hose, R. K., Armstrong, A. K., Harris, A. G., and Mamet, B. L. (1981) Devonian and Mississippian rocks of the northern Antelope Range, Eureka County, Nevada: U.S. Geological Survey Professional Paper 1182, 19 p.

Hose, R. K., and Blake, M. C., Jr. (1976) Geology and mineral resources of White Pine County, Nevada, Part I, geology: Nevada Bureau of Mines and Geology Bulletin 85, 35 p.

Hose, R. K., and Danes, Z. F. (1973) Development of the late Mesozoic to early Cenozoic structures of the eastern Great Basin, *in* DeJong, K. A., and Scholten, Robert, eds., Gravity and tectonics: New York, John Wiley, p. 429-441.

Hose, R. K., and Repenning, C. A. (1959) Stratigraphy of Pennsylvanian, Permian, and Lower Triassic rocks of Confusion Range, west-central Utah: American Association of Petroleum Geologists Bulletin, v. 43, no. 9, p. 2167-2196.

Hose, R. K., Wrucke, C. T., and Armstrong, A. K. (1979) Mixed Devonian and Mississippian conodont and foraminiferal faunas and their bearing on the Roberts Mountains thrust, Nevada: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 446.

Hotz, P. E., and Willden, R. (1964) Geology and mineral deposits of the Osgood Mountains quadrangle, Humboldt County, Nevada: U.S. Geological Survey Professional Paper 431, 128 p.

Howard, K. A. (1966a) Large-scale recumbent folding in the metamorphic rocks of the northern Ruby Mountains, Nevada [abs.]: Geological Society of America Special Paper 87, 210 p.

_____ (1966b) Structure of the metamorphic rocks of the northern Ruby Mountains, Nevada: Ph.D. thesis, Yale University, New Haven, Connecticut, 302 p.

_____ (1971) Paleozoic metasediments in the northern Ruby Mountains, Nevada: Geological Society of America Bulletin, v. 82, no. 1, p. 259-264.

_____ (1980) Metamorphic infrastructure in the northern Ruby Mountains, Nevada, *in* Crittenden, M. D., Jr., Coney, P. J., and Davis, G. H., eds., Metamorphic core complexes: Geological Society of America Memoir 153, p. 335-347.

Howard, K. A., and Armstrong, R. L. (1968) Metamorphic infrastructure of the Cordilleran miogeosyncline [abs.], *in* Abstracts for 1966: Geological Society of America Special Paper 101, p. 404.

Howard, K. A., Kistler, R. W., Snoke, A. W., and Willden, R. (1979) Geologic map of the northern Ruby Mountains: U.S. Geological Survey Miscellaneous Investigations Series Map I-1136, scale 1:125,000.

Howard, K. A., Offield, T. W., and Wilshire, H. G. (1972) Structure of Sierra Madera, Texas, as a guide to central peaks of lunar craters: Geological Society of America Bulletin, v. 83, no. 9, p. 2795-2808.

Hubbs, C. L., and Miller, R. R. (1948) The zoological evidence: Corelation between fish distribution and hydrographic history in the desert basins of western United States, Pt. 2 *of* The Great Basin, with emphasis on glacial and postglacial times: University of Utah Bulletin, v. 38, no. 20 (Biological Series, v. 10, no. 7), p. 17-166.

Johnson, J. G., and Sandberg, C. A. (1977) Lower and Middle Devonian continental-shelf rocks of the western United States, *in* Murphy, M. A., Berry, W. B. N., and Sandberg, C. A., eds., Western North America: Devonian: University of California, Riverside Campus Museum Contribution 4, p. 121-142.

Kauffman, E. G., and Runnegar, B. (1975) *Atomodesma* (Bivalvia) and Permian species of the United States: Journal of Paleontology, v. 49, no. 1, p. 23-51.

Kay, M., and Crawford, J. P. (1964) Paleozoic facies from the miogeosynclinal to the eugeosynclinal belt in thrust slices, central Nevada: Geological Society of America Bulletin, v. 75, no. 5, p. 425-454.

Kellogg, H. E. (1960) Geology of the southern Egan Range, Nevada: *in* Boettcher, J. W., and Sloan, W. W., Jr., eds., Geology of east-central Nevada: Intermountain Association of Petroleum Geologists, 11th Annual Field Conference, Guidebook, p. 189-197.

_____ (1963) Paleozoic stratigraphy of the southern Egan Range, Nevada: Geological Society of America Bulletin, v. 74, no. 6, p. 685-708.

Kerr, J. W. (1962) Paleozoic sequences and thrust slices of the Seetoya Mountains, Independence Range, Elko County, Nevada: Geological Society of America Bulletin, v. 73, no. 4, p. 439-460.

Ketner, K. B. (1970) Limestone turbidite of Kinderhook age and its tectonic significance, Elko County, Nevada, *in* Geological Survey research 1970: U.S. Geological Survey Professional Paper 700-D, p. D18-D22.

_____ (1973a) Preliminary geologic map of the Coal Mine Basin quadrangle, Elko County, Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-528, scale 1:24,000.

_____ (1973b) Preliminary geologic map of the Hunter quadrangle, Elko County, Nevada: U.S. Geologic Survey Miscellaneous Studies Map MF-539, scale 1:24,00.

_____ (1974) Preliminary geologic map of the Blue Basin quadrangle, Elko County, Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-559, scale 1:24,000.

_____ (1975a) Replacement barite deposit, southern Independence Mountains, Nevada: U.S. Geological Survey Journal of Research, v. 3, no. 5, p. 547-551.

_____ (1975b) Stratigraphic sequence of Paleozoic and Mesozoic rocks exposed in central Elko County, Nevada: U.S. Geological Survey Open-file Report 75-213, 120 p.

_____ (1977) Late Paleozoic orogeny and sedimentation, southern California, Nevada, Idaho, and Montana, *in* Stewart, J. H., Stevens, C. H., and Fritsche, A. E., eds., Paleozoic paleogeography of the western United States, Pacific Coast Paleogeography Symposium I: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 363-365.

Ketner, K. B., Evans, J. G., and Hessin, T. D. (1968) Geochemical anomalies in the Swales Mountain area, Elko County, Nevada: U.S. Geological Survey Circular 588, 13 p.

Ketner, K. B., and Smith, J. F., Jr. (1963) Geology of the Railroad mining district, Elko County, Nevada: U.S. Geological Survey Bulletin 1162-B, 27 p.

_____ (1974) Folds and overthrusts of Late Jurassic or Early Cretaceous age in northern Nevada: U.S. Geological Survey Journal of Research, v. 2, no. 4, p. 417-419.

King, C. (1876) Geological and topographical atlas accompanying the report of the U.S. geological exploration of the fortieth parallel: Washington D.C., U.S Government Printing Office.

_____ (1878) Systematic Geology—geological exploration of the fortieth parallel, v. 1: Washington D.C., U.S. Government Printing Office, 803 p.

Kirk, E. (1933) The Eureka quartzite of the Great Basin region: American Journal of Science, ser. 5, v. 26, no. 151, p. 27-44.

Kistler, R. W., and Willden, R. (1969) Precambrian-Cambrian boundary in the Ruby Mountains, Nevada: Geological Society of America Abstracts with Programs, v. 1, no. 3, p. 32.

Klapper, G. (1969) Lower Devonian conodont succession in central Nevada [abs.], in Abstracts for 1968: Geological Society of America Special Paper 121, p. 521-522.

Knopf, A. (1917) Tin ore in northern Lander County, Nevada: *in* Ransome, F. L., and Gale, H. S., geologists in charge, Contributions to economic geology, 1916. Part I.—Metal and nonmetals except fuels: U.S. Geological Survey Bulletin 640, p. 125-138.

Kopf, R. W. (1982) Hydrotectonics: Principles and relevance: U.S. Geological Survey Open-file Report 82-307, 13 p.

Langenheim, R. L., Jr., and Larson, E. R., co-chairmen (1973) Correlation of Great Basin stratigraphic units: Nevada Bureau of Mines and Geology Bulletin 72, 36 p.

Lawson, A. C. (1906) The copper deposits of the Robinson mining district, Nevada: University of California Publications, Department of Geology Bulletin, v. 4, no. 14, p. 287-357.

Little, E. L., Jr. (1971) Atlas of United States trees: Volume I. Conifers and important hardwoods: U.S. Department of Agriculture, Forest Service Miscellaneous Publication 1146.

_____ (1976) Atlas of United States trees: Volume 3. Minor western hardwoods: U.S. Department of Agriculture, Forest Service Miscellaneous Publication 1314.

Louderback, G. D. (1904) Basin Range structure of the Humboldt region [Nevada]: Geological Society of America Bulletin, v. 15, p. 289-346.

Lovejoy, D. W. (1959) Overthrust Ordovician and the Nannie's Peak intrusive, Lone Mountain, Elko County, Nevada: Geological Society of America Bulletin, v. 70, no. 5, p. 539-563.

Macdonald, G. A., and Katsura, Takashi (1964) Chemical composition of Hawaiian lavas: Journal of Petrology, v. 5, no. 1, p. 82-133.

_____ (1965) Eruption of Lassen Peak, Cascade Range, California, in 1915: Example of mixed magmas: Geological Society of America Bulletin, v. 76, no. 5, p. 475-482.

Mackin, J. H. (1960) Structural significance of Tertiary volcanic rocks in southwestern Utah: American Journal of Science, v. 258, no. 2, p. 81-131.

Malde, H. E., and Powers, H. A. (1962) Upper Cenozoic stratigraphy of western Snake River Plain, Idaho: Geological Society of America Bulletin, v. 73, no. 10, p. 1197-1219.

Mark, R. K., Lee-Hu, C., Bowman, H. R., Asaro, F., McKee, E. H., and Coats, R. R. (1975) A high $^{87}Sr/^{86}Sr$ mantle source for low alkali tholeiite, northern Great Basin: Geochimica et Cosmochimica Acta, v. 39, no. 12 p. 1671-1678.

Marshall, P. (1932) Notes on some volcanic rocks of the North Island of New Zealand: New Zealand Journal of Science and Technology, v. 13, no. 4, p. 198-202.

Mathias, D. E. (1959) Geology of the northern part of the Elk Mountains, Elko County, Nevada: M.S. thesis, University of Oregon, Eugene, 76 p.

McKee, E. H., and Coats, R. R. (1975) K-Ar age of ore deposition, Tuscarora mining district, Elko County, Nevada: Isochron/West, no. 13, p. 11-12.

McKee, E. H., and Silberman, M. L. (1970) Geochronology of Tertiary igneous rocks in central Nevada: Geological Society of America Bulletin, v. 81, no. 8, p. 2317-2328.

McKee, E. H., Tarshis, A. L., and Marvin, R. F. (1976) Summary of radiometric ages of Tertiary volcanic and selected plutonic rocks in Nevada, part V—northeastern Nevada: Isochron/West, no. 16, p. 15-27.

McKelvey, V. E., Williams, J. S., Sheldon, R. P., Cressman, E. R., Cheney, T. M., and Swanson, R. W. (1956) Summary description of Phosphoria, Park City, and Shedhorn Formations in the western phosphate field: American Association of Petroleum Geologists Bulletin, v. 40, no. 12, p. 2826-2863.

McKelvey, V. E., and others (1959) The Phosphoria, Park City, and Shedhorn Formations in the western phosphate field: U.S. Geological Survey Professional Paper 313-A, p. 1-49.

McKinney, F. K. (1972) Nonfenestrate Ectoprocta (Bryozoa) of the Bangor Limestone (Chester) of Alabama: Alabama Geological Survey Bulletin 98, 144 p.

Meinzer, O. E. (1922) Map of the Pleistocene lakes of the Basin-and-Range Province and its significance: Geological Society of America Bulletin, v. 33, p. 541-552.

Merriam, C. W. (1940) Devonian stratigraphy and paleontology of the Roberts Mountains region, Nevada: Geological Society of America Special Paper 25, 114 p.

_____ (1963) Paleozoic rocks of Antelope Valley, Eureka and Nye Counties, Nevada: U.S. Geological Survey Professional Paper 423, 67 p.

Merriam, C. W., and Anderson, C. A. (1942) Reconnaissance survey of the Roberts Mountains, Nevada: Geological Society of America Bulletin, v. 53, no. 12, p. 1675-1727.

Merriam, C. W., and McKee, E. H. (1976) The Roberts Mountains Formation, a regional stratigraphic study with emphasis on rugose coral distribution: U.S. Geological Survey Professional Paper 973, 51 p.

Merriam, J. C. (1914) The occurrence of Tertiary mammalian remains in northeastern Nevada: University of California Publications in Geological Sciences, v. 8, no. 12, p. 275-281.

Messin, G. M. L. (1973) Geology of the White Horse pluton, Elko County, Nevada: M.S. thesis, University of Nebraska, Lincoln, 100 p.

Mifflin, M. D., and Wheat, M. M. (1979) Pluvial lakes and estimated pluvial climates of Nevada: Nevada Bureau of Mines and Geology Bulletin 94, 57 p.

Miller, D. M. (1983) Allochthonous quartzite sequence in the Albion Mountains, Idaho, and proposed Proterozoic Z and Cambrian correlatives in the Pilot Range, Utah and Nevada, *in* Miller, D. M., Todd, V. R., and Howard, K. A., eds., Tectonic and stratigraphic studies in the eastern Great Basin: Geological Society of America Memoir 157, p. 191-213.

Miller, E. L., Bateson, J., Dinter, D., Dyer, J. R., Harbaugh, D., and Jones, D. L. (1981) Thrust emplacement of the Schoonover sequence, northern Independence Mountains, Nevada: Geological Society of America Bulletin, pt. 1, v. 92, p. 730-737.

Misch, P. (1957) Magnitude and interpretation of some thrusts in northeast Nevada [abs.]: Geological Society of America Bulletin, v. 68, no. 12, pt. 2, p. 1854-1855.

_____ (1962) Regional structural reconnaissance in central-northeast Nevada and some adjacent areas: Observations and interpretations, *in* Boettcher, J. W., and Sloan, W. W., Jr., eds., Geology of east-central Nevada: Intermountain Association of Petroleum Geologists, 11th Annual Field Conference, Guidebook, p. 17-42.

Misch, P., and Hazzard, J. C. (1962) Stratigraphy and metamorphism of late Precambrian rocks in central northeastern Nevada and adjacent Utah: American Association of Petroleum Geologists Bulletin, v. 46, no. 3, p. 289-343.

Moore, J. G. (1960) Curvature of normal faults in the Basin and Range Province of the western United States: U.S. Geological Survey Professional Paper 400B, p. B409-B411.

_____ (1962) K/Na ratio of Cenozoic igneous rocks of the western United States: Geochimica et Cosmochimica Acta, v. 26, no. 1, p. 101-130.

Morrison, R. B. (1965) Quaternary geology of the Great Basin, *in* Wright, H. E., Jr., and Frey, D. G., eds., The Quaternary of the United States: Princeton, New Jersey, Princeton University Press, p. 265-285.

Morrison, R. B., and Frye, J. C. (1965) Correlation of the middle and late Quaternary successions of the Lake Lahontan, Lake Bonneville, Rocky Mountain (Wasatch Range), southern Great Plains and eastern Midwest areas: Nevada Bureau of Mines and Geology Report 9, 45 p.

Muffler, L. J. P. (1964) Geology of the Frenchie Creek quadrangle, north-central Nevada: U.S. Geological Survey Bulletin 1179, 99 p.

Mullens, T. E. (1980) Stratigraphy, petrology, and some fossil data of the Roberts Mountains Formation, north-central Nevada: U.S. Geological Survey Professional Paper 1063, 67 p.

Mullens, T. E., and Poole, F. G. (1972) Quartz-sand-bearing zone and Early Silurian age of upper part of the Hanson Creek Formation in Eureka County, Nevada, *in* Geological Survey research 1972: U.S. Geological Survey Professional Paper 800-B, p. B21-B24.

Muller, S. W., Ferguson, H. G., and Roberts, R. J. (1951) Geology of the Mount Tobin quadrangle, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-7, scale 1:125,000.

Nelson, J. M., and Roberts, R. J. (1943) Quicksilver deposits in the Ivanhoe district, Elko County: U.S. Geological Survey, unpub. report.

Nelson, R. B. (1956) The stratigraphy and structure of the region surrounding Currie, Elko County, Nevada: M.S. thesis, University of Washington, Seattle, 66 p., map scale 1:62,500.

Nilsen, T. H. (1977) Paleogeography of Mississippian turbidites in south-central Idaho, *in* Stewart, J. H., Stevens, C. H., and Fritsche, A. E., eds., Pacific paleogeogrpahy of the western United States: Pacific Coast Paleogeography Symposium 1: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 275-299.

Nolan, T. B. (1928) A late Paleozoic positive area in Nevada: American Journal of Science, ser. 5, v. 16, no. 92, p. 153-161.

_____ (1930) Paleozoic formations of the Gold Hill quadrangle, Utah: Washington Academy of Sciences Journal, v. 20, no. 17, p. 421-432.

_____ (1935) The Gold Hill mining district, Utah: U.S. Geological Survey Professional Paper 177, 172 p.

_____ (1936) The Tuscarora mining district, Elko County, Nevada: Nevada Bureau of Mines and Geology Bulletin 25, 38 p.

_____ (1943) The Basin and Range Province in Utah, Nevada, and California: U.S. Geological Survey Professional Paper 197-D, p. 141-196.

Nolan, T. B., Merriam, C. W., and Williams, J. S. (1956) The stratigraphic section in the vicinity of Eureka, Nevada: U.S. Geological Survey Professional Paper 276, 77 p.

Olmsted, F. H., Glancy, P. A., Harrill, J. R., Rush, F. E., and Van Denburgh, A. S. (1975) Preliminary hydrogeologic appraisal of selected hydrothermal systems in northern and central Nevada: U.S. Geological Survey Open-file Report 75-56, 267 p.

Olsen, D. R. (1960) Geology and mineralogy of the Delno mining district and vicinity, Elko County, Nevada: Ph.D. thesis, University of Utah, Salt Lake City, 120 p.

O'Neill, J. M. (1968) Geology of the southern Pilot Range, Elko County, Nevada, and Box Elder and Tooele Counties, Utah: M.S. thesis, University of New Mexico, Albuquerque, 113 p.

Osmond, J. C., Jr. (1954) Dolomites in Silurian and Devonian of east-central Nevada: American Association of Petroleum Geologists Bulletin, v. 38, no. 9., p. 1911-1956.

_____ (1960) Tectonic history of the Basin and Range province in Utah and Nevada: Mining Engineering, v. 12, no. 3, p. 251-265.

_____ (1962) Stratigraphy of the Devonian Sevy Dolomite in Utah and Nevada: American Association of Petroleum Geologists Bulletin, v. 46, no. 11, p. 2033-2056.

Oversby, B. S. (1969) An early Antlerian Mississippian orogenic pulse, and post-Antlerian emplacement of allochthonous rocks in northeastern Nevada: Ph.D. thesis, Columbia University, New York, 152 p.

_____ (1972) Thrust sequences in the Windermere Hills, northeastern Elko County, Nevada: Geological Society of America Bulletin, v. 83, no. 9, p. 2677-2687.

_____ (1973) New Mississippian formation in northeastern Nevada and its possible significance: American Association of Petroleum Geologists Bulletin, v. 57, no. 9, p. 1779-1783.

Palmer, A. R. (1983) The decade of North American geology 1983 geologic time scale: Geology, v. 11, no. 9, p. 503-504.

Peck, R. E. (1951) Nonmarine ostracodes—the subfamily Cyprideinae in the Rocky Mountain area: Journal of Paleontology, v. 25, no. 3, p. 307-320.

Pennebaker, E. N. (1932) Geology of the Robinson (Ely) mining district in Nevada; a preliminary report on the primary monzonite porphyry intrusive ore bodies and how they are formed: Mining and Metallurgy, v. 13, no. 304, p. 163-168.

Peterson, B. L. (1968) Stratigraphy and structure of the Antelope Peak area, Snake Mountains, Elko County, northeastern Nevada: M.S. thesis, University of Oregon, Eugene, 78 p.

Pilger, R. H., Jr. (1972) Structural geology of part of the northern Toano Range, Elko County, Nevada: M.S. thesis, University of Nebraska, Lincoln, 65 p.

Plummer, F. B. (1950) The Carboniferous rocks of the Llano region of central Texas: University of Texas Publication 4329, 170 p.

Poole, F. G. (1974) Flysch deposits of the Antler foreland basin, western United States, *in* Dickinson, W. R., ed., Tectonics and sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 22, p. 58-82.

Radbruch-Hall, D. H., Varnes, D. J., and Colton, R. B. (1977) Gravitational spreading of steep-sided ridges ("Sackung") in Colorado: U.S. Geological Survey Journal of Research, v. 5, no. 3, p. 359-363.

Radbruch-Hall, D. H., Varnes, D. J., and Savage, W. Z. (1976) Gravitational spreading of steep-sided ridges ("Sackung") in western United States: International Association of Engineering Geology Bulletin, no. 14, p. 23-35.

Redfern, R. R. (1977) Geology and uranium deposits on the Prince claims, Elko County, Nevada: M.S. thesis, University of California, Los Angeles, 71 p.

Regnier, Jerome (1960) Cenozoic geology in the vicinity of Carlin, Nevada: Geological Society of America Bulletin, v. 71, no. 8, p. 1189-1210.

Repenning, C. A., and Coats, R. R. (1966) Early Miocene mammals in Nevada, *in* Geological Survey research 1966: U.S. Geological Survey Professional Paper 550-A, p. A117.

Repetski, John (1973) Conodonts from the Middle Ordovician Dutchtown Formation of southeast Missouri [abs.]: Geological Society of America Abstracts with Programs, v. 5, no. 4, p. 345.

Richards, R. W., and Mansfield, G. R. (1912) The Bannock overthrust: A major fault in southeastern Idaho and northeastern Utah: Journal of Geology, v. 20, p. 681-709.

Richardson, G. B. (1913) The Paleozoic section in northern Utah: American Journal of Science, ser. 4, v. 36, no. 214, p. 406-416.

Riva, J. F. (1962a) Allochthonous Ordovician-Silurian cherts, argillites and volcanic rocks on Knoll Mountain, Elko County, Nevada: Ph.D. thesis, Columbia University, New York, 103 p.

_____ (1962b) Easternmost occurrence of allochthonous Ordovician Silurian western facies in Nevada [abs.], in Abstracts for 1961: Geological Society of America Special Paper 68, p. 253-254.

_____ (1970) Thrusted Paleozoic rocks in the northern and central HD Range, northeastern Nevada: Geological Society of America Bulletin, v. 81, no. 9, 2689-2716.

Roberts, R. J. (1949) Structure and stratigraphy of the Antler Peak quadrangle, north-central Nevada [abs.]: Geological Society of America Bulletin, v. 60, no. 12, pt. 2, p. 1917.

_____ (1951) Geology of the Antler Peak quadrangle, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-10, scale 1:62,500.

_____ (1964) Stratigraphy and structure of the Antler Peak quadrangle, Humboldt and Lander Counties, Nevada: U.S. Geological Survey Professional Paper 459-A, 93 p.

_____ (1968) Tectonic framework of the Great Basin: University of Missouri at Rolla Journal, no. 1 (V. H. McNutt-Geology Department Colloquim Series 1), p. 101-119.

Roberts, R. J., Crittenden, M. D., Jr., Tooker, E. W., Morris, H. T., Hose, R. K., and Cheney, T. M. (1965) Pennsylvanian and Permian basins in northwestern Utah, northeastern Nevada, and south-central Idaho: American Association of Petroleum Geologists Bulletin, v. 49, no. 11, p. 1926-1956.

Roberts, R. J., Hotz, P. E., Gilluly, J., and Ferguson, H. G. (1958) Paleozoic rocks of north-central Nevada: American Association of Petroleum Geologists Bulletin, v. 42, no. 12, p. 2813-2857.

Roberts, R. J., Montgomery, K. M., and Lehner, R. E. (1967) Geology and mineral resources of Eureka County, Nevada: Nevada Bureau of Mines and Geology Bulletin 64, 152 p.

Roberts, R. J., and Thomasson, M. R. (1964) Comparison of late Paleozoic depositional history of northern Nevada and central Idaho, art. 122 *of* Short papers in geology and hydrology: U.S. Geological Survey Professional Paper 475-D, p. D1-D6.

Robertson, P. B. (1977) Economic aspects of terrestrial impact structures studied: Northern Miner, v. 63, no. 37 (annual review number), sec. D, p. D3.

Robinson, G. B., Jr. (1961) Stratigraphy and Leonardian fusulinid paleontology in central Pequop Mountains, Elko County, Nevada: Brigham Young University Geology Studies, v. 8, p. 93-146.

Ross, R. J., Jr. (1951) Stratigraphy of the Garden City formation in northeastern Utah, and its trilobite faunas: Yale University, Peabody Museum of Natural History Bulletin, 161 p.

_____ (1972) Fossils from the Ordovician Bioherm at Meiklejohn Peak, Nevada: U.S. Geological Survey Professional Paper 685, 47 p.

_____ (1977) Ordovician paleogeography of the western United States *in* Stewart, J. H., Stevens, C. H., and Fritsche, A. E., eds., Paleozoic paleogeography of the western United States: Pacific Coast Paleogeography Symposium 1: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 19-38.

Ross, R. J., Jr., and Berry, W. B. N. (1963) Ordovician graptolites of the Basin Ranges in California, Nevada, Utah, and Idaho: U.S. Geological Survey Bulletin 1134, 177 p.

Ross, R. J., Jr., and Cornwall, H. R. (1961) Bioherms in the upper part of the Pogonip in southern Nevada, art. 97 *of* Short papers in the geologic and hydrologic sciences: U.S. Geological Survey Professional Paper 424-B, p. B231-B233.

Ross, R. J., Jr., Jaanusson, V., and Friedman, I. (1975) Lithology and origin of Middle Ordovician calcareous mudmound at Meiklejohn Peak, southern Nevada: U.S. Geological Survey Professional Paper 871, 48 p.

Ross, R. J., Jr., Nolan, T. B., and Harris, A. G. (1980) The Upper Ordovician and Silurian Hanson Creek Formation of central Nevada: U.S. Geological Survey Professional Paper 1126-C, p. C1-C22.

Rowan, L. C., and Wetlaufer, P. H. (1973) Structural geologic analysis of Nevada using ERTS-1 images—a preliminary report, sec. A *of* Symposium on significant results obtained from the Earth Resources Technology Satellite-1, v. 1, Technical representations: National Aeronautics and Space Administration Paper G-20, p. 413-423.

Rubner, D. P. (1968) The petrology, stratigraphy and paleoecology of the Laketown Dolomite in east central Nevada: M.S. thesis, Northern Illinois University, De Kalb.

Sadlick, Walter (1960) Some preliminary aspects of Chainman stratigraphy, *in* Boettcher, J. W., and Sloan, W. W., eds., Geology of east-central Nevada: Intermountain Association of Petroleum Geologists, 11th Annual Field Conference, Guidebook, p. 81-90.

Sakagami, Sumio (1970) On the Paleozoic Bryozoa of Japan and Thai-Malayan districts: Journal of Paleontology, v. 44, p. 680-692.

Sandberg, C. A., and Poole, F. G. (1977) Conodont biostratigraphy and depositional complexes of Upper Devonian cratonic-platform and continental-shelf rocks in the western United States, *in* Murphy, M. A., Berry, W. B. N., and Sandberg, C. A., eds., Western North America: Devonian: University of California, Riverside, Campus Museum Contribution 4, p. 144-182.

Sando, W. J., Mamet, B. L., and Dutro, J. T., Jr. (1969) Carboniferous megafaunal and microfaunal zonation in the northern Cordillera of the United States: U.S. Geological Survey Professional Paper 613-E, p. E1-E29.

Schaeffer, F. E., and Anderson, W. L. (1960) Geology of the central and southern Silver Island Mountains, Box Elder and Tooele Counties, Utah, and Elko County, Nevada: Utah Geological Society Guidebook to the Geology of Utah 15, 185 p.

Schrader, F. C. (1912) A reconnaissance of the Jarbidge, Contact, and Elk Mountain mining districts: U.S. Geological Survey Bulletin 497, 162 p.

_____ (1923) The Jarbidge mining district, Nevada, with a note on the Charleston district: U.S. Geological Survey Bulletin 741, 86 p.

Scott, W. F. (1954) Regional physical stratigraphy of the Triassic in a part of the Eastern Cordillera: Ph.D. thesis, University of Washington, Seattle, 152 p.

Serpagli, Enrico (1967) Prima segnalazoine de conodonti nel siluriano della Sardegna e relative osservazioni stratigrafiche [First characterization of conodonts in the Silurian of Sardinia and related stratigraphic observations]: Accademia Nazionale dei Lincei, Atti, Rendiconti, ser. 8, v. 42, no. 6, p. 856-858 [in Italian, with English summary].

Sharp, R. P. (1938) Pleistocene glaciation in the Ruby-East Humboldt Range, northeastern Nevada: Journal of Geomorphology, v. 1, no. 4, p. 296-323.

_____ (1939a) Basin-range structure of the Ruby-East Humboldt Range, northeastern Nevada: Geological Society of America Bulletin, v. 50, p. 881-919.

_____ (1939b) The Miocene Humboldt formation in northeastern Nevada: Journal of Geology, v. 47, no. 2, p. 133-160.

_____ (1940) Geomorphology of the Ruby-East Humboldt Range, Nevada: Geological Society of America Bulletin, v. 51, no. 3, p. 337-371.

_____ (1942) Stratigraphy and structure of the southern Ruby Mountains, Nevada: Geological Society of America Bulletin, v. 53, no. 5, p. 647-690.

Sheehan, P. M. (1971) Silurian brachiopoda community ecology and stratigraphic geology in western Utah and eastern Nevada, *with a section on* Late Ordovician stratigraphy: Ph.D. dissertation, University of California, Berkeley, 492 p.

_____ (1979) Silurian continental margin in northern Nevada and northwestern Utah: University of Wyoming Contributions to Geology, v. 17, no. 1, p. 25-35.

Silberling, N. J. (1973) Geologic events during Permian-Triassic time along the Pacific margin of the United States, *in* Logan, Alan, and Hills, L. V., eds., The Permian and Triassic systems and their mutual boundary: Alberta Society of Petroleum Geologists, p. 345-362.

Silberling, N. J., and Roberts, R. J. (1962) Pre-Tertiary stratigraphy and structure of northwestern Nevada: Geological Society of America Special Paper 72, 53 p.

Silitonga, P. H. (1975) Geology of part of the Kittridge Springs quadrangle, Elko County, Nevada: M.S. thesis, Colorado School of Mines, Golden, 88 p.

Sirkin, G. L. (1970) The petrology and petrography of the Triassic-Jurassic sandstone, Currie, Nevada: M.S. thesis, University of Nebraska, Lincoln, 60 p.

Skipp, Betty, and Hall, W. E. (1975) Structure and Paleozoic stratigraphy of a complex of thrust plates in the Fish Creek Reservoir area, south-central Idaho: U.S. Geological Survey Journal of Research, v. 3, no. 6, p. 671-689.

Slack, J. F. (1974) Jurassic suprastructure in the Delano Mountains, northeastern Elko County, Nevada: Geological Society of America Bulletin, v. 85, no. 2, p. 269-272.

Slemmons, D. B. (1967) Pliocene and Quaternary crustal movements of the Basin-and-Range Province, USA, *in* Ikebe, Nobuo, ed., Sea level changes and crustal movements of the Pacific during the Pliocene and post-Pliocene time: Osaka City University, Journal of Geosciences, v. 10, p. 91-103.

Smith, J. F., Jr., and Howard, K. A. (1977) Geologic map of the Lee 15′ quadrangle, Elko County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1393, scale 1:62,500.

Smith, J. F., Jr., and Ketner, K. B. (1968) Devonian and Mississippian rocks and the date of the Roberts Mountains thrust in the Carlin-Pinon Range area, Nevada: U.S. Geological Survey Bulletin 1251-I, 18 p.

_____ (1972) Generalized geologic map of the Carlin, Dixie Flats, Pine Valley, and Robinson Mountains quadrangles, Elko and Eureka Counties, Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-481, scale 1:125,000.

_____ (1975) Stratigraphy of Paleozoic rocks in the Carlin-Pinon Range area, Nevada: U.S. Geological Survey Professional Paper 867-A, 83 p.

_____ (1976) Stratigraphy of post-Paleozoic rocks and summary of resources in the Carlin-Pinon Range area, Nevada, *with a section on* Aeromagnetic survey, by D. R. Mabey: U.S. Geological Survey Professional Paper 867-B, 48 p.

_____ (1977) Tectonic events since early Paleozoic in the Carlin-Pinon Range area, Nevada: U.S. Geological Survey Professional Paper 867-C, 18 p.

_____ (1978) Geologic map of the Carlin-Pinon Range area, Elko and Eureka Counties, Nevada: U.S. Geological Survey Miscellaneous Investigations Map I-1028, scale 1:62,500, 2 sheets.

Snelson, S. (1955) The geology of the southern Pequop Mountains, Elko County, Nevada: M.S. thesis, University of Washington, Seattle, 59 p., map scale 1:62,500.

_____ (1957) The geology of the northern Ruby Mountains and the East Humboldt Range, Elko County, northeastern Nevada: Ph.D. thesis, University of Washington, Seattle, 214 p., map scale 1:125,000.

Snoke, A. W. (1974) The transition from infrastructure to suprastructure in the northern Ruby Mountains, Nevada [abs.]: Geological Society of America Abstracts with Programs, v. 8, no. 3, p. 258.

_____ (1980) The transition from infrastructure to suprastructure in the northern Ruby Mountains, *in* Crittenden, M. D., Jr., Coney, P. J., and Davis, G. H., eds., Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, p. 287-333.

Snow, G. G. (1964) Mineralogy and geology of the Dolly Varden Mountains, Elko County, Nevada: Ph.D. thesis, University of Utah, Salt Lake City, 187 p.

Snyder, C. T., Hardman, G., and Zdenek, F. F. (1964) Pleistocene lakes in the Great Basin: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-416, scale 1:1,000,000.

Sohn, I. G. (1958) Middle Mesozoic non-marine ostracodes of the Black Hills [South Dakota and Wyoming]: Wyoming Geological Association, 13th Annual Field Conference, Guidebook, p. 120-126.

Solomon, B. J. (1981) Geology and oil shale resources near Elko Nevada: U.S. Geological Survey Open-file Report 81-709.

Solomon, B. J., McKee, E. H., and Andersen, D. W. (1979) Stratigraphy and depositional environments of Paleogene rocks near Elko, Nevada, *in* Armentrout, J. M., Cole, M. R., and TerBest, H., Jr., eds., Cenozoic paleogeography of the western United States: Pacific Coast Paleogeography Symposium 3: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 75-78.

Spencer, A. C. (1917) The geology and ore deposits of Ely, Nevada: U.S. Geological Survey Professional Paper 96, 89 p.

Stearns, H. T. (1926) Volcanism in the Mud Lake area, Idaho: American Journal of Science, ser. 5, v. 11, no. 64, p. 353-363.

_____ (1936) Origin of the large springs and their alcoves along the Snake River in southern Idaho: Journal of Geology, v. 44, p. 429-450.

Steele, G. (1959a) Stratigraphic interpretation of the Pennsylvanian Permian systems of the eastern Great Basin: Ph.D. thesis, University of Washington, Seattle, 382 p.

_____ (1959b) Basin and range structure reflects Paleozoic tectonics and sedimentation: American Association of Petroleum Geologists Bulletin, v. 43, no. 5, p. 1105.

_____ (1960) Pennsylvanian-Permian stratigraphy of east-central Nevada and adjacent Utah, *in* Boettcher, J. W., and Sloan, W. W., eds., Geology of east-central Nevada: Intermountain Association of Petroleum Geologists, 11th Annual Field Conference, Guidebook, p. 91-113.

Stevens, C. H. (1979) Lower Permian of the central Cordilleran miogeosyncline: Geological Society of America Bulletin, v. 90, pt. 1, no. 2, p. 140-142; pt. 2, p. 381-455.

Stewart, J. H. (1962) Variable facies of the Chainman and Diamond Peak Formations in western White Pine County, Nevada, art. 79 *of* Short papers in geology and hydrology: U.S. Geological Survey Professional Paper 450-C, p. C57-C60.

_____ (1974) Correlation of uppermost Precambrian and Lower Cambrian strata from southern to east-central Nevada: U.S. Geological Survey Journal of Research, v. 2, no. 5, p. 609-618.

_____ *(1980) Regional tilt patterns of late Cenozoic basin-range* fault blocks, western United States: Geological Society of America Bulletin, v. 91, no. 8, p. 460-464.

Stewart, J. H., and Carlson, J. E., compilers (1974) Preliminary geologic map of Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-609, scale 1:500,000, 4 sheets.

_____ (1978a) Geologic map of Nevada: U.S. Geological Survey, scale 1:500,000.

_____ (1978b) Sources of data for geologic map of Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-930, scale 1:000,000.

Stewart, J. H., and Johannesen, D. C. (1979) Map showing regional tilt patterns of late Cenozoic basin-range fault blocks in western United States: U.S. Geological Survey Open-file Map 79-1134, scale 1:2,500,000.

Stewart, J. H., and McKee, E. H. (1977) Geology and mineral deposits of Lander County, Nevada, part I, geology: Nevada Bureau of Mines and Geology Bulletin 88, 59 p.

Stewart, J. H., and Poole, F. G. (1974) Lower Paleozoic and uppermost Precambrian Cordilleran miogeocline, Great Basin, western United States, *in* Dickinson, W. R., ed., Tectonics and sedimentation: Society of Economic Paleontologists and Mineralogists, Special Publication 22, p. 28-57.

Stewart, *J. H., Walker, G. W., and Kleinhampl, F. J. (1975) Oregon-*Nevada lineament: Geology, v. 3, no. 5, p. 265-268.

Streckeisen, A. L. (1967) Classification and nomenclature of igneous rocks: Neues Jahrbuch für Mineralogie Abhandlungen, v. 107, no. 2, 3, p. 144-240.

Streckeisen, A. L., chairman (1973) Plutonic rocks: Classification and nomenclature recommended by the IUGS subcommission on the Systematics of Igneous Rocks: Geotimes, v. 18, no. 10, October 1973, p. 26-30.

Sweet, W. C., Ethington, R. L., and Barnes, C. R. (1970) North American Middle and Upper Ordovician conodont faunas, *in* Sweet, W. C., and Bergstrom, S. M., eds., Symposium on conodont biostratigraphy: Geological Society of America Memoir 127, p. 163-193.

Thorman, C. H. (1968) Mesozoic(?) and Tertiary strike-slip faulting, northeast Nevada [abs.]: Geological Society of America Special Paper 121, p. 570-571.

_____ (1970) Metamorphosed and nonmetamorphosed Paleozoic rocks in the Wood Hills and Pequop Mountains, northeast Nevada: Geological Society of America Bulletin, v. 81, no. 8, p. 2417-2447.

Thorman, C. H., and Ketner, K. B. (1979) West-northwest strike-slip faults and other structures in allochthonous rocks in central and eastern Nevada and western Utah, *in* Newman, G. W., and Goode, H. D., eds., Basin and Range Symposium and Great Basin Field Conference: Rocky Mountain Association of Geologists, p. 123-133.

Tooker, E. W., and Roberts, R. J. (1970) Upper Paleozoic rocks in the Oquirrh Mountains and Bingham mining district, Utah, *with a section on* Biostratigraphy and correlation, by MacKenzie Gordon, Jr., and H. M. Duncan: U.S. Geological Survey Professional Paper 629-A, p. A1-A76.

Tschanz, C. M. (1960) Geology of northern Lincoln County, Nevada, *in* Boettcher, J. W., and Sloan, W. W., Jr., eds., Geology of east-central Nevada: Intermountain Association of Petroleum Geologists, 11th Annual Field Conference, Guidebook, p. 198-209.

U.S. Geological Survey (1969) Aerial geologic and structural interpretation map of an area in the Sheep Creek Range, Lander County, Nevada: Denver, Colorado, U.S. Geological Survey Open-file Map, scale 1:24,000.

Van Houten, F. B. (1956) Reconnaissance of Cenozoic sedimentary rocks of Nevada: American Association of *Petroleum Geologists* Bulletin, v. 40, no. 12, p. 2801-2825.

Veatch, A. C. (1907) Coal fields of east-central Carbon County, Wyoming, *in* Campbell, M. R., geologist in charge, Contributions to economic geology; part II. Coal, lignite, and peat: U.S. Geological Survey Bulletin 316, p. 244-260.

Wahrhaftig, C., and Cox, A. (1959) Rock glaciers in the Alaska Range: Geological Society of America Bulletin, v. 70, no. 4, p. 383-436.

Wardlaw, B. R., and Collinson, J. W. (1977) Biostratigraphic zonation of the Park City Group: U.S. Geological Survey Open-*file Report 77-853, 15 p.*

Wardlaw, B. R., Collinson, J. W., and Maughan, E. K. (1979a) Stratigraphy of Park City Group equivalents (Permian) in southern Idaho, northeastern Nevada, and northwestern Utah: U.S. Geological Survey Professional Paper 1163-C, p. 9-16.

_____ (1979b) The Murdock Mountain Formation: A new unit of the Permian Park City Group: U.S. Geological Survey Professional Paper 1163-B, p. 5-8.

Webb, G. W. (1958) Middle Ordovician stratigraphy in eastern Nevada and western Utah: American Association of Petroleum Geologists Bulletin, v. 42, no. 10, p. 2335-2377.

Webster, G. D. (1969) Pennsylvanian conodonts from southern Nevada [abs.], *in* Abstracts for 1968: Geological Society of America Special Paper 121, p. 576.

Wentworth, C. K., and Williams, H. (1932) The classification and terminology of the pyroclastic rocks *in* Report from the Committee on Sedimentation 1930-32: National Research Council Bulletin 89, p. 19-53.

Westgate, L. G., and Knopf, A. (1932) Geology and ore deposits of the Pioche district, Nevada: U.S. Geological Survey Professional Paper 171, 79 p.

Wheeler, H. E., and McNair, A. H. (1950) Late Tertiary thrusting in northeastern Nevada [abs.]: Geological Society of America *Bulletin, v. 61, no. 12, pt. 2, p. 1513.*

Whitebread, D. H., Griggs, A. B., Rogers, W. B., and Mytton, J. W. (1962) Preliminary geologic map and sections of the Wheeler Peak quadrangle, White Pine County, Nevada: U.S. Geological Survey Mineral Investigations Field Studies Map MF-244, scale 1:48,000.

Widmier, J. M. (1960) Paleozoic rocks along lower North Fork canyon, Independence Mountains, Elko County, Nevada: M.A. thesis, Columbia University, New York, 34 p.

Willden, R., and Kistler, R. W. (1967) Ordovician tectonism in the Ruby Mountains, Elko County, Nevada, *in* Geological Survey research 1967: U.S. Geological Survey Professional Paper 575-D, p. D64-D75.

_____ (1969) Geologic map of the Jiggs quadrangle, Elko County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-859, scale 1:62,500.

_____ (1979) Precambrian and Paleozoic stratigraphy in central Ruby Mountains, Elko County, Nevada: *in* Newman, G. W., and Goode, H. D., eds., Basin and Range Symposium and Great Basin Field Conference: Rocky Mountain Association of Geologists, p. 221-243.

Willden, R., Thomas, H. H., and Stern, T. W. (1967) Oligocene or younger thrust faulting in the Ruby Mountains, northeastern Nevada: Geological Society of America Bulletin, v. 78, no. 11, *p. 1345-1357.*

Williams, H., and McBirney, A. R. (1979) Volcanology: San Francisco, Freeman, Cooper, 397 p.

Willson, R. E. (1961) Geology and mineral resources of T. 35 N., R. 63 and 64 E., MDBM, Elko County, Nevada: unpub. report to Southern Pacific Land Co.

Wilshire, H. G., Howard, K. A., and Offield, T. W. (1971) Impact structures in carbonate rocks, Sierra Madera, Texas: Geological Society of America Bulletin, v. 82, no. 4, p. 1009-1017.

Wilson, E. C., and Langenheim, R. L., Jr. (1962) Rugose and tabulate corals from Permian rocks in the Ely quadrangle, White Pine County, Nevada: Journal of Paleontology, v. 36, no. 3, p. 495-520.

Woodward, L. A. (1963) Late Precambrian metasedimentary rocks of Egan Range, Nevada: American Association of Petroleum Geologists, v. 47, no. 5, p. 814-822.

_____ (1965) Late Precambrian stratigraphy of northern Deep Creek Range, Utah: American Association of Petroleum Geologists Bulletin, v. 49, no. 3, p. 310-316.

_____ (1967) Stratigraphy and correlation of late Precambrian rocks of Pilot Range, Elko County, Nevada, and Box Elder County, Utah: American Association of Petroleum Geologists Bulletin, v. 51, no. 2, p. 235-243.

Yochelson, E. L., and Fraser, G. D. (1973) Interpretation of depositional environment in the Plympton Formation (Permian), southern Pequop Mountains, Nevada, from physical stratigraphy and a faunule: U.S. Geological Survey Journal of Research, v. 1, no. 1, p. 19-32.

Youngquist, W. L., and Haegele, J. R. (1956) Geological reconnaissance of the Cassia Mountain region, Twin Falls and Cassia Counties, Idaho: Idaho Bureau of Mines and Geology Pamphlet 110, 18 p.

Youngquist, W. L., Hawley, R. W., and Miller, A. K. (1951) Phosphoria conodonts from southeastern Idaho: Journal of Paleontology, v. 25, no. 6, p. 785-792.

Zoback, M. L., and Thompson, G. A. (1978) Basin and range rifting in northern Nevada: Clues from a mid-Miocene rift and its subsequent offsets: Geology, v. 6, no. 2, p. 111-116.

INDEX OF STRATIGRAPHIC UNITS

Adobe Range sequence, 32, 47, 95
Agort Chert, 11
Angel Lake unit 78, 79
Antelope Valley Limestone, 17-19
Antler Peak Limestone, 37
Arcturus Formation, 37, 40, 41
Arcturus Group, 40
Arcturus Limestone, 40
Aura Formation, 20
Banbury Volcanics, 65
Banner Formation, 28-30, 80, 86, 87, 95, 98
Banner Limestone, 29
Battle Formation, 37
Bay State Dolomite Member, 26
Beacon Flat Formation, 32, 38, 39, 89
Beacon Peak Dolomite Member, 26
Big Island Formation, 64-66, 102
Black Mountain sequence, 89, 91
Bonneville Formation, 72
Buckskin Mountain Formation, 32, 36, 38, 39, 89, 90
Bullwhacker Member, 16
Burns Creek sequence 20, 22
Carlin Canyon Formation, 32, 38, 39, 49, 63, 89, 90
Carlin sequence, 32, 35, 38, 39, 85, 89
Catlin Member, 16
Chainman Shale, 13, 28-34, 38, 44, 83, 86, 88-91, 95, 98, 101
Chellis Formation, 44, 45
Chinle Formation 49, 50
Circle Creek Rhyolite, 67, 102
Coffeepot stock, 80
Coldspring Mountain, rhyolite of, 69
Columbia stock, 74
Contact pluton, 75, 89
Copper Basin Formation, 29
Cornucopia, phenoandesite of, 61
Corset Spring Formation, 15
Cottonwood Creek pluton, 76
Cougar Point Welded Tuff, 63-66, 71, 102
Crystal Peak Dolomite, 18, 20
Danger Point Tuff, 71
Dead Horse Tuff, 54, 100
Devils Gate Formation, 26, 90
Devils Gate Limestone, 13, 26, 27, 34, 78, 89
Diamond A Formation, 30, 95
Diamond Peak Conglomerate, 35
Diamond Peak Formation 28, 31-35, 38, 44, 83, 84, 87-91, 95, 100, 101
Dinwoody Formation, 32, 48, 49, 90, 91
Dunderberg Shale, 15-17, 78
Edgemont Formation, 16
Edna Mountain Formation, 32, 45-47, 84-88
Eldorado Dolomite, 15
Elko Formation, 54, 55, 99
Ely Limestone, 31-37, 40, 43, 98, 101
Ely Springs Dolomite, 19-21, 80
Enright Hill pluton, 74
Eureka Quartzite, 17-21, 80, 91, 101
Ferguson Mountain Formation, 32, 35-40, 101
Ferguson Springs Formation, 36, 37, 39
Fish Haven Dolomite, 18-21, 28
Frenchie Creek Rhyolite, 50, 95
Garden City Formation, 18
Geddes Limestone, 15
Gerster Formation, 41, 42, 47, 49
Gerster Limestone, 40, 41
Gold Creek pluton, 74
Goodwin Limestone, 10, 17, 19, 83
Goughs Canyon Formation, 30
Grandeur Formation, 32, 42, 43
Grandeur Member, 40, 42, 43
Grossman Formation 19, 28-30, 80, 86, 98
Guilmette Dolomite, 26
Guilmette Formation, 25-29, 33, 78, 89, 90, 101
Hamburg Dolomite, 15, 16
Hammond Canyon Formation, 43
Hanson Creek Dolomite, 21
Hanson Creek Formation, 19-24, 80
Happy Camp Formation, 24
Harrison Pass pluton, 5, 74, 76, 77, 79, 99-101
Havallah Formation, 32, 45, 46, 86
Hay Ranch Formation, 69, 70
Hick's Mountain pluton, 70
Hogan Formation, 32, 35-37
Horse Mountain, sandstone and siltstone of, 32, 46
Humboldt Formation, 60, 62, 63, 67
Idavada Volcanics, 63, 65, 67
Indian Well Formation, 59
Jacks Peak Formation, 12
Jarbidge Rhyolite, 60, 62-64, 66, 69, 71, 77, 100-103
Jenny Creek Tuff, 62-65, 71
Joana Limestone, 27-29, 33, 98, 99
Johns Wash Formation, 15
Juab Limestone, 18
Kaibab Formation, 40
Kaibab Limestone, 32, 40-43
Kanosh Shale, 18
Kinsley pluton, 76, 77
Koipato Group, 88
Laketown Dolomite, 20, 21, 25, 26, 28
Lee Canyon, argillite of, 29, 96
Lehman Formation, 18
Lone Mountain Dolomite, 18-26, 80
Lone Mountain pluton, 76, 77
Long Canyon sequence, 32, 47, 95
Loray Formation, 32, 40, 41
McAfee Quartzite, 12, 86
McClellan Creek sequence, 26
McCoy Creek Group, 9, 75, 79, 80
McDonald Creek pluton, 76
Meade Peak Phosphatic Shale Member, 32, 40, 43, 46
Meadow Fork Formation, 54, 100
Mitchell Creek Formation, 32, 45, 85, 95
Moleen Formation, 32, 34, 35, 38
Mountain City Formation, 31, 86, 98
Mountain City pluton, 76, 86
Mount Neva pluton, 76, 77
Murdock Mountain Formation, 32, 42, 43
Nelson Formation, 30, 31, 45, 85-87, 95, 98
Nevada Formation, 13, 24-27, 89
Newark Canyon Formation, 50, 96
Ninemile Formation, 17
Noh Formation, 11, 90
Notch Peak Dolomite, 15, 17
Nugget Sandstone, 48, 50
Oquirrh Formation, 35, 37, 43
Osgood Mountain Quartzite, 14
Ottawanah Rhyolite, 58
Oxyoke Canyon Sandstone Member, 26
Palisade Canyon Rhyolite, 63, 67
Panguipah Spring, basalt of, 61
Park City Formation, 40, 42, 43
Park City Group, 32, 40-43
Pequop Formation, 32, 36, 37, 39, 40, 90, 98, 99, 101
Phosphoria Formation, 32, 38-43, 46, 48, 87, 90
Pilot Shale, 13, 28, 33
Pioche Formation, 15
Pioche Shale, 15, 80, 97
Plympton Formation, 32, 40-43
Pogonip Group, 10, 13, 17-20, 22, 78, 80, 83, 98
Pogonip Limestone, 17, 87
Pole Creek Dacite, 63, 65
Poorman Peak Formation, 43
Porter Peak Limestone, 16, 17
Prospect Mountain Quartzite, 9, 13-17, 75, 78-80, 83, 87, 100
Pumpernickel Formation, 46
Quilici Formation, 32, 36
Rabbit Hill Limestone, 24
Railroad mining district stock, 76, 77
Reservation Hill Formation, 32, 45, 46, 86, 87, 95, 98
Retort Phosphatic Shale Tongue, 43
Rex Chert Member, 32, 40, 42, 43
Rib Hill Formation, 32, 36, 37
Rib Hill Sandstone, 46
Riepe Spring Limestone, 32, 37, 98
Riepetown Sandstone, 37, 40
Roberts Mountains Formation, 13, 22-24, 45, 97
Robinson Creek Dacite, 63, 65
Schoonover Formation, 31, 32, 45, 47, 86, 88, 95
Scotty Wash Quartzite, 31
Secret Canyon Shale, 15
Seetoya sequence, 10
Sentinel Mountain Dolomite Member, 26
Seventy Six Basalt, 61
Sevy Dolomite, 21, 24-27
Shaver sequence, 74
Shinarump Conglomerate, 49
Sikikareh Mountain, slate of, 85, 95
Silver Creek pluton, 76
Silver Zone Pass pluton, 75, 97
Simonson Dolomite, 24-27, 78
Skull Creek pluton, 76
Slaven Chert, 13
Slide Creek Gravel, 62
Smith Creek sequence, 20
Snell Creek Marble, 78
Snow Canyon Formation, 12
Snow Water unit, 78, 79
Storff Formation, 44, 45
Strathearn Formation, 32, 36-38, 44, 80, 83-90
Sunflower Formation, 37, 38, 44, 87
Swales Mountain pluton, 76, 77
Swan Peak Quartzite, 18, 20
Taylor Canyon Formation, 24
Tennessee Mountain Formation, 17, 38, 80, 83, 87
Thaynes Formation, 32, 41, 48, 49
Thousand Spring sequence, 11, 89
Timothy Formation, 49, 50
Tiser Limestone, 11
Toano Springs pluton, 75
Tomera Formation, 32, 34-36, 38
Tonka Formation, 38
Tripon Pass Limestone, 29, 89
Valder Formation, 11
Valmy Formation, 10-12, 28, 30, 31, 33, 45, 55, 80, 83-91, 98, 103
Van Duzer Limestone, 32, 36, 44, 45, 84, 95
Vinini Formation, 10-12
Wah Wah Limestone, 18
Wasatch Formation, 51
Waterpipe Canyon Formation, 32, 86
Webb Formation, 12, 13, 29, 81
Weber Quartzite, 40
White Horse pluton, 75
White Rock stock, 74
Wildcat Peak, ignimbrite of, 103
Windfall Formation, 15, 16
Windmill Limestone, 24
Woodpecker Limestone Member, 26
Wood River Formation, 46
Woodruff Formation, 12, 13
Woodside Shale, 40
Young America Gravel, 63