Tectonic Events Since Early Paleozoic in the Carlin-Pinon Range Area, Nevada

GEOLOGICAL SURVEY PROFESSIONAL PAPER 867-C

Prepared in cooperation with Nevada Bureau of Mines and Geology

Tectonic Events Since Early Paleozoic in the Carlin-Pinon Range Area, Nevada

By J. FRED SMITH, JR., *and* KEITH B. KETNER

GEOLOGY OF THE CARLIN-PINON RANGE AREA, NEVADA

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Of seven recognized deformational episodes the earliest occurred in Late Devonian to Early Mississippian time and a principal orogenic event occurred in Mesozoic time

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1977

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress Cataloging in Publication Data

Smith, Joe Fred, 1911–
Tectonic events since early Paleozoic in the Carlin-Pinon Range area, Nevada. (Geology of the Carlin-Pinon Range area, Nevada)

(Geological Survey Professional Paper 867–C)
Bibliography: p.
Supt. of Docs. no.: I 19.16:867–C
1. Geology–Nevada–Elko Co. 2. Geology–Nevada–Eureka Co. I. Ketner, Keith Brindley, 1921– joint author. II. Nevada. Bureau of Mines and Geology. III. Title. IV. Series. V. Series: United States Geological Survey Professional Pa Paper 867–C.
QE138.E4S64 551.8'09793'16 76–608351

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock Number 024-001-02953-7

CONTENTS

ILLUSTRATIONS

TABLE

SYSTEM OF MEASUREMENT UNITS

This report uses both metric and English systems of units. In the text, metric units appear first and equivalent measurements in English units follow in parentheses. The units are abbreviated using the notation in the following list, and metric units were converted to English units by means of the multiplication factors shown.

To convert:	*To:*	*Multiply by:*
(Metric unit)	(English unit)	(Multiplication factor)
kilometers (km)	miles (mi)	0.6214
meters (m)	feet (ft)	3.281

TECTONIC EVENTS SINCE EARLY PALEOZOIC IN THE CARLIN-PINON RANGE AREA, NEVADA

By J. Fred Smith, Jr., and Keith B. Ketner

ABSTRACT

Following a long tranquil interval in early Paleozoic time, rocks of the area were subjected to at least seven distinct deformational episodes as follows: (1) multiple subparallel thrusts of great displacement in late Late Devonian to early Early Mississippian; (2) deep subsidence in the area coupled with strong uplift close to the west edge of the area beginning in middle Early Mississippian; (3) regional uplift and local folding and eastward-directed thrusting in late Middle to early Late Pennsylvanian; (4) renewed uplift and permanent end of marine conditions in early Mesozoic; (5) igneous intrusion followed by intense folding, some of very large scale, and westward-directed thrusting climaxing in Late Jurassic to Early Cretaceous; (6) igneous intrusion and local folding in early Oligocene; and (7) normal faulting climaxing in Miocene. Evidence from this area suggests that the displacement on the Roberts thrust at this latitude was at least 110 km (68 mi) and probably much more. The leading edge of the upper plate of that thrust probably lay diagonally or irregularly across the area after movement ceased. Sedimentation was scarcely interrupted near this leading edge of the upper plate, but other areas nearby to the west were emergent and were deeply eroded immediately after emplacement. Mesozoic tectonism involving prolonged uplift, injection of large igneous bodies, volcanism, intense folding, and thrusting constitutes a complex orogenic event of major importance and is a principal orogenic event in the history of the area.

INTRODUCTION

The country here designated the Carlin-Pinon Range area comprises four 15-minute quadrangles—the Carlin, Dixie Flats, Pine Valley, and Robinson Mountain quadrangles—in northeast Nevada (fig. 1). J. F. Smith, Jr., and K. B. Ketner have mapped the geology of these four quadrangles at a scale of 1:62,500 and prepared accompanying structure sections (Smith and Ketner, 1977).

Past work in the immediate area includes the reports of the 40th Parallel Survey, in which Hague (1877) alluded to structures in the Pinon Range. In an early report on the mineral districts of the region, Emmons (1910, p. 88–95) noted the anticlinal structure of the Pinon Range near the Railroad mining district. Kay (1952) and Dott (1955) recognized evidence of Paleozoic orogeny equivalent to the three separate tectonic events that we recognize between Late Devonian and Late Pennsylvanian time. Roberts, Hotz, Gilluly, and Ferguson (1958) described regional aspects of the Antler orogeny and presented convincing evidence of the age of that event that was based on our work in the Carlin-Pinon Range area.

Fieldwork for this report extended, with interruptions, mainly from 1955 to 1964; it was continued for a few days each year in 1965, 1969, and 1971.

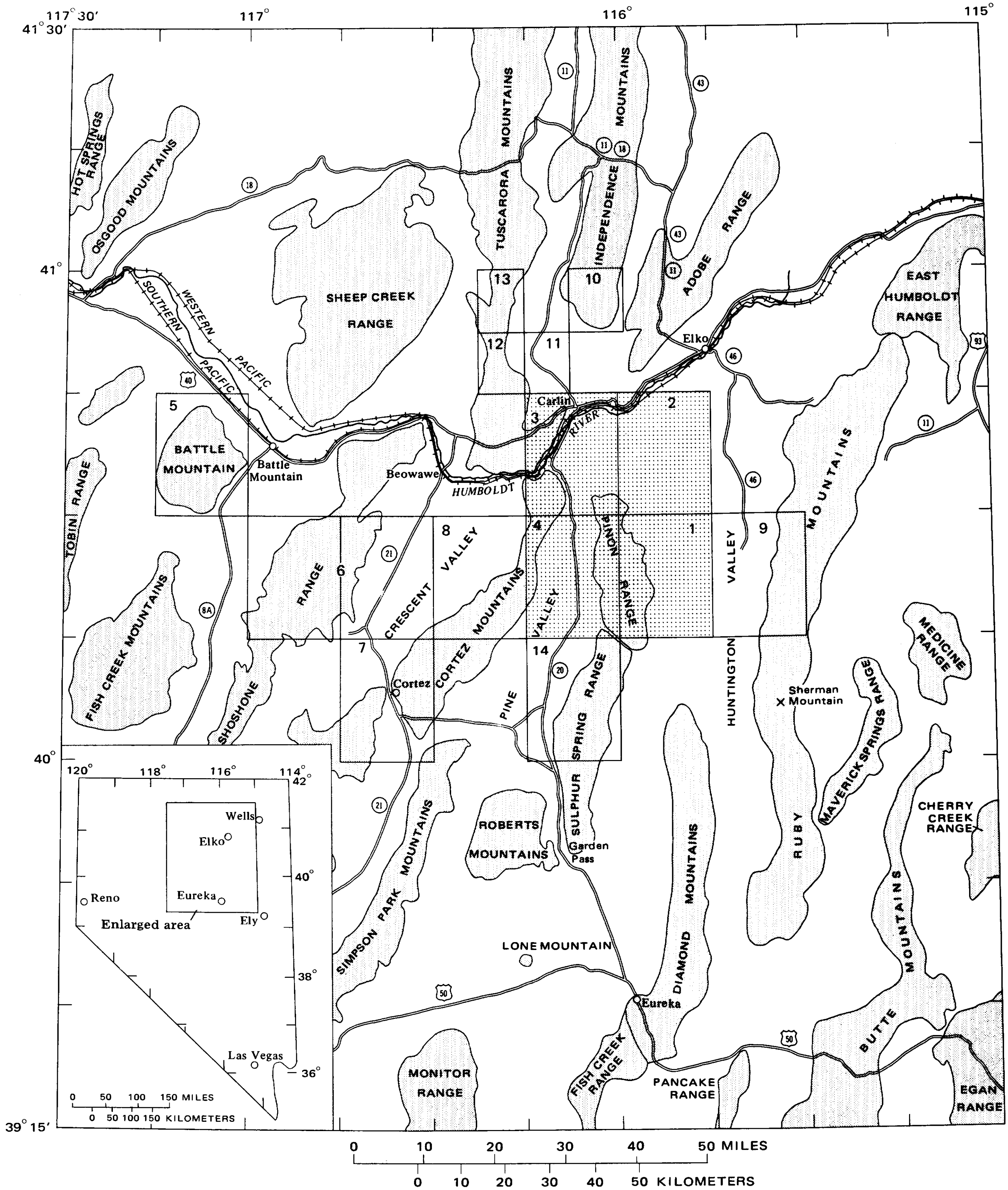
The stratigraphic sequence and structural relations could not have been determined without a large number of paleontologic and radiometric ages supplied by specialists. These paleontologists, geologists, and chemists are acknowledged individually at appropriate places in Chapters A (Smith and Ketner, 1975) and B (Smith and Ketner, 1976) of this report. We were fortunate in having the able assistance in the field of the following geologists: José B. Alarcon of Chile, John R. Algor, David D. Blackwell, William M. Briggs, John B. Corliss, Robert S. Crosson, Robert N. Diffenbach, George Ditsworth, Pedro A. Gelabert, Richard S. Kopp, William L. Lehmbeck, Lucian B. Platt, Robert K. Smith, Jack A. Wolfe, and John C. Young.

THE STRATIGRAPHIC COLUMN

Rocks ranging in age from Ordovician to Holocene make up the stratigraphic column in the Carlin-Pinon Range area and have been described in Chapters A (Smith and Ketner, 1975) and B (Smith and Ketner, 1976) of this report. Brief descriptions and thicknesses of the rock units are presented in table 1.

GENERAL STRUCTURE

Structural features in the Carlin-Pinon Range area include folds and both normal and thrust faults. A north-northwest-trending anticline follows the crest of the Pinon Range for much of its length; a northeast-trending syncline crosses the northern part of the area


117°30′
117°
116°
115°
41°30′
41°
40°
39°15′
HOT SPRINGS RANGE
OSGOOD MOUNTAINS
SHEEP CREEK RANGE
TUSCARORA MOUNTAINS
INDEPENDENCE MOUNTAINS
ADOBE RANGE
EAST HUMBOLDT RANGE
SOUTHERN PACIFIC
WESTERN PACIFIC
BATTLE MOUNTAIN
Battle Mountain
Beowawe
HUMBOLDT RIVER
Carlin
Elko
TOBIN RANGE
FISH CREEK MOUNTAINS
SHOSHONE RANGE
CRESCENT VALLEY
CORTEZ MOUNTAINS
Cortez
PINE VALLEY
PINON RANGE
SULPHUR SPRING RANGE
HUNTINGTON VALLEY
RUBY MOUNTAINS
Sherman Mountain
MEDICINE RANGE
MAVERICK SPRINGS RANGE
CHERRY CREEK RANGE
ROBERTS MOUNTAINS
Garden Pass
SIMPSON PARK MOUNTAINS
LONE MOUNTAIN
DIAMOND MOUNTAINS
Eureka
BUTTE MOUNTAINS
MONITOR RANGE
FISH CREEK RANGE
PANCAKE RANGE
EGAN RANGE
1 2 3 4 5 6 7 8 9 10 11 12 13 14
11 18 43 33 46 93 40 8A 21 20 50
120° 118° 116° 114°
42° 40° 38° 36°
Wells
Elko
Reno
Eureka
Ely
Enlarged area
Las Vegas
0 50 100 150 MILES
0 50 100 150 KILOMETERS
0 10 20 30 40 50 MILES
0 10 20 30 40 50 KILOMETERS

for about 24 km (15 mi); and shorter folds of varying trends occur throughout the area and are clustered in some parts of it, as from Smith Creek south to Willow Creek. East of the Pinon Range to Cedar Ridge, the older rocks are apparently synclinal. A fault bounds part of the west side of the Pinon Range, but no bounding fault is evident on the east side. A prominent basin-and-range fault bounding the west side of the Cortez Mountains extends into the mapped area for about 1.6 km (1 mi). Other normal faults of varying trends, mostly breaking Paleozoic rocks, are scattered throughout the area. Several thrust faults of different ages are recognized; none can be traced for more than a few kilometers.

STRUCTURAL EVENTS

During a long tranquil interval in early Paleozoic time, materials deposited in the Cordilleran geosyncline consisted of miogeosynclinal carbonate sediments in the east, including the area of this report, eugeosynclinal siliceous sediments in the west, and both carbonate and siliceous sediments transitional between the other two. This period of relative structural quiescence came to a close in Late Devonian time and the character of the Cordilleran geosyncline changed importantly, with the result that the regular east-to-west facies changes no longer persisted for the entire region. With this change in the Cordilleran geosyncline, rocks of the Carlin-Pinon Range area were subjected to at least seven distinct deformational (fig. 2) and igneous episodes: (1) multiple subparallel, generally eastward directed thrusts of great displacement in late Late Devonian to Early Mississippian; (2) deep subsidence generally north trending through the area coupled with strong uplift close to the west edge of the area, beginning about middle Early Mississippian; (3) regional uplift and local folding with northwest trends and eastward-directed thrusting in late Middle to early Late Pennsylvanian; (4) renewed uplift and permanent end of marine conditions in early Mesozoic; (5) igneous intrusion followed by intense folding, some of it on a large scale, and westward-directed thrusting climaxing in Late Jurassic to Early Cretaceous; (6) igenous intrusion and local folding with generally north trends in early Oligocene; and (7) normal faulting and volcanism climaxing in Miocene time. We are reluctant to assign these tectonic events to any previously recognized and named orogenies, such as the Antler, Sonoma, Nevadan, Sevier, or Laramide, until there is a clearer consensus on the temporal and geographic limits of orogenic events in the region. The major thrusting occurred during the Devonian-Mississippian and the major folding, during the Mesozoic.

FIGURE 1.—Part of northeast Nevada showing the locations of the quadrangle maps that make up the Carlin-Pinon Range area (shaded area): (1) Robinson Mountain, (2) Dixie Flats, (3) Carlin, and (4) Pine Valley; and the locations of recently published maps of nearby quadrangles: (5) Antler Peak (Roberts, 1964), (6) Mount Lewis and Crescent Valley (Gilluly and Gates, 1965), (7) Cortez (Gilluly and Masursky, 1965), (8) Frenchie Creek (Muffler, 1964), (9) Jiggs (Willden and Kistler, 1969), (10) Swales Mountain and part of Adobe Summit (Evans and Ketner, 1971), (11) Schroeder Mountain (Evans and Cress, 1972), (12) Welches Canyon (Evans, 1974a), (13) Rodeo Creek NE (Evans, 1974b), and (14) Mineral Hill (C. A. Nelson and D. C. Carlisle, unpub. mapping, 1960(?)).

Some structures, both folds and normal faults, may have been enhanced or reactivated during late deformations. The direction of displacement of some normal faults seems to have reversed during younger deformation. Older structural features have been so modified by younger tectonic events and so obscured by younger sedimentation that the geologic map shows no consistent structural grain. However, both local and regional evidence indicates that the deformational forces, whether compressional or tensional, have consistently operated in a generally east-west direction.

LATE LATE DEVONIAN TO EARLY EARLY MISSISSIPPIAN DEFORMATION

The oldest structures in the area are those formed when lower Paleozoic siliceous rocks were thrust from distant sites of deposition eastward over contemporaneous autochthonous carbonate rocks. Although certain breccias and small folds were formed at this time, the most important structures formed were the thrust faults within and at the base of the upper plate of the thrust. Generally, a thrust fault such as this one that separates the siliceous from the carbonate facies of lower Paleozoic rocks is conventionally called the Roberts Mountains thrust or, more simply, the Roberts thrust. We use this term in the generally accepted descriptive sense but with some misgivings, because we cannot be sure that our Roberts Mountains thrust fault is the same age as the corresponding fault of the type area in the Roberts Mountains (fig. 1). If future investigations in the Roberts Mountains show that they are of widely disparate ages, our use of the term could be questioned. As used in the present report, the Roberts Mountains thrust is a thrust on which lower Paleozoic siliceous and carbonate rocks were juxtaposed during late Late Devonian to early Early Mississippian time.

The Late Devonian or early Early Mississippian age of the Roberts Mountains thrust and genetically associated structures in this area is demonstrated in a previous report (Smith and Ketner, 1968). The youngest beds involved in this deformation are middle Famennian as indicated by goniatites (Mackenzie Gordon, Jr., in Smith and Ketner, 1975, p. A29) from the Woodruff Formation in the upper plate. According

TABLE 1.—*Rock units exposed in the Carlin-Pinon Range area, Nevada*

System	Series	Stratigraphic unit	Thickness in meters (ft)	Lithology and remarks
Quaternary		Landslide debris Alluvium and colluvium		
		Gravel, sand, and silt	Commonly 6–18 (20–60)	Nontuffaceous deposits on benches and terraces.
Quaternary and Tertiary	Pleistocene and Pliocene	Hay Ranch Formation	At least 400 (1,300)	Clay, tuff, limestone, tuffaceous siltstone, sandstone, and fanglomerate.
Tertiary	Miocene	[Probably about the same age] Basalt plugs		Small plugs at north end of Pine Valley.
		Andesite and basaltic andesite	Minimum about 305 (1,000)	Dark-gray to black, mostly dense and aphanitic flows.
		Humboldt Formation	About 580 (1,900)	Tuff, vitric ash, tuffaceous siltstone and sandstone, conglomerate, and limestone, some diatomite.
		Palisade Canyon Rhyolite	Maximum about 245 (800)	Rhyolite flows. Forms wedge in Humboldt Formation.
	Oligocene	Rhyolitic welded tuff	About 60 (200)	Covers small area on east flank of Cortez Mountains.
		Mafic to intermediate plugs and dikes		Dark-gray to black, dense, and aphanitic intrusive rocks.
		Younger intermediate to silicic volcanics	275–305 (900–1,000)	Mostly lavas ranging from andesite to quartz latite; some interlayered ash-flow tuffs and volcanic breccias.
		[Of about the same age] Indian Well Formation	1,015 (3,300) maximum measured	Rhyolitic to dacitic ash-flow tuffs ranging from nonwelded to densely welded. Tuffaceous sedimentary rocks. Upper, fluviatile tuffaceous sandstone dominant, but evenly bedded tuff and lacustrine limestone interbedded with sandstone. Lower 305–360 m (1,000–1,200 ft) are fluviatile deposits dominantly of sandstone with some conglomerate, siltstone, and mudstone; many beds tuffaceous. Interlayered ash-flow tuff and tuffaceous sedimentary rocks. Basal unit in scattered outcrops of tuff and tuffaceous sedimentary rocks; includes volcaniclastic conglomerate and sandstone, which also have fragments of Paleozoic rocks; some welded tuff.
		Silicic intrusive rocks		Mostly rhyolite. Stock near Bullion has outer shell of granite, quartz monzonite, monzonite, and quartz diorite and a core of rhyolite.
		Mafic to silicic volcanics	About 90–120 (300–400)	Dark fine-grained lavas; thin beds of volcaniclastic sandstone.

TABLE 1.—*Rock units exposed in the Carlin-Pinon Range area, Nevada*—Continued

System	Series	Stratigraphic unit	Thickness in meters (ft)	Lithology and remarks
Tertiary—Continued	Oligocene or Eocene	Older intermediate volcanics	150+ (500+)	Latitic to andesitic lavas.
		Elko Formation	Maximum about 760 (2,500)	Thin-bedded, light-gray and tan limestone with yellow tint; ostracode coquinites; laminated shale and siltstone; oil shale; claystone and marl; tuff in upper part.
	Eocene	Limestone	305 (1,000)	Gray to tan and white, dense, sugary, thick-bedded limestone.
		Cherty limestone	About 305 (1,000)	Gray and tan dense limestone; much black, brown, and tan opaline chert in pods and lumps; contains snail shells.
Tertiary(?)	Eocene(?)	Conglomerate, sandstone, siltstone and limestone	Maximum about 760 (2,500)	Pebble to boulder conglomerates of clasts derived from Paleozoic rocks; interbedded sandstone and siltstone; brown and gray limestone weathers tan, brown, and red.
		Limestone and limestone-clast conglomerate	Maximum 195 (635)	Gray limestone, commonly dense; conglomerate of pebble- to boulder-size clasts of mostly carbonate rocks derived from nearby Paleozoic formations.
Cretaceous	Upper and Lower Cretaceous	Newark Canyon Formation	Maximum about 885 (2,900)	Main body gray, tan, brown, and red sandstone and conglomerate with less siltstone and a little limestone in Cortez Mountains; gray shale, sandstone, conglomerate, and limestone in Pinon Range. Maximum thickness about 670 m (2,200 ft).
				Basal member of poorly consolidated, dark-gray to black mudstone, some siltstone, thin pebble layers, and sandstone and conglomerate lenses. Maximum thickness about 215 m (700 ft).
Jurassic	Upper Jurassic	Alaskite		Mostly fine grained to medium grained, much-altered intrusive rock.
		Granodiorite		Medium-grained, much-altered, gray intrusive rock. Outcrop area very small.
	Upper and Upper(?) Jurassic	Pony Trail Group: Frenchie Creek Rhyolite	Maximum may be 2,135 (7,000)	Mostly rhyolite to andesite lavas, commonly fine grained, porphyritic; light gray to black and reddish brown are most common colors. Flows, tuffs, and clastic sedimentary rocks. Rhyolite(?) plug much altered, with very small outcrop area.
		Pony Trail Group: Sod House Tuff	About 305 (1,000)	Mostly altered white silicic ash-flow tuff.
		Pony Trail Group: Big Pole Formation	At least 305 (1,000)	Mostly poorly sorted sedimentary rocks composed of volcanic fragments and plagioclase and quartz; some lava flows.

TABLE 1.—*Rock units exposed in the Carlin-Pinon Range area, Nevada*—Continued

System	Series	Stratigraphic unit	Thickness in meters (ft)	Lithology and remarks
Permian and Pennsylvanian			290+ (950+)	Mostly carbonate rocks (limestone to dolomite) containing much tan and brown chert in beds and pods; some siltstone.
			1,200± (4,000±)	Thin-bedded calcareous siltstone and sandstone that weather to yellow and tan platy fragments; limestone, dolomitic limestone, and dolomite; some black platy limestone; conglomerate and conglomeratic sandstone.
	Lower Permian and Upper Pennsylvanian	Strathearn Formation	365–610 (1,200–2,000)	Sandy limestone, tan and yellow calcareous quartz siltstone; crossbedded sandy and pebbly limestone; quartzite- and chert-clast conglomerate.
Pennsylvanian	Middle Pennsylvanian	Tomera Formation	520–610 (1,700–2,000)	Interbedded and interfingering limestone and conglomerate.
	Middle and Lower Pennsylvanian	Moleen Formation	365–490 (1,200–1,600)	Gray limestone, commonly ledgy, and interbedded silty and sandy limestone; pods and layers of chert; conglomerate lenses.
		Undivided Tomera and Moleen Formations	Maximum 1,005 (3,300)	Complete mixture of rock types that occur in the two formations. Mainly siliceous-clast conglomerate and sandstone.
Pennsylvanian and Mississippian	Lower Pennsylvanian, Upper and Lower Mississippian	Diamond Peak Formation	1,435± (4,700±)	Conglomerate of mostly chert and quartzite clasts ranging from pebbles to boulders; sandstone; some marl and shaly beds and limestone; lenticular units.
Mississippian	Upper and Lower Mississippian	Chainman Shale	About 490–760 (1,600–2,500)	Mostly gray and some almost black shale and sandstone of quartz and chert grains; some conglomerate lenses, some thin limestone and calcareous sandstone; pebbly mudstone.
		Undivided Diamond Peak and Chainman Formations	1,830–2,135 (6,000–7,000)	Conglomerate, sandstone, and shale; no one lithology dominant.
	Lower Mississippian	Webb Formation	0–245 (0–800)	Gray siliceous mudstone; black to gray, tan-weathering, dense limestone in lenses near top.
		Argillite of Lee Canyon	1,525+ (5,000+)	Black siliceous argillite and a little black chert; very little conglomerate and sandstone near top.
		Upper Plate of Roberts Mountains Thrust Siliceous assemblage		
Devonian	Upper to Lower Devonian	Woodruff Formation	915–1,830(?) (3,000–6,000?)	Dark-gray to black siliceous mudstone and chert; lesser amounts of shale, siltstone, dolomitic siltstone, dolomite, and limestone.
Silurian	Middle or Lower Silurian	Chert and siltstone	Few hundred meters (few hundred feet)	Gray, tan, brown, and green chert and lesser amounts of siltstone.

TABLE 1.—*Rock units exposed in the Carlin-Pinon Range area, Nevada*—Continued

System	Series	Stratigraphic unit	Thickness in meters (ft)	Lithology and remarks
Upper Plate of Roberts Mountains Thrust—Continued Siliceous assemblage—Continued				
Ordovician	Middle Ordovician	Valmy Formation	50+ (150+)	Shale, quartzite, and greenstone.
	Upper, Middle, and Lower Ordovician	Vinini Formation	Probably at least 1,000 (3,000)	Dominantly black chert, and shale and siliceous mudstone.
Upper Plate of Roberts Mountains Thrust Transitional assemblage				
Devonian	Upper and Middle Devonian	Limestone and chert	Few hundred meters (few hundred feet)	Gray limestone, sandy limestone, chert, and chert-pebble conglomerate.
	Lower Devonian	Roberts Mountains Formation	90± (300±)	Black shaly and platy carbonaceous silty dolomite and dolomitic marl; exposed in thrust slice. May not be in upper plate of Roberts Mountains thrust.
Ordovician	Upper, Middle, and Lower Ordovician	Claystone, shale, and limestone	490+ (1,600+)	Claystone, shale, sandy limestone, and chert, limestone, and quartzite.
Lower Plate of Roberts Mountains Thrust Carbonate assemblage				
Devonian	Upper and Middle Devonian	Devils Gate Limestone	285+ (940+)	Medium- to thick-bedded, light- and dark-gray limestone.
	Middle and Lower Devonian	Nevada Formation Upper dolomite member	257–630 (845–2,065)	Brown and gray dolomite in alternating layers.
		Oxyoke Canyon Sandstone Member	0–185 (0–600)	Quartzite and sandstone containing variable amounts of dolomite.
		Beacon Peak Dolomite Member	205 (675)	Thin- to thick-bedded, gray to brown dolomite; peculiar grainy-appearing texture and thin red stylolites are characteristic.
Devonian and Silurian	Lower Devonian and Upper Silurian	Lone Mountain Dolomite	425+ (1,400+)	Upper part mostly alternating brown and gray dolomite in beds 0.6–4 m (2–12 ft) thick. Lower part mostly obscurely thick bedded, gray dolomite. In Chapter A of this report (Smith and Ketner, 1975, p. A17 and pl. 1), the Lone Mountain Dolomite is shown to be of Silurian age, but a possible Devonian age is suggested for part of the formation. In keeping with this suggested age, we now show the Lone Mountain to be Early Devonian and Late Silurian.
Ordovician	Upper and Middle Ordovician	Hanson Creek Formation	40 (130)	Thin- to thick-bedded black and gray dolomite; dolomitic and limy siltstone, silty limestone, and very fine grained sandstone that weather yellow at top.
	Middle Ordovician	Eureka Quartzite	21 (70)	Thick-bedded to obscurely thin bedded white quartzite.
		Pogonip Group	About 105 (350) exposed	Mostly thin bedded gray dolomite, some thick bedded; interbeds of shale in upper part.

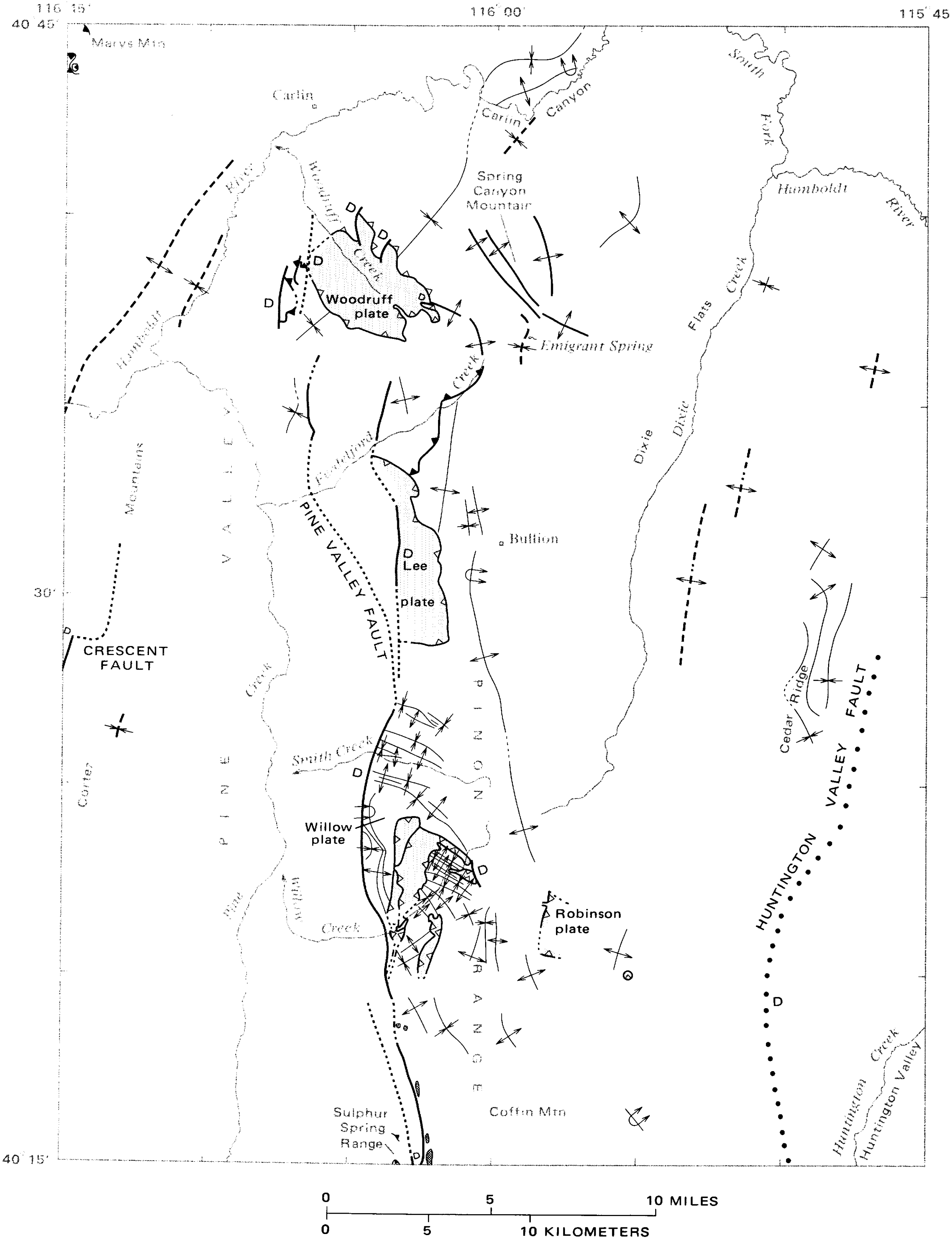


FIGURE 2.—Sketch map of the Carlin-Pinon Range area showing ages of principal folds and thrust faults. Geology by J. F. Smith, Jr., and K. B. Ketner, 1955–65. Base from U.S. Geological Survey, 1:62,500, Carlin, Dixie Flats, and Pine Valley, 1952; Robinson Mountain, 1956. Explanation on opposite page.

EXPLANATION

TERTIARY STRUCTURES

Anticline – Dotted where concealed

Syncline

LATE LATE JURASSIC OR EARLY CRETACEOUS STRUCTURES

Some of the folds may have been formed during Middle Pennsylvanian time and then folded again during Mesozoic time

Anticline – Dotted where concealed

Overturned anticline

Syncline – Dotted where concealed

Overturned syncline

Thrust fault – Dotted where concealed. Sawteeth on upper plate. Shaded areas include all exposed upper plate rocks

LATE MIDDLE TO EARLY LATE PENNSYLVANIAN STRUCTURES

Anticline

Syncline

Thrust fault – Dotted where concealed. Sawteeth on upper plate

LATE LATE DEVONIAN OR EARLY EARLY MISSISSIPPIAN STRUCTURES

Windows of lower plate rocks in Roberts Mountains thrust fault

Thrust fault – In upper plate of and assumed to be same age as Roberts Mountains thrust. Sawteeth on upper plate

NO AGE INDICATED

Normal fault – Dotted where concealed. D, downthrown side. Only a very few of the normal faults in the area are shown

Concealed normal fault – D, downthrown side. Plotted strictly on basis of geophysical data from Mabey (1964)

Stream – Arrow indicates direction of flow

to the time scale of Francis and Woodland (1964), this age would be about 349 m.y. The oldest beds that overlap rock units brought together on the Roberts thrust are early Kinderhookian on the basis of conodonts (J. W. Huddle, D. L. Clark, and W. H. Hass, in Smith and Ketner, 1975, p. A37–A38). According to the same time scale, this age is 343–344 m.y. Thus the maximum time interval during which thrusting took place in the report area was probably about 5 m.y.

Except for possible tectonic erosion and the formation of patches of silicified carbonate and patches of breccia just below the Roberts Mountains thrust, the lower plate rocks seem to have been remarkably little affected by the thrust. The thrust cuts beds in the area that range from the lowest member of the Nevada Formation to the Devils Gate Limestone, producing a stratigraphic relief at one place of about 760 m (2,500 ft) within a distance of about 1.6 km (1 mi). The amount of stratigraphic relief accords with that in some neighboring areas such as the southern Independence Mountains (Lovejoy, 1959) where thrusts fail to cut below Devonian carbonates; but it differs from some other areas such as the northern Shoshone Range (Gilluly and Gates, 1965) to the west and the Snake Mountains (Gardner, 1968) about 130 km (80 mi) to the northeast where rocks as old as Cambrian are cut by the Roberts thrust.

Relief on the lower plate could have been produced either tectonically during thrusting or by stream erosion immediately before thrusting. We find little convincing evidence to support either hypothesis. However, the greatest relief is in the southern part of the area close to a clastic carbonate deposit of uncertain affinities. We have interpreted this deposit as a transitional facies of the Devonian brought to the area on the Roberts Mountains thrust, but it could conceivably be a more local deposit eroded from the carbonate sequence immediately prior to thrusting.

The impression given by most exposures of the upper plate rocks in this and neighboring areas is that they have been only moderately disturbed when compared with a thrust plate that consists of a melange or chaotic assemblage of genetically incompatible rocks. Metamorphism and plastic deformation are absent. Breccias and tight folds are fairly common but are of local extent and uncertain age. Many small tight folds probably are restricted to single thrust platelets in which the rocks were crumpled, but the platelet boundaries were not appreciably folded. Very commonly the upper plate rocks dip steeply and consistently over large areas. Many of these attitudes, however, seem to be more logically attributable to younger, principally Mesozoic deformation than to folding related to the Roberts Mountains thrust. At Marys Mountain the Ordovician sequence overlies Devonian rocks and is itself overlain by Silurian rocks on a thrust which appears to be about parallel to the bedding. Moreover, reversals in the sequence of graptolite zones within the Ordovician beds there indicate the presence of several inconspicuous thrust faults. In neighboring areas to the north and northeast (Ketner, 1974, and unpub. data; Gardner, 1968), single beds of chert, quartzite, or limestone within the upper plate can be traced almost continuously for as much as 14 km (9 mi).

Rocks of the upper plate are much folded as well as thrust faulted (for example, Gilluly and Gates, 1965; Evans, 1974a), but some folding must be attributable to deformation younger than the time of the Roberts

Mountains thrusting. In the Pinon Range and in the Adobe Range to the northeast, we find that the major folding occurred during Mesozoic time; we believe that other nearby areas must also have been involved in folding at this time. It appears to us that in places the rocks of the upper plate are remarkably little deformed and altered for having traveled very long distances on thrust faults and for having undergone additional periods of deformation in late Paleozoic, Mesozoic, and Cenozoic times. When these younger structures are subtracted, the remaining deformation ascribable to latest Devonian and earliest Mississippian time seems to be largely a shuffling of broad thin plates on thrust faults that are commonly subparallel to the bedding of both the lower and upper plate of the Roberts thrust.

Data on the Lower Mississippian Webb Formation yield some information on events during the time of development of the Upper Devonian to Lower Mississippian unconformity. In the northern part of the area near Emigrant Spring, the Lower Mississippian (lower Kinderhookian) Webb Formation lies directly on the Middle and Upper Devonian Devils Gate Limestone. The short hiatus of this disconformity seems hardly long enough for thrusting, uplift, complete erosion of the upper plate, and resubmergence to have occurred. Supporting this hypothesis is the fact that little or none of the Devils Gate is missing. Thus, it seems quite possible that the upper plate was never present here and that the original leading edge of this plate lies covered by upper Paleozoic rocks 1–2 km (1 mi) to the southwest of Emigrant Spring. Probably the east edge of the thrust plate was irregular, and parts of the autochthon near the front edge could have been bypassed by the thrust.

In an area northwest of Coffin Mountain, near the south edge of the map (fig. 2), the Webb and Devils Gate Formations are absent and the Chainman Shale must have been deposited directly on lower and middle parts of the Nevada Formation. The hiatus of the unconformity was somewhat longer here than in the Emigrant Spring area. Upper plate rocks are exposed a short distance southeast of this locality where they have been dropped down on normal faults; they, too, probably rest on lower and middle parts of the Nevada Formation. It seems certain, therefore, that the upper plate covered this area and was completely eroded in places before the Chainman was deposited.

The composition of the Webb Formation in the northern part of the area indicates that its provenance, in large part, was the upper plate of the Roberts thrust. The age of the formation corresponds roughly to the hiatus between the Nevada and Chainman Formations in the southern part of the area near Coffin Mountain, although the Chainman in the south and the Webb are partly time equivalents. It could be concluded that the marine Webb Formation is a depositional product of the upper plate rocks that have been eroded from the southern part of the area. If so, the terrain immediately after thrusting was one of subdued relief where upper plate rocks near the leading edge of the thrust were being eroded and the resulting fine detritus was being deposited over the leading edge a short distance away.

EARLY MISSISSIPPIAN TO MIDDLE PENNSYLVANIAN UPLIFT AND DOWNWARP

Following emplacement of the upper plate of the Roberts Mountains thrust, a north-south linear uplift and a parallel downwarp on the east formed along the leading edge of the upper plate (Poole, 1974). The amount of uplift is unknown, but the amount of downwarp was probably on the order of 3.7 km (12,000 ft) in the Carlin-Pinon Range area. Although some coarse gravels from the uplifted upper plate were deposited very early in the Mississippian, the principal flood of coarse sediments and the required major uplift in the source area began about middle Early Mississippian time, somewhat later than cessation of movement on the Roberts thrust. Coarse gravels continued to be deposited at intervals through Early Pennsylvanian time. The lack of sorting and large size of the boulders in parts of the Pennsylvanian and Mississippian Diamond Peak Formation in the Pinon Range suggest that an uplifted source area was nearby, perhaps as close as the present position of the Cortez Mountains along the west edge of the report area.

LATE MIDDLE TO EARLY LATE PENNSYLVANIAN DEFORMATION

This event in the report area was one of moderate deformation in which the rocks were uplifted irregularly and much eroded in places. Folds and thrusts of small displacement formed locally, but the most characteristic regional feature of this event was a gentle upwarp resulting in an unconformity over most of northern Nevada (Steele, 1960; Roberts, 1964; Nolan and others, 1956). This deformational style was distinctly different from that of the Late Devonian to Early Mississippian event which featured multiple subparallel thrusts of great displacement, the basal thrust of this event being the Roberts Mountains thrust.

One clear indication of Pennsylvanian deformation occurs near the west end of Carlin Canyon where the Upper Pennsylvanian basal beds of the Strathearn Formation rest with an angular discordance of about

45° on middle Mississippian beds in the lower part of the Diamond Peak Formation. An indication of the long time break and locally extensive erosion during this interval is evident on the west side of the Pinon Range where lower Upper Permian strata lie concordantly but disconformably on Lower Mississippian beds. Elsewhere the Strathearn Formation is nearly concordant with the Tomera Formation of Middle Pennsylvania age.

This tectonic event is dated by the ages of the youngest beds underlying and the oldest beds overlying the unconformity. The youngest identified fossils in the deformed beds of the Tomera Formation below the unconformity are of early Des Moinesian age (Westphalian of European nomenclature). The oldest fossils in the Strathearn Formation above the unconformity are of Missourian age (Stephanian). According to the time scale of Francis and Woodland (1964), the age of the youngest beds beneath the unconformity is about 294–299 m.y. and the age of the oldest beds above the unconformity is about 288–293 m.y. Thus the duration of deformation and development of the unconformity approximates 6 m.y.

Certain folds are probably of Pennsylvanian age (fig. 2). Northwest-trending folds in Mississippian strata near Spring Canyon Mountain are truncated by much more gently dipping Permian strata and are therefore probably Pennsylvanian. Several folds in the Willow Creek to Smith Creek area that are more or less parallel to those of Spring Canyon Mountain may have formed initially during the same time of deformation. If so, they were refolded later because Permian rocks in the vicinity are similarly although more gently deformed. The axis of a broad, northwest-trending anticline in Mississippian rocks, paralleling Woodruff Creek, is crossed by a younger syncline and probably was modified by this syncline and mostly covered by the Woodruff thrust plate in Mesozoic time; the anticline is therefore possibly of Pennsylvanian age.

Two thrust faults are attributed to Pennsylvanian deformation. West of Woodruff Creek the Devonian Woodruff Formation was thrust over shale and sandstone of the Mississippian Chainman Shale, and east of the upper part of Ferdelford Creek the Woodruff, the Chainman Shale, and the Webb Formation were thrust over sandstone of the Chainman Shale. The thrust west of Woodruff Creek occurs in two parts, one dipping west, the other east (fig. 2). Movement was apparently generally eastward on both faults, and because no pronounced facies changes occur across the faults, it was probably of small magnitude. Although proof of their exact age is lacking, these two thrusts definitely postdate the Roberts Mountains thrust inasmuch as they involve Mississippian rocks. One of them is cut by the Mesozoic Lee thrust, but there is little other indication of a younger limit on their ages. They could be of Mesozoic age but somewhat older than the more definitely established Mesozoic thrusts. Movement on these possible Pennsylvanian thrusts was apparently eastward, whereas movement on the Mesozoic thrusts was generally westward.

EARLY MESOZOIC UPLIFT

Triassic rocks have not been found in the Carlin-Pinon Range area, and all younger rocks are continental deposits. Because marine Lower Triassic rocks are present a short distance north of the Carlin-Pinon Range area (Ketner, 1970), we tentatively conclude that correlative marine rocks formerly covered the area of the present report, and were uplifted and eroded in later Triassic or earliest Jurassic time. This uplift was of regional extent (McKee and others, 1959) and was permanent; the area has remained above sea level to the present time. The uplift foreshadowed the more violent events of later Mesozoic time and may have been genetically related to them.

LATE LATE JURASSIC OR EARLY CRETACEOUS DEFORMATION

Middle Mesozoic deformation in and near the report area 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-Pinon 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.

Prominent Mesozoic folds in the area include the following:

1. The crestal fold of the range—the Pinon Range anticline—trends slightly west of north and is traceable for almost 24 km (15 mi) although it is covered by younger material locally and is cut by a stock. Near its north end this anticline is sharply overturned to the west, and the overturned limb has dips as low as 20°.
2. The syncline near the north edge of the mapped area extends southwestward along a sinuous trace. This syncline continues also northeastward for about 65 km (40 mi) along the Adobe Range, beyond the area of the present report (Ketner and Smith, 1974).
3. An anticline and two synclines on Cedar Ridge have curving but generally north trending crestlines.
4. Folds in the Willow Creek area are Mesozoic; some may have been formed first during the Pennsylvanian deformation. The closely spaced anticlines and synclines near the head of Willow Creek are narrow sharp folds with limbs dipping as much as 70°.
5. The westward-overturned anticline, the southeasternmost fold in the area, is a prominent structure although it is exposed only on one small hill.
6. The anticline north of the Humboldt River is exceptional for this area because it is partially overturned to the southeast. In this it resembles the northern part of the Adobe syncline (north of the report area), part of which is overturned east and south. Possibly a significant change in structural style takes place near the Humboldt River.

The Carlin-Pinon Range area contains four distinct thrust plates whose emplacement we attribute to the Jurassic-Cretaceous deformational episode. They are here informally called the Woodruff, Lee, Willow, and Robinson plates. Three of these plates exhibit pronounced similarities, and if exposures were better, the fourth (Robinson) probably would be seen to fit the same pattern. Erosion has trisected the Willow plate and doubtless has altered the outlines of all of them, but it seems likely that steep (vertical to near-vertical) faults bounding the south sides of the Woodruff and Lee plates and the north side of the Willow plate mark the original edges of these essentially spoon-shaped plates.

The nature of the faults that bound two of these plates on the west is somewhat problematic. The fault along the west side of the Willow plate is straight and steep and could be interpreted as a post-thrust normal fault, but at the northwest corner of the plate it joins the north-side lateral tear and the two faults appear to be one. Such a relationship suggests that the west boundary of the plate is an upturned part of the thrust fault on which the plate moved. The westernmost part of the Woodruff plate terminates against a normal fault buried by Tertiary deposits. The northwest and southwest bounding faults apparently merge to form the west corner. The northeast side of the plate is marked by a thrust that overrides and is slightly younger than the thrust on which the Woodruff plate moved. Movement on this younger thrust probably was no more than a few thousand meters. The exposed part of the west edge of the Lee plate is at a steep normal fault which is younger than the thrusting. All these plates lie on various lithologic units of the Chainman Shale. The Woodruff plate, in addition, lies partly on the Diamond Peak Formation.

The Mesozoic age of movement of these plates is indicated principally by their relations to Mesozoic folds. The Woodruff plate lies discordantly across a Mesozoic syncline and the Lee plate is intimately associated with a westward-overturned anticline of Mesozoic age. The Robinson plate involves Permian rocks. Movement on the Willow plate cannot be dated closely from direct evidence, but this plate is structurally similar to the other plates and is inferred to be of the same age.

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 Pinon 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.

EARLY OLIGOCENE DEFORMATION

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. D. Mensik, written commun., 1965); in this respect early Oligocene and Jurassic-Cretaceous tectonic events are alike in the close association of igneous intrusion and compressional folding.

Limits on the duration of early Oligocene deformation and erosion are established by K–Ar ages, determined on units below and above the unconformity developed on the Elko Formation. These bracketing ages are 38.6±0.8 m.y. on biotite from tuff (McKee and others, 1971, p. 32, No. 73) in the upper part of the Elko Formation and 33.2±0.7 m.y. on sanidine and 34.9±0.7 m.y. on biotite from ash-flow tuff (McKee and others, 1971, p. 33, No. 76) in the Indian Well Formation. The time interval suggested from these figures is about 4 m.y.

MIOCENE AND YOUNGER DEFORMATION

Immediately before and during the deposition of the upper Miocene Humboldt Formation, the crust was broken by normal faults that completely disrupted the early Tertiary surface configuration and formed the blocky collapse features of the modern topography. The ubiquitous normal faults and the tensional stresses they imply set this tectonic episode apart from all the others, which were generally characterized by uplift, thrusting, or folding.

The principal normal faults of the area are the north- to northeast-trending Crescent, Pine Valley, and Huntington Valley faults. The Crescent fault (Gilluly and Masursky, 1965; Muffler, 1964) forms a spectacular scarp on the west side of the Cortez Mountains but it extends only a short distance into the Pine Valley quadrangle. Though the Pine Valley fault is inconspicuously exposed along part of the west side of the Pinon Range, as inferred from geophysical data (Mabey, 1964) it is a major fault that extends for a long distance between Pine Valley and the Pinon and Sulphur Spring Ranges. The Huntington Valley fault is not exposed; it is inferred strictly from geophysical data (Mabey, 1964) to separate Cedar Ridge from Huntington Valley. Although the topography might suggest the presence of a fault between the Pinon Range and Cedar Ridge, geophysical data indicate that the Tertiary beds in Dixie Flats are very thin and are probably not separated from the Paleozoic rocks of the Pinon Range or Cedar Ridge by a significant fault.

The combined topographic, geologic, and geophysical data (Mabey, 1964) suggest that the Cortez Mountains and the pre-Pliocene rocks underlying Pine Valley form a single east-tilted block that is faulted deeply downward against the Pinon Range, as originally indicated by Regnier (1960). Similar data indicate that the Ruby Mountains (Sharp, 1939; Mabey, 1964; Gibbs, Willden, and Carlson, 1968) and the pre-Tertiary rocks underlying Huntington Valley also constitute a single block tilted westward and faulted downward against Cedar Ridge. Some short faults are exposed on the uptilted side of Pine Valley, but their displacement evidently is only minor (Muffler, 1964). As a result of these major basin-and-range faults, the Pinon Range and outlying ridges of Paleozoic rock such as Cedar Ridge form parts of an untilted block or horst between two convergently rotated blocks. The moderate elevation and subdued relief of the area suggest that the Pinon-Cedar block was relatively stable in late Miocene and Pliocene time.

Within the Pinon-Cedar block are networks of lesser normal faults. Unlike the principal faults which trend north to northeast, these lesser faults trend in all directions. Whereas many of these faults have moderate vertical displacement, they tend to be relatively short; they terminate against other faults, merge with others, or simply die out. Most of the normal faults in the area seem to be concentrated in carbonate rocks. Presumably the carbonate rocks that underlie areas covered by siliceous detrital rocks are similarly faulted but these faults are not generally recognizable in the siliceous clastic rocks at the surface. Poor exposures in the clastic rocks may hide faults in some places, but even where exposures are excellent, few high-angle faults have been found. Apparently the siliceous detrital rocks, whether they be lower Paleozoic shales, upper Paleozoic conglomerates and sandstone, or Cenozoic gravels, may accommodate some differential vertical movement without development of distinct faults.

DEFORMATION OF UNCERTAIN AGE

A north-northwest-trending high-angle fault with some apparent strike-slip displacement cuts between the Sulphur Spring and Pinon Ranges near the south border of the mapped area. These two ranges stand on separate structural blocks of contrasting stratigraphy and structure. The Devonian limestone and chert unit of the transitional assemblage (table 1) is present only west of the fault. Ordovician rocks in the upper plate of the Roberts Mountains thrust possess contrasting lithology on opposite sides of the fault. Paleozoic carbonate rocks west of the fault in the Mineral Hill quadrangle to the south (C. A. Nelson and D. C. Carlisle, unpub. mapping, 1960(?)) dip 30°–45°E., whereas the equivalent rocks east of the fault commonly dip gently west. The Sulphur Spring Range south and west of the fault is topographically asymmetrical; the range has a somewhat steeper east face than the west face. Such asymmetry indicates that this range has been tilted westward in Tertiary time, whereas adjacent parts of the Pinon Range are virtually untilted. The Sulphur Spring Range west of the fault is out of alinement with the Pinon Range east of the fault. Although the Devonian transitional unit and the upper plate Ordovician rocks probably owe part of their positions west of the fault to original structures within the upper plate of the Roberts thrust, we tentatively conclude from their contrasting stratigraphy and structure that rocks making up the two ranges were brought together from a moderate distance on this high-angle strike-slip fault. However, the amount of topographic offset across the fault inferred from misalinement of the Sulphur Spring and Pinon Ranges is small. Therefore, most of the strike-slip movement on this fault evidently took place before Tertiary normal faulting, and a small amount took place during or afterward as present range forms developed.

CONCLUSION

Early Paleozoic time in the Carlin-Pinon Range area was one of remarkable tectonic tranquillity. Sediments deposited during this interval suggest little more than gradual subsidence. This tranquillity was broken permanently at the end of the Devonian Period by the first in a series of at least seven significant and many lesser tectonic events spanning the rest of geologic time. Each of these events apparently had a characteristic style; each seems to be separated from the others by lengthy intervals of relative quiet. From the local viewpoint, the tectonism was episodic and the principal events were not obviously related. Episodic tectonism and volcanism are suggested too in some other parts of the region as shown in figure 3. This chart also demonstrates that Mesozoic tectonism and volcanism were widespread in the region.

Data from the Carlin-Pinon Range region indicate that some previous estimates of the displacement on the Roberts thrust have been too conservative. No rocks of the upper plate have been positively identified directly east of the Pinon Range, but we infer that they extend, or formerly extended, several kilometers in that direction. As explained in another section of this report, we interpret some of the rocks of the upper plate of the Roberts Mountains thrust in the area to have ridden back westward on younger thrust faults from locations east of the Pinon Range. If this interpretation is correct (and it appears well founded), the determinable east-west extent of the upper plate is greater than was previously thought, and the determinable movement on the Roberts Mountains thrust is accordingly greater than was previously thought. The minimum distance of movement on the thrust between the easternmost exposure in the Pinon Range and the westernmost window in which lower plate rocks are exposed in the Shoshone Range (Gilluly and Gates, 1965) is 82 km (51 mi). Although Stewart (1971) argued persuasively that basin-and-range structure in general is essentially horst-and-graben structure and therefore the basin-and-range structure represents considerable crustal extension, the geomorphic and gravity evidence in the Carlin-Pinon Range area is more indicative of tilted-block structure and therefore that area represents minimal crustal extension. However, even by Stewart's estimates of crustal extension, the extension between the Pinon and Shoshone Ranges would amount to only 5 km (3 mi) and the pertinent distance from the westernmost window to the most easterly extent of the upper plate would be 77 km (48 mi) rather than 82 km (51 mi). Because the upper plate was folded in Mesozoic time (Ketner and Smith, 1974), its original extent between these two points, based on the form of mapped folds, is calculated to be 110 km (68 mi). To this must be added the inferred extent of the Roberts Mountains thrust plate east of the Pinon Range. If dark chert and siliceous shale now exposed on a Cenozoic thrust fault in the Ruby Mountains (Willden and Kistler, 1969) are part of the upper plate of the Roberts thrust (and if Cenozoic displacement has been relatively small), the movement on the Roberts thrust was at least 140 km (90 mi). The speculative extent of the upper plate west of the Shoshone Range added to 140 km (90 mi) equals the total minimum displacement of upper plate rocks. Part of this speculative distance to the west may be 64–80 km (40–50 mi) if the Lower Cambrian(?) Osgood Mountain Quartzite (which is probably correlative to part of the Precambrian Z and Lower Cambrian Prospect Mountain Quartzite and thus evidently part of the miogeosynclinal sequence that forms the autochthon) is autochthonous or parautochthonous in the Osgood Mountains (Hotz and Willden, 1964) and Sonoma Range (Gilluly, 1967). These two ranges are 64–80 km (40–50 mi) northwest of the Shoshone Range. With these additions the displacement is 210–225 km (130–140 mi), and it could be greater.

Upper plate rocks of the Roberts Mountains thrust in the Carlin-Pinon Range area are composed mostly of shale and chert, rocks not noted for resistance to deformation by compressive forces. As discussed previously, when the effects of post-Early Mississippian de-

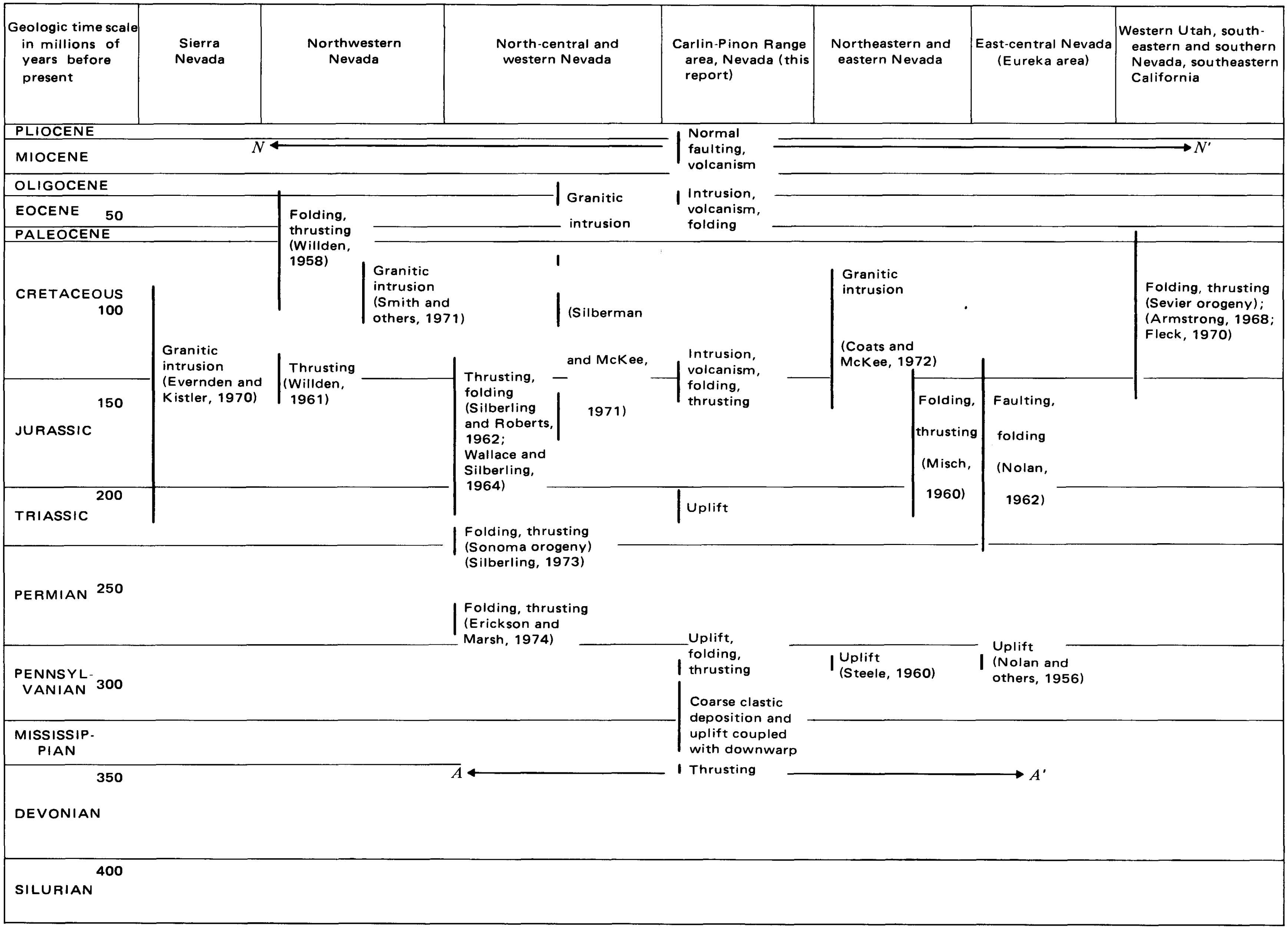


FIGURE 3.—Chart showing intervals of Devonian and younger tectonic and igneous activity, Carlin-Pinon Range area and some parts of the neighboring region. Ages of the time boundaries, except as noted, from Harland, Smith, and Wilcock, 1964, p. 260–262. Cretaceous-Paleocene boundary from Gill and Cobban, 1966; Mississippian-Pennsylvanian boundary from Francis and Woodland, 1964, table 1, p. 222. *N–N'*, Normal faulting of Miocene and younger age is recorded for most of the region (for example, Stewart, 1971; Ekren and others, 1968). *A–A'*, Deformation (Antler orogeny) beginning at about this time is recorded for a number of areas (for example, Roberts, 1964; Gilluly and Gates, 1965; Nolan, 1974; Roberts and others, 1958).

formational events are removed, the Roberts Mountains allochthon appears to consist of shuffled platelets separated by thrusts that are not greatly folded. In places these thrusts are subparallel to the bedding within the platelets, and in other places they bound platelets having highly crumpled and tightly folded beds. Much, if not most, of the major folding of these rocks can be attributed to Mesozoic compression. It is unlikely that these broad thin sheets were pushed great distances against friction and the force of gravity. On the contrary, they must have been drawn by gravity.

No mechanism known to us, however, appears to be completely satisfactory for placing these rocks into a position from which they might have moved by gravity. Any plate tectonics model that involves development of melanges or of high pressure–low temperature metamorphism and the incorporation within the allochthon of extensive ophiolite suites is unlikely, as little evidence of these effects has been found. Poole and Desborough (1973), however, have reported small elongate bodies of alpine-type serpentinites which they infer to be detached fragments of Paleozoic or older upper mantle incorporated into oceanic crustal and sedimentary rocks during lithospheric plate convergence. Any model that requires extensive lateral push to raise the rocks into a position for sliding is also unlikely because of the observed condition of the thin plates. If obduction (a little understood process) could have placed the rocks into position without excessive lateral push and could have peeled off the top of the eugeosynclinal deposits so as not to leave remnants of extensive ophiolite suites and high pressure metamorphic rock, it might serve as a helpful method, as recently suggested by Poole (1974) and Burchfiel and Davis (1975). We are reluctant, however, to accept any current plate tectonics model as affording a completely satisfactory solution to all the problems involved in the movement of the Roberts Mountains allochthon.

We are equally reluctant to accept the notion that the allochthonous rocks simply slid, under the influence of gravity, off a static uplifted area. Using this hypothesis, the area tectonically denuded of Ordovician, Silurian, and Devonian rocks that rode eastward on the Roberts Mountains thrust would have to be at least as wide as the upper plate and probably much wider, because repetition of stratigraphic units is characteristic of that thrust plate. The combined width of the allochthon and the area of tectonic denudation from which it came must be at least 220 km (136 mi), double the provable minimum width of the allochthon. A static sloping surface that is steep enough to permit the movement of the platelets by gravity alone from the crest of the area of denudation to the east edge of the upper plate entails an almost impossibly high elevation of the crest. The existence of such an eastward-sloping surface would imply a corresponding west slope of equal width and another, western allochthon corresponding to the Roberts Mountains allochthon somewhere west of the area of denudation. More liberal (and more plausible) estimates of the east-west extent of the Roberts Mountains thrust correspondingly imply an even more liberal width of the area of denudation and a completely unrealistic elevation of the area of denudation. We therefore feel that this concept is untenable.

We find it more plausible and more in accord with the evidence to envision a succession of crustal waves, each of modest proportions, that migrated from the west edge of the denuded area to the east limit of thrusting. According to this hypothesis, the component platelets of the allochthon rode independently down the forward slope of the advancing waves like surfboards and eventually beached themselves in random order as the crustal waves lost their initial amplitude. This hypothesis is similar to a concept for nappe transport suggested by Wunderlich (1973, p. 283) but considered improbable by Lemoine (1973, p. 211-212). Probably the growing mass of the upper plate contributed to the progressive decrease in amplitude. The Roberts thrust is thus seen simply as the surface on which the upper plate accumulated by piecemeal accretion.

Late Jurassic to Early Cretaceous uplift, plutonism, volcanism, folding, and thrusting constitute the major tectonic events of the Carlin-Pinon Range area. The principal tectonic events of the Late Devonian-Early Mississippian orogeny, although they were of first-order magnitude, took place mainly to the west; and their expression in the Carlin-Pinon Range area located at the east limit of thrusting was relatively subdued. Although the temporal limits of the Mesozoic tectonic events cannot be fixed exactly in the Carlin-Pinon Range area, these events occurred within the time span of similar activity elsewhere in the region (fig. 3). Westward-directed thrusting and overturning of some beds occurred during Mesozoic time in this area in contrast to eastward-directed thrusting that occurred during earlier times of deformation. No known evidence indicates whether this westward-directed movement was more regional or was essentially restricted to the area of this report.

Little real distinction in the region may exist between tectonic events that have been labeled Sonoma, Nevadan, and Sevier. The entire region now occupied by the Great Basin was affected by intense unrest throughout Mesozoic time. The eastern part of the Great Basin was permanently elevated by the Middle Triassic. Granitic plutonism began in Late Triassic time and continued in the western and northern parts to Late Cretaceous. Folding and thrusting began in Early Triassic time and continued through the Mesozoic. As more data have become available, it seems apparent that folding and thrusting were characteristic of the entire region and that these events cannot yet be dated with sufficient precision to determine whether they took place at distinctly different times from place to place.

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Geology of the Carlin-Pinon Range Area, Nevada

GEOLOGICAL SURVEY PROFESSIONAL PAPER 867

This volume was published
as separate chapters A–C

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

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CONTENTS

[Letters designate the chapters]

☆U.S. GOVERNMENT PRINTING OFFICE: 1977 - 789-025/44