Geology of the Cortez Quadrangle Nevada

By JAMES GILLULY *and* HAROLD MASURSKY

With a section on

Gravity and Aeromagnetic Surveys

By DON R. MABEY

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Prepared in cooperation with the Nevada State Bureau of Mines

The area includes a thick section of Paleozoic and Tertiary rocks, a window of the Roberts thrust, and a bonanza silver camp

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By JAMES GILLULY and HAROLD MASURSKY

ABSTRACT

The Cortez quadrangle, in north-central Nevada, is of interest geologically because of the formerly active bonanza silver camp at Cortez and because of the exposure of the Roberts thrust, one of the great structural features of the Cordillera.

The area embraces the extreme north end of the Toiyabe Range and the southernmost part of the Cortez Mountains, together with very small parts of the Shoshone and Simpson Park Ranges and the great intermontane valleys, Grass and Crescent Valleys.

The rocks exposed involve representatives of Paleozoic, Mesozoic, and Cenozoic time. The Paleozoic rocks include representatives of three depositional facies, of which the first two have been brought into juxtaposition by movement of many miles on the Roberts thrust and the third has been deposited upon the eroded stumps of the mountains formed during the thrusting.

The rocks of the lower plate of the Roberts thrust, the eastern or carbonate facies, include representatives of Cambrian, Ordovician, Silurian, and Devonian ages, all closely resembling their correlatives in the Eureka district and elsewhere in eastern Nevada. The formations are: Hamburg Dolomite (Cambrian), Eureka Quartzite and Hanson Creek Formation (Ordovician), Roberts Mountains Limestone (Silurian) and Wenban Limestone (new formation) and Pilot Shale (Devonian). Except for the Eureka Quartzite, all are dominantly carbonate formations, in marked contrast with their approximate correlatives of the western facies.

The rocks of the upper plate of the Roberts thrust, of the western or siliceous facies, include the Valmy and Vinini Formations (Ordovician), Elder Sandstone and Fourmile Canyon Formation, a new unit (Silurian), and the Slaven Chert (Devonian). These are all overwhelmingly siliceous in composition and include very little limestone.

Local evidence does not suffice to date the Roberts thrust more closely than post-Late Devonian (Pilot Shale) and pre-Jurassic, but stratigraphic information from elsewhere in the region fixes its date as latest Devonian or Early Mississippian.

After deep erosion of the structures formed during the Roberts thrusting, in Pennsylvanian and Permian time, the Brock Canyon Formation, composed of dolomite, limestone, conglomerate, and sandstone, was deposited, either virtually where it is now found, or not far to the west. It shows everywhere a basal shear plane, so it probably was dragged from its site of deposition by an overriding thrust; but inasmuch as the formation is not sheared in with others or badly deformed internally, it probably did not move far. It is part of a group of formations of similar relation to the thrust that has been called the "overlap facies." The thrust, if there was one, that displaced it from its depositional

locus may be part of the post-Triassic(?) deformation that has been recognized in the Shoshone Range to the northwest and elswhere in the general region.

The only record of the Mesozoic Era is a series of igneous rocks: quartz monzonite and alaskite making up a stock and several dikes and quartz porphyry dikes and augite syenite sills. The assumption of a Mesozoic age is based on a potassium-argon age of 151 million years on biotite from the stock; this age would conform to the Jurassic.

The Tertiary is represented by several volcanic formations, mostly of rhyolitic composition, including both lava and ash flows but with a few andesites, by gravels of variable thickness that bury an erosion surface of high relief and by a few dikes and intrusive plugs that are probably related to the volcanics. Radiometric ages of about 37 and 37½ million years suggest assignment to Eocene and Oligocene or Oligocene, respectively, for two of the rhyolitic formations; stratigraphic and physiographic relations suggest that the basaltic andesite flows and some younger rhyolites are probably much younger, perhaps Pliocene.

A wide variety of deposits represents the Quaternary: colluvium; alluvium, both in fans and confined stream channels; beaches and bars related to an ancient lake; lake and playa silts; and clay dunes, which seem to be forming today.

The main pre-Tertiary structure of the area is the Roberts thrust, which is exposed at the borders of several windows in the Cortez Mountains and Toiyabe Range. The folding in the thrust which has allowed erosion to expose the windows is probably in part coeval with the thrust itself, but there has been some exaggeration of the relief of the thrust surface in much later time, during the development of the Basin Range faults. The rocks beneath the thrust appear to be much less deformed than those of the upper plate, and in fact much of the structure of the Cortez window is virtually homoclinal, with minor faults which do not cut the thrust and thus are considered either to antedate or to correlate with it.

The structure of the volcanic rocks is in part homoclinal and in part irregular; presumably much of it was related to magmatic movements during or following volcanism.

The dominant structural features affecting the present relief of the area are the Basin Range faults, which originated in Pliocene time and have been active in post-Pleistocene time also. The movement on the Crescent and Cortez faults amounts to many thousands of feet, most of which took place before the Pleistocene lake of Grass Valley was formed. Another fault of this family is indirectly shown along the west side of the Toiyabe Range.

The major ore deposits of the quadrangle are those of Cortez. These are chiefly manto deposits in the Hamburg Dolomite, but considerable tonnage has also been won from fissure veins, most of which were associated with quartz porphyry dikes. Some ore occurred in the Eureka Quartzite and a little in the Hanson Creek Formation. The ore was much oxidized on the upper levels but at lower levels consisted chiefly of galena, stibnite, pyrite, sphalerite, stromeyerite, tetrahedrite, and other antimonial and arsenical minerals, in a gangue of quartz and calcite.

There has been minor production from fissure veins in the Mill Canyon stock and in the Wenban Limestone close to it in Mill Canyon, also from veins in Copper Canyon. None of the mines were being actively worked at the time of the survey (1957–60). The total production since the discovery of the district in 1863 is estimated at about $13 million.

Gem turquoise has been mined in small amounts for many years near the mountain front west of Cortez Canyon, and there are promising showings of barite in replacement bodies in the Slaven Chert on Bald Mountain.

Abstract of section on "Gravity and aeromagnetic surveys," by Don R. Mabey.—Gravity data indicate that both Crescent and Grass Valleys are underlain by several thousand feet of low-density Cenozoic rocks. Both valleys contain a wedge-shaped mass of Cenozoic fill on the depressed side of east- or southeast-tilted blocks. A single fault in Crescent Valley at the front of the Cortez Mountains coupled with lateral density variations within the valley fill could produce the measured gravity anomaly. At the north end of Grass Valley, a major fault is buried by the alluvium on the east side of the valley. A large deep-seated magnetic high occurs at the south end of the Cortez Mountains; strong local highs produced by basalt flows and dikes are superimposed on it. In the north end of the Toiyabe Range, relatively small irregular magnetic anomalies coincide with the area underlain by Tertiary volcanic rocks.

INTRODUCTION

GEOLOGIC INTEREST OF THE CORTEZ QUADRANGLE

The Cortez quadrangle, Nevada, commands geologic interest in two notable respects: as the site of Cortez, one of the earliest of the bonanza silver mining camps of the State, and as exposing stratigraphic and structural features related to the Roberts thrust, critical to an understanding of the geologic evolution of the Cordillera.

Where one great mineral deposit has been found, it is a truism of geology that there is a better than normal probability of finding others—"One hunts for elephants in elephant country." Nearby, across the corner of Crescent Valley, in a geologic setting somewhat analogous, are the Gold Acres and Tenabo districts. The Cortez silver area has never been described in print except in the most cursory fashion. It is clearly desirable both to survey the geology and to place on record what is known of the mine workings of the Cortez camp before the maps of the currently inactive district are irretrievably lost. Some geochemical studies made by our colleagues during our work in the Cortez area indeed offer reasons for optimism in the hope of further metal discoveries (Erickson and others, 1961).

The Roberts thrust has been sufficiently surveyed to show that it is one of the great structural features of the Cordillera. The Roberts Creek Mountains, where it was first recognized, lie about 20 miles southeast of Cortez (fig. 1); and the westernmost window certainly exposing it, in the Mount Lewis quadrangle, is about the same distance to the northwest. The Cortez area is thus strategically situated: it exposes the Roberts thrust, an excellent section of the strata of the lower plate, and a most diverse group of formations of the upper plate, one of which has not hitherto been recognized. Though perhaps not so significant regionally, the Tertiary geology of the quadrangle is also both complex and well exposed.

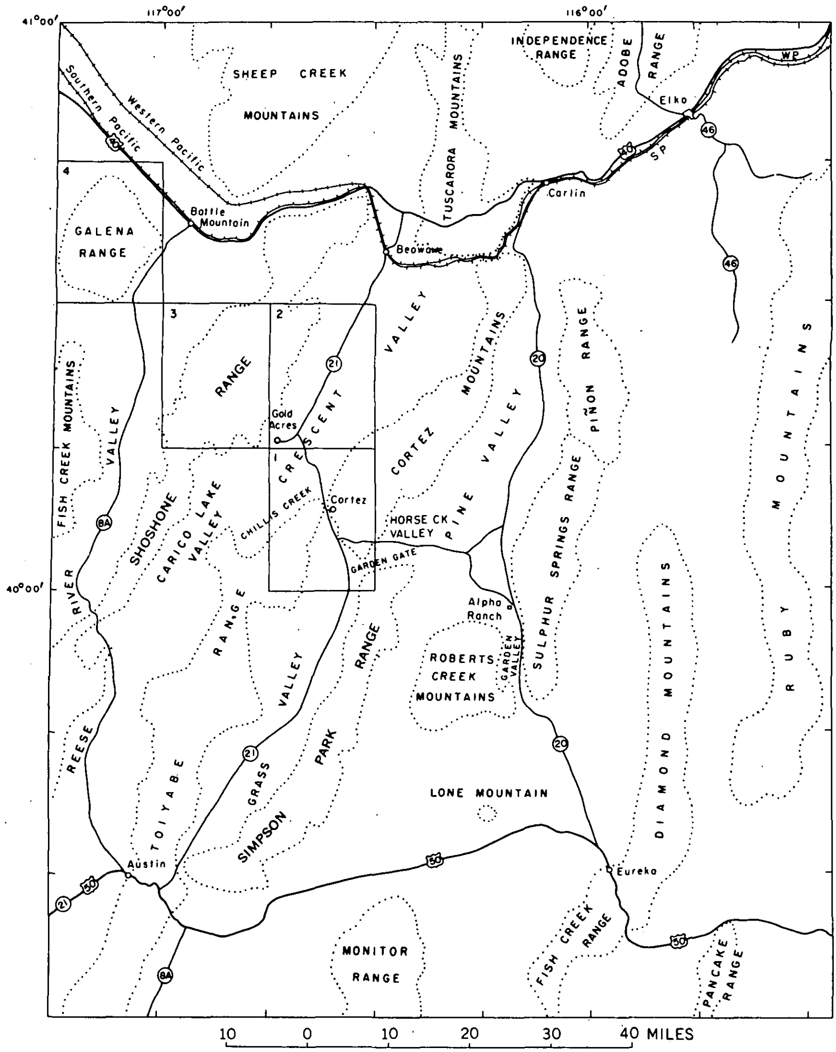

FIGURE 1.—Index map showing the location of the Cortez quadrangle in relation to the topographic features of north-central Nevada. Quadrangles are: 1, Cortez; 2, Crescent Valley; 3, Mount Lewis; 4, Antler Peak.

LOCATION AND ACCESSIBILITY

The Cortez quadrangle lies astride the boundary between Eureka and Lander Counties, Nev., with its northern border about 25 miles south of Beowawe, the nearest railroad point. At the time of this survey, 1957–59, there were no paved roads in the quadrangle; but Nevada State Highway 21 is paved from Beowawe to Gold Acres, whence

Cortez is readily accessible by a good gravel road (10 miles). Other gravel roads lead from Austin, about 50 miles to the southwest, and from Pine Valley (the Eureka-Carlin Highway at the Alpha Ranch) about 20 miles to the east. Only a few people live in the quadrangle throughout the year, though cattlemen and prospectors are commonly active in it.

PHYSICAL FEATURES

The dominant topographic features of the area are the Cortez Mountains, whose southern end lies along the east boundary, and the Toiyabe Range, whose northern extremity lies along the west side (fig. 1). Between these lies the north end of Grass Valley, an intermontane basin about 50 miles long; to the north of the Toiyabe and northwest of the Cortez Mountains is Crescent Valley, also a closed basin separated from the Humboldt River by a low alluvial divide near Beowawe.

The main topographic feature of the Cortez Mountains is Mount Tenabo (9,162 ft), from whose crest the range divide falls off steeply to the south to the alluvial divide below 6,000 feet that marks both the end of the range and the pass referred to as Garden Gate between Horse Creek Valley, a tributary of Pine Valley, and Grass Valley. Northeast of Mount Tenabo the crest of the Cortez Mountains also descends, but more gradually, so that most of it is above 8,000 feet to the border of the quadrangle. The scarp on the west side of the range from a point east of Cortez to the northeast corner of the quadrangle, is extremely steep and rugged; this is a fault scarp of one of the most dramatic of the Basin Range mountains fronts (fig. 2, 3). The back slope of the range, the southeastern, falls away gradually into Horse Creek Valley; most of it is readily accessible by jeep or horseback.

Only the extreme north end of the Toiyabe Range lies in the area. (See fig. 4.) The altitude of Bald Mountain (Railroad Peak of the 40th Parallel Survey), the highest point, is 8,553 feet. Though less rugged than the northwest side of the Cortez Mountains, the Toiyabe Range is relatively steep and difficult of access. The road across the divide west of Wenban Spring is not maintained and is hardly traversable except by cars having four-wheel drive.

A small part of the southeastern end of the Shoshone Range extends into the northwest corner of the quadrangle; diagonally opposite, at the southeast corner, is the northwestern piedmont slope of the Simpson Park Range.

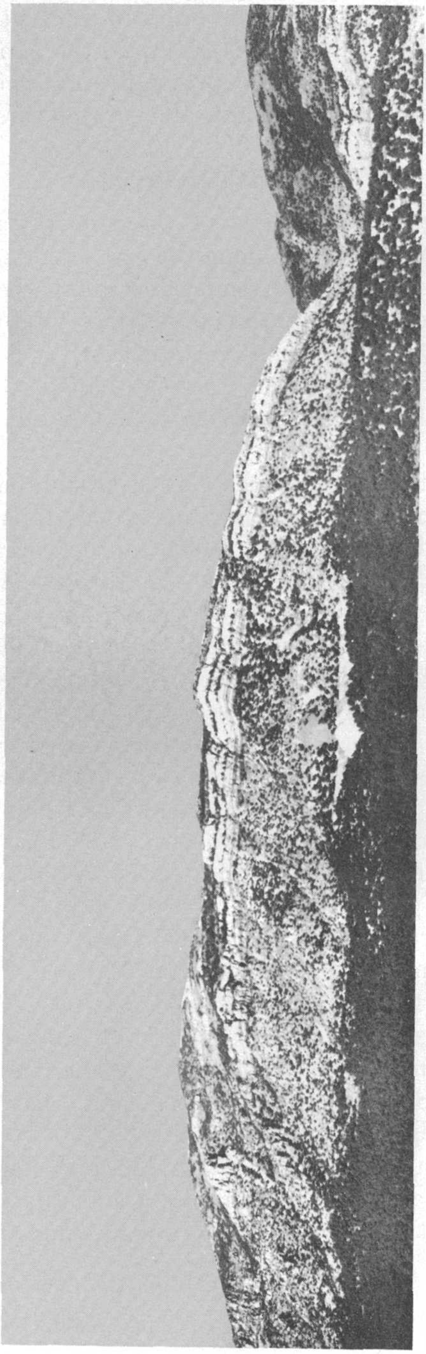

FIGURE 2.—Scarp of the Cortez Mountains east and north of Cortez. Mount Tenabo on the left; Arctic Canyon on the right; Cortez at the right center. Lower slopes above mine dump are of Hamburg Dolomite. The triple cliff above is of Eureka Quartzite. Pediment to right center is on Wenban Limestone, downfaulted along the Cortez fault that passes along the base of the scarp.

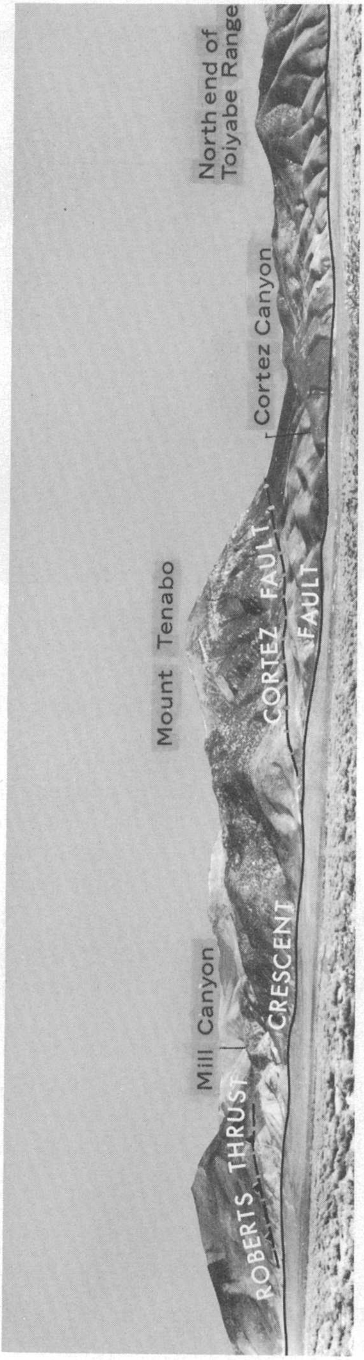

FIGURE 3.—Cortez Mountains from Crescent Valley, showing scarp of Crescent fault.

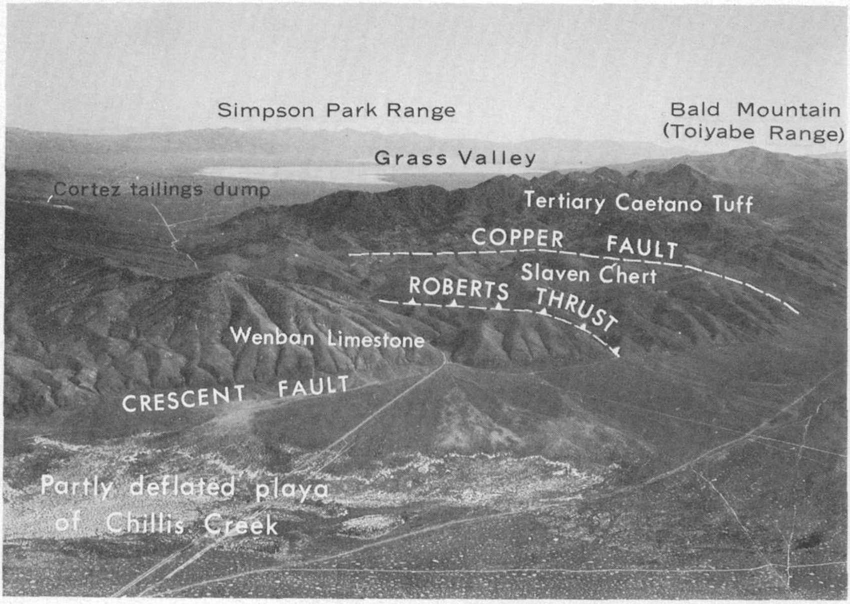

FIGURE 4.—Aerial photograph from a point over Crescent Valley. View south-southeast to the mouth of Cortez Canyon.

CLIMATE AND VEGETATION

Like most of the Basin and Range province, the area is very arid. There are no weather stations nearby, but presumably the mean rainfall at Cortez (alt about 6,100 ft) would be nearer that of Austin (alt 6,880 ft), which is about 12 inches, than it would be that of Beowawe (alt 4,700 ft), which is 6.4 inches. The summit area of Mount Tenabo possibly receives as much as 15 inches annually. Short segments of Fourmile, Mill, Willow Creek, and Horse canyons are occupied by nearly perennial streams, but most of the drainage courses carry water only during storms.

The vegetation is a sparse representative of the Upper Sonoran association, with piñon, juniper, mountain mahogany, and a few shrubs high on the mountains, boxelder and willow along the streams, and greasewood, sage, rabbit brush, and sparse grasses on the valley floors and alluvial fans.

PREVIOUS WORK

The earliest geologic work in the Cortez area was that of the 40th Parallel Survey (Hague, 1870; Emmons, 1877; King, 1878, Atlas Map IV). This hasty reconnaissance recognized the rhyolite of the northern Toiyabe Range and the basalt of the east side of the Cortez

Mountains, the Mill Canyon stock (which was, however, considered Precambrian rather than intrusive into the overlying Paleozoic strata), and the late Carboniferous age of the rocks here mapped as Brock Canyon Formation. The map, however, identified all the homoclinal strata south of Mount Tenabo as of Carboniferous age, correlating the Eureka Quartzite with the Weber Quartzite of Utah. The rocks of the Bald Mountain area in the Toiyabe Range were also called upper Carboniferous. In view of the haste of this early survey, the map is remarkably good in showing the distribution of the rocks, though understandably deficient in the age assignments made.

The literature records no discussion of the geology from the time of the 40th Parallel Survey to that of W. H. Emmons' reconnaissance of the mining district in 1908 (Emmons, 1910), but the map of plate I of the Lake Lahontan monograph (Russell, 1885) shows the existence of a Pleistocene lake in Grass Valley, from which some reconnaissance in the interval may be inferred. Emmons corrected the interpretation of the Mill Canyon stock, which he recognized as intrusive. He also recognized the Eureka Quartzite and made the natural assumption for his day, when so little stratigraphic work had been done in the region, that the rocks here considered Hamburg Dolomite belong to the Pogonip Group. The rocks overlying the Eureka were called Lone Mountain(?).

No systematic areal mapping has been done until this survey, but Merriam (Merriam and Anderson, 1942, p. 1684) long ago suggested that the pre-Eureka rocks exposed at Cortez are probably Cambrian rather than equivalent to the Pogonip. More recently, Webb (1958) discussed the stratigraphy of the Eureka in the area. The economics of the mining industry as of the late 1930's was described by Vanderburg (1938).

FIELDWORK

The fieldwork on which this report is based began in June 1957 and was completed in October 1959. We spent a total of about 14 man-months in the field and were assisted for several months each by Messrs. Peter Birkeland, Wesley LeMasurier, William Hays, L. J. P. Muffler, and Richard Alvord. During 1959–61, Messrs. Ralph Erickson and A. P. Marranzino of the U.S. Geological Survey spent several days in geochemical testing of the various springs and some rocks of the quadrangle and made their results available to us.

ACKNOWLEDGMENTS

Messrs. R. J. Ross, Jr., Mackenzie Gordon, Jr., and C. W. Merriam, all of the U.S. Geological Survey, visited the area and assisted greatly in stratigraphic studies. D. R. Mabey of the Geological Survey provided gravity and aeromagnetic contour maps of the area. The kindness of Mr. E. A. Scholtz and A. G. Horton of the American Mining and Exploration Co. in providing maps of the Cortez workings and samples of the rocks from underground is appreciated. V. A. Scheid, Director, Nevada Bureau of Mines, and E. H. Lawrence, of that organization, kindly furnished samples of the ore from the Cortez mine from the Museum at Reno and from the lowest workings of the mine, reopened in 1960. G. H. Curtis of the University of California, Berkeley, kindly provided radiometric age determinations on biotite samples from the igneous rocks. George Cone assisted in the preparation of the report.

GENERAL GEOLOGY

PRINCIPAL FEATURES

The rocks of the area include Paleozoic sedimentary rocks, with minor volcanics, possibly Mesozoic intrusives, Tertiary sedimentary, intrusive, and volcanic rocks, and Quaternary colluvial, alluvial, lacustrine, and eolian deposits.

The rocks of early and middle Paleozoic age include strata of two distinct facies. One sequence, which includes rocks of Cambrian, Ordovician, Silurian, Devonian, and possible Misisssippian ages, consists almost wholly of carbonate rocks. It resembles the classic stratigraphic section of Eureka, Nev. (Hague, 1883, 1892; Merriam and Anderson, 1942, p. 1680–1693; Nolan, Merriam, and Williams, 1956), but is dominantly limestone, whereas the Eureka section is dominantly dolomite. The second facies includes rocks of Ordovician, Silurian, and Devonian ages, of which both the Ordovician and Silurian are represented by contemporaneous formations of differing character, even though all are siliceous and contain very sparse carbonates. The carbonate facies is everywhere in fault contact with the siliceous facies; and since the rocks of the two facies include many of similar age, it is clear, as was pointed out by Merriam and Anderson (1942), that the fault dividing them has brought into juxtaposition deposits originally far apart. As the carbonate facies closely resembles the rocks of similar age at Eureka and thence east as far as the Wasatch Range, it is considered autochthonous, or nearly so; it is therefore called the eastern or carbonate facies. The rocks of the second facies must clearly have been transported on the fault from an area some distance to the west; they are called the western or siliceous facies. The fault separating the two facies is undoubtedly the Roberts thrust of areas to the east and west (Merriam and Anderson, 1942; Roberts and others 1958; Gilluly and Gates, 1965).

The formations of the eastern facies include the Hamburg Dolomite of Middle and Late Cambrian age, of which about 1,200 feet is exposed; the Eureka Quartzite (Middle Ordovician) about 400 feet thick; the Hanson Creek Formation (Middle(?) and Late Ordovician) about 500 feet thick; the Roberts Mountains Limestone (Silurian) about 1,000 feet thick; the Wenban Limestone (a newly recognized formation of Devonian age) about 2,500 feet thick; and the Pilot Shale (Late Devonian) about 300 feet thick. Of these, there is some question as to the identification of the Hamburg Dolomite and perhaps of the Pilot Shale.

The western facies consists of different formations of mainly the same ages but whose contrast in facies does not demand telescoping on the same scale as that involved in the Roberts thrust. Thus there are, in the western facies, two partly contemporaneous formations of Ordovician age, both clastic, but of notably contrasting grain size. The coarser, the Valmy Formation, includes much pure quartzite and relatively less siltstone and cherty shale; it also contains relatively much more greenstone than its correlative, the Vinini Formation. Both formations are so much faulted as to prevent accurate measurements of thickness but probably include several thousand feet of strata. The Silurian is also represented by two distinct formations: the Elder Sandstone and the Fourmile Canyon Formation, here recognized for the first time. The Elder is chiefly a feldspathic sandstone, with minor siltstone, shale, and pale chert; its thickness is perhaps several hundred feet in this quadrangle, though it is much thicker in the Mount Lewis and Crescent Valley quadrangles (Gilluly and Gates, 1965), where it is about 4,000 feet thick. The Fourmile Canyon Formation, probably slightly older than the Elder, contains much less sandstone, and is composed dominantly of chert, argillite, and siltstone. At least 3,000 feet—perhaps 6,000—is represented in the type area. The only Devonian formation recognized in the western facies is the Slaven Chert, which consists very largely of chert but contains a little greenstone, limestone, and sandstone: its thickness is several thousand feet in the Shoshone Range (Gilluly and Gates, 1965) but much less in this quadrangle. (See table 1).

Fault blocks of the Brock Canyon Formation rest on the Valmy Formation of the Cortez Mountains. These are considered as parautochthonous and not involved in the Roberts thrust.

No close age bracketing of the Roberts thrust is possible from data derived from this area. Regional relations (Roberts and others, 1958) suggest that it is of Early Mississippian age, thus allowing the Brock Canyon Formation to be deposited on a block of Valmy Formation that had already been transported by the thrust.

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TABLE 1.—*Paleozoic rocks of the Cortez quadrangle, showing distribution between eastern, western, and "overlap" facies*

"Overlap facies"		
Brock Canyon Formation		Permian or Pennsylvanian.
——Great unconformity (Antler orogeny)——		
Western facies (siliceous)	*Eastern facies* (carbonate)	
	Pilot Shale	Devonian.
Slaven Chert	Wenban Limestone	Devonian.
—Fault contact—		
Elder Sandstone		Silurian.
—Fault contact—		Silurian.
Fourmile Canyon Formation	Roberts Mountains Limestone	Silurian.
—Fault contact—		
Valmy Formation; Vinini Formation	Hanson Creek Formation	Ordovician.
	Eureka Quartzite	Ordovician.
	——Unconformity——	
	Hamburg Dolomite	Cambrian.

There is no definite record of Mesozoic time in the quadrangle. Quite probably the fault that involved the Brock Canyon Formation formed during that time (Gilluly and Gates, 1965).

A large stock of post-Devonian quartz monzonite occupies the spur of the Cortez Mountains west of Mill Canyon. Minor alaskite bodies are associated with it. A potassium-argon age of biotite from the quartz monzonite implies a Jurassic age, but regional relations suggest that it is perhaps early Tertiary. A very similar intrusive in the Shoshone Range 15 miles to the northwest has furnished biotite whose potassium-argon age implies an early Tertiary assignment. Erosion exposed the stock prior to the deposition of a thick, but very irregular body of conglomerate which fills the valleys of a deeply dissected terrain on the east side of the Cortez Mountains and on the west side of the Toiyabe Range. A thick series of pyroclastic rocks of possible Oligocene age, chiefly welded tuffs of rhyolitic composition, occupies an area north and northwest of Bald Mountain. Flows of basaltic andesite overlie the gravels of the east slope of the Cortez Mountains, and were perhaps fed by the swarm of dolerite dikes that crop out in the north part of this quadrangle and in the adjoining Crescent Valley quadrangle. The last volcanic activity recorded was the injection of the rhyolite plugs through the basaltic andesite at the head of Horse Canyon.

The major structure of the area is the Roberts thrust. It is exposed around the borders of several windows in the Toiyabe Range and across its northern end, just southwest of Cortez Canyon. It is buried beneath the pediment gravels west of Cortez, but is well exposed in the Cortez Range about 3 miles south of Cortez. Here it can be traced from the mountain front around an arcuate outcrop forming the south end of the large Cortez window before being buried beneath Tertiary gravels. The east side of the window is exposed to the north of the Tertiary cover, at the head of Horse Canyon and in the walls of Mill Canyon. The folding of the thrust probably dates from the time of thrusting, as there are several branch thrusts at the axis of the fold.

The structural effects of the emplacement of the quartz monzonite stock seem negligible; there is neither deflection of the homoclinal structure of the lower plate of the thrust nor any observable relation of the stock to the fold axes.

The rhyolitic welded tuffs of the northern Toiyabe Range may represent the infilling of a volcanic caldera; but in absence of detailed mapping to the west, this cannot be considered as demonstrated (Masursky, 1960, p. 281).

The Basin Range fault that bounds the west and northwest sides of the Cortez Mountains is undoubtedly the major structural feature of Tertiary age and is responsible for the present relief of the range. The fault displaced the basaltic andesite forming the dip slope of the range by at least 8,000 feet—perhaps 12,000. This is shown not only by the projection of the andesite cuesta, which must formerly have been continuous with the dip slope of the Mal Pais in the Shoshone Range to the northwest across Crescent Valley, but also by the gravity deficiency exhibited in Crescent Valley, which testifies to a great thickness of light alluvium (Donald Plouff, in Gilluly and Gates, 1965; and D. R. Mabey, this report, p. 105–111). The movement on the range-front fault has continued into Recent time, as most of the alluvial cones have been displaced as much as 15 feet.

The mineral deposits of the quadrangle include the formerly mined antimonial silver deposits of the Cortez area, some gold-silver veins in Mill Canyon, some small mercury deposits in Horse Canyon, turquoise deposits in the Toiyabe Range, and some bedded replacement deposits of barite.

STRATIGRAPHY OF THE LOWER PLATE OF THE ROBERTS THRUST (EASTERN OR CARBONATE FACIES)

CAMBRIAN SYSTEM

HAMBURG DOLOMITE

Name.—The Hamburg Dolomite was originally described by Arnold Hague (1883, p. 255, 1892, p. 39–41) as the Hamburg Limestone and subsequently designated as the Hamburg Dolomite by Wheeler and Lemmon (1939, p. 25). The type locality is at the Hamburg mine in the Eureka mining district about 50 miles southeast of Cortez.

Distribution.—The Hamburg Dolomite is beautifully exposed in the steep cliffs extending half a mile south and 1½ miles north of the site of Cortez in the central part of the quadrangle (fig. 2). The gray dolomite cliffs end abruptly on the north against the Mill Canyon stock, where the dolomite is altered to white marble that shows clearly on the cliffs next to the dark rock of the stock.

Most of the ore mined at Cortez came from the upper part of the Hamburg Dolomite. The mine workings of the district are lined up along the outcrop of the Hamburg Dolomite and are described in "The Mines" section.

Lithology.—The Hamburg Dolomite is a thick uniform sequence of gray parallel-bedded dolomite sandstones. The beds range from 6 inches to 10 feet in thickness. Colors are dark, medium, or light gray in alternating beds. Sedimentary structures are abundant: cross lamination, slump structures, mottles of medium sand size in a matrix of silt to very fine sand size. The darker layers are fetid on a fresh break and contain abundant microscopic blebs of organic material and pyrite. The dark beds consists of fine- to medium-sand-size—angular to subround dolomite fragments. The light-colored beds contain very fine to fine-sand-size angular clasts of dolomite.

The dolomite is pervasively altered. At the south end of the belt of outcrop, tremolite needles altered to talc occur sporadically. Northward the silicates are more abundant and the clastic fabric of the rock is more obscure where the dolomite grains have recrystallized. Rhombs are abundant in the central part of the outcrop belt, and within a thousand feet of the stock the rock is altered to a white dolomite marble with mosaic fabric.

Thickness.—The maximum thickness of the formation occurs in the cliffs north of the Cortez mine, where the following section was measured:

	Thickness (ft)
Eureka Quartzite:	
Quartzite, fine-sand-size, black, parallel-bedded.	
Unconformity.	
Hamburg Dolomite:	
10. Dolomite, medium-dark-gray mottled with medium-gray; contains intercalated fine-grained medium-light-gray beds; in beds 5–10 ft thick	149
9. Dolomite, white; weathers very light gray, in beds 2–3 ft thick	37
8. Dolomite, medium dark-gray to medium light-gray, very fine sand size, massive	120
7. Dolomite, fine-grained to very fine grained, mottled dark-gray and medium-gray; weathers medium dark gray; in beds 3–5 ft thick which break to angular blocks; grades upward to lighter gray with less mottling	77

	Thickness (ft)
Hamburg Dolomite—Continued	
6. Dolomite, fetid, very fine to fine-sand-size, dark-gray to medium dark-gray; weathers medium gray; in parallel beds 5 ft or more in thickness which break down to angular blocks; brecciated, but probably tectonic; outcropping knobs are slightly more rounded than those of light-colored dolomite	305
5. Dolomite, light-gray to medium light-gray, fine-sand-size, massive, parallel-bedded; breaks down to angular blocks	180
4. Dolomite, medium light-gray; weathers light yellowish-gray, parallel bedded in beds about 3 ft thick; breaks down to angular blocks	56
3. Dolomite; interbedded fine-grained light-gray and medium-grained dark-gray layers 2–3 ft thick	127
2. Dolomite, very light gray, mottled medium dark-gray to medium light-gray; in places weathers yellowish gray, very fine sand size, in beds about 5 ft thick with irregular fracture; and medium dark-gray, fine- to medium-sand-size dolomite. Cross-laminated dolomite with pebbles to 10 mm long, weathers medium light gray. In upper 30 ft, alternations are thinner; beds are about 6–10 in. thick	130
1. Dolomite, fine-sand-size to very fine sand size, thick-bedded, mottled, medium light-gray; weathers light olive gray	42
Total Hamburg Dolomite (approx.)	1,200
Fault contact.	
Wenban Limestone:	
Limestone, brownish-gray, massive, thick-bedded, brecciated, poorly exposed.	

A supplementary section about 300 feet thick was measured on the north face of Arctic Canyon where the rocks are best exposed and least altered. The rock is dolomite, medium dark gray, finely crystalline, in parallel beds 3–5 feet thick. A series of samples collected from this section were dissolved in formic acid but no microfossils were found.

The base of the Hamburg Dolomite is not exposed; the bottom workings of the Cortez mine, although 200 feet below the adit, are within the Hamburg and do not reach the normally underlying Secret Canyon Shale.

At the top, black argillaceous quartzite of the Eureka Quartzite unconformably overlies the Hamburg Dolomite. Local relief on the contact is very small but talus from the quartzite cliff obscures the actual contact in most places.

Conditions of deposition.—The alternating light- and dark-colored dolomite beds with abundant sedimentary structures show that the Hamburg Dolomite was deposited in a relatively shallow marine shelf environment. It is difficult to determine whether dolomitization was penecontemporaneous with deposition or diagenetic. The textural patterns indicate that the rocks were deposited as a carbonate sand-, silt-, and clay-size sequence. Compaction, relatively greater in the fine-size fraction, resulted in the distortion of the lenticular sand layers into the irregular mottles so characteristic of Middle and Upper Cambrian clastic carbonates elsewhere (Hanson, 1951).

Age and correlation.—Sparse trilobite faunas from the Hamburg Dolomite and fossils from the underlying and overlying shales at Eureka imply a Middle and Late Cambrian age for the formation (A. R. Palmer, in Nolan, Merriam, and Williams, 1956, p. 18). No diagnostic fossils were found at Cortez.

Basically, the distinction between the lower Middle Cambrian Eldorado Dolomite and the upper Middle and Upper Cambrian Hamburg Dolomite of the Eureka district, and their regional correlation depend on the recognition of overlying and underlying units with their contained fossils. In this area the base of the Hamburg is concealed by faulting, and overlying units are missing under the unconformably overlying Eureka Quartzite. The designation of these rocks as Hamburg then rests on their similarity in lithology and thickness to the type section.

To the northwest, the Harmony Formation, a coarse-grained arkose of Late Cambrian age, is exposed in the Hot Springs area of the Osgood Mountains (Roberts and others, 1958, p. 2827) where it indicates near-shore conditions of deposition. At Cortez the Upper Cambrian rocks are massive dolomite—the Hamburg Dolomite. To the southeast the massive dolomite continues to Eureka where Arnold Hague (1892, p. 40) described 1,200 feet of Hamburg Dolomite. Nolan, Merriam, and Williams (1956, p. 17) showed that the Eureka section is highly faulted and altered, and they estimated that about 1,000 feet is present.

CAMBRIAN AND ORDOVICIAN HIATUS

At Cortez the upper Middle and lower Upper Cambrian Hamburg Dolomite is succeeded by the Middle Ordovician Eureka Quartzite. Twenty-five miles to the west in the Shoshone Range the Eureka rests with fault contact on the Middle Cambrian Shwin Formation (Gilluly and Gates, 1965). Toward the southeast, first the higher part and then the lower part of the Lower Ordovician rocks appear under the Eureka Quartzite. In a distance of about 100 airline miles to the southeast, about 5,500 feet of beds occurs that is missing at Cortez (Nolan, Merriam, and Williams, 1956; Young, 1960; Webb, 1958).

The facies distribution above and below the regionally discordant Eureka Quartzite and associated Middle Ordovician clastics is discussed further in the section on paleogeography of the Paleozoic carbonate rocks.

ORDOVICIAN SYSTEM

EUREKA QUARTZITE

Name.—The Eureka Quartzite was also named in the Eureka area by Arnold Hague (1883, p. 262; 1892, p. 54–57). Owing to obscure relations in that tectonically disturbed and mineralized area, Kirk (1933, p. 34) proposed that the type locality be shifted to the well-exposed section at Lone Mountain, 15 miles to the northwest. In this prescient paper Kirk pointed to the critical role of the Eureka Quartzite in Great Basin stratigraphy. This role has been clarified by Merriam and Anderson (1942), Hintze and Webb (1950), Nolan, Merriam, and Williams (1956), Webb (1956, 1958), and Rigby (1960).

Distribution.—At Cortez the Eureka Quartzite crops out as a spectacular white cliff along the mountain front east of Cortez. It extends about 1 mile south of Cortez where it is cut off against the Cortez fault. About 1½ miles north of Cortez it passes through the contact aureole and abuts against the Mill Creek stock. Half a mile farther north a small heavily silicated mass of Eureka Quartzite forms a screen in the stock south of Lewis Canyon.

Stratigraphy.—The Eureka Quartzite cliff rises in three steps: the bottom part of the lowest is brown and discolored, the upper two are gleaming white. The benches are formed by more easily eroded dolomite-cemented sandstone layers. In many places the 100-foot-high steps rise at 65° and are nearly impassable.

The basal contact is knife sharp, with gray saccharoidal dolomite of the Hamburg overlain by a dark reddish-brown shaly sandstone 5 feet thick. The stain is caused by iron oxide derived from weathered pyrite. The shaly sandstone is parallel bedded and breaks into irregular shaly laminae about 4 mm thick. This lowest member of the Eureka is about 55 feet thick and is made up of alternating argillite, shaly sandstone, and quartzite; the sandstone grains are fine to medium size. The quartzite beds have sweeping cross lamination as much as 5 feet in amplitude, strikingly brought out by the iron staining.

The cliff continues upward for about 130 feet and is composed of slightly stained yellowish-gray to white quartzite in 1- to 3-foot beds composed of fine sand grains.

A 2-foot-thick white to yellowish-gray dolomitic sandstone bed makes a bench here. This is the basal bed of the middle unit which is about 100 feet thick. It is composed of thick-bedded (3 ft or more) white fine-grained quartzite with a few interbedded, 1- to 3-feet-thick dolomitic sandstones. The dispersed dolomitic cement is partially dedolomitized and is converted to calcite and fibrous aggregates of talc.

The succeeding bench is formed on a medium dark-gray dolomitic sandstone 10 feet thick. The dolomite has parallel beds 3–6 inches thick and is composed of subround dolomite clasts as much as 0.1 mm in diameter and dolomite rhombs, probably formed by recrystallization, as much as 0.3 mm in diameter. The succeeding interval is underlain by dolomite-cemented sandstone but is largely masked by talus from the overlying quartzite cliff. The fossil corals, described subsequently, come from the base of this interval.

The highest member is cliff-forming white quartzite. The quartzite is fine grained, very thick bedded, and weathers to a light gray.

At the top of the formation is a ½-foot interval of medium light-gray sandy dolomite that probably represents reworking of Eureka Quartzite by the Hanson Creek sea (Kirk, 1933). The basal unit of the Hanson Creek Formation is a dark-gray fine-grained massive cliff-forming dolomite.

The following section was measured in Arctic Canyon in the cliffs behind Cortez:

Measured section of Eureka Quartzite in Arctic Canyon, NE¼ sec. 8, T. 26 N., R. 46 E., Eureka County, Nev.

Hanson Creek Formation:

Dolomite, dark-gray, fine-grained; in massive beds; contains white dolomite veinlets.

	Thickness (ft)
Eureka Quartzite:	
25. Quartzite, fine-grained, thick-bedded, white; weathers very light gray	78
24. Dolomite sandstone, poorly exposed; forms bench	24
23. Dolomite sandstone, very fine sand size, parallel-bedded, medium dark-gray; weathers light gray; in beds 3–6 in. thick. Corals from base of unit	10
22. Quartzite, white; in beds 7 ft thick; forms cliff	34
21. Quartzite, limy, yellow-gray, thin-bedded; forms slight recess	1
20. Quartzite, white, thick-bedded; forms cliff	24
19. Quartzite, limy, yellow-gray; in beds 2 in.–4 ft thick; forms bench	1
18. Quartzite, white; in beds 3 ft or more thick; forms cliff	15
17. Quartzite, limy, white to very light gray; forms bench	3
16. Quartzite, white; in parallel beds 6 in–2 ft thick; some laminated beds ½ in. thick; forms cliff	20
15. Quartzite, limy, white, thin-bedded, poorly exposed; forms bench	2
14. Quartzite, white; in parallel beds 1–2 ft thick; forms cliff	56
13. Quartzite, medium light-gray, fine-grained, parallel-bedded	2
12. Quartzite, white; weathers white	1.5
11. Quartzite, fine-grained, medium light-gray; weathers light brown	2.5
10. Quartzite, fine-grained; white; weathers white; in parallel beds 1–3 ft thick	35
9. Quartzite, medium light-gray, fine-grained, parallel-bedded	2
8. Quartzite, fine-grained, white; weathers white; in parallel beds 1–2 ft thick	22

	Thickness (ft)
Eureka Quartzite—Continued	
7. Quartzite, yellowish-gray; weathers pale yellowish brown; gradational base; sharp color break at top in parallel beds about 1 ft thick	6
6. Quartzite, white; weathers very light gray to white and grades upward into dark quartzite with sharp break at top; sharp break at base	4
5. Argillite, fine-sand-size, medium-gray; weathers dark gray; interbedded with black quartzite which weathers grayish black; in parallel beds about 2 ft thick	16
4. Quartzite, pyritic, white; weathers pinkish gray; in parallel beds about 2 ft thick	13
3. Quartzite, fine- to medium-grained, massive; light brown at base; grades to white upward	2
2. Siltstone, medium dark-gray; weathers moderate reddish brown, in parallel beds, 1/5–4/5 in. thick	3
1. Quartzite, fine- to medium-grained, light-brown; weathers medium brown; obscure massive bedding; weathers to angular blocks. Actual contact concealed	22
Total Eureka Quartzite (approx.)	400
Hamburg Dolomite:	
Dolomite, medium dark-gray, fine-sand-size; in obscure parallel beds 3–5 ft thick	20

Microscopic examination of the quartzite reveals fine- to medium-sand-size grains of quartz with quartz cement. The rock is well sorted; grains range from round to subround and have high sphericity. The quartzite is extraordinarily pure; heavy minerals observed are green tourmaline, purple zircon, water-clear amphibole, and pyroxene; authigenic pyrite, iron ore, and barite occur. The silty sandstone layers near the base of the formation contain from 15 to 45 percent silt-size matrix, consisting of quartz, minor clay, and iron ore. (See fig. 5.) The formation has nearly everywhere been considerably deformed, altered, and partially recrystallized. The grain boundaries are frayed and intergrown, but the detrital shapes are still clearly visible. Microshears are common; quartz and talc fill crosscutting veinlets. Near the stock, mosaic fabric and abundant tremolite and diopside have formed. The dolomitic layers are altered to calcite, talc, and calcic scapolite (meionite), and the iron ore to hematite and rutile.

The only other units that might be confused with the Eureka Quartzite are the quartzites of the Valmy and Vinini. These may readily be distinguished by the contrast in size distribution between the two groups. The quartzites of the Valmy and Vinini consist of fine- to medium-sand-size grains in a quartz silt and very fine sand matrix. Except for the basal silty beds, the Eureka has been so winnowed that the fines have been removed, leaving an even-grained texture.

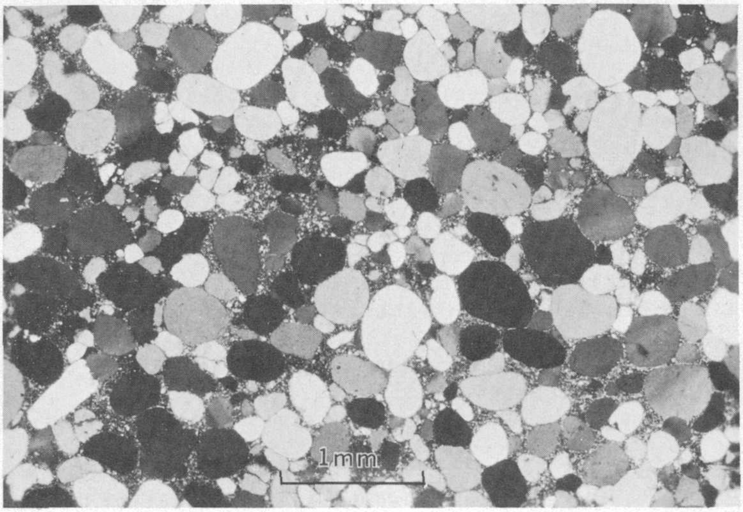

FIGURE 5.—Photomicrograph of quartzite from low in the Eureka Quartzite. Note well-rounded quartz grains in a silty matrix. Crossed nicols.

Breccia "reefs" of jasperoid in the overlying Hanson Creek Formation and Roberts Mountains Limestone superficially resemble the Eureka Quartzite. The reefs, about 100 feet long and 10 feet wide, are parallel to the frontal fault. Anastomosing veins of siliceous material fringe the reefs and show that the bodies are silica replacements of carbonate rock along minor faults. Microscopically the rock is seen to be a microcrystalline (0.005 mm) aggregate of quartz with veinlets of granular quartz as much as 1 mm thick that contain relict blebs of carbonate.

Age and correlation.—A single collection of corals was made from the upper dolomite zone by Gilluly and students from the University of California at Los Angeles in 1949. This collection was made available by Prof. C. A. Nelson and was examined by W. A. Oliver, Jr., of the U.S. Geological Survey, who stated:

> The collection consists of small horn corals, most of which are preserved as quartzite molds of the calice or exterior, and only one of which shows any internal structure. The external molds cannot be identified but probably belong to the same genera and species as the other corals. The calice molds provide a certain amount of structural information: (1) the septa are well developed so that the depth of the calice is not more than half the length of the coral; (2) most, if not all, of the specimens have a raised axial structure formed by the twisting of the major septa; and (3) the curvature of the specimens seems to bear a constant relationship to the cardinal-counter plane of the coral. Exact generic assignment cannot be made but the specimens are all streptelasmids and probably represent only one genus.

On a purely objective basis the structures would indicate post-early Trenton age since Black River-early Trenton horn corals lack both the well developed axial structure and oriented curvature.

Corals which would form similar molds are known from rocks at least as young as Devonian, but the lack of characteristic Late Ordovician angulate coralla and of typical Silurian or Devonian forms further suggests that the corals are of pre-Bighorn (pre-Richmond) age. The listed structures and the lack of other morphologic types are compatible with a post-early Trenton, pre-Bighorn age for the collection. * * *

The environment in which the corals lived was marine. Each coral horizon represents the settlement of the area by coral planulae during a time of depositional quiescence when the corals would be able to grow on the stable sand surface. Renewed sand deposition would bury the corals and settlement from another area would be required to form the next coral horizon.

The Eureka Quartzite crops out prominently in the ranges to the south and east, thinning gradually in those directions (Webb, 1958). Young (1960) showed that east of Eureka the Eureka Quartzite lies on the highest formation of the Pogonip Group; Nolan, Merriam, and Williams (1956) showed that at Western Peak in the Roberts Creek Mountains it lies on the Goodwin Limestone at the base of the Pogonip Group. At Cortez the Eureka lies on the Hamburg Dolomite.

From Cortez 50 miles southward to Antelope Valley, the Eureka Quartzite changes facies at the base and interfingers with the Antelope Valley Limestone—the highest unit of the underlying Pogonip Group (Kirk, 1933; Merriam and Anderson, 1942). The northward thickening of the quartzite in Nevada and Utah indicates that the Eureka may have had a northern source and, like the laterally equivalent quartzites of the Valmy, may be equivalent to the thick Kinnikinic Quartzite of central Idaho (C. P. Ross, 1937; 1947).

The sedimentary structures, composition, fossils, and lateral extent of the Eureka Quartzite all show that it was deposited as a polycyclic very mature sediment on a shallow marine shelf.

The limestone and dolomite of the Comus Formation of Early and Middle Ordovician age in the Osgood Mountains, 80 miles to the northwest, indicate that the carbonate facies continued at least that far to the northwest and that the eroded uplift across which the Eureka was deposited did not completely separate basins of deposition of the siliceous and carbonate facies (cf. Nolan, Merriam, and Williams, 1956, p. 32).

HANSON CREEK FORMATION

Name.—The Lone Mountain Limestone, as originally defined by Arnold Hague (1883; 1892, p. 57–62) included Upper Ordovician beds (Kirk, 1933, p. 30) which were later separated as the Hanson Creek Formation by Merriam (1940, p. 10–11). The type locality is on the northwest side of Roberts Creek Mountains, about 20 miles southeast of Cortez.

Distribution.—The Hanson Creek Formation crops out in the cliffs behind Cortez as two dolomite ledges with an intervening limestone slope. The formation extends about 1½ miles south of the Cortez mine, where it is overlapped by the Roberts Mountains Limestone and cut off against the Cortez fault. To the north of the mine the formation is well exposed in broken cliffs above the Eureka Quartzite and extends 1½ miles to where it abuts the Mill Canyon stock. The gray to black upper dolomite ledge is converted to a brilliant white marble in the contact aureole of the stock. Half a mile farther north intensely silicated dolomite of the Hanson Creek in contact with the stock crops out in small exposures on the side of Lewis Canyon.

Another group of exposures lies at the south end of the Cortez window where many interlayered slices of the dolomite and limestone members of the Hanson Creek Formation and Ordovician western facies rocks underlie the hills at the foot of Wenban Peak.

A small ledge of dolomite of the Hanson Creek crops out on the southwest side of Bald Mountain in a small window in the overthrust Slaven Chert of Devonian age.

Stratigraphy.—The basal black dolomite of the Hanson Creek Formation contrasts radically with the white quartzite of the underlying Eureka. At many places the base of the Hanson Creek is marked by a ½-foot-thick unit of light-gray sandy dolomite (partly converted to calcite by contact alteration). This bed probably includes reworked quartzite grains from the Eureka held in a carbonate matrix (Kirk, 1933, p. 28–31; and Merriam, 1940, p. 11). This sandy zone lies at the base of a 160-foot-thick dolomite member, in black to gray massive beds as much as 10 feet thick. Black elongate nodules of chert are abundant, as are white fragments of fossils, including brachiopods, corals, and crinoids. A cherty zone in the middle of the dolomite member is tectonically brecciated. The medium-gray, dolomite sandstone beds in the middle of the member are cross laminated.

The microscope shows that the dolomite ranges from coarse-silt to fine-sand size. The fine size and later alteration result in an "angular" texture; the dolomite grains are rhombic or have a mosaic fabric. Little perceptible clastic fabric remains even in the cross-laminated dolomite sandstones. At the south end of the outcrop belt, farthest from the stock, tremolite needles and talc sheaves are common. Closer to the stock tremolite and diopside are abundant and the dolomite is recrystallized to a brilliant white marble with mosaic fabric.

The middle member is thin-bedded dark bluish-gray limestone that weathers pale orange and breaks into chips and plates. The limestone is about 120 feet thick and is very fossiliferous, containing abundant trilobites, brachiopods, corals, and graptolites, along with nodular black chert and irregular nodules of limestone with shaly partings. Abundant black, rounded, contorted ridges on the bedding surfaces may be worm burrows.

Under the microscope the limestone is seen to be finer grained than the dolomite members—it is dominantly very fine to medium silt-size calcite grains with a mosaic fabric and extremely fine argillaceous material. Calcite and quartz veinlets are common and incipient silicification has started along the margins of fossils. Prismatic scapolite crystals are scattered through the limestone.

The upper member is massive cliff-forming light to medium-gray dolomite about 90 feet thick. Sparse unidentifiable fossil fragments occur, and the cliff is capped by a black dolomite 5 feet thick that is overlain conformably along a knife-edge contact by the thin-bedded dark-gray laminated limestone of the Roberts Mountains Limestone.

The dolomite grains range from coarse-silt to fine-sand size and are rhombic or disposed in a mosaic fabric. The sedimentary fabric is largely destroyed and tremolite needles altered to talc are common.

The following section of the Hanson Creek Formation was measured on the south side of Arctic Canyon and continues upward from the section of the Eureka Quartzite:

Measured section of Hanson Creek Formation on south side of Arctic Canyon NE ¼NW¼ sec. 8, T. 26 N., R. 48 E.

	Thickness (ft)
Roberts Mountains Limestone:	
Limestone, poorly exposed, dark-gray, laminated; contains pyrite; limestone weathering light gray.	
Hanson Creek Formation:	
11. Dolomite; black with white mottles of calcite; weathers dark gray	5
10. Dolomite, mottled, medium-gray; in layers 1–5 in. thick; composed of very fine and medium-sand-size grains; weathers light olive gray to medium dark gray, contains fossil fragments	10
9. Dolomite, very fine sand size, very thick bedded, medium-gray; weathers very light gray; breaks to angular sharp-cornered blocks; forms cliff	49
8. Dolomite, thin-bedded, poorly exposed, medium light-gray; weathers pale yellow gray	25
7. Limestone, dark-gray; weathers very pale orange; in parallel beds 1–4 in. thick; breaks into angular blocks and fragments; more massive than unit 6; contains fossiliferous rounded chert nodules	56
6. Limestone, thin-bedded, poorly exposed, dark-gray, very fossiliferous; weathers very pale orange to yellowish gray; breaks to chips and plates; black irregular blobs conspicuous. Dolomite ledge crops out 49 ft above base. Rounded black chert nodules, of sausage and dumbbell shape, occur in middle of unit	165

Measured section of Hanson Creek Formation on south side of Arctic Canyon NE¼NW¼ sec. 8, T 26 N., R. 48 E.—Continued

	Thickness (ft)
Hanson Creek Formation—Continued	
5. Dolomite, calcareous, very fine grained, dark-gray; weathers very light grap; in parallel beds ½–2 in. thick. Intercalated black chert beds and rounded elongate nodules ½–2 in. thick; some beds tectonically disturbed, so that back chert fragments are irregularly dispersed in the dark-gray dolomite	50
4. Limestone, dolomitic, medium dark-gray; in poorly exposed thin parallel beds	44
3. Dolomite, dark-gray; in poorly exposed parallel beds	19
2. Dolomite, dark-gray, fine-grained; in parallel beds 2–6 in. thick that thicken upward to 2 ft; weathers to irregular blocks; contains white dolomite veinlets and a little black dolomite with white fossils, such as crinoids. Rounded black chert nodules, 38 ft above base, are 2 in. thick, 6 in. long	53
1. Dolomite, sandy, medium light-gray; weathers yellowish gray; quartz grains in carbonate matrix; probably reworked Eureka Quartzite	0.5
Total Hanson Creek Formation (rounded)	480
Eureka Quartzite:	
Quartzite, fine-grained, thick bedded, white; weathers very light gray.	

The dolomite beds of the lower member of the Hanson Creek Formation are darker and thicker than those in the Hamburg Dolomite. The even gray color and uniform texture distinguishes the upper dolomite from the Hamburg. The knobby bedding and yellow-orange color of the weathered shaly interlayers in the blue-gray limestone are not matched in any limestone unit in the area.

Age and correlation.—Fragmental brachiopod, coral, and echinoidal debris from the lower and upper dolomite members is not identifiable. The localities are shown on plate 2. Collections from the middle limestone member at Arctic Canyon contain the following fossils identified by R. J. Ross, Jr., U.S. Geological Survey:

USGS colln. D451 (€O). At base of middle slabby unit of N½NE¼SE¼ sec. 5, T. 26 N., R. 48 E., on east slope at 8,000 ft. Cortez quad., Nevada.

Cryptolithoides sp.

All specimens poorly preserved. This genus has previously been reported only from Middle Ordovician rocks.

USGS colln. D452 (€O). Hanson Creek Formation, top of middle limestone unit. SW. cor. SW¼ sec. 4, T. 26 N., R. 48 E., on southwest-facing slope. Cortez quad., Nevada.

Orthid brachiopod, vaguely resembling *Austinella* in shape.

Strophomena? sp.

Sowerbyellid brachiopod, not identifiable as to genus.

Rhynchonellid brachiopod.

Trilobite, asaphid, indeterminate.

This poorly preserved assemblage could be of either Middle or Late Ordovician age.

Two inflated graptolites, preserved unflattened in the carbonate rocks, were also found at this locality but unfortunately were lost before they were identified.

At the type locality Merriam (1940, p. 10) designated the Hanson Creek Formation as Middle and Late Ordovician. Merriam and Anderson (1942, p. 1685) in a later paper called it Late Ordovician. Nolan, Merriam, and Williams (1956, p. 34) stated that the faunas indicate a Richmond (Late Ordovician) age.

The 480-foot thickness of dolomite and limestone in the Hanson Creek Formation at Cortez compares with the 560-foot thickness of limestone and dolomite at the type locality 25 miles southeast of Cortez. At Lone Mountain, 20 miles farther southeast, the Hanson Creek is 318 feet thick and is all dolomite. This Middle(?) and Upper Ordovician dolomite and its correlatives, the Fish Haven and Ely Springs Dolomites, extend across eastern Nevada and western Utah with little change in thickness and lithology (Nolan, Merriam, and Williams, 1956, p. 33–34; Hintze, 1960, p. 61).

The change in facies from dolomite to limestone between Lone Mountain and Cortez is further discussed along with similar changes in the other middle Paleozoic carbonate formations.

The fine-grained clastic carbonate rocks with their contained fossils (trilobites, corals, and thick-shelled brachiopods) indicate that these are shallow-water marine deposits. The middle argillaceous limestone may indicate an environment somewhat off the west edge of the dolomite-forming shelf environment (Nolan, Merriam, and Williams, 1956, p. 33).

SILURIAN SYSTEM

ROBERTS MOUNTAINS LIMESTONE

Name.—The Roberts Mountains Formation was defined by Merriam (1940, p. 11–12) with its type locality on the west side of the Roberts Creek Mountains about 20 miles southeast of Cortez. The type section is composed of dark slate-gray limestones about 1,900 feet thick and contains an abundant Silurian fauna. In the Shoshone Range, about 25 miles northwest of Cortez, Gilluly and Gates (1965) have amended the name to Roberts Mountains Limestone.

Distribution.—At Cortez the Roberts Mountains Limestone crops out in a band extending from a point 1½ miles south of Cortez, where it is exposed in gullies at the head of the pediment, to the point 1½ miles north of Cortez, where it abuts the Mill Creek stock. The thin-bedded slope-forming limestone forms the summit of Mount Tenabo, the highest point in the area. The east side of Mount Tenabo is a long dip slope that descends more than a thousand feet into the head of Mill Canyon. Here the thin-bedded limestone is bleached, hardened, and silicated in the contact aureole of the Mill Canyon stock. Another small area of highly silicated Roberts Mountains Limestone is on the southwest side of Lewis Canyon, northwest of Mount Tenabo.

Near the mouth of Cortez Canyon the Roberts Mountains Limestone crops out at the stream bottom. Its outcrops extend nearly 2 miles east along the Crescent fault, where they are discolored by hot-spring waters, bleached, and heavily silicated by quartz porphyry plugs and dikes.

In general the Roberts Mountains Limestone forms smooth scree-covered slopes between the underlying dolomite ledges of the Hanson Creek Formation and the overlying ledges of massive Wenban Limestone.

Lithology.—The 1,000-foot-thick black laminated silty graptolitic limestone of the Roberts Mountains Limestone is the most homogeneous unit in the stratigraphic section. Except for slight differences in thickness of laminae and in the size of the plates and chips into which the limestone breaks down and an upward increase in the coarseness and abundance of silt, the rocks are remarkably uniform. The limestone commonly weathers to ½- to 3-inch chips but breaks down to 9- to 12-inch plates in places. The spalls are tan, gray, pink, and purple from oxidation of abundant pyrite.

Microscopically, the rock is seen to be composed of about 80 percent calcite, about 15 percent angular fragments of quartz, about 5 percent potassium feldspar, and less than 1 percent muscovite flakes. All the grains are silt size. The rock is microlaminated and parallel bedded. Abundant organic matter helps define the bedding, and authigenic pyrite crystals as much as 5 mm across occur throughout the rock.

At the base of the section the quartz and feldspar silt makes up about 5 percent of the rock; near the top of the section it amounts to 15–20 percent. There is also, at the top of the section, segregation of the components into nearly pure very fine silt-size calcite in layers about 0.3 mm thick, with layers of coarse-silt-size siliceous material about 2.0 mm thick. Round very fine sand-size grains of quartz and calcite abound in the slightly coarser rock.

At the head of Mill Canyon the dark-gray limestone is bleached nearly white and contains abundant scapolite (meionite) with sieve texture, that is, poikilitically enclosed calcite. Near the mouth of Cortez Canyon, columnar scapolite as much as 2 mm long occurs, but the rock has the normal dark-gray color.

As much as 3 percent organic carbon (J. J. Frost, analyst) was found in samples of the limestone but it is so finely dispersed that James Schopf, U.S. Geological Survey, could not discern structure in the organic matter in ultra-thin slices of the rock. The unweathered organic limestone from a prospect pit in Arctic Canyon will dirty the hand.

The following section of the Roberts Mountains Limestone was measured in the steep slopes south of Arctic Canyon:

Measured section of Roberts Mountains Limestone 1 mile south of Arctic Canyon, NE¼NW¼ sec. 9, T. 26 N., R. 48 E.

Wenban Limestone:

Limestone, coarsely crystalline, bioclastic, thick-bedded; weathers grayish orange; interbedded with laminated light-gray limestone; forms ledge; break in slope marks contact.

	Thickness (ft)
Roberts Mountains Limestone:	
7. Limestone, medium dark-gray; weathers medium light gray, pale red, and grayish orange; in thin parallel beds; weathers to plates 5 mm thick and blocks as much as 3 in. thick; contains scattered pyrite cubes; forms ledge; *Monograptus* sp. abundant	211
6. Limestone, medium dark-gray; in thin parallel beds; weathers to prominent plates 9×12 in. across; this unit resembles Wenban Limestone	173
5. Limestone, medium dark-gray, weathers medium light gray, pale red, and grayish orange; contains scattered pyrite cubes; laminae, 1–10 mm thick, are thinner and more continuous than below	126
4. Limestone, medium dark-gray; weathers medium light gray, pale red, and grayish orange; contains scattered pyrite cubes; weathers to plates 5 mm thick and blocks as much as 8 cm thick; forms ledge in creek bottom; graptolites found in middle of unit	456
3. Limestone, thinly laminated, poorly exposed, medium-gray; weathers light gray, grayish orange, and pale red; forms ½- to 2-in. plates	4
2. Limestone, medium-gray; weathers light gray; in laminae 5–10 mm thick which form 6-in. plates; poorly exposed, but makes ledge	5
1. Limestone, poorly exposed, medium-gray; weathers light gray in laminae 2–4 mm thick; weathers to plates and chips	54
Total Roberts Mountains Limestone	1,029

Hanson Creek Formation:

Dolomite, medium-crystalline, black mottled, massive, parallel-bedded; forms ledge.

The Roberts Mountains Limestone is quite distinctive in large outcrop but in narrow fault slices can be confused with the calcareous shales in the Pilot Shale. Most difficulty was found in distinguishing it from the thin-bedded limestones interbedded with organic clastic limestone in the basal part of the overlying Wenban Limestone. The Roberts Mountains Limestone, however, breaks down to chips and plates a few inches across. In contrast the shaly limestones of the Wenban commonly form plates half an inch or less thick and several

756-537 O—64——3

feet across. Critical, of course, are the almost ubiquitous monograptids in the Roberts Mountains Limestone.

Age and correlation.—The abundant graptolites allow the assignment of the Roberts Mountains Limestone to the Silurian. However, only in the middle part of the unit is the preservation adequate to allow more specific age assignment. Collections from the middle of the section were examined by R. J. Ross, Jr., of the U.S. Geological Survey who identified:

Monograptus sp. with long straight thecal denticles, generally characteristic of Late Llandovery and early Wenlock (Middle Silurian) and, in another collection; *Monograptus* cf. *M. pandus* (Lapworth) and *Monograptus* sp. (long narrow form); Late Llandovery or early Wenlock (Middle Silurian).

No collections were made from the lower part of the unit; those from the upper part, although abundant, are poorly preserved and could only be identified as *Monograptus* sp., Silurian. Thus the middle of the unit is Middle Silurian in age but the time span of the whole formation is unknown. In places the monograptids are very abundant and, even though broken off at each end, are more than 12 inches long.

The 1,000-foot thickness of the Roberts Mountains Limestone at Cortez contrasts with the 1,900-foot thickness at the type locality in the Roberts Creek Mountains 20 miles to the southeast (Merriam and Anderson, 1942, p. 1686–87). The Cortez section may actually be equivalent to the lower 1,100 feet of flaggy, platy, and shaly limestone of the Roberts Mountains section (Nolan, Merriam, and Williams, 1956, p. 37). At Lone Mountain, 20 miles farther southeast, the formation is 741 feet thick and largely dolomitic (Merriam and Anderson, 1942, p. 1687). Farther east, the facies changes to the approximately equivalent Laketown Dolomite which persists unchanged into western Utah (Nolan, Merriam, and Williams, 1956, p. 37).

Winterer and Murphy (1960) inferred that the Roberts Mountains Limestone is laterally equivalent to the Lone Mountain Dolomite and pointed to an intergrading zone in the Roberts Creek Mountains. This problem is discussed in the section "Wenban Limestone."

Conditions of deposition.—In fossil content, grain size, and mineral constitution, the Roberts Mountains Limestone closely resembles the siltstone and very fine grained sandstone of the Elder Sandstone of the western facies. The difference is the dilution of the siliceous silt of the Elder by the fine-grained clastic calcite that makes up 80 percent of the Roberts Mountains Limestone. It is thus transitional between the siliceous rocks of the geosynclinal facies and the carbonates of the shelf facies. The fine laminations, graptolitic fauna, and abundant pyrite and organic matter indicate that it was deposited in somewhat deeper water, where the sediments were little disturbed by waves or scavengers and the bottom was anaerobic.

DEVONIAN SYSTEM

WENBAN LIMESTONE

Name.—The Devonian limestone, best exposed on the western flank of Wenban Peak (8,220-ft hill) south of Cortez, is here called the Wenban Limestone. The Nevada Limestone was defined by Arnold Hague (1883, p. 264–67; 1892, p. 63–84) from exposures at Eureka to include the carbonate beds above the Lone Mountain Limestone and the overlying shales (Arnold Hague, 1892, p. 57). Merriam (1940) and Nolan, Merriam, and Williams (1956) restricted the Nevada Formation to the dolomite, limestone, and sandstone of late Early and early Middle Devonian age, and recognized the Devils Gate Limestone above, of late Middle and Late Devonian age. The boundary was placed at the *Stringocephalus* faunal zone, which at Eureka coincides with a distinct lithologic change. The Wenban Limestone as here recognized includes limestone of Early, Middle, and Late Devonian age and is thus an approximate equivalent of both the Nevada, as restricted, and the Devils Gate Limestone.

Distribution.—The Wenban Limestone crops out extensively in the quadrangle. It underlies the crest of the Cortez Mountains for 3 miles south and 2 miles north of Cortez where it enters the contact aureole and abuts the Mill Canyon stock. At Cortez and sporadically north and south of the townsite small outcrops of Wenban Limestone project through the pediment gravels. There is about half a square mile of outcrop at the mouth of Mill Canyon where the limestone is contorted and silicated by the adjoining stock.

About 3 square miles, near and east of the mouth of Cortez Canyon, is underlain by Wenban Limestone. Two windows through the overthrust Slaven Chert expose the Wenban Limestone on the west side of the Bald Mountain in the Toiyabe Range. The northern window is about 1 square mile in extent; the southern about 2 square miles. In all these areas, the Devonian limestone commonly supports more vegetation than the surrounding overthrust siliceous rocks.

Stratigraphy.—The Wenban Limestone has a gradational boundary with the underlying Roberts Mountains Limestone. The base of the unit is taken at the first bioclastic limestone bed above the thin-bedded gray pyrite-bearing limestone with monograptids of the Roberts Mountains Limestone. Above this lies 2,000 feet of the inter-bedded dark-gray thick-bedded bioclastic limestone interbedded with thin-bedded argillaceous gray to yellow-gray weathering slabby limestones. The beds become lighter gray, finer grained, and more massive upward. No monograptids were found in the thin-bedded limestones above the basal bioclastic bed, and no shelly fauna was found below this horizon.

The following section of the lower part of the Wenban Limestone was measured west of the mouth of Cortez Canyon in an area less faulted than the west side of Wenban Peak where the section is thicker and more fossiliferous, but considerably tectonically disturbed.

Measured section of Wenban Limestone, west side of mouth of Cortez Canyon, unsurveyed, 7,000 ft N., 1,500 ft W. of NE. cor. sec. 2, T. 26 N., R. 47 E.

	Thickness (ft)
Wenban Limestone:	
14. Limestone, heavily silicated, thin-bedded, shaly, dark-gray; weathers to light olive gray; breaks to irregular plates; becomes more massive upward to form ledges of lighter and darker gray limestone. Light layers ½ in., dark layers 4 in., in massive beds as much as 5 ft thick. Several hundred more feet of beds to north of ridge crest but increasingly shattered near the range front fault so not measured	379
Fault(?).	
13. Limestone, grayish-black, black-weathering, 2- to 6-in.-thick beds; breaks down to angular blocks; forms ledges	55
12. Limestone, finely crystalline, thin- to medium-bedded, grayish-black; contains pyrite; weathers medium dark gray; breaks to small angular blocks	348
11. Limestone, grayish-black; weathers medium light gray; 2-mm-thick laminations break to chips ½–4 in. across; contains pyrite. This looks much like Roberts Mountain Limestone. Contorted beds indicate fault	340
10. Limestone, grayish-black; weathers medium gray to light olive gray; alternating 2½-ft-thick intervals of shaly limestone and laminated thick-bedded limestone; weathers to very rough surface and form scattered ledges	234
9. Limestone, finely crystalline, thin- to medium-bedded, medium dark-gray; weathers light olive gray; breaks to small blocks; intermittent exposures	136
8. Limestone, laminated, slope-forming, poorly exposed, medium-gray; in parallel beds 1–2 in. thick	55
7. Limestone, finely to very finely crystalline, medium-bedded, grayish-black; weathers light olive gray; breaks in irregular blocks; forms ledges	17
6. Limestone, shaly, thin-bedded, slope-forming, dark-gray; weathers medium gray; contains abundant pyrite; top 7 ft is sill of latite	41
5. Limestone, dark-gray, thin- to thick-bedded (laminated to 1 mm thick, but breaks in beds ½ in.–4 ft thick); forms intermittent ledges; breaks to irregular blocks	93
4. Limestone, dark-gray; weathers light olive gray in beds 1–5 mm thick; hornfelsed; forms slope	10

Measured section of Wenban Limestone, west side of mouth of Cortez Canyon, unsurveyed, 7,000 ft N., 1,500 ft W. of NE. cor. sec. 2, T. 26 N., R. 47 E.—Con.

	Thickness (ft)
Wenban Limestone—Continued	
3. Limestone, very finely crystalline; dark gray to grayish black in parallel beds to 3 ft thick, with interlayered zones 10 mm thick that weather to grayish orange; thicker beds laminated in part; contains white calcite veinlets; hornfelsed; forms cliff	16
2. Limestone, finely crystalline, dark-gray; weathers brownish gray; breaks in layers 1–50 mm thick; laminae 0.5 mm thick; breaks into irregular plates; forms slope	23
1. Limestone, laminated to thin-bedded, finely crystalline, dark-gray; weathers medium to light gray; beds up to 2 in. thick; breaks into irregular pieces and plates; forms cliffs	8
Wenban Limestone (partial section; rounded)	1,800

Roberts Mountains Limestone (partly covered interval):
Limestone, dark-gray, finely laminated; contains abundant pyrite. *Monograptus* sp.

The following groups of ostracodes from near the base of the Wenban Limestone were identified by Jean M. Berdan of the U.S. Geological Survey, who reported as follows:

FC–8 (USGS 4930–SD). Alt 6,550 ft; 400 ft N., 300 ft E., SW. cor. sec. 16, T. 26 N., R. 48 E. Gray limestone with abundant crinoid debris, siliceous, ostracodes as follows:

Mesomphalus sp.
Velibeyrichia sp.
N. gen. aff. *Welleria*.
Saccarchites sp.
Aechmina? sp.
Acanthoscapha sp.
Tricornina sp.
Tubulibairdia sp.
Bairdia sp. aff. *B. leguminoides*

Mesomphalus was originally described by Ulrich and Bassler from the Keyser formation of Maryland, and has since been found in the Manlius and Coeymans limestone of New York and rocks correlated with the New Scotland formation in Maine. Although most of the other genera associated with it range from the Silurian to the Middle Devonian, the collection also contains an undescribed genus which has hitherto been found only in rocks of Late Silurian age in Maine. Because of lack of knowledge of the stratigraphic and geographic range of many of these genera in the West, any statements as to age are subject to change without notice, but on the basis of the ostracodes alone I would think that this association is Late Silurian or Early Devonian in age, with the probabilities being that it is Late Silurian.

Brachiopods found since then in the Simpson Park Range indicate that the equivalence of these strata to the Coeymans Limestone of New York (lowest Devonian) is valid.

Fossils from somewhat higher in the unit were identified by J. T. Dutro, Jr., U.S. Geological Survey, who reported as follows:

Field No.: F–121 (5298–SD). Nevada, Eureka Co., Cortez quad.; unsurveyed, T. 27 N., R. 48 E.; from "Wenban" limestone at mouth of Mill Canyon, alt. 5,300 ft.

Leptocoelia cf. *L. infrequens* (Walcott)
Styliolina? sp.
Odontopleurid trilobite (cf. *Leonaspis*)

From this locality W. A. Oliver identified:

Favo sites sp.
Cladopora? sp.
"*Hindia*" sp. (lithistrotid sponge)
Crinoid columnals
Brachiopod fragments.

Fossils indicate a probable Early Devonian age. The key form here is *Leptocoelia* cf. *L. infrequens* (Walcott). Leptocoelids occur in Lower and lower Middle Devonian rocks elsewhere in the world, but are most common in the Lower Devonian. The trilobite *Leonaspis* apparently ranges no higher than the Lower Devonian in North America but is known from the Middle Devonian of Bohemia.

The following collections have been identified by C. W. Merriam, U.S. Geological Survey, who commented as follows:

FC–34. SE. cor., sec. 21, T. 26 N., R. 48 E.
Mystrophora cf. *M. areola* (Quenstedt)
Leptocoelia sp.
Nervostrophia sp. B.
Styliolina sp.

F–38. SW. cor., sec. 21, T. 26 N., R. 48 E.
Leptocoelia sp.
Nervostrophia sp. B.
Spirifer cf. *S. pinyonensis*
Styliolina sp.

F–50. SE. cor., ?, T. 27 N., R. 47 E.
?Leptocoelia sp.
Fragmentary orbiculoid brachiopods

F–43. NE. cor. sec. 8, T. 26 N., R. 48 E.
Chonetes sp. cf. *C. filistriata* Walcott
?Phacopid thoracic segments

F–54. NE. cor. sec. 8, T. 26 N., R. 48 E.
Leptocoelia sp.
?*Ambocoelia* sp.
Fragmentary phosphatic brachiopods, include linguloids and orbiculoids, undet.

Collection F–95, from a fault block on the Cortez front.
Treatment with acid yielded poorly preserved silcified fossils among which are the following:
Dalmanellid brachiopods
?Spiriferoid brachiopod
?*Pleurodictyum* sp.
?*Syringaxon* sp.

This assemblage is too poorly preserved for positive identification but suggests an Early Devonian age.

Collection F–98, 2 miles south of Cortez

Favositid corals

Leptaena sp.

?*Coelospira* sp.

?*Atrypa* sp.

Large rhynchonellid brachiopods

Age: Early Middle or Early Devonian.

Leptocoeliae are most abundant in the lower part of the Nevada Formation which is Early Devonian but they do range up into the *Spirifer pinyonensis* zone.

From higher in this unit Miss Berdan found ostracodes on which she reported as follows:

F–39 (USGS 4938–SD). Alt. 7,400 ft; 2,900 ft N., 4,500 ft E., SW. cor, of sec. 21, T. 26 N., R. 48 E. Hand specimen dark-gray platy limestone, weathers drab to buff, with brachiopods, trilobites, ostracodes, and corals exposed on the bedding surfaces. Ostracodes as follows:

Falsipollex? sp.

Parabolbina sp.

Thlipsura sp. aff. *T. furcoides* Bassler

Aechmina sp.

Smooth ostracodes, undet.

Thlipsura of the type of *T. furcaoides* is not known above strata correlated with the Onondaga in the Eastern States, whereas *Falsipollex* has hitherto been considered as occurring in the Hamilton or Traverse rocks. On the basis of the ostracodes the age is considered to be late Early or early Middle Devonian.

F–50 (USGS 4945–SD). Alt 5,050 ft; 7,900 ft N., 8,100 ft W. of SE. cor., T. 27 N., R. 47 E. Hand specimen pinkish siltstone with calcareous cement, *Tentaculities* and ostracodes weathered in relief on bedding surfaces. Ostracodes as follows: *Thlipsura* sp. aff. *T. furcoides* Bassler, smooth ostracodes, undet. This collection may be late Early Devonian or early Middle Devonian like others containing *Thlipsura* aff. *T. furcoides*.

F–53 (USGS 4946–SD). Alt 6,275 ft, 4,500 ft N., 160 ft E., SW. cor. sec. 8, T. 26 N., R. 48 E. Hand specimen gray to pinkish siliceous limestone with brachiopod fragments and one *Tentaculites* on bedding surface. Ostracodes are *Thlipsura* sp. aff. *T. furcoides* Bassler and smooth ostracodes, undet. Age possibly late Early Devonian or early Middle Devonian.

F–55 (USGS 4948–SD). Alt 5,600 ft; 4,900 ft N., 3,600 ft W., SE. cor., T. 27 N., R. 47 E. Hand specimen very dark platy siliceous limestone or siltstone, weathers light gray, with brachiopod fragments, trilobite fragments, *Tentaculites* and ostracodes on bedding surfaces. Ostracodes are *Thlipsura* sp. aff. *T. furcoides* Bassler and smooth forms, undet. Age possibly late Early Devonian or early Middle Devonian.

The time span represented by these faunas may be Helderberg and Deer Park in the standard section.

The basal contact of the Wenban Limestone appears conformable with the Roberts Mountains Limestone at Cortez and similar conformability has been reported from the Simpson Park Range by

Winterer and Murphy (1960, p. 135). This contact surely represents locally the Silurian-Devonian systemic boundary, for the rocks above it in both areas contain fossils correlative with those of the Coeymans of the New York section, that is earliest Devonian (Helderberg). Helderberg fossils have also been collected from the lower part of the Nevada in the Roberts Creek Mountains (Merriam, 1940, p. 51), but in the Eureka district (Nolan, Merriam, and Williams, 1956, p. 46), and in the Sulphur Springs and Piñon Ranges (Carlisle and others, 1957, p. 2180), the earliest Devonian fossils recognized indicate equivalence to the somewhat younger Oriskany, rather than to the Helderberg. It is thus possible, in these more easterly areas, that the Silurian-Devonian boundary lies at a lower stratigraphic level, that is, somewhere in the upper part of the Lone Mountain Dolomite there recognized (Merriam, 1940, fig. 7; 1954, p. 1284; Nolan, Merriam, and Williams, 1956, p. 39; Carlisle and others, 1957, p. 2180; Winterer and Murphy, 1960, p. 133). Merriam, Nolan, Winterer, and Murphy all believe, however, that this possibility is not as likely as that an unconformity is present at the contact between the Lone Mountain and Nevada in these eastern localities, thereby accounting for the absence of Helderberg equivalents.

The only fossils ever reported from the very sparsely fossiliferous Lone Mountain Dolomite have been assigned a Silurian age, and except for those from near Wood Cone, southwest of Eureka, which are considered Late Silurian (Merriam, in Nolan, Merriam, and Williams, 1956, p. 39), all have been called Middle Silurian. There is therefore only permissive evidence that any of the Lone Mountain of the general region is of Devonian age.

Winterer and Murphy (1960, p. 119–122) have pointed out that in the Roberts Creek Mountains the Lone Mountain Dolomite passes gradually or abruptly laterally westward and northward into the Roberts Mountains Formation. It is thus possible that the highest beds of the Roberts Mountains at Cortez are equivalent to parts of the Lone Mountain Dolomite of areas farther east and south. As in most of the Lone Mountain, no fossils of definite Late Silurian Age have ever been recognized in the Roberts Mountains Formation; those definitely assignable to subdivisions of the Silurian are of Middle Silurian age. It is therefore highly likely that despite the appearance of conformity between the Roberts Mountains and Wenban Limestones at Cortez, there is a considerable hiatus in deposition. This seems especially probable because of the very extreme changes in facies and thickness of the Silurian in the region between Cortez and Lone Mountain (Winterer and Murphy, 1960, p. 134–138).

In summary, the lower part of the Wenban Limestone appears to correlate with the lower part of the Nevada Limestone in the Roberts Creek Mountains and the time interval is represented farther east by the widespread unconformity that has long been recognized in Nevada and western Utah (Hazzard, 1937, p. 327; Nolan, 1935, p. 18).

The next higher member of the Wenban Limestone is best exposed in the middle ridge of the creek 2 miles south of Cortez and is composed of about 500 feet of interbedded gray limestone and yellow-weathering argillaceous limestone. The gray limestone is in 2- to 10-foot-thick beds; the argillaceous limestone is thin bedded and in places, shaly. An abundant fauna of brachiopods, trilobites, corals, and bryozoa is present.

C. W. Merriam, of the U.S. Geological Survey, examined these collections and identified the following:

F–39. SW. cor. sec. 21, T. 26 N., R. 48 E.
Small *Ambocoelia*-like brachiopod, abundant
?*Chonetes* fragment

F–45. SE. cor. sec. 4, T. 26 N., R. 48 E.
Nervostrophia sp. cf. *N.* sp. B.
Spirifer sp. undet. Could be *S. pinyonensis*
Styliolina sp.
Probably late Early Devonian.

Additional collections have not yet been identified.

This argillaceous limestone, from its stratigraphic position and contained fauna, is probably the correlative of the Oxyoke Canyon Sandstone Member of Eureka (Nolan, Merriam, and Williams, 1956) and the Union Mountain Member of the Nevada Formation in the Sulphur Springs Range (Carlisle and others, 1957).

The next overlying member of the Wenban Limestone is composed of thick- and thin-bedded, gray, lithographic and bioclastic limestone. Beds of medium-gray limestone as much as 10 feet thick alternate with pale-gray to yellow-gray thin-bedded argillaceous limestone. These cliff-forming limestones are about 500 feet thick and crop out south of Cortez and on the eastern dip slope of Wenban Peak and Mount Tenabo. The upper contact of these beds is mechanical; the Pilot Shale lies in thrust contact on the limestone. Similar rocks about 400 feet thick crop out in a fault slice in the main zone of thrust faulting south of Cortez where both upper and lower contacts are faults.

Jean M. Berdan, of the U.S. Geological Survey, identified and reported on the ostracodes from these beds as follows:

FC–10 (USGS 4931–SD), Alt 6,100 ft, 3,000 ft N., 600 ft W., SE. cor. sec. 20, T. 26 N., R. 48 E. Hand specimen gray platy argillaceous limestone, buff weathering, with *Styliolina* and brachiopod fragments on weathered surfaces. Ostracodes as follows:

Hanaites fragment
Chironiptrum? sp.
Birdsallella sp.

Age: Middle Devonian, probably about the same as the Slaven Chert.

FC–26 (USGS 4933–SD). Alt 7,350 ft; 900 ft N., 6,200 ft E., SW. cor. sec. 21, T. 26 N., R. 48 E. Hand specimen light-gray platy very argillaceous limestone, turning pinkish on etched pieces. *Styliolina*, brachiopod fragments, and bryozoan fragments on bedding surfaces. Ostracodes as follows:

Chironiptrum? sp.
N. gen. aff. *Halliella*
N. genus of hollinid
Birdsallella sp.
Berounella? sp.
Smooth forms, undet.

None of the forms cited above are especially helpful for age determinations. However, the new genus aff. *Halliella* occurs in a collection (54F37) made by R. E. Lehner which also contains a conodont identified by Hass as *Icriodus* sp. aff. *I. latericrescens* Branson and Mehl, which is Middle Devonian in age. Also the ostracode cited as a new genus of hollinid is similar to one in collection FC–29, which is believed to be Middle Devonian. Consequently this collection is probably also Middle Devonian.

FC–29 (USGS 4935–SD). Alt 6,850 ft; 2,300 ft N., 3,600 ft E., SW. cor. sec. 21, T. 26 N., R. 48 E. Hand specimen dark-gray platy limestone, weathers drab with brachiopods, trilobite fragments, *Styliolina* sp. on bedding surfaces. Etched fragments very argillaceous. Brachiopods reported by Merriam, corals reported by Oliver. Ostracodes as follows:

Hanaites sp.
Hollinella? sp.
N. gen. of hollinid, like that in FC–26
Aechmina sp.
Tricornina sp.
N. gen. aff. *Thlipsurina*

The presence of *Hanaites* suggests a Middle Devonian age, close to that of the Slaven Chert.

Corals were examined by W. A. Oliver, Jr., who reported:

FC–3. Columnariid? coral. The single specimen in this collection is poorly preserved but very interesting. It is a cerioid rugose coral, probably of an undescribed genus, which seems most closely related to the family Columnariidae. The specimen is certainly post-Ordovician and is probably pre-Mississippian in age.

FC–4. Rugose coral, undet. Crinoid columnals (common).

Two incomplete rugose corals in this collection are unassignable to genus because of inadequate material. They are of types known only from the Middle Silurian to Middle Devonian and previously unreported from the Western United States.

FC–7. *Spongophyllum* sp. (4 good specimens). Crinoid columnals.

The specimens of *Spongophyllum* (cerioid rugose coral) are apparently assignable to a new species. The genus ranges from Middle Silurian to Middle Devonian, but the present specimens are most closely allied to described Middle Devonian forms. Further, the genus is most common around the world in rocks of Middle Devonian age. The collection is probably Devonian and most likely Middle Devonian in age.

The specimen labeled F–48, from alt 7,400 ft, 100 ft S., 400 ft E., SW. cor. sec. 3, T. 26 N., R. 48 E., is a piece of clastic limestone which includes a few fragments of unidentifiable *Cladopora*-like corals and ramose (branching) stromatoporiods.

With regard to the stromatoporoids R. S. Boardman reports as follows: "Poorly preserved branching stromatoporoids that are limited to the Middle and Upper Devonian in this country. The specimens probably belong to the genus *Idiostroma*."

The corals are of wide ranging types and add nothing to the age indication of the stromatoporoids. Considering (1) the age indicated by the stromatoporoids, and (2) the clastic nature of the limestone, it can only be said that the rock is post-Early Devonian in age.

Brachiopods, trilobites, and pteropods were examined by C. W. Merriam, who commented as follows:

FC–29. SW. cor. sec. 21, T. 26 N., R. 48 E.
Mystrophora cf. *M. areola* (Quenstedt)
?*Nervostrophia* sp. B.
Styliolina sp.
Phacops sp.
Age: Middle Devonian.

F–37. SW. cor. sec. 21, T. 26 N., R. 48 E.
Pteropods abundant.
Tentaculites sp.
?*Styliolina* sp.
Phosphatic brachiopods, undet.
Rhynchonellid brachiopod, undet.
Age: Probably Middle Devonian.

F–46. SW. cor., T. 27 N., R. 48 E.
Cladopora sp.
?*Martiniopsis* sp. (small form)
Fragmentary rhynchonellids, undet.
Styliolina sp.
Age: Probably Middle Devonian.

Fossil evidence for Middle Devonian age of the collections with *Mystrophora* and *Styliolina* is good, but not entirely conclusive. *Mystrophora* areola is a Middle Devonian brachiopod in Europe, but has not previously been recognized in the Great Basin. *Styliolina* is most abundant in the middle Nevada, where it often occurs with *Martinia kirki.* A *Styliolina* shale bed occurs at Lone Mountain at the base of the middle Nevada.

From its stratigraphic position and contained fossils this part of the Wenban Limestone may be equivalent to the middle part of the Nevada at Eureka, that is, the Sentinel Mountain Dolomite Member and the Woodpecker Limestone Member (Nolan, Merriam, and Williams, 1956).

The highest member of the Wenban Limestone comprises about 200 feet of thick-bedded gray lithographic limestone and bioclastic limestone and interbedded thin-bedded sandy limestone. It is intensely brecciated for it lies with fault contact on the Pilot Shale below and is overlain conformably(?) by the Pilot Shale which in turn is cut off by a thrust fault.

The following conodonts from the limestone directly below the Pilot Shale were identified by the late W. H. Hass, U.S. Geological Survey, who reported:

F-35. Bioclastic limestone; Devonian, undifferentiated; from top of unit. Alt 6,950 ft; 300 ft N., 3,800 ft E. SW. cor. sec. 21, T. 26 N., R. 48 E.

Conodonts are rather common but fragmentary in this collection. I could not recognize with certainty any species; genera present indicate Middle or Late Devonian age: *Palmatolepis* (recorded range high Middle to Upper Devonian); *Icriodus* (Devonian); *Polygnathus* (Lower Devonian to Lower Mississippian); *Ancyrodella* (Middle to Upper Devonian). The collection also contains specimens of *Spathognathodus*, *Hindeodella*, and *Ligonodina*; these genera have long stratigraphic ranges.

This unit is therefore tentatively correlated with the upper part of the Devils Gate Limestone (Merriam, 1940), with an unknown thickness of beds equivalent to the lower part of the Devils Gate and upper part of the Nevada probably cut out by faulting.

PILOT SHALE

Name.—The Pilot Shale was named by Spencer (1917, p. 26) near Ely, 100 miles southeast of Cortez. In the Eureka area 50 miles southeast of Cortez, Nolan, Merriam, and Williams (1956, p. 52–53) applied the name to the basal beds of the White Pine Shale of Hague (1892, p. 68–69). Gilluly and Gates (1965) applied the name to rocks exposed in the Gold Acres window of the Roberts thrust in the Shoshone Range 12 miles northwest of Cortez.

Distribution.—The Pilot Shale crops out in two arcuate bands at the south end of the Cortez Mountains in the low hills ringing Wenban Peak (8,220-ft hill) about 3 miles south of the Cortez mine. The thin-bedded shaly limestone forms saddles or lies on long dip slopes of Wenban Limestone. Only two very small outcrops were seen; elsewhere the unit is masked by scree of small chips of shale and limestone.

Lithology.—As the shale crops out in the main Roberts thrust zone and is poorly resistant, accurate measurements of thickness and determinations of lithologic sequences are impossible. In one body both contacts are mechanical; the lower fault brings the Pilot into contact with upper Lower Devonian limestone, containing fossils of the *Spirifer pinyonensis* zone. The upper fault brings slices of Hanson Creek dolomite, Vinini Formation, and lower parts of the Wenban Limestone into contact with the Pilot Shale. In this exposure the thin-bedded dark-gray shaly limestone weathers to shades of pink and yellow and is much contorted. About 200 feet of beds may be contained in this fault slice.

In the second belt of outcrop, the Pilot Shale forms "flatirons" on the dip slope of the thick-bedded upper part of the Wenban Limestone. The rock is dark-gray thin-bedded shaly limestone that becomes less calcareous upward. Interbedded are thin (< 1 in. thick) dark-gray calcite sandstones and black chert beds one-fourth of an inch thick. The rocks weather into small chips, colored pale yellowish brown, grayish orange, pale red, grayish red, and shades of lavender. About 300 feet of beds is present. The top is cut off by the Roberts thrust, along which slices of Vinini Formation, Hanson Creek Formation, and Wenban Limestone are exposed.

The microscope reveals 10–25 percent medium to coarse quartz silt, 5–15 percent silt-size calcite fragments, and less than 1 percent colorless mica flakes set in a matrix of clay minerals of fine-silt to clay size. Euhedral authigenic pyrite 0.1 mm in diameter is common, as are spherules of iron oxide 0.01–0.001 mm in diameter derived from pyrite. Microlamination is defined by angular spalls of quartz and mica flakes, and pyrite-rich layers.

Age and correlation.—Although several samples of shale and limestone were disaggregated, only one contained conodonts. These were examined by the late W. H. Hass, of the U.S. Geological Survey who stated:

> Collection F–87b from the Pilot Shale, south of Cortez, 1,900 feet north, 200 feet east of the SW. cor. sec. 21, T. 26 N., R. 48 E., contains two recognizable conodonts. One specimen belongs to the long-ranging genus *Neoprioniodus* and the other to *Palmatolepis*. *Palmatolepis* is a common genus of the Upper Devonian. It may range into the uppermost part of the Middle Devonian but has never been found in the Lower Devonian. The age of the rock containing this fossil is considered by me to be more likely Late Devonian than late Middle Devonian because the specimen bears a resemblance to *Palmatolepis glabra*.

Echinodermal debris and questionable syringoporoid coral fragments were found in the thin limestone beds but are not diagnostic of age.

No fossils were found by Spencer (1917) at the type locality near Ely but extensive collections of conodonts were made at Eureka in the lower calcareous part of the formation. These are considered by

Hass to be from the lower half of the Upper Devonian (Nolan, Merriam, and Williams, 1956, p. 53).

Fossils have not been found in the upper unit of the Pilot Shale at Eureka but Nolan, Merriam, and Williams (1956, p. 53) stated that at Eureka black shales similar to the Devonian part of the Pilot Shale are interbedded with the overlying Joana Limestone of Early Mississippian age, and that therefore the Devonian-Mississippian boundary may fall within the unit. This was the opinion of Walcott (1884, p. 5). In absence of fossil evidence of Mississippian rocks at Cortez, the Pilot Shale is here considered Late Devonian.

The appearance of the Pilot Shale signaled the end of the carbonate deposition that was little interrupted over a wide region here and to the east between Middle Ordovician and Late Devonian time. The fine clastic finely laminated nature of the rock, the abundant pyrite, and the contained conodont fauna indicate that a fairly deep water marine (euxenic) environment obtained, much like that of the Roberts Mountains Limestone.

STRATIGRAPHY OF THE UPPER PLATE OF THE ROBERTS THRUST (WESTERN OR SILICEOUS FACIES)

ORDOVICIAN SYSTEM

VALMY FORMATION

Name.—The Valmy Formation was named in the Antler Peak quadrangle (Roberts, 1951), where it consists of several thousand feet of interbedded chert, quartzite, argillite, slate, and greenstone. It is widely exposed also in the northern Shoshone Range where it has similar characters (Gilluly and Gates, 1965) so that the rocks referred to the formation in the Cortez quadrangle can be confidently traced to the type area with interruptions only by alluvial cover of Crescent Valley and the Reese River Valley.

Distribution and topographic expression.—The Valmy Formation crops out over an area of about 4 square miles in the northeast corner of the quadrangle, on the steep northwest slope of the Cortez Range. Other bodies crop out on the east, north, and northwest slopes of Bald Mountain, on Squaw Butte, in the northwest corner of the quadrangle, and at the mountain front between 3 and 4 miles south of Cortez. Most of these exposures are topographically conspicuous, for the quartzite of the Valmy, though a subordinate part of the formation, is one of the most erosion-resistant rocks of the area.

Stratigraphy.—The Valmy Formation of the Cortez area consists chiefly of dolomitic sandstone, chert sandstone, quartzite, chert, and conglomerate, with very minor amounts of dolomitic siltstone, shale, limestone, and greenstone.

Most of the sandstone is thin bedded, relatively fine grained, gray on fresh fracture, and weathers to brown hues. The principal components are (1) quartz, which ranges from well-rounded grains 0.5 mm in diameter downward through more angular ones to fine angular silt particles; and (2) black chert, most of which, even in the coarser sizes, is subangular and which also has about the same size range as the quartz. A few detrital grains of chalcedony also occur. There is a little muscovite in most specimens, but feldspar, if present at all (except in the greenstones and closely associated beds), is very scarce. By variations in the relative proportions of quartz and dark-gray chert grains, the rocks vary considerably in color. Generally the cement is calcite or dolomite, but in the purer quartz rocks it is silica, so that the rocks are true quartzites that fracture across the grains. Locally the cement is phosphatic, containing an apparently ferrian member of the variscite group [$(Al,Fe^{+3})PO_4 \cdot 2H_2O$], according to an X-ray determination by A. J. Gude 3d, of the U.S. Geological Survey. This phosphate is probably related to the common turquoise mineralization in the region.

The sparse heavy minerals of the sandstones and quartzites include zircon, green tourmaline, brown tourmaline, biotite, epidote, hornblende, augite, authigenic barite, and pyrite, most of which has weathered to iron oxides near the surface.

Granule conglomerate is present in beds a few feet thick in many places, but the only considerable body is in the foothills of the Cortez Mountains about 3–4 miles south of the mine at Cortez. Here conglomerate makes up most of a section several hundred feet thick. It is a dark-gray rock, owing to the abundant clasts of dark chert, which make up far the greater part of the rock. Most of the chert is poorly rounded and is less than 1 cm in size. As is general throughout the formation, there are abundant well-rounded grains of quartz 0.5 mm in diameter, some muscovite, but no feldspar. Siltstone is abundant, perhaps more so than any other constituent, but it is generally poorly exposed. It consists of relatively thin beds, some parted by thin films of muscovite, but few showing any shaly fissility. The silt is almost all quartz, with a small amount of chert and randomly oriented flakes of muscovite. Some, despite its fine grain, shows excellent current bedding, emphasized by carbonaceous material.

The most conspicuous, though not the most abundant, constituent of the Valmy Formation, here as well as elsewhere, is a remarkably pure quartzite, some of which contains more than 99 percent silica. Beds of this rock as much as several scores of feet thick form prominent ledges and cliffs. The quartzite differs from the sandstone of the formation only in the paucity of chert grains; it is essentially all quartz. As in the sandstone, the largest grains, as much as half a millimeter across, are extremely well rounded; they are set in a matrix of smaller, more angular quartz grains, which in some rocks are badly crushed. The contrast in texture is such as to give the impression that the grain size distribution is bimodal. This impression is probably false, however, as there seems to be a continuous gradation from the well-rounded large grains down to silt-size ones. (See fig. 6.) This rock is so characteristic of the Valmy Formation as to be almost diagnostic. Similar rocks do occur in the Vinini, but far more sparsely than in the Valmy.

The chert of the Valmy ranges from dark gray, almost black, to very light gray. None of the red or green cherts found in the Shoshone Range, across Crescent Valley, have been seen in this area. All are thin bedded and appear aphanitic under the hand lens. Under the microscope the chert is seen to be almost all extremely fine silt-size grains of quartz, with scattered flakes of muscovite, most of which are not obviously oriented parallel to bedding. There is also some carbonaceous matter in some beds. Sporadic round grains of quartz, of the same size and degree of sphericity as those in the quartzite, are present in some specimens, though not in all. Many of the chert beds are veined with quartz. Very few radiolaria, such as are common in the chert of the Slaven Chert, have been observed in the Valmy.

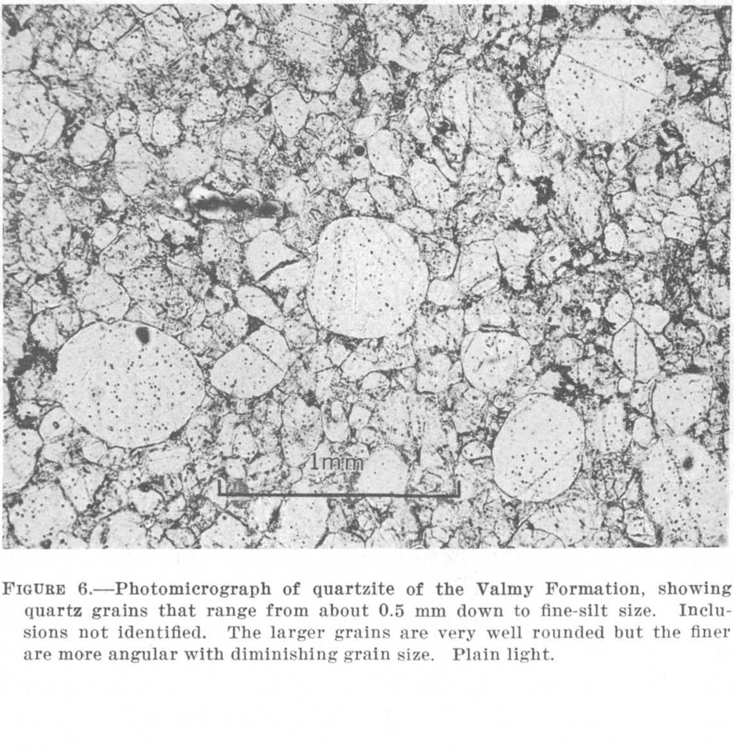

FIGURE 6.—Photomicrograph of quartzite of the Valmy Formation, showing quartz grains that range from about 0.5 mm down to fine-silt size. Inclusions not identified. The larger grains are very well rounded but the finer are more angular with diminishing grain size. Plain light.

Greenstone, in beds as thick as 150 feet, is present in the Valmy south of Cortez and in many thinner beds on Bald Mountain and north of Fourmile Canyon. None of these bodies preserves pillow structure such as is common in the Shoshone Range. All are highly altered and calcitized; their original composition cannot be accurately determined. Most show divergent granular textures but the ferromagnesian minerals have all been altered to chlorite and the feldspar to albite and calcite. Probably the rocks were originally basalts or andesites.

Limestone is very rare in the Valmy Formation, but a few lenses up to a few hundred yards long occur, chiefly closely associated with greenstones. The beds, which are as much as 10 feet thick but generally much thinner, are poorly defined. The limestones contain abundant clastic fragments of trilobite carapaces and shells of brachiopods and gastropods. None of these fossil fragments from this quadrangle has proved identifiable generically, though beds similar to the ones that these were found in have yielded a rich fauna in the Mount Lewis quadrangle (R. J. Ross, Jr., 1958). There is commonly an admixture of volcanic fragments. (See fig. 7.)

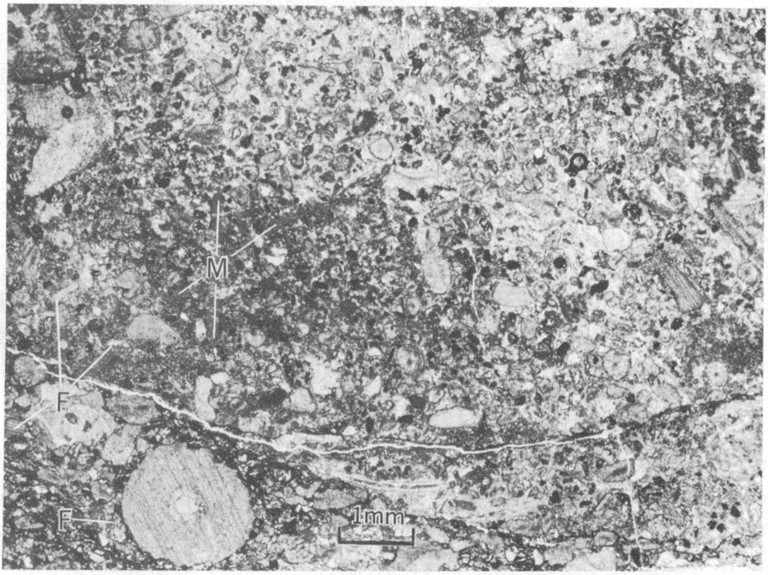

FIGURE 7.—Photomicrograph of limestone of the Valmy Formation. The rock is a clastic limestone with 80 percent fragments of trilobites, crinoids, brachiopods, and gastropods from 0.05 to 10 mm across and 20 percent volcanic fragments from 0.05 to 0.2 mm across. The calcitic shell fragments are very poorly sorted. The volcanic fragments resemble the adjacent pillow lavas and consist of feldspar laths (F) , now albite, and chloritized mafic phenocrysts (M), in a matrix stained with iron oxide. Plain light.

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As in other areas, the Valmy Formation is here so badly disrupted by faulting as to make impossible the determination of the original succession of the strata, except for local partial sections. A striking characteristic, already emphasized, is the unusual association of pure quartzite with greenstone, chert-bearing sandstone, and chert.

Diagnostic features.—All the formations of the western facies have in common a siliceous composition so that each in some respects resembles the others. Criteria for distinguishing them are far from diagnostic as to bodies of strata only a few tens of feet thick, except for the dark quartzite of the Valmy. Thin beds of similar quartzite are present in the Vinini, but beds as much as 40 feet thick have been here referred to the Valmy. Such a reference generally implies a like assignment for the conglomerate beds and for the thick greenstones. In other words, the coarser clastic rocks of the area have been classed in this report as Valmy, and many of the finer ones as Vinini, though the Valmy also contains a little shale and considerable siltstone.

The Valmy is distinguished from the Elder Sandstone by the facts that the Elder is everywhere notably feldspathic or even arkosic, and its chert beds are generally tan, yellow, or light gray, rather than dark gray as in the Valmy. The distinction from the Fourmile Canyon Formation is based on the abundance and thickness of the shaly beds of the Fourmile Canyon, which are notably greater than anything seen in the Valmy. Similarly, gray cherts thicker than a few scores of feet have been assigned to the Slaven Chert, which is almost free of greenstone, quartzite, and siltstone.

We would not, of course, insist that we have everywhere been consistent in the discrimination of the several formations we recognize in the area. Doubtless many small bodies of strata have been miscorrelated on the map (pl. 1), but we feel that we have been consistent in the assignment of all the larger masses. This confidence is supported insofar as the rather sparse paleontological evidence may be used to test it.

Conditions of deposition.—It is clear from the graptolite fauna that much of the Valmy Formation is of marine origin and more than likely all of it is. The unusual associations of clean quartzite with mixed quartz and chert sandstone, chert, and greenstone, however, suggest that the formation represents the accumulation of material from two sources. The one source, which furnished the very clean quartz sand, must clearly have been a terrain exposing a rather pure quartz sandstone of an earlier sedimentary cycle, for only resistate minerals are present and these are unusually well rounded. On the other hand, the chert grains in the fine conglomerates and chert-quartz sand resemble the cherts of the formation itself in their texture and mineral composition. Their angularity suggests short transport; probably they were locally derived.

The greenstones of this quadrangle have no fossils closely associated with them, but in the nearby Mount Lewis quadrangle a rich fauna of trilobites and gastropods has been found in direct association with a pillow lava of this formation (R. J. Ross, Jr., 1958). That fauna undoubtedly lived in the photic zone of the sea, a shallow-depth environment. Presumably a similar depth is not excluded for the volcanic eruptions represented in this area.

Current bedding is common, and although there is no lack of load markings at the base of several of the sands and quartzites, there seems no reason to suppose that the cherty sandstones and siltstones were deposited at an unusually great oceanic depth.

Perhaps all these characteristics are consistent with origin of the formation in an area to which clean quartz was being continually supplied by far-traveling currents but in which local welts were subject to erosion to furnish chert fragments to the same sea. When the local welts were reduced by erosion the quartz sand deposition dominated; when the welts were uplifted, the cherty sands and conglomerate were formed. Intermittent volcanic eruptions perhaps supplied much of the silica for the chert of the formation, possibly in silled depressions with an anaerobic regimen, for many cherts are black with carbon.

Age and correlation.—The only fossils found in the Valmy Formation of the Cortez quadrangle were graptolites and a few fragments of the crustacean, *Caryocaris*. These were examined by R. J. Ross, Jr., of the U.S. Geological Survey, and by Mr. Ross and W. B. N. Berry of the University of California, Berkeley, in conjunction. Their diagnoses of the collections are presented in table 2.

As shown in table 2, the graptolites have been assigned by Messrs. Ross and Berry to the biozones 4 to 11 of the British Ordovician as classified by Elles and Wood (1914; fig. 8 this report). This range corresponds with Lower and Middle Ordovician, as generally understood in America, where zones 1–3 of the Elles and Wood scheme are considered Cambrian. This is the same range as is given to the Valmy in the type locality at Antler Peak (Roberts, 1951), but probably somewhat less than that represented by the formation in the northern Shoshone Range, where it probably embraces some Upper Ordovician beds (Gilluly and Gates, 1965).

TABLE 2.—*Graptolites of the*

[Srm, Roberts Mountains Limestone; Ovi, Vinini Formation; Sf, Fourmile Canyon Formation; Ov, 2, determined by

Field colln. No.	2	6	12	13	19	20A	22	24	25	27	30	51	52
Formation	Srm		Ovi			Sf	Ovi	Sf				Srm	Ovi
Zones of Elles and Wood (1914)	22–24	22–24	8–11	11	Late MO	S	10	16–21	O or S	S?	17–21	S	10
U.S. Geol. Survey reference No.	D65(SD)	D66(SD)	D392(Co)	D393(Co)	D539(Co)	D92(SD)	D394(Co)	D68(SD)	D69(SD)	D70(SD)	D71(SD)	D95(SD)	D395(Co)
Monograptus sp.	1	1										1	
cf. *M. regularis* Törnquist.													
aff. *M. convolutus* Hisinger													
cf. *M. vomerinus*											?1		
cf. *M. turriculatus*											1		
cf. *M. pandus* (Lapworth)		1											
aff. *M. varians* Wood						?1							
Trigonograptus ensiformus (Hall)													
Orthograptus sp.							?1						?1
aff. *O. whitfieldi*					1								
calcaratus var.				?1									
Glyptograptus sp. or *Orthograptus* sp.													
sp. (probably n. sp.)						1	1	1	1				?1
cf. *G. teretiusculus* (Hisinger)			1	1									
cf. *G. serratus*								1					
aff. *G. euglyphus* var. *pygmaeus*													
altus Ross and Berry													
Amplexograptus sp.													
cf. *A. perexcavatus* Lapworth													1
aff. *arctus* Elles and Wood													
Diplograptus sp.								?1					
aff. *D. foliaceus* Murchison													
Climacograptus sp.			1	1		1	1		1	1			1
sp. (small)													
sp. (twisted)													
bicornis (Hall)							1						
cf. *C. spiniferus* Ruedemann				1									
cf. *C. scalaris* (Hisinger)								1					
cf. *C. rectangularis* (McCoy)?								?1					
aff. *C. medius* Törnquist										?1			
cf. *C. scharenbergi* (Lapworth)													
eximius Ruedemann													
cf. *C. parvus* (Hall)													
Dicellograptus cf. *D. intortus* (Lapworth)													
aff. *D. divaricatus* var. *salopiensis* Elles and Wood													
sp. or *Dicranograptus* sp.				1									
sp.							1						

Cortez quadrangle, Nevada

Valmy Formation; Se, Elder Sandstone. 1, determined jointly by R. J. Ross, Jr., and W. B. N. Berry; R. J. Ross, Jr.]

57	58	62	63	64	65	67	68	69	70	83	84	86	101	103	CSM 3	CSM 4	(1)
Srm		Ov								Ovl					Sf	Ovl	Se
S?	S?	9–10	7	7–10	10 (11?)	8 or higher	2–3	O?	2–4	10	9–10 (?)	7–10	9–10	8? or S	S	6–13	----
D93(SD)	D94(SD)	D444(Co)	D445(Co)	D446(Co)	D447(Co)	D482(Co)	D483(Co)	D484(Co)	D485(Co)	D486(Co)	D487(Co)	D488(Co)	D556(Co)	D557(Co)	D175(SD)	D782(Co)	----
?1	?1	----	----	----	----	----	----	----	----	----	----	----	----	----	2	----	1
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TABLE 2.—*Graptolites of the*

[Srm, Roberts Mountains Limestone; Ovi, Vinini Formation; Sf, Fourmile Canyon Formation; Ov
2, determined by

Field colln. No.			12	13	19	20A	22	24	25	30	30	51	52
Formation	Srm		Ovi			Sf	Ovi	Sf				Srm	Ovi
Zones of Elles and Wood (1914)	22–24	22–24	8–11	11	Late MO	S	10	16–21	O or S	S?	17–21	S	10
U.S. Geol. Survey reference No.	D65(SD)	D66(SD)	D392(Co)	D393(Co)	D539(Co)	D92(SD)	D394(Co)	D68(SD)	D69(SD)	D70(SD)	D71(SD)	D95(SD)	D395(Co)
Glossograptus hincksii Hopkinson	----	----	1	----	----	----	----	----	----	----	----	----	----
cf. *hincksii* Hopkinson	----	----	----	----	----	----	----	----	----	----	----	----	----
Cryptograptus tricornis (Carruthers)	----	----	----	----	----	----	----	----	----	----	----	----	----
schaferi (Lapworth)	----	----	----	----	----	----	----	----	----	----	----	----	----
sp.	----	----	?1	----	----	----	----	----	----	----	----	----	----
Didymograptus extensus (Hall)	----	----	----	----	----	----	----	----	----	----	----	----	----
sp.	----	----	?1	----	----	----	----	----	----	----	----	----	----
sp. or *Tetragraptus* sp.	----	----	----	----	----	----	----	----	----	----	----	----	----
Tetragraptus n. sp. aff. *quadribrachiatus*	----	----	----	----	----	----	----	----	----	----	----	----	----
fruiticosus (Hall)	----	----	----	----	----	----	----	----	----	----	----	----	----
sp.	----	----	----	----	----	----	----	----	----	----	----	----	----
Clonograptus sp.? or *Didymograptus* sp.?	----	----	----	----	----	----	----	----	----	----	----	----	----

[1] As determined in Mount Lewis-Crescent Valley quadrangles (Gilluly and Gates, 1965, table 4); no

This age implies rough contemporaneity with the Vinini Formation of the Roberts Creek Mountains (Merriam and Anderson, 1942), and with the Comus Formation of the Edna Mountains area (Ferguson, Roberts, and Muller, 1952), both of which are western facies formations. It also implies essential contemporaneity with the Pogonip Group and Eureka Quartzite of the eastern facies (Nolan, Merriam, and Williams, 1956). The paleogeographic implications of these correlations are discussed following the description of the other formations of this area that are concerned.

VININI FORMATION

Name.—The Vinini Formation was named by Merriam and Anderson (1942) from Vinini Creek, on the northeast flank of the Roberts Mountains, about 15 miles east-southeast of this area. In the type locality the formation consists of quartzite, gray sandy limestone, sandy siltstone, chert, clay shale, organic shale, and a few andesitic volcanic rocks. Although the rocks referred to the Vinini Formation

Cortez quadrangle, Nevada—Continued

Valmy Formation; Se, Elder Sandstone. 1, determined jointly by R. J. Ross, Jr., and W. B. N. Berry R. J. Ross, Jr.]

57	58	62	63	64	65	67	68	69	70	83	84	86	101	103	CSM 3	CSM 4	(1)
Srm		Ov								Ovi					Sf	Ovi	Se
S?	S?	9–10	7	7–10	10 (11?)	8 or higher	2–3	O?	2–4	10	9–10 (?)	7–10	9–10	8? or S	S	6–13	----
D93(SD)	D94(SD)	D444(Co)	D445(Co)	D446(Co)	D447(Co)	D482(Co)	D483(Co)	D484(Co)	D485(Co)	D486(Co)	D487(Co)	D488(Co)	D556(Co)	D557(Co)	D175(SD)	D782(Co)	--------
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fossils from Cortez area.

in the Cortez quadrangle differ in minor respects from those of Vinini Creek, we consider these differences insufficient to justify establishing a new formation.

Distribution and topographic expression.—Rocks here assigned to the Vinini are exposed in four areas in the Cortez quadrangle: (1) In a belt paralleling the Roberts thrust across the north end of the Toiyabe Range, just southwest of Cortez Canyon; (2) on the divide between the heads of Mill Canyon and Willow Creek, and thence extending southward into the head of Horse Canyon; (3) along the western slopes of the Cortez Mountains from the foothills almost to the range divide on both sides of the road to Horse Creek Valley that crosses the range about 5 miles south of Cortez; and (4) in the southeast corner of the quadrangle, on either side of Fye Canyon.

In all these areas except at the divide between Willow Creek and Mill Canyon, erosion of the formation molds a rolling topography with a few inconspicuous ledges, but the thick ledges of brecciated chert on the ridge crest east of Mill Canyon form very rugged and difficult cliffs, among the most conspicuous in the quadrangle.

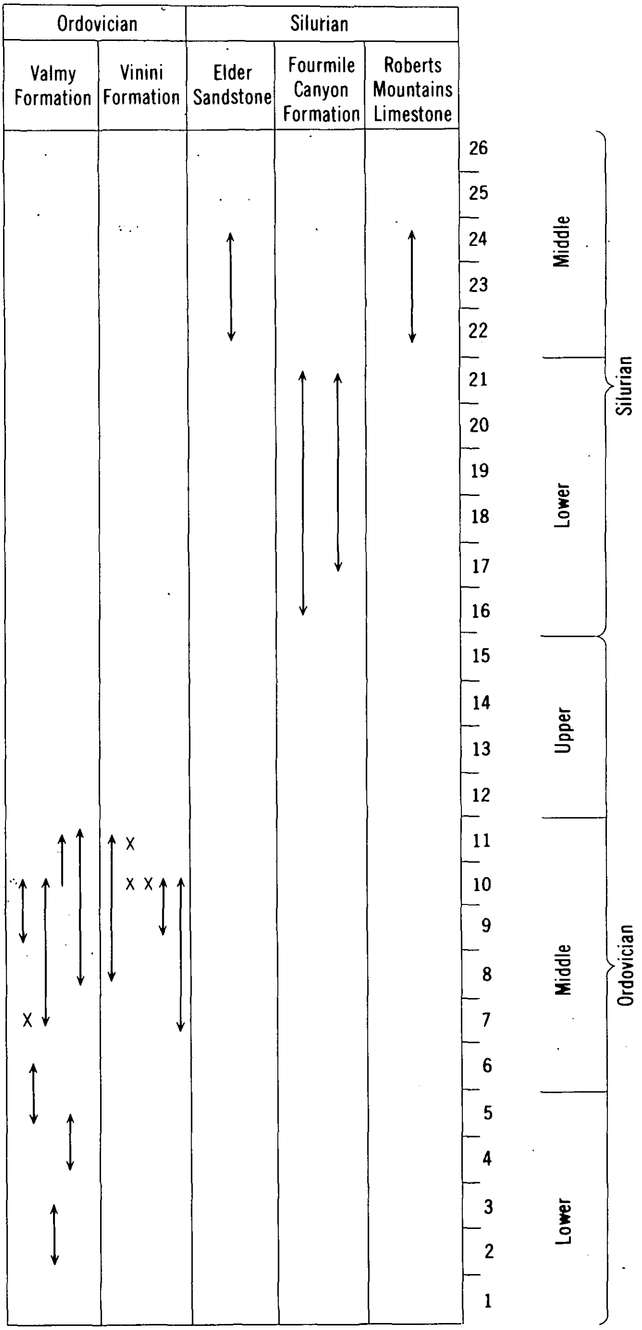

FIGURE 8.—Diagram showing the graptolite zones of Elles and Wood (1914) found in the formations of the Cortez quadrangle. Only diagnoses restricted to brackets of five zones or less are here indicated; less narrowly restricted ranges in table 2 ignored. Zones in Elder Sandstone as determined in Mount Lewis-Crescent Valley quadrangles (Gilluly and Gates, 1965, table 4); no fossils from Cortez area.

Stratigraphy.—Wherever exposed in this area—and in fact in all areas where it has thus far been recognized—the Vinini Formation is resting on a fault surface; the original depositional base is unknown. Furthermore there is everywhere notable internal shearing of the fault blocks so that it has proved impossible to work out a stratigraphic succession applicable beyond very local areas. We have been unable to recognize mappable members that would correspond in any way with the subdivisions described (but not mapped) by Merriam and Anderson (1942) in the type locality. The upper limit is everywhere a fault or an erosion surface so that nothing is known of the original top of the formation nor of its relation to the several Silurian formations recognized. We have accordingly made no effort to arrange the descriptions of the rocks that compose the formation in anything like a chronological sequence; the rock varieties are described below in the order of our impression of their decreasing abundance, but exposures are not continuous enough, in absence of distinctive marker beds, for us to support our impression by actual measurements of sections.

The principal constituents of the formation in this area are siltstone, shale, siliceous shale, sandstone, chert, and quartzite. There are a few thin layers of greenstone in the southern part of the Cortez Mountains, but most of the greenstones in this quadrangle are associated with strata that seem to us to resemble those of the Valmy Formation more than those of the Vinini, and accordingly have been mapped with that formation.

Much more than half of the exposures of the Vinini in this area are of fine-grained clastic rocks—either sandy siltstone, siltstone, or poorly fissile shale. Most of these are notably carbonaceous and very dark gray to black on fresh fracture, but they weather to light-gray hues beneath a surficial film of iron stain. Most of these rocks show extremely fine grains under the hand lens; only a few are truly aphanitic. The microscope shows that even the finest grained of these rocks contain notable quantities of quartz, in angular silt-size particles; muscovite is subordinate. Doubtless this fact accounts for the irregular fracture of nearly all these rocks and the scarcity of good shaly fissility.

Despite the fine grain of the siltstones, many show excellent current bedding, with the laminations emphasized by carbonaceous material or by minute rhombs of dolomite. Some of the siltstones contain as much as 40 percent of dolomite rhombs, though most of them are free from carbonate. Many resemble argillite and were so called in the field. They are highly siliceous and cemented by silica so that they break with conchoidal fracture like chert, but under the microscope are seen to be quartzite siltstone. Such rocks are not confined to this formation but have also been seen in the Fourmile Canyon Formation.

The sequences of siltstone and shale are interrupted by interbedded sandstone, chert, and quartzite, generally in sequences of a few feet or at most a few tens of feet thick. The sandstone, nearly all in beds a few inches thick, ranges in color on fresh fracture from light gray to nearly black, depending on the relative proportions of the constituent grains of quartz and of chert. The light-gray sandstone contains well-rounded grains of quartz as much as 0.4 mm in diameter in a matrix of finer grained quartz and poorly rounded or subangular grains of chert. Some beds contain a few fragments of siltstone, but no true graywacke (in the sense of having abundant clay in the matrix) was seen. In a score of thin sections only a few grains of plagioclase were seen and none of potassium feldspar. The darker gray sandstone contains a higher proportion of chert fragments, but even the darkest contains abundant well-rounded grains of quartz. The cement is generally dolomitic.

There are a few thin beds of conglomerate in the formation. These consist of poorly rounded to angular fragments of chert as much as 2 cm across, in a matrix of finer fragments of chert and quartz. Both these rocks and the cherty sandstones appear to have been largely supplied by local sources; for the chert shows little abrasion and could have been furnished by nearby rocks.

Chert, generally black or very dark gray from contained carbonaceous matter, forms sporadic ledges that may reach several scores of feet in thickness. Generally the chert is in beds ½–5 inches thick, with shaly partings a fraction of an inch thick. The microscope reveals nothing but quartz and a few flakes of muscovite. No radiolaria were seen in the rocks of this area, although they have been found in the Vinini of the Roberts Mountains (Merriam and Anderson, 1942, p. 1696).

Quartzite, almost identical with that so prominent in the Valmy Formation, is represented in the Vinini as mapped by us, but in far less amount and in thinner beds, rarely more than 20 feet thick. It should be noted, of course, that our classification is arbitrary, being based on the distinctly greater abundance and thickness of quartzite in the Valmy of the type area in the Galena Range near Antler Peak than in the Vinini of Vinini Creek, Roberts Mountains. Inasmuch as the two formations contain the same kinds of rocks and differ only in their respective proportions, we have felt justified in discriminating between them here on this basis, even though the risk of circular reasoning with respect to their provenance and depositional relations is thereby introduced. In support of our decision, however, is the fact that the thick quartzites locally are also associated with greenstones as they are in Antler Peak and the northern Shoshone Range (Roberts, 1951; Gilluly and Gates, 1965). Greenstone is present in the type Vinini, but much less abundantly than in recognized Valmy elsewhere.

Diagnostic features.—The Vinini has been recognized as distinct from the Valmy primarily on the basis of a relatively higher proportion of finer grained rocks. It is recognized that almost any rock of either formation can be matched with one of the other; we have chosen to emphasize the relation of some lithic associations with those of the Valmy because of the prominence of quartzite and greenstone relative to siltstone and shale, and of others with the Vinini because of the converse relation. Although this distinction is arbitrary, we feel that in most associations of strata more than a few hundred feet thick there is little question.

The Vinini is readily distinguished from all the other formations of western facies—the Elder, Fourmile Canyon, and Slaven—by the abundance of cherty sandstone and the sporadic beds of clean quartzite, of which there are no counterparts in any western formations other than the Valmy.

Thickness.—Because of the faulted base and top and the internal faulting of the formation wherever mapped in this area, we have made no attempt to measure the thickness accurately. Our estimate, though based only on outcrop width, relief, and general attitudes of the rocks, is that at least 6,000 feet and perhaps 10,000 feet of strata is represented in the quadrangle.

Conditions of deposition.—The fauna of the Vinini indicates a marine deposit, and the abundant crossbedding suggests that moderate currents prevailed. There is little evidence of graded bedding and if turbidites occur they are rare. The composition and bedding suggest an origin similar to that of the Valmy and probably in a closely associated site of deposition. It is indeed likely that the two formations graded into each other as they were deposited. This matter is further discussed in connection with the paleogeographic implications.

Age and correlation.—The only identifiable fossils found in the Vinini Formation of this area have been graptolites and phosphatic brachiopods. The graptolite collections have been examined by Messrs. Ross and Berry, jointly, or by Mr. Ross alone, and their diagnoses are recorded in table 2, together with their interpretation of the probable correlations with the numbered zones of the British Ordovician as established by Elles and Wood (1914).

The conclusion of Messrs. Ross and Berry is that the Vinini of this area contains correlatives of zones 7–11 of Elles and Wood, corresponding to most of the Middle Ordovician as usually classified in America. No fossils of the lower zones represented in the type locality (Merriam and Anderson, 1942, p. 1695) have been identified from this quadrangle.

This age assignment implies that the Vinini here recognized is essentially of the same age as the upper part of the Valmy Formation as represented in this quadrangle. This conclusion is not at all surprising in view of the many stratigraphic similarities of the two formations. It also implies correlation with the upper part of the Pogonip Group and with the Eureka Quartzite of the Eureka district (Nolan, Merriam, and Williams, 1956, p. 25, 36). The possible paleogeographic implications of these correlations are discussed on pages 62–64.

SILURIAN SYSTEM

FOURMILE CANYON FORMATION

Name.—The rocks exposed on both sides of Fourmile Canyon, near the northeast corner of the quadrangle, differ so much from those of the previously recognized formations of the general region that they are here newly designated as the Fourmile Canyon Formation.

Distribution and topographic expression.—The Fourmile Canyon Formation crops out over an area of nearly 10 square miles in the drainage areas of Fourmile and Mill Canyons, and the unnamed stream next northeast of Fourmile Canyon. The rocks make up a thrust slice that rests directly on the Roberts thrust along the east wall of Mill Canyon and is overridden at the north by a higher slice of the Valmy Formation and at the south by one of the Vinini. Another small mass referred to the formation crops out south of Cortez Canyon, on the opposite side of the window in the Roberts thrust.

The Fourmile Canyon Formation is chiefly thin bedded and its rocks break into slabs and splinters that mantle most slopes with smooth aprons of scree, interrupted by low cliffs supported by the few more massive beds. As a result, many slopes cut on the formation are very difficult to traverse because of the poor footing.

Stratigraphy.—Both upper and lower contacts of the Fourmile Canyon Formation are mechanical, so that nothing is known of its original depositional relations.

The principal rocks of the formation are chert, siltstone, argillite, and shale, but there are also a few thin beds of fine-grained sandstone. We have found no carbonate rocks in the formation, but there is some dolomitic material in the siltstone and dolomitic nodules in some of the chert. On fresh fracture nearly all the rocks are very dark gray to almost black. The finer grained chert and shale retain their dark hue on weathering, but most of the siltstone weathers to a light tan and some of the thin shale units to a pale pinkish yellow, because of their contained pyrite.

The lower part of the formation as exposed consists chiefly of aphanitic chert and shaly siltstone, some of which splits parallel to bedding and some with a conchoidal fracture. There are a few beds of current-bedded siltstone that are as much as 10 feet thick even low in the formation, but they become more common on the higher slopes. It did not, however, seem feasible to recognize distinct members anywhere in the area. The only truly fissile shale recognized forms belts a few feet thick, perhaps as much as 20 feet thick in some beds high in the formation, as exposed on the divide between Mill and Fourmile Canyons.

The siltstone and chert interfinger on a scale of feet or even on one of fractions of an inch, both along and across the bedding. Many of the siltstone beds show very conspicuous current bedding. A few show grading, but these are subordinate. (See fig. 9.)

The chert is aphanitic quartz, colored gray by abundant organic matter. It closely resembles the chert of the Vinini and Slaven, and in the canyon just north of Fourmile Canyon is so abundant as to raise the doubt that some Slaven Chert may here have been mapped

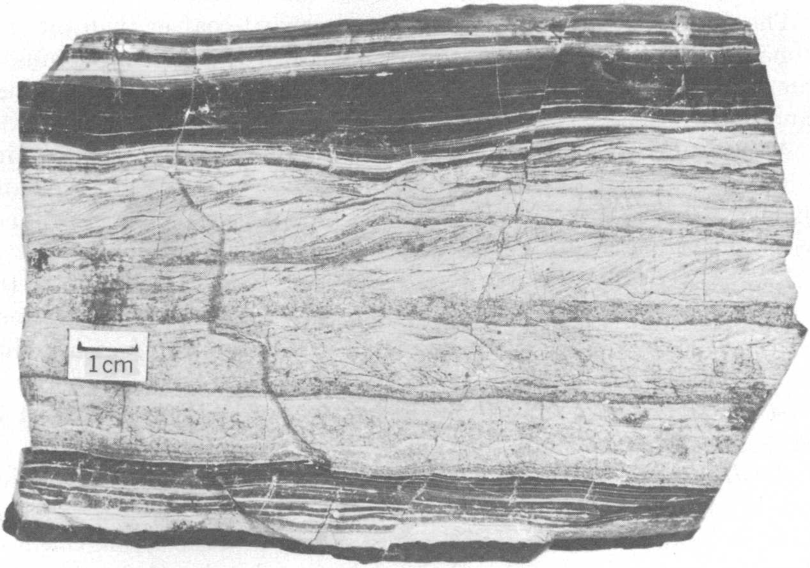

FIGURE 9.—Dolomitic siltstone of the Fourmile Canyon Formation, showing chert parting at base and near top and strong current bedding. The dark partings are finer grained and more carbonaceous than the body of the rock.

as Fourmile Canyon. As the map shows we tentatively consider this chert a part of the Fourmile Canyon Formation. It is in beds ½–8 inches thick and contains nodules of dolomite ⅛–4 inches across. Such nodules have not been recognized in other chert bodies of the region. The chert seems to pass gradationally into extremely fine grained siltstone. Much of the siltstone is silica cemented and breaks with conchoidal fracture so that it resembles an argillite—in the sense of Grout (1932)—and was so considered in the field. There is, however, very little mica and no chlorite or other clay mineral visible under the microscope.

The siltstone is composed of quartz (60–75 percent), dolomite rhombs (20–40 percent), muscovite (5 percent), and orthoclase, much of it in cleavage fragments (10–15 percent). There is also a little carbonaceous material and some pyrite. The maximum grain size appears less than 0.04 mm and much of the material is less than 0.02 mm in diameter. A little of the quartz appears rounded but most is angular as are the dolomite rhombs and the orthoclase splinters. This siltstone greatly resembles some beds in the Vinini Formation but is here much more abundant.

There are a few beds of true shale, with excellent fissility roughly parallel to bedding, and from these have come most of the graptolites which are the only fossils found. None of these shale beds seems calcareous or dolomitic, as so many of the siltstone beds are.

The few sandstone beds are merely somewhat coarser than the siltstone, and like them contain chiefly quartz with subordinate muscovite, orthoclase, and dolomitic cement. All are very fine grained sandstone.

As noted earlier, except for a suggestion that the formation contains a higher proportion of chert in the lower part and of sandstone and shale in the upper, the several varieties of beds seem to interfinger without noticeable system both along and across the bedding.

Thickness.—The lack of marker beds and the irregularity of the attitudes of the formation throughout its area of outcrop preclude accurate measurement of thickness. The nearly 3,000 feet of relief and the considerable area covered by the formation, which locally at least has fairly steep dips, imply a thickness of at least 4,000 feet; an estimate of 6,000 feet or more is not unreasonable.

Conditions of deposition.—The graptolites found in the formation indicate its marine origin and the fine grain of the rock suggests an offshore locale. Widespread current bedding and the arrangement of the carbonaceous material and the dolomite rhombs of the siltstones show that the accumulation was of discrete grains and not by large-scale slumping. The minor examples of graded bedding are no more necessarily indicative of turbidite deposition than are many stream-laid beds and we see no indication of unusual depth of the basin of deposition.

Age and correlation.—The only fossils found in the formation are graptolites. These were referred to Messrs. Ross and Berry, whose diagnoses are reported in table 2. Although a narrow zonal assignment is not possible from the material at hand, Messrs. Ross and Berry regard the age as Early Silurian, somewhere between zones 16 and 21 of the classification of Elles and Wood (1914). No other Early Silurian formations have been recognized in the general region, but it is interesting to note that the somewhat younger Elder Sandstone, next to be described, is also noteworthy in containing a considerable amount of potassium feldspar. The Elder is coarser, on the average, than the Fourmile Canyon Formation, but there seems to be a strong possibility that both formations were deposited in the same basin and were perhaps not very distant from each other when formed. Inasmuch as the upper contact of the Fourmile Canyon Formation is mechanical, it is indeed possible that the slight coarsening of grain of the Fourmile Canyon Formation suggested in the type locality may have continued upward so that the Elder Sandstone originally succeeded and overlay the Fourmile Canyon in its area of deposition.

ELDER SANDSTONE

Name.—The Elder Sandstone was named from Elder Creek, in the Shoshone Range, about 5 miles northwest of the Cortez quadrangle (Gilluly and Gates, 1965).

Distribution and topographic expression.—The only outcrops of the Elder Sandstone in this area are (1) in the northwest corner, where a thrust sliver of the formation covers about 60–80 acres in the immediate hanging wall of the Roberts thrust and also overriding part of a similar block of Valmy, and (2) low on the eastern slope of the Toiyabe Range at the south border of the map area. The formation is topographically inconspicuous, but is set apart from its neighbors by its notably lighter yellow-tan hue, identical with that in the type locality.

Lithology.—Only a few score feet of the formation is present in this quadrangle, whereas several thousand feet crops out in the northern Shoshone Range farther northwest. The rocks represented are chiefly fine-grained sandstone, with a little light-colored chert that weathers yellow. The sandstone is notable for its content of feldspar, which sets it apart from the sandstone of the Valmy, Vinini or Slaven Formations and allies it with the Fourmile Canyon. It is not an arkose, but 10–20 percent of the grains are feldspar, as is recognizable under the hand lens; under the microscope, the feldspar is seen to be potassic.

Some beds contain a little muscovite, which also is visible with the hand lens, but the main constituent is quartz. Some tuffaceous beds occur in the formation near Elder Creek, so that it is inferred that the feldspar and muscovite were perhaps derived from siliceous ash that fell into an area receiving normal quartz sand deposits. The rock is less well cemented than much of the sandstone of the Vinini and Valmy, and is distinguishable from these rocks by the distinctly more yellowish tones on the weathered surface, as contrasted with the brownish hues of the Ordovician rocks.

The Elder also contains considerable very fine sandy siltstone as well as the dominant silty sandstone. Some of the siltstone is composed of 70–80 percent quartz, 15–25 percent potassium feldspar, and about 5 percent muscovite, with a little albite. Ghosts of pumice shards also occur; the rock thus records both pyroclastic and normal sedimentation.

The minor chert of the Elder Sandstone also appears to contain a pyroclastic fraction as it contains as much as 20 percent sericite and 10 percent potassium feldspar. There are also a few beds of limy siltstone—a black laminated carbon-rich rock composed of 70 percent calcite, 20 percent quartz, 5 percent potassium feldspar, 2 percent muscovite, and 3 percent authigenic pyrite, in grains as much as 1 mm across.

The current bedding, ripple marks and similar features indicate current transport, but absence of fossils other than graptolites gives no other clue to depositional conditions.

Age and correlation.—Fossils are extremely scarce in the Elder Sandstone and none were collected in the Cortez quadrangle. Those found in the Mount Lewis and Crescent Valley quadrangles are graptolites of Middle Silurian age. (See table 2.) These have been recorded for comparison with the graptolitic faunules collected from the Cortez area.

Although the fossil evidence does not suffice to show precise contemporaneity of any two of the Silurian formations, the Elder Sandstone and Roberts Mountains Limestone probably are approximately contemporaneous, and owe their distinctive features to differences in environment within the same depositional basin. It has already been suggested that the slight tendency toward upward coarsening of the Fourmile Canyon Formation may have continued so that the somewhat younger Elder Sandstone may once have been deposited in the same site as the Fourmile Canyon. The general lithologic similarity, except for grain size, of the two formations would be consistent with such a sequence.

DEVONIAN SYSTEM

SLAVEN CHERT

Name.—The Slaven Chert was named from its exposures in Slaven Canyon, in the northern Shoshone Range, on the boundary between the Mount Lewis and Crescent Valley quadrangles (Gilluly and Gates, 1965).

Distribution and topographic expression.—In the Cortez quadrangle, the only two outcrops of the formation are in the Toiyabe Range. The larger one forms an irregular belt averaging nearly 2 miles in width that extends diagonally northwestward across the range from the east side at the south border of the map area to the west side near the north border of T. 25N., R. 46 E. Most of this belt is a thrust sliver between the Roberts thrust below and a higher thrust within the upper plate of the Roberts, on which the Valmy Formation has come to overlie the Slaven. The second outcrop is in the hanging wall of the Roberts thrust at the north end of the range just south and southwest of Cortez Canyon, and structural relations are comparable.

Although in both these exposures the Slaven Chert makes some bold cliffy outcrops, for the most part the slopes it underlies are relatively smoothly rounded because of the abundant scree furnished by the thin-bedded chert that composes most of the formation.

Lithology.—As the name implies, the Slaven Chert is composed predominantly of chert, with very minor amounts of thin-bedded sandstone and shale. The chert is dark gray to almost black on fresh fracture and weathers with a brownish rind. Generally it is in beds ½–4 inches thick, highly contorted and broken so that the local attitude of an individual bed gives no clue as to the overall attitude of the formation. (See fig. 10.) The beds are generally separated by very thin films of shale and part readily. They are also closely jointed and break up into abundant angular fragments, which form great streams of scree that mask the slopes below.

Individual outcrops of the chert cannot be distinguished from those of chert beds in the Valmy and Vinini Formations, but in neither of these formations does chert form unbroken sequences more than 200 or 300 feet thick and most sequences are much thinner. Thus in most exposures of 200 or 300 feet of beds, the Valmy and Vinini Formations show interbeds of other rock varieties, such as greenstone, quartzite, cherty sandstone or siltstone, in beds several tens or scores of feet thick. Such a wide variety of rocks is not found in the Slaven, nor do the sparse interbeds of sandstone and siltstone it contains form sequences more than a few feet thick. There is no quartzite in the Slaven, nor cherty sandstone. The few sandstone beds commonly

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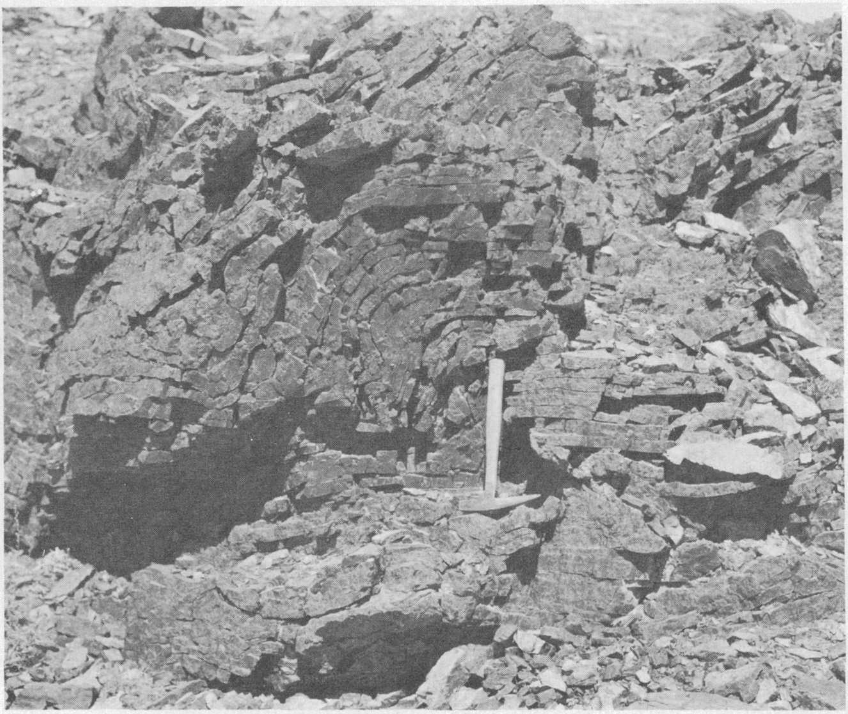

FIGURE 10.—Outcrop of chert of the Slaven Chert, southwest of Cortez Canyon. Both the thickness and the contortion of the bedding shown in this outcrop are representative of many other outcrops in the area.

are medium grained and rather loosely cemented with calcite, some are true graywackes with fine rock fragments in a sericitic groundmass, and many contain conodonts and ostracodes that are visible with a hand lens.

There is, however, more limestone in the Slaven Chert of the Cortez quadrangle than there is in the type locality of the formation. In the area southwest of Cortez Canyon there are several interbeds of clayey limestone, some several scores of feet thick. These beds are distinguishable from the Wenban Limestone only by their associated chert and sandstone beds. They resemble some limestone beds in the Slaven Chert near the Greystone barite deposit on Cooks Creek in the Mount Lewis quadrangle, and like those, contain brachiopods (Gilluly and Gates, 1965). The fossils collected in the Cortez quadrangle are not identifiable; some of those from the Greystone barite deposit are *Halorella*.

As in many other places in the general region (K. B. Ketner, in Gilluly and Gates, 1965) the Slaven Chert is here the host for several large replacement bodies of barite; the largest seen is high on the southeast slope of Bald Mountain.

In all exposures in this area both upper and lower contacts of the Slaven Chert are mechanical. The intense local contortion and generally poor exposures, together with the lack of recognized marker beds, preclude an accurate estimate of the thickness of the formation represented. The considerably larger exposures in the Shoshone Range are also not suitable for accurate measurement, but certainly must embrace several thousand feet of strata. Perhaps a thousand feet is the greatest thickness demanded by any single structural block in the Cortez quadrangle, but nevertheless, in view of the lack of marker beds, the true thickness here may be as great as that in the Shoshone Range.

Age and correlation.—No identifiable fossils were collected in the rocks here correlated as Slaven Chert, so that nothing can be added to the information obtained in the Shoshone Range, whence all the fossils are referable to a Middle Devonian age (Gilluly and Gates, 1965). Such an age implies contemporaneity of deposition with some part of the Wenban Limestone of the Cortez quadrangle and with the upper part of the Nevada Formation and lower part of the Devils Gate Limestone of the Eureka region (Nolan, Merriam, and Williams, 1956, p. 46–49, 50–52).

None of these formations of the eastern facies contain chert like that of the Slaven, and the Slaven contains only local beds of limestone that suggest similarity in depositional conditions with these dominantly carbonate formations. The Slaven Chert of this area apparently was deposited in an environment wholly different from that of the Wenban Limestone; this suggests that the movement on the Roberts thrust that has brought the two formations into contact was very large. The intercalations of limestone in the chert of this area indeed suggest facies convergence between the Devonian rocks of the two plates of the Roberts thrust, but the convergence becomes marked only in the northern tip of the Sulphur Springs Range, 20 miles to the east, where chert resembling that of the Slaven is interbedded through a section several hundred feet thick with limestone like that of the Wenban Limestone (J. Fred Smith, Jr., oral commun., 1961). These occurrences suggest that the minimum travel of the Roberts thrust is at least equal to the breadth of the belt of windows west of the Sulphur Springs Range—a distance of at least 50 miles.

TRACE ELEMENTS IN THE SEDIMENTARY ROCKS

As part of the U.S. Geological Survey's general geochemical inventory, a considerable number of samples of the sedimentary formations were analyzed by semiquantitative spectrography. The results pertaining to both siliceous and carbonate facies are shown in table 3. The most noteworthy data are the relatively high contents of titanium, barium, manganese, zirconium, and vanadium in the western facies, and of strontium in the calcitic rocks of the eastern facies.

PALEOGEOGRAPHY PRIOR TO THE ANTLER OROGENY

Regional relations show rather conclusively that a major mountain-building episode—the Antler orogeny of Roberts (1949)—took place in central Nevada in Early Mississippian time (Roberts and others, 1958). This was the date of formation of the Roberts thrust which so drastically telescoped the formations just described. It is of interest to compare these formations, in order to reconstruct, if possible, the geography of Cambrian to Devonian time during which they were deposited.

The amount of telescoping of the facies clearly has been at least of the order of the width of the belt of windows now known in the Roberts thrust and may have been even greater. Of course there may have been some thinning of the upper plate during the sliding so that it now covers a wider area than its rocks did when they were deposited but such a spreading out of the upper plate, even if it took place, would require only a minor correction to the original statement of this paragraph.

The generally finer grain of the Vinini as compared with the Valmy can hardly be considered as more than a faint suggestion of a facies transition from west to east in the siliceous facies toward the carbonate facies. It seems reasonable that several miles must have intervened between the realms of deposition of the finest grained and most carbonate rich of the Vinini beds and any of the limestones of the Pogonip Group of the eastern facies. The overlap of the Eureka downward across the Lower Ordovician and highest Cambrian beds between Eureka and Cortez suggests a possible removal by erosion of former transitional beds from an axis at and west of Cortez.

The similarity between Valmy and Vinini except for grain size (or rather, except for the relative abundance of coarser and finer facies) suggests that they were deposited in the same basin and merely represent dominantly coarser and dominantly finer facies, respectively, of a single deposit. The eastern edge of the basin in which these beds were laid down must have been at least as far west as the Reese River Valley (see fig. 1) and may have been even farther west.

The composition of Valmy and Vinini suggests two sources; one a terrane supplying essentially unmixed quartz, of which the coarser fraction was remarkedly well-rounded, implying a polycyclic history,

TABLE 3.—*Trace-element composition of formations of siliceous and carbonate facies*

[Semiquantitative spectroscopic analyses, in grams per metric ton, by P. R. Barnett (siliceous facies) and Uteana Oda (carbonate facies). For each formation, values in top line are maximums; middle line, averages; bottom line, minimums. Where only 1 value appears, it is the limit of sensitivity of the method]

Formation	Number of analyses	Ti	Ba	Sr	Mn	Zr	V	Cu	Ni	Pb	Cr	B	Co	Y
Siliceous facies														
		7,000	2,000	150	>10,000	700	200	100	150	15	70	100	30	20
Valmy	12	1,140	780	16	985	109	60	39	33	4	27	3	4	7
		150	100	<1	30	10	10	5	10	<1	<10	10	<1	<1
		5,000	5,000	1,500	3,000	700	3,000	700	200	50	300	500	15	150
Vinini	37	1,951	1,492	212	331	147	248	210	33	10	67	97		23
		200	200	20	10	10	10	3	5	<5	5	<10	<10	<10
		5,000	1,500	200	300	200	1,500	100	70	15	500	200	15	50
Fourmile Canyon	14	3,700	910	54	88	87	332	58	31	4	114	59	2	21
		300	300	20	20	30	100	30	20	<10	50	10	<10	10
		5,000	1,500	200	1,000	2,000	200	150	70	30	70	70	10	50
Elder	5	2,900	840	42	440	516	134	88	30	12	66	36		24
		500	200	<10	100	30	20	20	10	<10	50	10	<10	<10
Carbonate facies														
		20	15	200	50									
Hamburg	6	15	10	150	20	<10	<10	<2	<5	<10	<5	<10	<10	<10
		10	10	150	15									
		5,000	300	200	100	700	50	7	10		50	150		20
Eureka	12	800	120	<50	30	150	15	4	5		15	20	<10	<10
		20	20	20	10	10	10	1	5		5	10		<10
		300	100	700	200		30	7		50	30	10		10
Hanson Creek	11	170	40	200	170	<10	20	4	<5	10	15	<10	<10	10
		10	10	100	50		10	2		10	5	<10		10
		1,000	300	700	200	150	300	7	30	10	70	20		20
Roberts Mountains	9	700	150	400	70	100	100	4	10	<10	30	10	<10	10
		300	70	200	30	30	20	2	5	<10	20	10		<10
		1,500	200	7,000	300	70	150	20	20	15	50	100		
Wenban	13	450	70	1,500	100	30	40	5	5	<10	20	15	<10	10
		70	20	100	50	20	10	2	5	<10	10	10		

and a second, local, source of mixed volcanics and chert. The first source may well have been the Belt quartzites of central Idaho (C. P. Ross, 1947); the second was probably a welt or series of welts in the depositional basin. The pure quartzite beds represent dominance of material from the first source; the cherty sandstones and clastic cherty siltstones represent material supplied locally. The Eureka Quartzite may possibly represent a great expansion of one of the thicker quartzites of the Valmy—one that overlapped the Shoshone-Cortez axis of uplift and extended far to the east and south.

The Fourmile Canyon Formation shows no similarity to any of the Silurian formations of the eastern facies, so presumably a wide gap intervened. The area of clastic deposition must have receded westward again because the Roberts Mountains Limestone is parautochthonous in the western part of the northern Shoshone Range (Gilluly and Gates, 1965). There is, however, the interesting fact that the siltiest facies of the Roberts Mountains Limestone contains potassium feldspar, as do both the Fourmile Canyon and Elder Formations. It is thus likely that these formations were deposited in the same basin, which was receiving a considerable proportion of potassic pyroclastics as well as the same quartzose sediment that characterizes the older formations of the western facies.

The Devonian formations are the first that show recognizable transitional members between the eastern and western facies. Here in the Cortez quadrangle the Slaven Chert contains a few limestone beds and farther east, near Mineral Hill, the similar chert is interbedded with limestone virtually indistinguishable from the limestones of the Devonian of the eastern facies. This interbedding suggests that no barrier existed between the sites of deposition of the carbonate and siliceous facies of Devonian age. Nevertheless, the eastern edge of the transitional facies must have lain to the west of the eastern slopes of the Shoshone Range, for the Devonian limestone exposed in a window of the Roberts thrust near Gold Acres shows no chert intercalations (Gilluly and Gates, 1965). The eastern limit of notable siliceous deposition probably remained to the west of the Reese River Valley throughout Ordovician, Silurian, and Devonian time.

PRE-PENNSYLVANIAN UNCONFORMITY (ANTLER OROGENY)

Regional relations show that the major orogenic episode, during which the Roberts thrust was formed, took place in Mississippian time. This is the Antler orogeny of Roberts (1949). Nothing in the Cortez quadrangle, however, contributes to a close dating of this episode. It is recorded in a sheared unconformity beneath the Brock Canyon Formation in the northeast corner of the quadrangle. Here three bodies of the Brock Canyon Formation in a north-south line rest on the Valmy formation. As the Brock Canyon Formation is of Pennsylvanian or Permian age, were the unconformity unfaulted this relation would suggest deep erosion to remove beds equivalent to the Silurian and Devonian of the Western facies prior to deposition of the Brock Canyon. There is an element of uncertainty, however, in that the basal contact of the Brock Canyon seems everywhere locally to be near-bedding shear. It seems, from the somewhat larger exposures in the Crescent Valley (Gilluly and Gates, 1965) and Frenchie Creek (L. J. P. Muffler, oral commun., 1960) quadrangles, that the Brock Canyon is essentially parautochthonous on the Valmy and hence that the bedding shears do not indicate long distance transport of the remnants. In other words, the basal fault is essentially along a prior unconformity that indeeed records the Antler, rather than a younger orogeny.

PALEOZOIC ROCKS YOUNGER THAN THE ANTLER OROGENY

PENNSYLVANIAN OR PERMIAN SYSTEM

BROCK CANYON FORMATION

Name.—The Brock Canyon Formation was named from Brock Canyon, just northeast of this quadrangle, where it is widely exposed (Gilluly and Gates, 1965).

Stratigraphy.—In Brock Canyon, the Brock Canyon Formation consists of several thousand feet of dolomite, conglomerate, sandstone, limestone, and carbonaceous shale, and farther east in the Frenchie Creek quadrangle, of quartzite and siltstone also. Of this great thickness only a few score feet of dolomite and conglomerate is exposed within the Cortez quadrangle.

The dolomite consists of brecciated coarse-grained gray rock in beds 2–10 feet thick. The basal contact is everywhere faulted.

The conglomerate, which apparently overlies the dolomite in proper sequence, also rests on a fault. It consists of pebbles, as large as 3 or 4 inches in diameter, set in a finer groundmass. The pebbles consist of black chert, gray chert, quartzite, quartz, and sandstone. The larger are mostly well rounded, but the finer grade sizes are more angular. All the rock varieties are such as could have been derived from the Valmy formation.

Age and correlation.—No fossils were found in the Brock Canyon Formation in the map area, but mollusks from the formation in the Frenchie Creeek quadrangle have been assigned to the Late Pennsylvanian or Early Permian by Mackenzie Gordon, Jr., of the U.S. Geological Survey. Plant remains collected by L. J. P. Muffler in the Frenchie Creek quadrangle have also been assigned to Late Pennsylvanian or Early Permian time by S. H. Mamay of the U. S. Geological Survey (L. J. P. Muffler, written commun., 1961).

This age assignment is the same as that of the Antler Peak Limestone of the Galena Range (Roberts, 1951) and Mount Lewis quadrangle (Gilluly and Gates, 1965) and of unnamed limestone, sandstone, dolomitic sandstone, and siltstone in the Osgood Mountains quadrangle (Hotz and Willden, 1961), toward the northwest. The Brock Canyon Formation is also equivalent in part to the Carbon Ridge Formation of the Eureka area and the Garden Valley Formation of the southern Sulphur Springs Range to the southeast (Nolan, Merriam, and Williams, 1956), and to the Strathearn Formation of Dott (1955) and overlying beds to the east, near Elko.

All these variable formations have in common a notable basal unconformity. They constitute part of what Roberts and others (1958) have called the overlap assemblage and doubtless represent deposits in and near an archipelagic sea that submerged the irregular topography carved on the Antler orogenic belt in Late Mississippian and Early to Middle Pennsylvanian time.

POST-PERMIAN HIATUS

In the Cortez quadrangle, the Brock Canyon is the youngest pre-Tertiary rock, and the Caetano Tuff is the oldest Tertiary sedimentary formation. The long span of Mesozoic and early Tertiary that intervened between the deposition of these formations is not recorded by any local strata.

The basal shear of the remnants of the Brock Canyon Formation may record the drag of an overriding thrust sheet,[1] and such a sheet—involving rocks of probable Early Triassic age—has indeed been identified in the Mount Lewis quadrangle to the northwest (Gilluly and Gates, 1965). Post-Permian–pre-Cretaceous and post-Cretaceous orogenies have been recognized in the Eureka area (Nolan, Merriam, and Williams, 1956, p. 68–70); post-Early Cretaceous–pre-mid-Tertiary orogenies have been identified to the northwest in the Jackson Mountains (Willden, 1958). None of these disturbances are specifically recorded here, but there was clearly a long period of erosion following the shearing of the Brock Canyon Formation from its roots.

Clearly many thousands of feet of rock was removed by this erosion, for the Caetano Tuff rests on Valmy quartzite near Francis Cabin. Also, much of the erosion recorded by the extremely irregular un-

[1] L. J. P. Muffler (oral commun., 1961), U.S. Geological Survey, considers it likely that the basal and internal shearing of the Brock Canyon was caused by shouldering action of a large plutonic mass just to the east in the Frenchie Creek quadrangle.

conformity beneath the gravels of Horse Canyon and of the Toiyabe Range probably took place during this interval and thereby exposed the Roberts thrust at the surface.

ROCKS OF MESOZOIC AGE

QUARTZ MONZONITE OF THE MILL CANYON STOCK

Location.—The Mill Canyon stock is about 4 miles long and 1½ miles wide in greatest exposed dimensions. It occupies most of the north slope of the Cortez Mountains west of Mill Canyon and extends eastward as a narrower body to the upper part of Fourmile Canyon. It is exposed from the mountain front to the shoulder of Mount Tenabo, over a vertical distance of nearly 3,000 feet. Minor plugs of similar rock occur in the head of Fourmile Canyon.

Structural setting and wallrock relations.—The position of the stock near the axis of the window in the Roberts thrust suggests the possibility that it has been forcefully injected, thereby bowing up the thrust in a laccolithic form. This suggestion is to some extent fortified by the attitude of the bordering rocks of the intrusive along the north and northeast sides, for throughout this part of the border the adjacent rocks dip away from the stock at angles of 25°–40°.

The western, roughly rectangular block of the stock shows sharply cross-cutting contacts. The Paleozoic border rocks abut the south side of the stock without the slightest deflection in attitude (fig. 2). The homoclinal dip of the entire section from the Hamburg Dolomite through the Wenban Limestone that characterizes the structure to the south continues right up to the contact of the intrusive. The small outcrops of highly hornfelsed Roberts Mountains Limestone, Hanson Creek Formation and Eureka Quartzite along the west side of the stock in Lewis Canyon (the straight canyon, unnamed on the map, that drains to Crescent Valley from the scarp front west of the Rock House north of Cortez) are tilted up to a high angle. It is, however, impossible to determine whether these are distorted screens along the margin of the stock or whether they are rotated along the Cortez fault.

At least part of the folding of the Roberts thrust in the Cortez area may have taken place during the time of thrusting (see p. 93); if it did, the position of the Mill Creek stock near the axis of the warping may be purely fortuitous. This possibility is consonant with the fact that the much larger stock to the northeast in the Frenchie Creek quadrangle, Cortez Mountains, has not uplifted the thrust nor, indeed, notably deflected the structures of the surrounding rocks. The eastern elongate lobe of the stock, although cross cutting at the lower levels at the west end in Mill Canyon, apparently distorts the thrust plates at higher level. The stock is thus a composite body, whose western half is cross cutting and whose eastern half is laccolithic or bysmalithic.

Contact effects are inconspicuous in general. Locally there is a chilled border a few inches wide, but much of the contact shows almost negligible chilled selvages. The Wenban Limestone has been notably altered to marble and tremolitic hornfels locally but for only a few feet from the contact. The Hamburg Dolomite has been altered intensely near the stock and mildly for a long distance to the south. The Roberts Mountains Limestone and the Fourmile Canyon Formation have been baked to dense hornfels also, but only close to the contact.

Petrography.—The dominant rock of the stock is a biotite-quartz monzonite, but it ranges somewhat in composition, from quartz diorite to alaskite. The alaskite facies seems to be somehat younger than the rest of the mass and has been separately mapped on plate 1.

On fresh fracture the dominant rock is light gray, with a pepper-and-salt appearance. Some is porphyritic, with phenocrysts of plagioclase, as much as 3 mm in diameter, set in an equigranular groundmass whose grain size is perhaps 0.5 mm or even smaller. Biotite is conspicuous but the potassium feldspar content is only suggested by a flesh-pink hue to the fine-grained matrix of the white plagioclase crystals. Quartz is abundant, but not in phenocrysts. The rock weathers to a tan or light-brown hue.

In thin section the commonest rock shows euhedral plagioclase, widely zoned from about An_{55} to An_{25}, averaging perhaps An_{40}; euhedral biotite, pleochroic in notably reddish-brown hues; quartz, commonly in polycrystalline aggregates; and the accesssory minerals, magnetite, zircon, and minor apatite, all set in a mosaic of perthitic microcline to form a monzonitic texture. Much of the rock is mildly altered, so that the biotite is partly replaced by muscovite, chlorite, and pistacite, the plagioclase by sericite and minor zoisite. Analyses of two such specimens appear in table 4, Nos. 1 and 2. A photomicrograph of one is shown in figure 11. A few specimens show grains of green hornblende partly altered to biotite, even though most of the biotite is euhedral. In some, the hornblende, though rounded rather than euhedral, does not seem to be altered to biotite; the biotite in these rocks is poikilitic, enclosing plagioclase and quartz. One of these slightly more mafic rocks has been analyzed (table 4, No. 4). A photomicrograph is shown in figure 12. By increase of plagioclase and diminution of the perthitic feldspar the rock passes into quartz diorite, but only a few specimens studied have this composition and in the field they were not recognized as making a distinct body.

FIGURE 11.—Photomicrograph of coarse-grained biotite-quartz monzonite from the Mill Canyon stock (table 4, No. 2). Euhedral plagioclase crystals (pl) zoned from andesine to oligoclase are as much as 3 mm long. Many have vermicular intergrowths with quartz (Q) and are partly altered to sericite and clinozoisite (?). Potassium feldspar (kf), commonly microperthitic, is anhedral and cloudy; red-brown biotite is partly altered to chlorite, iron oxides, and rutile. Accessories are sphene, rutile, and apatite. Crossed nicols.

The alaskite is chiefly porphyritic, with phenocrysts of plagioclase, microcline perthite, and quartz as much as 3 mm across set in a much finer groundmass of the same minerals with a little biotite and the usual accessories. The plagioclase is somewhat more sodic and less zoned than that in the quartz monzonite, and averages An_{15}–An_{20}. An analysis is given in table 4, No. 3.

Chemical composition.—Four rocks, representing the mafic and alaskitic facies and two intermediate ones, have been analyzed. The results and the norms of the rocks appear in table 4.

These analyses show that although there is a range of about 10 percent in silica content, all facies of the stock are characterized by relatively high alkali content with respect to lime; the more siliceous rocks tend toward the composition of granite. The alaskite is readily distinguished in the field from other parts of the stock, but the more mafic rocks, such as No. 4 represents, are apparently not separable in mapping from those corresponding to Nos. 2 and 1. The low sums shown by the analyses probably reflect the omission to determine baria gravimetrically; at least 0.1 percent baria probably is present and perhaps No. 4 contains as much as 0.2 percent, as suggested by the spectrographic analyses. Such relatively high contents of baria are common in igneous rocks of the eastern Great Basin.

TABLE 4.—*Analyses and norms of rocks of the Mill Canyon stock, Cortez quadrangle*

[Chemical analyses, in percent, by P. M. Montalto; semiquantitative spectrographic analyses, in parts per million, by E. F. Cooley]

	1	2	3	4
Chemical analyses				
SiO_2	70.85	72.48	75.45	65.70
Al_2O_3	15.05	14.59	13.33	15.81
Fe_2O_3	.27	.33	.17	1.34
FeO	2.23	1.72	.71	2.58
MgO	.92	.70	.23	1.44
CaO	2.11	1.58	.95	3.60
Na_2O	3.12	3.12	3.45	3.71
K_2O	3.74	3.93	4.88	3.60
H_2O+	.69	.64	.27	.54
H_2O-	.11	.09	.08	.11
TiO_2	.38	.30	.14	.80
P_2O_5	.14	.13	.02	.25
MnO	.06	.05	.05	.07
Co_2	.01	.01	.00	.07
Cl	.02	.02	.03	.03
F	.05	.05	.03	.08
Subtotal	99.75	99.74	99.79	99.73
Less O	.02	.02	.02	.04
Total	99.73	99.72	99.77	99.69
C.I.P.W. norms				
Q	31.32	34.14	34.56	19.86
or	21.68	23.35	28.91	21.13
ab	26.20	26.20	28.82	31.44
an	9.73	7.23	4.73	16.96
C	2.35	2.45	.61	.61
en	2.30	1.70	.60	3.60
fs	4.22	2.38	.13	2.38
mt	.46	.46	.23	1.86
il	.76	.61	.30	1.52
ap	.34	.34		.34
Symbol	I''.(3)4.2.3	I.3(4).2.3	I.(3)4.(1)2.3	I'.4.(2)3.3(4)
Semiquantitative spectrographic analyses				
Pb	30	30	30	20
Cu	<5	5	7	50
Zr	200	300	100	500
Ni	10	20	7	15
Co	5	5	<5	10
V	50	30	10	150
Ba	1000	700	700	1500
Sr	300	300	200	700

1. Quartz monzonite from point at alt 6,250 ft on nose 0.4 mile southwest of Mineral Monument No. 1 west of Mill Creek.
2. Quartz monzonite from point at alt 7,800 ft on spur 1 mile north of Mount Tenabo.
3. Alaskite from saddle at alt 7,000 ft on spur northeast of the Mill Canyon mine.
4. Granodiorite from point at alt 7,850 ft about 200 ft north of the south contact of the stock on the divide between Mill and Fourmile Canyons.

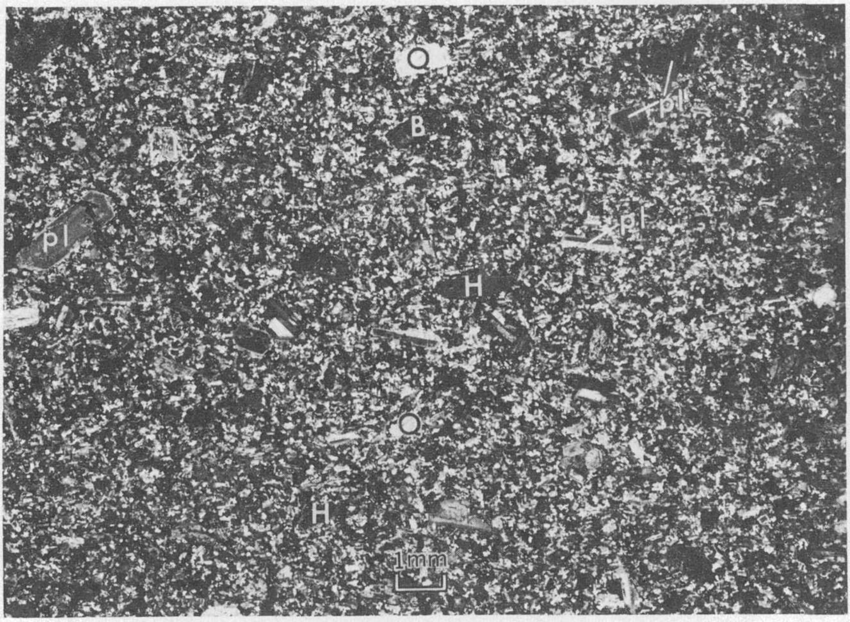

FIGURE 12.—Photomicrograph of hornblende-biotite granodiorite porphyry from eastern lobe of the Mill Canyon stock (table 4, No. 4). Contains euhedral plagioclase phenocrysts (pl), zoned from andesine to oligoclase, as much as 2 mm long. Green to yellow-green hornblende crystals (h) with augite cores are as much as 6 mm long and poikilitically hold grains of andesine and microperthite. Anhedral red-brown biotite (b), partly altered to chlorite, iron oxides, and sphene, also contains grains of plagioclase, and potassium feldspar. Sparse quartz phenocrysts (Q). Groundmass contains euhedral plagioclase and potassium feldspar as much as 0.1 mm in diameter enclosed in interstitial quartz (Q). Ilmenite (?) and apatite are abundant accessories. Crossed nicols.

Age.—From contact relations the age of the Mill Canyon stock can be bracketed only as younger than the Roberts thrust, that is, post-Early Mississippian, and earlier than the probable Pliocene age of the basaltic andesite which caps the cuesta to the east. Even though the basaltic andesite does not contact the stock, the erosion surface on which it lies surely represents a level much lower in the crust than the surface at the time of stock intrusion.

Garniss H. Curtis of the University of California, Berkeley (written commun., 1961), kindly supplied a radiometric age determination on a biotite concentrate of rock from the Mill Canyon stock. This analysis yielded an age of 151 my (million years) by the potassium-argon method. According to most estimates, such an age would correspond to a time in the Jurassic. It is approximately the same as the ages determined by the lead-alpha method on zircons from intrusives farther east in Nevada at Ruth (160 ± 20 my), in the Snake Range (145 ± 20 my), and at Seligman, in the White Pine Range (128 ± 15 my) (Don Whitebread, U.S. Geol. Survey, written commun., 1961).

A lead-alpha determination by T. W. Stern, U.S. Geological Survey (written commun., 1962), on zircons from the closely similar stock at Granite Mountain in the northern Shoshone Range yielded a much younger date: 50±10 my, corresponding to an early Tertiary age.

Presently available data indicate a wide spread of radiometric ages of both intrusive and extrusive rocks in eastern Nevada, but it is premature to attempt to evaluate any possibly systematic arrangement, spatial or temporal, of the regional igneous activity.

QUARTZ PORPHYRY AND AUGITE SYENITE

Dikes of many kinds abound in the map area. It seems certain that they belong to more than one igneous epoch, but criteria for distinguishing their ages are almost entirely lacking. We have arbitrarily classified those with notable contact aureoles as belonging to the same epoch as the quartz monzonite of the Mill Canyon stock which has a definite contact aureole. The rocks with contact aureoles are also considered of Mesozoic age. Those lacking such aureoles are classed as Tertiary. This arbitrary division has some other evidence favoring it: several of the dikes without aureoles resemble chemically the Caetano volcanics more than the quartz monzonite of Mill Canyon; several of them follow faults that closely parallel the Cortez faults and thus are probably also of Tertiary age. On the other hand, this criterion of separation leads to the assignment of closely neighboring dikes of comparable composition to different epochs as, for example, near the mountain front northeast of Cortez Canyon. We have found no unambiguous solution to this problem.

The dikes and sills attributed to the Mesozoic includes alaskite like that in the stock itself, quartz porphyry, and augite syenite. One quartz porphyry dike in Fourmile Canyon is nearly 1 mile long. The small plug at the mountain front about 1½ miles northeast of the mouth of Cortez Canyon has a conspicuous contact aureole, with much grossularite, idocrase, and meionite in the wallrock alongside. Both these rocks contain phenocrysts of quartz, sanidine, and biotite in a fine-grained groundmass of the same minerals, together with chlorite, sericite, and a little andesine.

There are a few thin sills of quartz porphyry but the only noteworthy sill is one of augite syenite northeast of the Rock House in Cortez Canyon. This sill is over half a mile long and ranges from a few feet to as much as 100 feet in thickness; it is conspicuous because of the bleaching, marmorization, and metasomatic alteration of the Wenban Limestone on either wall. Idocrase and grossularite have been identified here. The sill rock is dark green, equigranular, and about 0.5 mm in grain size. The microscope shows it to consist of abundant alkaline feldspar (probably anorthoclase, some with minor graphic intergrowth with quartz), considerable augite (some of which has reacted to form green hornblende), a few grains of quartz and labradorite, and accessory sphene, apatite, much calcite, and ilmenite.

A chemical analysis of this rock follows. As there is 10 percent calcite in the rock no norm has been computed.

Chemical analysis of augite syenite from sill crossing ridge 1 mile east of the mouth of Cortez Canyon

[Analyst, P. M. Montalto]

	Percent		Percent		Percent
SiO_2	58. 71	K_2O	0. 74	Cl	0. 01
Al_2O_3	9. 67	H_2O+	1. 15	F	. 02
Fe_2O_3	. 30	H_2O-	. 17		
FeO	2. 88	TiO_2	. 51	Subtotal	99. 73
MgO	6. 46	P_2O_5	. 08	Less O	. 01
CaO	11. 22	MnO	. 07		
Na_2O	2. 91	CO_2	4. 83	Total	99. 72

TERTIARY SYSTEM

CAETANO TUFF

Name.—The name Caetano Tuff is here applied to the body of welded and water-laid tuff and associated conglomerate and sandstone that crops out over most of the northern Toiyabe Range north of the Wenban fault and south of Cortez Canyon. The name is derived from the Caetano Ranch, which is situated on and surrounded by the formation.

General features.—As the name implies, tuff is the dominant rock of the formation. Most of the tuff is rhyolite welded tuff but there is subordinate andesitic tuff, mostly water laid, both near the base and top of the formation. There are also some lenses of conglomerate and sandstone embraced in the formation as here recognized. The total thickness is about 8,000 feet, on the assumption that the formation is almost completely duplicated by normal faulting. (See pl. 1, section *C–C′*.)

Stratigraphy.—The only exposure of the base of the formation is southwest of Francis Cabin, 2 miles north of the Caetano ranchhouse. There the normal fault—on line with, but probably not a continuation of the Crescent fault to the north (see p. 96)—which we consider to have duplicated the tuff, has brought up a mass of quartzite of the Valmy Formation about half a mile long. The actual contact of the tuff on the Valmy is largely concealed beneath alluvium but is clearly unconformable where exposed at the south end of the outcrop.

A thick sequence of nonresistant rocks is exposed on the east side of the valley in which the Caetano Ranch lies. The stratigraphic relations of the east-dipping sequence are obscured by the paucity of exposures and the numerous faults. At the base is an 800-foot-thick sequence of yellow-gray and grayish-orange sandstone and siltstone with a few thin beds of carbonaceous mudstone. Along most of their outcrop these beds are in fault contact with the adjacent rocks but in one small exposure that may represent bedrock, they rest unconformably on chert and limestone of the Devonian Slaven Chert.

Overlying these beds is a 1,200-foot sequence of red conglomerate, sandstone, and dark-gray andesite flows and tuff. The cobbles of the conglomerate are as much as 5 inches in diameter and are composed of chert, quartzite, argillite, and limestone, all of which could have been supplied from the Paleozoic rocks exposed nearby, south of the Wenban and north of the Copper faults. Both sandstone and conglomerate are poorly sorted and contain angular fragments, so a local source seems likely.

The red conglomerate and andesite beds are cut off southward against the Wenban fault. In slices along the fault near Wenban Spring, the conglomerate and sandstone with red silt matrix may be several thousand feet thick. In another unit higher in the section conglomerate with red-stained matrix fills channels cut in water-laid tuff and tuffaceous siltstone. This unit pinches out in less than half a mile north of the Wenban fault. These rocks may represent fan gravels derived from nearby highlands.

The main mass of the Caetano Tuff consists of pinkish-gray to light-gray vitric crystal tuff, with very minor interbeds of water-laid tuff and conglomerate derived from Paleozoic rocks. Much of the formation is almost massive, with a very crude parting; in places the bedding is brought out by differences in hardness of layers or by bands of black vitrophyre. The scale of the geologic map (pl. 1) did not allow us to distinguish the flow units. The bands of vitrophyre were not everywhere discriminated and they are more numerous in the field than would appear from the map, which shows only the more conspicuous.

The tuff is mostly composed of welded ash-flow material, with only minor water-laid interbeds. Individual flow units range in thickness from a few hundred to more than a thousand feet. Within a particular ash flow four zones can commonly be recognized, as shown in table 5.

The few interbeds of gravel are as much as 200 feet thick but are generally much thinner. Most are pebble conglomerates with a red silt matrix. The pebbles are of chert, quartzite, argillite, and limestone, all rock varieties available from the nearby Paleozoic rocks.

TABLE 5.—*Sequence of rock types in an ash-flow unit*

Lithology	State of consolidation	Thickness (ft)
Pale red-purple to medium-gray vitric crystal tuff containing abundant fragments of white devitrified pumice. (Probably largely an accumulation of dispersed tuff fragments.)	Partly welded.	150–500.
Pale red-purple vitric crystal tuff; crude layering due to schlieren and blebs of deformed glass, flattened and agglutinated shards, mostly devitrified. (Main ash flow.)	Thoroughly welded.	200–800.
Black vitrophyre, interbedded with medium light-gray vitric crystal tuff (partly devitrified). Commonly 2, to as many as 5, layers of vitrophyre, separated by equal thicknesses of partly devitrified tuff. (Irregularity perhaps due to differential chilling in turbulent layer of ash flow near the ground.) In many places absent.	do	Individual vitrophyre layer, 0–50; aggregate in a flow unit, 0–200.
Pinkish-gray vitric crystal tuff (probable chilled front of ash flow).	Not welded	0–20.

In sec. 3, T. 26 N., R. 47 E., there are lenses of tuff several thousand feet long that contain large blocks of chert and quartzite. Many blocks are more than 40 feet across and 15 feet thick. They are contained in platy white tuff and overlain by black vitrophyre 30 feet thick. In places these lenses are bordered by vitrophyre on both sides and thus appear to be intercalated in a zone low in a flow unit. But toward the north the chert blocks seem to be as much as 150 feet long and not interrupted by tuff, so that they may be pinnacles of a buried ridge of bedrock. A bedrock pinnacle here would imply a relief of several thousand feet on the prevolcanic surface. While relief this great is possible, the blocks are on strike of a gravel lens and seem more likely to record a volcanic mudflow.

West of the Caetano ranchhouse, white to pinkish-gray tuff, tuffaceous siltstone, and claystone interfinger with the welded tuff flows at the top of the Caetana Tuff (shown as Tcs on geologic map, pl. 1). The water-laid tuff is brilliantly reflective where free from vegetation and erodes into typical badland forms.

Almost throughout its area of exposure, the Caetano Tuff is standing at angles of 20°–70°. The homogeneity of the formation is such that major faults could readily be overlooked in traverses. Therefore, a fully confident measure of the thickness of the formation cannot be given; however, an estimate of 8,000 feet is surely not excessive.

Emplacement.—The Caetano Tuff is homoclinal over most of its exposure, and dips rather steeply east. Both to north and south it is sharply cut off by high-angle faults so that it occupies a graben, that on the east is obviously cut off by a fault beneath the alluvial fill of Grass Valley. The displacement on all these faults must be several thousand feet, for no considerable bodies of tuff resembling the Caetano are exposed nearby. No feeding dikes or extrusion centers related to the tuff have been recognized.

Because the fault that bounds the tuff on the north is roughly in line with a fault trending west-northwest at Wilson Pass in the Sho-

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shone Range, across Carico Lake Valley to the northwest, and as the interbedded gravels in the Caetano Tuff may represent fans derived from the scarps of active faults, Masursky suggested (1960) that the tuff was deposited in a volcano-tectonic depression of very large dimensions.

This suggestion cannot be tested at present because so little mapping has been done in the volcanics of the Shoshone Range and other areas to the west. In the Shoshone Range, however, the tuff clearly is not limited to the region south of Wilson Pass, but extends well to the north over a very irregular topography, wedging out against former high ground several miles north of the major fault and reappearing 10 miles to the north, beyond a frontal fault of the Shoshone Range (Gilluly and Gates, 1965). Wherever exposed in the northern Shoshone Range the tuff also dips eastward as it does in this area. The attitude of the homoclinal blocks seems to bear no relation to the major faults bounding the graben, either here or in the Shoshone Range. Much further mapping must be done before the hypothesis of a volcano-tectonic depression can be evaluated.

Petrography.—The dominant rock of the formation is red-purple to gray crystal tuff, containing abundant phenocrysts of quartz and sanidine and fewer of plagioclase and biotite in a streaky aphanitic groundmass. There are many inclusions of chert and some of quartzite, as much as 1 cm across, so abundantly scattered throughout that nearly any outcrop 4–5 feet across shows several.

Under the microscope the rocks show excellent vitroclastic texture, with deformed and agglutinated glass fragments; obviously they are welded tuff. Many are partly devitrified and of course some at the base or top of flow units show no welding. Mineralogically they are extremely uniform from top to bottom. The abundant quartz phenocrysts, as much as 3 mm in diameter but averaging perhaps 1 mm, are associated with somewhat smaller phenocrysts of sanidine, much smaller phenocrysts of oligoclase-andesine (An_{30}) that rarely attain 1 mm in diameter, and notably reddish-brown biotite of about the same size. Magnetite, zircon, and apatite are accessories.

The minor andesitic volcanics near the base of the formation are purplish gray to greenish gray, with phenocrysts of plagioclase and either hornblende or pyroxene in a finer grained groundmass. The microscope shows andesine-labradorite, ranging from An_{55} to An_{45}; augite, green hornblende, or both, much glass, considerable apatite, and magnetite. Much of the hornblende has been oxidized to oxyhornblende.

Chemical composition.—Chemical analyses of representative specimens of the welded tuff are included in table 6.

TABLE 6.—*Analyses and norms of vitrophyre and welded tuff of the Caetano Tuff*

[Analyst, P. M. Montalto. Chemical analyses in percent]

	1	2	3	4	5	6	7	8
Chemical analyses								
SiO_2	73.91	71.82	75.23	74.85	76.89	75.02	74.02	75.41
Al_2O_3	13.78	14.69	12.67	12.72	12.52	11.24	12.85	12.53
Fe_2O_3	.63	1.20	.96	.45	.28	.29	.46	.45
FeO	.25	.27	.00	.37	.54	.09	.58	.59
MgO	.26	.27	.32	.12	.17	.18	.21	.29
CaO	1.33	1.81	.96	.61	.49	.95	1.04	.90
Na_2O	2.71	3.06	3.02	4.25	3.26	.62	3.09	2.60
K_2O	4.95	4.90	4.63	3.61	4.31	7.62	4.80	5.05
H_2O+	.59	.51	.62	2.22	.59	1.84	2.08	.61
H_2O-	1.02	.84	1.20	.39	.58	1.39	.29	1.05
TiO_2	.16	.23	.08	.03	.03	.14	.11	.13
P_2O_5	.05	.07	.02	.02	.05	.06	.04	.04
MnO	.01	.01	.02	.08	.06	.00	.05	.01
CO_2	.03	.05	.04	.05	.01	.15	.01	.00
Cl	.01	.01	.09	.03	.01	.03	.03	.01
Subtotal	99.73	99.78	99.91	99.89	99.88	99.64	99.73	99.71
Less O	.02	.02	.04	.05	.04	.02	.04	.02
Total	99.71	99.76	99.87	99.84	99.84	99.62	99.69	99.69
C.I.P.W. norms								
Q	36.84	31.20	37.80	35.04	39.66	42.24	34.98	38.70
or	28.91	28.91	27.24	21.13	25.58	45.04	28.36	29.47
ab	23.06	25.68	25.15	35.63	27.77	5.24	26.20	22.01
an	6.39	8.90	4.73	3.06	2.50	.83	5.00	4.45
C	1.63	1.12	1.12	.82	1.53	1.63	.71	.20
en	.60	.70	.80	.30	.40	.40	.50	.70
fs	----------	----------	----------	.40	.66	----------	.53	.53
mt	.46	.23	----------	.70	.46	----------	.70	.70
hem	.32	1.12	.96	----------	----------	.32	----------	----------
il	.15	.46	----------	----------	----------	.15	.15	.15
Symbol	I.3(4) 2.3	I.″4. 2.3	I.3(4). (1)2.3	I.(3)4. I(2).(3)4	I.3″. 1″.3	I.3. 1.1(2)	I.(3)4. (1)2.3	I.3″. (1)2.3

1. Welded tuff, partly devitrified, from crest of 5,685-foot hill in NE¼ sec. 3, T. 26 N., R. 46 E.
2. Welded tuff from upper part of Caetano Tuff, at point on saddle in middle of the west line of sec. 13, T. 26 N., R. 26 E.
3. Welded tuff from point on saddle just north of 7,318-foot hill in SW¼sec 27, T. 26 N., R. 46 E.
4. Vitrophyre from mapped vitrophyre member due east of the Caetano Ranch, in SW¼ sec. 21, T. 26 N., R. 46 E.
5. Welded tuff from just above the vitrophyre of No. 4, largely devitrified.
6. Nonwelded tuff from high in the Caetano Tuff, at point on saddle in ridge in west center of sec. 1, T. 26 N., R. 46 E.
7. Vitrophyre closely above the vitrophyre of No. 6, but not known to belong to the same ash-flow unit.
8. Welded tuff, partly devitrified, immediately overlying the vitrophyre of No. 7 and definitely a part of the same ash-flow unit.

These analyses clearly show what the microscope suggests—that the rocks are all rhyolites. The extremely low content of lime and mafic minerals is in notable contrast with the otherwise somewhat similar composition of the rocks of the Mill Canyon stock. It is perhaps also noteworthy that, unlike most of the welded tuffs of the Great Basin, these rocks are not quartz latites but rhyolites.

Age.—Evidence as to the age of the Caetano Tuff is obscure and in part contradictory. Interbedded water-laid tuffs have yielded pollen that Estella B. Leopold of the U.S. Geological Survey assigned an age of Miocene or older (E. B. Leopold, written commun., 1960). Vertebrate and invertebrate fossils from similar rocks in the Shoshone Range have been identified by Edward Lewis and Dwight W. Taylor as of Miocene or early Pliocene age (Gilluly and Gates, 1965). The correlation of the tuffs in the Shoshone Range with those of the Caetano Ranch locality is of course uncertain, as similar petrography and chemical composition may not preclude a considerable age difference, and it is impossible to trace the rocks across the Crescent and Carico Lake Valleys. A radiometric date obtained by the potassium-argon method by G. H. Curtis of the University of California, Berkeley, is 31.5 my, which Curtis regards as an Oligocene date (G. H. Curtis, written commun., 1961). If the radiometric date is correct, we would have two identical welded tuffs in the general area, the Caetano of Oligocene(?) age and the unnamed one in the Shoshone Range of Miocene and Pliocene age. On the other hand, if the petrographic similarity is to be taken as evidence of identity of the tuffs in the two ranges, we would have to assume that the radiometric age is too great, perhaps because of contamination. At present it does not seem possible to make an unequivocal decision.

QUARTZ PORPHYRY DIKES

Distribution.—As mentioned in describing the dikes associated with the Mill Canyon stock, we have been unable to find unambiguous criteria for distinguishing the dikes associated with that intrusive from others of later date, which we consider probably to be allied magmatically to the Caetano Tuff. Dikes in the northern Toiyabe Range, just west of the road up Cortez Canyon, and in the Cortez Mountains, north, south, and east of Cortez, all show chemical characters that suggest association with the Caetano Tuff. The north-trending dikes parallel to the range-front fault (the Cortez fault of pl. 1) north of Cortez near the mountain front seem in part to be controlled by parallel faults. They are therefore included as Tertiary rocks despite their chemical resemblance to and close association with the Mill Canyon stock. These are the rocks considered here (shown on plate 1 by Tqp). None are more than a few hundred yards long and a few hundred feet wide and most are much smaller.

Petrography.—The rocks of these dikes are all porphyritic, with quartz and biotite as phenocrysts. Some also show phenocrysts of sanidine and rare plagioclase. The groundmass is aphanitic. Thin sections commonly show that the sanidine in the groundmass has a spherulitic habit, in some being "seeded" on phenocrysts of quartz. In this groundmass are held euhedral crystals of sanidine, quartz, and biotite, with sporadic andesine. In some rocks the only phenocrysts are quartz. Many of the rocks are highly altered to clay, especially in the Cortez mine and to the north of it.

Two of the dikes were analyzed chemically, with the results shown in table 7.

TABLE 7.—*Analyses and norms of quartz porphyry of dikes in the Cortez quadrangle*

[Analyst, P. M. Montalto. Chemical analyses in percent]

	1	2		1	2
Chemical analyses					
SiO_2	76.17	76.16	P_2O_5	0.01	0.00
Al_2O	11.90	12.15	MnO	.02	.07
Fe_2O_3	.35	.35	CO_2	.21	.04
FeO	.47	.28	Cl	.01	.00
MgO	.34	.25	F	.02	.19
CaO	.82	.48	BaO	.20	--------
Na_2O	1.73	2.36			
K_2O	5.94	5.10	Subtotal	100.11	99.79
H_2O+	1.00	.89	Less O	.01	.08
H_2O-	.82	1.45			
TiO_2	.10	.02	Total	100.10	99.71
C.I.P.W. norms					
Q	41.40	40.86	il	0.15	--------
or	35.03	30.02	mt	.46	0.70
ab	14.15	19.91	fs	.53	.26
an	33.89	2.50	en	.80	.60
C	1.33	1.94	Symbol	I.3.(1)2.2	I.3''.1''.''3

1. Quartz porphyry of dike in foothills south of Cortez, in SW¼ sec. 21, T. 26 N., R. 48 E.
2. Quartz porphyry of dike on hill 2,500 ft N. 45° W. of the Rock House in Cortez Canyon.

The resemblance of these analyses to those of the Caetano Tuff is so close that it offers strong though of course not conclusive evidence for the assumption that they all belong to the same igneous episode.

VOLCANICS OF FYE CANYON

In the southeast corner of the Cortez quadrangle, in Fye Canyon and on both sides of the canyon east of the Isaacs ranchhouse, volcanic rocks cover a square-mile area.

The volcanics of this area are chiefly flow-banded and autobrecciated rhyolite, with a single mass of hypersthene andesite flow breccia near the apparent base, in Fye Canyon. The base is not exposed but the volcanics presumably rest unconformably on a surface of moderate relief carved on the Vinini Formation; both east and west of the Isaacs ranchhouse the volcanics are preserved on downthrown fault blocks, presumably of the Basin Range suite. The structure of the block of rhyolite is difficult to determine because of the highly contorted flow layering and breccia structures so that it is impossible to measure an accurate thickness, but it is clear that as much as 500 feet may be present.

The andesitic breccia at the base as exposed is only a few feet thick and is composed of light-gray porphyritic scoriaceous breccia blocks as much as several feet in diameter, set in a fine-grained gray powdery matrix. The boulders contain abundant phenocrysts of plagioclase and sparse ones of hornblende and pyroxene as much as 4 mm long set in an aphanitic groundmass. Under the microscope the plagioclase is identifiable as zoned from about An_{60} to An_{40}. It makes up more than half the rock and is accompanied by hypersthene in rounded grains as much as 2 mm long, hornblende, pleochroic in brown and green, and a few small grains of augite. Magnetite and apatite are accessory.

Though the contact is not exposed, there is little doubt that the flow-brecciated rhyolite overlies the andesite breccia directly. The rhyolite is highly variable, ranging from black obsidian through gray, greenish-gray, and pink, flow-banded, glassy, and lithoidal rocks, to fine-grained, pink, porphyritic, lithoidal breccia. No tuffs, either welded or unwelded, have been recognized in the Fye Canyon area.

Phenocrysts of quartz and plagioclase attain 3 mm in diameter and are accompanied by sparser and smaller ones of biotite. Under the microscope the rocks are monotonously alike. The plagioclase is unusually calcic for a rhyolite, averaging nearly An_{50}, and in some specimens even An_{60}, with even the outer zones no more sodic than An_{40}. Much of the biotite is oxidized and altered to hematite; the unaltered is normal brown, not reddish as is most of that in the Caetano Tuff. The quartz shows considerable resorption and much of it is bordered with radiating sheafs of extremely fine grained sanidine. The groundmass contains spherulitic sanidine, but no euhedral crystals of this mineral were noticed, though the chemical analyses show it must constitute much of the rock. Many rocks have only glass in the groundmass and even the lithoidal specimens contain much. Magnetite, zircon, and a little apatite are accessories.

Table 8 presents the chemical analyses of glassy and lithoidal specimens of these rhyolites. Their similarity is notable.

The principal differences clearly are the higher content of volatiles, H_2O+, Cl, and F, in the obsidian, and the higher ratio of ferric to ferrous iron in the lithoidal rock. The analyses are closely similar to those of the Caetano Tuff but are higher in silica and perhaps a little higher in combined alkalis than most of those. Nothing so distinctive as to demand a wholly different provenance from that formation, however, seems to be indicated. It should perhaps be emphasized that no tuff has been recognized among these rocks nor any lava flows among the Caetano Tuff flows.

TABLE 8.—*Analyses and norms of rhyolite from the volcanics of Fye Canyon*

[Analyst, P. M. Montalto. Chemical analyses in percent]

	1	2		1	2
Chemical analyses					
SiO_2	73.32	72.30	P_2O_5	0.04	0.02
Al_2O_3	13.53	13.30	MnO	.05	.05
Fe_2O_3	1.40	.60	CO_2	.04	.02
FeO	.11	.74	Cl	.01	.06
MgO	.29	.25	F	.02	.05
CaO	1.15	1.22	BaO	.13	--------
Na_2O	3.10	3.18			
K_2O	5.00	4.64	Subtotal	99.64	99.64
H_2O+	.58	2.93	Less O	.01	.03
H_2O-	.74	.16			
TiO_2	.13	.12	Total	99.63	99.61
C.I.P.W. norms					
Q	33.30	32.76	fs	--------	0.66
or	29.47	27.24	il	0.15	.15
ab	26.20	27.23	hem	1.44	--------
an	5.84	5.84	mt	--------	.93
C	.82	.82	Symbol	I. (3) 4.''2.3	I. (3) 4.''2.3
en	.70	.60			

1. Lithoidal rhyolite (pink) from point 1 mile north-northeast of Isaacs ranchhouse, in sec. 19, T. 25 N., R. 48½ E.
2. Porphyritic obsidian (nearly black), from same locality as No. 1 but a different flow.

These volcanics extend for several miles south and east of the Cortez quadrangle. Perhaps it will there be possible to fix their stratigraphic relations closely enough to provide evidence as to their age. In this area such evidence is lacking. We have been fortunate, however, in the generosity of Prof. G. H. Curtis, of the University of California, Berkeley, who kindly made a radiometric analysis of biotite from the rhyolite of this unit. By the potassium-argon method he obtained an age of 36.8 my, which he estimated to be near the Oligocene-Eocene boundary, somewhat older than his determination for the Caetano Tuff (G. H. Curtis, written commun., 1961).

GRAVELS OF HORSE CANYON AND THE TOIYABE RANGE

Distribution.—From the head of Horse Creek to the south end of the Cortez Mountains, the eastern slope is masked by gravels almost to the summit. Gravel also crops out beneath the basaltic andesite on the east side of Horse Creek, in the drainage of Willow Creek, and beneath the basaltic andesite cuesta forming the mountain crest east of Fourmile Canyon. Very similar gravel crops out in the southwest part of the map area, on the west flank of the Toiyabe Range. Although the stratigraphic equivalence of these bodies cannot be proven, they are conveniently considered together because of their similar appearance, and the facts that all contain detrital volcanics and overlie and bury highly irregular topography.

Stratigraphy.—Exposures of these gravels are few and poor so that both contacts and composition are generally determinable only from float. The body in Horse Canyon and to the southwest of the Horse ranchhouse overlies a topography with relief of at least 1,300 feet, and as it must dip at least as steeply as the overlying andesite, the minimum stratigraphic thickness must be about the same amount. On the divide east of Fourmile Canyon at least 750 feet of gravel underlies the andesite capping. Although the upper contact is badly obscured by landslides that involve the overlying basaltic andesite, the andesite seems to have flowed over a relatively smooth surface, perhaps that of a fan.

The gravel of the Toiyabe Range is at least 400 feet thick. The only formation overlying it is the Quaternary alluvium, so nothing is known of its original thickness.

In both ranges the gravel is poorly sorted, to judge from the sporadic exposures and the wide range in grade size of the float. Blocks of quartzite and chert as much as 20 feet long are not uncommon in the slopes west of Horse Canyon, and many of 3- or 4-foot diameter can be seen. The large masses are angular but many of the cobbles and pebbles are well rounded. Although the most abundant pebbles and boulders are of Paleozoic rocks—quartzite, chert, limestone, and sandstone—there are also many clasts and rounded pebbles of welded tuff resembling the Caetano Tuff and sparser ones of quartz monzonite. Some of the finer beds of the gravel contain considerable pyroclastic material, and there is a suggestion, on the east side of Horse Creek, not far above the ranchhouse, that some of this pyroclastic material is essentially a water-laid tuff, intercalated in the normal coarser gravel.

Age.—No fossils have been found in any of the gravel bodies here considered. Clearly the gravels post-date either the Caetano or another petrographically similar tuff, and predate the cuesta-forming basaltic andesite. A Pliocene age probably would not be inconsistent with the geologic history as we now understand it, but if the Caetano Tuff should prove to be of Oligocene age, the gravel could of course be Miocene.

BASALTIC ANDESITE

A great cuesta of basaltic andesite covers the east flank of the Cortez Mountains for more than 6 miles north of the point where Horse Canyon leaves the map area. This is undoubtedly the faulted extension of a comparable group of flows that covers the dip slope of the Shoshone Range across Crescent Valley to the northwest. In both ranges the flows dip east or southeast at moderate angles that range from about 3° to 16°.

The flows overlap westward and southwestward against the prelava topography and thicken toward the northeast. Although the upper surface of the flows is erosional, much of the thickening probably is depositional, for where the capping flow leaves the quadrangle east of Fourmile Creek it is underlain by at least eight flows, whereas 3 miles to the southwest the same flow is underlain by only four and the total thickness of the lavas has diminished from 350 feet to only 120 feet. In general the flows rest on poorly sorted gravel, but at the head of Willow Creek, on the Fourmile Canyon divide, the basal flow rests directly on the Vinini Formation.

The individual flows range in thickness from a wedge-out to 80 or 90 feet and generally can be traced for several miles. Some are platy, with strong flow banding; others are more massive except for abundant vesicles. No sediment intercalated between the flows was noted, so they apparently resulted from eruptions in close succession.

The rocks are dark gray, weathering to dark brown. The only minerals recognizable with a hand lens are plagioclase, in crystals as much as 2 mm long, pyroxene, in somewhat smaller grains, and magnetite, all in a felty groundmass. Under the microscope the plagioclase is identifiable as labradorite, zoned from about An_{65} to An_{55}, with somewhat more sodic laths in the felty groundmass. Pyroxene is chiefly augite, but some sections from the Shoshone Range contain kernels of pigeonite. Magnetite is abundant and apatite is present as a minor constituent. There is a little interstitial glass in most specimens examined. The texture is divergent granular in the massive flows, and strongly fluxional in some of the platy ones. The abundant vesicles in some layers are filled with chalcedony.

Analyses of a specimen from near the head of Willow Creek in this area, and of one from the Shoshone Range, are reported in table 9.

It is evident that the rock is neither a typical basalt nor a typical andesite in bulk composition; perhaps it is nearer to the average quartz basalt than to either. The quartz of the norm is wholly occult however, so that it appears best to name the rock basaltic andesite, as has been done in the northern Shoshone Range (Gilluly and Gates, 1965).

The basaltic andesite has not been found in contact with fossiliferous Tertiary rocks, although it is considered to be probably late Tertiary. This inference is based upon its superposition on the unconsolidated rhyolite-bearing gravels, which do not appear ever to have been deeply buried, and upon the fact that the flows seem to have been affected by relatively little disturbance other than the Basin Range faulting, which is clearly younger than the Miocene and Pliocene beds of the Shoshone Range (Gilluly and Gates, 1965), and presumably of similar late Tertiary age in this area. It is true that the flows are cut along Willow Creek by rhyolitic plugs and there buried by rhyolitic flows, but this does not imply great age. As a guess, the flows are probably of middle or late Pliocene age, and there is a possibility that they are still younger.

DOLERITE DIKES

The steep front of the Cortez Mountains in the northern part of the quadrangle is cut by a swarm of north-northwest-trending dikes of dolerite. Several are nearly 3 miles long. Where they join, the width is as much as 800 feet, though most average considerably less and the width of many as shown on plate 1 is much exaggerated. For convenience a sill and a small dike in the Toiyabe Range at the south edge of the quadrangle are also shown under the same rubric on plate 1, but these are petrographically distinct.

The dikes cut several small dikes and pipes of quartz latite and quartz porphyry, but have not been found in contact with either the Tertiary gravel or the basaltic andesite.

TABLE 9.—*Analysis and norms of basaltic andesite from the Cortez Mountains and Shoshone Range*

[Chemical analyses in percent. No. 1 analyzed by P. M. Montalto; No. 2, by L. N. Tarrant]

	1	2		1	2
Chemical analyses					
SiO_2	55.01	55.89	P_2O_5	0.37	0.46
Al_2O_3	15.01	14.70	MnO	.15	.16
Fe_2O_3	3.22	2.90	CO_2	.03	.02
FeO	6.31	7.37	Cl	.01	--------
MgO	4.14	3.98	F	.05	--------
CaO	8.09	7.39	BaO	--------	.03
Na_2O	3.02	3.11			
K_2O	1.52	1.84	Subtotal	99.67	100.03
H_2O+	.68	.34	Less O	.02	--------
H_2O-	.76	.48			
TiO_2	1.30	1.36	Total	99.65	100.03
C.I.P.W. norms					
Q	9.48	9.36	fs	7.13	9.11
or	8.90	10.56	mt	4.64	4.18
ab	25.15	26.20	il	2.43	2.58
an	23.07	26.20	ap	1.01	1.34
wo	6.03	6.61	Symbol	II″.4	II″.4
en	10.30	8.60		(5).3″.4	(5).3.4

1. Basaltic andesite from 7,476-ft shoulder south of Willow Creek, about 1¼ miles west of the east boundary of the Cortez quadrangle.
2. Basaltic andesite from point east of Slaven Canyon, in sec. 7, T. 30 N., R. 47 E., Crescent Valley quadrangle, Shoshone Range.

The dikes of the northern group are basaltic and considerably altered hydrothermally. The minerals are labradorite, now in part considerably albitized; pyroxene, probably augitic and considerably altered to chlorite; and opaque oxides. Considerable calcite and saussurite is also present. The composition of these dikes is consistent with their having served as feeders of the basaltic andesite flows on the back slope of the range. There is a little quartz in some of them. If they indeed represent feeders of the basaltic andesite flows, the quartz that remains occult in the flows (see C.I.P.W. norms) is here crystallized. The dikes have not, however, been found either to cut or to unite with any of these flows.

The dike and sill in the southern part of the quadrangle, in the Toiyabe Range, are also composed of dark rocks, but these are hornblendic and contain andesine feldspar; doubtless they are true andesite and not related to the cuesta-forming basaltic andesite flows of the Cortez Mountains. They are in contact only with Paleozoic rocks, so that nothing can be determined as to their relations with the other presumably Tertiary rocks.

RHYOLITES OF HORSE AND WILLOW CANYONS

Rhyolite plugs and flows crop out over areas comprising about 1 square mile in upper Willow Creek and on the Horse Canyon divide that culminates in the 8,200-foot hill in sec. 2 (unsurveyed), T. 26 N., R. 48 E. One plug, in Willow Creek, cuts the basaltic andesite and the underlying gravel as well as the Vinini Formation; a second, which composes the 8,200-foot hill, cuts only the gravel and Vinini, but flows emanating from it overlie the basaltic andesite to the southeast. A third plug of this suite crops out on the west side of Horse Canyon, in sec. 9 (unsurveyed), T. 26 N., R. 48 E.

The plugs probably represent only slightly dissected domes, for the rock composing them is extremely platy parallel to the borders, and shows very pronounced flow structures, strongly streaked in the direction of the dip. The contacts of the intrusive on the divide with the flows to the east and south are concealed by talus, but the rock of the flows is so closely similar to that of the plugs that the flow almost certainly represent effusions from the adjacent plugs.

The rock of the plugs is lithoidal and highly vesicular, with sporadic phenocrysts of sanidine as much as 3 mm long and biotite books 1 mm long in an aphanitic groundmass. Some specimens show botryoidal lining of the vesicles. Under the microscope, in addition to the phenocrysts, minute crystals of sanidine, oligoclase (An_{15}), and quartz are identifiable in a devitrified groundmass too fine grained for resolution. Scattered through the rock and lining the vesicles is cristobalite, which obviously composes the botryoidal lining of the vesicles apparent in hand specimens. Its identification has been verified by Theodore Botinelly of the U.S. Geological Survey by X-ray methods. The microscope shows that most of the biotite is oxidized to hematite and sericite and that considerable clay, probably kaolinite has formed in the sanidine.

The rock of the flows is essentially the same as that of the plugs except that on fresh fracture it is more uniformily reddish brown, rather than gray, and contains much larger vesicles and abundant lithophysae. The microscopic character of the rock is also identical with that of the plug filling.

A chemical analysis shows that the rhyolite of this area is notably different from those of the other bodies. It is considerably richer in silica and lower in alumina. Although the calcium content is not very different, it is noteworthy that these rocks contain the most sodic plagioclase of any in the area. (See table 10.)

TABLE 10.—*Analysis and norms of the intrusive rhyolite of Horse Canyon, from plug on west side of Horse Canyon, 3,000 feet due east of 8,288-foot summit on divide of the Cortez Mountains*

[Chemical analysis in percent. Analyst: P. M. Montalto]

Chemical analysis			
SiO_2	79.15	H_2O-	0.64
Al_2O_3	10.69	TiO_2	.06
Fe_2O_3	.21	P_2O_5	.00
FeO	.26	MnO	.02
MgO	.20	CO_2	.14
CaO	.91	Cl	.01
Na_2O	2.41	F	.01
K_2O	4.29		
H_2O+	.54	Total	99.54
C.I.P.W. norms			
Q	46.20	il	0.15
or	25.58	mt	.23
ab	20.44	fs	.26
an	4.45	en	.50
C	.41	Symbol	1.3."2.3

The rhyolites of Horse Canyon are clearly younger than the basaltic andesite flows and are thus the youngest igneous rocks in the Cortez quadrangle. The gravels that overlie them have not yielded fossils, so that stratigraphic control of their age is lacking. The remarkable abundance of such an unstable mineral as cristobalite, the vesicular texture, and the relation to the adjacent lava flows all testify to the fact that we are seeing an extremely shallow level in the eruptive vent.

Probably not more than a very few hundred feet, perhaps only a few score feet, have been eroded from the summit vent since it was active. This suggests that its age is probably not greater than late Pliocene.

PLIOCENE SEDIMENTS AND TUFF

Along the west side of the quadrangle north of the Wenban fault there are a very few small exposures through the gravel of a formation that a short distance to the west, in the drainage of Chillis Creek, is widely exposed. These rocks have been called the vitric tuff unit and referred to the "Humboldt formation" by Van Houten (1956) in reconnaissance; he obtained Pliocene mammalian remains from them.

Brief excursions into the Chillis Creek exposures show that they include fluviatile and perhaps lacustrine beds, most of which are highly tuffaceous. Not enough attention was given to these rocks, which are of trivial extent in this quadrangle, to justify further comment. The exposures are, however, recorded on the map, for they supply suggestive evidence of the existence of a Basin Range fault intervening between them and the Caetano Tuff. The fault is not exposed, but the Pliocene beds just out of the quadrangle to the west dip toward the Toiyabe Range at moderate angles. It would require an extremely sharp flexure to permit these strata to overlie the Caetano volcanics normally; a fault is much the more probable relation.

QUATERNARY SYSTEM

A wide variety of deposits is shown on plate 1 as of Quaternary age. They include colluvium and minor landslide deposits, alluvial cones and pediment gravels, lake and playa deposits, and the rather unusual clay dunes that almost encircle the north end of the Grass Valley playa. No fossils have been obtained from any of these deposits, but a Quaternary age seems clearly indicated by their obvious connection with current processes of erosion and deposition.

Float and minor landslide deposits are widespread in the mountain areas. Only those large areas through which the bedrock geology could not be traced by float are indicated as colluvial on plate 1. Most of those shown involve the Tertiary gravels beneath the basaltic andesite. Some of the slides in Horse Canyon are still active but it seems that many of those in Fourmile Canyon are essentially stable and perhaps date from Pleistocene time.

Most of the streams of the area are degrading in their upper courses, but all are aggrading where they debouch from the mountains and hills into Grass and Crescent Valleys. Here they are building alluvial cones that coalesce into piedmont alluvial slopes. Where the shorelines of the Pleistocene lake that occupied Grass Valley are preserved, most of the cones are obviously older than the preserved lake shorelines; the part of the fans added in Recent time is trivial in comparison with that that antedated the lake.

On plate 1 the fluvial deposits of the present streams are mapped as alluvium and distinguished from deposits of older gravels (from the same and comparable streams) which are shown as Quaternary terrace deposits. This distinction is based chiefly on physiographic relations: the terrace gravels are separated from the modern fluvial deposits. In Grass and Crescent Valleys, however, the modern alluvium is deposited on and blends with the older fan deposits so that the distinction is no longer feasible. Here the gravels of the higher slopes are distinguished from the alluvium solely on the basis of grade size of the component materials. In this respect our mapping is inconsistent, for of course the alluvium of the higher stream courses is fully as coarse as that distinguished as gravel in the fans of Crescent Valley. In other words, plate 1 is not consistent either as a portrayal of geologic history (the alluvium being younger than the gravel), nor as depicting grade size of the surficial materials (all alluvium being finer than the Quaternary gravels of Crescent and Grass Valleys). It has nevertheless seemed useful to show the general pattern of distribution of grade size of the valley deposits.

Abundant inliers of bedrock in the gravels near Fye Canyon, north of Cortez, and in the higher part of the drainage of the east fork of Chillis Creek, indicate that these are pediment areas. Uplift along the Crescent fault has allowed Lewis Canyon to dissect the pediment north of Cortez enough to show that the gravels are about 20 feet thick.

That a Pleistocene lake occupied Grass Valley has long been recognized (Russell, 1885, pl. 1; Meinzer, 1922). It has been called Lake Gilbert by Hubbs and Miller (1948). The highest recognizable shoreline is near an altitude of 5,730–5,740 feet. It appears to be essentially undisturbed, except that it has been displaced a few feet by faults northwest of the mouth of Fye Canyon. The shoreline is marked by beaches, spits and bars, some of which have undrained depressions behind them. Except for the large embankment that crosses Grass Valley near the south boundary of T. 26 N., the volume of material in the beaches and bars is not very large. This is not a measure of the duration of the lake, however, for the part of the lake in this quadrangle was not much more than 120 feet deep at its highest recorded stage. The lowest point of potential overflow to Crescent Valley via Cortez Canyon is at least 120 feet higher than the highest recognizable water level. Despite this difference, the fish faunas of streams tributary to Grass Valley are so similar to that of the Humboldt River as to suggest that the Grass Valley lake overflowed into the Humboldt at one time (Hubbs and Miller, p. 35–36). If so, it must have been early in Pleistocene time. The lowest strand line of the receding lake marked by a beach bar is at about 5,655 feet altitude.

Most of the old lake bottom is occupied by fine sandy clay deposits and the part below about 5,620 feet is even now flooded during the rainy season and desiccated during the dry, as a typical playa.

Surrounding the normal playa floor in Grass Valley is a belt of dunes about a third of a mile wide. These are not migrating very rapidly, but they are still being added to. Each is surmounted by a clump of shrubs which apparently serves to trap clay galls blown from the mud-cracked surface of the playa during the dry season. These rolling clay pellets accumulate in piles and are stabilized during the next rainy season when they are saturated with water and the clay particles clotted into the individual clay galls lose cohesion and collapse into a massive deposit.

There is no readily recognizable record of a perennial lake in the part of Crescent Valley embraced in this quadrangle; all the deposits here seem referable to the flood plain of Chillis Creek as it debouches into the playa. The deposits are very fine grained sandy silt with very fine grained sand. Probably some formed in a lake, however, as faint shore features have been recognized farther northeast in Crescent Valley at altitudes of 4,760–4,830 feet (L. J. P. Muffler, written commun., 1962). At present the playa of Crescent Valley rarely rises above an altitude of 4,730 feet and thus lies several miles north of the map boundary.

STRUCTURAL GEOLOGY

GENERAL FEATURES

Because of the dramatic facies contrasts represented by Paleozoic rocks of essentially equivalent ages, it has been necessary to anticipate some of the results of structural investigations merely to describe the stratigraphy. This section describes the structural geology of the area systematically, in the order in which the several elements seem to have developed. The fault names are shown on plate 1.

Structures of four distinct episodes have been recognized in the Cortez area; there may have been at least two more, but the record is obscure. The earliest episode is that of the Antler orogeny (Roberts, 1951), during which we infer the Roberts thrust to have been formed. Although the evidence is not conclusive, it seems that the warping of the thrust into the antiforms in which erosion has exposed the large window of the Cortez Mountains and northern Toiyabe

Range, and the smaller ones south of the Wenban fault in the Toiyabe Range, also developed at the same time. The age of this deformation we consider, on regional evidence, to be probably latest Devonian or Early Mississippian (Roberts and others, 1958; Gilluly and Gates, 1965).

Deep erosion followed the Antler orogeny, and the Brock Canyon Formation, of Pennsylvanian or Permian age, was deposited with marked unconformity on the stumps of the mountains of the Antler orogeny. Later, at a time not locally determinable, but perhaps Triassic or Jurassic, the area may have been overridden by a higher thrust sheet which has since been removed by erosion, but has left its mark in the shearing off of the Brock Canyon Formation from its depositional site. No other structures of the area can confidently be attributed to such an episode, but the Mill Canyon stock may have been emplaced late in the mountain-building cycle, as so many stocks have been elsewhere.

A third episode of deformation is recorded by the Copper and Wenban faults and the homoclinal tilting of the Caetano volcanics. These two phenomena may not have been connected, either mechanically or in time, but in absence of definite evidence to the contrary it is convenient to consider them together. The age of this deformation is known only as some time in the mid-Tertiary.

The last recognizable chapter of structural history involved the formation of the Basin Range faults, a process that is undoubtedly still going on. This episode blocked out the present ranges and major valleys. Tilting of the blocks between the major faults has produced the southeastward dip of the basaltic andesite of the Cortez Mountains and steepened the eastward dip of the Caetano tuff of the Toiyabe Range.

STRUCTURES RELATED TO THE ANTLER OROGENY

The Antler orogeny involved intense deformation over an area extending at least as far west as the Sonoma Range (60 miles to the west) and as far east as the Sulphur Springs Range and over a wide belt north and south (Roberts and others, 1958). In the Cortez quadrangle it is recorded by the Roberts thrust and the deformation of the rocks associated with it. If any structures in the area were formed prior to the Roberts thrust, the Antler orogeny has so modified them that their distinction has become impossible.

ROBERTS THRUST

The Roberts thrust is widely exposed in the Cortez quadrangle, in all three of the mountain ranges represented here. In the northwest corner of the quadrangle, in the foothills of the Shoshone Range, it bounds the limestones of the eastern facies at the southern end of the Gold Acres window (Gilluly and Gates, 1965). The thrust is here considerably warped and broken by subsidiary shears so that its outcrop pattern is complex, but it clearly dips generally west southwestward and passes beneath the alluvium of Crescent Valley. The hanging wall here is composed of the Valmy Formation.

The Roberts thrust reappears in the Basin Range scarp of the Toiyabe Range at a point about 1 mile southwest of Copper Canyon where it brings Slaven Chert in the hanging wall over Wenban Limestone. The dip here is almost south. There is a sliver of Slaven Chert dragged into the Wenban block, but this is cut off on the spur south of Copper Canyon, where the trace of the thrust turns southeastward to the alluvial cover at the head of Cortez Canyon. The dip in this area is at moderate angles to the southwest, and there are many exposures of the actual fault. Locally, near Copper Canyon the thrust is followed by a dike. The hanging wall here is composed of Fourmile Canyon, Slaven, and Vinini Formations at various places; the footwall is Wenban Limestone.

The fault is buried beneath the alluvium of the north end of Grass Valley and must, of course, be considerably offset by the Cortez fault. It appears in the scarp of the Cortez Mountains about 3 miles south of Cortez where it has Vinini Formation in the hanging wall, resting on a considerably sliced body of Pilot Shale, Wenban Limestone, and Hanson Creek Formation. The fault here dips 30°–50° SW. The trace gradually climbs the mountain front to the southeast for about 1 mile and then swings gently eastward and then northeastward to the mountain crest, on the east side of which it passes trending north beneath the Tertiary gravels of Horse Creek. In this segment the dip swings gradually from southwest through south, southeast, and east, and the fault is much complicated by minor branching slivers. It here constitutes a zone more than one-fourth of a mile wide at the fold axis, made up of a complex of lenses of rocks of both eastern and western facies. The Vinini forms the hanging wall throughout this extent, but the footwall is a complex of Wenban Limestone, Pilot Shale, and perhaps Hanson Creek dolomite, in slivers too small to distinguish on plate 1. This piling up of minor thrust slivers on the axis of the fold in the thrust is a suggestion, though of course not a proof, that the folding of the thrust as concurrent with the translation of hanging wall over footwall rather than having been brought about by subsequent folding of a fault no longer active (Gilluly, 1960).

On the east flank of the range the Roberts fault is buried by Tertiary gravels for about 1½ miles, but reappears for a short distance on a

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low spur of the range about 3 miles west-northwest of the Horse ranchhouse, and thence northward can be closely bracketed by exposures of eastern and western facies rocks through the Quaternary gravels. At the head of Horse Canyon the fault is well exposed, with Vinini in the hanging wall and Wenban Limestone in the footwall. It dips about 30°–50° E. and strikes nearly north across the head of Willow Creek and into Mill Canyon, where the Fourmile Canyon Formation overlies the Wenban Limestone of the eastern facies.

The thrust is cut out by the Mill Canyon stock for about 1 mile but reappears on the east wall of Mill Canyon about 1¼ miles above the mouth, with a moderate eastward dip which it maintains to the Crescent fault, half a mile north of the canyon mouth. In much of this segment the fault is a zone of slivers of Wenban Limestone and Fourmile Canyon Formation, some large enough to map and others much too small, shown on plate 1 as "Undifferentiated Paleozoic."

This whole window of the Cortez Mountains seems almost certainly the continuation of the Gold Acres window of the Shoshone Range, interrupted by the great Crescent fault and the alluvial fill of Crescent Valley.

South of the Wenban fault in the Toiyabe Range the Roberts thrust also appears, bounding several windows in which the Wenban Limestone is exposed. The largest of these, exposed from the hillside north of Woods Spring to the south edge of the map area, is bounded by a warped surface of the Roberts fault which swings with centrifugal dips about the Wenban exposure. For the most part the Slaven Chert forms the frame of the window and there is a klippe of this formation on the spur south of Woods Spring; at the southeast side of the window the hanging wall is Valmy.

The southwest side of this window is masked by Tertiary gravel and alluvium, but the fault probably swings in an arc beneath this cover to reappear in the southernmost canyon of the Carico Lake drainage, southwest of Bald Mountain, where more than 1 square mile of Wenban exposures lie. The fault here has a relief of more than 800 feet and rises to the divide west of Bald Mountain only to drop into the next valley to the north with a dip approaching 60°. As it is followed along the northeast side of this window, it is actually nearly vertical in places, though the general dip is probably about 50°. The frame of this window is Slaven Chert, but the west side is masked by Tertiary gravel.

Two other much smaller windows of Wenban Limestone appear just south of the Wenban fault. The eastern is framed by Valmy, and the short exposed section of the western is also overlain by this formation before being covered on the west by gravel.

The warping of the Roberts thrust in the Toiyabe Range south of the Wenban fault seems to be considerably more irregular than that in the northern Toiyabe Range and Cortez Mountains, although the exposed relief of the fault is only a few hundred feet in the southern area and more than 4,000 feet in the northern. This difference perhaps might be due to the fact that the Slaven Chert (which forms one wall of the thrust over much of the southern area) is much more plastic than the bulk of the Fourmile Canyon, Vinini, and Valmy Formations which overlie the fault around most of the northern window. (See fig. 10).

STRUCTURE OF THE LOWER PLATE OF THE ROBERTS THRUST

In the Cortez Mountains, the dominant structure of the rocks of the eastern facies is a remarkably even southeast-dipping homocline that extends from Mount Tenabo almost to the south end of the window. Only at the sharply folded thrust is the homoclinal structure interrupted by thrust slivers of parautochthonous formations more or less parallel to the fault itself. In the north end of the Toiyabe Range the well-exposed Wenban Limestone has been much more folded, on northerly axes near the Roberts thrust, but on more irregular trends farther east. In the country south of the Wenban fault the exposures of the eastern facies rocks are poor, but there is a suggestion of anticlinal folding somewhat like the antiform of the Roberts thrust itself.

The rocks beneath the Roberts thrust in the Cortez Mountains are cut by many normal faults. Most of these trend generally east, northeast, or southeast, and several can be traced to the junction with the Roberts thrust, which they fail to cut. It is evident, therefore, that these faults are either older than the Roberts or of essentially the same age. They were probably formed in response to the differential stresses that must have prevailed during the thrusting of the great pile of rocks of the western facies over the underlying plate. Similar faults have been mapped in the Gold Acres window across Crescent Valley to the northwest. Comparable structures have not been recognized in the windows south of the Wenban fault, perhaps because only the Wenban Limestone appears beneath the thrust, and it is poorly exposed, with much shaly limestone scree covering the slopes.

STRUCTURE OF THE UPPER PLATE OF THE ROBERTS THRUST

The upper plate of the Roberts thrust is composite; it is composed of many slivers of rock of the western facies, all faulted together with little apparent system. In general the fault slivers roughly parallel the Roberts thrust and join at narrow angles; there are no high-angle transcurrent faults between them. The slivers are relatively thin normal to their extent and generally are roughly parallel to the bedding of the component formations. Several of them are nevertheless several thousand feet thick. The implication is clear that there was a very thick pile of thrust plates overlying the Roberts thrust is this area; it was not here an erosion thrust. Despite the thickness of the upper plate, there is no notable metamorphism along the thrust. The rocks are sheared, sliced, and drawn out parallel to the fault, but there has been no observable neomineralization. Although the rocks are folded with a structural relief measurable in thousands of feet, these folds seem generally coaxial with the folds of the thrust and not simple folds developed independently within the thrust mass.

AGE OF THE ROBERTS THRUST

The age of the Roberts thrust is determinable in the Cortez quadrangle merely as post-Pilot Shale (Devonian and Mississippian(?) and as pre-Jurassic, on the premise that the radiometric date for the Mill Canyon stock is correct. Regional evidence suggests a Late Devonian or Early Mississippian age, however. This is the date of deposition of thick conglomerates derived from western-facies rocks in the areas of the Piñon and northern Sulphur Springs Ranges (Roberts and others, 1958; J. Fred Smith, Jr., oral commun., 1959).

STRUCTURES OF THE POST-TRIASSIC(?)–PRE-TERTIARY OROGENY

The only structure recognized that is referred with some question to the post-Brock Canyon–post-Triassic(?)–pre-Tertiary orogeny is that recorded by the basal shearing off of the Brock Canyon Formation in the three small outcrops in the northeast corner of the map. It has already been suggested that the Brock Canyon here is probably parautochthonous and not far removed from the site of its deposition. The basal shearing seems to imply that the rocks were dragged along by an overriding thrust sheet. No remnants of such a sheet are preserved in this area, but there are several in the Shoshone Range 15 miles to the northwest. These thrusts involve rocks as young as Triassic(?) (Gilluly and Gates, 1965).

If the Mill Canyon stock is connected with this orogeny, as seems possible, its emplacement involved only minor deformation of the wall rocks.

STRUCTURES OF THE EARLIER VOLCANIC ROCKS

Most of the Caetano Tuff has a homoclinal dip to the east, much steeper than can be accounted for by tilting during the Basin Range faulting. The mass is cut off abruptly by the Wenban and Copper faults and, since it is absent in the Cortez Mountains, by a fault concealed beneath the alluvium of Grass Valley to the east. Although the western exposures of the tuff exhibit a westward dip and thereby a flexture in the mass, most of the eastward tilting is presumably due to faulting, perhaps before the close of the volcanic episode, as would be implied if the tuff were really deposited in a volcanic-tectonic depression such as has been suggested (Masursky, 1960). On the other hand, the consistent attitudes of the several fault blocks of tuff, both here and in the Shoshone Range to the west, and their independence of the faults that terminate the volcanics on strike both seem to suggest structure not necessarily related to volcanism. The steep tilt, however, seems to have been confined to the graben as, judging by present attitudes, it can hardly have affected the country to the south of the Wenban fault nor that to the north of the Copper fault. In other words, the tilting of the Caetano volcanics is not the simple result of repeated block tilting such as characterizes the Basin Range fault blocks in general, but is localized within the graben, at least in the Toiyabe Range.

So little of the area of rhyolite of Fye Canyon is in the map area that little can be said as to the general structure associated with that rock. The tilting, though dominantly eastward, is highly irregular and also seems not to be connected with the Basin Range faulting, which it surely preceded, at least in part. The suggestion is that the faulting, both of these rocks and of the Caetano Tuff, was probably related to vertical displacements of magma at depth during the several volcanic episodes.

BASIN RANGE FAULTS

The faults to which most of the present major relief features are due are those of the Basin Range system. The great fault, here called the Crescent fault, fronting the Cortez Mountains on the west and northwest, enters the quadrangle from the north, where it presents one of the most impressive scarps of the entire province, curves through an arc of nearly 90° to a nearly west trend, and then swings in an inverse convexity back to a south-southeast trend along the front of the northern Toiyabe Range. At the west-trending segment, a large branch, the Cortez fault, splits off on a trend slightly east of south to front the Cortez Mountains.

The displacement on the Cortez fault near Tenabo Peak is at least 2,000 feet and may be as much as 3,000. The displacement must diminish southward but cannot be measured beyond the last exposure of the Wenban Limestone in the hanging-wall block. Possibly the fault is continuous with the one fronting the Simpson Park Range in the southern part of the quadrangle. Toward the south the fault becomes distributive over a zone more than half a mile wide. Movement along some of the branches has offset some of the high beach lines of the Pleistocene Lake Gilbert in Grass Valley; other scarps have been crossed by the beaches.

The displacement on the Crescent fault is about 10,000 feet, on the assumption that the cuesta-forming basaltic andesite covering the east slope of the Shoshone Range continues southeastward beneath Crescent Valley at the same general dip until it meets the Crescent fault. On the upthrown side of the Crescent fault, in this quadrangle, the dip of the basaltic andesite, projected to the fault, would bring it to about 9,400 feet, whereas the altitude as projected to the fault from the Shoshone Range in the hanging wall is roughly at sea level or perhaps 1,000 feet below. That the depth of alluvium in Crescent Valley is consonant with such a displacement as these figures imply is supported by the gravity measurements by Don Plouff, of the U.S. Geological Survey, reported elsewhere (Gilluly and Gates, 1965).

West and south of the point where the Cortez fault splits off, the displacement of the Crescent fault cannot be accurately measured. It continues south into the Caetano Tuff which appears to be repeated by it in the area near Francis Cabin. The duplication is real but probably antedates the Crescent fault, as discussed in the next paragraph.

The Crescent fault probably is not responsible for the duplication of the Caetano Tuff but is alined by chance with an older fault which had already duplicated the tuff section before the Basin Range faulting began. The fact is that the topographic displacement, which everywhere to the north marks the Crescent fault, diminishes abruptly south of Copper Canyon. The presumed older fault on strike, which has repeated the tuff (a displacement of about 8,000 ft) probably could not have undergone anything like this much movement in time so geologically recent as that of the Basin Range faults. Not only is there no topographic evidence of the fault that duplicates the tuff, but the fault is offset at Francis Cabin by a cross fault which also has no topographic expression except that drainage follows the breccia zone. For these reasons, the Crescent fault is considered to die out in the mouth of the canyon that drains the Francis Cabin area, even though a major fault extends on its trend up this canyon.

A branch of the Crescent fault probably extends almost west from the point where the Crescent fault trends west, a mile or so northeast of the mouth of Cortez Canyon. Such a branch is suggested by the curved scarp which has displaced the surface of the alluvial fans by as much as 25 feet in the area just east of the northwest tip of the hills underlain by the Caetano Tuff. Presumably the fault responsible for this scarp may continue eastward to a junction with the Crescent fault but has not undergone any displacement in its eastern segments recently enough for scarps to be preserved.

Toward the north, the Crescent fault has offset the surfaces of alluvial fans by as much as 15 feet vertically, but evidence of displacement so young as to be expressed in such evanescent features diminishes southwestward, and none was seen south of Copper Canyon.

The tilting of the cuesta of basaltic andesite that forms the southeast slope of the Cortez Mountains is attributed to a "trap-door" tilting of the whole range, through an angle of about 5°–8°. Presumably the tilting of the northern Toiyabe Range was somewhat less, as the scarps die out in that area, but there is no reference surface, such as is supplied by the basaltic andesite of the Cortez Mountains, with which to check this inference.

The west side of the Toiyabe Range very probably is also determined by a Basin Range fault, but one that is somewhat older than the Crescent fault so that its scarp has become reduced by erosion.

Age of the Basin Range faults.—The local preservation of scarps in very weak, unconsolidated alluvium clearly suggests that some movement of the Basin Range faults has taken place in Recent time. Indeed, the historic earthquakes of the Cedar Mountains (Gianella and Callaghan, 1934), Stillwater (Slemmons, 1956), and Mount Tobin (Page, 1935) Ranges to the west suggest the possibility that movement may resume on these at any time; the faults may be only quiescent, not dead. The date of their beginning is uncertain, but from the fact that they displace fossiliferous lower Pliocene rocks in the Shoshone Range (Gilluly and Gates, 1965), their oldest movement here is probably Pliocene. Certainly the basin of Grass Valley, which was formed by this kind of faulting, had much its present shape during the pluvial time of the late Pleistocene.

MINING HISTORY

The history of mining in the Cortez area up to 1936 was summarized by Vanderburg (1938), and his account furnishes the principal basis for the present statement.

Prospectors from Austin located silver veins in the Cortez district in 1863. The discovery lode was the St. Louis, on the southwest flank of Mount Tenabo. Simeon Wenban, one of the original locators, remained very active in the mining industry of the district for more than 30 years. In association with George Hearst, Wenban formed the Tenabo Mill and Mines Co. and bought up most of the principal properties, including the Garrison, St. Louis, Mount Tenabo, Fitzgerald, and Arctic mines. Altogether they controlled 690 acres of mineral land and 520 acres of mill sites and water rights. In 1867 Wenban purchased Hearst's interest; it is said that the profit from the transaction was an important factor in the foundation of the Hearst fortune. At first the ore was hauled 60 miles by pack train to Austin for reduction. One shipment of 62 tons yielded $36,997 or nearly $600 per ton (Raymond, 1869). In 1869 an 8-stamp mill in Mill Canyon was acquired. This mill was later enlarged to 16 stamps and 4 roasting furnaces.

In 1886 a new mill was built near the Garrison mine. It achieved a silver recovery ranging from 85 to 90 percent. From 1889 to 1892 the Tenabo Mill and Mines Co. was operated by the Bewick-Moreing group, an English syndicate, under the name of Cortez Mines, Ltd. The lease expired in 1892. Wenban died in 1895, and his heirs continued to operate the mine until 1903. Only lessees operated the mine from then until 1919, when the property was sold to the Consolidated Cortez Silver Mines Co. The production between 1908 and 1915 was largely from retreatment by cyanidation of the tailings from the Garrison mine.

In 1923 the Consolidated Cortez Silver Mines Co. built a cyanide plant of 125 tons daily capacity at Cortez. This plant was operated until late 1927 when it was converted into a flotation plant with capacity of 150 tons per day. Most of the mill heads were old dump. The operations stopped in January 1930 because of low silver price and depleted reserves, and the company became bankrupt. In 1937 the receiver was instructed by the court to accept an offer from a new Nevada company, the Cortez Metal Co., to distribute stock representing 45 percent of its capital to the creditors of the old company in return for title. The reorganized company has never operated the mines on its own account; in recent years only minor leasing operations have gone on at Cortez.

Mill Canyon is generally included in the Cortez district, but its production has been very small, even though many properties have been intermittently active for many years. The majority of the properties are owned by the Roberts Mining and Milling Co., which operated a 25-ton cyanide plant for a short time in the late 1930's.

The total production of the Cortez district up to 1908 was estimated by W. H. Emmons (1910, p. 101) at $10 million. Vanderburg gave the same estimate for the period 1863–1903. He estimated the total production of the Mill Creek area at about $200,000, chiefly in shipping ore (1938, p. 23). Production records since 1901 are given in table 11.

TABLE 11.—*Production of gold, silver, copper, lead, and zinc, in terms of recovered metal, from the Cortez district, 1902–57*

[Data from annual volumes of Mineral Resources of the United States, published by the U.S. Geological Survey to 1925 and by the U.S. Bureau of Mines from 1925 to 1931, and from annual volumes of Minerals Yearbook, U.S. Bureau of Mines, 1932–57]

Year	Gold (fine oz)	Silver (fine oz)	Copper (lb)	Lead (lb)	Zinc (lb)	Total value
1902	289. 28	214, 094	5, 907	12, 564	--------	$120, 686
1903	858. 46	149, 343	3, 100	20, 489	--------	99, 332
1904	489. 60	115, 902	13, 963	16, 726	--------	79, 330
1905	96. 75	37, 540	64	56, 827	--------	27, 354
1906	66. 81	8, 792	--------	21, 315	--------	8, 487
1907	42. 33	5, 000	--------	--------	--------	4, 175
1908	73. 00	18, 700	7, 773	9, 095	--------	12, 828
1909	283. 62	40, 459	1, 000	10, 721	--------	27, 493
1910	--------	--------	--------	--------	--------	--------
1911	26. 99	7, 712	2, 022	31, 970	--------	6, 337
1912	294. 97	52, 429	803	46, 893	--------	40, 584
1913	282. 36	54, 196	1, 581	83, 791	--------	42, 503
1914	192. 13	44, 185	402	179, 599	--------	35, 463
1915	816. 84	67, 873	2, 543	84, 068	--------	55, 692
1916	268. 42	42, 139	1, 373	36, 922	--------	36, 162
1917	161. 50	26, 950	7, 434	148, 741	--------	40, 367
1918	101. 52	31, 578	4, 614	160, 030	--------	46, 178
1919	. 78	11, 387	780	63, 358	--------	16, 272
1920	21. 98	7, 872	1, 084	45, 945	--------	12, 908
1921	11. 70	8, 416	368	24, 959	--------	9, 829
1922	35. 09	39, 386	2, 764	26, 625	--------	41, 948
1923	272. 45	172, 466	2, 216	30, 705	--------	149, 529
1924	713. 78	423, 163	5, 021	67, 041	--------	304, 295
1925	671. 68	366, 350	2, 419	46, 417	--------	272, 514
1926	742. 02	345, 381	3, 308	38, 580	--------	234, 406
1927	304. 25	544, 646	13, 770	176, 959	--------	328, 055
1928	443. 22	785, 980	25, 031	364, 617	--------	493, 713
1929	515. 19	493, 766	17, 990	435, 990	--------	304, 460
1930	39. 55	44, 423	1, 768	37, 252	--------	20, 014
1931	13. 53	618	--------	1, 636	--------	519
1932	(1)	(1)	(1)	(1)	--------	(1)
1933	74. 42	18, 424	1, 368	25, 640	--------	9, 022
1934	6. 72	341	--------	240	--------	464
1935	2. 97	3, 829	142	1, 268	--------	2, 919
1936	(1)	(1)	(1)	(1)	--------	(1)
1937	670	16, 772	700	5, 800	--------	36, 850
1938	3, 563	32, 085	1, 000	27, 000	--------	146, 786
1939	6, 354	64, 683	2, 700	27, 000	--------	267, 846
1940	3, 726	82, 585	6, 700	78, 500	271	193, 819
1941	839	9, 145	2, 000	19, 600	8, 000	37, 821
1942	451	6, 598	2, 000	15, 400	--------	21, 751
1943	84	48	--------	--------	--------	2, 974
1944	32	1, 554	--------	7, 000	9, 200	3, 834
1945	--------	--------	--------	--------	--------	--------
1946	--------	--------	--------	--------	--------	--------
1947	43	21, 493	1, 900	33, 000	11, 000	27, 438
1948	40	26, 716	2, 200	50, 700	21, 100	37, 937
1949	20	10, 534	1, 000	15, 400	--------	12, 864
1950	242	25, 092	2, 700	25, 800	--------	35, 225
1951	--------	--------	--------	--------	--------	--------
1952	--------	--------	--------	--------	--------	--------
1953	6	1, 945	400	6, 300	--------	2, 911
1954	35	12, 985	400	67, 700	45, 800	27, 361
1955	35	10, 906	200	42, 600	19, 500	19, 847
1956	--------	--------	--------	--------	--------	--------
1957	13	3, 662	--------	--------	--------	3, 769
Total	24, 418	4, 521, 931	155, 722	732, 893	114, 871	3, 773, 951

[1] Bureau of Mines not at liberty to publish figures, but concealed figures are included in totals.

THE MINES

MINES OF THE CORTEZ SILVER MINES CO.

Nearly all the production of the Cortez district has been derived from the group of mines now consolidated as the mines of the Cortez Silver Mines Co. (See fig. 13.) The principal production has been from the Garrison mine and the Arctic tunnel. Each of these levels has several thousand feet of workings and innumerable inclines, raises, and winzes, driven in following the tortuous manto ore bodies from which the major production of the mine has been derived.

Most of the ore bodies were in the Hamburg Dolomite, beneath the Eureka Quartzite, but they did extend across the quartzite locally; some ore was won in the basal part of the Hanson Creek Formation. Mine maps indicate, and W. H. Emmons reported (1910, p. 103–105), that the ore bodies were of two kinds: blanket and pipe replacement bodies (mantos) in the Hamburg Dolomite, and fissure veins. Of these, the manto deposits were far the more productive, even though there have been many thousand feet of work done on the veins.

The mantos are highly irregular bodies. (See stope patterns in figs. 14, 15.) Although some of the blanket deposits tend to lie roughly parallel to the bedding, for the most part the replacement has been highly irregular and localized by obscure factors. Some individual bodies as much as 100 feet wide and several scores of feet high have been followed for many hundreds of feet.

The minerals composing the ore are quartz, calcite, galena, stibnite, pyrite, sphalerite, stromeyerite, tetrahedrite, and other minerals containing antimony and arsenic; in the upper levels the ore bodies were highly oxidized and consisted of silver chloride, copper carbonates, and oxides of iron and manganese. The galena was very rich in silver, especially where coated by films of sooty sulfide, presumably argentite. Commonly, mill heads ran 30–80 ounces silver and 0.15 ounces gold to the ton (Emmons, 1910, p. 104).

The fissure veins are commonly localized along and near dikes, of which several are cut in the workings. Most trend east-southeast and dip steeply. The dikes, although now highly decomposed to kaolin and calcite, were presumably quartz porphyry. Locally they are bordered by hornfels containing tremolite, actinolite, orthoclase, pyrite, sericite, biotite, quartz, and calcite (Emmons, 1910, p. 104).

W. H. Emmons reported (1910) that the dikes have been strongly sheeted parallel to their extent and the sheeting extends into the wallrock in places. The fissures were filled with banded sulfide ore; where it was oxidized in the upper levels these veins were profitable, but on the lower levels most were of too low grade. Evidently gold was associated with the pyrite in ore which locally yielded 0.75 ounce of gold to the ton but which averaged only about a fifth of that.

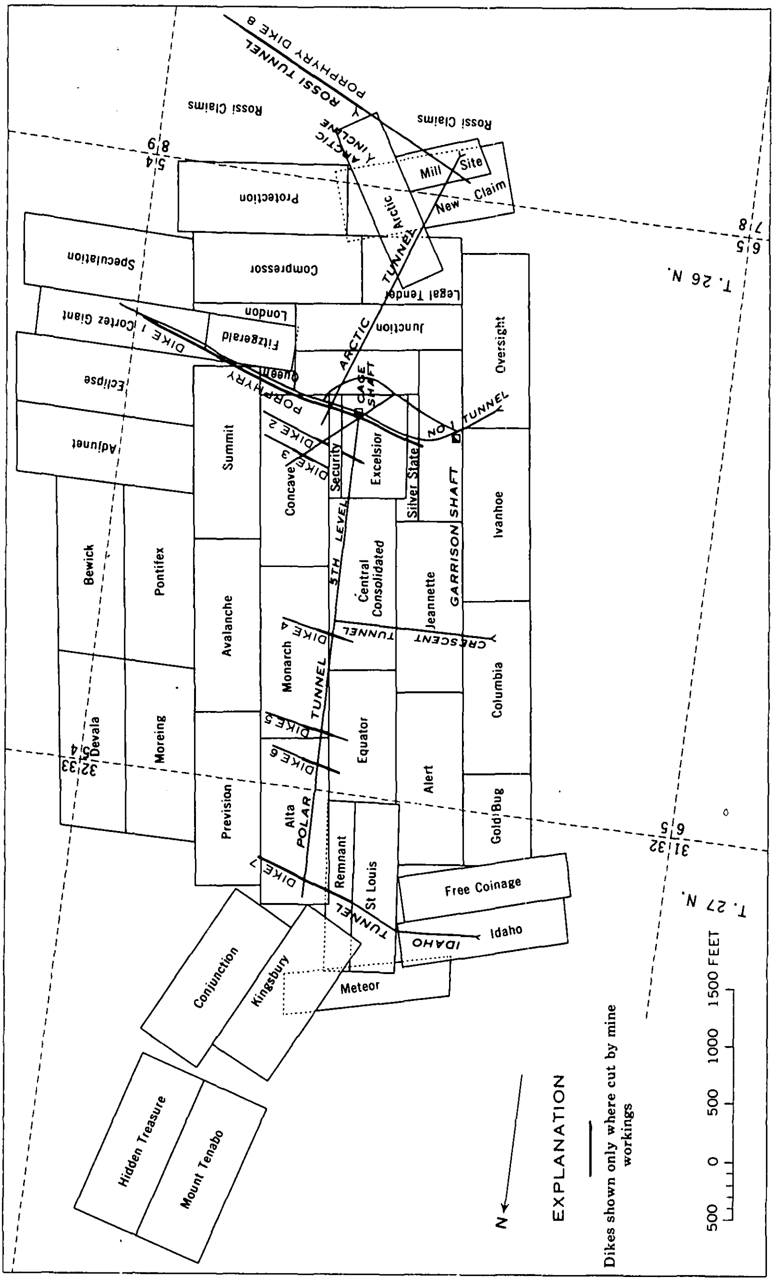

FIGURE 13.—Map showing the principal claims of Cortez Silver Mines Co., Cortez, Nev.

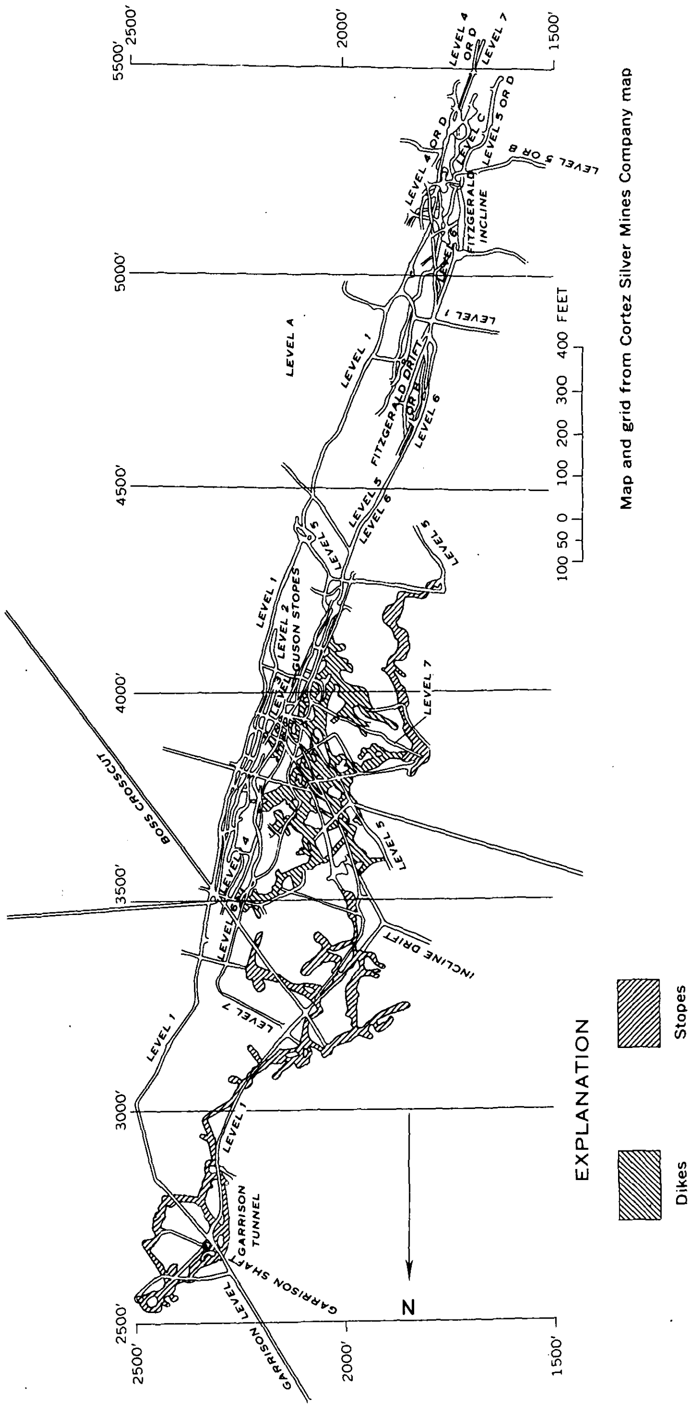

FIGURE 14.—Composite map of the mine workings of the Cortez Silver Mines Co.

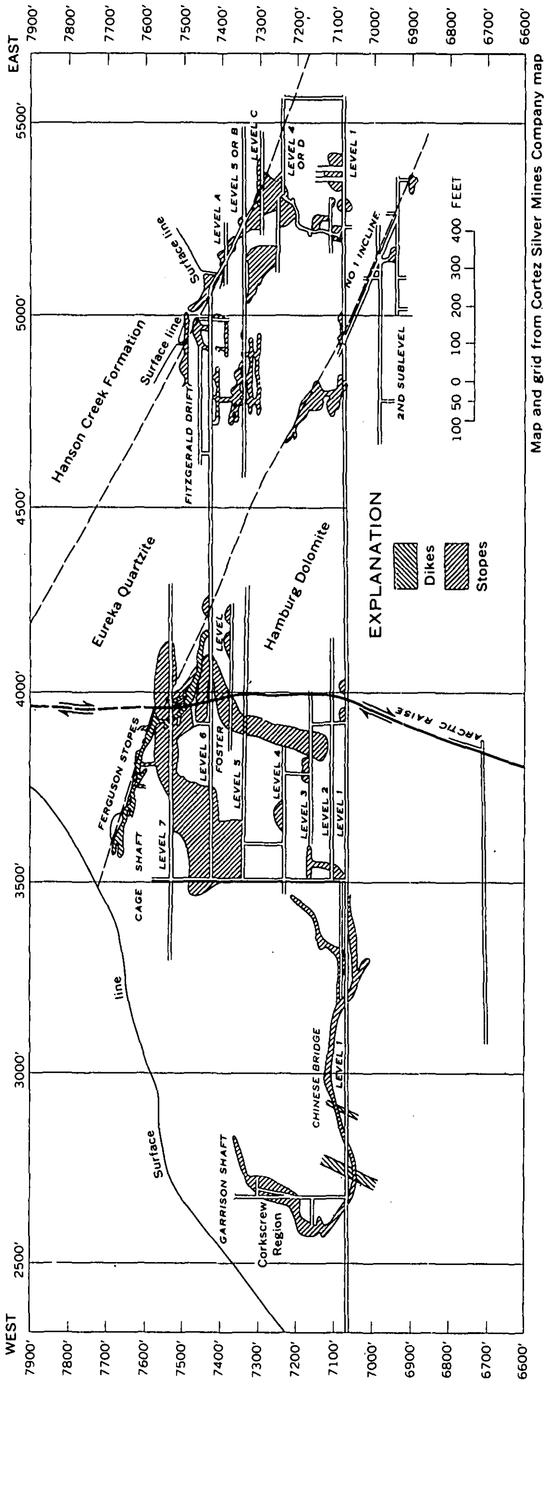

Figure 15.—Composite section of the mines of the Cortez Silver Mines Co.

The deepest workings of the Cortez mines are about 200 feet below the Arctic tunnel. At this depth there are only seams of oxidized material in the veins and mantos; most of the sulfides are unaltered. Water is scarce in the mine, and pumping costs can hardly have been an important element in the economics of the operation.

MILL CREEK MINES

The area north of Mount Tenabo that drains to the north front of the range rather than to Grass Valley is called the Mill Creek area; it is part of the Cortez mining district. The quartz monzonite and its bordering rocks are widely mineralized, but thus far none of the deposits discovered has been a large producer. Most workings were inaccessible at the time of this survey.

According to W. H. Emmons (1910, p. 107–108), most of the deposits are fissure veins that strike nearly north, dip east at moderate angles, and consist of banded quartz and sulfides. Intense hydrothermal alteration of the wallrock was accompanied by formation of abundant pyrite, sericite, calcite and quartz. The ore bodies, which consist of quartz, calcite, galena, sphalerite, pyrite, argentite, stephanite, tetrahedrite, and stibnite, have been altered in zones as deep as 100 feet below the surface to spongy quartz that contains cerargyrite, cerussite, and other oxidation products.

Besides the fissure veins there are manto deposits in the Wenban Limestone. According to W. H. Emmons, most of these are close to the intrusive border. They are irregularly shaped, some following fissures and others locally following the bedding. The minerals are calcite, quartz, galena, pyrite, sphalerite and chalcopyrite. Most of the values were in silver, but some deposits also contained considerable gold.

COPPER CANYON AREA

Considerable prospecting has been done in and near Copper Canyon, west of Cortez Canyon in the northern Toiyabe Range, apparently because of abundant small outcrops of copper carbonates. The country rock is Wenban Limestone, cut by highly altered dikes of quartz porphyry, now reduced to clay. According to W. H. Emmons, the Valley View mine, which was active during his visit in 1908 but is now caved, followed a southeast-trending vein along such a porphyry dike. A few hundred feet of workings showed the vein to range from 1 to 5 feet in width and to consist of quartz, galena, pyrite and cerargyrite. The values were in lead, silver, and gold. The production must have been small and is not of record.

TURQUOISE DEPOSITS

Turquoise deposits have been worked in the Toiyabe Range both in the area west of Cortez Canyon and on the south-facing hills at the south side of the quadrangle.

The White Horse turquoise mine has opencuts that expose a white highly altered dike that cuts the Slaven Chert. Veinlets of turquoise 1/16–1 inch thick cut the dike rock and extend into the altered chert. This deposit, which has been known for many years, has yielded some good gem material which has been sold to the Indians of Arizona and New Mexico. Other deposits nearby were found by J. A. Boitano in 1929. These are in veins that cut silicified limestone. Mr. Boitano has reported shipping more than 600 pounds of crude turquoise from this property. James Allen of Austin has also mined a little turquoise in sec. 27, T. 25 N., R. 47 E., which lies both in this quadrangle and in the Walti Hot Springs quadrangle just to the south. In this deposit, turquoise forms veins along the bedding partings in the Slaven Chert.

BARITE

At the time of this survey no barite had been mined in the quadrangle. There had been considerable prospecting, however, both by bulldozer and drill, of a large body of bedded replacement barite in the Slaven Chert of the Bald Mountain area. There appears to be a considerable tonnage of barite in this deposit, but the long haul to the railroad at Beowawe is a drawback to its early exploitation. The Slaven Chert has been similarly baritized over smaller areas in several other parts of the quadrangle.

QUICKSILVER

Bleached and silicified rocks of the Vinini Formation crops out over an area of perhaps 10 acres, just southeast of the forks of Horse Canyon. Sporadic narrow veins of cinnabar have been found in this obviously altered rock, but attempts to exploit them have thus far not been successful.

GRAVITY AND AEROMAGNETIC SURVEYS

By Don R. Mabey

In 1955 Donald Plouff made a reconnaissance gravity survey of Crescent Valley in support of the geologic studies of Gilluly and Gates in the Shoshone Range to the northwest of the Cortez quadrangle (Plouff, 1965). This gravity coverage was extended by Mabey and others to an area of several thousand square miles (Mabey, 1964), and an aeromagnetic survey of the Cortez quadrangle was flown in 1960 under the direction of J. L. Meuschke. The contours based on the gravity and magnetic data collected in the Cortez quadrangle are shown on plate 3.

The gravity data are simple Bouguer-anomaly values referred to Woollard's airport stations at Reno, Tonopah, and Ely (Woollard, 1958). A density of 2.67 g per cu cm (grams per cubic centimeter), is standard for most regional surveys, was assumed in making the altitude corrections. The gravity data of the map are not corrected for terrain effect. The terrain corrections would be small in the valleys and large (as much as 8 mgal) in parts of the ranges, but they would not substantially change the main features of the contour map. Terrain corrections have been applied to the data used in the profile analysis.

The magnetic data were obtained with a fluxgate magnetometer along north-south flight lines 1 mile apart and 9,000 feet above sea level. The magnetic contours show total intensity relative to an arbitrary datum.

GRAVITY ANOMALIES

The Cortez quadrangle is on the northwest side of an extensive regional gravity low centered over a regional highland in east-central Nevada (Mabey, 1960a). The regional gravity gradient across the Cortez quadrangle is a north-northwest increase of about 0.3 milligal per mile.

The most prominent local gravity anomalies in the Cortez quadrangle, as in most areas of the Basin and Range province, are the large gravity lows over the basins. These lows are produced by the contrast between the less dense sedimentary and volcanic rocks of Cenozoic age and the generally denser underlying older rocks, which are exposed in the ranges. Although the largest gravity anomalies are associated with the basins, significant variations do occur in the ranges. The gravity values over the Tertiary volcanic rock at the north end of the Toiyabe Range are lower than those on Paleozoic sedimentary rocks in this and adjoining ranges. Within these ranges gravity anomalies are also produced by the density contrast between the tectonically juxtaposed siliceous and carbonate facies of the lower and middle Paleozoic rocks; these data on the Cortez quadrangle, however, are not sufficiently detailed to define anomalies of this type. In the Bull Run quadrangle in northern Nevada, R. W. Decker (written commun., 1958) has successfully defined the gravity anomaly produced by this density contrast.

Large local gravity lows, which extend beyond the limit of the Cortez quadrangle, occur in both Crescent and Grass Valleys. The gravity lows extend onto the Tertiary volcanic rocks in the north end of the Toiyabe Range. Only a few stations were established in the volcanic rocks, and these do not suffice to define even the main features of the gravity field. The gravity values over the volcanic rocks are, however, low relative to the pre-Tertiary rocks, and considerable gravity relief associated with the volcanic rocks indicates major variations in thickness or density. The gravity values in Grass Valley are lower than those on the volcanic rocks, but the gravity low in Crescent Valley extends onto the volcanic rocks without any large gravity break.

ROCK DENSITIES

The densities of representative samples of the major bedrock types are given in table 12. The eastern facies of the Paleozoic sedimentary rock includes the rocks of highest density, averaging about 0.1 g per cu cm denser than the rocks of the western facies. The quartz monzonite is intermediate and the Tertiary volcanic rocks are less dense than the older rocks. The average density of the Cenozoic sedimentary rocks is difficult to measure directly; in other areas of the Basin and Range province, however, the average densities range from about 2.0 to 2.5 g per cu cm, depending upon the degree of sorting and induration.

TABLE 12.—*Densities of representative samples of major bedrock varieties in the Cortez quadrangle*

Rock type	Number of samples	Density (g per cu cm)	
		Range	Average
Tertiary volcanic rocks (Toiyabe Range)	11	2.23–2.48	2.42
Tertiary basalt	4	2.72–2.81	2.76
Paleozoic sedimentary rocks (eastern facies)	11	2.45–2.81	2.68
Paleozoic sedimentary rocks (western facies)	13	2.43–2.69	2.57
Intrusive rocks	8	2.60–2.69	2.64
Cenozoic sedimentary rocks (fanglomerates)		Estimated	2.3
Cenozoic sedimentary rocks (lacustrine)		do	2.1

GRAVITY PROFILES

Three gravity profiles across the valleys have been analyzed to determine a mass distribution that will produce the measured anomalies. The profiles were computed assuming a two-dimensional model, a reasonable assumption in view of the uncertain density contrasts involved. A density contrast of 0.4 g per cu cm is assumed between the pre-Tertiary bedrock and the Tertiary sedimentary and volcanic rocks and the coarse, poorly sorted or highly indurated Quaternary rocks. The lacustrine sediments underlying the Recent playa are assumed to be 0.6 g per cu cm less dense than the bedrock. These density contrasts are based on analysis of similar gravity

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anomalies in the Basin and Range province, where the thickness of the Cenozoic rocks is known.

The gravity low in Crescent Valley has a marked asymmetry with the lowest values along the southeast side of the valley at the front of the Cortez Mountains. This indicates that the basic structure is an east-southeast-tilted block with the valley fill lying in the down-dropped side of the block. A profile *W–W′* across the front of the Cortez Mountains is shown on plate 3. Plouff (1965), interpreting a similar profile, inferred that the area of deeepest Cenozoic fill is approximately under the lowest anomaly values. His interpretation is based on the assumption that all of the gravity gradient observed in the valley directly northwest of the Cortez Mountains is produced by relief on bedrock underlying the valley and that the only important variation in the density of the fill is vertical. It has been pointed out that lateral density variations within the basin fill must be considered in interpreting gravity data in the Basin and Range province (Mabey, 1960b; Kane and Pakiser, 1961).

If it is assumed that the gravity gradient northwest of the Cortez Mountains is at least partly produced by a density contrast between the coarse, poorly sorted material along the mountain front and the less dense lacustrine sediments in the center or low part of the surface basin, then the gravity data are consistent with a gross structure of a single tilted fault block bounded by a projection of the steep front of the Cortez Mountains. Although I prefer the interpretation shown, it should be pointed out that the gravity data do not preclude the possibility that the contact between the fill and bedrock on the southwest side of Crescent Valley is a more gently dipping surface or is formed by a series of faults such as Plouff has inferred. The depth to bedrock of 7,000 feet indicated on the profile is probably near the minimum that can be expected in the deepest part of the basin. If the density of the fill is higher than that assumed, the depth to bedrock may be considerably greater. Rough geologic projections suggest a depth of 9,000–10,000 feet (James Gilluly, written commun., 1961).

In the northern part of Grass Valley, the gravity low is near the center of the valley. South of the Cortez quadrangle where the valley widens and the western front of the Simpson Park Range becomes more abrupt, the gravity-low configuration is markedly asymmetrical with the lowest values on the east edge of the valley near the abrupt front of the Simpson Park Range.

Profile *X–X′* (pl. 3) extends from the Toiyabe Range near Wenban Spring across Grass Valley and the south end of the Cortez Mountains. In the Toiyabe Range the profile lies very near and parallel to the fault contact between Tertiary volcanic rocks to the north and Paleozoic rocks to the south. Therefore, this end of the gravity profile is not effectively anchored with a station on bedrock. At the west end of the profile, the Cenozoic rocks, which overlie Paleozoic rocks, are denser than the Quaternary sedimentary rocks in the valley. The density distribution within the material overlying the Paleozoic bedrock in the Grass Valley part of this profile is probably much more complex than indicated on the profile. If it is assumed that a vertical fault underlies and is parallel to the west end of the profile, the thickness of Cenozoic material north of the fault probably is half the thickness indicated by the profile. The surface of the pre-Tertiary bedrock slopes east from the Toiyabe Range with no indication in the gravity data of a major structural break on the west side of the valley. The abrupt rise of gravity values directly to the east of the minimum is interpreted as indicating a high-angle fault within the valley. The gravity evidence of a second inferred small fault east of the gravity minimum is not strong, but a fault is suggested by a local steepening the gravity gradient at the contact between the Tertiary gravels and the Paleozoic bedrock.

The amplitude of the small gravity low near the east end of profile *X–X′* indicates that the surface gravels are not more than a few hundred feet thick. The gravity data are not sufficiently detailed to indicate the shape of this gravel body.

The pronounced asymmetry in Grass Valley south of the Cortez quadrangle is apparent on profile *Y–Y′* (pl. 3). The gravity stations along this profile are 1 mile apart and justify only generalized interpretations. The large features on profiles *X–X′* and *Y–Y′* are similar, and apparent differences in the smaller features on bedrock profile may be largely due to the more detailed gravity data available on *X–X′*.

The thickest section of low-density Cenozoic rocks underlying the valley appears to be east of the center of the valley. The inferred maximum thickness of fill in Grass Valley within the quadrangle is about the same as that in Crescent Valley. The upward slope of bedrock to the west is fairly uniform from the deep part to the outcrops in the Toiyabe Range. On the east the deep part of the basin is bounded by an inferred fault which may be continuous with the Cortez fault along the west front of the Cortez Mountains to the north and that along the west front of the Simpson Park Range south of Walti Hot Springs. East of this fault the valley area south of the Cortez Mountains is underlain by bedrock at depths that are shallow relative to that of the area to the west.

MAGNETIC ANOMALIES

The most prominent feature on the aeromagnetic contour map (pl. 3) is the large magnetic high along the northeast edge of the map. The extreme magnetic relief along the easternmost flight line is produced by basalt flows that lay only about a thousand feet below the airplane during the flight. However, a strong local magnetic high extends northwest beyond the flows and marks a swarm of steeply dipping dolerite dikes that cut the Paleozoic sedimentary rocks. This anomaly, which extends several miles to the southeast beyond the edge of the quadrangle, appears to be produced by the dolerite dikes with the effect of the flow material locally superimposed. To the north, the anomaly ends at the Crescent fault. An anomaly in Crescent Valley similar in character and trend to that in the Cortez Mountains is offset about 3 miles to the southwest and may indicate lateral movement along the Crescent fault.

The quartz monzonite stock at Mill Canyon does not produce a large local magnetic anomaly. A high of less than 100 gammas near the south edge of the stock is superimposed on the larger magnetic high to the east. The maximum magnetic intensity of this local feature occurs in a west-trending zone of quartz porphyry dikes and altered sedimentary rock.

The extensive magnetic high on which more local anomalies are superimposed extends beyond the effects of the exposed rocks which cause the local anomalies. This more extensive anomaly, which is only partly defined by this survey, appears to record a deep-seated feature, either an uplift of magnetic basement rock or a large intrusive mass of which the Mill Creek stock is an exposed cupola.

Over the thick Tertiary volcanic rocks in the north end of the Toiyabe Range, the magnetic anomalies are small but the pattern distinctly differs from that over other rocks in the quadrangle. The direct cause of the individual anomalies is not certain, however.

The magnetic high north of Wenban Spring may be a topographic effect at least in part. The magnetic low trending northeast in the Francis Cabin–Caetano Ranch area, may be related to an extension of the Crescent fault and to sedimentary rocks interbedded with the volcanics.

The fault boundaries of the volcanic trough are more apparent on the profile *Z–Z′* than on the contour map (pl. 3). The Wenban fault, along the southern limit of the volcanic rocks, is marked by a steepening magnetic gradient. At the southwest end of Crescent Valley, the volcanic rocks underlie an area covered by Quaternary alluvium. The northern limit of the near-surface volcanics is inferred to be along the south edge of the sharp negative pip on the low-level profile that may mark the buried extension of the Copper fault.

In the area southwest of the pump station at the north end of Grass Valley, the magnetic data indicate that the volcanic rocks underlie the western part of the valley.

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