

GEOLOGIC MAP OF THE PINTO SUMMIT QUADRANGLE,
EUREKA AND WHITE PINE COUNTIES, NEVADA

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By

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INTRODUCTION

The Pinto Summit quadrangle, enclosing an area of a little more than 229 square miles, lies in east-central Nevada; the boundary between Eureka and White Pine Counties runs north-south through the center of the quadrangle.

The region is the site of some of the earliest geologic work in the Great Basin. Most of the quadrangle was included in the area mapped during the survey of the Eureka mining district in the early 1880's under the direction of Arnold Hague (Hague, 1892; Curtis, 1884; Walcott, 1884). The stratigraphic section established during this survey has remained a standard for this part of Nevada, and Curtis (1884) presented not only one of the first descriptions of limestone replacement ore bodies, but also described early examples of geochemical and geophysical exploration methods.

A geologic resurvey of the mining district was begun in 1932 as a cooperative program with the Nevada State Bureau of Mines; it has continued with many interruptions to the present and has extended over all, or parts of, nine 15-minute quadrangles and has been participated in by a number of geologists. Several publications have resulted: a general review of the stratigraphy was published by Nolan, Merriam, and Williams (1956), and papers on the Mississippian strata in the Diamond Range were prepared by Brew (1961a, b, 1971) and on the Chainman and Diamond Peak Formations by Stewart (1962). Merriam (1963) reported on the geology on the west side of Antelope Valley; a report on the Eureka quadrangle, adjoining the Pinto Summit quadrangle on the north, was presented by Nolan, Merriam, and Brew (1971). The geology in the immediate vicinity of the mining district was published by Nolan (1962), and the Ruby Hill ore bodies were described by Nolan and Hunt (1968). Aspects of the paleontology of the Cambrian have been treated by Palmer (1960a, b), the Ordovician by Ross (1970), the Silurian and Devonian by Merriam (1940, in press), the Carboniferous and Permian by Gordon (in Brew, 1971), and the Cretaceous by MacNeil (1939). Blake and others (1969) summarized the Tertiary volcanic history.

In addition to those mentioned above, a number of geologists and paleontologists have been participants in the study of the geology. Bruce Bryant, J. G. Stone, Carl Wentworth, and G. C. Cone have mapped parts of the quadrangle; the areas for which they are responsible, as well as those mapped by Stewart, are shown on an index. J. W. Huddle has provided some most useful information on the conodonts in the Mississippian formations that has been a valuable supplement to the reports of the paleontologists listed above.

Finally, we have benefited greatly from advice and criticism from a number of colleagues. James Gilluly has provided continuing stimulation both in the field and in his review of manuscripts; Robert L. Smith, during a visit in the field in 1970, provided explanations for many of the features of the rhyolite domes and their associated vitrophyres that had previously puzzled us; and R. F. Marvin, E. H. McKee, and M. L. Silberman provided many of the isotopic ages quoted for the igneous rocks, based on material collected in the quadrangle from 1964-70.

The greater part of this text was prepared by the senior author; Blake provided most of the material on the igneous rocks, and Merriam is largely responsible for the Devonian stratigraphic nomenclature and paleontology. The senior author, however, assumes responsibility not only for the structural interpretations, but for all the errors and inconsistencies that inevitably creep into a study in which so many individuals have participated.

SUMMARY OF THE GEOLOGY OF THE REGION

Parts of two of the linear ranges of the Great Basin are included within the Pinto Summit quadrangle. The northwestern part of the quadrangle is occupied by the north end of the Fish Creek Range, just south of the region in which it bifurcates to form Whistler Mountain and the Sulphur Spring Range to the west and the Diamond Range to the east. The town of Eureka lies in this region just north of the quadrangle boundary, at the south end of Diamond Valley.

The southeastern corner of the quadrangle includes the northwestern end of the Pancake Range, which terminates a short distance farther north just east of the eastern edge of the quadrangle.

Separating these two mountain areas is the long belt of relatively low-lying country known as Newark Valley to the north and Fish Creek Valley further south.

The Pinto Summit quadrangle, like the Eureka quadrangle to the north, lies just east of the major structural feature of central Nevada, the Roberts Mountains thrust. This thrust, which was formed in Late Devonian and Early Mississippian time, has brought "western facies" rocks tens of miles eastward over lithologically dissimilar "eastern facies" Paleozoic rocks. The rocks east of the thrust have been deformed and cut by thrust faults; these thrust plates have been folded into a series of north-trending antiforms and synforms. Like the Roberts Mountains thrust, these structurally lower thrust plates have brought into juxtaposition lithologically different facies of contemporaneous rocks, though the degree of difference in the facies is far less than that involved in the major thrust. Unlike it, however, these thrust plates involve rocks of Carboniferous and Permian age, and hence the thrusting in this area must have continued for some time after the main movement on the Roberts Mountains thrust.

In this part of the Fish Creek Range, four antiforms and four synforms (some of them compound) have been recognized. All but the most easterly of the antiforms involve only lower and middle Paleozoic rocks which are, in general, considerably deformed; the synforms are composed dominantly of Carboniferous and Permian sedimentary rocks as well as Cretaceous sedimentary rocks and Tertiary volcanic rocks; the two western ones, however, also include exposures of older rocks.

In the Pancake Range, on the other hand, two synforms are separated by a wide antiform; most of the rocks involved, other than Oligocene volcanic rocks, are relatively undeformed Upper Devonian and Mississippian beds; there are sparse outcrops of a folded plate of Devonian dolomite and limestone on the flanks of the central antiform.

Post-Paleozoic rocks include a thick series of freshwater Cretaceous sedimentary rocks, an Upper Cretaceous granitic stock or plug, and several units of Oligocene igne-

ous rocks; these latter include small intrusive plugs, pyroclastics, flows, and ignimbrites. Both the Cretaceous sedimentary rocks and the Oligocene volcanic rocks are localized in the synforms and were apparently emplaced within them following the folding that formed the antiforms and synforms. Locally, at least, deposition of the younger rocks occurred shortly after the antiforms were relatively elevated along steep "normal" faults that developed along the boundaries of the folded belts.

Local exposures of younger Oligocene and Miocene flows and ash-flows are found in the quadrangle; most of them occur near the eastern boundary, where they seem, in part at least, to be parts of units that are widespread to the east and south (Cook, 1965).

Much of the quadrangle was covered by a thick blanket of middle and upper Tertiary and Quaternary gravel; it is now being stripped as a result of elevation of the mountain areas along so-called basin and range faults. Some of these faults appear to have followed in part the older faults that separate antiforms and synforms. Others, however, transgress the older structures at considerable angles; they branch and die out, and locally a few exhibit curved traces.

The quadrangle includes the southern part of the Eureka mining district, including the southern continuation of that district into the Secret Canyon area. Farther east, the Silverado district and the Alhambra Hills have also been productive, though much less so. Essentially all of the mineralization, as well as the small plug of Cretaceous intrusive rock, are restricted to the antiforms.

STRATIGRAPHY

All divisions of the Paleozoic are represented within the quadrangle by marine sedimentary rocks; Cretaceous beds are, however, all of nonmarine origin, as are the widespread Tertiary and Quaternary gravels, stream deposits, and lake beds.

The existence of different lithologic facies in superposed or adjoining thrust plates in the vicinity of Eureka has been noted in previous reports (Nolan and others, 1956, p. 3-5; Nolan and others, 1971). The newer geologic mapping in the Pinto Summit quadrangle has confirmed, and extended, knowledge of these facies changes. The additional knowledge, and some examples of facies changes that are especially well shown in this quadrangle, are briefly noted below.

The earlier noted transition from dolomite in the originally more easterly facies to limestone in the westerly facies is well shown within the quadrangle by some of the Devonian units; the change correlates with the approach to a eugeosynclinal environment from miogeosynclinal deposition to the east. Higher in the section, some of the Carboniferous and Permian formations, through the presence of both fine-grained and coarse clastics in the originally more westerly facies, reflect changes in proximity to a western shoreline that was nearer at hand than during the earlier Paleozoic sedimentation.

Cambrian and Ordovician rocks.—The thick sequence of Cambrian and Ordovician rocks in the Eureka district was originally described by Hague (1892) and Walcott (1884); it has been the standard section for this part of Nevada. In the Pinto Summit quadrangle the rocks are mainly restricted to the most westerly antiform; this block encompasses all of Prospect Ridge and the adjoining hills to the east and south and is here called the Prospect Ridge antiform. These older formations are economically important, in that they form the wall rocks for most of the ore bodies of the Eureka mining district.

The Cambrian rocks are both more poorly exposed and more highly deformed in the Secret Canyon area than farther north. There has been, moreover, less extensive mining development in the southern area, and hence fewer underground exposures.

The geologic sections that cross this southern area are of necessity speculative because of the poor exposures, and the thicknesses of the several formations shown are those measured in the regions to the north. The thicknesses of some of the units may be found to be quite different as a result of the considerable deformation they have undergone. This is particularly true of the Dunderberg Shale, which has acted as the gliding plane at the base of a fault that in Ratto Canyon appears to form the boundary between the Prospect Ridge antiform and the synform to the west.

The Ordovician rocks are also both poorly exposed and deformed in the southern extension of the Prospect Ridge antiform. On Round Top Mountain, in Secret Canyon, limestones of the Pogonip Group are exposed both above and below the Dugout Tunnel thrust fault; Eureka Quartzite in the upper plate of this thrust overrides Pogonip limestone in a number of places, both here and in Rocky Canyon.

The largest exposure of the uppermost Ordovician formation, the Hanson Creek Formation, is near the mouth of New York Canyon. It, like smaller exposures on Hoosac Mountain and on the southwest flank of Prospect Peak, is thoroughly brecciated.

Less extensive exposures of Cambrian and Ordovician rocks are found in two other structural blocks. In the eastern part of the Grays Peak synform, which borders the Prospect Ridge antiform on the west, a linear belt of recrystallized and mineralized Eureka Quartzite caps the ridge on the west side of Ratto Canyon. It dips steeply and is bounded on the east, at least locally, by a steep fault that separates it from poorly exposed, folded outcrops of Dunderberg Shale, Windfall Formation, and beds of the Pogonip Group.

A second exception to the restriction of the Cambrian and Ordovician rocks to the Prospect Ridge antiform is just east of South Gate on the southwest flank of English Mountain. Here a small exposure of east-dipping, uniformly dark-brown dolomite that locally shows a fine banding conformably underlies light-gray dolomite assigned to the Lone Mountain Dolomite (Silurian). The brown dolomite is similar in appearance and position to exposures of the Hanson Creek Formation (Upper Ordovician) on Lone Mountain, and has therefore been so mapped.

The limestone facies of the Hanson Creek (Nolan and others, 1956, p. 32-33) that is found to the west is not exposed within the quadrangle.

Silurian rocks.—Massive light-gray coarsely crystalline dolomite assigned, on the basis of lithology, to the Lone Mountain Dolomite of Silurian age occurs in four of the structural blocks within the quadrangle. In none of the occurrences have identifiable fossils been found nor, unfortunately, were any complete sections exposing both top and bottom of the formation recognized. It is, therefore, uncertain what the total thickness of the unit may be or if, as is perhaps probable, the thickness of the unit varies from one structural block to another. The maximum thickness exposed in the quadrangle is about 1,000 feet, at a locality east of U.S. Highway 50 about $\frac{3}{4}$ mile southeast of Pinto Summit, but section *H-H'*, constructed from the poor exposures in the vicinity of South Gate, suggests that there may be about 2,000 feet of beds here. This latter figure is closer to those obtained in the more complete sections west and north of Eureka (Nolan and others, 1956, p. 38-39).

The only outcrops of the Lone Mountain Dolomite in the Grays Peak synform are two small exposures along the western border of the quadrangle in the unnamed canyon west of lower Grays Canyon. In both, the dolomite appears to rest on Lower Devonian formations above a minor thrust fault. Of some interest is the fact that locally, near

the contact, a sedimentary breccia, similar lithologically to one found in the more easterly occurrences, may be found.

Extensive exposures of Lone Mountain Dolomite are found in the Richmond Mountain synform and the Oxyoke Canyon antiform. No distinctive lithologic differences between the two occurrences were recognized, though the immediately overlying Devonian beds are clearly of different facies.

The remaining exposure of the Lone Mountain Dolomite is along the southern border of the Alhambra Hills, where three small outcrops are overlapped to the south by the gravels of Newark Valley. They are believed to be within the Pinto Creek synform, a conclusion that is consistent with the absence of the basal quartzite in the overlying Beacon Peak Dolomite Member of the Nevada Formation.

If the apparent conformity of the Lone Mountain Dolomite above the Hanson Creek Formation at South Gate is in fact the case, it indicates that limestones of the Roberts Mountains Limestone (Merriam, 1940, p. 11-12) are absent here, and strengthens the suggestion that the limestone may be the time equivalent of the lower beds of the Lone Mountain Dolomite (Nolan and others, 1956, p. 40).

Devonian rocks.—Devonian rocks are widely distributed throughout the quadrangle, occurring in all but one of the structural blocks. Because of this and the fact that they are found in a number of different thrust plates, they show marked facies differences from one exposure to another. In general, the progression from dolomite in the originally more easterly facies to limestone in the more westerly is characteristic. In the lower part of the sections, lenticular quartzite units appear at different stratigraphic levels; they are crossbedded, the quartz grains are well rounded, and in one occurrence, for which fossil evidence seems good, quartzite is represented in a more westerly facies by thin-bedded sandy limestone.

The five members of the lowermost Devonian formation, the Nevada Formation as defined in a previous report (Nolan and others, 1956, p. 42-48), occur in the five more easterly structural blocks; three of them, together with two members not recognized in the eastern sections, also are found in the most westerly block, or Grays Peak synform.

In all of the occurrences, the Beacon Peak Dolomite Member is the lowermost unit of the Nevada Formation. It is uniformly a fine-grained, dense, almost lithographic dolomite, pale gray with a slight bluish tinge where it can be compared with the more coarsely crystalline Lone Mountain Dolomite, which has a slight yellowish component in its prevailing light-gray color.

In the Oxyoke Canyon and Diamond Mountains antiforms, the Beacon Peak includes a thin sandstone band at its base, as much as 100 feet thick. The presence of this basal sandstone in the Oxyoke Canyon antiform contrasts with its absence in the Sentinel Mountain synform to the east; determination of the boundary between the two structural blocks is assisted by this difference.

The cliff-forming Oxyoke Canyon Sandstone Member overlies the Beacon Peak Dolomite Member in the four most easterly structural blocks, although satisfactorily complete sections are found chiefly in the Sentinel Mountain synform, where it is 400 feet thick, slightly less than in some complete sections in the Diamond Range to the north. At the south end of the Alhambra Hills, however, an apparently complete section is scarcely 200 feet thick.

In lower Grays Canyon along the western border of the quadrangle, the Beacon Peak Dolomite Member is overlain by sandy limestone containing an abundant fauna that in earlier reports (Nolan and others, 1956, p. 46) was called the "*Spirifer* [now *Eurekaspirifer*] *pinyonensis* zone." We here propose the name Grays Canyon Limestone Member for this unit, which crops out in the Grays Can-

yon drainage both 1 mile to the north and 1 mile to the south of South Hill. Better exposures of the unit, however, are found in the adjacent Bellevue Peak quadrangle in the unnamed canyon west of Grays Canyon. The type section is designated in this canyon in the low hills west and southwest of South Hill. No complete sections were recognized as the member, in all of the mapped occurrences, is limited upwards by a low-angle fault. The maximum thickness in this area is about 300 feet.

At Lone Mountain, more than 20 miles to the northwest, beds containing the *Eurekaspirifer pinyonensis* fauna are very well exposed; they were first described from here by Merriam (1940, p. 9). Other exposures occur west and northwest of the Pinto Summit quadrangle, and Merriam (unpub. data) has designated the unit as Nevada Formation unit 2. Faunal studies by him of collections from these localities have led to the conclusion that the beds are of latest Early and early Middle Devonian age. That unit 2 (and hence the Grays Canyon Limestone Member) includes the time-stratigraphic interval of the nearly unfossiliferous Oxyoke Canyon Sandstone Member is suggested both by its stratigraphic position and by the presence within it of white quartzitic sandstone tongues like the Oxyoke Canyon Sandstone Member.

The Sentinel Mountain Dolomite Member is well exposed in the four most easterly structural blocks; in the most westerly block, the Grays Peak synform, a very poorly exposed, highly brecciated dark dolomite, that is similar lithologically to some of the beds in the more easterly exposures, occurs above a minor thrust fault in about the proper stratigraphic position. The apparent thickness here is less than 200 feet, which contrasts with approximately 600 feet in the Sentinel Mountain and Pinto Creek synforms. In the Diamond Mountains antiform, however, only about 450 feet are found.

The Sentinel Mountain Dolomite Member is overlain in most places in the quadrangle by the Woodpecker Limestone Member. In these occurrences, the unit exhibits the transition from dolomite and dolomitic limestone in the originally more eastern sections (that are now found in the antiforms) to fossiliferous, rather thin-bedded limestone in the synforms.

Along the western border of the quadrangle, however, in the Grays Peak synform, the Woodpecker interval is occupied by a sandstone unit that is lithologically very similar to the Oxyoke Canyon Sandstone Member. It is best exposed along the west side of Grays Canyon and is here named the South Hill Sandstone Member from the outcrop on the northwest slope of South Hill, some 1,500 feet from the summit. Here about 200 feet of crossbedded sandstone, quartzite, and sandy dolomite rest on the Sentinel Mountain Dolomite Member, below the Bay State Dolomite Member. The upper contact here, however, appears to be a minor thrust fault. The unit is presumably of Middle Devonian age.

The Bay State Dolomite Member is exposed in all the structural blocks except the Prospect Ridge antiform, the Richmond Mountain synform, and the Oxyoke Canyon antiform. It is everywhere a massively bedded dolomite, though in the Grays Canyon area some finely laminated dolomites similar to those found in the Sentinel Mountain Dolomite Member are common. Here, however, as in some other atypical dolomites in the core of the Silverado antiform, the presence of *Stringocephalus* identifies the unit. These fossils, incidentally, are present in great numbers along the summit and upper east slope of South Hill.

The best exposure of the Devils Gate Limestone is along the plunging axis of the Oxyoke Canyon synform, along the south end of which both the Meister and Hayes Canyon Members can be recognized. In most occurrences, however, the combination of complex structure and the difficulty of tracing the characteristic beds that mark the

boundary between the two members make it difficult to confidently distinguish them. In such places the formation was not divided. This has been particularly true of the outcrops in the Silverado antiform, the Pinto Creek synform (where there appear to be dolomite beds in the formation), and the small exposures in the lower Grays Canyon area of the Grays Canyon synform.

Carbonate rocks of Ratto Canyon.—Two discontinuous bands of massive carbonate rock are exposed in the southern part of the Prospect Ridge antiform. The more extensive of the two occurs in Ratto Canyon, where it caps the ridge on the east side of the canyon. A northern extension of the band is found in Rocky Canyon about a half mile west of north from Ratto Springs. The more easterly band crops out along Dale Canyon just west of the boundary between the Prospect Ridge antiform and the Richmond Mountain synform.

The western band is composed almost wholly of massive bleached recrystallized and sheared limestone that most closely resembles, where least altered, thick-bedded Devils Gate Limestone. Towards the base, the rock is largely massive dolomite, which has an irregular and obscure contact with the overlying limestone. Locally included are patches of dark dolomite that resemble parts of the Hamburg Dolomite (Cambrian). The eastern band is made up largely of massive dolomite, much of it highly brecciated.

Both bands rest upon folded lower Paleozoic beds in thrust contact, and are overlain by remnants of Eureka Quartzite that belong to the Dugout Tunnel thrust plate.

These rocks are considered to make up a thrust slice that thickens westward but is absent in most places between the two bands. The slice intervenes between the Dugout Tunnel thrust plate above and the lower Paleozoic formations that themselves lie above the Ruby Hill thrust zone.

The mixed lithology is believed to have resulted from the overriding of a minor thrust slice of Hamburg Dolomite by a later thrust plate of Devils Gate Limestone, with consequent welding of the two sheets along the contact zone.

In the Grays Peak synform west of Ratto Canyon are extensive exposures of Devonian rocks, including the Devils Gate Limestone, which form a complex thrust plate beneath the Eureka Quartzite of the Dugout Tunnel thrust zone and above lower Paleozoic rocks. The exposures of the lower Paleozoic rocks, incidentally, do not include the Hamburg Dolomite, suggesting that thrusting along the Dunderberg Shale may have eliminated it. These relationships are suggested in section *H-H'*.

Devonian and Mississippian rocks.—The Pilot Shale, exposed in the four most easterly structural blocks, contains a Late Devonian fauna in its lower part. J. W. Huddle has found a conodont fauna of Kinderhookian (Early Mississippian) age in uppermost beds of the Pilot Shale in exposures of the formation in the Pancake Range in the southeastern corner of the quadrangle.

Only a few feet of poorly exposed shale, mapped as the Pilot, are found along the axis of the Sentinel Mountain synform. Similarly, the only exposure in the Diamond Mountains antiform is a small one at the mouth of Tollhouse Canyon.

Well-exposed sections are found in Packer Basin and in what are believed to be the southern extensions of the Silverado antiform and the Pinto Creek synform in the Pancake Range in the southwestern part of the quadrangle. The formation in the Pancake Range has been divided into a lower and upper member; in the more westerly band of exposures the total thickness is about 400 feet, but in the eastern or Pinto Creek synform about 1,000 feet are exposed.

Mississippian rocks.—Known Mississippian rocks are exposed chiefly in the Richmond Mountain and Pinto Creek synforms and in the southern extension of the Silverado antiform in the Pancake Range. Small outcrops are found to the northeast in the Diamond Mountains antiform.

The four formations in this system exhibit notable facies changes, both in different structural blocks as well as in different thrust plates within a single block. These are the result of changes in the rate and nature of sedimentation in the Mississippian seaway consequent upon a rising land mass to the west. They are marked, in the sequences that were originally laid down relatively farther west, by an increasing proportion and coarseness of clastic material; by lesser thicknesses, in part at least the result of local nondeposition; and by a more pronounced lenticularity in individual sequences.

The youngest of the four units, the Joana Limestone of Early Mississippian (Kinderhookian) age, crops out in three linear bands within the quadrangle, as well as in several smaller occurrences. The section exposed along the western margin of Packer Basin in the Pinto Creek synform resembles that in the Pancake Range along the southeastern margin of the quadrangle. In both, the total thickness varies considerably along the strike and is in most places a few hundred or less feet thick. At one locality in the Pancake Range, the Joana is absent, and the Chainman Shale rests directly on the upper member of the Pilot Shale. The beds included in the Joana are lenticular, ranging from massively bedded reeflike limestone to moderately coarse conglomerates.

The most westerly band of Joana Limestone in the Pancake Range, however, has a much more uniform thickness and lithology: four distinctive members were recognized that persisted throughout the length of the outcrop band, although they are not separately shown on the geologic map. This exposure is considered to be in a southern extension of the Silverado antiform, and to have originally been far to the east of the other two sections, which were brought to their present position by overthrust sheets and preserved in the relatively down-dropped synform.

The next higher Mississippian unit was recognized only in the Richmond Mountain and Pinto Creek synforms. It is a coarse grit, with some interbedded fine conglomerates, and some thin black shale bands that are lithologically similar to those in the conformably overlying Chainman Shale. The name Dale Canyon Formation, here given to this unit, is taken from exposures in lower Dale Canyon, southwest of Pinto Peak. A more complete section, designated the type section, is exposed in sec. 23, T. 18 N., R. 54 E., in Packer Basin; here it was described by Stewart (1962) as the 1,750-foot-thick lower unit of an undifferentiated sequence of Chainman and Diamond Peak Formations overlying, probably unconformably, the Joana Limestone. The Dale Canyon appears to have a minimum thickness of 1,700 feet in Dale Canyon. No identifiable fossils have been found, although plant fragments occur in the coarse grits in the Dale Canyon area, and Stewart reports that carbonaceous material and crinoid columnals are present in Packer Basin. As the formation lies above the Joana Limestone, and below the Chainman Shale, the Dale Canyon Formation is Mississippian; it may be of Osagean age, as beds of this age are absent in the Pancake Range, where Kinderhookian fossils are present in the Joana Limestone, and Meramecian fossils occur in the unconformably overlying Chainman Shale.

The Chainman Shale, composed dominantly of black shale and siltstone, with only minor interbedded sandstone, calcareous siltstone, and local conglomerate, is exposed chiefly in the Richmond Mountain and Pinto Creek synforms, and in that part of the Silverado antiform that lies in the Pancake Range. A small outcrop in the north-

east part of the quadrangle at the mouth of Tollhouse Canyon is the southern extension of a much larger occurrence in the Diamond Range.

The Chainman has gradational contacts both with the Diamond Peak Formation above and, where it is present, the Dale Canyon Formation below; in earlier reports (Nolan and others, 1956, p. 56-61; Stewart, 1962) the Upper Mississippian rocks above the Joana Limestone were not separately mapped, although facies variation in different outcrops was recognized. In more recent reports, however (Brew, 1971; Nolan and others, 1971) the Chainman was not only mapped separately, but Brew (1961b) had earlier distinguished two rather different facies. Similarly, Stewart (1962) had described two sequences, in Packer Basin and in the Pancake Range, in which the rocks now assigned to the Chainman exhibit both slight differences in lithology and very considerable differences in thickness, 2,100 feet and 1,070 feet, respectively.

Outcrops of the Chainman Shale in the Richmond Mountain synform are found in Windfall Canyon and in the lower reaches of Secret Canyon. In Secret Canyon, the Chainman has an apparent thickness of over 4,000 feet, but as noted by Nolan, Merriam, and Williams (1956, p. 59-60), the section here may be repeated by folding or faulting.

Gordon (in Brew, 1971, p. 37) has summarized the evidence for the age of the Chainman Shale; a fossil collection from the southeast corner of the quadrangle, made by Gordon and F. G. Poole from a bed between 250 and 300 feet above the base of the formation, is of Late Mississippian age, and Gordon has suggested a Meramecian assignment for the Chainman in this area. As noted below, however, Gordon believes that faunal evidence from the occurrences in the Richmond Mountain synform indicates that in this region the highest beds in the Chainman are equivalent in age to Diamond Peak beds that in the Diamond Range are nearly 2,000 feet above the base of that formation.

The Diamond Peak Formation of Late Mississippian (Meramecian and Chesterian) age is exposed in the Richmond Mountain and Pinto Creek synforms, in the Pancake Range extension of the Silverado antiform, and in scattered outcrops of the Diamond Mountains antiform in the northeastern part of the quadrangle.

The formation exhibits striking differences in thickness in different thrust plates, as well as differences in lithology. Perhaps the most notable contrast is on either side of a minor thrust in Windfall Canyon near Conical Hill. In the lower thrust plate, the Diamond Peak is locally absent and is no more than 100 feet thick, whereas in the upper plate, a rather uniform thickness of about 400 feet of beds is present. Both of these facies contrast with the more than 3,500 feet of beds in the Diamond Range (Brew, 1971, p. 18) and 2,450 feet exposed in an incomplete section in the Pancake Range (Stewart, 1962, p. C59). In the latter locality, beds assigned to the Diamond Peak constitute the three upper units distinguished by Stewart.

In the Diamond Range, Brew distinguished eight units of the Diamond Peak with distinctive lithology and faunas. Gordon's (in Brew, 1971, p. 48) studies of the faunas, however, indicate an intertonguing relationship between the Chainman and the Diamond Peak, and that in the Conical Hill area of Windfall Canyon, the lowermost beds mapped as Diamond Peak are equivalent in age to beds nearly 2,000 feet higher in the Diamond Range.

Mississippian and Pennsylvanian rocks.—The only extensive outcrops of the Ely Limestone are in the northeastern part of the quadrangle. The basal beds of the formation are of Late Mississippian age, but the greater part is of Early Pennsylvanian age. The formation is exposed in two of the minor thrust plates that are present

in the Pinto Creek synform. One very tiny outcrop, lying within the southern extension of the Diamond Mountains antiform, occurs about a mile and a half southeast of the Pinto Creek Ranch.

Two other small outcrops that have been mapped as Ely Limestone are found in the Richmond Mountain synform, much farther to the west. Both are believed to be a part of a folded thrust plate that lies beneath the main exposures of Mississippian and Permian rocks in this region; in the well-exposed sections of these rocks close at hand, the Ely Limestone is absent, and the Carbon Ridge Formation of the Permian rests unconformably on the Diamond Peak Formation.

Permian rocks.—The Carbon Ridge Formation, of Early Permian age, is exposed only in the Richmond Mountain synform. The type area (Nolan and others, 1956, p. 64-66) is just north of the mouth of Secret Canyon, on Carbon Ridge, where 1,750 feet of beds are exposed below an upper unit of siliceous conglomerate that is about 1,400 feet thick; these measured sections are in sec. 30, T. 18 N., R. 54 E., within the type area. This upper unit was earlier tentatively assigned to the Newark Canyon Formation (Cretaceous) (Nolan and others, 1956, p. 69-70); more recent mapping has shown that this unit, which had earlier been recognized as being approximately conformable to the underlying beds, is indeed a conformable part of the Carbon Ridge, and is itself unconformably overlain by typical Newark Canyon.

Cretaceous sedimentary rocks.—Most of the outcrops of the Newark Canyon Formation are in the northern third of the quadrangle in the Richmond Mountain and Pinto Creek synforms; they exhibit the usual lithologic characteristics of the Newark Canyon (Nolan and others, 1956, p. 68-70).

Two atypical exposures mapped as Newark Canyon are composed of rather coarse-cemented conglomerate. They rest on the older Paleozoic rocks with marked angular unconformity. One of these localities is in the side canyon about ½ mile east of Pinto Summit in the NE¼ sec. 7, T. 18 N., R. 54 E.; the other is in the north-draining canyon about ¼ mile west of Summit 7943 in secs. 3 and 10 of the same township.

Cretaceous igneous rocks.—Recent drilling by the Ruby Hill Mining Company has shown that the small plug of quartz diorite exposed south of Ruby Hill (Nolan, 1962, p. 13-14; Nolan and Hunt, 1968, p. 972) expands downward from the small surface exposure. Three recent isotopic age determinations made on the stock indicate that it is somewhat older than the 62 ± 12 m.y. date reported by Jaffe and others (1959, p. 73). The new dates are 101 ± 2 m.y., reported by Armstrong (1970b, p. 235), 99.5 m.y. by R. F. Marvin (written commun., 1968), and 99.8 ± 2.0 m.y. by M. L. Silberman (written commun., 1971). These place the intrusion as occurring in mid-Cretaceous time.

An intrusive mass of dacite barely extends into the quadrangle; it occurs in the Pancake Range 1.9 miles west of the southeast corner of the quadrangle. It appears to be slightly older than the Ruby Hill plug, R. F. Marvin (written commun., 1968) reporting a K-Ar age of 108 m.y.

Oligocene and Miocene volcanic rocks.—Two major groups of volcanic rocks occur within the quadrangle. The older one, of Oligocene age, is composed of flows, pyroclastic rocks, and local intrusions of limited areal extent, which were derived from local sources; the younger, which contains units of both Oligocene and Miocene age, is made up largely of welded ash-flow sheets that are widely distributed over eastern Nevada and adjacent Utah (Blake and others, 1969; Cook, 1965). Thirty-one of these volcanic rocks have been isotopically dated, as well as four of the older Cretaceous intrusive rocks. The loca-

tion of the dated specimens is shown on the geologic map; the individual determinations and the analysts are listed in table 1.

TABLE 1.—K-Ar age determinations of Cretaceous and Tertiary igneous rocks

[Material used for determination: B, biotite; H, hornblende; M, muscovite; P, plagioclase; S, sanidine; W, whole rock]

Map unit	Sample No.	Age (m.y.)	Material	Analyst
Tmh, Magpie Hill Basalt	B67-48	20.2±0.8	P	E. H. McKee
	E-7	19.6±0.6	W	M. L. Silberman
Tbm, Bates Moun- tain Tuff	PS65B-27	22.1±0.9	S	E. H. McKee
	B68-119	23.1±0.9	S	Do.
Tps, Pancake Sum- mit Tuff	PS65B-24	32.9±1.3	B	Do.
	PS65B-1	32.6±0.7	B	R. F. Marvin
	PS65B-11	33.1±1.1	B	Do.
Trm, Richmond Mountain Andesite	E-8	33.8±1.0	W	M. L. Silberman
	E-12	33.2±1.0	W	Do.
	PS68-6	35.6±1.3	H	E. H. McKee
	PS65B-35	34.7±1.9	P	Do.
	E-21	34.3±0.7	B	M. L. Silberman
Tss, Sierra Springs Tuff Member of Pinto Peak Rhyolite	PS66B-31	34.3±1.9	B	E. H. McKee
	PS66B-59	35.3±1.9	H	Do.
Tv, vent breccia.....	PS66B-55	34.8±1.4	B	Do.
Td, rhyolite domes..	PS64B-18	35.0±1.1	B	R. F. Marvin
	E64B-3	34.5±1.4	B	E. H. McKee
	E-14	34.6±0.7	S	M. L. Silberman
	E-19	35.5±0.7	B	Do.
		35.0±0.7	S	Do.
	E-13	34.7±0.7	B	Do.
	E-15	33.0±0.7	B	Do.
	34.7±0.7	S	Do.	
Trt, Pinto Basin Tuff Member of Pinto Peak Rhyolite	PS66B-81	34.6±1.9	B	E. H. McKee
	E-32	33.7±0.7	S	M. L. Silberman
	E-27	33.9±0.7	B	Do.
	PS68-3	34.7±1.3	H	E. H. McKee
Tra, Ratto Spring Rhyodacite	E-29	35.3±0.7	B	M. L. Silberman
	E-16	36.2±0.7	B	Do.
	PS68-5	37.8±1.3	H	E. H. McKee
	PS68-1	36.8±1.3	B	Do.
	PS68-2	36.4±1.3	B	Do.
	PS64B-17	38.0±0.8	B	R. F. Marvin
Kqp, porphyritic dike	E-3	103±2	M	M. L. Silberman
Kqd, quartz diorite	AD-39	99.8±2.0	B	Do.
	PS64B-14	99.5±3.0	B	R. F. Marvin
Kdi, intrusive dacite	PS64B-31	108±3	B	Do.

The first group includes three lithologically different assemblages: an earlier one of rhyodacite flows, breccias, and intrusive rocks; an intermediate extensive rhyolitic assemblage that includes lithic breccias, air-fall tuffs, rhyolite flows, intrusive domes (with which are associated "vitrophyres" of at least two different origins), and a welded ash-flow tuff; and a youngest unit that is made up of andesitic rocks and is found in many parts of the quadrangle.

The oldest assemblage is here named the Ratto Spring Rhyodacite from exposures in the vicinity of Ratto Spring near the head of Ratto Canyon. Its type section is designated as one-half mile north of west from Surprise Peak, in sec. 27, T. 18 N., R. 53 E. (unsurveyed). Most of the rocks mapped and described by Hague (1892, p. 233-234; Iddings, in Hague, 1892, p. 364-368) as "hornblende andesite" are included in this unit.

The Ratto Spring Rhyodacite is largely confined to a rather narrow, north-trending belt extending from New York Canyon south to Ratto Spring. The flows and intrusive rocks are all porphyritic, containing about 30 to

40 percent phenocrysts of hornblende, plagioclase, biotite, and scarce quartz, in a fine-grained flow-banded groundmass that is gray to light brown in the freshest specimens but often reddish brown as a result of later alteration of the iron-bearing minerals. The intrusive varieties, which are present at the surface and in underground workings, often contain inclusions of the country rock, particularly sandstone and conglomerate of the Diamond Peak Formation (Mississippian). A complete gradation can be seen between the intrusive and extrusive phases along the old road that leads from the Windfall mine to the Hoosac mine (Hague, 1892, p. 235; Nolan, 1962, p. 14). Other less common lithologic types seen are dark-gray to black autobrecciated vitrophyre (near Ratto Spring), and thin, waterlaid tuffaceous sandstone, which appears to locally underlie the flows at the head of Dale Canyon. Several K-Ar age determinations have been made on both intrusive and extrusive phases of the rhyodacite from exposures in Windfall and Ratto Canyons. They range from 35.3 m.y. to 38.0 m.y. (McKee and others, 1971, p. 36-37). An earlier Pb-α determination by Jaffe and others (1959, p. 73) was reported as about 50 m.y.; Armstrong (1970a, p. 212-213) reports an age of 35.8±0.7 m.y. for a specimen that was probably collected from near the Windfall mine.

A rhyolite assemblage exposed in and around Pinto Peak was called the Pinto Peak Rhyolite by Iddings (in Hague, 1892, p. 374-379). This name is adopted and its type section designated as in NW¼, sec. 19, T. 18 N., R. 54 E. The assemblage is composed of six units of similar composition and age. It includes lithic breccias, flows, tuffaceous rocks, welded ash-flow tuff, vitrophyres, and intrusive domes and dikes. All of the units except for the ash-flow tuff are related to one or another of six intrusive centers which extend from Target Hill, at the northwest corner of the quadrangle, to Grays Canyon near the west edge. Most of the centers are small, being one-half mile or less in diameter, but that of Pinto Peak has an east-west extent of a mile and a half.

The Pinto Peak Rhyolite is clearly younger than the Ratto Spring Rhyodacite, as in places units of the assemblage rest unconformably on the intrusive phase of the rhyodacite, which must therefore have been unroofed by erosion before eruption of the rhyolite.

A lithic breccia member is believed to be the oldest unit of the rhyolite assemblage. It is exposed chiefly along the western side of Dale Canyon, west of the Pinto Peak center, and apparently represents an early explosive phase, during which the vent was cleared, and fragments of older rocks deposited against what must have been the rather steep slope that marked the eastern boundary of the Prospect Ridge antiform. The breccia contains clasts of Ratto Spring Rhyodacite and fragments of lower Paleozoic sedimentary rocks, as well as blocks of normal rhyolite.

A much more widespread member is a white tuffaceous sequence, which is here named the Pinto Basin Tuff Member from its type section in Pinto Basin in secs. 19 and 20, T. 18 N., R. 54 E. The Pinto Basin Tuff Member consists of white to gray (locally pink or green) air-fall vitric-crystal tuff, lithic-pumice breccia, and tuffaceous sandstone. These tuffs probably once covered an area of more than 500 square miles judging from isolated patches preserved far beyond the limits of the Pinto Summit quadrangle. The tuff was erupted from a number of vents extending from Target Hill in the Eureka quadrangle south to Grey Fox Peak. Each of these vents is marked by a broad apron of fine-grained tuff which near the vent grades into a coarse breccia made up of lumps and blocks of pumice and intrusive rhyolite as much as several feet in length.

There were probably eruptions of the tuff over a considerable period of time, as exposures in several places

show local unconformities and intra-unit minor faulting. Four K-Ar dates gave results of 33.7 to 34.7 m.y. (McKee and others, 1971, p. 36-38).

Numerous small dikes of white rhyolite occur throughout much of the length of the Prospect Ridge antiform. The intrusive centers, on the other hand, occur both in the antiform and in the Richmond Mountain synform to the east.

The main part of the intrusive domes or plugs is a white to light-gray porphyritic rhyolite with phenocrysts of biotite, sanidine, plagioclase, and quartz in a fine-grained flow-banded groundmass. Small pink garnets are a distinctive accessory mineral. The domes are commonly surrounded by a vent breccia that is transitional outwards into bedded tuff. The contact is usually marked by a zone of light- to dark-gray vitrophyre, which is generally 10 to 20 feet wide but locally as much as 50 feet. It represents the rapidly cooled margin of the intrusive but in a few places the vent breccia has also been fused to glass.

At the south end of the exposed belt of rhyolite plugs, on Grey Fox Peak between South Hill and Ratto Canyon and at the south end of Carbon Ridge, the intrusive rhyolite including the vitrophyre, is characterized by a pronounced laminated structure defined by closely spaced flow bands which average about a millimeter in width. In addition to the thin laminated structure, these rhyolites differ from those of the Pinto Peak and Target Hill variety by having fewer phenocrysts and, more importantly, no sanidine phenocrysts and very scarce quartz. The vent breccia and vitrophyre associated with these intrusives are identical to the other structures, however.

On the geologic map, some smaller bodies of vitrophyre and tuff have been included with the intrusive rhyolite as in many places the boundaries between these units are too irregular to be shown accurately at the scale of the map.

As also suggested by the evidence from the tuffs, the intrusions were probably spasmodic over a rather long period of time. Eight K-Ar determinations ranged from 33.0 m.y. to 35.5 m.y. with an average of 34.6 m.y. (McKee and others, 1971, p. 36-38). Jaffe and others (1959, p. 73) had earlier reported a Pb- α age of 38 ± 5 m.y., from the Target Hill dome at the north edge of the quadrangle, and Armstrong (1970a, p. 213-214) found 35.6 m.y. from the same intrusion.

Locally, the intrusive rhyolite in the domes breached the surface and flowed out over both the surrounding vent breccias and the nearby Paleozoic rocks. The extrusive rhyolite appears identical, but its outcrops are characterized by well-developed columnar jointing normal to the flow banding.

The only ash-flow tuff recognized in the rhyolite assemblage is found along the southwest margin of the Pinto Summit quadrangle and to the west in the Bellevue Peak quadrangle. Although its relationships, and isotopic age, place the unit within the rhyolite assemblage, its mineral composition is that of a quartz latite. This tuff overlies the Pinto Basin Tuff Member and is in turn intruded by a small dome of laminated rhyolite near South Hill. This tuff is here named the Sierra Springs Tuff Member with the type section located in Ratto Canyon (sec. 2, T. 17 N., R. 53 E., unsurveyed), about 2 miles east of south from the upper Sierra Spring. At this locality the tuff consists of three cooling units with a total thickness of about 600 feet. The two lower cooling units are very similar, each having a nonwelded base which grades through a highly welded zone with moderate development of eutaxitic vitrophyre, to a nonwelded top. The average phenocryst composition of the middle unit, which was quarried for building stone during the 1880's, is 13 percent quartz, 3 percent sanidine, 59 percent plagioclase, and 25 percent mafic minerals including biotite, hornblende, augite, hypersthene, and magnetite. The upper member is considerably more

mafic than the lower ones and is characterized by a black, glassy eutaxite near the base. This member contains abundant phenocrysts of pyroxene which can be seen with the hand lens and serve to distinguish it from the other members. Two K-Ar mineral ages were determined, one from the quarry in Ratto Canyon (34.3 m.y.) and one from the extreme western margin of the quadrangle, near South Hill (35.3 m.y.) (McKee and others, 1971, p. 35).

Iddings (in Hague, 1892, p. 374-379) recognized three varieties of rhyolite in the Eureka district. One, which he called the Pinto Peak Rhyolite, was areally the most extensive, and in this report is extended to include all the rocks of the rhyolite assemblage. A second variety from "south of Carbon Ridge" is apparently identical with the material noted above from Grey Fox Peak and is a phase of the rhyolite intrusive domes. However, Iddings' third variety, from Rescue Canyon, appears to be identical with the Pancake Summit Tuff of this report. The Sierra Springs Tuff Member as described above is shown on the Hague map and described in his text (1892, p. 236-237) as dacite.

The youngest of the three local assemblages is here named the Richmond Mountain Andesite. It is extensively exposed in the Richmond Mountain and Sentinel Mountain synforms. It forms one small outcrop in the Pinto Creek synform in the northern part of the quadrangle, and also constitutes large masses in the Sentinel Mountain and Pinto Creek synforms to the south. It occurs mainly as flows, but some dikes and small intrusive plugs are also found. These rocks were called andesite and basalt by Iddings (in Hague, 1892, p. 348, 386). Most of the rocks he called basalt are darker, glassy varieties, and his andesites are the more crystalline flows. All of the rocks, however, are chemically high-potassium andesites or trachyandesites, though they vary in texture, mineralogy, and chemistry. A number of dikes are exposed in the area south of Richmond Mountain around Hornitos Cone; they have fused the Pinto Basin Tuff Member and tuffaceous sandstone to a number of interesting varieties of buchites.

The type locality is designated as Richmond Mountain (secs. 19 and 20, projected, T. 19 N., R. 54 E.) where the total thickness is about 700 feet. Several small dikes of lamprophyre are separately shown on the geologic map; mineralogically they resemble the andesite although their texture is considerably different.

The andesite rests unconformably on the Pinto Basin Tuff Member of the Pinto Peak Rhyolite as well as on different formations of the older sedimentary rocks. The several K-Ar ages, however, indicate that there was a very short time lapse between its eruption and those of the older rhyolite units. Five determinations range from 33.2 to 35.6 m.y. (McKee and others, 1971, p. 37-38). A tuffaceous rock immediately below the andesite at Black Point is only slightly older. Its K-Ar age (on hornblende) is 34.7 m.y.

The younger group of volcanic rocks, though widely distributed in the eastern Great Basin, has only a limited extent within the Pinto Summit quadrangle. Most of the exposures are in Rescue Canyon in the vicinity of Magpie Hill, and along the eastern border of the quadrangle, south of U.S. Highway 50. Two small outcrops are found in the Pinto Creek synform, one north and one south of the Alhambra Hills.

Like the older group there are three different assemblages of these rocks, the two older being composed of ash-flow sheets, and the younger, flows of alkali-basalt. The ash-flow sheets appear to have been derived from the south and east, because they thicken greatly in that direction.

The oldest unit of this younger sequence is the Pancake Summit Tuff (Armstrong, 1970a, p. 212; Hose and Blake, in press). Its type section is designated as the

exposures about a half mile north of U.S. Highway 50 on the boundary between sec. 25, T. 18 N., R. 55 E., and sec. 30, T. 18 N., R. 56 E. This lies a few miles east of the quadrangle boundary in the Pancake Summit quadrangle. The Pancake Summit Tuff is a light-gray to reddish-brown crystal-rich tuff made up of roughly equal amounts of smoky quartz, sanidine, and plagioclase plus minor biotite. The lower part is distinctly finer grained and less crystal-rich than the upper part, but chemically they are both rhyolites. Within the quadrangle the thickness varies from about 100 to 200 feet.

Three K-Ar age determinations averaged 32.9 m.y. (McKee and others, 1971, p. 38-39).

The next younger unit, named the Bates Mountain Tuff by Stewart and McKee (1968), is also an ash-flow tuff and consists of several crystal-poor cooling units all very similar in the field and under the microscope, but paleomagnetic studies (Grommé, and others 1972) indicate that at least three separate welded ash-flow sheets are included within the unit in the Eureka area. They appear to overlie the Pancake Summit Tuff with slight angular unconformity. At the 18-Mile House, the three cooling units are all characterized by sparse phenocrysts of quartz, biotite, plagioclase, and sanidine in a pink to red-brown, dense, highly welded groundmass of devitrified glass shards.

The total thickness at both the 18-Mile House and in Rescue Canyon is about 100 feet. The Bates Mountain Tuff is significantly younger than the Pancake Summit Tuff, two K-Ar dates giving ages of 22.1 and 23.1 m.y. (McKee and others, 1971, p. 38). It is thus of early Miocene age.

The youngest of the volcanic rocks are small extrusions of alkali olivine basalt. In the Pinto Summit quadrangle, the few outcrops of this rock are here named the Magpie Hill Basalt from its type section on Magpie Hill (sec. 34, T. 18 N., R. 54 E.) on the east side of Rescue Canyon. The basalt is fine grained with microphenocrysts of olivine (usually altered to iddingsite or serpentine) and larger phenocrysts of plagioclase, plus somewhat smaller grains of augite and magnetite in a groundmass of vesicular brown glass or devitrified glass containing plagioclase and minor biotite. Inclusions are particularly abundant in the basalt and include partly digested quartzite, limestone, and hypabyssal igneous rock. Chemically these rocks are very different from the earlier calc-alkaline series being of a pronounced alkalic trend. A K-Ar determination from the exposure in sec. 2, T. 17 N., R. 54 E. gave an age of 19.6 m.y. (M. L. Silberman, written commun., 1971). A similar basalt from just south of the quadrangle boundary gave an age of 20.2 m.y.

Tertiary and Quaternary unconsolidated sediments.—The unconsolidated sediments that blanket much of the Pinto Summit quadrangle have been rather arbitrarily separated into three map units: older piedmont gravels, recent piedmont and stream gravels, and Quaternary lake deposits. The boundaries between them shown on the map are not accurate, having been sketched in large part from aerial photographs. Detailed mapping would probably significantly change the generalized map patterns.

The older gravels were laid down during an earlier physiographic cycle. They cap many ridges in the higher parts of the quadrangle, forming the surface at Pinto Summit, for example. In places they are deeply dissected, and between Secret Canyon and Ratto Canyon the present-day stream channels expose as much as 200 feet of coarse gravel, some beds of which are cemented by caliche.

The gravels were deposited over a considerable period of time and in the Pinto Summit quadrangle, they appear to be younger than the Oligocene volcanic rocks, although initiation of gravel deposition may have followed rather closely cessation of eruption of the lavas; both were deposited on a topography that seems to have been locally

quite rugged. East of the Pinto Creek Ranch, the older gravels are tilted to the west and dip beneath the recent gravels that floor Packer Basin; this suggests that they had formed prior to some of the faulting along the east front of the range. Similarly, the occurrence of terraced older gravels high on the south slopes of Prospect Peak indicates that here older gravel deposition preceded the uplift of Prospect Ridge by recent faulting along the west base of the Ridge in Spring Valley.

The younger gravels include stream alluvium, the relatively undissected piedmont slopes, slope wash, and the beach and bar deposits of the Quaternary lake that occupied Newark and Fish Creek Valleys.

Only the playa deposits that occur in Newark Valley in the northeast corner of the quadrangle are shown on the map as Quaternary lake beds; the coarser sediments contemporaneous with the lake, or that were reworked during the period of the lake's existence, are included with the younger gravels.

STRUCTURAL GEOLOGY

The Pinto Summit quadrangle, like the Eureka quadrangle to the north (Nolan and others, 1971, p. 4-5), can be divided into a series of north-trending linear structural blocks, which differ from one another in structural style, in the formations exposed within them, and in the facies of many of the individual formations.

Each structural block is composed of two or more thrust plates, which in alternate blocks are folded into anticlinal or synclinal forms; because the folding refers to the thrusts, rather than stratigraphic units, they are referred to in this report as antiforms and synforms.

In the northern half of the quadrangle, which comprises the elevated tract that bounds Diamond Valley to the south and connects the Diamond Mountains with the Fish Creek Range, eight structural blocks can be recognized. Their boundaries are shown on an index. Three similar blocks are found in the southeastern corner of the quadrangle, south and east of the Newark Valley-Fish Creek Valley depression. These are thought to be southern extensions of blocks recognized to the north, although they are not exactly in alignment.

The individual structural blocks are separated by steeply dipping faults or fault zones that in places at least appear to be oversteepened parts of the folded thrust faults that are exposed within the blocks. The faults have relatively elevated the antiforms and depressed the synforms. Movement along them has, however, continued later than the main movement along the thrusts, since the boundary faults involve the post-thrust Newark Canyon Formation and the Tertiary volcanic rocks.

The youngest structural event is the so-called Basin-and-Range faulting that is responsible for the present elevations of the mountainous areas above the adjoining valleys. In part at least, some of this young faulting appears to have occurred along the pre-existing faults that form the boundaries of the structural blocks.

The geologic sections show these several structures; boundaries between the blocks are indicated above each section.

Antiforms and synforms.—The eight structural blocks are shown on the index.

The most westerly of these, the Grays Peak synform, is only partly exposed within the quadrangle; it is made up of a south-southeast-trending belt of lower and middle Paleozoic rocks that lie on the west side of Ratto Canyon between Rocky Canyon on the north, and extending beyond South Hill on the south. This eastern part of the synform exposes several minor thrust faults, notably within the belt of Silurian and Devonian rocks in the Grays Canyon drainage. Here, individual sedimentary units are separated from one another by thrusts, and in places have been

completely eliminated. West of lower Grays Canyon about a mile south of the summit of South Hill, for example, a folded contact between the Grays Canyon Limestone and Beacon Peak Dolomite Members of the Nevada Formation is truncated by a plate of the overlying Bay State Dolomite Member.

To the east of these thrusts, another one must be present on the west side of Ratto Canyon; along this, the Eureka Quartzite that caps the ridge of which Pinnacle Peak is a part, is separated from the older Paleozoic beds to the east by what appears to be a steeply west-dipping thrust.

The rocks of the Grays Canyon synform probably overlie a larger thrust, as the members of the Nevada Formation that are exposed within it are of a markedly different facies than those of the formation in the structural blocks to the east. The relationship of this thrust with those exposed in the Prospect Ridge antiform to the east is unknown; it may, however, be equivalent to one underlying the "carbonate rocks of Ratto Canyon" and, like it, be beveled by the Dugout Tunnel thrust zone of the antiform.

The most westerly antiform, the Prospect Ridge antiform, is a complex assemblage of folded thrust plates. (Prospect Ridge has long been used (Hague, 1892, p. 19 et seq.) for the linear topographic feature shown on the topographic map of the Eureka quadrangle as Prospect Mountain.) The plates are not continuous, partly because parts have been removed by erosion, and partly because folding proceeded concurrently with the thrusting, and the crests of older folded thrusts were beveled by the next younger one.

The Prospect Ridge antiform has an exposed N-S extent of somewhat over 12 miles, the northern 2 miles of which is beyond the north limit of the quadrangle, and a width of over 2 miles. It appears to be narrower at the south end, where the antiform disappears beneath a cover of older gravels.

Four major thrust zones have been recognized in the antiform; each is composed of two or more branches which merge or diverge from one another along both strike and dip. In addition, there are several other thrust faults, which are either less extensively, or so poorly, exposed that their relative importance is uncertain.

The lowest, and presumably oldest, of the thrusts has been called the Diamond Tunnel thrust zone (Nolan, 1962, p. 19) and is exposed only in a small area at the head of New York Canyon above the Diamond Tunnel portal. The next higher thrust, the Ruby Hill thrust zone (Nolan, 1962, p. 19-20), is well exposed in the vicinity of Ruby Hill at the northwest corner of the quadrangle, on the ridge east of Zulu Canyon, in places along the west side of Prospect Ridge, and on the ridge itself just north of Prospect Peak.

A third thrust zone is exposed only at the south end of the block. The rocks above this thrust are made up of the "carbonate rocks of Ratto Canyon" described above. They form a discontinuous thrust plate that is beveled and completely cut out by the overlying Dugout Tunnel thrust zone (Nolan, 1962, p. 20-21) in both Secret and Rocky Canyons.

The highest of the major thrust zones—the Dugout Tunnel thrust zone—has brought Eureka Quartzite and Pogonip Group limestones over the rocks of the two lower thrust plates. The contact between the Eureka and the Pogonip is itself a thrust in most places, and is irregularly folded as is illustrated on Round Top Mountain in Secret Canyon, where patches of Eureka and Pogonip rest with marked discordance on the Cambrian and Lower Ordovician rocks that lie above the Ruby Hill thrust zone.

The Dugout Tunnel thrust zone exhibits broad gentle folding in Rocky Canyon south of Prospect Peak. The

ridge west of the Burning Moscow mine here is underlain by Eureka Quartzite that occupies a pronounced syncline nearly one-half mile across and with an amplitude of about 1,000 feet.

There are probably a number of steep thrusts or reverse faults within the major thrust plates, but in general exposures are either too poor to distinguish clearly between repetition by folding or thrusting, as is true of the bands of Secret Canyon Shale in New York, Windfall, and Secret Canyons, or are inconclusive as to the absence of beds along shear planes parallel to the bedding. Palmer (1960a, p. B289) has suggested that lower beds of Dunderberg Shale, present in districts to the east, may have been eliminated by faulting at the contact of the shale with the underlying Hamburg Dolomite, which is commonly a zone of silicification and shearing.

Still another possible thrust zone is believed to exist in Ratto Canyon, as the absence of Hamburg Dolomite between the exposures of Secret Canyon Shale on the east side of the canyon and those of Dunderberg Shale and Windfall Formation on the west side requires some form of faulting.

The Richmond Mountain synform to the east has very nearly the same dimensions as the Prospect Ridge antiform, being covered by older gravels both to the north (beyond the boundary of the quadrangle) and to the south. Its maximum width is about 2 miles. The sedimentary rocks that compose the block are for the most part of Carboniferous and Permian age, but a considerable mass of Oligocene rhyolitic rocks interrupts the continuity of the Paleozoic strata about midway between their exposures south of Eureka and those in Secret Canyon. Richmond Mountain Andesite outcrops occupy the north end of the block in the quadrangle and extend about 2 miles further north.

The northern exposure of the Paleozoic rocks includes a broad syncline whose axis approximately parallels U.S. Highway 50 south of Eureka, and which is bordered on the west by a narrow, compound anticline that is itself broken by a minor thrust fault. This thrust is of some interest in that it brings together two quite distinct facies of the Mississippian: the lower one beneath the thrust to the east including over 400 feet of the Diamond Peak Formation, while the higher western exposures exhibit either a much thinner sequence or none at all.

Apart from this minor thrust, and what may be its poorly exposed northern continuation just east of the County Hospital at the north edge of the quadrangle, the only major thrust fault within the block is a poorly exposed structure that was recognized in two widely separated localities. This structure exposes beneath it rather highly altered and fractured Ely Limestone, and must therefore separate the sequence above it, from which the Ely Limestone is completely absent, from an over-ridden block in which it is present. One of these exposures is on the west side of Windfall Canyon, about 1,250 feet west of Conical Hill; the other is on the east side of Dale Canyon, about 3,000 feet east of north from Sugarloaf.

The Oxyoke Canyon antiform is composed of badly fractured and locally highly silicified Silurian and Devonian sedimentary rocks. Its contact with the Richmond Mountain synform to the west is distinct and is marked (where not concealed by gravel or by volcanic rocks) by a nearly vertical fault that separates the Carbon Ridge and Diamond Peak Formations on the west from Lone Mountain Dolomite on the east. The eastern boundary is less distinct, as members of the Nevada Formation occur on either side. The presence of the thin quartzite at the base of the Beacon Peak Dolomite Member outcrops in the antiform, and its absence in the synform to the east, however, permits the boundary to be established with considerable confidence.

In the vicinity of South Gate, at the southern end of the exposure of the antiform, two faults, believed to be folded thrusts, are exposed in the low hills on the east side of the gate. Exposures are not sufficiently extensive to establish with certainty the true extent or nature of these faults, but *H-H'* and *I-I'* present what is believed to be their relationships.

The Sentinel Mountain synform dominates the north-central part of the quadrangle, and what is thought to be a southern extension of the synform occurs south of U.S. Highway 50. Both at the north end, around Angelo Belli Flat, and at the south, southeast of Black Point Well, the synform is completely occupied at the surface by Richmond Mountain Andesite. In between, from Basalt Peak south to Rescue Canyon, it is characterized by a north-plunging syncline, 2½ miles from east to west. The beds involved include Lone Mountain Dolomite at the base to a small outcrop of Pilot Shale exposed at the north end of the plunging synclinal axis; patches of a rubble conglomerate assigned to the Newark Canyon Formation (Cretaceous) are also found along the northern part of the axial zone.

The Sentinel Mountain synform is characterized not only by the distinctive lithologic facies of several of its component formations, as noted above, but also by the notably lesser degree of deformation as contrasted with rocks of the same age in the antiforms to the east and west. The synform also differs from the other structural blocks in the apparent absence of significant folded thrust faults within it. Some minor thrusts are, however, present, notably one near the center of sec. 27, T. 18 N., R. 54 E., where quartzite of the Oxyoke Canyon Sandstone Member has overridden the underlying Beacon Peak Dolomite Member along a nearly flat-lying fault.

The Silverado antiform is the most complex of the several blocks. North of U.S. Highway 50 it appears to be composed of two en echelon units, a pattern that was believed to be characteristic of the antiform in the area to the north (Nolan and others, 1971, p. 5).

The more northerly unit extends from the north boundary of the quadrangle in sec. 22, T. 19 N., R. 54 E., southwards for nearly 3 miles to the vicinity of Rose Springs and is characterized by a sharp north-plunging anticlinal fold in the Diamond Peak Formation, flanked in a few places by overlying Ely Limestone. The fold was not recognized south of Rose Springs where it is concealed by older gravels and Tertiary volcanic rocks.

The en echelon extension to the south is offset a mile to the west and is first recognized in the vicinity of Angelo Belli Cabin. From here south to the jeep trail at the north end of Silverado Mountain, the antiform is represented by a steeply dipping zone of fault slivers between the simple syncline of the Sentinel Mountain synform on the west and the east-dipping sequence of Mississippian rocks on the west side of the Pinto Creek synform on the east.

Further south, however, the antiform exhibits a spectacular sequence of closely folded thrust plates, all involving Devonian rocks. The steep south-facing slope of Century Peak in particular, as well as the ridge of Silverado Mountain itself, provides an excellent illustration of an antiform that is composed of a series of folded thrust plates (sections *H-H'* and *I-I'*).

South of U.S. Highway 50, the probable southern extension of the Silverado antiform extends for 5 miles within the quadrangle and for some distance beyond to the south; at the south boundary of the quadrangle it has a maximum width of 2 miles. The antiform is bounded both to the east and west by normal faults that separate the Devonian and Mississippian rocks of the antiform from the Richmond Mountain Andesite that occupies the synforms that flank it.

This part of the Silverado antiform is unusual in that the map pattern indicates that the structure is that of a major syncline of Mississippian rocks, with a smaller domelike anticline of Devonian rocks to the west. However, remnants of an anticlinally folded thrust plate of Devonian strata occur on both sides of the syncline and at one time must have extended over the top of the ridge capped by the Diamond Peak Formation (sections *J-J'* and *K-K'*). On both sides of the ridge are steep shear zones that may represent other folded thrusts; these have walls of Chainman Shale, but locally include thin slivers, 5 to 20 feet wide, of Joana Limestone, Pilot Shale, and Diamond Peak Formation. They are reminiscent of the thin band of Dunderberg Shale within the Hamburg Dolomite in the Prospect Ridge antiform (Nolan, 1962, p. 19).

The Pinto Creek synform is exposed discontinuously over much of the eastern third of the quadrangle. To the north in the region north of the Pinto Creek Ranch, it exposes considerable amounts of Newark Canyon Formation (Cretaceous) as well as Diamond Peak Formation and Ely Limestone. The two latter formations are repeated by two minor thrust faults (section *E-E'*) that are older than and partly concealed by the Cretaceous sedimentary rocks.

The synform is also exposed in Packer Basin and the Alhambra Hills. In the latter, particularly, there are several rather gently folded thrusts that involve Devonian and Mississippian rocks (sections *H-H'* and *I-I'*).

The largest exposure of the synform underlies the southeastern corner of the quadrangle. To the west and north in the area the synform is occupied by Richmond Mountain Andesite, together with smaller outcrops of both older and younger Tertiary volcanic units. The southeastern corner of the quadrangle, however, is underlain by sedimentary rocks ranging in stratigraphic position from the Devils Gate Limestone to the Diamond Peak Formation. No thrust faults were recognized in this sequence, although there is minor faulting in the northern part of the belt, and a number of cross faults of relatively small throw displace the Joana Limestone.

The Diamond Mountains antiform is represented by discontinuous exposures in the northeastern corner of the quadrangle. Its main exposure is in the Eureka quadrangle to the north (Nolan and others, 1971).

Block formation.—The folding that produced the antiforms and synforms was not in itself the origin of the linear blocks that form the structural framework of the quadrangle. Block development, however, is regarded as related in origin to the folding, and as being a later stage in the history of deformation undergone by the Paleozoic rocks.

The blocks are characterized by the presence within them of sedimentary sequences and structural patterns that are for the most part different from the sequences or structures of the adjoining blocks. They are separated from one another by steeply dipping faults, or fault zones, in most instances; the Silverado antiform, however, is to some extent an exception, in that on the east it is separated from the Pinto Creek synform by two en echelon faults, and on the west, in the vicinity of Sentinel Mountain, the antiform itself does not crop out as a result of the convergence of the two boundary faults (section *G-G'*).

The presence of contrasting sedimentary sequences is the most striking characteristic of the eight structural blocks. This may be expressed either by considerable age differences of the rocks in adjoining blocks, by the juxtaposition of notably different facies in formations of the same age, or by both of these features.

The Carboniferous and Permian rocks of the Richmond Mountain synform are stratigraphically far removed from the Cambrian and Ordovician rocks in the Prospect

Ridge antiform to the west and from the Silurian and Devonian rocks in the Oxyoke Canyon antiform to the east. Any estimate of the displacement based on this stratigraphic discordance is brought into question by recognition of the fact that the formations exposed at the surface in these blocks rest on one or more thrust plates, whose relations to the thrust plates in the adjoining blocks have not been established, other than the recognition that the plates in the synforms were rather certainly derived from areas originally much farther to the west.

Juxtaposition of different facies in adjoining blocks is perhaps best shown by the presence in the Oxyoke Canyon antiform of the basal quartzite unit of the Beacon Peak Dolomite Member throughout the north-south extent of the antiform and its absence in the Beacon Peak in the Sentinel Mountain synform immediately to the east.

The contrast in structural pattern is well shown by the rather open synclinal folds that characterize the Richmond Mountain and Sentinel Mountain synforms as opposed to the closely appressed anticlinally folded thrust plates of the Silverado antiform that lies between them. Perhaps more significant, though, is the fact that in the three western antiforms, the formations are much more highly fractured and sheared than in the more open folds of the synforms. This difference may reflect the probability that the rocks that compose the thrust plates of the synforms were deformed at shallower depths and under a lesser load than those in the antiforms.

In several of the blocks, minor folds, both of thrusts and of the formations, have been superposed on the major folding. Similarly, in a few places faults or fault zones, parallel to the border faults and comparable in their displacement, occur within the main block. Perhaps the most prominent of these is the Jackson-Lawton-Bowman fault in the Prospect Ridge antiform (Nolan, 1962, p. 22-23), which extends from the northern boundary of the quadrangle to the vicinity of the Geddes-Bertrand mine in Secret Canyon.

The boundary faults clearly elevated the antiforms relative to the synforms by what must be several thousand feet. Locally, they seem to have utilized steeply dipping parts of the folded thrust faults as the locus of the vertical movement; the resulting relationships of the blocks result in a horstlike structure for the antiforms, and grabenlike for the synforms (Nolan and others, 1971, p. 6).

The formation of the structural blocks appears to date from Cretaceous time; outcrops of the Newark Canyon Formation are to a large extent localized within the synforms and the lithology of the unit indicates that it was largely deposited in depressions that received their debris from the adjoining antiforms. The megabreccias exposed in the Eureka quadrangle to the north (Nolan and others, 1971, p. 3-4) also point to this conclusion.

Movement along the faults bounding the blocks continued after Cretaceous time and seems, in some instances at least, to have occurred in Miocene time. The Oligocene volcanic rocks are largely restricted in their outcrop areas to the synforms; in Rescue Canyon, Pinto Basin Tuff Member of Pinto Peak Rhyolite, Pancake Summit Tuff, Bates Mountain Tuff, and Magpie Hill Basalt all crop out in the Sentinel Mountain synform immediately west of the Silverado antiform and were deposited against the fault scarp that bounded the antiform.

In the Pinto Creek synform, and less clearly in the other synforms, the Newark Canyon Formation is folded into an open syncline along the same axis as the synform in which it was deposited. As suggested by Nolan, Merriam, and Brew (1971, p. 6), this seems to imply "that block formation and the vertical movements along the boundary faults that define the blocks, are surficial expressions of deep seated folding and thus a part of the

long continued epoch of orogeny that earlier, and at greater depths in the crust, produced the thrusts, and then folded them."

Recent faulting.—The mountainous areas in both the northwestern part of the quadrangle and in the part of the Pancake Range in the southeastern corner, are in large part the result of uplift along recent, or basin-and-range, faults.

The northwestern area includes the southern end of the Diamond Range and a northeastern prong of the Fish Creek Range, together with the rugged country connecting them. This elevated tract forms the southern boundary of Diamond Valley and the northern limit of Fish Creek Valley; Newark Valley lies to the east of the Diamond Range; Fish Creek Valley drains into it.

The fault that was responsible for the elevation of the northern part of this area above Diamond Valley is marked by a curving scarp that has a topographic displacement of 20 feet or more. This scarp is believed to be the surface expression of a major fault whose throw must be several thousand feet. It lies just to the north of the Pinto Summit quadrangle, though one of the north-south faults that are thought to be branches of it extends into the quadrangle just southeast of the town of Eureka. It dies out a short distance south of the quadrangle boundary.

The southern and eastern boundary of the mountainous area, as represented by the bedrock-gravel contact, is quite irregular, and clearly does not reflect movement along a single fault. Rather, it seems to be best interpreted as resulting from a series of en echelon north- and northeast-striking faults.

The relatively recent movement along some of the north-striking faults is in part the result of renewed movement along the boundary faults separating the structural blocks. The most striking example of this is the fault bounding the east face of Silverado Mountain. To the north it changes strike to northeasterly and dies out in the alluvium. To the south, the topographic expression decreases abruptly in the foothills that flank Silverado Mountain on the southeast; it is, however, taken up along the east-northeasterly fault that marks the southern boundary of the high part of Silverado Mountain. The fault plane dips 62° S. The total topographic throw is in excess of 700 feet, a figure that is comparable to both the topographic throw along the north-south fault, and to the displacement of the folded thrust beneath the Oxyoke Canyon Sandstone Member.

Three other east-northeast faults or fault zones are believed to have had significant displacements in relatively recent time.

Two appear to be largely responsible for the topographic break between the mountainous area and the northern boundary of Fish Creek Valley.

One of the two is found along the southeastern front of the Alhambra Hills; several faults of this system crop out in bedrock along the front and have, in places, brought down parts of the thrust plates of Devils Gate Limestone that cap the hills to the north. A major fault of this group probably occurs beneath the adjoining gravels, however, and accounts for the gravel-filled depression that separates these hills from the Pancake Range to the southeast.

The second fault is also composed of several branches; it limits the hilly area of English, Red, and Leader Mountains to the southeast. The total topographic displacement must be close to 1,000 feet.

The remaining northeasterly fault enters the quadrangle from the north at the mouth of Tollhouse Canyon and limits to the northwest the low-lying country in which Pinto Creek Ranch is located.

In the southeastern part of the quadrangle, the north-trending ridge that constitutes the probable southward extension of the Silverado antiform, is delimited both to the east and west by relatively recent normal faults. On both flanks the Devonian carbonate rocks that are the eroded remnants of the folded thrust plate that once continued over the ridge are cut off by normal faults that dip steeply away from the ridge.

The time at which the recent faulting occurred cannot be determined closely. It seems clearly to be younger than the Oligocene volcanic rocks; the Richmond Mountain Andesite and Pinto Basin Tuff Member of the Pinto Peak are cut by one of the recent faults east of the town of Eureka. Much of the faulting must also be younger than at least some of the older gravels. To judge from their present location in such places as Pinto Summit on the divide between Diamond Valley and Fish Creek Valley drainages, the gravels must have been deposited either before or during the uplifts resulting from the faulting.

It is perhaps likely that the faulting occurred over a protracted period of time from late Miocene, or Pliocene, up to recent time; locally, well-marked fault scarps can be recognized in the piedmont gravels.

ORE DEPOSITS

Evidences of mineralization are widespread throughout the Pinto Summit quadrangle. The numerous prospects in the parts of the area underlain by the Paleozoic rocks testify both to the wide distribution of mineralizing solutions, and even more to the thoroughness with which the army of prospectors searched the hills during the mining excitement that followed the discoveries at Austin, Hamilton, and Eureka itself in the 1860's and 1870's.

Although prospect pits are found in most parts of the quadrangle, they are far more abundant in the antiforms; and essentially all of the productive mines are limited to these structural blocks. The correlation is not without exception, however, as the Oxyoke Canyon antiform exhibits very few signs of prospecting, although the dolomites that compose most of the block are not only intensely brecciated but also are locally silicified and iron stained.

The Pinto Creek synform constitutes another exception, in that there has been a considerable amount of prospecting at the southeastern end of Packer Basin in the Alhambra Hills. There seems to be no record of significant production from this area, however, although the numerous pits and shafts in the vicinity of the Fair Play mine and the open cuts across the ridge to the south testify to the presence of galena and other ore minerals along, and in the walls of, the several synclinally folded thrust faults that characterize the structure here.

Thompson and West (1881) described four districts, in addition to the Eureka district, as being more or less active in 1880.

The Newark district (Thompson and West, 1881, p. 655) encompasses the Newark Mountain area on the west side of Newark Valley and for the most part lies north of the north boundary of the quadrangle. Newark Mountain itself is a part of the Diamond Mountains antiform. No prospects of significance occur within the southern extension of the district unless the quarries in sandstone of the Diamond Peak Formation west of the Pinto Creek Ranch are so considered. More extensive quarries in this sandstone in the Pancake Range (sec. 27, T. 17 N., R. 55 E.) were the main source of the "Pancake Rock" that was widely used as a furnace lining in the Eureka smelters. Both of these areas, however, are structurally within the Pinto Creek synform.

The Pinto or Silverado district, according to Thompson and West (1881, p. 435-436, 662-663), was discovered in 1867 and seems originally to have been considered to lie in both Eureka and White Pine Counties. All of the workings now visible, however, lie 2 to 3 miles within White Pine County, on the steep western and southern slopes of Silverado Mountain within the Silverado antiform.

On the western slope of the mountain are a number of shafts, stopes, and tunnels along steep fractures in limestone and dolomite of the Devils Gate. Thompson and West (1881) report that the quartz veins contained ore that was "generally adapted for smelting and average[d] \$300 per ton" in silver and gold, chiefly in silver. The workings on the southern face of the mountain also occur along fracture zones, but here the wall rock is Bay State Dolomite Member, and the quartz ores contained copper, now in oxidized form.

The remaining three districts listed by Thompson and West, the Eureka, Secret Canyon, and Sierra, all lie within the Prospect Ridge antiform and are now commonly considered to be part of the Eureka district.

Most of the production of the Eureka district has come from the Ruby Hill area, just beyond the northern boundary of the quadrangle (Nolan and others, 1971, p. 7). The district was discovered in 1866, and has been described in a number of papers (Curtis, 1884; Sharp, 1948; Nolan, 1962; Nolan and Hunt, 1968). The production has amounted to well over \$100,000,000; gold, silver, and lead have contributed about equal amounts to the dollar value.

Although the greater part of this production has come from the area north of the quadrangle, there are, nevertheless, extensive workings and a considerable production record from the numerous mines within the Pinto Summit quadrangle. The properties now largely consolidated into the Consolidated Eureka Mining Company have mined ore from replacement bodies in the Hamburg Dolomite on either side of Prospect Ridge at the head of New York Canyon, and smaller mines to the north found ore in the Eldorado Dolomite (Nolan, 1962, p. 67-70). Another group of productive mines was located to the east, extending from Goodwin Canyon on the north to Windfall Canyon on the south (Nolan, 1962, p. 70-71). The Dunderberg, Croesus, and Hamburg were perhaps the most productive in this belt; they mined ore from replacement bodies in the Hamburg Dolomite. A different type of ore was produced from the Windfall mine; it yielded about \$350,000 in gold from pulverulent dolomite in the Hamburg Dolomite adjacent to its contact with the Dunderberg Shale.

Smaller amounts of ore have come from a number of other properties. The Seventysix mine in lower New York Canyon is reported to have been the scene of the original discovery in the district; it produced a small amount of ore from deposits in thoroughly fractured dolomite of the Hanson Creek Formation. The Hoosac mine, near the southern summit of Hoosac Mountain, according to Couch and Carpenter (1943, p. 63) produced over \$150,000 in silver and lead between 1872 and 1882. Eureka Quartzite formed the wall rock of the ore shoots.

The Secret Canyon area was originally considered as a separate mining district (Thompson and West, 1881, p. 436) but is now a part of the Eureka district. Geologically it is the southern extension of the Prospect Ridge antiform. The first locations in the district were made in 1869, and by 1870 the flourishing town of Vanderbilt had been established. Now, however, only a few foundations of stone cabins can be recognized.

The Geddes-Bertrand mine, in Secret Canyon proper, was probably the most productive property; it mined lead-silver ore from replacement deposits in the Eldorado Dolo-

mite. The ore was treated in a large mill whose stone foundations still present an imposing reminder of the past activity. A number of other properties were located southeast of the Geddes-Bertrand mine on the north side of Round Top Mountain. The Page and Corwin mine here produced some ore from irregular workings in the Windfall Formation and Pogonip Group, just beneath remnants of Pogonip limestone and Eureka Quartzite that are eastern outliers of the Dugout Tunnel thrust zone. The ores from these properties are reported to have been treated at a mill in Pinto Canyon just east of Schaefer Ranch.

The Sierra district was also described by Thompson and West (1881, p. 436) as a separate district; it is now a part of the Eureka district. It apparently included the area in the vicinity of Sierra and Ratto Springs in Ratto Canyon. The foundations of an old mill just south of Sierra Springs may still be seen. The mill was apparently built to treat ore from what is now the Oswego mine in Rocky Canyon. In more recent years the Oswego was operated by the Eureka Corporation, Ltd., and a considerable amount of ore was mined from open cuts along the contact of the Eldorado Dolomite with the Secret Canyon Shale. The principal values were in gold; the disseminated ore, which occurred in both dolomite and shale, contained small amounts of arsenic in the form of realgar and orpiment.

More recently the Cordero Company has conducted a considerable amount of drilling and trenching on the west side of Ratto Canyon, exploring several geochemical anomalies found there; the area explored lies in the Grays Peak synform, just west of the Prospect Ridge antiform. Also in this general area, the Newmont Company has drilled several holes to investigate a pronounced magnetic anomaly centered at the head of Rocky Canyon, about on the border between the synform and the antiform.

The apparent restriction of ore bodies to the antiformal blocks would seem to provide a useful guide to prospecting and exploration in the area. There are, however, significant differences between ore deposition in the several antiforms. The Oxyoke Canyon antiform, for example, seems to have very little, if any, mineralization. The Diamond Mountains and Silverado antiforms are characterized by a predominance of deposits, many in veins or shear zones, that contain silver in the form of argentiferous tetrahedrite, galena, quartz, and in places barite. In these antiforms granitic intrusive rocks are absent at or near the surface. The Prospect Ridge antiform, in which the most productive mines are located, contains deposits of the base metals, as well as gold and silver, with a considerable content of arsenic, and relatively little quartz.

The cause of these differences is not entirely clear, but it may be a reflection of the relative amount of uplift and erosion that has taken place in the different blocks; the base metal deposits and the intrusive plug in the Prospect Ridge antiform may have been emplaced at a greater depth below the then-existent surface than the telethermal silver deposits of the more easterly antiforms.

A relationship of ore deposition to intrusive rocks similar to the quartz diorite exposed at Ruby Hill has been generally assumed (Nolan, 1962, p. 48-49; Nolan and Hunt, 1968, p. 985). This implies that the time of mineralization was in the latter part of the Cretaceous.

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