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BASIN-RANGE FAULTING OF 1915 IN PLEASANT VALLEY, NEVADA

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ABSTRACT

Fault scarps of at least three ages are found on the eastern side of Pleasant Valley, Nevada. Of these, the most recent were formed in 1915, when a displacement occurred along the western base of the Sonoma Range. Two fault blocks rose relative to the adjacent valley, producing low scarps at the foot of the mountains. The movement was a dip-slip displacement on normal faults which trend north and northeast.

INTRODUCTION

The Pleasant Valley earthquake of October 2, 1915, received much attention both because it was of major intensity and because it resulted from displacements which reached the surface of the earth. Some of these displacements were mapped by the author and are the principal subject of this article. They had previously been described in part by the late Dr. J. C. Jones[1] and by S. L. Berry,[2] and have been alluded to by many others.

PLEASANT VALLEY AND THE SOUTHERN SONOMA RANGE

Pleasant Valley is in Pershing County, north-central Nevada, and is best reached by a road which proceeds southward from Winnemucca. The valley is an elongated, north-south depression between the Sonoma Range (on the east) and the East Range, its dimensions being roughly 5×25 miles. The valley floor, which is estimated to be about 4,300 feet above sea level, is in part a playa. From this flat area, overlapping alluvial fans rise gradually to the bases of the mountain ranges on either side; at their juncture with the Sonoma Range are the recent fault scarps described below. The alluvium diminishes in thickness at the south end of Pleasant Valley and gives way to a pediment cut in tilted Tertiary rocks of volcanic, fluviatile, and lacustrine origin.

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[1] J. C. Jones, "The Pleasant Valley, Nevada, Earthquake of October 2, 1915," *Seism. Soc. Amer. Bull.* 5 (1915), pp. 190–205.

[2] S. L. Berry, "An Earthquake in Nevada," *Mining Sci. Press*, Vol. CXIII (1916), pp. 52–53.

The general region is characterized by fairly youthful basins and ranges. The portion of the East Range adjacent to Pleasant Valley presents a somewhat subdivided lava cap which slopes gently eastward and perhaps extends beneath the valley sediments. The nearby

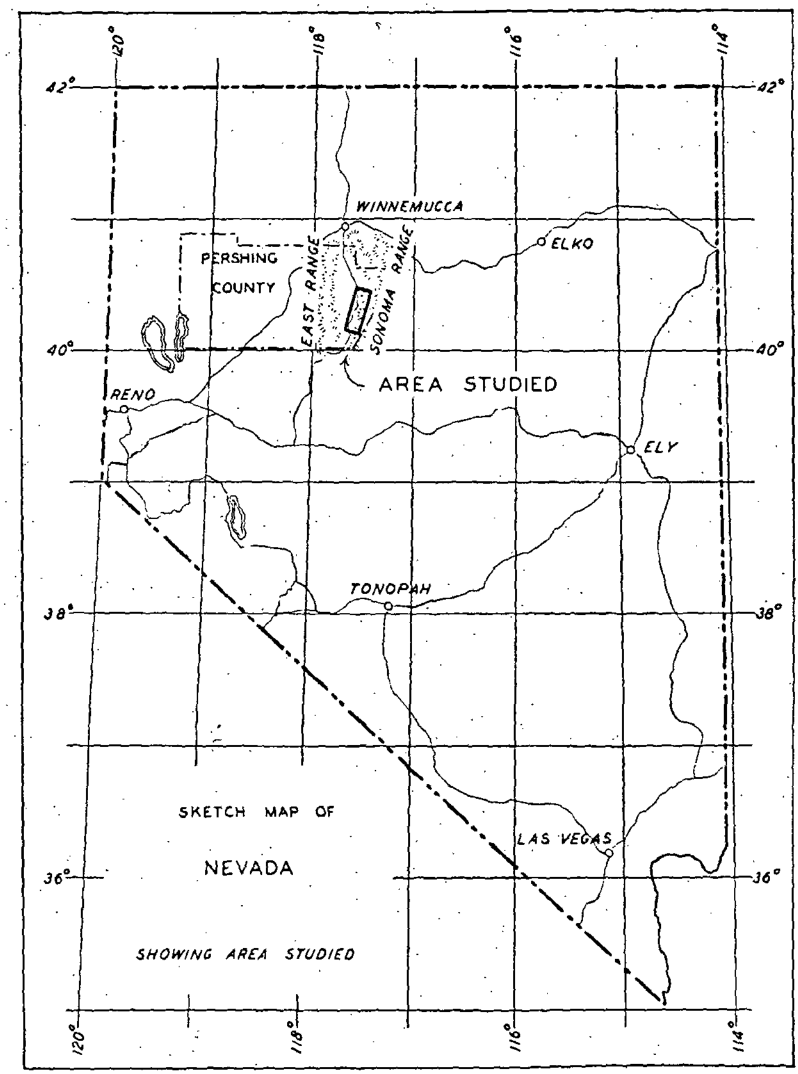

FIG. 1.—Sketch map of Nevada

Stillwater Range to the south has a steep and impressive eastern escarpment, while the western slope is comparatively gentle. The Star Peak Range, to the west, has a western escarpment and a faulted bajada at the north end. The Humboldt Lake Range, about 45 miles to the west of Pleasant Valley, has pronounced fault-block characteristics.[3] To the east, the Battle Mountain Range is in topographic accord with the foregoing examples. All of these ranges show escarpments, which, although not so youthful as many others in the Basin-Range province (notably those in southern Oregon), are nevertheless not extensively embayed by erosion.

The Sonoma Range[4] itself is similar to its neighbors in many respects. Like most of the nearby ranges, it consists of several parts that are distinct both structurally and physiographically. Only the southern portion is treated here. This portion is composed principally of two fault blocks, which in this paper are designated as the "Tobin block" and the "Pearce block." Their relation to each other is shown in Figure 2.

THE TOBIN BLOCK

The Tobin block is a high north-south ridge about 9 miles long and 4 miles wide, attaining an elevation of 9,779 feet at the summit of Mount Tobin. It is partly made up of pre-Tertiary rocks, the age of which is unknown. These rocks include quartzites, phyllites, grits, limestone, and shale. The sedimentary beds are considerably folded[1] and are locally intruded by dikes of andesite and rhyolite. No lava cap exists on the Tobin block.

The horst nature of the block is indicated topographically (Fig. 2). The Pleasant Valley side and the Buffalo Valley side are both eroded escarpments that consist partly of alined facets sloping about 26°.

The Tobin block has been dissected to maturity. The canyons, which are youthful, terminate in V-shaped mouths, emptying out upon fans which locally slope as much as 7° but which are mostly less steep. On the western side of the block the juncture of mountain and fan is at a very high level (Fig. 2). The western fans are incised by gullies 50 or 60 feet deep which are continuations of the canyons in the mountains. Possibly fault movements have been smaller or less frequent than formerly and the fans are doomed to complete dissection. On the other hand, it is possible that the margin of the valley is clinging to the rising mountains and that elastic rebound may eventually restore it to its original position.

The fault which bounds the Tobin block on the west is (in this paper) called the "Tobin fault." It was active, in part, at the time of the Pleasant Valley earthquake of 1915.

FIG. 2.—The southern part of the Sonoma Range. This shows the Tobin block and an end view of the low Pearce block. At the base of each is a fault scarp of 1915 origin, too distant to be visible. The fresh scarp of the Pearce block would appear as a point at the foot of the slope at the right-hand edge of the picture, as it proceeds directly away from the observer.

THE PEARCE BLOCK

The Pearce block is a low, wide fault block adjoining the Tobin block on the south and southwest (Fig. 2). It trends about N. 20° E. and is over 20 miles long and 5 miles wide. Parts of it consist of rocks similar to those of Mount Tobin. Other parts are folded Mesozoic marine quartzites and dolomites which are overlain unconformably by a thick Tertiary (presumably) volcanic series including rhyolite, andesite, and basalt, together with agglomerates and tuffs. A volcanic neck is exposed at the mountain front just north of Pearce's ranch.

The Tertiary volcanic rocks do not occur as a continuous cap, but for the most part dip eastward in a series of hogbacks and cuestas. They are locally repeated by faulting. Either these rocks are part of an anticlinal limb or they have been tilted by faulting parallel to the trend of the range; their strike is roughly that of the mountains.

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[3] G. D. Louderback, "Basin Range Structure of the Humboldt Region," *Geol. Soc. Amer. Bull. 15* (1904), pp. 289–346.

[4] The Sonoma Range is designated by King as the "Havallah Range" (C. King, *U.S. Geol. Explor. 40th Parallel*, Vols. I and II [1878]).

In the Pearce block a few of the canyons which empty into Pleasant Valley contain small aggraded flood plains in their lower courses. These plains have been trenched, owing to the 1915 rejuvenation. One or two sets of terraces are discernible above the last plains, suggesting earlier rejuvenations of the same order of magnitude as the movement of 1915.

The western side of the Pearce block is an escarpment similar to that of the Tobin block, except that facets make up more of the mountain front. Flanking this escarpment are alluvial fans which are not deeply cut by gullies except where headward erosion has proceeded from a rather recent canyon draining Pleasant Valley to the south.

The eastern side of the block does not resemble the western side, as the mountains slope down to a dissected pediment in Jersey Valley. The pediment is cut in Tertiary rocks which are partly tuffaceous shales in lacustrine beds. The absence of fans and fault-scarp features indicates that the Pearce block is being tilted eastward, the Pleasant Valley side being the (relatively) rising portion.

The fault bordering the Pearce block on the west was active at the time of the Pleasant Valley earthquake; it is here called the "Pearce fault."

THE OLDER FAULT SCARPS OF PLEASANT VALLEY

Fault scarps of at least three ages are situated on the eastern side of Pleasant Valley near or at the juncture with the Sonoma Range.

The oldest scarps include much of the front of the southern Sonoma Range: the western sides of the Tobin block, the Pearce block, and a southern continuation of the latter, which is offset a mile or two to the east. The last-mentioned scarp was not augmented by the uplift of 1915, but the other two rise above fresh scarps which resulted from that movement. The older scarps mostly consist of large facets which are separated by V canyon mouths. The facets were not observed to slope more than 30°, even at the base, which in most cases is steeper than the upper portions. They do not extend entirely to the crest of the mountains. They are alined, but in an irregular rather than a straight line. In a few places the alinement is broken by small salients which are step blocks (Fig. 5).

More recent than the oldest scarps are a few low escarpments in the bajadas and pediments at the north and south ends of Pleasant Valley. These features trend roughly parallel to the Sonoma Range, but lie a mile or so to the west of the mountains. For the most part they do not exceed 20 feet in height, and now appear as gentle slopes. There is some similarity to shore lines, but the fans are transected rather than contoured. (No shore lines of Pleistocene lakes were observed in Pleasant Valley.) In a few places the fan scarps and pediment scarps have been slightly augmented by displacements of 1915. These scarps on the whole cannot be considered as old as much of the mountain front, as they consist of alluvium and must therefore be comparatively short-lived.

THE SCARPS OF 1915

The fault scarps of 1915 are the most notable geological feature of the region. Only the scarps of Pleasant Valley are here described; but [illegible]mporaneous displacements occurred in Pumpernickle Valle[illegible] branch of the Sonoma Range to the northeast, and in the S[illegible] Range to the south. These localities have not yet been fu[illegible] studied.

The course of the fresh scarps.—The course of the fresh scarps in Pleasant Valley is shown on the accompanying map (Fig. 3). There are two main scarps, belonging to the Tobin fault and the Pearce fault, respectively, and they will be designated by the names of these faults. They closely follow the older escarpments forming the mountain front.

The Tobin scarp does not occupy the entire length of the Tobin fault. At the south end of this fault, where the two fault blocks join, the Tobin scarp dies out while the fault continues. The northern extremity of the Tobin fault was likewise inactive in 1915. Near the northern end of the active portion, another small scarp of 1915 parallels the Tobin scarp, following one of the older scarplets in the bajada.

The Pearce scarp, on the other hand, occupies the entire length of the Pearce fault. Near the south end of Pleasant Valley the Sonoma Range is sharply offset a mile or so to the east. The Pearce scarp does not follow the offset, but continues southwest along a low eroded scarp in the pediment for 2 miles before coming to an

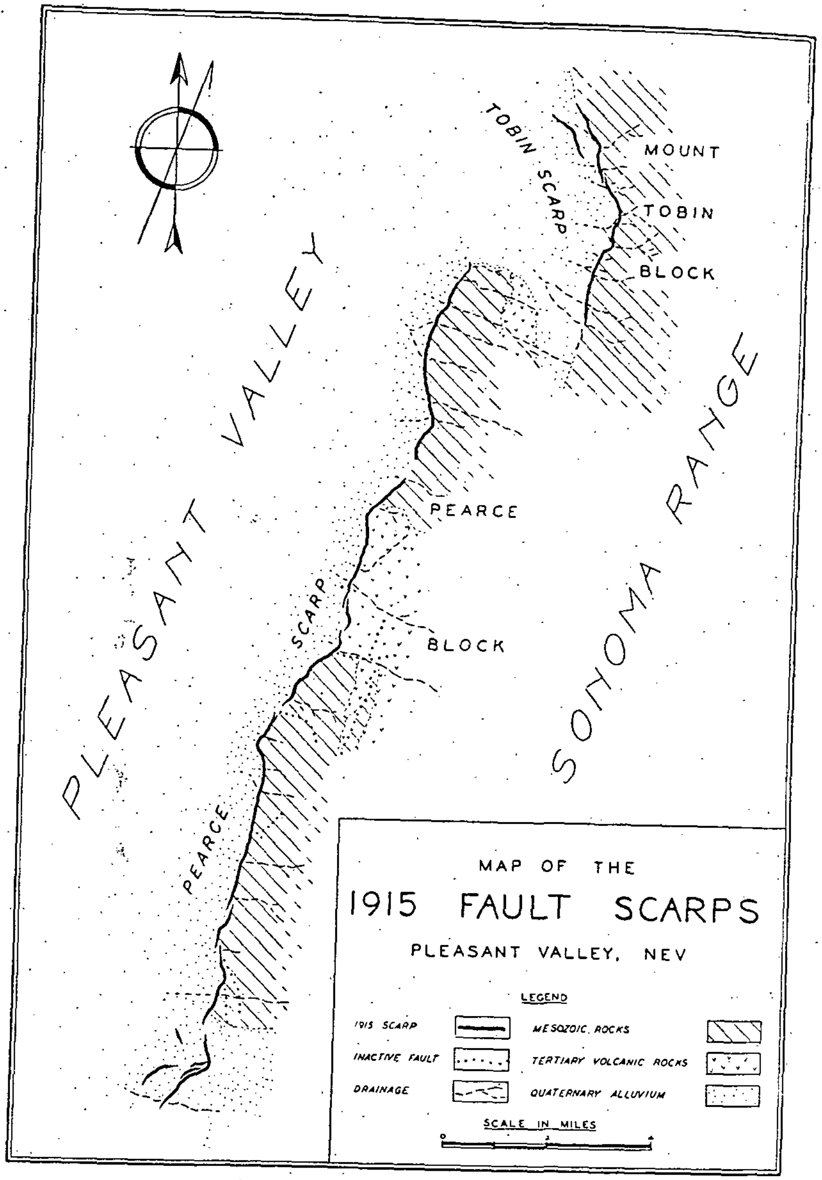

FIG. 3.—Map of the 1915 fault scarps

end. The pediment here is also the site of other small scarps of 1915 origin, these being independent of the Pearce scarp.

The Tobin scarp is oriented nearly north and south, while the Pearce scarp trends about N. 20° E. As shown on the map, they are far from straight, making several large deviations and innumerable small ones of the order of 50 feet or so. As the scarps do not consistently deviate either upstream or downstream where canyons are crossed, their relation to the topography does not reveal the dip of the faults.

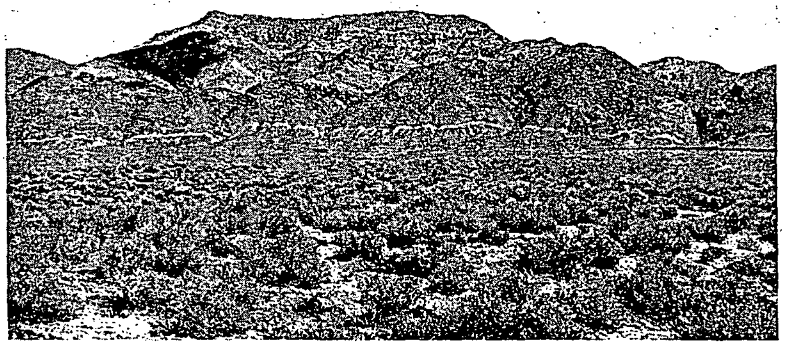

FIG. 4.—The Pearce scarp. This fresh scarp (appearing as a white line in the picture) was formed in 1915 at the foot of the older, eroded fault scarp which constitutes the mountain front.

The Tobin scarp rises gradually toward the south, while the Pearce scarp maintains a more nearly constant elevation. Both sink abruptly where canyons and gullies are crossed, and in some other situations climb a short distance above the foot of the mountain.

The two main scarps are almost continuous, though interrupted in a few places. Also, each has locally small branches and short parallel scarps which are prominent where the rock is very weak, as in the neighborhood of an inactive transverse fault (Fig. 5).

Dimensions.—The Tobin scarp is 4.6 miles long and varies in height from 0 to about 10 feet, dying out gradually at both ends.

On the bajada at the north end of Pleasant Valley, the fresh fan scarp is from 0 to 3 feet high.

The Pearce scarp is 16.7 miles long and ranges up to 16 feet in height near the middle of its length. On the pediment at the south end of Pleasant Valley, the Pearce scarp is from 0 to 5 feet high and the smaller ones attain 4 feet or less.

As a group the 1915 scarps in Pleasant Valley are 21.3 miles long, disregarding curves; yet the variation in height is only 16 feet throughout a distance of 112,644 feet (a variation of 1 in 7,040).

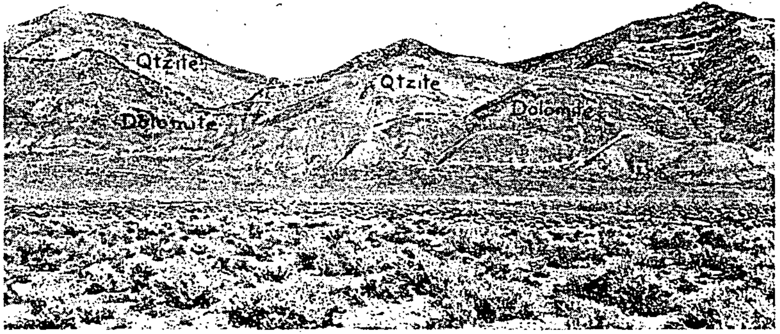

FIG. 5.—The Pearce scarp, showing its behavior where an inactive transverse fault is transected. Note also the two step blocks at the right.

The height of the scarps at any one point is not a true measure of the fault displacement because the scarps are steeper than the faults, as will be explained below.

Other features of the fresh scarps.—The fresh scarps are mostly vertical, or nearly so, though in places eighteen years of erosion have somewhat modified the original steepness. The fault surfaces are rarely seen because, for the most part, only alluvium is exposed. This alluvium, clinging to the fault surfaces, has produced the vertical escarpments, masking the true fault dip and permitting a superficial branching of the scarps (Figs. 6 and 7).

Slickensided dolomite is exposed by the Pearce scarp at one place

and shows the fault dip to be 49° W. at that point (Fig. 8). At another place, where the same fault traverses the pediment at the

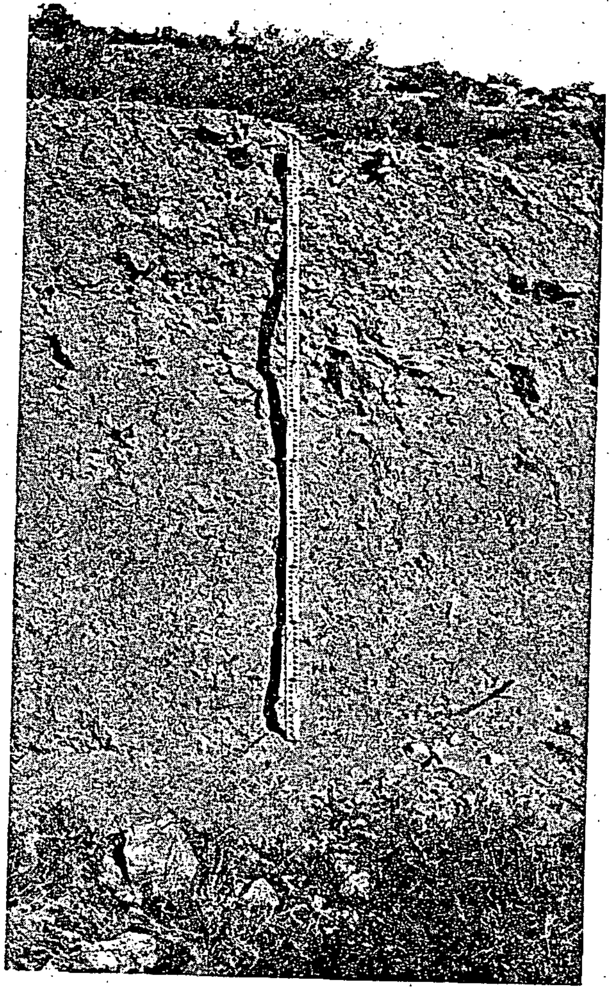

FIG. 6.—Close-up of the Pearce scarp, showing its composition and its height near Pearce's ranch. No bedrock is exposed. (The stadia rod is 12 feet long.)

southern end of Pleasant Valley, the actual caliche-covered fault surface is shown (Fig. 9) and here dips from 75° to 81° W. Elsewhere the true dip can be ascertained only where canyons cross the scarps and reveal the true fault profiles (Fig. 10).

Near several of the canyons the fault scarps are accompanied by a trench, perhaps 10 feet wide and 10 feet deep (Fig. 11), which lies at their foot. This feature is due to the fact that the footwall carried adhering alluvium relatively eastward as well as upward (Fig. 7).

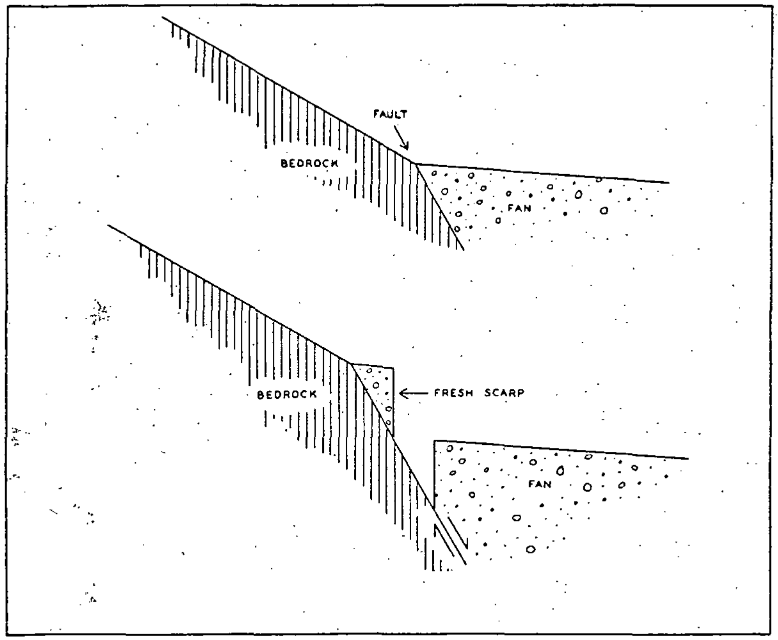

FIG. 7.—Relation of fresh scarp to the fault surface

In most places no single trench follows the scarps, but at the base of the latter the ground appears to have been torn up by an immense plow. In other places alluvium has settled into miniature grabens adjacent to the scarps. These features originated in about the same manner as the "plowed" areas.

Many different kinds of rock were cut by the faults. For the most part the behavior of the latter was not greatly affected by the type of rock at any one point, although the scarps are subdivided most where the material is weakest. In two places the Pearce scarp swings about 1,000 feet to the west in a broad arc, then returns to its former course. The northernmost arc of this sort is a mile or so north of Pearce's ranch. Here a Tertiary volcanic neck, which is harder than the adjacent rock, makes up the mountain front and may be supposed to have deflected the course of the fault. However, the

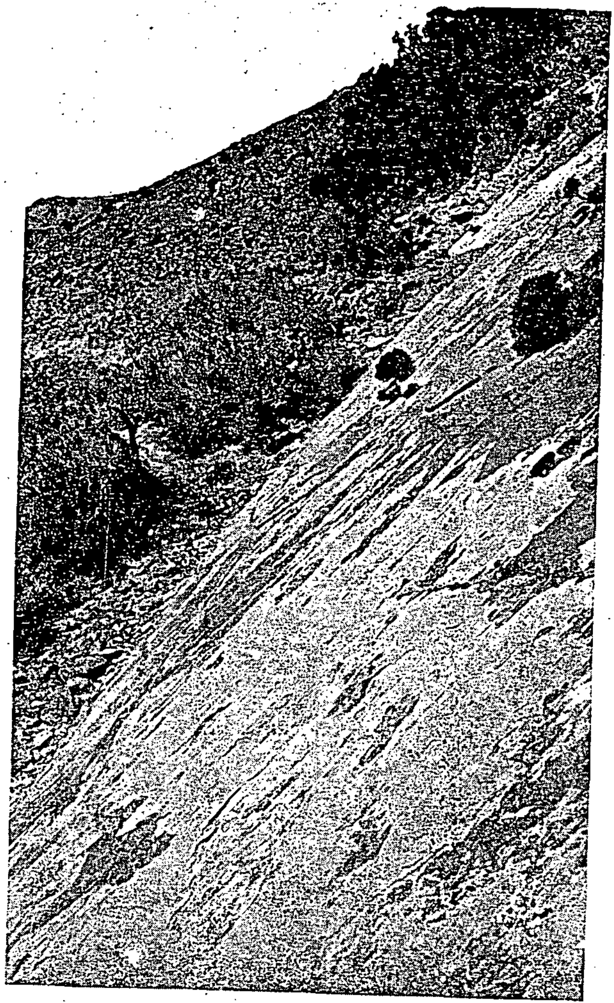

FIG. 8.—Fault surface dipping 49° W. In this one instance bedrock constitutes the Pearce scarp. The rock is slickensided dolomite, covered with caliche.

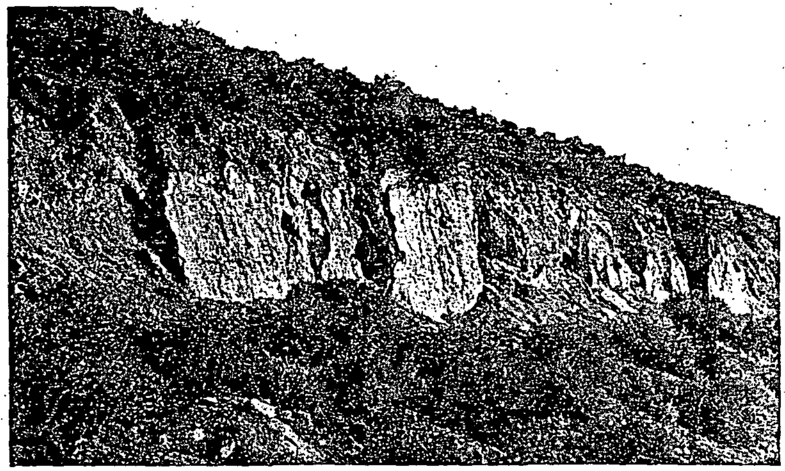

FIG. 9.—The Pearce scarp in alluvium at the south end of Pleasant Valley. The caliche-covered fault surface, exposed by the 1915 displacement, dips 75°–81° W.

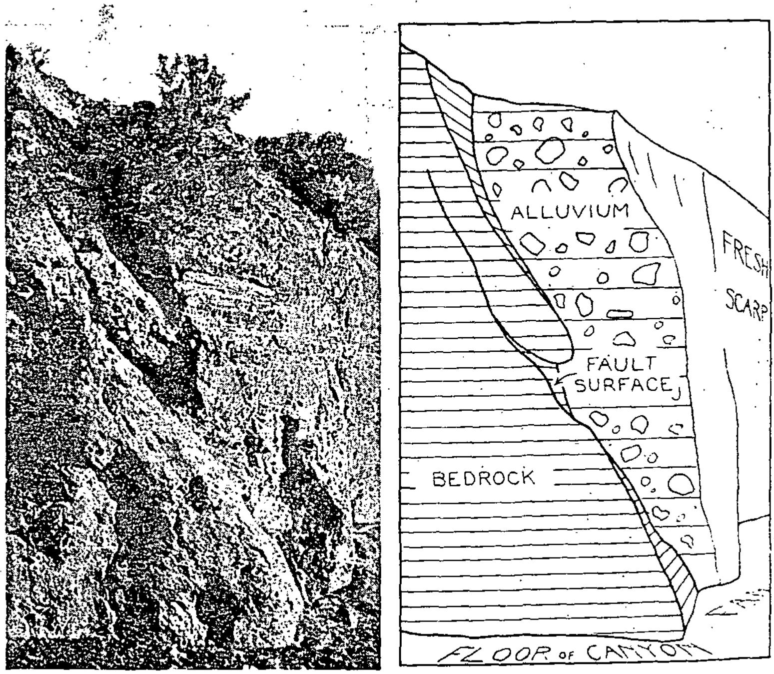

FIG. 10.—Cross section of the Pearce fault and fresh scarp. Fault and scarp are shown in profile at the mouth of a canyon that was deepened artificially after the uplift of 1915.

southernmost of the two great deviations is situated in dolomite which extends well beyond the "deflected" portion of the fault. Thus in this second instance, at least, the strength of the surface rock does not account for deviation in the course of the fault.

THE NATURE OF THE FAULTING

Figures 11 and 13 supply some evidence as to the nature of the 1915 movement. The displacement was in a direction parallel to the dip of the faults, which are normal. In other words, the components were vertical and about east-west. The former was between 0 and 15 feet; the latter between 0 and 13 feet. Assuming a uniform fault dip of 60° and an average throw of 10 feet, the average heave would be 5.7 feet. This figure is probably fairly representative.

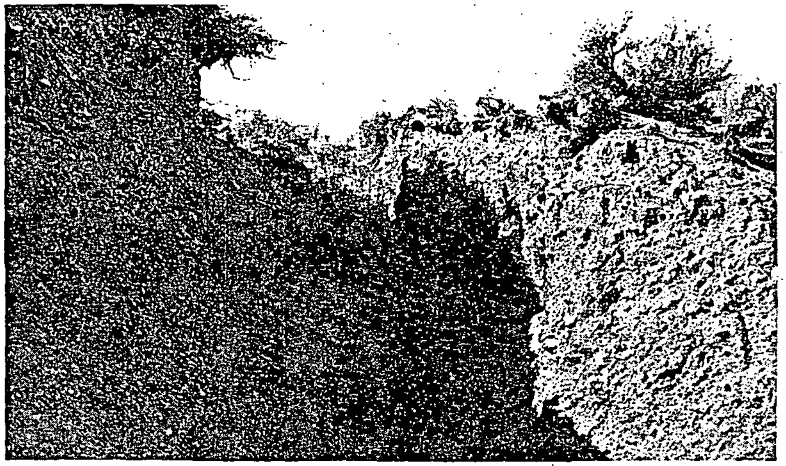

FIG. 11.—Gap between the Tobin scarp and alluvial fan. The footwall carried some adhering alluvium upward and to the left (east), leaving a gap between it and the fan (right).

Did the mountains rise or the valley sink? The answer is largely speculative, as there were no benchmarks here in 1915. The elastic rebound theory leads one to suspect that at the time of the earthquake the margins of both the mountain and valley blocks sprang into comparative equilibrium, one upward and the other downward. Mr. W. L. Pearce, whose ranch is alongside the Pearce fault, observed that water in his orchard ran sluggishly after the earthquake, whereas previously it had run swiftly toward the bottom of the valley. This may indicate a change in slope due either to elastic rebound or to a settling of the alluvium next to the fault. A long-continued, slow movement probably led up to the displacement of 1915, but its character is unknown.

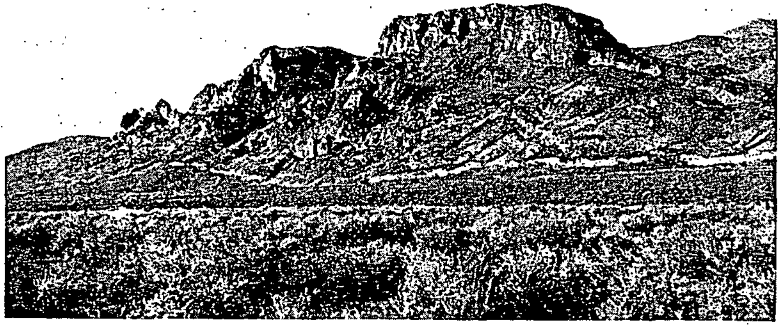

FIG. 12.—Pearce scarp at the base of a volcanic neck. Bedrock is not exposed here on the scarp, contrary to appearance.

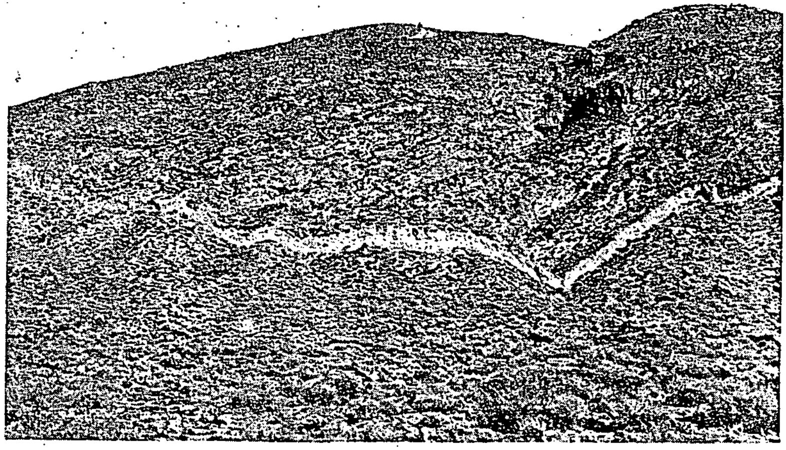

FIG. 13.—The Pearce scarp, showing its form at a gully. The equally broad sides of the V indicate that practically no displacement occurred parallel to the strike of the fault when the scarp was formed.

COMPARATIVE DISPLACEMENTS

Within historical times two somewhat similar dislocations are known to have occurred in North America. In 1872 scarps were formed at the eastern base of the Sierra Nevada and the Alabama Hills in Owens Valley, California.[5] This movement, however, had a large strike-slip component and somewhat resembled that which produced the Cedar Mountain earthquake[6] of 1932 in Nevada. In 1887 a displacement left a long escarpment on one or both sides of the San Bernardino Mountains in Sonora, Mexico.[7]

TABLE I

Location	Date	Maximum Vertical Displacement in Feet	Maximum Horizontal Displacement in Feet
Assam, India*	1897	35	0
Owens Valley, California†	1872	23	12
San Andreas fault, California‡	1906	3	21
Mino-Owari, Japan§	1891	20	13
Sonora, Mexico‖	1887	20	0?
Pleasant Valley, Nevada	1915	16	1
Wellington, New Zealand¶	1855	9	0?
Honshu, Japan**	1896	6	?
Formosa, Japan††	1906	6	8
Baluchistan‡‡	1892	0?	$2\frac{1}{4}$

* R. D. Oldham, "Report on the Great Earthquake of 12th of June 1897," *Mem. Geol. Surv. India*, Vol. XXIX (1899), pp. 1–379.

† W. H. Hobbs, "The Earthquake of 1872 in the Owens Valley, California," *Beitr. Geophysik*, Band X (1910), p. 379.

‡ A. C. Lawson *et al.*, "The California Earthquake of April 18, 1906," *Rept. of State Earthquake Investigation Commission, Carnegie Inst. Wash. Publ. 87* (1909–1910).

§ B. Koto, "On the Cause of the Great Earthquake in Central Japan, 1891," *Jour. College Sci., Tokyo Imper. Univ.*, Vol. V (1892), pp. 295–353.

‖ G. F. Goodfellow, "The Sonora Earthquake," *Science*, O.S., Vol. XI (1888), pp. 162–68.

¶ C. Lyell, *Principles of Geology* (11th ed.; New York: D. Appleton & Co., 1892), Vol. II, pp. 82–89.

** A. W. Grabau, *A Comprehensive Geology* (New York: D. C. Heath & Co., 1920), Part I, *General Geology*, pp. 664–88.

†† W. H. Hobbs, *Earthquakes* (New York: D. Appleton & Co., 1907), pp. 66–67.

‡‡ C. L. Griesbach, "Notes on the Earthquake in Baluchistan on the 20th of December, 1892," *Rec. Geol. Surv. India*, Vol. XXVI (1893), pp. 57–64.

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[5] W. H. Hobbs, "The Earthquake of 1872 in the Owens Valley, California," *Beitr. Geophysik*, Vol. X (1910), p. 379.

[6] V. P. Gianella and E. Callaghan, "The Earthquake of December 20, 1932, at Cedar Mountain, Nevada, and Its Bearing on the Genesis of Basin Range Structure," *Jour. Geol.*, Vol. XLII (1934), pp. 1–22.

[7] G. F. Goodfellow, "The Sonora Earthquake," *Science* O.S., Vol. XI (1888), pp. 162–68.

For comparative purposes, the Pleasant Valley movement is placed among a list of some of the most notable recent displacements that have appeared as such at the earth's surface (Table I).

A number of other slips are known to have had displacements similar in magnitude to those listed in the table. In addition there have been large changes of level which may or may not have involved the formation of definite scarps. For instance, Chile, Jamaica, Italy, and notably Alaska[8] have suffered sudden and local changes in level which seem to imply the existence of unseen scarps. However a few sudden displacements have been known to produce rising and sinking of the ground without scarps, even when the magnitude of the changes was 20–30 feet, as in the Mississippi Valley at the time of the New Madrid earthquake (1811).[9]

CONCLUSIONS

The following are some of the more important facts connected with the Basin-Range faulting of 1915:

1. The southern Sonoma Range in the locality studied consists of two adjacent fault blocks.

2. These two blocks could easily have been recognized as such prior to 1915, thus proving the validity of conventional fault scarp criteria.

3. The facets of the mountain front mostly slope less than 30°.

4. At the western base of each block is an irregular normal fault, dipping more steeply than the facets (41°–81°).

5. On October 2, 1915, the two marginal faults suffered a dip-slip displacement. There was no appreciable strike-slip component.

6. The two blocks behaved more or less as a unit during this recent movement.

7. Fresh fault scarps appeared at the immediate base of the mountains.

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[8] R. S. Tarr and L. Martin, "The Earthquakes at Yukatat Bay, Alaska, in September, 1899," *U.S. Geol. Surv. Prof. Paper 69* (1912), pp. 1–135.

[9] M. L. Fuller, "The New Madrid Earthquake," *U.S. Geol. Surv. Bull. 494* (1912), pp. 1–119.

8. The fresh scarps are composed of alluvium clinging to fault surfaces that are less steep and more regular than the scarps themselves.

9. The maximum throw indicated by the fresh scarps (about 16 feet) is of the same order of magnitude as some past displacements in this locality and of quite a few historical fault movements in other localities.

ACKNOWLEDGMENTS.—This study was suggested and aided by Dr. Aaron C. Waters. Dr. Siemon W. Muller, Henry M. Page, and the inhabitants of Pleasant Valley were also of very great assistance.

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Nickel Deposits In Cottonwood Canyon, Churchill County, Nevada

By H. G. Ferguson
Geologist, U. S. Geological Survey

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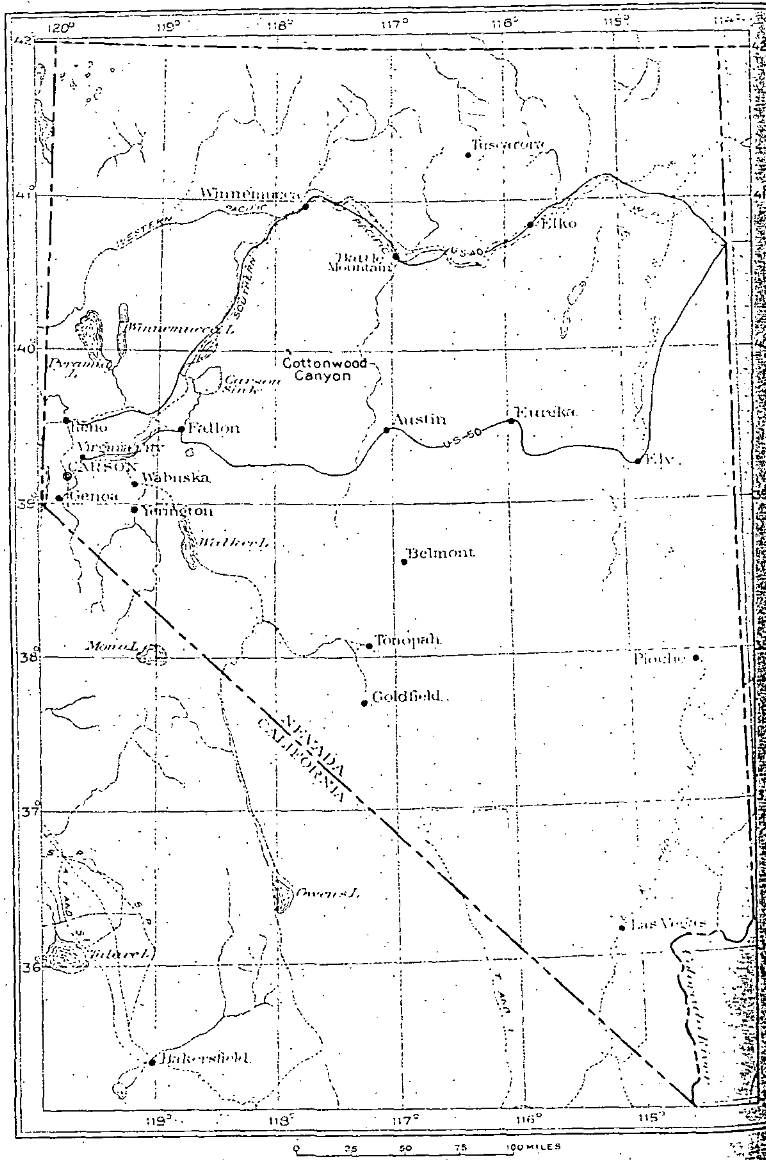

FIGURE 1. Index map showing the location of Cottonwood Canyon, Churchill County, Nevada.

NICKEL DEPOSITS IN COTTONWOOD CANYON, CHURCHILL COUNTY, NEVADA*

By H. G. Ferguson

ABSTRACT

Nickel and cobalt deposits, formerly productive, occur in Cottonwood Canyon at the northern end of the Stillwater Range. A large mass of diorite, with accompanying smaller masses and dikes of aplite, has intruded into and altered sedimentary and overlying volcanic rocks. The nickel and cobalt minerals occur in small fissures in the altered rocks. Near Corral Canyon, five miles south of Cottonwood Canyon, veins and lenses of gold-bearing quartz are associated with altered aplitic dikes that contain anatase (octahedrite). As little could be seen of the old workings of the nickel deposits, no definite opinion can be offered as to possible future production, but the ore-bearing fissures are small and discontinuous and there is little ore in sight. The titanium-bearing dikes do not contain a sufficiently high content of TiO_2 to warrant exploitation at present. The gold-quartz veins, on the other hand, are being developed with encouraging results.

INTRODUCTION

During the summer of 1938, a short visit was paid to the nickel and cobalt occurrences in Cottonwood Canyon, Churchill County, Nevada (see Figure 1).† The work was done, under grant from the Public Works Administration, as part of a general investigation of strategic minerals. In the study of the geology, to which four days were devoted, the writer was assisted by A. E. Granger and George P. Sopp. The work included a brief visit to the titanium and gold deposits near Corral Canyon, five miles south of Cottonwood Canyon.

The topographic and geologic map (Figure 2) is controlled by points fixed by a plane-table traverse made by R. M. Dreyer, with the assistance of George P. Sopp and Craig Moore. The writer is indebted to Mr. C. S. Ross for study of the rock and mineral specimens collected and to R. C. Wells and J. G. Fairchild

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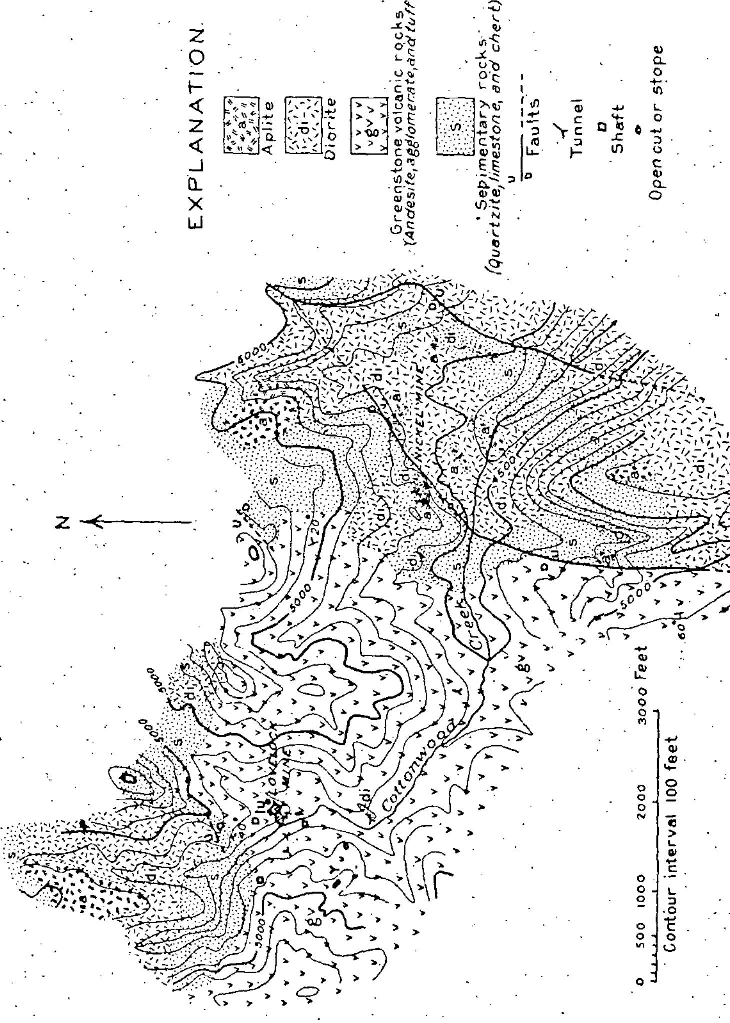
†It is possible that the nickel and cobalt mines described in this report are, at least in part, within Pershing County.



for identification of the ore minerals and analyses of the ore of the nickel mine.

LOCATION

The nickel and cobalt mines of Cottonwood Canyon are in the Table Mountain district, also known as the Cottonwood or Boyer District, which occupies part of the Stillwater Range in Churchill and Pershing (formerly a part of Humboldt) Counties. According to Lincoln,[1] the district contains a wide variety of mineral deposits, including nickel, cobalt, copper, silver, lead, gold, kaolin, oil shale, and gypsum. Except, however, for the gold and titanium deposits near Corral Canyon, discovered since the publication of Lincoln's compilation, the present investigation was confined to the nickel and cobalt deposits of Cottonwood Canyon.

Cottonwood Canyon, in the northern part of Churchill County, cuts the steep, eastern flank of the Stillwater Range. The mouth of the canyon can be reached by automobile over roads that are passable in good weather, either by a route about 55 miles in length through Dixie Valley from Highway U S 50 or one about 70 miles southward from Winnemucca on U S 40, through Grass and Pleasant Valleys. In the fall of 1938 work was planned on a road to connect the two east-west highways through Dixie, Pleasant, and Grass Valleys. Completion of this road will render the district much more easily accessible. There was formerly a road up the canyon to the mines, but it has been completely washed out and the mines at present can be reached only on foot through the steep-walled canyon.

The Stillwater Range and its northern continuation, the East Range, rise abruptly from the valley in a steep, eastward-facing scarp. Two or 3 miles north of the mouth of Cottonwood Canyon, the horizontal distance between the 4,000- and 7,000-foot contours is less than 1½ miles, as shown in the southern-most part of the topographic map of the Sonoma Range quadrangle. Cottonwood Creek flows through a narrow box canyon, crossing the ridge that borders the front of the range. Near the mines, 2 or 3 miles back from the front of the range, the canyon is much wider, and west of the Lovelock mine it becomes a shallow valley cut only slightly below a broad bench that has an altitude of about 5,500 feet. This bench is apparently about coincident with the position of the contact of the older rocks and overlying Tertiary lavas. To the west these lavas, which form the crest of the range, rise to an altitude of about 7,500 feet.

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[1] Lincoln, F. C., Mining districts and mineral resources of Nevada, pp. 11–13, Reno, Nevada, 1923.

PREVIOUS WORK

Cottonwood Canyon lies within the area covered by the map of the Fortieth Parallel survey, but it is doubtful whether the geologists of this survey actually visited the locality. The nickel and cobalt deposits, as well as the copper deposits near the crest of the range south of the canyon, were visited by Ransome in 1908. The present writer can add little to Ransome's description of the deposits.[2] The map of the area around the two mines and the notes on the recently discovered gold and titanium deposit near Corral Canyon are the principal new contributions to the geology of the district. The copper deposit, not visited by the writer, has been described by Carpenter.[3] Lincoln's compilation gives notes on mining developments and a concise summary of earlier publications.

GEOLOGY

COTTONWOOD CANYON

ROCK FORMATIONS

The rocks of the area studied include highly altered sedimentary and volcanic rocks cut by a large mass of diorite and by aplitic dikes, all of which are now highly altered.

The oldest rocks in the vicinity of the nickel deposits are sedimentary and consist chiefly of quartzite, but they also include altered limestone, in part silicified, together with a white chert-like rock, that may be either bleached chert or silicified limestone. The total thickness is uncertain, but probably is not over a few hundred feet.

Overlying the sedimentary rocks is a considerable thickness of altered volcanic flows, with smaller amounts of agglomerate and obscurely bedded tuff. The flows were probably of andesitic composition originally, but are now so highly altered that it seems preferable to describe them by the noncommittal term of greenstone. Little remains of their original texture. Over most of the area, particularly near the two mines shown in Figure a considerable part of the rock has been replaced by platy hematite. In part, this hematite is hydrated to a brown iron oxide. Elsewhere, as on the ridge north of the two mines, they have been impregnated with fine-grained silica and the silicified rocks form bold craggy outcrops.

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[2] Ransome, F. L., Notes on some mining districts in Humboldt County, Nevada: Geol. Survey Bull. 414, pp. 55–58, 64–66, 71, 1909.

[3] Carpenter, A. H., Boyer copper deposits, Nevada: Mining and Scientific Press, vol. 103, pp. 804, 805, 1911.

[4] Lincoln, F. C., *op. cit.*, pp. 11–13.

The age of these volcanic rocks is unknown; they bear a certain resemblance to interbedded sedimentary and volcanic rocks of Permian age in the north part of the Sonoma Range quadrangle. (Recent areal studies in the Sonoma Range quadrangle suggest that these rocks may be of Pennsylvanian rather than Permian age.) Less metamorphosed sedimentary rocks, also cut by diorite, crop out at the mouth of the canyon, about 2 miles southeast of the Nickel mine. These include limestone, slate, and conglomerate, and bear some resemblance to rocks of known Lower Triassic age in the Sonoma Range quadrangle.

Diorite is the principal rock of the area. The canyon for the 2 miles between the Nickel mine and the range front is cut in diorite. The same mass extends southward along the range front and is probably continuous with that at the titanium prospects near Corral Canyon, 5 miles south of Cottonwood Canyon. Diorite also cuts the sedimentary and volcanic rocks north of the Lovelock mine. The diorite varies greatly in texture and composition, but is, in general, coarse- to medium-grained. Plagioclase, augite, hornblende, and biotite are present in varying amounts, with sphene, magnetite, and apatite as primary accessories. All of the rock examined in thin sections by Mr. Ross was altered. The feldspars are everywhere partly sericitized. Other secondary minerals include dickite (one of the kaolin minerals), clinozoisite, chlorite, quartz, and calcite. Replacement of plagioclase by albite is also common, and near some of the aplite dikes there appears to have been nearly complete replacement of the original rock by albite accompanied or followed by calcite, sericite, quartz, and dickite.

At the margins of the diorite mass there are small dikes of a fine-grained, white feldspathic rock (aplite). These crop out within the diorite mass and are in contact with the sedimentary rocks close to the diorite. None was found in the altered volcanics in the central part of the mapped area nor in the main mass of diorite in the lower part of Cottonwood Canyon. Essentially, the aplite is a fine-grained aggregate of feldspar and a little quartz. In one of the specimens examined by Mr. Ross the feldspar proved to be a mixture of oligoclase and microcline; in all the others examined, albite is the only feldspar present. In most of the specimens examined additional later minerals include dickite, quartz, calcite, sericite, and anatase. The anatase where present is in extremely small crystals, so well scattered through the rock that Ransome, who did not see the much more altered

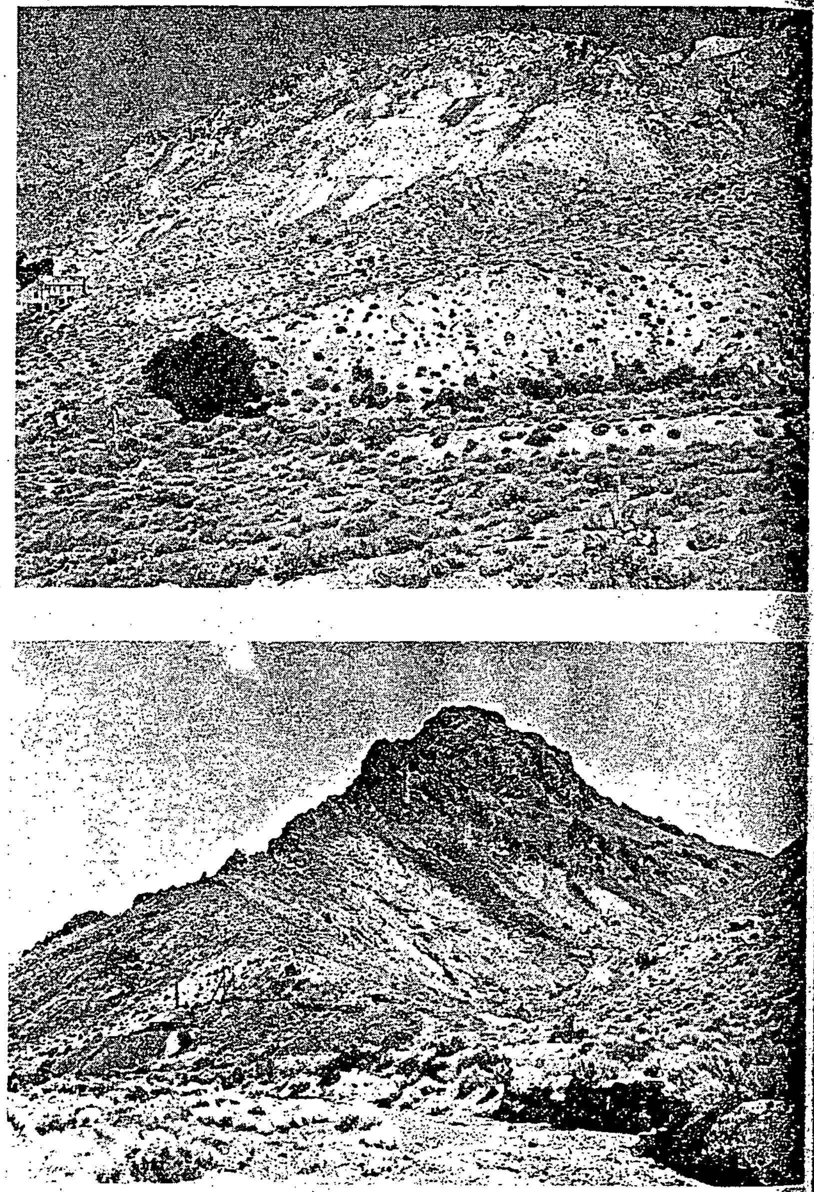

FIGURE 3. A. View of Nickel mine from east. Foreground consists of diorite cut by aplite dikes. The workings are in the more resistant altered sedimentary rock west of the fault shown in Figure 2. B. View of Lovelock mine from south. In foreground is greenstone. High hill to south consists of quartzite.

dikes of the Corral Canyon area (pp. 15, 16), considered it an original mineral.[5] The chemical analysis given by Ransome shows only 0.97 percent TiO_2. In a dike near the Nickel mine, however, anatase apparently replacing sphene was found completely enclosed in calcite.

STRUCTURE

The altered volcanic rocks, cut by the diorite, lie in a syncline, bordered on the west, north, and east by the altered sedimentary rocks. Their southward extension is unknown, but apparently they crop out on the high ridge that separates Cottonwood Canyon from the next canyon to the south.

There are two faults of northerly trend, both with downthrow on the west, in the eastern part of the mapped area. The western fault cuts off the mineral-bearing fissures of the Nickel mine and probably branches out from the eastern fault in the valley northeast of the mine. Its dip averages about 45° to the west. The eastern fault also has a westerly dip, but is steeper and probably everywhere dips over 60°. Over most of its course within the mapped area, it is traceable only as a shear zone in the diorite, but on the north bank of Cottonwood Creek it forms the boundary between a downfaulted roof pendant of quartzite and the main mass of the diorite. The amount of displacement along these faults is not measurable, but may amount to several hundred feet, for the greenstone crops out only in the area west of the western fault.

A fault that is the apparent continuation of that crossing Cottonwood Canyon displaces middle or late Tertiary bedded tuffs[6] a short distance north of the area mapped. Therefore, it is probable that the faults within the district may also be of late Tertiary age.

Probable faults of smaller throw, inferred from the nature of the contacts rather than from direct observation, form the boundaries between the sedimentary and volcanic rocks at one place north of the Nickel mine and between the sediments and diorite at one place northwest of the Lovelock mine. The shaft of the Lovelock mine is along a fault that separates heavily hematitized greenstone from less altered rock.

NICKEL AND COBALT DEPOSITS

According to Lincoln,[7] the nickel and cobalt deposits of Cottonwood Canyon were discovered by George Lovelock and Charles

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[5] Ransome, F. L., Notes on some albitite dikes in Nevada: Washington Acad. Sci. Jour., vol. 1, pp. 114–118, 1911.

[6] Muller, S. W., personal communication.

[7] Lincoln, F. C., op. cit., p. 11.

Bell about 1882. Production began shortly afterwards, and the early volumes of "Mineral Resources" contain notes on production. Apparently the larger part of the earlier production was derived from the Lovelock mine and continued until about 1886. According to "Mineral Resources":[8] "Since the first opening of the mines in 1883 about 200 tons were shipped for reduction to England, of which 90 tons were shipped during 1885. * * * The general average of the 200 tons shipped to England was said to have been 12 percent nickel and 14 percent cobalt." Ransome says that the mine is reported to have shipped a total of about 500 tons of high-grade nickel-cobalt ore. The mine was reopened about 1898 by an English company and an attempt made to smelt the ore, but little or no production was made.

The ore deposits of the Nickel mine were probably discovered at about the same time as the Lovelock mine, but, so far as known, less work has been done on this deposit. According to Ransome[10] the principal period of activity was between 1882 and 1890, and at least one car of ore, with a content of 26 percent nickel, was shipped to Camden, N. J. The mine was reopened in 1904 and an attempt made to leach the ore with sulphuric acid. A small smelter was also built, but the production was very small, probably not over 50 tons of matte, according to Ransome.[11] The mine has been idle since 1907. In 193[illegible] the patented claims covering the property were purchased at a tax sale by the present owners.

As far as could be observed, the nickel and nickel-cobalt ores of the two mines occur as small discontinuous stringers that cut the rocks immediately surrounding the diorite. These stringers are composed essentially of ore minerals and iron oxide with very little quartz. At the Nickel mine such stringers cut a highly altered rock that was probably an aplite dike originally, and also cut the adjoining altered sedimentary rocks; at the Lovelock mine the stringers cut highly altered greenstone. No stringers of this type were found within the diorite, though veins of white quartz cut the diorite and have been prospected in places, apparently without success.

Although the type of mineralization seems to have been the same throughout the area, the mineral content of the small stringers varies greatly in the different mines and prospects. At the Nickel mine the ore minerals present are combinations of nickel, arsenic, iron and sulphur.

The nickel minerals present in the stringers are almost completely oxidized and consist principally of the hydrous nickel arsenate, annabergite, the sulphate, morenosite, possible garnierite, and an unidentified bright-green nickel-bearing mineral. Sulphide present in one of the stringers was identified by C. F. Park as dominantly niccolite, which, however, by its crystal form, appears to have replaced millerite. Millerite occurs in part as rare residual grains within the niccolite and in part as thread-like veinlets, probably accompanied by a little marcasite, that cut the niccolite and apparently the annabergite also. The second mode of occurrence is presumably supergene, but the total secondary enrichment thus indicated is negligible. Gangue minerals are not abundant and include limonite, quartz, and dickite. The following analysis by R. C. Wells of a sample cut from a 4-inch stringer at the end of the principal stope, indicates the composition of the purest ore obtainable:

Analysis of Nickel Ore

(R. C. WELLS, Analyst)

	Determined		Calculated
SiO_2	14.78		14.78
Al_2O_3	1.61		1.61
Fe_2O_3	.71		.71
NiO	29.67	NiO	18.37
		Ni	8.49
As_2O_5	36.20	As_2O_5	22.07
		As	9.21
MgO	1.27		1.27
CaO	.83		.83
Na_2O	.22		.22
H_2O-	2.56		2.56
H_2O+	11.04		11.04
TiO_2	Trace		Trace
S	1.70		1.70
SO_3	1.83		1.83
	102.42		95.19

Mr. Wells comments on the analysis as follows:

"The calculated composition shown is based on subtraction of assumed constituents in the following order and percentages:

	Percent
Water-soluble As_2O_5	4.07
Water-soluble morenosite, $NiSO_4.7H_2O$	5.33
Millerite, NiS	4.82
Annabergite, $Ni_3As_2O_8.8H_2O$	46.50
Niccolite, $NiAs$	8.04
Violarite, $NiAs_2$	6.54

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[8] Mineral Resources of the United States for 1885, p. 361. 1886.

[9] Ransome, F. L., op. cit., p. 58.

[10] Ransome, F. L., op. cit., p. 57.

[11] Ransome, F. L., op. cit., p. 12.

"From the summation of the calculated percentages it appears that the reduction has been too great. This might be explained in part by the presence of garnierite, which was not allowed for or by a partial dehydration of the hydrated minerals previous to analysis. If the proportion of water had been higher, the calculation would have resulted in more annabergite and less of the last two arsenides, bringing the summation closer to 100. Water was determined by the Penfield tube, using sodium tungstate as a retainer of the arsenic and sulphur. The ore carried 23.3 percent nickel expressed as metallic nickel."

The low iron content shown by this analysis is not representative of the deposits as a whole. Most of the stringers show abundant brown iron oxide with, here and there, green streaks indicating the presence of nickel, whereas others show only limonite and a little quartz.

In the greenstone area between the Nickel and Lovelock mines in the prospects on the hill west of the Lovelock mine the filling of the small fissures is predominantly iron oxide, with, here and there, a little green copper sulphate and carbonate, but no nickel minerals.

At the Lovelock mine the mineral composition is more complex; ores of copper, cobalt, and arsenic are all present, and according to reports, nickel ore was mined as well. According to Ransome,[12] "The minerals recognized are tetrahedrite, erythrite (cobalt bloom), azurite, and green crusts that, according to Mr. Schaller, contain copper and nickel arsenates and sulphates and consequently may be a mixture of annabergite and brochantite." Specimens from a small pile of picked ore at the mouth of a tunnel leading to the open stope of the Lovelock mine and from stringers on the walls of the stope were examined by J. G. Fairchild, of the Geological Survey. He reports as follows: "A basic sulphate of copper, resembling brochantite, is the abundant green mineral. Cobalt bloom, or erythrite, was identified chemically in two specimens. No nickel mineral was identified. The light-green mineral is also a basic sulphate of copper with some arsenic, possibly chalcophyllite. An oxide of manganese is present in dark-brown seams and black patches." The approximate metal content of the material, according to Mr. Fairchild, is percent copper, 1 percent arsenic, 1 percent cobalt, and 0.6 percent nickel.

No consistent orientation of the mineralized fractures is apparent. In the Nickel mine (Figure 4) the principal stopes are along a flat fissure with a dip of about 20° to the southwest. This has been followed along the strike for about 100 feet and stoped over about one-half this distance. Probably this stringer yielded a relatively large amount of nickel, in spite of its small length, for the sample taken from a 4-inch vein of green material left at the end of the stope assayed 23.3 percent nickel. Nearby, in the same tunnel, a stringer with a northerly trend and a westerly dip of 60° to 70° has been followed for about 80 feet, and has been stoped for about 30 feet.

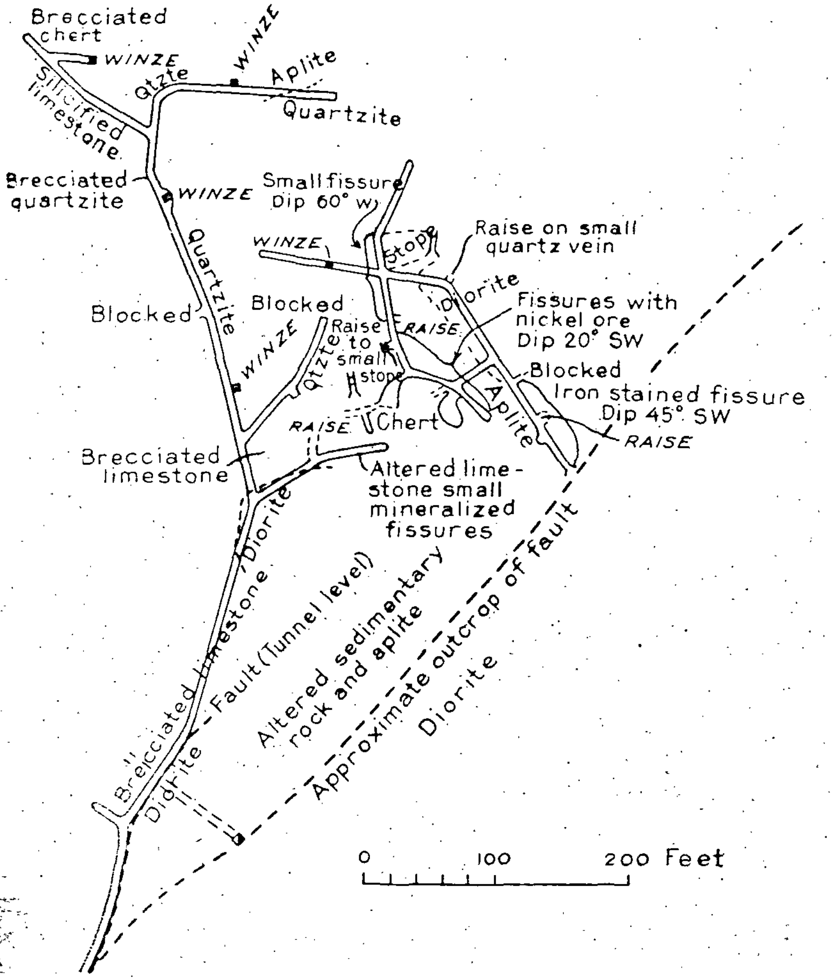

FIGURE 4. Map of a portion of the workings of the Nickel mine, based on a pace and compass survey. Relative positions of the different workings are approximate only.

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[12] Ransome, F. L., op. cit., p. 58.

Similar discontinuity of fissuring was observed in the prospect between the Nickel and Lovelock mines and in the workings south of the creek. The workings of the Lovelock mine were inaccessible, but according to Ransome,[13] "comprise a labyrinth of superficial burrowings by which miners have followed or sought for the small erratic veinlets of ore, and a precarious shaft that no attempt was made to explore." A stope about 50 feet by 20 feet, open at the surface, trends N. 75° W., but, as far as could be observed, the stringers remaining on the walls have no consistent direction.

It seems probable that individual mineral-bearing fissures are at least as discontinuous in a vertical direction as in the outcrop. According to Ransome, the shaft of the Lovelock mine is apparently not much more than 100 feet deep. The accessible part of the lower tunnel of the Nickel mine (Figure 4) does not cross mineral-bearing fissures such as have been stoped in the tunnel about 60 or 70 feet above.

The inaccessibility of the workings of the Lovelock mine prevents any speculation as to the possibility of renewed production from this mine. According to Ransome, considerable work has been done in the 100-foot zone above water level, both in following the mineralized fissures and in searching for others. Apparently nothing was found to justify exploration at greater depth. It was observed, however, that the stope and nearly all the small tunnels and inclines are east of the main shaft, and that at the shaft itself there was a steep fault with northerly strike which separates the highly altered and mineralized greenstone from less altered rock on the west. It is possible, therefore, that here, as at the Nickel mine, there has been post-mineral faulting with downthrow on the west, and that the extension of the productive zone is west of the shaft and at greater depth than present workings have reached.

The ore deposit of the Nickel mine (Figure 4), on the other hand, occurs within a downfaulted segment of a mineralized area, the eastern portion of which has been eroded. The major production seems to have been derived from a gently-dipping stringer, which has been stoped above the upper tunnel and possibly also between the upper and lower tunnels. It does not, however, extend to the lower tunnel 60 or 70 feet below. Similarly, the steeply-dipping stringer to the north, on which there has been some stoping, was not cut in the lower level unless in the inaccessible cross-cut north of the diorite. The entire production apparently came from the upper workings. In the lower tunnel, near the face of the eastern branch, the silicified limestone close to the intrusive diorite west of the fault is cut by small iron-stained fissures, which, here and there, contain a little green stain, probably due to nickel. Elsewhere the accessible workings of this level are completely barren. Although such work as has been done on this level seems to eliminate the possibility of any large body of ore, it is not unlikely that other small nickel-bearing stringers may be encountered on this level below the productive zone in the upper workings.

Should further work be undertaken, the area east of the lower tunnel should be explored as far as the fault, as the upper workings indicate that the stringers, though not continuous, may be rich in nickel. This may have been the intention of the last operators when they started the east branch at the northern end of the lower tunnel.

It is not known how much work was done below the lower tunnel. There are several winzes in the northern part of the lower tunnel, and the shaft also extends below the tunnel level, but these deeper workings were not accessible. No further deep work would appear justified without better indications at the level of the lower tunnel than now appear.

It is believed that the fault is post-mineral and that the ore deposition was pre-Tertiary. If so, no exploration is justified along the fault itself. This belief is based on the apparent late Tertiary age of the fault, as shown by its inferred northerly extension; also by the complete lack of primary mineral deposits along the fault itself in the vicinity of the mine, both at the surface and in the small tunnel along the fault. North of the mine, however, there are small prospect pits along the fault in which the fault gouge contains a little limonite and faint green stains, which may be due to either nickel or copper. These may be the result of supergene deposition, which is shown in the mine itself by the presence of secondary millerite and marcasite. Ransome,[14] however, points out that, as copper ores occur in the Tertiary tuffs near the crest of the range south of the canyon, a Tertiary age of these deposits cannot be excluded. As will be shown below, this suggestion appears to be unlikely, but there remains the possibility that the association of the nickel-bearing stringers with the fault is not fortuitous. If the ores are of Tertiary age,

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[13] Ransome, F. L., op. cit., p. 58.

[14] Ransome, F. L., op. cit., pp. 58, 71.

ore deposition may have followed faulting; if they are pre-Tertiary, there may have been renewed movement on an older fault, and the mineral-bearing stringers may be associated with the original major fracture.

There are numerous small prospect tunnels in the hills bordering Cottonwood Creek between the two mines, but in those that were accessible there was nothing seen to indicate the likelihood of any mineral deposit of commercial promise. Most of these tunnels follow iron-stained fissures with only here and there a little green stain. It is doubtful, however, whether the area has been so intensively prospected as to eliminate the possibility of new discoveries. The writer, for example, found an unexplored small copper-bearing stringer in the altered greenstone near the crest of the steep ridge about half a mile northwest of the Nickel mine. Except for the Nickel mine, where the mineral deposits are in the sedimentary rocks at the diorite contact, the fissures sufficiently well defined to encourage prospecting are all within the greenstone and the great majority of them are in the portion of the greenstone that shows replacement by hematite. The silicified zones in the greenstone, which form the craggy outcrops on the ridges north of Cottonwood Creek, show no nickel or copper stains.

CORRAL CANYON

GOLD AND TITANIUM DEPOSITS

Part of a day was devoted to a visit to prospects close to the front of the range near Corral Canyon, about 5 miles south of the mouth of Cottonwood Canyon. No attempt was made to study the geology in any detail, nor was the intervening area examined. The writer is indebted to C. S. Ross for mineralogic and petrologic determinations of material collected.

The country rock of the region is diorite, presumably a part of the same mass as that of Cottonwood Canyon. The diorite is cut by a number of dikes, originally of feldspathic rock, which contains abundant anatase (octahedrite) and are associated with veins or segregations of gold-bearing quartz.

The white, fine-grained dikes have a general northerly trend and stand out sharply against the surrounding diorite. It is probable that here, as in the Cottonwood Canyon area, the dikes originally consisted of an aplitic rock, composed of feldspar with a little quartz, and their present peculiar mineral composition is the result of pegmatitic and hydrothermal alteration. A specimen from the apparently least altered part of one of the dikes was found to consist essentially of microcline and oligoclase, with only minor replacement by calcite and sericite. In most of the dike rocks in the small area examined the original minerals have been completely altered. The only feldspar present is albite, probably a replacement of the original feldspars of the dike, and the rock consists essentially of dickite, quartz, anatase (octahedrite), calcite, and sericite, named in approximate order of their abundance. The anatase is sporadic in its distribution. In places it forms over 5 percent of the rock and in small segregations a much larger proportion; elsewhere it may be lacking or present only in small specks. Where most abundant it forms sharply outlined lozenge-shaped masses, the largest nearly 2 inches in length, which suggest that it was formed by the replacement of earlier sphene.

The quartz that is now being mined for its gold content forms very elongate lenticular bodies within and along the margins of the dikes. Single quartz masses a few feet in width may be traceable for as much as 100 feet. There has, however, been complex later faulting close to the range front and it has not been determined to what extent discontinuity of the outcrops of the dikes and quartz veins may be due to later faulting.

The quartz is milky white and of medium grain, and some calcite is also present. The only visible metallic minerals are pyrite and very rare sphalerite. There is also everywhere more or less brown iron oxide, presumably the result of oxidation of pyrite. The gold is free but so finely divided that it is visible only in the pan. Assays of samples taken from the outcrops are reported to show a tenor of about an ounce to the ton along ore shoots as much as 75 feet in length. A little ore mined by lessees from one of the faulted segments close to the range front yielded a return of a little over $21 a ton. Assays show a ratio of gold to silver of about 10 to 1.

ORIGIN OF THE DEPOSITS

It is thought that the origin of both the nickel and cobalt deposits of Cottonwood Canyon and the titanium and gold deposits of Corral Canyon is closely related to the intrusion of the diorite. The sequence seems to have been as follows:

Intrusion of the aplite dikes closely followed that of the diorite. In their original form the dikes consisted essentially of quartz and sodic plagioclase. The sphene present in both the dikes and the parent diorite suggests a relatively high content of titanium in the original magma. Following the consolidation of the dikes came widespread albitization, resulting in nearly complete alteration of the feldspars, not only in the dikes but in the adjacent parts of the diorite. Albitization was widespread both at Cottonwood Canyon and at Corral Canyon, but the succeeding mineral changes differed in the two areas, perhaps owing to differences in distance from the source, for at Cottonwood Canyon the downfaulted roof of the diorite batholith is preserved, whereas at Corral Canyon erosion has reached a deeper level below the original cover of the diorite.

Although sericitization was widespread, the principal later stages of hydrothermal alteration at Corral Canyon were confined to the dikes and their immediate vicinity. The first stage was the introduction of the titanium-bearing minerals with accompanying dickite, sericite, and quartz and calcite. The titanium crystallized first as sphene, in much larger crystals than the original sphene of the diorite and the unaltered aplite dikes. Later, but presumably during the same stage of hydrothermal alteration, this sphene was replaced by an aggregate of anatase crystals. Possibly the early calcite and quartz, which accompany the anatase, were formed from the breaking down of the sphene with release of lime and silica during the transformation. The last stage of the mineralization at Corral Canyon involved the introduction of the gold-bearing quartz along the margins of the altered dikes with accompanying continued sericitization and calcitization of both the dikes and the diorite.

In the Cottonwood Canyon area the effects of the presumed earlier stages of mineralization are less marked. Albitization of the dikes and adjoining parts of the diorite took place, as in the Corral Canyon area, but the introduction of anatase into the dikes took place on a much smaller scale.

There was also an introduction of silica in the Cottonwood Canyon area. Quartz veins cut the diorite in places. The limestone, and probably to some extent the aplite near the Nickel mine were partly replaced by fine-grained silica and the greenstone became irregularly silicified as in the craggy outcrops on the north wall of the canyon. Quartz veins also cut the diorite but, as far as known at present, gold did not accompany the quartz in the Cottonwood Canyon area. As in the Corral Canyon area, sericite and calcite were deposited in the diorite, even where no alteration effects are apparent in the field.

The platy hematite in the greenstones was presumably in part the result of alteration of iron-bearing minerals originally present in these basic rocks, but the large amounts present in places where the original rock has been almost completely replaced implies introduction of iron.

The final stage of mineralization by the magmatic solutions in the Cottonwood Canyon area is believed to have been the introduction of sulphides and arsenides of nickel, cobalt, and copper, with subordinate pyrite and gangue minerals along small fissures in the already altered country rock. At the Nickel mine, at least, this was not a simple process, for the sulphide, millerite, appears to have been first formed, followed by its almost complete replacement by the arsenide, niccolite. The paragenesis of the even more complex ores of the Lovelock mine is unknown, nor can any explanation be offered as to why only nickel minerals are found at the Nickel mine, whereas the similar fissures of the nearby Lovelock mine contain a greater variety of metals.

It is thought that the relation of the nickel and nickel-cobalt ores to the diorite roof indicates that the deposition of these ores was the last observable event in an unusual and complex sequence of end products of the diorite magma, but, as Ransome[15] has pointed out, the possibility of a Tertiary age for these deposits, though it seems unlikely, cannot be completely excluded.

It is possible that the silver-lead ores in the northern part of the district mentioned by Lincoln[16] may represent more usual types of sulphide mineralization at a greater distance from the margin of the intrusive.

OUTLOOK FOR FUTURE PRODUCTION

It seems probable that the titanium content of the aplitic dikes of Corral Canyon is too low to justify any hope of immediate commercial exploitation. On the other hand, the gold-bearing quartz associated with these dikes gives promise of future production, the scale of which will depend on the degree of continuity of the valuable portions as determined by future development.

The data available concerning the nickel and cobalt deposits of Cottonwood Canyon do not warrant a dogmatic statement regarding the possibility of future production, but the inference is that no large output is to be expected even under conditions much more favorable for operation than the present. On the other hand, parts of the area are not easily accessible and prospecting may not have been sufficiently intensive to eliminate the possibility of new discoveries.

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[15] Ransome, F. L., Notes on some mining districts in Humboldt County, Nevada: Geol. Survey Bull. 414, pp. 58; 71, 1909.

[16] Lincoln, F. C., op. cit., p. 12.

UNIVERSITY OF NEVADA BULLETIN
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Leach Hot Sp
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LATE CENOZOIC STRUCTURAL, VOLCANIC, AND HYDROTHERMAL HISTORY OF THE LEACH HOT SPRINGS GEOTHERMAL AREA, PERSHING COUNTY, NEVADA

Noble, Donald C., Mackay School of Mines, University of Nevada, Reno, Nevada 89507; Wollenberg, Harold J., Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720; Archibald, Douglas, Department of Geological Sciences, Queen's University, Kingston, Ontario, Canada; Silberman, Miles L., U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025

In the Goldbanks Hills-Table Mountain area between Grass and Pleasant Valley faulted coarse-grained conglomerates of Miocene age overlie an irregular surface cut on pre-Tertiary strata. At the Pronto Plata mine and the Squaw Butte area, these conglomerates are intensively silicified and cemented by opal and chalcedony. Hg mineralization locally is present. The altered rocks are overlain by unaltered lacustrine sedimentary rocks that in turn are intruded and overlain by distinctive basalts and derivative silicic tuffs and lava. These basalts and rhyolites have yielded K-Ar ages from 12 to 15 m.y.

Quaternary tectonism in southern Grass Valley is concentrated within a long, narrow north-northwest-trending complex graben located in the lowest part of the valley and along a swarm of irregular faults along the east side of the valley. A dike of 14-15-m.y.-old basalt intrudes one of the later group of faults, indicating that the system was established in the early Miocene. The highly fractured and actively subsiding north-northwest-trending graben, and particularly where it is downdropped to the northwest by arcuate faults splaying out from the east-side fault system, has the greatest geothermal potential.

Silicification near Leach Hot Springs in southern Grass Valley appears very similar to that in the Goldbanks Hills-Table Mountain area to the south. However, the early Miocene age of the latter rules out the possibility that this period of hydrothermal activity represents an early phase of the convective system presently responsible for Leach Hot Springs. Rather, the alteration appears to be a shallow manifestation of the hydrothermal systems that produced the many 14-16 m.y. precious metal deposits in northern Nevada.

STRUCTURAL ANALYSIS OF A COLLISION BETWEEN AN OCEANIC PLATE AND A CONTINENTAL PLATE PRESERVED ALONG THE LOWER KINGS RIVER IN THE SIERRA NEVADA

Nokleberg, Warren, Department of Geology, California State University, Fresno, California 93740

Structural analysis of metamorphic and igneous rocks along the lower Kings River indicates a deformation in Late Jurassic consisting of oblique-slip underthrusting. Two major suites of rocks occur: a continental margin sequence of schists, quartzites, and marbles towards

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Age Relationships of the Golconda Thrust Fault, Sonoma Range, North-Central Nevada

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Stanford, California 94305

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Abstract

Previous structural interpretations of the Sonoma Range in north-central Nevada have concluded that the Tobin thrust fault—regarded as the equivalent of the Golconda thrust fault—is younger than other thrust faults of post-Triassic age in the range. However, thrust emplacement of the distinctive oceanic upper Paleozoic rocks of the Golconda allochthon over a large region in western and north-central Nevada, and perhaps even beyond, seems to have taken place prior to deposition of Triassic strata in the region. Hence, the structural relationships in the Sonoma Range that bear on the age of the Golconda thrust fault have been questioned.

Restudy of the critical part of the Sonoma Range in the vicinity of Clear Creek shows that the oldest faults in the area that bound rocks of the Golconda allochthon and therefore may represent the Golconda thrust fault are, in fact, segments of a single fault that has been displaced by several successive slices of the Clear Creek thrust fault, the north end of which cuts Triassic rocks exposed in the northwestern Sonoma Range. Furthermore, the geometry of rocks displaced since Triassic time on the Clear Creek system of thrust faults suggests that the faults regarded as parts of the Golconda thrust fault in the Sonoma Range are offset segments of the type Golconda thrust fault as exposed about 15 km to the northeast. Consequently, the Golconda thrust fault in its type locality, as well as in the Sonoma Range, is evidently older than faults that cut Triassic rocks, and its age relationships do not conflict with the generally accepted Late Permian or Early Triassic time of emplacement of the Golconda allochthon.

Integrated into this structural reinterpretation of the Sonoma Range are several other conclusions and findings of more than local significance, including the following: (1) Prior to emplacement of the Golconda allochthon, lower Paleozoic rocks in the Sonoma Range area, such as the Harmony and Valmy Formations and perhaps the Preble Formation, were intricately deformed and faulted together, presumably during the middle Paleozoic Antler orogeny. (2) Coarse clastic detritus derived from the Harmony and Valmy Formations occurs in the Golconda allochthon of the Sonoma Range, which suggests that it was originally deposited along the North American continental margin. (3) Radiometric ages of plutonic rocks in the Sonoma Range suggest that post-Triassic displacement, perhaps as gravity slides, of parts of the Golconda allochthon on the Clear Creek system of thrust faults took place between about 170 and 100 m.y. ago.

Key words: areal geology, Nevada, structural geology, Paleozoic stratigraphy, orogeny.

Introduction

The Golconda thrust fault in north-central Nevada is evidently one of the major thrust faults[1] in the western cordillera, having juxtaposed strongly contrasting upper Paleozoic facies over a wide area. Its age, however, has been a matter of interpretation; on the basis of different lines of evidence, the time of thrusting has been suggested as late Mesozoic on the one hand and Late Permian or earliest Triassic on the other—a difference of perhaps 100 m.y. within the past 200 to 250 m.y. The older of these two possible age assignments is now generally accepted, as discussed below. This paper documents the conclusion (Silberling, 1970) that geologic relationships in the Sonoma Range do not contradict this age assignment, as has been thought to be the case.

DEFINITION OF THE GOLCONDA THRUST FAULT

As originally described by Muller and others (1951, Fig. 1; Ferguson and others, 1952), the trace of the type Golconda thrust fault runs through the Edna Mountain and Battle Mountain ranges, which lie to the east of the Sonoma Range within the Sonoma Range 1° quadrangle (Fig. 1). In these ranges the thrust fault has carried rocks grouped together as the "Havallah sequence" by Silberling and Roberts (1962) over the partly correlative "Antler sequence" of upper Paleozoic rocks or the lower Paleozoic rocks that unconformably underlie the Antler sequence. The Havallah sequence that makes up the Golconda thrust plate in its type area includes rocks originally assigned to the Havallah and Pumpernickel Formations, but even in the vicinity of their type localities, tectonic effects preclude deciphering the actual stratigraphic section and relationships of these formations. Thus the Havallah sequence is actually a tectonic complex of distinctive, and presumably genetically related, rock types rather than a stratigraphic unit. Consequently, now that the age of thrusting of these rocks is better understood, the term "Golconda allochthon," introduced by Speed (1971a) for the upper-plate rocks of the Golconda thrust fault, is more objective for use where the genetic connotation of this term is not misleading.

Despite the lack of a coherent stratigraphy within the Golconda allochthon, it is characterized by a great thickness of marine bedded chert, primarily

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[1] The term "thrust fault" is used herein in a purely descriptive sense for a fault whose surface had a low inclination at the time of displacement; no particular mechanism of displacement is implied.

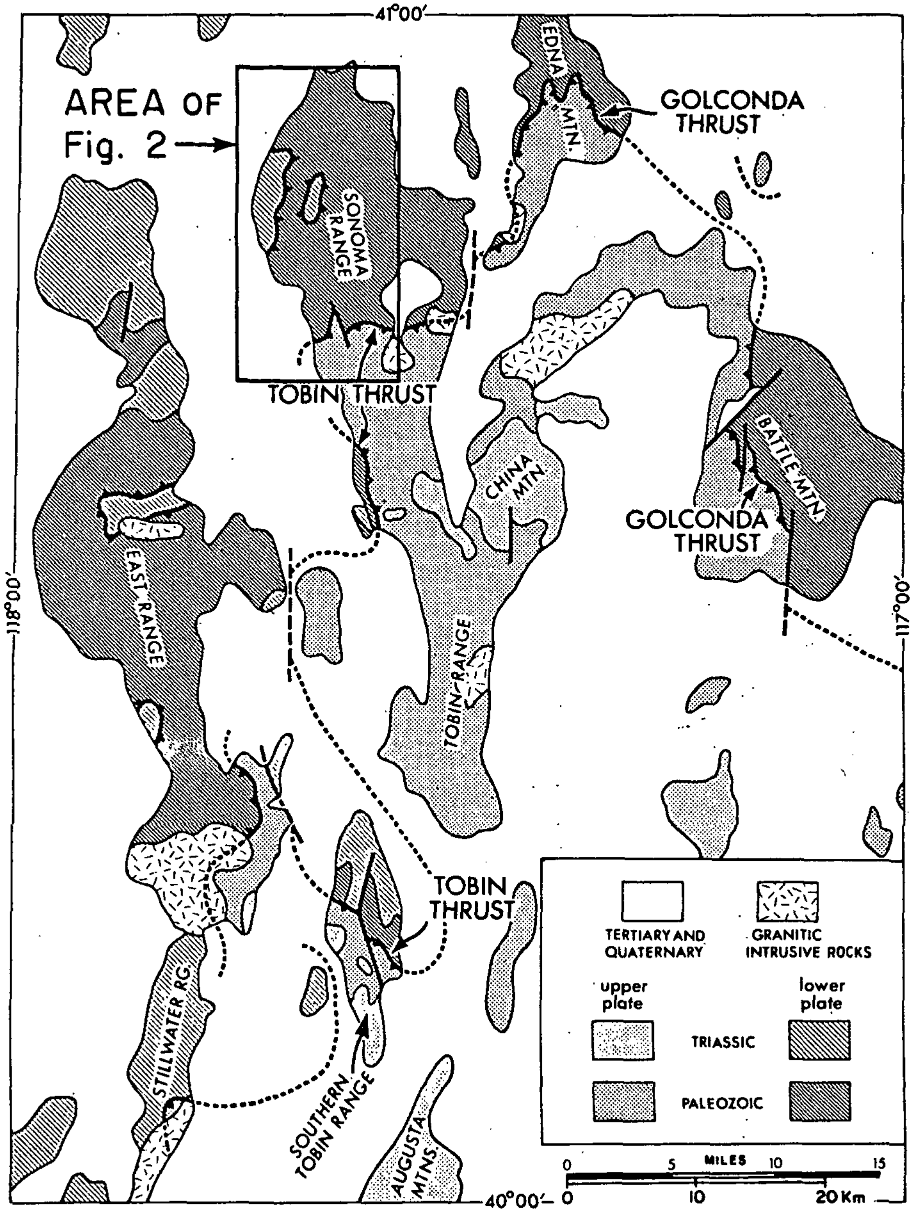


Figure 1. Original concept of extent and geologic relationships of Golconda thrust fault. Modified copy of original figure from geologic quadrangle maps of the Sonoma Range quadrangle by Ferguson and others (1951a, 1951b, 1952; Muller and others 1951), as adapted and annotated by Burke (1973). In general, both upper-plate and lower-plate Triassic rocks include the Koipato, Star Peak, and Auld Lang Syne Groups; upper-plate Paleozoic rocks belong to the Havallah sequence; lower-plate Paleozoic rocks comprise all other Paleozoic rocks in the area.

siliceous clastic sedimentary rocks, and mafic, commonly pillowed volcanic rocks. Major eastward displacement of these rocks of oceanic character is indicated by their strong contrast with the much thinner and generally less deformed succession of detrital clastic material and calcareous shallow-water deposits of the lower-plate Antler sequence, which includes formations such as the Edna Mountain, Antler Peak, Battle, and Highway. A full description of the Havallah and Antler sequences at Battle Mountain, where they are separated by part of the type trace of the Golconda thrust fault, was given by Roberts (1964).

Scattered exposures of both the Golconda allochthon and Antler sequence extend well beyond the boundaries of the Sonoma Range quadrangle to the north, east, and south in north-central Nevada. According to Speed (1971b), rocks still farther south, in west-central Nevada, also belong to the Golconda allochthon, which thus characterizes a generally north-trending belt having a total length of more than 400 km through north-central and west-central Nevada. Beyond this region, rocks resembling those of the Golconda allochthon in character and age occur to the south in southeastern California (Roberts and others, 1958, p. 2849), to the northeast in the northernmost part of western Elko County, Nevada (Coats, 1969, p. A26–A27), and perhaps even as far as central Idaho (Roberts and Thomasson, 1964). In northern Nevada to the west of the belt that includes outcrops of the Golconda allochthon and Antler sequence, pre-Mesozoic rocks are everywhere obscured beneath younger strata, except in the northwesternmost corner of the state, where andesitic volcanic rocks and shallow-water carbonate rocks of Permian age crop out in several places. To the east of the belt characterized by the Golconda allochthon, rocks of the Havallah sequence are absent, and the Antler sequence is represented by other Pennsylvanian and Permian shelf deposits such as those of the Eureka-Carlin sequence of Roberts and others (1958).

Even though the Golconda allochthon can be recognized over a wide area, away from the type trace of the Golconda thrust, the fault is difficult to identify with certainty. As is the case with other major thrust faults, such as the Roberts Mountains thrust fault of middle Paleozoic age in central and northeastern Nevada, the name of the fault can represent two different concepts. First, the name is applied to the physical structure that can be mapped in its type area regardless of its interpreted age and tectonic history. Even the type trace of the Golconda thrust fault, which jumps from one mountain range to another, is quite discontinuous and open to interpretation, although its various type segments are quite reasonably connected. Second, the name can be applied in a model sense to the hypothetical structure that originally juxtaposed rocks of certain contrasting facies or tectonic fabrics. At a distance from the type area, where rocks assigned to the Golconda allochthon are separated by thrust faults from strata of the Antler sequence, it may be difficult or impossible to demonstrate that these faults are identical geometrically and in age with the type

Golconda thrust fault. In the following discussion the Golconda is regarded as the sole thrust fault along which the distinctive upper Paleozoic rocks of the Golconda allochthon were first emplaced. Evidence presented below indicates that the type Golconda thrust fault conforms to this definition.

GENERAL AGE RELATIONSHIPS

Despite the great areal extent of the hypothetical Golconda thrust fault, documentation for its age has accumulated slowly. In their original description of the areas containing its type trace and the adjoining parts of the Sonoma Range 1° quadrangle, Ferguson and others (1951a, 1951b, 1952) and Muller and others (1951) regarded the Golconda thrust fault as the probable equivalent of the Tobin thrust fault, various segments of which were mapped and connected to form a sinuous southwesterly continuation of the Golconda fault (Fig. 1). As the Tobin thrust fault was interpreted to have juxtaposed what were regarded as two major facies of Triassic rocks in the region, both the Tobin and Golconda faults were believed to be post-Triassic in age.

Subsequent study of Triassic strata in the region showed that eastward displacement of the Triassic rocks on the supposed upper plate of a Tobin-Golconda thrust fault was highly unlikely in view of their geographic and facies relationships with the correlative strata that would be in the lower plate, and yet displacement in this general direction of the Golconda allochthon seems mandatory. For this reason, Silberling and Roberts (1962, p. 51–53) suggested that the Golconda thrust fault might predate deposition of the Triassic rocks and thus would not have secondarily influenced their geographic distribution. In this case, the Golconda plate would have been emplaced after deposition of the youngest part of the lower-plate Antler sequence—the Edna Mountain Formation of middle Permian age—but before deposition on the deformed upper-plate rocks of the predominantly volcanic and volcaniclastic Koipato Group, whose age is poorly established but is at least, in part, late Early Triassic (Silberling, 1973). In support of this interpretation, the Havallah sequence displays tight folds and internal thrust faults beneath the angular unconformity at the base of the Koipato Group or, where the Koipato is missing, at the base of the disconformably overlying Triassic rocks of the Star Peak Group (Nichols, 1972). This deformation, which occurred prior to the deposition of the Koipato Groups, documents the so-called Sonoma orogeny.

More recently, detailed geologic mapping in the southern Tobin Range by Burke (1970, 1973) has shown conclusively that the Tobin thrust fault, as originally mapped by Muller and others (1951; Fig. 1), does not exist and that thrust faulting was not responsible for the rapid lateral changes in the character of the Triassic section. Connection of the Golconda thrust fault with a post-Triassic Tobin thrust fault is thus not a feasible way of establishing an older limit for the time of thrusting.

Although they placed no particular interpretational significance on it, Gilluly and Gates (1965, p. 48–49, Pl. 1) first described direct evidence for the age of the Golconda thrust fault in the Mount Lewis area of the northern Shoshone Range, just east of the Sonoma Range quadrangle. Rocks that they tentatively assigned to the China Mountain Formation (now recognized as part of the Koipato Group [Nichols, 1971; Burke, 1973] that unconformably overlies the Havallah sequence farther west) rest here, in some places depositionally, on strata of the Antler sequence and at one place on the Havallah sequence as well. Upon reexamining these relationships, Nichols (1971) found that the rocks originally assigned with some question to the China Mountain Formation can in fact be recognized as the Panther Canyon Formation, an areally restricted and lithologically distinctive upper Middle Triassic part of the Star Peak Group, which in the Sonoma Range quadrangle locally overlies the Koipato Group disconformably or even rests directly on the Havallah sequence. As the Panther Canyon Formation in the Shoshone Range is in depositional contact with the Antler sequence as well, original juxtaposition of these two upper Paleozoic sequences—presumably by the Golconda thrust fault—must have taken place prior to deposition of both the Triassic rocks of the Panther Canyon Formation and those of the Koipato Group, which in places concordantly underlies the Panther Canyon Formation.

In addition to this evidence for stratigraphic overlap of the Golconda thrust fault by Triassic rocks, the pre-Triassic (that is, before Koipato deposition) age of thrusting has also been demonstrated by MacMillan (1971, 1972) on the basis of both the fold geometry and sedimentologic character of the pre-Tertiary rocks in the New Pass Range about 30 km south of the Sonoma Range quadrangle. In the New Pass Range, MacMillan found that folds generated in rocks of the Golconda allochthon as it overrode the lower-plate Paleozoic rocks of the Golconda thrust fault are not represented in the Triassic strata that unconformably overlie the allochthon. Also, distinctive coarse clastic material in the Triassic beds that rest on the upper-plate rocks was apparently derived from a local source in the lower plate, again indicating thrust emplacement of the allochthon prior to deposition of its sedimentary cover of Triassic rocks.

Dating of the rocks that would have to bracket the Golconda thrust fault in age at first cast doubt on the suggested origin of the fault during the Sonoma orogeny (Silberling and Roberts, 1962, p. 52). This was because the Koipato Group, which postdates the orogeny, was supposed to be largely or entirely Permian in age; thus, there would be insufficient time for thrust faulting to have occurred after deposition of the Middle Permian Edna Mountain Formation, the youngest of the Paleozoic rocks cut by the fault. New discoveries of fossils, however, show that higher parts of the Koipato Group are as young as late Early Triassic (Silberling, 1973). As the Koipato might thus be entirely Early Triassic, its age does not necessarily conflict with a Late Permian–earliest

Triassic age for the Golconda thrust fault in the vicinity of the Sonoma Range quadrangle.]

In view of the various lines of new evidence outlined above and in consideration of how emplacement of the Golconda allochthon would best fit into the regional tectonic history, the Late Permian–Early Triassic age of the Golconda thrust fault seems to be well established (Speed, 1971a; Burchfiel and Davis, 1972; Silberling, 1973). Relationships in the Sonoma Range, however, have remained unreconciled with this viewpoint.

The Sonoma Range has a critical bearing on the age of the Golconda thrust fault because of the intersections between thrust faults that cut Triassic rocks in the northwestern part of the range and other thrust faults farther south that may in part represent the Golconda fault. This latter complex of faults crosses the central part of the range in the vicinity of Clear Creek and separates the Antler sequence and lower Paleozoic rocks to the north from the Havallah sequence that forms all of the Paleozoic exposures in the southern part of the range (Fig. 2). In the original interpretation by Ferguson and others (1951a), the Havallah sequence was regarded as being bounded by a single thrust fault that was offset by normal faults. This thrust fault, which was interpreted to have moved the Havallah sequence over the other pre-Tertiary rocks of the Sonoma Range, was designated as part of the Tobin thrust fault. It was interpreted as truncating another thrust fault, the Clear Creek fault, whose trace was mapped northward to the Sonoma Canyon area, where Triassic rocks were regarded as belonging to the lower plate of the Clear Creek thrust fault. As this fault would thus be post-Triassic in age, the structurally higher Tobin thrust fault would also be post-Triassic, and probably also would be the Golconda fault because of its supposed connection with the Tobin thrust fault.

The thrust fault carrying the Havallah sequence in the Sonoma Range, as mapped by Ferguson and others (1951a), was regarded as part of the Golconda fault by Silberling and Roberts (1962). In order to make a pre-Triassic age of the Golconda possible, we offered a reinterpretation of the original mapping, whereby the segments of the Clear Creek thrust fault to the north and south of the window of Triassic rocks in Sonoma Canyon were regarded as older than and cut by the thrust faults that bound the window (Silberling and Roberts, 1962, p. 47–49, Fig. 6). It was then suggested that these segments of the Clear Creek fault might be an effect of the Paleozoic Antler orogeny analagous to the pre-Pennsylvanian Dewitt thrust fault at Battle Mountain. If this were true, the Golconda fault could be as old as Late Permian, because the part of the Clear Creek fault truncated by it would be of still older age.

Subsequently, Gilluly (1967) remapped the geology of the Winnemucca 15′ quadrangle, which includes the northern part of the Sonoma Range, and he concluded that the history of thrust faulting in the area was more like that originally pictured by Ferguson and others (1951a). All of the thrust faults in the northern Sonoma Range were regarded by Gilluly as post-Triassic in age and as having a generally uniform westward or southwestward sense of tectonic overriding. His mapping did not extend far enough south to include most of the complex of faults that bounds the Havallah sequence, and rocks of the Golconda allochthon were not recognized within the area mapped by him. Gilluly (1967, p. 4) did note, however, that the Tobin thrust fault in the Sonoma Range must be of post-Triassic age because, as mapped by Ferguson and others (1951a), it would override the post-Triassic thrust faults a short distance to the south of the area where they were mapped by him. Thus, for interpretating the age of the Golconda (or Tobin) thrust fault he reemphasized the importance of understanding the relationships between the faults in the Sonoma Range that bound the Havallah sequence and those farther north that are, in part, definitely of post-Triassic age.

Geology of the Clear Creek Area

To understand the age relationships of the thrust faults that involve the Havallah sequence in the Sonoma Range, Gilluly's (1967) recent mapping of the Winnemucca 15′ quadrangle was extended southward in the vicinity of Clear Creek on the west side of the range. During parts of the summers of 1968 and 1969, this area, in the northern part of the Leach Hot Springs and southernmost Winnemucca quadrangles, was mapped in detail on 1:20,000 air photographs; other parts of the Sonoma Range were studied less methodically. The result of this mapping is shown in Figure 3, and it is integrated into the map of the northern Sonoma Range (Fig.2), the northern part of which is generalized and slightly modified from Gilluly (1967).

ROCK UNITS MAPPED

The rock units in the Clear Creek area are largely the same as those recognized previously by Ferguson and others (1951a) and Gilluly (1967), and for the most part they have already been adequately described as exposed in the Sonoma Range or in ranges to the east and north. Although little evidence was found for the relative ages of the various pre-Tertiary stratified rocks in the Clear Creek area, these are discussed below approximately in the order of their age as determined elsewhere. With the possible exception of the Antler Peak Limestone that may rest depositionally on the Harmony Formation, none of the named formational units are in stratigraphic relationship to one another. Instead, they are bounded by faults everywhere in the Clear Creek area, and some of them have probably been transported into the area for long distances by thrust faulting.

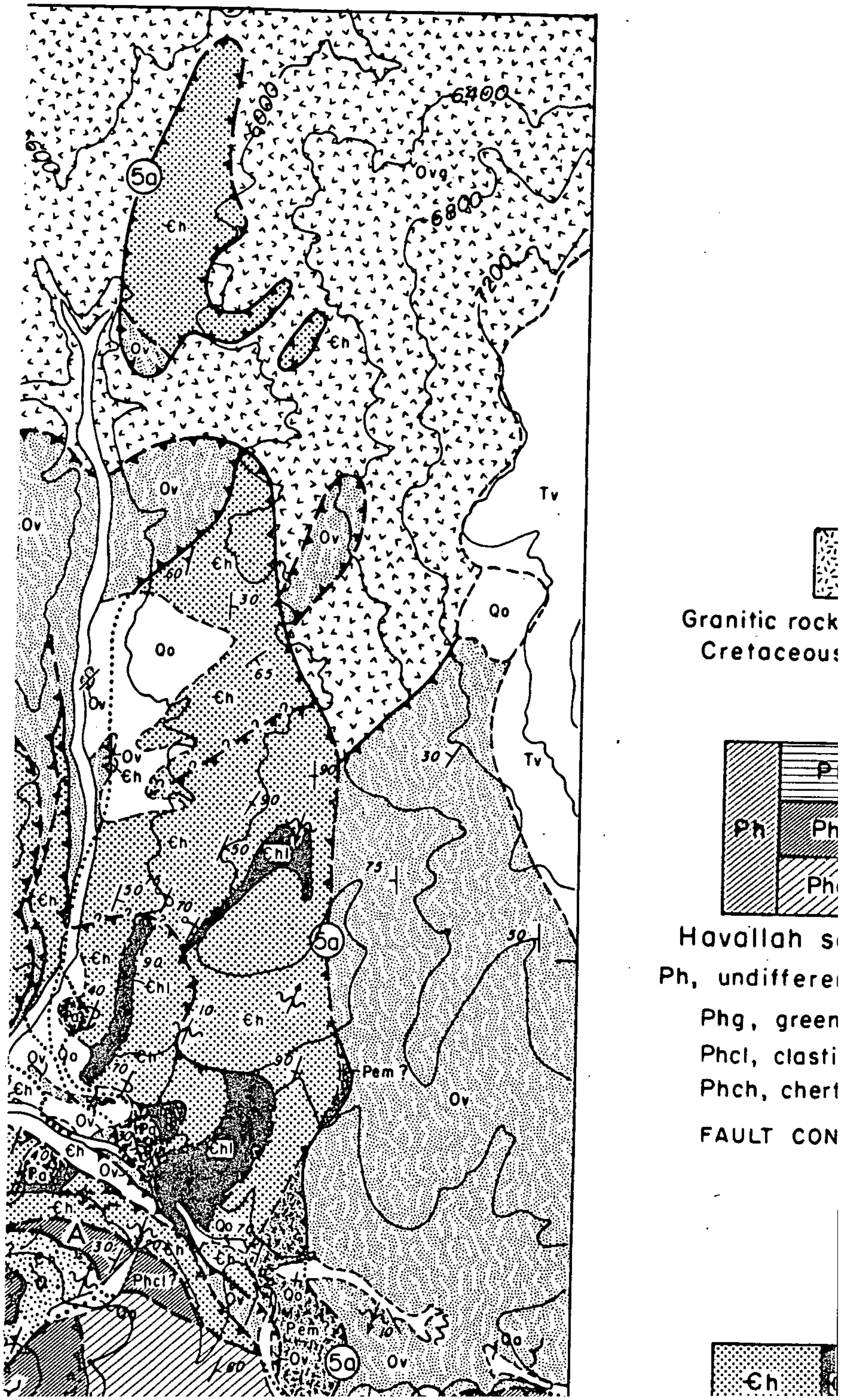
Fault-bounded strata believed to be part of the Preble Formation are, if correctly assigned, the oldest rocks in the area. Fossils have not been found in the Preble Formation in the Sonoma Range; however, in the Osgood Mountains, 50 to 65 km farther northeast, the Preble Formation has yielded trilobites and other fossils ranging from early Middle to early Late Cambrian in age (Hotz and Willden, 1964, p. 12–13). In the Clear Creek area the rocks assigned to the Preble Formation form a distinctive unit that crops out in the same structural setting in several different places. The predominant rock type is intricately contorted olive-gray phyllite or laminated argillite thinly interbedded with medium- to light-gray, discontinuous limestone layers that are commonly less than 1 cm thick. Massive, thick beds of dark chert, limestone, or limestone sedimentary breccia crop out sporadically and are the only other rock types represented. Essentially identical strata of the Preble Formation occur on the east flank of the Sonoma Range in the easternmost part of the Adelaide mining district, where they seem to represent the upper part of the formation.

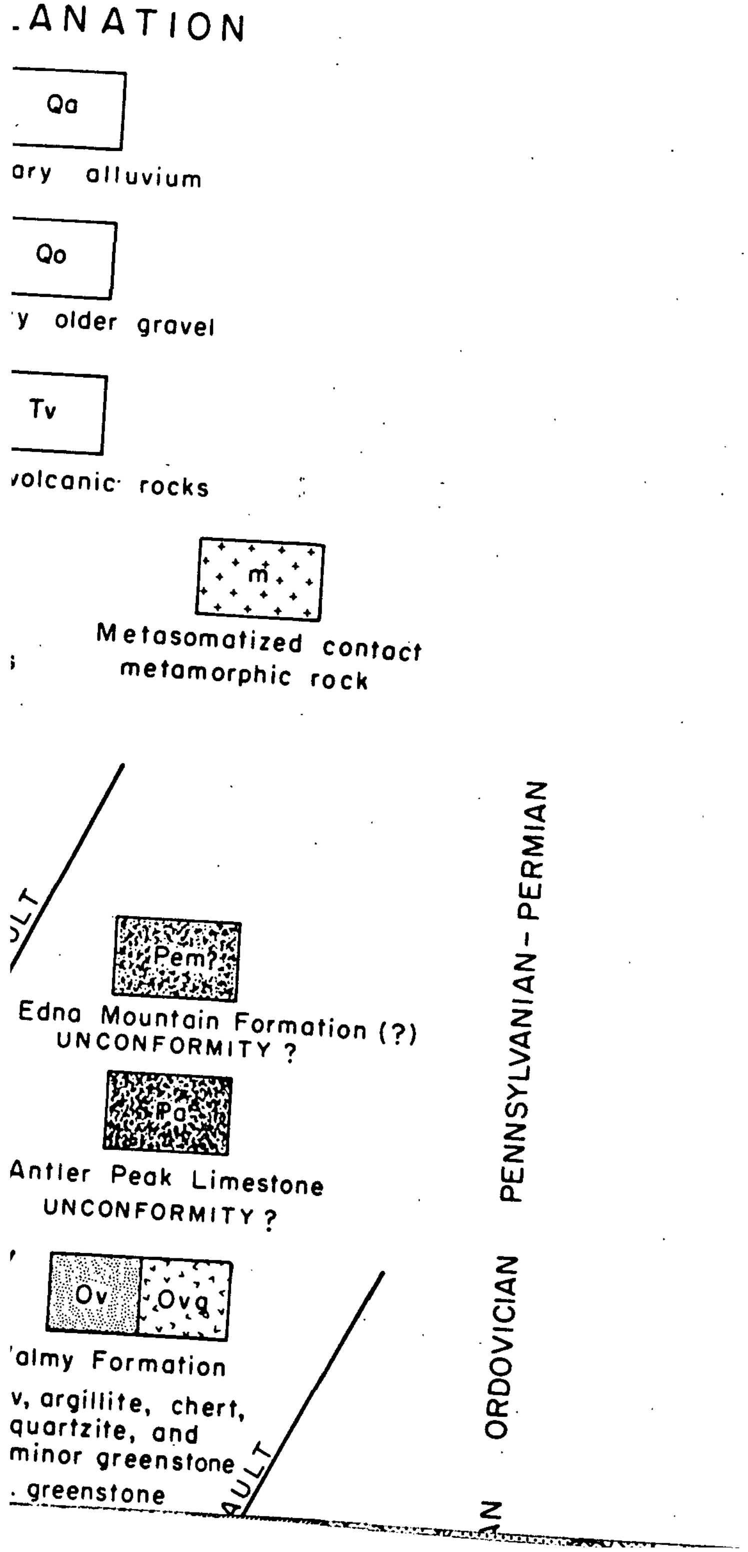
The Harmony Formation, along with the Valmy Formation, makes up most of the Paleozoic exposures in the Sonoma Range north of Clear Creek. Strata having the distinctive lithologic character of the Harmony Formation crop out widely in several nearby ranges and are dated as Late Cambrian in the Osgood Mountains (Hotz and Willden, 1964, p. 18–19).

In the Clear Creek area, most of the Harmony Formation is lithologically uniform and consists of structurally incoherent and broken but evenly bedded feldspathic and micaceous sandstone that on fresh and weathered surfaces is principally yellowish brown and olive gray. The sandstone beds vary in thickness proportionally to their grain size and range from beds a few centimetres thick of very fine or fine grained, conspicuously micaceous sandstone to beds that are a metre or more in thickness, contain quartz grains as much as a centimetre in diameter, and are commonly graded. Dark slate or highly sheared argillite separates the sandstone beds but is subordinate in thickness. The color of the sandstone, conspicuous detrital mica flakes, and gritty beds containing tightly packed, large white quartz grains distinguish the Harmony Formation even in small exposures. As viewed in thin section, Harmony sandstone from the Clear Creek area is essentially like specimens illustrated by Hotz and Willden (1964, p. 16), presumably from the Osgood Mountains, and by Roberts (1964, p. A24) from Battle Mountain. The Harmony Formation originally had regular bedding, which, along with other features such as graded bedding, suggests turbidity-current deposition. In the Clear Creek area, however, the Harmony is commonly so highly deformed that even clean exposures may locally appear unbedded. Segments of thick sandstone beds, blocks of strata, and pieces of folds have been rotated and mixed in complex orientations within a sheared, fine-grained matrix. Despite this pervasive megascopic deformation, the coarse-grained beds are not internally sheared or foliated, although the sericitic matrix of the coarser sandstone has been highly compacted between sand grains.

East of the forks of Clear Creek Canyon, about 5 km above the canyon mouth, the Harmony Formation is unusual in containing conspicuous units of limestone as thick as a few tens of metres. Some of the limestone is silty, and it commonly has a platy parting or shows small-scale cross-bedding, but much of it is massive, thin- to thick-bedded, and uniformly gray. Superficially, some of it thus resembles the conspicuous massive gray limestone of the Antler Peak Formation, which is locally in fault contact with limestone of the Harmony.

This coincidence, in which the only significantly calcareous part of the





Harmony Formation in the area is juxtaposed with the only exposures of Antler Peak Limestone in the Sonoma Range, may explain why Ferguson and others (1951a) assigned a large area in the Clear Creek drainage to the Edna Mountain Formation, the part of the Antler sequence that would ordinarily rest on the Antler Peak Formation and be associated areally with it. Gilluly (1967, p. 2) was correct, however, in regarding most of the rocks so assigned as belonging to the Harmony Formation. Only a small outcrop area beyond the southern limit of Gilluly's map is considered here (Figs. 2 and 3) as possibly representing the Edna Mountain Formation. Besides being interbedded with micaceous sandstone characteristic of the Harmony Formation, as pointed out by Gilluly, limestone of the Harmony differs petrographically from that of the Antler Peak Formation in that allochems in the original lime packstone or wackestone of the Harmony are completely unrecognizable owing to recrystallization. However, all samples of Antler Peak limestone—even from small, highly sheared fault slivers—contain abundant recognizable skeletal grains derived from crinoids, bryozoans, foraminifers, corals, and other organisms.

Following Gilluly (1967), the rocks originally named the Sonoma Range Formation by Ferguson and others (1951a) are assigned to the Valmy Formation, which elsewhere in north-central Nevada ranges in age through most of the Ordovician Period. In the Sonoma Range the Valmy Formation is represented mainly by black, evenly bedded chert, gray or black argillite, dark orthoquartzite, and altered mafic volcanic rock that in most places is highly weathered and nonresistent, but in exceptional exposures shows pillow structures. Although these different rock types may be interbedded in some places, they commonly occur as tectonically shaped masses that are in mechanical contact with other parts of the Valmy Formation or other pre-Tertiary rock units. The highly faulted, internally mixed map pattern within the Valmy Formation of the Sonoma Range, as depicted by Gilluly (1967) at quadrangle-map scale, would appear about the same even at much larger scales. Dark, massive orthoquartzite is distinctive of the Valmy Formation, but in limited exposures that chert and volcanic rock could easily be confused with the similar rocks of the Havallah sequence. As a general rule, however, even though bedding characteristics of the chert belonging to the Valmy Formation and the Havallah sequence are essentially alike, chert of the Valmy is usually black, whereas that of the Havallah sequence is mostly light colored.

The rocks in the Clear Creek area assigned to the Havallah sequence are generally the same as those characteristic of the Golconda allochthon. For the most part they were regarded by Ferguson and others (1951a) as belonging to the Pumpernickel Formation; however, because the definition of this unit and its distinction from the Havallah Formation is uncertain, the rocks of the Golconda allochthon in the Clear Creek area are all informally lumped into the Havallah sequence, which includes both the Pumpernickel and Havallah Formations of Ferguson and others (1951a).

In contrast to the pervasive, tectonically disrupted character of the Valmy and other lower Paleozoic formations in the area, part of the Havallah sequence northwest of Grand Trunk Canyon is fairly coherent stratigraphically over an area of several square kilometres. Three distinctive units, each at least a few hundred metres thick, occur in a generally upright stratigraphic succession and are informally designated here as, in ascending order, the chert, clastic, and greenstone units. The Golconda thrust fault forms the lower boundary of the chert unit and cuts across it, so that the chert is locally missing at the base of the section near the mouth of Clear Creek Canyon. In composition the chert unit is uniformly thin to medium bedded and is commonly light shades of yellowish brown, but it ranges from white to black. Locally it is tightly and complexly folded or sheared into boudins.

The overlying clastic unit of the Havallah sequence is more heterogeneous but consists mostly of black siliceous argillite or olive-gray phyllite interbedded with massive quartzose sandstone that is generally dark gray or black on fresh exposures, weathering to various shades of brown. Poorly rounded, "floating" granules of black chert and quartz are characteristic of the sandstone, which in places grades into grit or fine-grained siliceous conglomerate. Although composed almost entirely of compositionally mature quartz, chert, and sericite-microquartz lithic grains, in thin section the grains are poorly sorted and rounded, and the sandstone contains appreciable amounts of dark, recrystallized, quartz-sericite matrix material. Graded bedding within some medium and thick beds points to turbidity-current deposition. Less well represented in the clastic unit are greenstone tuff and breccia and sandy, crystalline gray limestone which, although recrystallized, contains recognizable crinoidal debris. These rocks appear to have been current-deposited, coarse-grained, impure lime grainstone, and they occur abruptly in the section in beds as thick as several metres.

Directly above the clastic unit of the Havallah sequence is the greenstone unit, which weathers to large blocks and is composed of dense, altered mafic volcanic rock, much of it massive and free of vesicles or amygdules. Spectacular pillow-lava structures occur in this unit, especially on the north-facing slope high on the spur between Clear Creek and Grand Trunk Canyons.

Near the plutonic rocks at the range front south of Clear Creek and within the mapped area southeast of Grand Trunk Canyon, large areas are underlain by metasomatized contact-metamorphic rock in which the original stratigraphic characteristics of the Havallah sequence rocks are completely eradicated. Both quartz-sericite and quartz-diopside hornfels, like those described by Neff (1969) from near the margins of the Buffalo Mountain pluton about 15 to 25 kilometres east of the Clear Creek area, crop out as massive, white to light-gray aphanitic rock that usually preserves no trace of primary bedding or textural features. Although largely unrecognizable as to original kind, all of these metasomatized rocks are probably part of the Golconda allochthon, which is widely exposed to the exclusion of any other Paleozoic rocks in the southern part of the Sonoma Range and southward throughout the Tobin Range.

A minor but highly significant part of the Havallah sequence is as much as a few tens of metres of conglomerate and sedimentary breccia that occur at the base of the clastic unit on the south side of Clear Creek about 1.5 km from its mouth. The conglomerate and breccia thin rapidly along strike in either direction and are seen at the same stratigraphic level within the Havallah sequence at only one other place, which is in a structurally higher thrust slice about 0.8 km northeast of the mouth of Clear Creek Canyon. Among the poorly sorted but rounded pebbles, cobbles, and boulders of the conglomerate are abundant, easily recognizable pieces of micaceous sandstone from the Harmony Formation and black orthoquartzite from the Valmy Formation, along with other less distinctive clasts of black chert and light-colored quartzitic rocks. Poor exposures partly obscure the relationships of the conglomerate lens to the adjacent rocks, but large blocks of bedded chert as wide as 6 m appear to be mixed in the conglomerate. Emplacement of the conglomerate, perhaps as a submarine slide onto the upper surface of the chert unit, apparently contorted the bedding of the underlying chert. The depositional characteristics of these rocks of the Golconda allochthon and the occurrence in them of coarse clastic debris from the Harmony and Valmy Formations have considerable paleotectonic importance. They demonstrate that these lower Paleozoic rocks were exposed and being eroded—presumably at the continental margin—during the time of deposition of the Havallah sequence, and they give support to the interpretation that at least some of the Golconda allochthon was deposited on the late Paleozoic continental rise or slope (Silberling, 1973).

The conglomerate and breccia that occur as a depositional lens in the Havallah sequence are also significant in suggesting an explanation for three small, isolated, fault-bounded exposures of conglomeratic rocks whose distribution is apparently related to the "Preble-Harmony" fault. The largest and easternmost one of these exposures, all of which occur high on the southeast wall of Clear Creek Canyon 3 to 5 km from its mouth, is interpreted as a sliver along the Preble-Harmony fault (fault 2 in Figs. 2 and 3), where its trace undergoes an abrupt bend and truncates the generally parallel Golconda thrust fault (fault 1 in Figs. 2, 3). This sliver (A in Fig. 3) consists of dark argillite and lithic sandstone that grades across strike into poorly sorted conglomerate and coarse sedimentary breccia containing blocks as large as a few metres. Much of this coarse clastic debris is micaceous sandstone derived from the Harmony Formation and black orthoquartzite and chert from the Valmy Formation. The rocks of this exposure thus closely resemble the conglomeratic lens near the base of the clastic unit of the Havallah sequence just described. However, they are peculiar in having yielded a few rounded cobbles and boulders of sandy, crinoidal, and bryozoan limestone like that of the Antler

Park Limestone, as well as one boulder from which C. H. Stevens (1968 written commun.) recognized the brochiopods *Neospirifer* and *Linoproductus* of probable Middle Permian age. Coarse clastic debris from rocks this young would indeed be surprising in the Golconda allochthon, and inclusion of these rocks in the Havallah sequence is best treated as provisional.

Like the conglomeratic part of this exposure, the other two outcrops of enigmatic conglomeratic rocks that are questionably affiliated with the clastic unit of the Havallah sequence are composed entirely of poorly sorted, crudely stratified, unfolded and unsheared, cobble and boulder conglomerate in which fragments derived from the Harmony and Valmy Formations predominate. One of these conglomerate bodies (B in Fig. 3) apparently rests on a shallowly dipping fault surface that separates it from the underlying Preble Formation, and the other (C) is a small sliver along the Preble-Harmony fault. Other slivers along this fault are of Antler Peak Limestone. Provisional assignment of these isolated exposures of fault-bounded conglomeratic rocks to the Havallah sequence dictates a complex history for the Preble-Harmony fault, as follows. After deposition of the Antler sequence and subsequent emplacement of the Golconda allochthon, the lower Paleozoic rocks of the Harmony and Valmy Formations on the northwest side of this fault would have first been uplifted against the upper Paleozoic rocks of the Antler and Havallah sequences that overlay the Preble Formation on the southeast side of the fault. They were then dropped down, dragging with them the slivers of these contrasting upper Paleozoic rocks that now occur along the Preble-Harmony fault zone. Although this explanation fits all of the observations, the geologic complexity of this part of the area may defy proof. A variety of other interpretations are possible if other faults are hypothesized to pass through the homogeneous rocks of the Harmony and Preble Formations, but such hypothetical alternative explanations would not necessarily alter the age relationships of the Golconda thrust fault as interpreted herein.

In contrast to rocks of the Golconda allochthon are those of the Antler sequence, which in nearby mountain ranges consist of upper Paleozoic marine shelf deposits that overlap structures formed during the Antler orogeny and that are in turn overridden by the Golconda allochthon. In the Clear Creek area they are represented by the Antler Peak Limestone and a small exposure questionably assigned to the Edna Mountain Formation. None of the small, isolated exposures of the Antler Peak Limestone in and around the main southeast fork of Clear Creek contain more than a hundred metres of section, and each of these partial sections stratigraphically or tectonically overlies rocks of the Harmony Formation. Each of these exposures may repeat the basal part of the Antler Peak Limestone resting unconformably on the Harmony Formation, because bedding in the Antler Peak parallels the lower contacts of the formation. However, faulting along these contacts cannot be precluded. The lithologic similarity of the brown calcareous sandstone and the sandy, crinoidal, gray limestone containing fossil fragments to the basal part of the Antler Peak Limestone near Golconda Pass at Edna Mountain was demonstrated to me by R. J. Roberts. He also convinced me that sandstone beds similar to the Harmony Formation and apparently in sequence with some of the Antler Peak calcareous rocks at Clear Creek are in fact thrust slices of the Harmony Formation rather than being interbedded with upper Paleozoic limestone and part of the Antler sequence. Fusulinids from the Antler Peak Limestone at Clear Creek were identified as *Triticites* cf. *T. beedei* and *T.* cf. *T. milleri* of Virgilian (Late Pennsylvanian) age by C. H. Stevens (1968 written commun.); these fusulinids agree in age with those from the lower part of the formation elsewhere.

In the southeast fork of Clear Creek, a small outcrop area of brown fine-grained calcareous sandstone is provisionally assigned to the Edna Mountain Formation primarily to draw attention to this possibility. However, these rocks could be another unusual phase of the limestone-bearing part of the Harmony Formation, with which they are in contact.

No obvious relationships exists between any of the upper Paleozoic rocks in the Clear Creek area and the Tallman Fanglomerate, which occurs only about 19 km farther north near the mouth of Thomas Canyon (Fig. 2), where it underlies volcanic rocks of the Koipato Group. The Tallman is a thick, monotonous, nearly unbedded sedimentary breccia of mostly angular, somewhat calcareous sandstone that weathers to yellowish brown and is mixed with subordinate chert cobbles and pebbles. It could have been derived from erosion of the Havallah sequence and is perhaps best regarded as an unusual local phase of the Koipato Group.

Although distinctive Triassic rocks belonging to the Koipato, Star Peak, and Auld Lang Syne Groups are represented in the northwestern part of the Sonoma Range, none of these is represented in the Clear Creek area. Therefore, they cannot be directly related structurally to the Havallah sequence rocks of the Golconda allochthon.

STRUCTURAL RELATIONSHIPS

For clarifying the relative age of the Golconda thrust fault in the Sonoma Range, the critical structural relationships are those between the thrust faults that involve Triassic rocks in the northwestern part of the range and those farther south that bound the Havallah sequence. The tectonic conclusions by Gilluly (1967) regarding the northern part of the Sonoma Range are generally accepted here, particularly his recognition of a series of major, superimposed, post-Triassic thrust faults on which displacement was generally toward the west.

The structurally highest and youngest of these post-Triassic thrust faults is the Clear Creek fault. Beneath it, in the northwestern part of the range, are the Tallman thrust fault of post-Triassic age and the Sonoma thrust fault, which is regarded as post-Triassic by Gilluly. The "Forks thrust" of Gilluly (1967, p. 3, Fig. 2), however, as shown in his cross sections but not as described in his text, seems to be an unnecessary complication. Interpretation of Mesozoic thrust faulting in the area is simplified if the Clear Creek fault is regarded as carrying previously deformed lower Paleozoic rocks, which were already tectonically mixed by an older thrust fault that brought the Harmony over the Valmy Formation, presumably during Antler orogenesis. This postulated older structure is perhaps homologous to the Dewitt thrust fault at Battle Mountain (Roberts, 1964), and it must exist farther south in the Clear Creek area of the Sonoma Range, where the complicated map relationships between the Harmony and Valmy Formations are inexplicable by post-Triassic faulting alone.

The elaborate thrust-segment nomenclature of Silberling and Roberts (1962) is abandoned here, as it was by Gilluly (1967). The Clear Creek thrust fault (fault 5 in Fig. 2) is recognized as having a more or less continuous trace, extending northward from near the mouth of Sonoma Canyon along the east side of the Triassic rocks at the range front and then swinging into the range. It then turns southward along the west and south sides of the Triassic strata that make up the "Sonoma window" in the upper part of Sonoma Canyon and from there continues on southward toward Clear Creek. South of the Sonoma window the Clear Creek fault dips west and at the surface carries the Harmony Formation over the Valmy Formation.

The major result of the present study is the characterization of the southern extremities of the Clear Creek thrust fault. On the maps by Ferguson and others (1951a) and Gilluly (1967), the trace of the Clear Creek fault is shown swinging sharply eastward as it approaches Clear Creek from the north, and all of the Harmony Formation exposed in the Clear Creek area is included in the upper plate of the thrust fault. My interpretation differs in that south of the Sonoma window, the south-trending trace of the Clear Creek thrust fault is considered to continue in a southerly direction, cutting through the Harmony Formation, crossing Clear Creek Canyon about 2.5 km upstream from its mouth, and eventually becoming unrecognizable in the metasomatized rocks southeast of Grand Trunk Canyon. Where it cuts across the Harmony Formation, The fault trace (5c in Figs. 2 and 3) is well marked by a continuous zone of deformation and alteration, and a sliver of the lithologically distinctive Preble Formation occurs in one place along it. This trace of the Clear Creek thrust fault, which is the continuation of the fault regarded by all previous workers as the Clear Creek fault farther north, displaces the stratigraphic units recognized within the Havallah sequence, the fault interpreted here as the Golconda thrust fault, the belt of Preble Formation, and the fault separating the Preble from the Harmony Formation—the Preble-Harmony fault (fault 2). Geometrically, this branch of the Clear Creek thrust fault could be a range-front normal fault except that locally its dip is as low as 30° and it has a considerable apparent component of right-lateral slip. It is one of several imbricate thrust faults in the Clear Creek area on which the same assemblage of rock units and older structures were transported in a generally westward direction. All of these thrust faults thus seem to represent the same phase of deformation and are considered branches or strands of the Clear Creek thrust fault.

To the west of strand 5c, near the range front north of the mouth of Clear Creek Canyon, two structurally higher strands of the Clear Creek thrust fault (faults 5d and 5e) are required to explain the repetition two more times of the Havallah sequence, Golconda thrust fault, Preble Formation, and Preble-Harmony fault.

Branching to the east of strand 5c of the Clear Creek thrust fault, the structurally lower strand 5b follows a generally southeastward course across Clear Creek Canyon to the crest of the range (Fig. 2). Here, beyond the area included in Figure 2, its trace is offset by Cenozoic normal faults and is concealed beneath Cenozoic volcanic rocks and alluvial gravel. On the east side of the Sonoma Range, however, it may correspond to a fault, mapped in reconnaissance by Ferguson and others (1951a), that separates the Valmy Formation on the north from the Havallah sequence to the south. The east end of this possible extension of fault 5b is truncated near Gregg Canyon, about 3 km east of Figure 2, by plutonic rocks having a K-Ar age of 104 ± 2 m.y. (Silberman and McKee, 1971). In the Clear Creek area, the northern part of the plate above fault 5b consists of the Harmony Formation, which is overlain by patches of the Antler Peak Limestone and is believed to be structurally underlain by the Valmy Formation (see cross section C–C', Fig. 2). Farther southeast, the upper plate of fault 5b includes the Preble-Harmony fault zone and slivers of upper Paleozoic rocks along it, the Preble Formation, a segment of the Golconda thrust fault, and rocks of the Golconda allochthon. Fault 5b thus cuts across a variety of older structures, including the Golconda thrust fault, as interpreted herein. At its northwestern end, fault 5b appears to be the same as part of the Clear Creek thrust fault mapped in reconnaissance by Ferguson and others (1951a), but to the southeast it corresponds to part of what they incorrectly regarded as the Tobin (Golconda) thrust.

A structurally still lower fault (5a) is also regarded as part of the Clear Creek series of imbricate thrust faults, but it could be an older and genetically unrelated structure. In any event, its trace is truncated at its northwest end by strand 5c and at its south end by strand 5b of the Clear Creek thrust fault. Because fault 5a is the same as the southeastern part of what was mapped by Gilluly as the "Clear Creek thrust," the fact that it is clearly truncated at its south end by a structurally higher strand (fault 5b) of the post-Triassic Clear Creek thrust rather than by the Tobin (Golconda) thrust, as originally interpreted by Ferguson and others (1951a), effectively removes the condition that led Gilluly (1967, p. 4) to conclude that the Tobin (Golconda) thrust "must be of post-Triassic age."

The Clear Creek thrust fault is definitely of post-Triassic age because of its cross-cutting relationship with Triassic rocks in the northwestern part of the Sonoma Range. A still younger maximum age for the thrust faults of the Clear Creek system might be established by relating them to the granitic rocks that crop out in the vicinity of Grand Trunk Canyon and for which discordant K-Ar ages of 155 ± 3 m.y. (biotite) and 168 ± 3 m.y. (hornblende) have been obtained by M. L. Silberman (1972 personal commun.) for one sample.[2] The aureole of metasomatism apparently related to this dated pluton is offset by strand 5c of the Clear Creek thrust fault. If this displacement relates to that of the system of Mesozoic thrust faults rather than to subsequent normal faulting, it suggests a maximum age of Middle Jurassic for the time of thrusting, accepting 170 m.y. as the approximate age of the Lower Jurassic–Middle Jurassic boundary.

In the Clear Creek area the Preble-Harmony fault (fault 2) and the Golconda thrust fault (fault 1) are displaced by all of the higher branches of the Clear Creek thrust fault system (Fig. 3). Moreover, just south of the mouth of Clear Creek Canyon they are truncated by a quartz monzonite intrusive rock that is lithologically the same as that at Grand Trunk Canyon, which has been dated as Early or Middle Jurassic. Consequently, these more or less parallel structures are no younger than Middle Jurassic, but there is no definite evidence in the Clear Creek area for an age before or after deposition of the Triassic rocks in the region. Of the two faults, the Preble-Harmony fault is younger, because in places it cuts across the Golconda thrust fault, and fault slivers probably derived from the upper plate of the Golconda fault occur along it.

Older faults (shown in the figures but not designated by number) include thrust faults that are folded and even overturned. These thrust faults, separating the Harmony and Valmy Formations, are especially conspicuous near the range front a few kilometres north of Clear Creek, where they have been regarded previously as parts of the Clear Creek thrust fault (Ferguson and others, 1951a; Silberling and Roberts, 1962; Gilluly, 1967). As portrayed here they probably do not express the full amount of structural complexity between and within these formations; however, these faults can all be interpreted as folded and faulted parts of a single thrust fault that originally carried the Harmony over the Valmy Formation. Scattered small windows of rocks of the Valmy Formation appearing through the Harmony Formation indicate the presence of the Valmy structurally beneath the Harmony throughout the Clear Creek area.

Detailed analysis of tectonic fabrics in the rocks of the Clear Creek area is beyond the scope of this study. Nevertheless, folding in the Havallah sequence as well as in the Preble Formation (over which the Havallah sequence was carried by the Golconda fault) has a notably uniform pattern. On a stereographic plot, poles to bedding in these units describe a well-formed girdle whose axis of rotation corresponds to the approximately horizontal minor fold axes that trend about N. 20° E. Data on axial surfaces are few but suggest a shallow west-northwest dip. This fabric is far simpler than that which could be derived from any large part of the Harmony and Valmy Formations, and it apparently has not been disrupted by the folds in the northwest part of the range that characterize the Triassic rocks that are folded about axes plunging gently south-southeast. The fold geometry apparently associated with emplacement of the Golconda thrust fault in the Clear Creek area is identical to that described by MacMillan (1972) for the New Pass Range about 110 km to the south. However, in the New Pass Range an earlier, before-emplacement phase of folding is also recognized by MacMillan in the rocks of the Golconda allochthon.

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[2] Sample no. MB43. Location NW¼ SE¼ sec. 31, T. 33 N., R. 39 E. Collector: M. L. Silberman. Analytic data: biotite, $K_2O = 9.08$ percent, radiogenic $Ar^{40} = 2.172 \times 10^{-9}$ moles/g, radiogenic Ar^{40}/total $Ar^{40} = 94.0$ percent; hornblende, $K_2O = 0.701$ percent, radiogenic $Ar^{40} = 1.821 \times 10^{-10}$ moles/g, radiogenic Ar^{40}/total $Ar^{40} = 86.7$ percent. Constants: $\lambda_E = 0.585 \times 10^{-10}$ yr^{-1}, $\lambda_B = 4.72 \times 10^{-10}$ yr^{-1}, K^{40}/total $K = 1.22 \times 10^{-4}$ g/g.

Conclusions and Interpretations

The fault regarded as the Golconda thrust fault in the Sonoma Range has carried rocks of the Havallah sequence over the Preble Formation, much as the Golconda fault has done along part of its type trace 10 km or so farther east at Edna Mountain. In the Sonoma Range, however, the Golconda thrust fault is disrupted by the Clear Creek system of younger imbricate thrust faults of post-Triassic Mesozoic age. The Golconda thrust fault is therefore older than the Clear Creek thrust faults, and it is also older than intrusive rocks of Early or Middle Jurassic age; nothing prevents it from being still older within the early Mesozoic or latest Paleozoic. An age for the Golconda thrust fault of latest Permian or Early Triassic—the age currently favored throughout its regional extent—is thus acceptable, although it cannot be proven by geologic relationships in the Sonoma Range.

This conclusion regarding the age of the Golconda thrust fault holds true even if the fault (5c in Figs. 2, 3) that most obviously cuts across the thrust fault in the Clear Creek area is interpreted as a Cenozoic normal fault rather than a Mesozoic thrust fault, because this fault is the direct continuation of part of what is regarded as the Clear Creek thrust fault farther north. The part of the Clear Creek thrust fault that cuts Triassic rocks of the Sonoma Canyon window would thus either be this same normal fault or else be cut off by it. Thus, if fault 5c is a relatively young normal fault, the post-Triassic thrust faults in the northern part of the Sonoma Range could not be directly related to the Golconda thrust fault, and an older age for the Golconda thrust fault is again permissible.

Accepting this conclusion, the major pre-Tertiary tectonic events in the Clear Creek area can be interpreted as follows, from oldest to youngest:

1. During the Late Mississippian to Early Devonian Antler orogeny, the lower Paleozoic Valmy and Harmony Formations were thrust together so that in their present position the Harmony is generally above the Valmy.[3]
2. During the latest Permian or Early Triassic Sonoma orogeny, the

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[3] Early Paleozoic tectonism resulting from strong compressional forces prior to the Antler orogeny has recently been hypothesized by Erickson and Marsh (1974) on the basis of studies at Edna Mountain. Some of the pre-Sonoma orogenic structures of the lower Paleozoic rocks in the Sonoma Range could be related to such tectonism, but the thrust emplacement prior to the Sonoma orogeny of the Harmony Formation over the Valmy in the Sonoma Range, as well as at Battle Mountain, might be difficult to reconcile with the local sedimentary source ascribed to the Harmony by Erickson and Marsh.

Golconda allochthon overrode the Preble Formation and upper Paleozoic strata of the Antler sequence in places where they rested unconformably on the Preble.

3. Following Golconda thrust faulting, complicated movement (or renewed movement) on the Preble-Harmony fault occurred. As a result, fault slivers of the Antler sequence and rocks possibly belonging to the Golconda allochthon were emplaced along the Preble-Harmony fault, which in places cuts the Golconda thrust fault.

4. In post-Triassic time, earlier structures were all displaced in a generally westward direction on the Clear Creek system of thrust faults.

Interpreting the Clear Creek thrust-fault system in this way, it is significant that the principal formations and structures within its imbricately faulted upper plate apparently can be related to comparable features 10 to 15 km northeast of the Clear Creek area that would be in the lower plate of the Clear Creek system of thrust faults, as shown diagrammatically in Figure 4. The Preble Formation of the Clear Creek area, which is fault bounded on its west or northwest side by the Harmony and Valmy Formations and on the other side by the Golconda allochthon, may have been displaced on the Clear Creek thrust fault system from the belt of the Preble Formation now exposed along the east flank of the Sonoma Range and the west side of Edna Mountain. This belt of Preble Formation is also fault bounded on its west and east sides, respectively, by the Valmy Formation and the Golconda allochthon (Ferguson and others, 1951a, 1952). This interpretation implies original continuity between the Preble-Harmony fault of the Clear Creek area and the Adelaide fault on the east side of the Sonoma Range, imparting to the latter structure a complex pre-Tertiary history. Although Roberts and Hotz (in Roberts and others, 1958, p. 2851) speculated that the high-angle Adelaide fault might date back to the Antler orogeny and be genetically related to, or a proxy for, the Roberts Mountains thrust fault, Gilluly (1967, p. 2) discounted this and regarded it as a "minor structure belonging to the basin-range suite of [Cenozoic] normal faults." Granted that some Cenozoic normal-fault displacement along the Adelaide fault has occurred, Gilluly's cross sections show displacement on it of more than 3 km between the Preble Formation on one side and the Harmony and Valmy Formations on the other. Thus, the Adelaide fault does seem to be the principal structure separating these rocks of widely different provenance and kind, and it may well have had a long and complex history of activity.

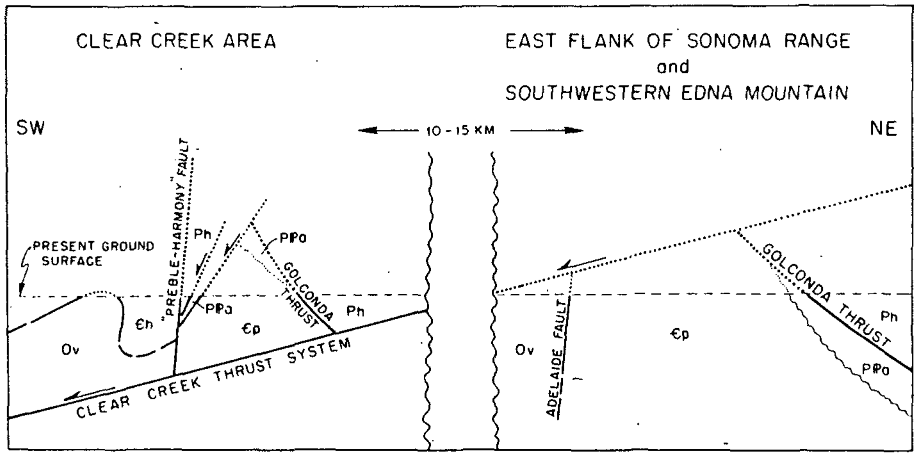

Figure 4. Diagrammatic structure section of pre-Tertiary geologic features in and northeast of the Clear Creek area, showing matching of segments of the Golconda thrust fault and nearby faults and formations on the upper and lower plates of the Clear Creek thrust fault. Geologic relationships on the east flank of the Sonoma Range and southwest side of Edna Mountain are from Ferguson and others (1951a, 1952). Symbols: Cp, Preble Formation; Ch, Harmony Formation; Ov, Valmy Formation; Ph, Havallah sequence; PPa, Antler sequence, including here the Edna Mountain Formation and Antler Peak Limestone.

Correlating the pre-Tertiary geologic features of the Clear Creek area with those farther east not only puts the Clear Creek system of thrust faults in regional context but also identifies the parts of the supposed Golconda thrust fault in the Clear Creek area with the type Golconda thrust fault on the west side of Edna Mountain. Just as the Golconda fault in the Sonoma Range is either older than post-Triassic structures or cannot be related to them, so too is the type Golconda thrust fault. Thus, the Golconda, both in the Sonoma Range and in its type area, could be the sole thrust fault on which the regionally extensive Golconda allochthon was emplaced during latest Permian o Early Triassic time.

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