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GEOLOGY OF THE COLADO GEOTHERMAL AREA
PERSHING COUNTY, NEVADA

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July 1980

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EARTH SCIENCE LABORATORY
University of Utah Research Institute
Salt Lake City, Utah

ESL

Prepared for
U.S. Department of Energy
Division of Geothermal Energy

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ABSTRACT

The Colado geothermal area in south-central Pershing County, Nevada is defined by hot water wells in alluvium just west of the West Humboldt Range. Geothermal gradient holes have encountered temperatures up to 113.5°C at a depth of 76 m (250 ft) with a gradient reversal in the alluvium below this depth.

The West Humboldt Range consists mainly of Triassic to Jurassic slaty shale to quartzite of the Auld Lang Syne Group. Carbonate rocks of the Jurassic Lovelock Formation have been thrust over pelitic rocks on the south end of the area. Erosional remnants of Tertiary tuffs and sediments overlay the metasediments in the West Humboldt Range.

The principal structures are high-angle faults striking north-northwest, northeast and north-south. The horst-to-graben transition along the range front consists of several step faults trending irregularly north. The structural pattern in the west edge of the range probably continues to the west under the Quaterary alluvium where the source of the hot water is located. Thermal waters probably rise along a major fault intersection in the Mesozoic rocks then spread out in an aquifer in the alluvium. Several thrust faults are exposed south of Coal Canyon, and a structural break in the Mesozoic rock exists under the canyon. Several low-angle faults are present north of Coal Canyon but their effect, if any, on the geothermal occurrence is not known.

INTRODUCTION

The Colado geothermal area is located in the Humboldt Valley about 10 km northeast of Lovelock, on the west edge of the West Humboldt Range, Pershing County, Nevada (Figure 1). Several warm water wells with temperatures up to 66°C are present in the area; there are no hot springs or sinter deposits.

The Colado area was mapped on a reconnaissance basis by the Southern Pacific Company (Oesterling and Pruss, 1960; and Coonrad and Cohen, 1957). Speed (1974 and 1976) mapped a large area south of the present study area and Sulima (1970) mapped the stratigraphy of Coal Canyon.

Getty Oil Company is currently exploring the geothermal potential of the Colado area and has drilled 18 thermal gradient holes and two medium-depth temperature and stratigraphic test holes. This study of the geology of the Colado area was done as part of the Department of Energy, Division of Geothermal Energy Industry Coupled Program.

LITHOLOGIES OF THE COLADO AREA

Geologic Setting

The Humboldt Valley is a northeast-trending graben in the western part of the Basin and Range Province. The central part of the valley is covered with Quaternary Lake Lahontan sediments. Alluvium composes the gentle slopes near the range fronts (Plate I). Normal step faults form the structural boundary between the valley graben and the horst of the West Humboldt Range.

The West Humboldt Range consists of a thick sequence of lower to middle

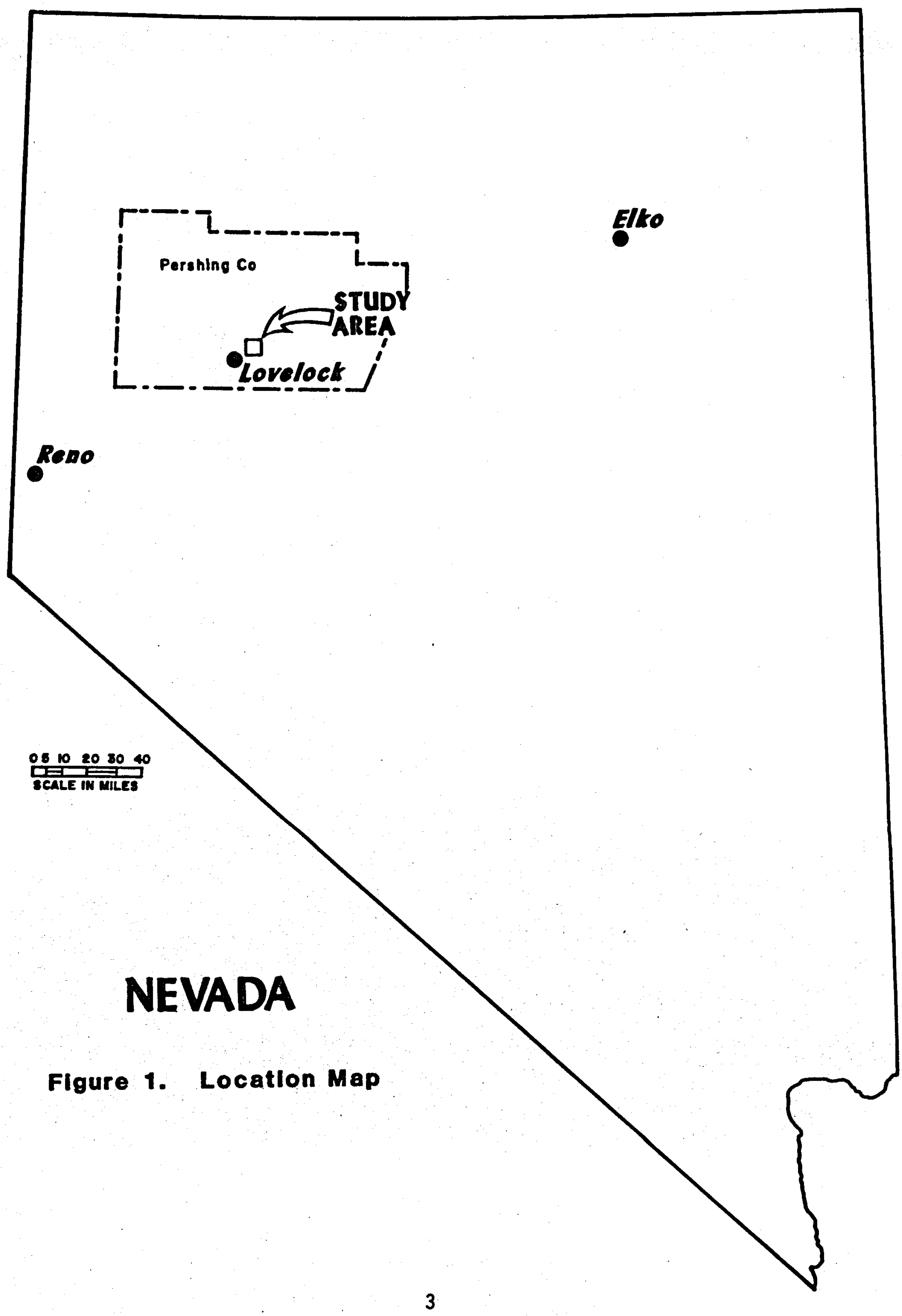


Figure 1. Location Map

Mesozoic, eugeosynclinal rocks partially covered by erosional remnants of Tertiary rhyolitic rocks. This sequence consists mainly of pelites of the Auld Lang Syne Group (Burke and Silberling, ,1973). Limestone beds of the Lovelock Formation (Speed, 1974) are exposed in the southern part of the area. The surface exposures are considered to be a succession of thrust nappes (Speed, 1976) with the Fencemaker thrust the sole thrust at an unknown depth below the allocthonous West Humboldt Range (R. C. Speed, per. comm.).

Mesozoic Rocks

The Mesozoic pelite sequence of the Colado Area is part of the Triassic to Jurassic Auld Lang Syne Group (Burke and Silberling, 1973). The exposed section may belong to the Grass Valley or Raspberry Formations; previous investigators have not assigned formation names to the pelite sequence in the area and stratigraphic correlation is beyond the scope of this study. The limestone units in the thrust nappes which Speed (1976) believes are Jurassic in age have been mapped as Lovelock Formation; this formation was not correlated with other formations in Nevada. The Mesozoic rocks in the area have undergone low-grade regional metamorphism.

Limestone Breccia (TR lsb)

South of Coal Canyon, limestone breccias are exposed at the base of thrust nappes (Plate I). A typical exposure has a lower zone 1 to 3 m thick of bedded gray limestone characterized by large blocks several feet across which locally contain intensely folded limestone beds. The coarse breccia is cemented and veined with white calcite. An upper zone is 1/3 to 2 m thick and consists of limestone fragments one to a few cm in size in a light olive to olive gray sandy limestone matrix. Siltstone and mudstone fragments make up 1/10 to 1/4 of the breccia with some open spaces between fragments.

The limestone breccia generally rests on shale or slate, and these beds are truncated at a very low angle to the bedding. A shale breccia is present below the limestone breccia in a few outcrops. Although the limestone breccia is 5 to 20 feet thick along most of the thrust fault traces near the south end of the map area, it usually forms a cliff and is overlain by a siltstone (T̄R s), and therefore has a very narrow surface exposure. Limestone breccia is present in the thrust fault southwest of hill 5388, SW 1/4 Sec.11, T27N, R32E, and thins to the northeast along this fault.

The relative age of the limestone breccia is uncertain. Speed (1976) mapped the breccia as Jurassic with a thrust fault at the lower and upper contact. The present study confirmed faulting at the lower contact but the upper contact is poorly exposed and its nature could not be determined. The siltstone (T̄R s) overlies the breccia in the klippes along the south edge of the study area (Plate I) which suggests that the two units are related.

Siltstone (T̄R s)

A clean, well sorted siltstone to very fine-grained sandstone forms several klippes on the south edge of the study area (Plate I). The unit is texturally uniform, massive, and weathers to yellow and tan tones. The siltstone is distinct from any of the other units in the study area.

The siltstone was assigned a Triassic age by Speed (1976) although it is not clear if there is any fossil evidence for its age. The unit crops out only in the uppermost thrust plate in the area and overlies the limestone breccia which forms the base of the thrust.

Slaty Shale and Mudstone (J̄R s)

A thick sequence of slaty mudstone or silty shale, shale, and thin siltstone beds forms most of the bedrock exposure in the study area. The shale is thinly bedded and weathers to tan, light brown, purple, olive or light gray, forming thin sheets. The shale or low grade slate has a micaceous sheen in most areas and the poorly developed foliation is usually coplanar with bedding, although the foliation is at a low angle to bedding in some outcrops and at a right angle to bedding at the north end of the map area.

With increasing silt content the shale grades to mudstone. The mudstone is poorly bedded and, although a general trend can be seen in outcrops, an accurate strike and dip usually cannot be measured. The mudstone forms rough, irregular brown fragments and foliation often can not be distinguished from bedding. A typical sample contains 20 to 30 percent 0.03 to 0.07 mm equant, angular quartz grains, and about 10 percent diagenetic opaques in a matrix of recrystallized sericite, quartz and possibly minor feldspar. A few grains of glauconite are present. Small scale cross bedding is present in some outcrops.

A few siltstone beds 1/3 to 1 m thick are present in the slates. South of Coal Canyon a few thin limestone beds, not mapped separately, are present in the slate unit.

The slaty mudstone and shale sequence was not subdivided in this study due to the lack of tracable or unique marker beds. In general the lower part of the sequence, which is exposed in the east and northeast part of the study area, is dominantly shales with minor mudstone and siltstone beds and zones. To the west mudstone and siltstone are more prevalent. The more resistant and locally faulted and silicified mudstone forms ridge crests and gentle west-facing slopes. The shale is exposed on the steep east slopes and in the drainages. No fossils were found in the slates.

Large areas of poor exposure and the structural complexity (Plate I) prevents tracing individual beds any distance. Previous workers in the area have relied on outcrop color as a stratigraphic guide. We found many color changes to be independent of bedding. Cuttings from mineral exploration holes around the south Willard Mine and geothermal temperature holes in the study area indicate that outcrop color is produced by weathering and all of the unit is dark gray a few feet below the surface.

Quartzite (J₨q)

Limited exposures of orthoquartzite are present in the northwest part of the study area. The quartzite is gray to olive or reddish brown, with fine sand to silt-size cemented grains. The quartzite is usually intensely faulted and consists of cemented breccia in the SW 1/4 Section 26, T28N, R32E (Plate I). The brecciation of the quartzite is probably due to its elastic failure when the less competent enclosing shales deformed. Much of the quartzite occurs along the highly faulted range front. Although thick, the quartzite beds have limited lateral extent due to facies changes, incomplete cementing along strike, and faulting. Much of the silica cementing of the quartzite may be hydrothermal in origin rather than diagenetic.

The quartzite is a part of the slaty mudstone and shale sequence which has sufficiently distinct outcrop characteristics to be mapped separately. The quartzite seems to occur in the upper part of the slaty sequence, although faulting makes this conclusion uncertain.

Limestone (J₹ l)

A few limestone beds of mappable thickness occur within the slaty mudstone and shale sequence. The carbonate outcrops are medium to dark gray, generally massive and up to 12 m thick.

Limestone, Quartzite and Mudstone (J₹ w)

In the southwest corner of the study area a sequence of thick limestone, quartzite, and mudstone beds are exposed. The limestone is light gray to tan, thin to medium bedded, forming thick units. The quartzite is gray, weathers tan to brown, and is composed of silica-cemented, well-sorted fine sand. The mudstone is similar to the other mudstones in the area.

The limestone-quartzite-mudstone sequence is exposed in a thrust plate. The beds within the sequence dip steeply to the west (Plate I) and are discordant to the lower dips in the thrust plates above and below it.

The age of this unit is not known but its lithology is similar to the Winnemucca Formation of the Auld Lang Syne Group (Burke and Silberling, 1973).

Lovelock Formation (Jl)

The Lovelock Formation (Speed, 1974) is exposed along the range front a mile and a half south of Coal Canyon. The formation consists predominantly of thick, light-to-dark gray limestone with associated minor amounts of shale. The Lovelock Formation in the Gypsum Mountain area, south of the study area, has been described in detail by Speed (1974).

Diorite (Jd)

A medium-grained diorite intrudes the Mesozoic rocks in the southwest part of the study area. The diorite is greenish gray and weathers to dark brown. The rock contains mostly euhedral andesine strongly altered to sericite, epidote and calcite. Hornblende, partially altered to tremolite, composes about a third of the rock. Minor interstitial quartz is present. Intrusive contacts were observed at the lower and upper contacts of the sill-like intrusive body. The structural setting (Plate I) suggests that the diorite intruded a thrust fault. The age of the diorite is not known, but it is different in composition and grain size from the Tertiary igneous rocks. Other gabbro-to-diorite intrustions to the south have yielded Jurassic age dates (Speed, 1976).

Tertiary Rocks

The Tertiary rocks in the West Humboldt Range occur as isolated erosional remnants of volcanic and sedimentary rocks. Tertiary rocks are more extensive to the east of the study area and are not encountered west of the range under the Quaternary sediments.

Andesite Flows (Ta)

Several andesite flows are exposed in the section north of the mouth of Coal Canyon; the flows overlie Mesozoic rocks and are overlain by Tertiary alluvium and tuff. The andesite is dark gray, purple, dark olive or red. The andesite contained small plagioclase laths and mafic crystals which are now completely altered to sericite, chlorite, actinolite, calcite, clays and hematite. Flow textures and amygdules of quartz and zeolites are present in some outcrops.

Basalt Sill (Tbs)

A basalt sill has intruded the slate east and southeast of the south Willard Mine (Plate I). The basalt is tholeiitic and characterized by a diabasic texture. The plagioclase laths are 0.3 mm long.

Although the sill closely parallels a rhyolite sill, about three feet of slaty shale separate the sills. The relative age of the basalt sill is unknown and it lacks the olivine phenocrysts present in the Tertiary basalt flows east of the study area.

Pyroclastics (Tp)

A thick pile of pyroclastics, mostly altered to clay, and a perlite form the hills south of the mouth of Coal Canyon. The white-to-tan pyroclastics consist of non-welded tuff with some cinders and lithic fragments in the lower part. The steep dip of the material (Plate I) is due to rotational slumping and initial dip. The pyroclastics are probably part of an ash and cinder pile formed during the early part of the eruptive event that produced the intrusive plugs or domes (Tri). The perlite does not show pyroclastic textures and may be an obsidian flow.

Rhyolite Intrusive Plugs (Tri)

Two intrusive plugs are exposed south of Coal Canyon and consist of pale yellowish-brown, flow-banded felsite. The rock is columnar jointed and has a spherulitic devitrificaton texture. The west plug intruded through the slaty shale and into its own pyroclastic pile (Plate I and Plate II, C-C'). The orientation of the plugs has been influenced by the west-dipping sedimentary rocks.

Rhyolite Flow (Trf)

The rhyolite flow which caps the ridges south of the mouth of Coal Canyon is probably the extrusive equivalent of the plugs (Tri). The flow lacks phenocrysts and consists of alteration and devitrificaton minerals with possible minor glass remaining.

Conglomerate (Tal)

A boulder conglomerate overlies the andesite and is overlain by the tuff west of the Willard Mine (Plate I). The conglomerate is poorly sorted with clasts of limestone, quartzite and shale being the most abundant. Andesite and diorite boulders are also present in a coarse sandy matrix. The conglomerate is heavily hematite and limonite stained. The unit is a channel fill and varies from 0 to 24 m thick. The conglomerate is present in some places under the tuff in sections 25 and 31, T28N, R33E, but could not be mapped due to poor exposure. Loose boulders on a covered slope can be identified as Tertiary gravel by their hematite rind and sphericity.

Rhyolite Sills and Dikes (Trd and Trb)

Felsic rhyolite sills and a few dikes crop out in the study area. The sills are grayish orange to pale pink, strongly flow foliated, and 1 to 3 m thick. The felsite is hypocrystalline, leucocratic, partially devitrified and contains some sericite and clay. The sills and dikes are most numerous just north of Coal Canyon where they intrude the thrust fault (Plate I). In section 6, T27N, R33E, the sills grade to tuff-breccia up-dip and were the feeders for the tuff (Tt) to the east.

Younger rhyolite dikes form breccia dikes (Trb) which intrude the tuff in the northeast corner of section 6. The breccia dikes contain clasts of tuff in a glassy ground mass.

Tuff (Tt)

Isolated areas of white to tan vitric ash-flow tuff overlie the Mesozoic rocks, and Tertiary andesite and gravels north of Coal Canyon; some exposures are over 100 m thick. The tuff is slightly to moderately welded and contains a few embayed quartz phenocrysts. The extent of alteration and devitrification varies from area to area. A basal, non-welded, zone of pumice is exposed on the east edge of the tuff in Section 35, T28N, R32E (Plate I).

The tuff overlies the older Tertiary conglomerate and is overlain by younger Tertiary sediments. The relative age of the tuff, pyroclastics, and plugs south of Coal Canyon is unknown but their similar composition suggest they are comagmatic.

Alluvium (Tal2)

Poorly sorted gravels with a silt to clay matrix and interbedded mudstones overlap the down-dip terminus of the tuff unit north and east of the Willard Mine (Plate I). The clasts consist mostly of tuff and minor amounts of Mesozoic lithologies, fragments of the calcite and quartz veins, and petrified wood. The alluvium is poorly consolidated and the silt and clay fractions compose most of the unit.

Non-welded Tuff (Tt2)

A pink, non-welded, silicified ash-flow tuff caps several hills of Tertiary alluvium north of the south Willard Mine (Plate I). The tuff contains a few altered feldspar crystals and lithic fragments in devitrified glass shards. Fine-grained secondary quartz occurs between the shards.

Limestone (Tls)

Pink to gray Tertiary limestone beds with interbedded sandstone are exposed on the east side of the study area in section 32, T28N, R33E (Plate I). The limestone overlies the Tertiary alluvium (Tal2) and is overlain to the east by poorly consolidated mudstone. The limestone and probably most of the West Humboldt Range have been tilted to the east by block faulting.

Alluvium (Ts)

A thick sequence of poorly consolidated tuffaceous mudstones and other fine-grained sediments are present to the east of the study area. Basalt flows cap these sediments east of the study area.

Quaternary Deposits

The Quaternary sediments consist of Lake Lahontan deposits and alluvium in the Humboldt Valley. The lake sediments include beds of sand, silt and clay, and beach gravels. The alluvium consists of poorly sorted gravels in alluvial fans, stream beds, and colluvium on steep slopes. The Mesozoic pelites disaggregate rapidly and are therefore under-represented in the alluvial clasts which are dominantly Tertiary volcanic rocks.

As Lake Lahontan dried up, the prevailing winds transported vast quantities of sand and silt from the beach and lake bottom deposits and deposited this material in the range (Plate I). Most of the aeolian deposits have been stabilized by sagebrush and are now being eroded out of the small drainages they filled.

All of the landslides in the study area are associated with Tertiary volcanic and sedimentary rocks.

STRUCTURES OF THE COLADO AREA

Low-Angle Faults

The Mesozoic rocks were thrust and folded during late Jurassic time. The Lovelock Formation was thrust into nappes over the older Trassic-Jurassic pelititic rocks in the Gypsum Mountain area (Speed, 1974) south of Coal Canyon. These thrust faults extend into the south end of the study area (Plate I and cross section C-C', Plate II).

A low-angle fault is exposed on the north side of Coal Canyon (Plate I). Although relative offset could not be determined, it was mapped as a thrust because of its structural similarity to the thrusts to the south. Mudstone and siltstone have been thrust over shales and a rhyolite dike has intruded the fault (Plate II, cross section B-B'). The location of the thrust north of the landslide is uncertain. However, the rhyolite dike follows a thin breccia zone to the north and then west (Plate I) with the mudstone-over-shale relationship continuing, and this is thought to be the thrust fault.

Another low-angle fault forms the main structure at the Rosal Mine in the north-central part of the study area. Quartzite in the upper plate is highly faulted and brecciated. Relative offset on secondary faults indicate that the hanging wall is down-thrown, therefore indicating a normal fault.

Several low-angle faults are exposed near ridge crests in the north Willard Mine area (Plate II, cross section A-A'). The relative movement on these faults is unknown, but they generally place fractured and silicified mudstone over shale. The low-angle faults are typically at a small angle to the bedding. Where fault and bedding become coplanar, the fault trace disappears.

Normal Faults

The Colado area is highly faulted, especially near the range front. The dominant fault trends are north-northwest, north-south and northeast. The lack of marker beds in the slaty shale and mudstone sequence make determination of fault throw difficult. Generally the relative offset is only tens to a few hundred feet. The faults and veins of the Willard mines trend northeast and dip northwest. These faults are probably Mesozoic in age because they are terminated and offset by faults which predate the Tertiary volcanic rocks. The north-south high-angle fault through the south Willard mine has 540 feet of relative vertical displacement if the major northeast-trending fault, which dips 40 to 42 degrees north, is used as a reference plane (Plate I).

A major structure is inferred in Coal Canyon; the evidence for this is the lack of any structure or bed crossing the Canyon. One unique marker bed, a monolithologic chert conglomerate, is exposed in section 12 south of Coal Canyon. The 1 to 2 m thick conglomerate dips 15 degrees west and extends from near the rhyolite plug to the north end of the section but is not present north of Coal Canyon. On the north side of Coal Canyon, a 1 m thick limestone bed extends from the southwest quarter of section 36 through the west side of section 1 but does not cross the Canyon. To the east the Tertiary volcanic rocks extend across the canyon. The structure in Coal Canyon is therefore thought to be Mesozoic.

It can be seen on Plate I that northeast- and northwest-trending faults have controlled the shape of the range front, especially in section 26, T28N, R32E. Some are probably pre-existing faults which were reactivated along the range front. The competent quartzite has been fractured and brecciated where the northeast and northwest fault trends intersect the range front.

Surface exposure and drill hole data indicate that the horst-graben boundary consists of several step faults (Plate II).

Quaternary faulting is evident in two locations in the northern part of the study area. In section 12, T28N, R32E, coarse alluvium with beach lines on it has been offset 1 to 2 m. The scarp cuts Lake Lahontan beach features which are about 18,000 years old (Morrison, 1964). In section 23, southeast of Woolsey, a trough which appears to be a fault line graben separates the range front from its alluvial apron (Plate I). The graben may have been modified by Lake Lahontan.

No offset of the Lake Lahontan beds was found along the Humboldt River in the study area.

Folds and Tilting

The Mesozoic rocks have undergone irregular folding, but no general pattern of folding was noticed. The folds were not studied in detail because it is felt that they are not important to the geothermal system due to the low porosity of the slates and shale. The folding along Coal Canyon was studied in some detail by Sulima (1970).

The beds generally dip west to south and have a somewhat uniform dip in the eastern half of the study area. Near the range front, dips are more variable and measured dips are representative of an area smaller than the symbol covers on the map. Many of the dips are fault produced.

The Tertiary limestone beds (Tls) dip to the east 5 to 15 degrees. The basalt flows a mile east of the study area also dip east, indicating that the West Humboldt range has been tilted east.

Alteration and Mineralization

Gold, antimony and minor copper and silver values were produced from the study area between 1905 and 1951 (Johnson, 1977, p. 102). Gold production came from quartz veinlets in fracture zones and breccia along northeast-striking faults that dip northwest at the Willard mines. The ore was free-milling gold and silver from surface exposures (Johnson, 1977, p. 103). Copper, lead and zinc were associated with the gold in the quartz veins.

Antimony was produced from the Johnson-Heizer and Adriene mines which are both located on northwest-striking faults that dip southwest (Plate I). A total of 527 tons of ore was mined at the Johnson-Heizer mine during 1916 and 1946 (Johnson, 1977). The Adriene mine produced 15 tons of antimony and the Rosal mine was developed for antimony but no production was reported.

Current activity in the area consists of exploration drilling around the south Willard mine and cat work at the Johnson-Heizer mine.

Quartz veins are abundant in sections 26, 35 and 36 of T28N, R32E (Plate I). There are two types of quartz veins: fracture fillings and massive veinings. The fracture fillings consist of a braided network of 2.5 cm and thinner veins in a fracture system or fault breccia. These are the type of veins along which the Willard mines are developed and may be Mesozoic in age.

The massive quartz veins are one to several m wide, white-to-hematite-stained quartz. No significant diggings were located on these veins. Some of the massive veins are part calcite and part quartz. Generally the quartz post dates the calcite. The massive quartz veins cut Tertiary rocks.

The calcite veins are 1 to 3 m thick, and gray, containing medium-crystalline calcite and minor dolomite and are barren of sulfides. They cut the altered andesite flows (Ta) and form resistant wall-like outcrops. One of the calcite veins extends a short distance into the overlying tuff (Tt), but this is probably due to an underlying resistant wall which the tuff covered. The calcite veins are therefore younger than the andesite, but older than the rhyolite tuff. Clasts of vein calcite are present in the Tertiary gravel (Tal2) which overlies the tuff.

The most notable alteration at the antimony mines is hematite staining (Figure 2). The hematite at the Johnson-Heizer mine is limited to the fault zone and is hard to distinguish from the red-brown weathering of the enclosing Mesozoic sediments. Hematite is more widespread in the fractured quartzite of the Rosal Mine. Quartz veins were not found at the antimony mines.

Hematite staining is also associated with the quartz veinlets and faults at the Willard mines. Here again the enclosing mudstone and siltstone weather to reddish brown, making it hard to delineate hydrothermal-produced hematite, but the staining is widespread and more intense than at the antimony mines (Figure 2). Silicification of the mudstone along the mineralized, northeast-trending structures is also strong. The north-south faults cut the mineralized structures, are not mineralized or silicified, and therefore postdate the mineralizing event.

The most extensive and strongest hematite staining is exposed along the range front, north of Coal Canyon (Figure 2). Hematite staining is pervasive in the Tertiary and Mesozoic rocks along this zone. The andesite lava flows (Ta) are strongly altered to sericite, calcite, chlorite, quartz, clay and hematite. The abundant quartz and calcite veins along the range front are devoid of hematite staining or sulfides and therefore postdate the hematite

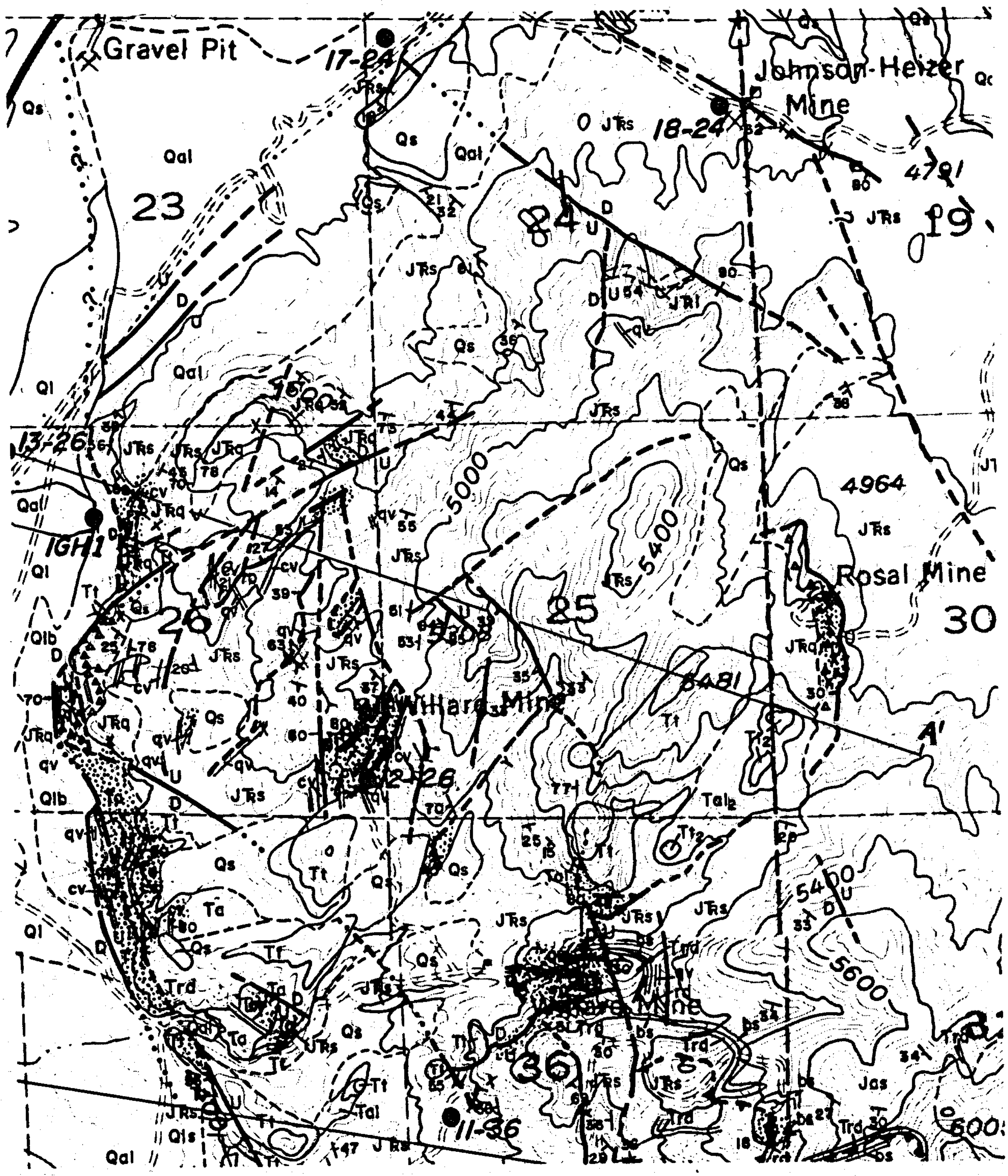


Figure 2. Areas of strong hematite staining

staining in the rocks they cut. Some hematite staining, argillic alteration and silicification extend into the tuff (Tt), which postdates the veining, but it is limited to fault zones. This suggests there were two periods of alteration and hematite staining. Areas of silicification are present in the tuff and quartzite in the hematite-stained areas along the range front.

The Tertiary rhyolites have been altered to montmorillonite at several locations in the Colado area (Papke, 1970). Production has been small and the quality marginal. Most of the clay deposits were formed by hydrothermal alteration of tuff or perlite. A perlite within the pyroclastic (Tp) unit in section 2, south of Coal Canyon (Plate I), has been partially altered to clay. Some production has come from this deposit. Shard texture could not be seen in a thin section of the perlite and it is probably an obsidian flow.

Some propect trenches have been dug on montmorillonite deposits in the NW 1/4, section 8, and NE 1/4, section 6, T27N, R33E. At both these locations the tuff (Tt) was the host rock.

The small clay deposit on the east side of section 11, T27N, R32E, which was explored with an adit (Plate I), is an altered rhyolite sill in the Mesozoic sedimentary rocks.

All of these montmorillonite deposits are outside of the areas of hematite staining and their relationship to mapped structures could not be determined. The formation of these clay deposits is discussed by Papke (1970).

A clay deposit in the NW 1/4 of section 35 on the range front occurs in tuff and is heavily hematite stained. This deposit is mostly kaolinite.

Permeability and Fluid Channelways

The Mesozoic clastic sediments probably have a very low intergranular permeability. The Tertiary extrusive rocks have some permeability along cooling fractures and joints and the older alluvium (Tal) has a sand matrix which probably has good permeability. The Tertiary rocks are limited to erosional remnants, however.

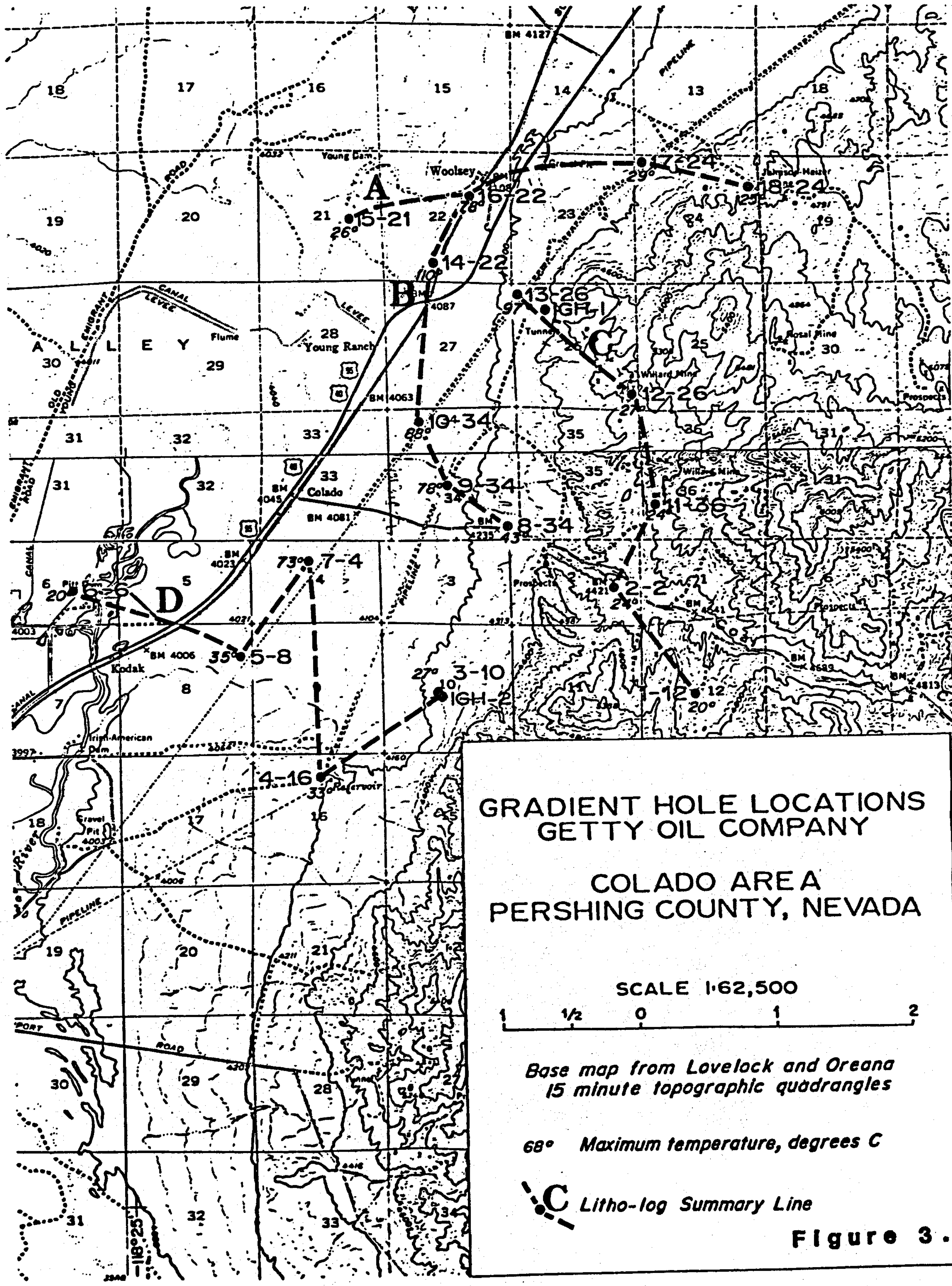
Faults provide the best subsurface channelways for fluid movement in the area. Although limited to the south end of the study area, the lower massive zone of the limestone breccia contains small solution cavities along stylolites. Breccia and solution porosity, with open spaces up to a few millimeters in size, is present in the upper zone of the limestone breccia and in a quartzite breccia lens within the thrust fault north of Coal Canyon. Cooling joints in the rhyolite dike which intruded the thrust fault may provide some permeability also. Open spaces were observed in fault breccias along high-angle faults in section 26, T28N, R32E. Fault breccias along the range front appear to have considerable permeability and the strong hematite staining and silicification along the range front (Figure 2) indicate fluid flow in the past.

Subsurface Data

During 1979 to 1980, 18 shallow thermal gradient holes and 2 intermediate-depth holes were drilled by Getty Oil Company to evaluate the geothermal potential of the Colado area. The cuttings were subsequently released for study to the Earth Science Laboratory, UURI, through the DOE/DGE Industry Coupled Program. The locations, numbers and bottom hole temperatures for each hole are shown in Figure 3. Figures 4-7 illustrate the stratigraphic relationships between the drill holes across several sections. The shallow holes were 150 m (500 feet) deep and the intermediate holes 354 m and 457 m (1160 and 1500 feet). Log summaries of intermediate holes IGH-1 & 2 are presented in Figure 8. The bedrock consists of slate, siltstone and sandstone of Triassic to Jurassic age (Johnson, 1977). Milky to clear quartz is widely scattered throughout the slate and pyrite occurs separately within the slate. The pyrite and quartz may have formed from original constituents in the rock during metamorphism.

Hole IGH-2 in section 10 (Figure 3) encountered calcareous slate at 347 m (1140 feet) with quartzite-bearing alluvium or a quartzite bed in the 20 foot sample interval above the slate. Although carbonate of the Lovelock Formation would be expected at this location (Plate I), the slate may be the limestone-quartzite-mudstone unit (Js) or the slaty shale and mudstone unit (JRs). There are some slaty shale beds within the Lovelock Formation.

In general the Quaternary sediments consist of poorly consolidated gravel, sand and mudstone. The gravels contain poorly sorted clasts of diverse lithologies; the sand and gravel are poorly cemented by clay and calcite. Mudstones contain subordinate amounts of coarse sand and gravel, which probably occur as thin lenses. No stratigraphy or marker beds could be found in the alluvium. The upper one-to-two hundred feet of mudstone in the western holes is probably Lake Lahontan sediments.


GRADIENT HOLE LOCATIONS
GETTY OIL COMPANY
COLADO AREA
PERSHING COUNTY, NEVADA
SCALE 1:62,500
1 1/2 0 1 2
Base map from Lovelock and Oreana 15 minute topographic quadrangles
68° Maximum temperature, degrees C
C Litho-log Summary Line
Figure 3.
A
B
C
D
15-21
16-22
14-22
17-24
18-24
13-26
IGH-1
12-26
10-34
9-34
8-34
11-36
7-4
2-2
5-8
3-10
IGH-2
4-16
Woolsey
Young Dam
Young Ranch
Colado
Kodak
Flume
Pipeline
Irish-American Dam
Willard Mine
Reservoir
Gravel Pit

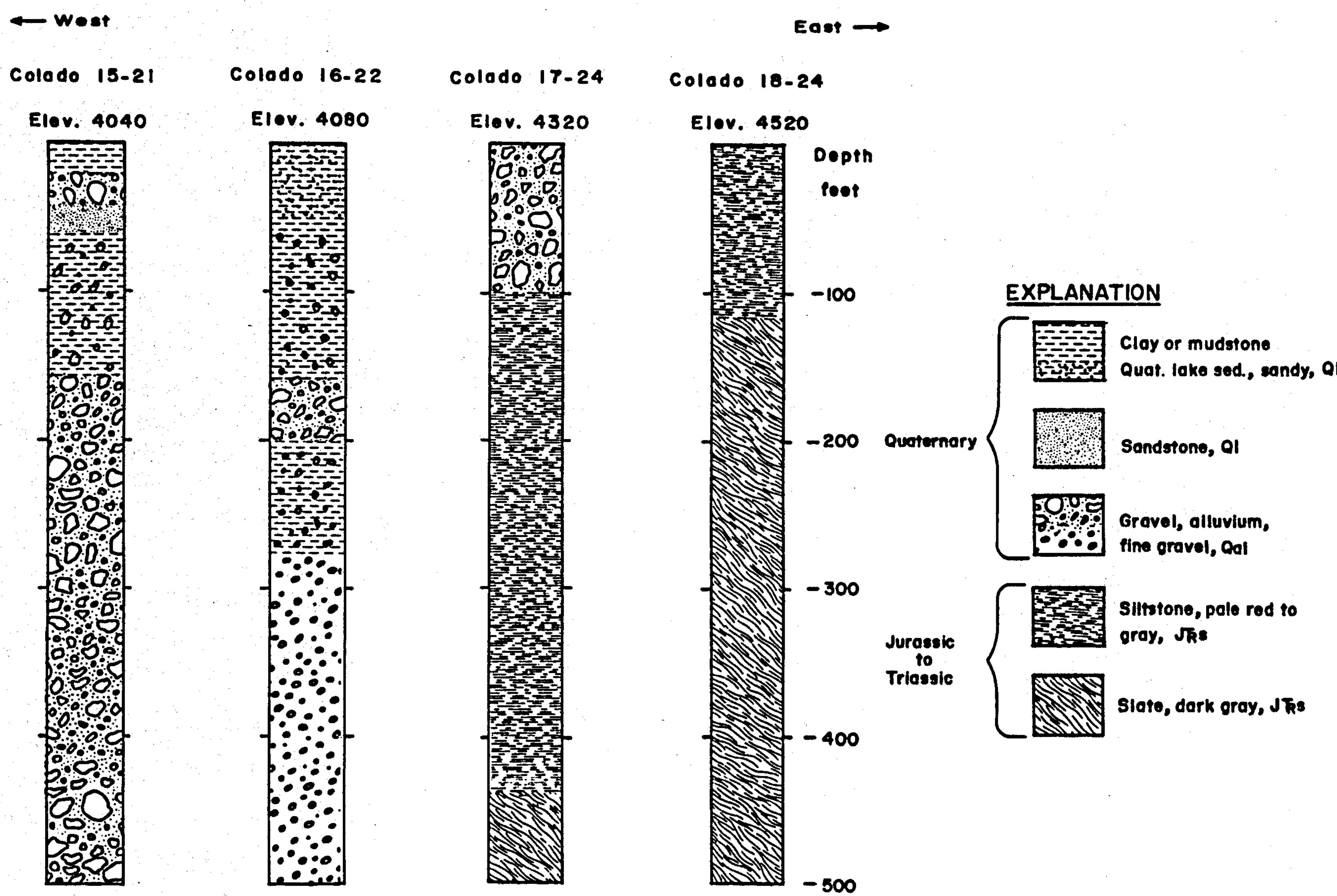


FIGURE 4 Lithologic Logs; line A

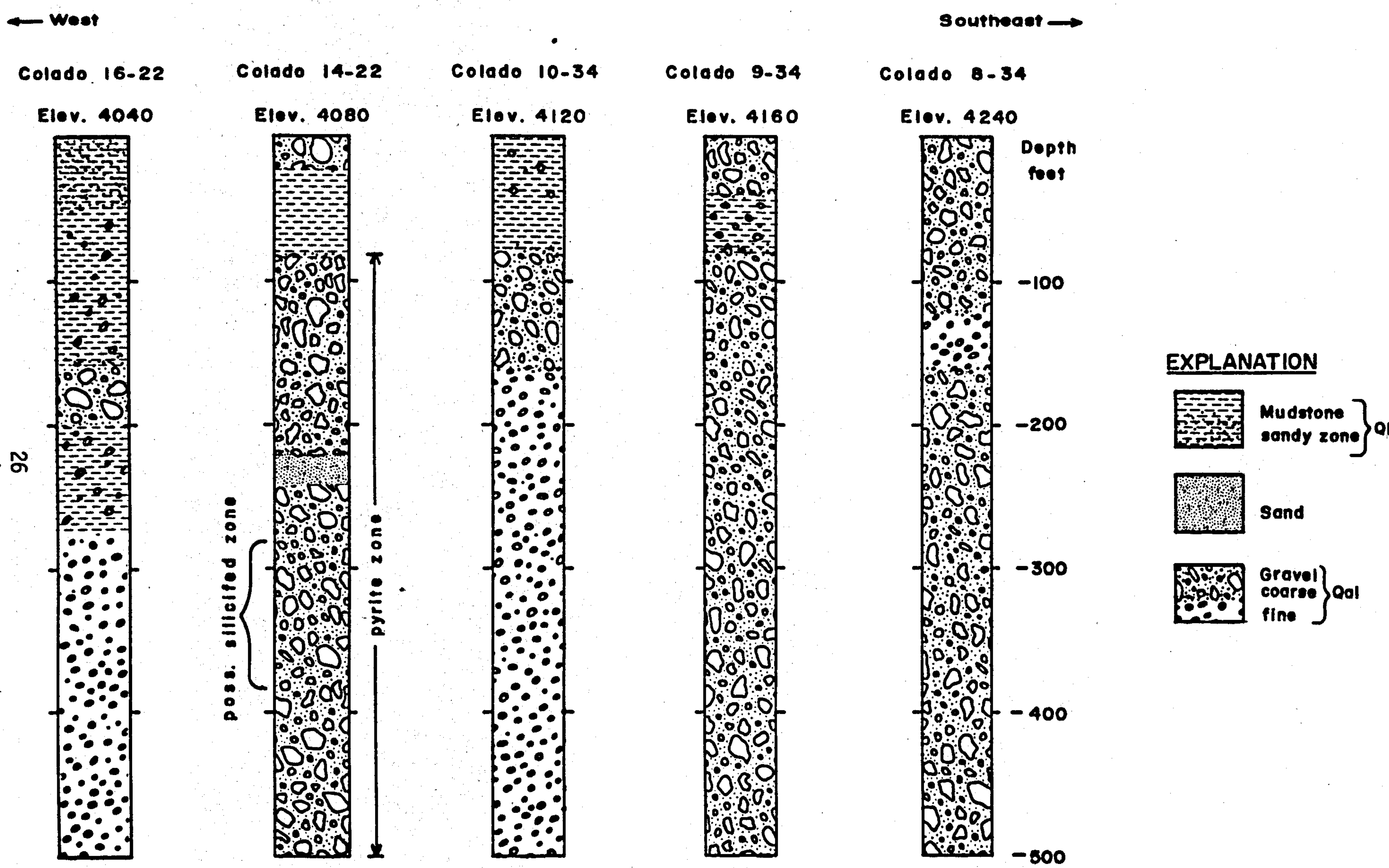


FIGURE 5 Lithologic Logs; line B

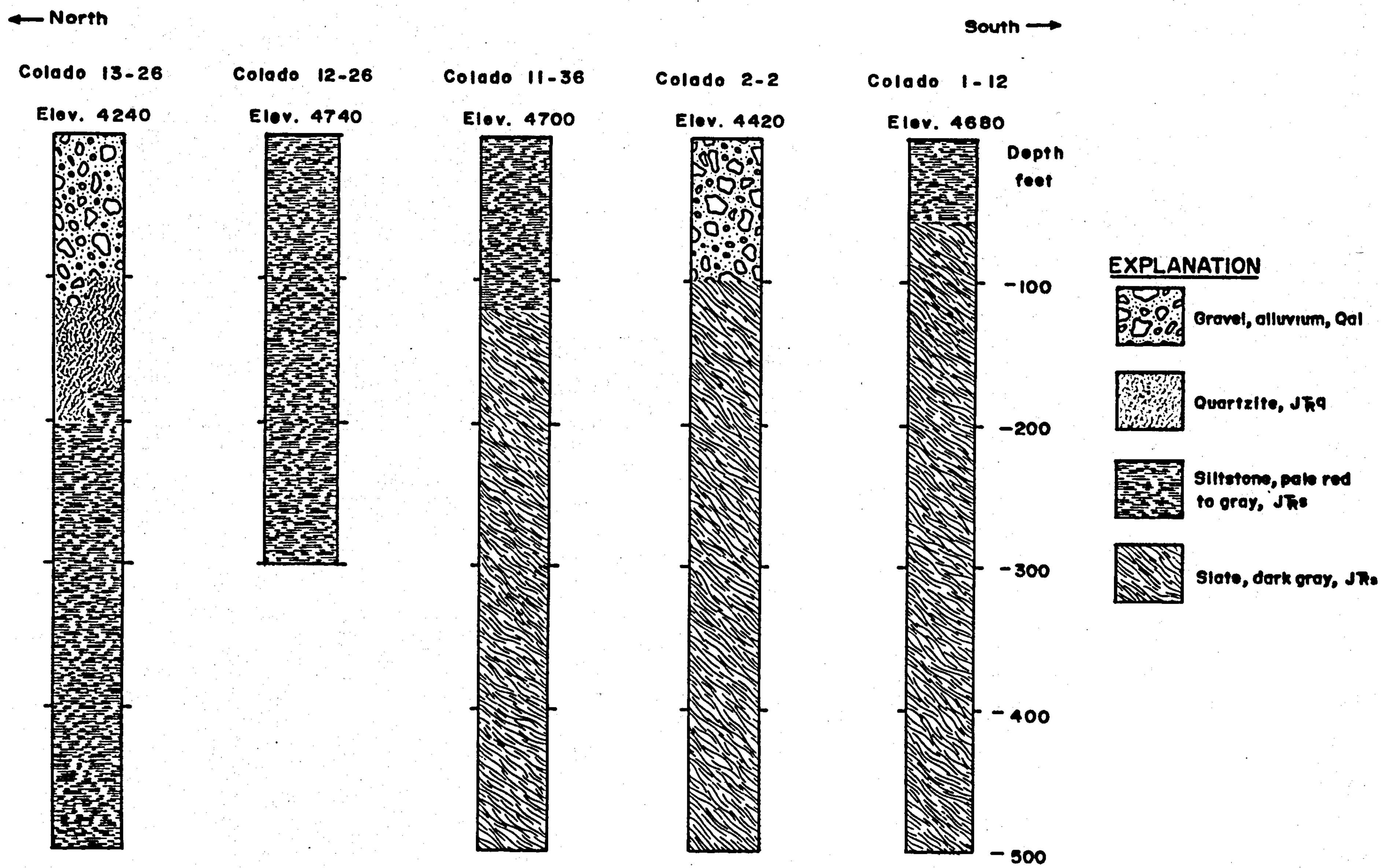


FIGURE 6 Lithologic Logs; line C

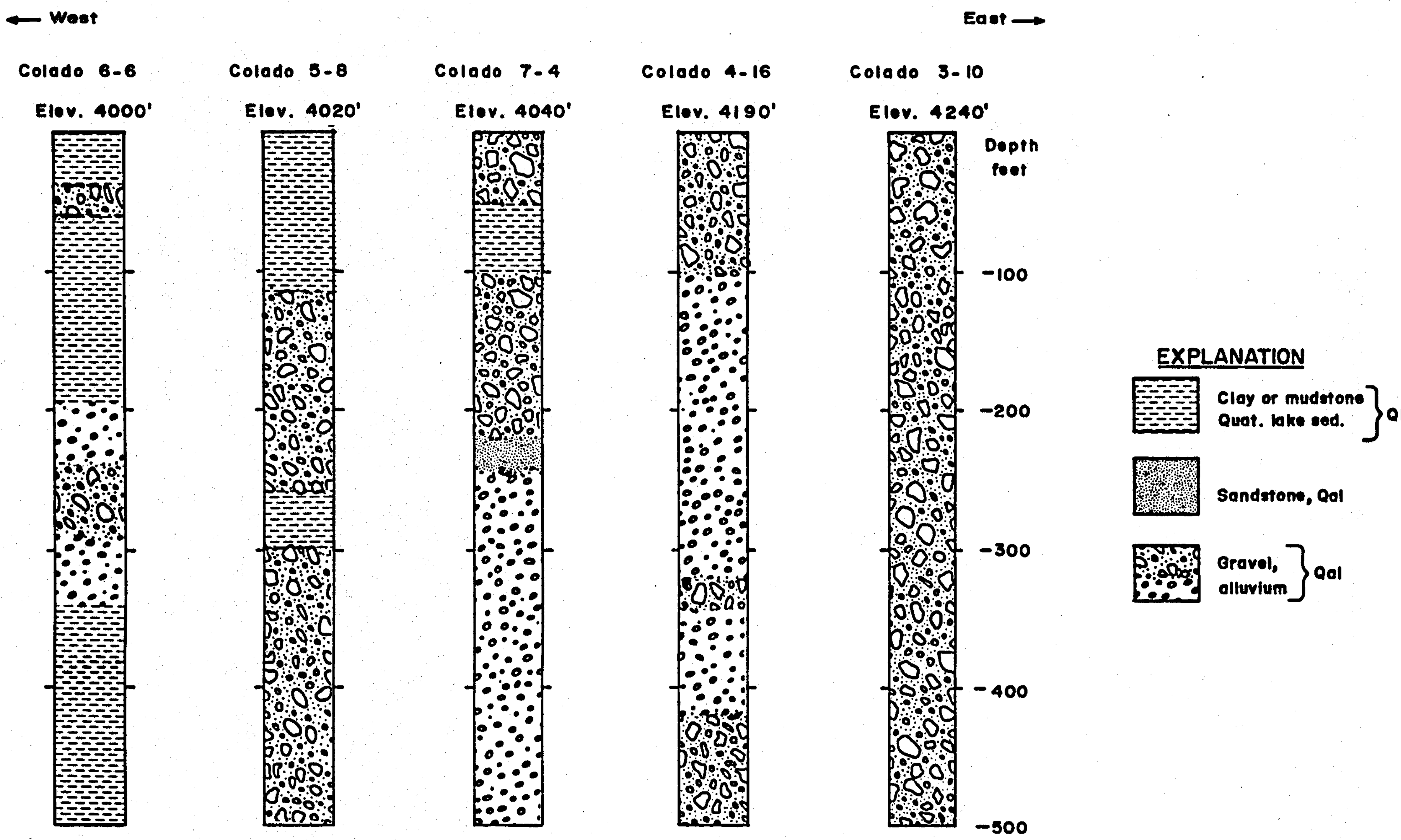


FIGURE 7 Lithologic Logs; line D

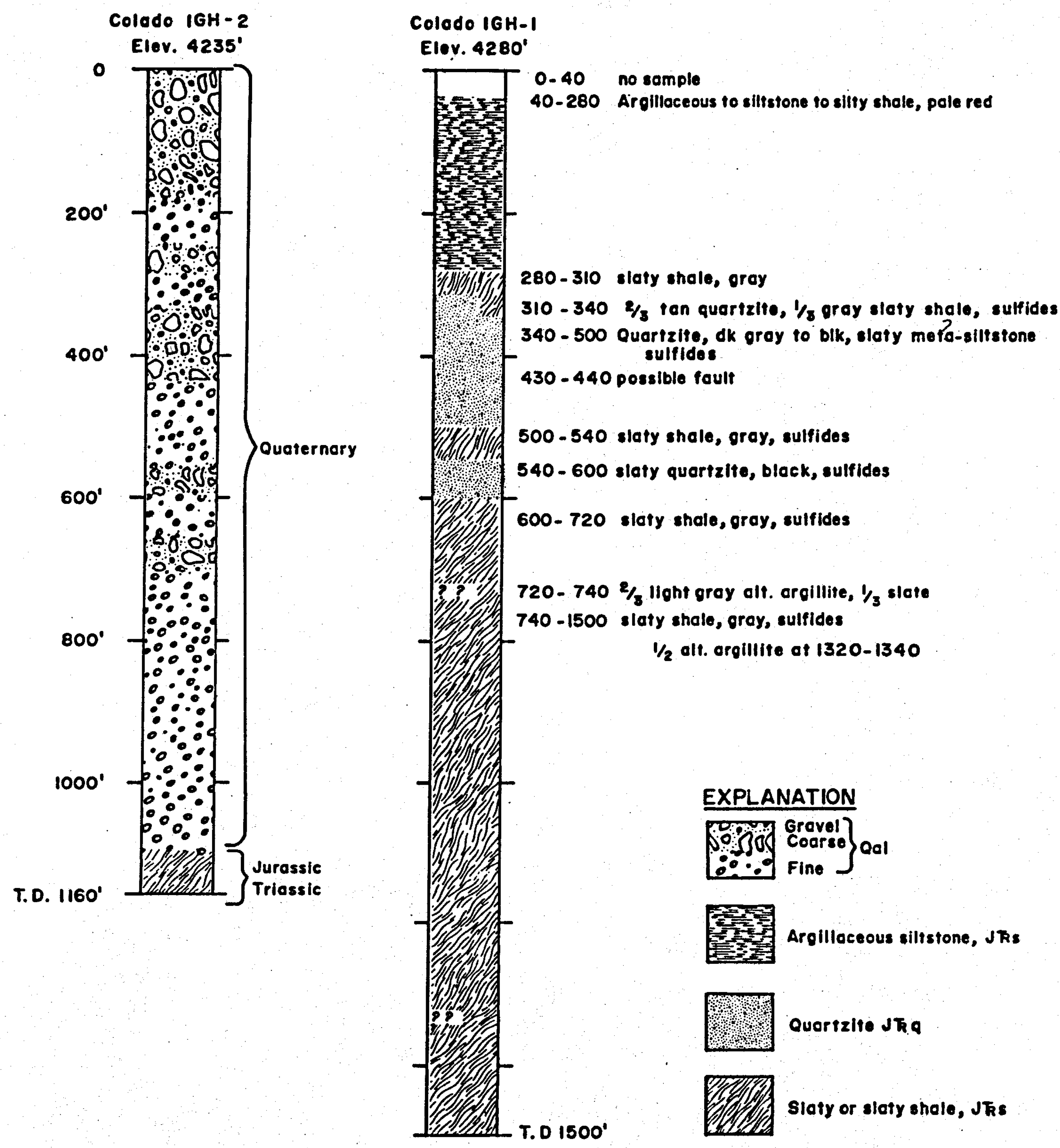


Figure 8. Lithologic logs for holes IGH-1 and IGH-2

Mineralization of possible significance occurs in hole 14-22. Pyrite cubes occur interstitially within the gravel and sand at depths of 24 to 152 m (80 to 500 feet) (Figure 5), and appear to have formed after deposition of these sediments. Pyrite is particularly abundant and also occurs within clasts between depths of 85 and 116 m (280 and 380 feet). The cuttings are angular, green, and appear silicified in this zone. Some rounded silicified clasts are also present in this zone, and some of this mineralization may therefore predate deposition of the sediments. Colado 14-22 is also the hottest of the gradient holes with a temperature of 112.6°C at 61 m (200 feet). The bottom hole temperature is 110.3°C at 152 m (500 feet).

Minor pyrite is present in the lower half of hole 16-22, one-half mile north of 14-22.

Geothermal System

Only very limited information on the geothermal system exists at the present time. It is a hot water system with no surface expression. An industrial well in alluvium at Colado has a temperature of 66°C (Garside and Schilling, 1979), and several hot domestic wells are known in the Lovelock area. A temperature of 112.6°C was encountered by Getty Oil Co. at a depth of 61 m (200 feet) (Earth Science Lab., 1979) in shallow gradient hole 14-22 (Figure 3). Pyrite and alteration are evident in the Quaternary alluvium in hole 14-22, and a trace element anomaly is centered on the hole (Christensen, 1980). Temperature and trace element distributions indicate that the thermal water is entering the shallow ground water system near 14-22 and spreading to the southwest in the alluvium.

No geothermometer calculations have been done for the Colado area, and how much mixing has occurred before the thermal waters reach 14-22 is not known.

CONCLUSIONS

The Colado geothermal occurrance consists of a warm water aquifer in Quaternary alluvium in the Humboldt River valley. This shallow aquifer has a temperature of 113.5°C in one gradient hole.

The bedrock exposed in the adjacent West Humboldt Range is Triassic and Jurassic slaty pelites with lenses of orthoquartzite of the Auld Lang Syne Group (Burke and Silberling, 1973). The carbonate rocks of the Lovelock Formation (Speed, 1974) have been thrust over the pelitic rocks on the south end of the area but are not present in the center of the area, near the thermal anomaly. A limestone breccia which occurs along the thrust faults south of Coal Canyon is absent to the north.

The Mesozoic pelitic rocks are incompetent and do not maintain open fractures. The thick limestone sequence on Gypsum Mountain consists of thrust nappes. These thrust nappes have been eroded off to the north in the geothermal area.

The Tertiary rocks are surficial remnants on the western part of the range, and they are not present under the valley alluvium where drill holes have penetrated to bedrock.

The Colado area is a structurally complex area with low-angle faults in the Mesozoic rocks dipping west, and high-angle faults of several ages trending northwest, northeast and north-south. A limestone breccia with significant permeability is present along the low-angle faults south of Coal Canyon. North of Coal Canyon, permeable lenses of quartzite breccia and silicified fault breccia are present along low-angle faults. In general the exposure of low-angle faults and the amount of breccia within the faults decrease to the north. The high-angle faults are vertical to west dipping and some permeability is present in silicified fault breccia. Coal Canyon follows a structural break within the Mesozoic rocks.

The range front north of Coal Canyon, to where the front turns northeast, is a zone of structural weakness. Extensive fracture and breccia zones have formed along the range front where faults have intersected within Mesozoic quartzite.

The horst-graben transition between the West Humboldt Range and adjacent graben consists of several step faults. Only a few hundred feet of displacement occurs on the fault exposed at the range front. The trace of the range front faults has been influenced by pre-existing northwest- and northeast-striking faults. Faults along the range front dip west 50 to 80 degrees. This structural pattern probably continues to the west under the Quaternary sediments.

The size of the geothermal system is not yet known. If a reservoir did exist, it would most likely be a fracture-controlled reservoir in Mesozoic quartzite, down dip from where the thermal waters enter the alluvium. The few, thin limestone beds present within the pelites south of Coal Canyon pinch out to the north. Another possibility would be a reservoir in coarse basin sediments capped by a clay bed in the deeper part of the basin, to the west of the highway. There is a possibility of a fracture-controlled reservoir within breccia along a thrust fault deep under the West Humboldt Range.

The thermal waters are probably rising along the intersection of two normal faults in the SE 1/4 of section 22, T28N, R32E, one striking northeast and the other north-northwest or north. The thermal water is probably produced by deep circulation of meteoric water along Basin and Range faults.

ACKNOWLEDGEMENTS

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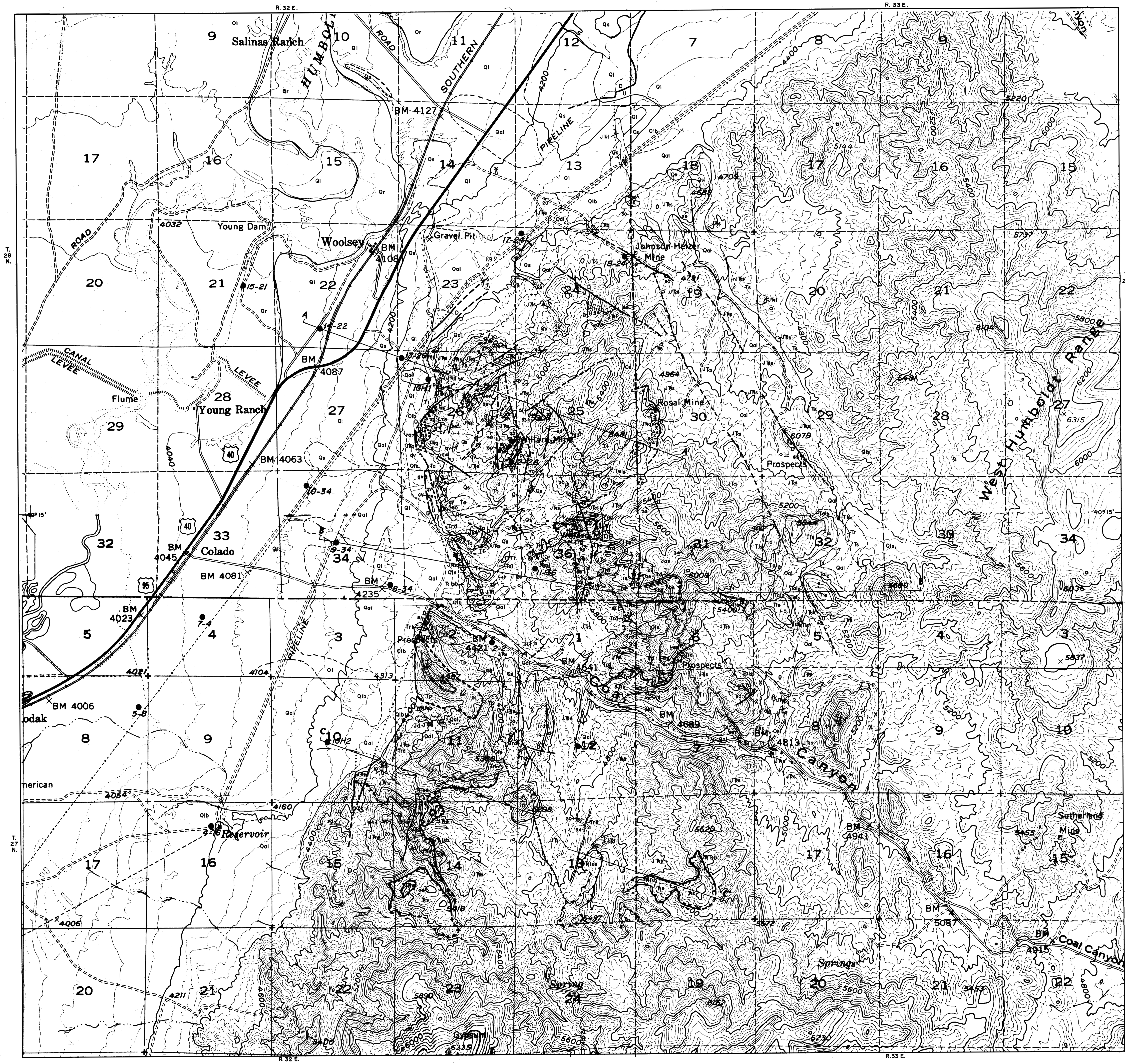
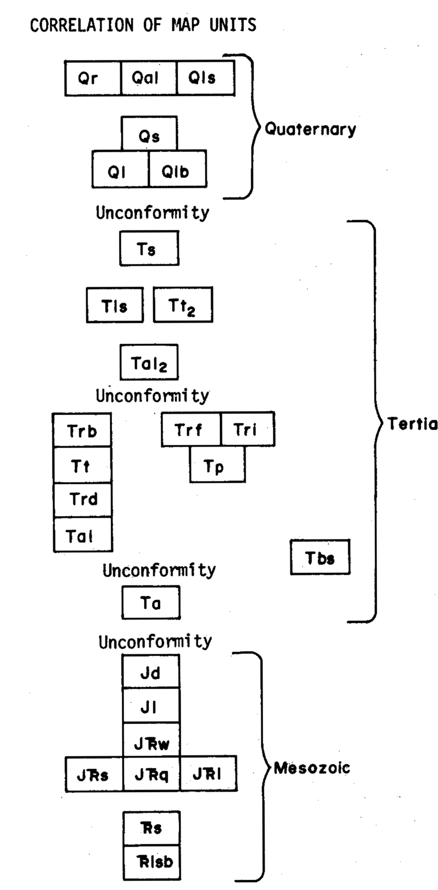
Plate I





DESCRIPTION OF MAP UNITS

Quaternary

Qr	Humboldt River channel and flood plain.
Qls	Landslide deposits.
Qal	Alluvial fans and colluvium.
Qs	Wind-deposited sand and silt, active and inactive, fills valleys in Humboldt Range and reworks Lahontan sediments.
Ql	Lake Lahontan deep water deposits.
Qlb	Lake Lahontan shore deposits, beach and deltas.

Tertiary

Tertiary units north of Coal Canyon

Ts	Tuffaceous mudstone and minor sand and gravel.
Tls	Lacustrine limestone with interbedded clastic sediments.
Tt2	Pink non-welded ash-flow containing a few altered feldspar phenocrysts, devitrified glass shards, and fine-grained secondary quartz between the shards.
Tal2	Alluvium, containing cobbles of ash-flow tuff in a clay and silt matrix.
Trb	Rhyolite breccia dikes contain fragments of ash-flow tuff in a glassy matrix and cut Tt.
Tt	White, welded ash-flow tuff, crystal poor with a few quartz phenocrysts.
Trd	Rhyolite sills and dikes, crystal poor, strongly flow banded. Some dikes are feeders to Tt and grade into pyroclastic dikes.
Tal	Coarse conglomerate containing clasts of limestone, quartzite and andesite in a sandy matrix.
Ta	Andesite lava flows which contain small plagioclase and altered mafic phenocrysts. The flows are dark gray to olive.
Tbs	Basalt sill with a diabasic texture. The sill intrudes JTRs but its age is unknown.

Tertiary units south of Coal Canyon.

Trf	Rhyolite lava flow, crystal poor, devitrified.
Tri	Rhyolite intrusive dome or plug, yellowish brown, flow banded felsite.
Tp	Pyroclastic deposits, include perlites, minor ash-flow tuff, and tuff or ash altered to clay.

Triassic and Jurassic

Jd	Diorite, greenish gray and medium-grained. It is tentatively assigned a Jurassic age based on lithologic similarity to age dated rocks to the south (Speed, 1976).
Jl	Lovelock Formation, thick beds of gray limestone with minor shale beds (Speed, 1974).

Auld Lang Syne Group

JTRw	Thick beds of light gray to tan limestone, gray orthoquartzite, and brown mudstone. The 50 to 100 feet thick limestone beds distinguish the sequence from the thin limestone beds in the pelite sequence (JTRs, JTRl, JTRq).
JTRl	Dark gray lenses of limestone within the pelite (JTRs).
JTRq	Orthoquartzite, gray to olive or reddish brown, fine-grained quartzite.
JTRs	Slaty-shale, mudstone and minor siltstone beds. The shale which grades to slate is thinly bedded and weathers tan. The mudstone is medium-to dark-brown and poorly bedded. Thin argillaceous siltstone beds of limited extent are present within the slates.
TRs	Siltstone, clean, well sorted siltstone to very fine sandstone, weathers to yellow and tan tones, occurs only in detached thrust plate. Assigned a Triassic age by Speed (1976).
TRlsb	Limestone solution breccia exposed at the base of thrust sheets. The upper zone is an olive gray collapse breccia. The lower zone contains large blocks of folded gray limestone. The age of the limestone is unknown but it seems to underly the Triassic siltstone.

EXPLANATION OF MAP SYMBOLS

- Contact, dashed where approximate
- Fault, dashed where inferred, dotted where covered
- Thrust fault, dashed where inferred
- Breccia zone
- cv — Calcite vein
- qv — Quartz vein
- 35 — Strike and dip of bedding or compaction foliation
- 15-21 — Thermal gradient hole
- x — Prospect pit
- Adit
- Shaft

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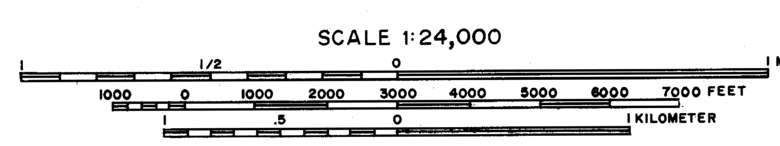
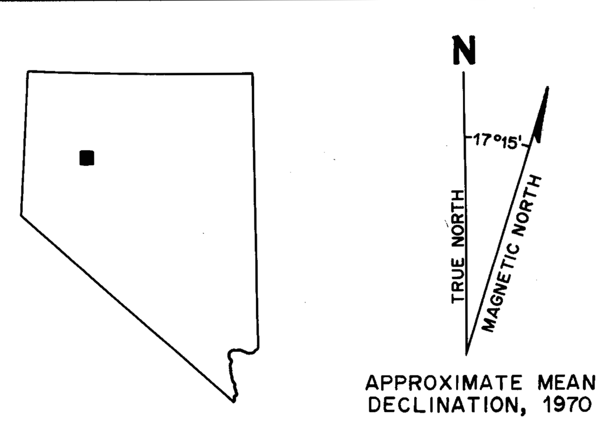




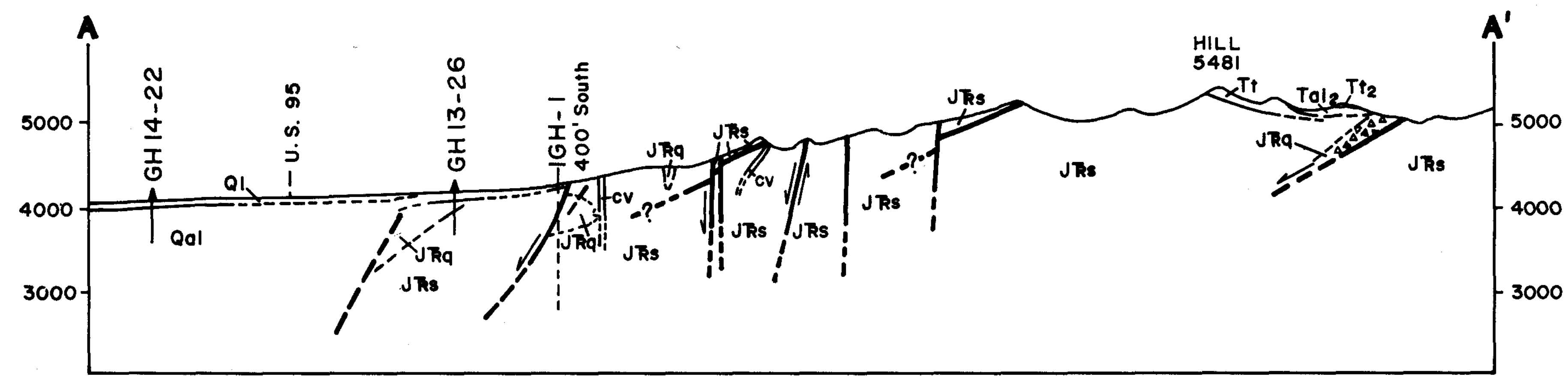
APPROXIMATE MEAN DECLINATION, 1970

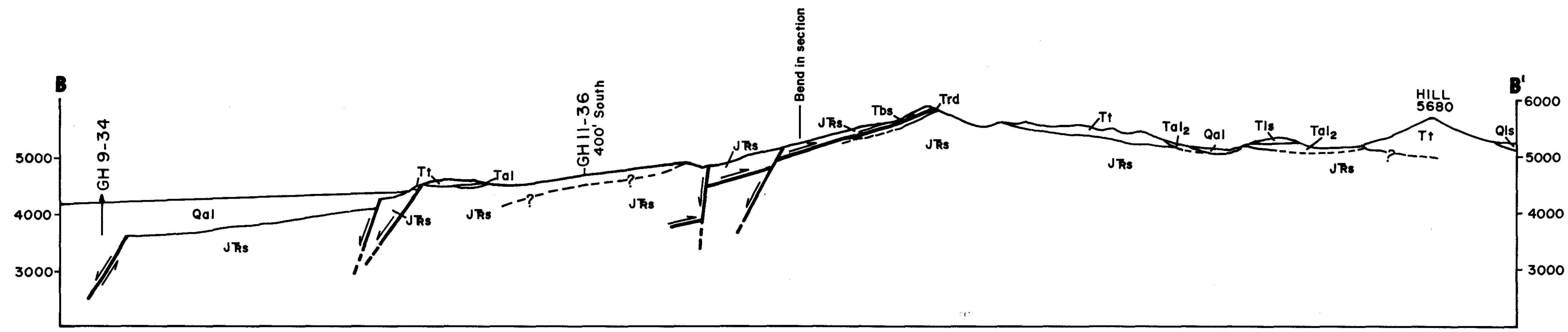
Plate I

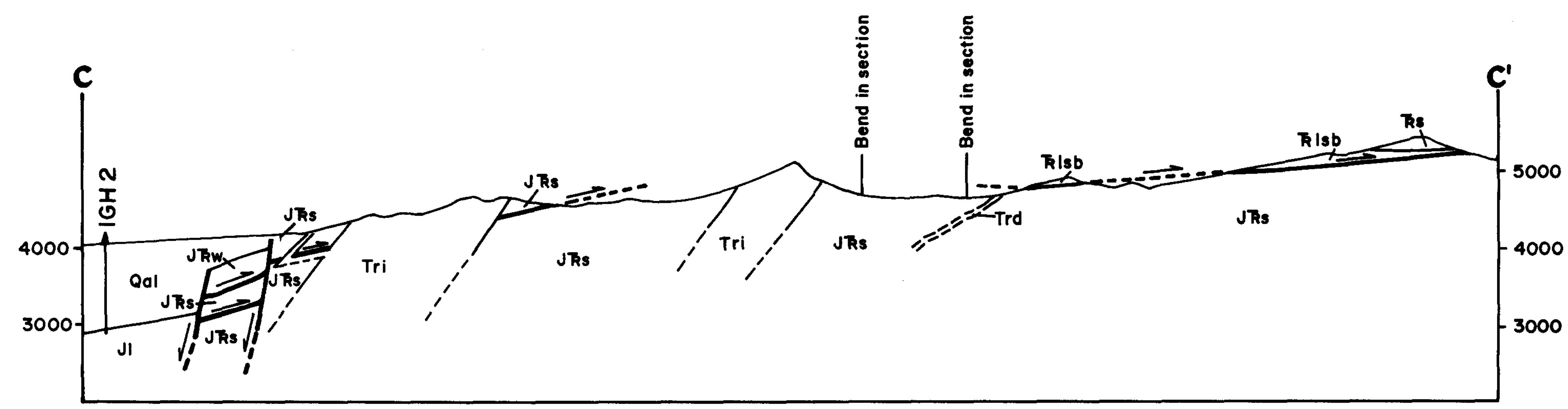
GEOLOGY MAP OF THE COLADO AREA PERSHING COUNTY, NEVADA

GEOLOGY BY BRUCE S. SIBBETT, 1980

Plate II







SCALE 1:24,000

1 — 1/2 — 0 — 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

no vertical exaggeration

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CROSS SECTIONS OF THE COLADO AREA PERSHING COUNTY, NEVADA

GEOLOGY BY BRUCE S. SIBBETT

1980