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GEOLOGY AND MINERALOGY OF THE DELNO MINING DISTRICT AND VICINITY, ELKO COUNTY, NEVADA

by

Donald Ray Olsen

A thesis submitted to the faculty of the University of Utah in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Mineralogy

University of Utah

June 1960

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This thesis for the Ph.D. degree

by

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INTRODUCTION

Location and Accessibility

The Delno mining district is located in a prominent range of mountains north of the Toano Mountains in northeastern Elko County, Nevada in the south half of T.44 N., R.68 E., and the north half of T43 N., R.68 E. Mt. Diablo Base and Meridian. The mountains have no local name, and will be referred to for convenience as the Delno Range. The district is reached from Wendover, Utah by following U. S. Highway 40 west from Wendover for 11 miles, then turning north on an improved gravel road for about 28 miles to the rail town of Montello, Nevada. From Montello a gravel road leads north 37 miles to the Delno district.

The district is accessible also from Wells, Nevada, and Twin Falls, Idaho, via U. S. Highway 93. Leaving Highway 93 at Thousand Springs Trading Post the road continues east to the Eccles Ranch, north to the Rock Springs Ranch, and east to the Delno mine. The gravel roads are maintained by Elko County and are passable except at rare periods in the winter.

About 3 miles east of the Delno district across a shallow valley is the Granite Creek-Mill Creek area, which has been included in this report because of the role of the Granite Creek intrusive in the formation of the Delno ore deposits. The two areas occupy together about 60 square miles.

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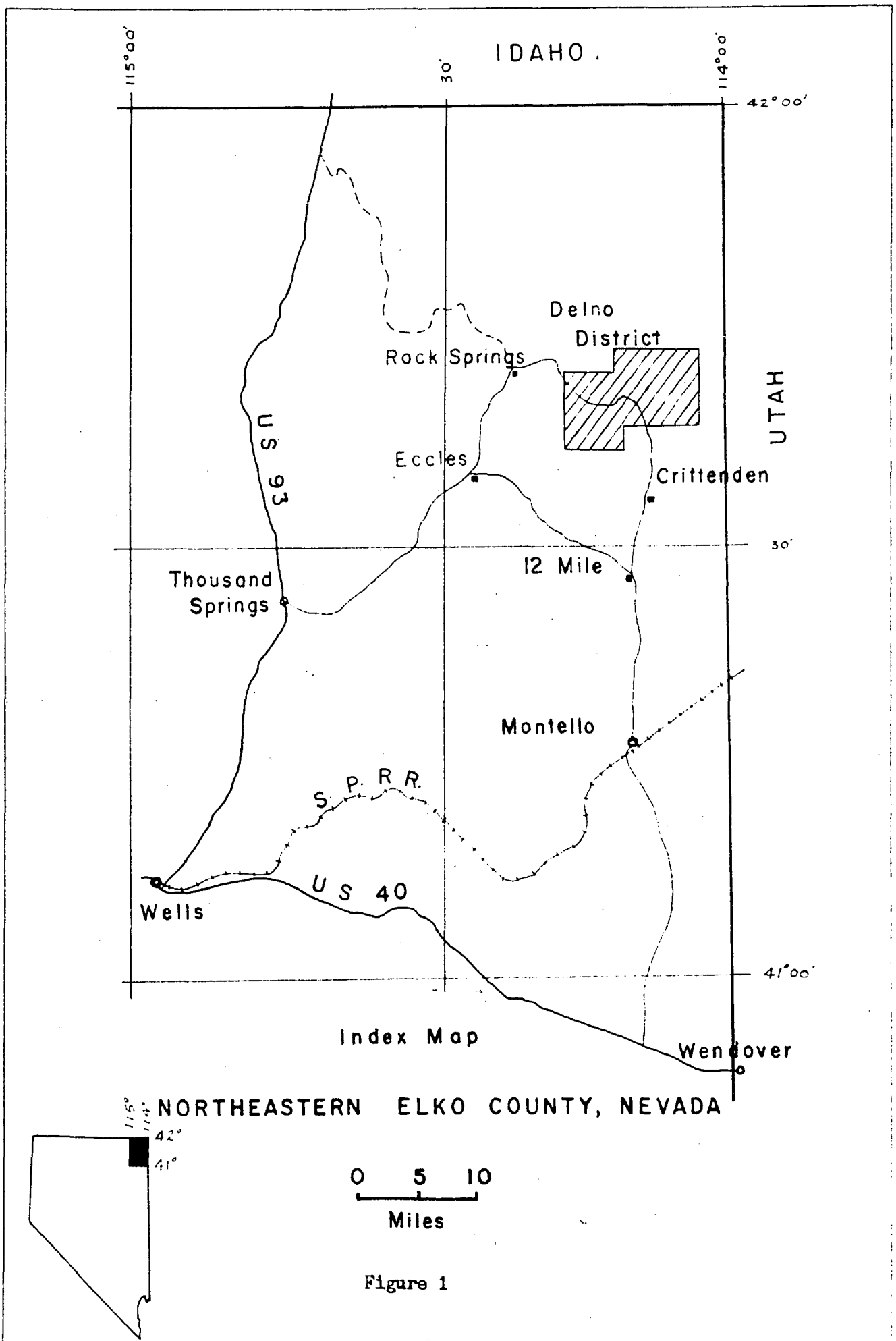

Figure 1

Drawn by D·R·Olsen, 1959

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Physiography and Climate

The Delno district is located at the north margin of the Basin and Range province as defined by Nolan (1943), who draws the province boundary along the Idaho-Nevada border. Goose Creek to the northeast of the district and Trout Creek to the northwest drain northward to the Snake River, while Granite Creek and Mill Creek to the east, Rock Springs Creek to the west, and Thousand Spring Creek to the south all drain into the Great Basin.

The climate of the Delno district is arid. Rainfall is uncommon in the summer months except for occasional thunder showers. Only two springs are found in the Delno district, Mitche's spring and Indian spring. Both are located on fractures within the granite at the south end of the district. There are many springs in the valleys of Granite and Mill Creeks to the east and Rock Spring Creek to the west. Their location has been determined by faulting and fracturing in the sedimentary rocks and the normally non-permeable rhyolite porphyry. (Van Heise, 1948).

Because of the high elevation of the district (6,400 plus), summer temperatures are comfortable. Only occasionally does the temperature attain the high 90's or over. Most night-time temperatures are cool, with frost beginning in September and continuing until late April. Vegetation, which is sparse in the Delno district, except near springs and in gullies on north-facing slopes, consists mainly of sage brush, snow berries, quaking aspen, choke cherries, and perennial grasses. Cedar is common in ghe Granite Creek area.

The Delno Range is one of moderate to sharp relief. The highest part of the range is slightly above 7,800 feet in elevation. The valleys to the east and west vary between 5,000 and 6,000 feet in

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elevation, giving a maximum relief of about 2,800 feet.

The mountains and valleys follow, in general, the northerly trend of the Basin and Range topography, and have apparently been controlled in their location and shape by normal faulting. Within the Delno Mountains the drainage pattern exhibits both structural and stratigraphic control. It is seen to follow both fault lines and contacts between rock units of different resistance to erosion.

The mountains are well drained. Gullies are steep and form a semi-radial pattern around the Delno Range. The major drainage feature of the range is Cotton Thomas Canyon which follows an arcuate path northward approximately parallel to the outcrop pattern of the Paleozoic sediments from a point 2.5 miles southwest of the Delno mine until it reaches the Cotton Thomas fault 1 mile south of the mine. From this point the canyon cuts across the strata and continues in a northwesterly direction through the Delno campsite toward Rock Spring Ranch. School House Canyon drains from the crest of the range south toward Thousand Spring Creek.

All other drainage features are minor and are tributary to one of the above canyons or to Crittenden Valley to the east or Rock Spring Valley to the west.

In the Granite Creek-Mill Creek area the relief is not so high as in the Delno Range, but is much more abrupt. This portion of the subject area is generally low-lying as compared with the Delno Range. However, the slope changes are rapid and very irregular. The major drainage channels are Granite Creek on the west and north sides of the area and Mill Creek on the south and east sides. These are small perennial streams draining generally south, fed by several small springs in the northeast portion of the area. The drainage pattern is primarily dendritic in the porphyry between Granite Creek and Mill

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Figure 2. A view of Cotton Thomas Canyon looking to the southwest

The great lack of outcrops and vegetation in the district may be noted.

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Creek. Apparently considerable fault control is exhibited in the drainage in the northeastern part of the area and some stratigraphic control of drainage accompanies the structural control in the east-central portion. The streams here trend southeasterly along the contact--frequently a fault contact--between sedimentary rocks and intrusive rhyolite porphyry.

Between drainage channels the ridges are sharp and rocky in contrast to the rounded, soil-covered ridges in the Delno Range. The difference in topography seems to be caused by the difference in weathering of the intrusive porphyry of the Granite Creek-Mill Creek area as compared with the sedimentary rocks in the Delno district.

Previous Work

Very little geological and mineralogical work has been done in the Delno district in past years. The Engineering and Mining Journal in 1944 listed some notes on mineral production in the district and a report was compiled by E. W. Newman (1950) which contains a sketchy geologic map of the mine area and plans and cross sections of the Delno and Cleveland mines. Van Heise, et al. (1948) compiled a report for the Water Resources Division of the United States Geological Survey, dealing mainly with ground water resources, but covering in a general way the geology of the Delno Range. The most recent work was done in connection with the Elko County geology and mineral resources report by Granger, et al. (1957). This report covers very briefly the geology and production of the Delno and Cleveland mines.

At the time of the present field work no topographic base map was available covering the district. Aerial photographs were available at a scale of 1:20,000 and mapping was under way by the United States Geological Survey on the Wells, Nevada-Utah-Idaho map at a scale of 1:250,000 and the Contact, Nevada map at a scale of 1:62,500.

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Field Work

The author's interest in the Delno district was aroused by a sample of tin-bearing quartz shown him by S. R. Zimmerley, director of the Kennecott Research Center in Salt Lake City, Utah. The sample had been found near the Cleveland mine in the Delno district and contained 2 percent tin as a yellow, earthy material in quartz. The author visited the district on May 8, 1954 in the company of L. F. Pett and George Robbe to examine the field occurrence of the tin. The brief visit indicated that this tin occurrence was probably different from others reported in the United States and convinced the author of the value of a more detailed study of the district.

For the purposes of mapping the region was divided into two distinct areas; the Delno district and the Granite Creek-Mill Creek area east of the Delno district. The immediate vicinity of the Delno and Cleveland mines was mapped during the summer of 1956. On the basis of the initial field work a genetic relationship between the rhyolite porphyry in the Granite Creek-Mill Creek area and mineralization in the Delno district was suspected. Further field examination in the summer of 1958 gave additional evidence of the association, so mapping of the porphyry was undertaken in 1959. The two areas are presented on a single map to facilitate explanation of the association between intrusion and ore deposition.

Rock types and alteration effects in and around the igneous rocks were determined by means of microscopic study of thin sections and rock and mineral grains and by x-ray diffraction. Ore samples were examined in polished section, and by x-ray, infrared, and chemical methods.

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The author acknowledges his indebtedness to his wife, Lois, who read, criticised and typed the manuscript through its several drafts.

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PRINCIPAL GEOLOGIC FEATURES

The rocks exposed in the Delno district range in age from Mississippian to Quaternary. The upper Paleozoic rocks are represented by more than 2,500 feet of carbonaceous limestone, sandy limestone, quartzite and conglomerate of the Upper Mississippian and Lower Pennsylvanian system, by about 2,350 feet of Lower Pennsylvanian cherty limestone, sandy limestone and sandstone; and by 700 feet of dolomite, and more than 1,800 feet of sandstone, limestone and dolomite of Middle (?) Pennsylvanian age. Rocks of Mesozoic age are not known, with the possible exception that the granite pluton in the southern part of the district and the rhyolite porphyry in the Granite Creek area may be late Cretaceous in age. However, an early Tertiary age is suggested for the granite and the porphyry. Tertiary rocks include also the Oligocene and Miocene-Pliocene Humboldt formation. Quaternary sediments include gravels covering the gentle slopes east of the district, and minor landslide debris within the district.

Folding is minor. One anticline, the axis of which is approximately parallel to the long axis of the granite pluton, occurs in the southern part of the district. Regional dips are to the west. Faulting is complex. A general conjugate pattern of northerly, northwesterly and north-northeasterly faults displaying both normal and reverse movement covers the Delno district and the northeastern part of the Granite Creek area. Normal faults outline the eastern side of the Delno Range. Faulting has been of long duration, probably beginning in late Mesozoic time and continuing to the present. The mineralization is probably of early

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Tertiary age, and is related to the rhyolite porphyry stock (?) in the Granite Creek area.

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SEDIMENTARY ROCKS

General Statement

No detailed work was done in the Delno district prior to the present study. The reports by Newman (1950), Van Heise (1948), and Granger (1957) simply refer to the sediments within the district as Upper Paleozoic. The nearest study of the Paleozoic section was made by Schrader (1912) in the Contact district about 20 miles northwest of the Delno district. Schrader correlates the sediments at Contact with the Carboniferous rocks described by King (1878) about 10 miles south of Contact.

Outcrops are rare and a thin veneer of soil covers most of the district. The rocks of the district are so badly faulted that none of the stratigraphic units can be measured with confidence. The sediments have been altered by intrusion of rhyolite porphyry and granite to the extent that detailed descriptions of their mineral content are only of local significance.

In addition to the Paleozoic sediments, rocks of possible Oligocene age, and of Miocene and Pliocene and perhaps Pleistocene age are found in and around the district. These sediments make up the Humboldt formation. Overlying part of the Humboldt formation is a thin cover of Quaternary alluvium.

Mississippian and Pennsylvanian System

Lithologic units

The Paleozoic sediments may be separated into three units on the basis of lithology: A lower unit of carbonaceous limestone, quartzite,

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sandy limestone and conglomerate; a middle unit of sandy, cherty limestone and sandstone; and an upper unit of dolomite, limestone, and sandstone. The rock types grade into each other throughout each unit. Complete descriptions are lacking except for the middle unit. The reason for this is two-fold: The base of a lower unit is not known because it is truncated by the granite pluton; the top of the upper unit is not found within the district. Faulting offsets the units to the extent that true thicknesses could not be measured for either the lower or the upper units. The one section measured across the middle unit is only approximate.

Stratigraphy of the lower unit

Distribution. The outcrop of the lower unit almost encircles the granite in the southern part of the district (Plate 1). The unit does not not crop out north of the Cotton Thomas fault and is probably covered there by the other units. The maximum width of the outcrop at the south end of the granite is about 4,500 feet. The north end of the outcrop is 1 mile northwest of the granite outcrop. Three small inliers of the lower unit are exposed in the middle unit outcrop about 0.5 mile west of the granite. Toward the east the outcrop varies up to 0.25 mile in width between the granite and Tertiary and Quaternary sediments. The lower unit is not found in the Granite Creek-Mill Creek area.

Lithology. The unit consists of alternating beds of dark blue carbonaceous and sandy limestone and dark gray quartzite with minor conglomerate. The individual beds appear to be from a few inches to a few feet in thickness. Changes in lithology cannot be noted with any assurance because of the scarcity of outcrops, extreme faulting, and alteration changes in the rocks.

The lowest stratigraphic exposures are found at the south end of

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the granite. The unit here is composed of dark gray quartzite and blue sandy limestone with occasional thin beds of shaly limestone. The quartzite and limestone are highly altered, locally becoming unrecognizable.

At the north end of the granite, and higher in the lower unit the sediments are more calcareous and contain much free carbon. Within a few tens of feet of the north end of the granite an outcrop of conglomerate occurs. It is 5 to 8 feet thick, highly silicified and metamorphozed. The individual pebbles have been elongated so they have a length to thickness ratio of about 4:1. The colors of the pebbles indicate a variety of rocks in the original conglomerate, probably mostly limestone and dolomite. All individual characters of the pebbles have been submerged in a general silicification of the rock.

The top of the lower unit is a coarse-grained, thin-bedded, carbonaceous limestone. Under the microscope the rock appears to be highly recrystallized and almost schistose in texture. Free carbon grains are concentrated along thin parallel bands giving the rock in hand specimen a shaly appearence. In cutting the rock with a trim saw the carbon breaks free and forms a black scum on the water in the drip pan. The carbon has evidently been mobilized in the rock. It is quite patchy and may be found concentrated in spots in a given thin section, whereas adjoining areas in the same section are almost free of carbon. Samples containing small white elongate pods about 1 millimeter long were collected from all parts of the outcrop. The pods were identified microscopically as diopside. The diopside crystals are found up to 1 mile from the contact between the lower unit and the granite, and constitute up to 25 percent of the rock in areas close to the granite.

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Contacts. The contact of the granite and the lower unit displays a crosscutting relationship. The lower unit is interrupted by the granite, and its total thickness cannot be determined. It has a stratigraphic thickness of about 2,500 feet exposed above the granite. The contact between the lower and middle units is obscure, but strikes and dips obtained 0.5 mile northwest of the north end of the granite and 1 mile west of the granite suggest an angular unconformity.

Structure section B-B' (Plate 2) shows an angular unconformity between the lower and middle units. As determined from dips along the section the angle between the planes of the two units would be about 30 degrees.

An unconformity has been reported between the Oquirrh and Manning Canyon formations in the Wasatch Mountains by Hintze (1913) and between the Oquirrh and Brazer formations in the Cache Valley region by Williams (1948). However, Gilluly (1932) and Bissell (1959) report that the Oquirrh formation in the Oquirrh Mountains rests conformably on the Manning Canyon formation, and Dott (1955) reports that the Moleen formation is conformable with the underlying Tonka formation in northeastern Nevada. This would indicate that the contact is highly variable in nature from one area to another.

If the formations here are equivalent to the Moleen and Tonka formations (or the Oquirrh and Manning Canyon formations) the implied unconformity in the Delno district may or may not exist on the basis of the previous authors' findings. The discrepancy in dips could easily be explained as the result of crenulations near the base of the middle unit, or as poor attitude determinations in the poorly exposed formations.

In short, although the author believes an unconformity exists between the lower and middle units and shows the contact as such, he recognizes that the information on which the unconformity has been constructed is susceptible of other interpretations.

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In short, although the author believes an unconformity exists between the lower and middle units and shows the contact as such, he recognizes that the information on which the unconformity has been constructed is susceptible of other interpretations.

Age and correlation. There are very few fossils in the lower unit. Most of those present have been made unrecognizable in the general alteration and recrystallization of the unit. The fossils found to date have been provisionally identified by Dr. J. Stewart Williams as Chonetes, sp., Cleiothyridina, sp., and several species of bryozoans of the orders Trepostomata and Cryptostomata.

On the basis of the available fossil evidence, the dark color, shaly appearence, high carbon content, lithologic types present, and its relationship to the overlying units this unit is tentatively correlated with the Manning Canyon shale of Mississippian and Pennsylvanian age as described by Nolan (1935) in the Gold Hill district, and the Tonka formation described by Dott (1954) in Northeastern Nevada.

Stokes describes a positive area in northwestern Utah during the Mississippian and Pennsylvanian, and shows for the Mississippian a large area on the western Utah border from which the rocks have either been removed or were never deposited. Since the Delno district lies so close to the Utah state line it is suggested that if the tentative correlation given here is valid, the uplift shown by Stokes will be narrowed toward the east except for that period marking the end of deposition of the Manning Canyon shale, modifying somewhat the picture of the positive area in northwestern Utah.

Stratigraphy of the middle unit

Distribution. In the southern part of the Delno district the middle unit crops out in a band 0.5 to 1 mile wide to the south and

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Figure 3. Cherty limestone near the base of the middle unit.

The chert is distinctive for the middle unit, but is not found everywhere at the same horizon throughout the district.

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west of the lower unit (Plate 1). The outcrop in the northern part of the district is wedge-shaped against the Cotton Thomas fault. A band of the middle unit about 1/8 mile wide extends north across the northeast front of the range.

The middle unit crops out in the Granite Creek-Mill Creek area as a band about 0.5 mile wide and 3 miles long on the north edge of the rhyolite porphyry. This identification is on the basis of lithology only and may not be valid.

Lithology. The middle unit is composed of thin-bedded, buff-weathering, light gray limestone, cherty limestone, and brown-weathering sandy limestone and sandstone. A section was measured acorss this unit in Cotton Thomas Canyon about 2 miles south of the Delno mine. The results should not be considered completely reliable since two high angle faults of unknown displacement cut the unit across the line of the section. The faults appear, however, to be minor so the section will approximate the thickness and lithologic types of the unit.

Top	Buff, sandy limestone. No fossils . . .	85 feet
	Buff, sandy limestone as above. More sand near top, becoming less sandy downward. Fragments of Syringopora (?) and brachiopods	245 feet
	Sandstone and buff-colored calcareous sandstone. No fossils	95 feet
	Limestone and sandy limestone forming ridges. Thin-bedded, weathering brown in sandy portions. Contains a few pentagonal crinoid columnals. Two high angle faults occur in this part of the section	1,470 feet
	Light blue, silty, cherty limestone. Crenulated, brecciated, soft, easily	
Base	weathered. No fossils	450 feet
Unconformity		
	TOTAL	2,345 feet

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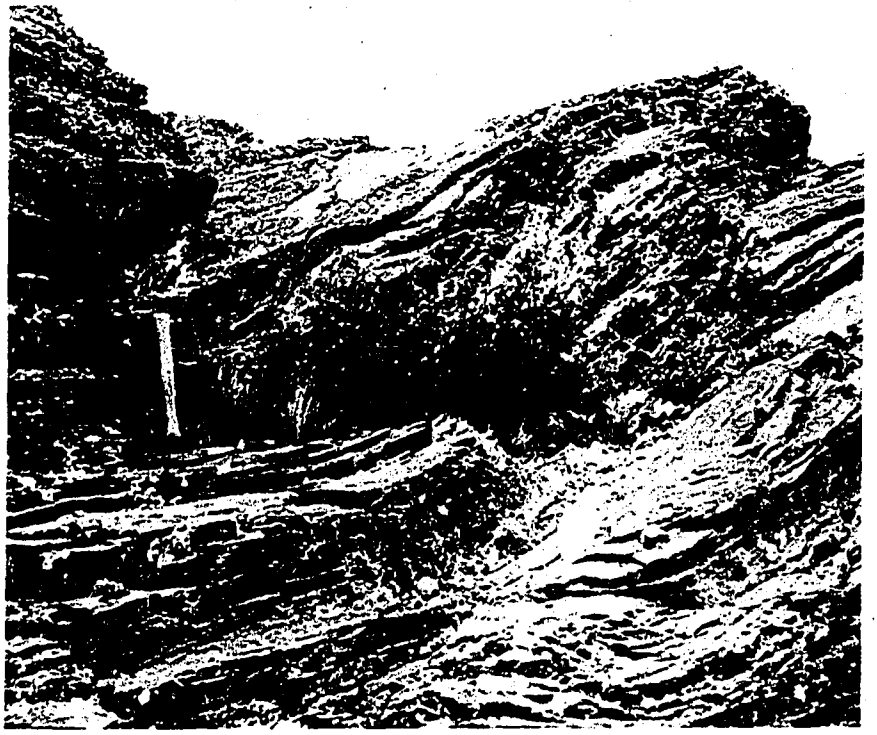

Figure 4. Crenulations in the lower part of the middle unit.

Since the folds are local in effect they were probably formed during diagenesis. The apparent unconformity at the base of this unit may be the result of these crenulations.

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The basal part of the unit, as noted above, contains a cherty zone. The chert occurs as elongated nodules up to 3 inches thick and several feet long. The chert imparts a very distinctive look to the formation where present, but cannot be used as a marker zone since it is not continuous throughout the district. The chert is dark gray on fresh surfaces, but weathers to a drab brown. In some samples the chert grades into the limestone rather than displaying an abrupt contact.

The limestone in the unit is typically broken and thin-bedded, with the beds frequently contorted and undulating. The soft sandstone in the unit is commonly covered with soil. As a result it is difficult to obtain reliable strikes and dips in the unit. One characteristic of the middle unit, especially near the base is its tendency to form small arches and caves. This is perhaps one of the most distinctive features of the unit and serves to identify it wherever the base is exposed.

Thin sections of the middle unit show very finely crystalline limestone with detrital quartz grains up to 0.25 millimeter in diameter. A few scattered pyrite crystals found in the unit have altered to limonite. Quartz and calcite veinlets cut the rock, and a very fine silica replacement of calcite is common throughout the unit. The silicification of the unit shows especially well in samples leached in dilute hydrochloric acid. In the leaching process a spongy mass of silica supporting loose quartz grains is left. The replacement of calcite by silica is apparently no more common in the fossils than in the mass of the rock since few silicified fossils are left in the leaching process.

One zone found on the ridge south of the Gold Note workings contains numerous concretions of calcite and iron oxide formed around shell fragments. The zone contains common bryozoan remains, some of which are partially replaced by quartz. None of the bryozoans were identifiable as to species.

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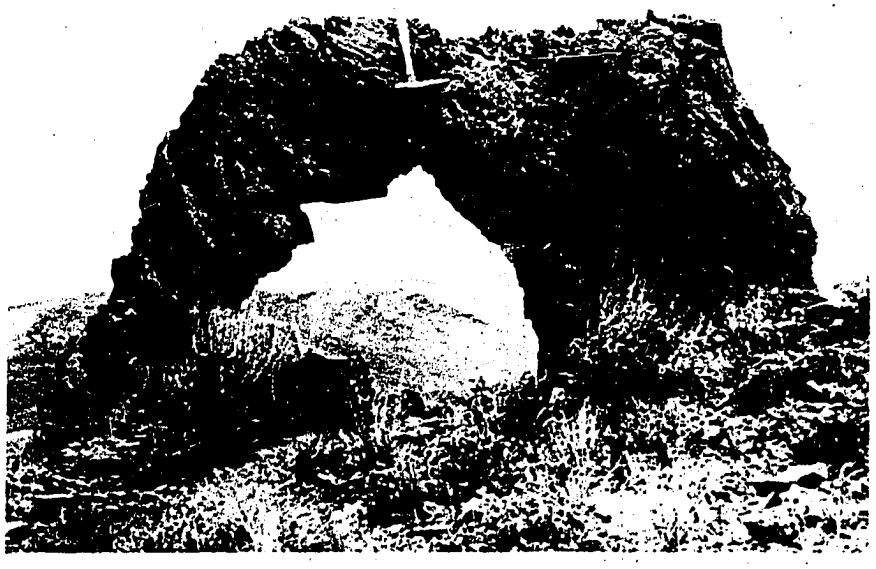

Figure 5. Natural arch in the base of the middle unit.

Arches and caves are distinctive of this part of the sedimentary sequence.

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The middle unit in the Granite Creek-Mill Creek area is for the most part, highly silicified. The effect is especially noted in the west center of sec. 17, T.44 N., R.69 E. where the entire rock is a breccia composed of fine quartz, chalcedony and opal.

Contacts. The contact between the middle unit and the lower unit appears to be an angular unconformity, as previously described. The contact between the middle unit and the upper is exposed on the redge west of Cotton Thomas Canyon. There is no apparent unconformity. It is thought that the middle and upper units represent a period of continuous deposition. The major change going from the middle to the upper unit is a lithologic one. The base of the upper unit is marked by the beginning of dolomite in the section.

Age and correlation. The middle unit is essentially devoid of fossils. The few forms found, namely; bryozoans, *Syringopora* sp., and a few small brachiopods are so badly broken and deformed by recrystallization that they are almost useless as formational guides.

Lithologically the middle unit resembles the lower unit of the western facies of the Oquirrh formation in the Gold Hill area as described by Nolan (1935). The description of the Moleen formation in the Elko region by Dott (1954) resembles the middle unit in the Delno district and seems to indicate a correspondence of the middle unit with the Springeran and Morrowan of the immediate area in the Great Basin. Dott and Nolan indicate that the Springeran and Morrowan of the central Great Basin are devoid of fusulines, and to date no fusulines have been found in the formations of the Delno district.

The middle unit of the Delno district is thus tentatively correlated with the lower unit of the western facies of the Oquirrh formation of lower Pennsylvanian age in the Gold Hill area and the lower part of the

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Moleen formation near Elko.

Stratigraphy of the upper unit

Distribution. The upper unit, which rests conformably on the middle unit, crops out in a broad band across the southern, western, and northern parts of the district. The upper unit probably crops out also in the mass of upper Paleozoic sediments east of the district (Plate 1). The sedimentary rocks found cropping out around the Granite Creek porphyry, with the small exception noted previously, are all correlated with the upper unit in the Delno district. The lateral extent of the unit in this area was not noted since the prime object in examining the area was to determine the relationship between the porphyry and mineralization in the adjacent Delno district.

Lithology. The upper unit has a thickness of about 2,500 feet below the horizon in which the ore occurs in the district. The thickness above the "ore bedding" has not been determined since the top of the formation has not been mapped in the district. Thicknesses measured above the "ore bedding" are unreliable because of soil cover and faulting in the unit.

The upper unit is composed of dolomite, limestone, and sandstone beds and beds gradational from one type to another. The carbonate rocks contain several percent of scattered quartz grains, and are, in addition, silicified. Silica has been added partly as replacement of calcite and dolomite and partly as vein filling. Where sandstone beds have been silicified the rocks are almost quartzitic. The basal 700 feet of the unit is composed of light blue-gray dolomite. Above the light dolomite the slopes are mainly covered. Occasional outcrops of dark gray dolomite, limestone and samdstone are seen. The beds above

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the lower dolomite weather tan to brown in color. Lithologic changes are obscure in the part of the upper unit above the light dolomite because of faulting and soil cover.

In thin section a great variation in grain size is seen. The dolomite beds, especially those lower in the unit are aphanitic in texture. The limestones vary from aphanitic to coarsely crystalline in texture. The difference in grain size seems to be controlled by the degree of recrystallization. The samples showing the greatest degree of recrystallization are those with the largest grain size.

In the Granite Creek-Mill Creek area the upper unit has suffered considerable brecciation and silicification. Areas outlined on Plate 1 are meant to show those areas of complete replacement by silica, having in most instances a high degree of brecciation. The limits of this zone are only approximate as given on the map. There is a tendency for the intense silicification to grade out to a general silica content of only a few percent. There is apparently a universal silicification of the sediments around the porphyry. An attempt has been made to outline only in general those areas where silicification has been complete.

Age and correlation. Fossils are found at three horizons in the upper unit. The lower horizon is in the light gray dolomite about 680 feet above the base of the upper unit. The fossils in the lower horizon consist of numerous small gastropods in a thin bed ranging from 0.5 to 1.5 feet in thickness. Identification of these fossils is not possible because of poor preservation.

In the footwall of the Cleveland ore body several fragments of *Schizoporia* sp. have been found. The state of preservation of these fossils is so poor that identification as to species was not possible. *Schizophoria* ranges in age from Silurian to Permian, and without

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identification of the species may not be used to establish the age of the formation except for these very broad limits. Several tiny star-shaped crinoid columnals have been noted in the rocks, but not identified.

The third fossil horizon is a limestone bed a few feet thick occuring from 5 to 50 feet above the "ore bedding" throughout the district. The upper horizon is distinguished by the extremely abundant crinoid columnals found in it. This fossil zone has been used as a key horizon in locating the "ore bedding" in the district. On the southwest side of the district the upper fossil horizon contains numerous fragments of bryozoans, corals, and brachiopods in addition to the common crinoid columnals. The fossils have been too badly broken for specific identification, but the bryozoans are represented by Trepostomata and Cryptostomata and the brachiopods by Chonetes sp., and Cleiothyridina sp. One partial Dictyoclostus sp. was found. Dictyoclostus occurs from the Mississippian to the Permian.

Fossils found at the head of School House Canyon in sec. 8, T.43 N., R.68 E., provide the best evidence of the age of the upper unit. Two brachiopods collected from a ridge south of the top of Cotton Thomas Canyon and near the head of School House Canyon have been identified, one of them with surity. The horizon where the fossils were collected resembles the crinoid bed near the Delno mine, but is more dolomitic; perhaps the result of different alteration types in the two areas. The unit is composed of highly silicified sandy limestone and dolomite. Numerous brachiopods and brachiopod fragments replaced by quartz are found in a layer 5 to 10 feet thick. The state of preservation of these fossils is better than any others in the district. The brachiopods have been identified as Orthotetes sp., a Mississippian to Permian genera and Composita subtilita of Pennsylvanian age.

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The same fossil horizon is found in sections 25 and 36, T.44 N., R.69 E., on the east edge of the Granite Creek porphyry. It is on this basis supplemented by lithology that the sedimentary rocks around the porphyry are designated as "upper unit". On the basis of lithology and until more firm fossil evidence is available the entire upper unit is provisionally correlated with the upper unit of the western facies of the Oquirrh formation in the Gold Hill area, and the Moleen formation near Elko. Certainly the upper part of the unit as exposed in the area is Pennsylvanian in age. The major difference in the two areas is that dolomite is more abundant and clastic sediments less abundant in the unit in the Delno district than at Gold Hill. Clastic grains are common, however, but generally measure less than 0.25 millimeter in diameter in the carbonate rocks in the Delno district.

Tertiary and Quaternary Sediments

Distribution

For the sake of convenience the Tertiary and Quaternary systems are here treated as a unit.

The Tertiary and Quaternary sediments crop out north and east of the Delno district in a gently sloping alluvial plain, and in a basin about 1.5 miles wide and 3 miles long in the Paleozoic sediments east of the south half of the district. The present positions of gullies in the Tertiary and Quaternary sediments have been established as a result of the older drainage pattern in the mountain range and the initial sloping surface of the younger sediments.

Except for the areas noted above and the thin recent valley fill in some of the more gentle canyons, the only Tertiary and Quaternary sediments in the Delno district are found as a small patch a few rods

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in diameter at the south end of the Delno mine campsite, and an outcrop in a road cut 0.5 mile north of the Delno mine.

A considerable area of tuff, conglomerate, and gravel is found at the south edge of the porphyry in sections 32 and 33 T.44 N., R.69 E., and in sections 2, 3, 4, and 5, T.43 N., R.69 E. The major part of the outcrop in sections 32 and 33 is tuff with minor conglomerate, covered in places with a thin veneer of gravel. The remainder of the outcrop is essentially recent stream gravel. The tuff is found in general in patches on the sides of the present drainage channels, and at elevations above the more recent gravels. The recent gravels are found in the bottoms of the present drainage channels.

Two small patches of fresh water limestone are seen as a capping on the silicified and opalized limestone of the upper unit in Sec. 34, T.44 N., R.69 E., near Little Rock spring. The outcrops are on the southwest side of a small valley connecting Mill Creek and one of its small tributaries. Only two small areas are left of what must have been a rather extensive deposit of the limestone.

Lithology

The tertiary and Quaternary sediments in the Delno district consist of three units, excluding recent sediments. The basal unit is composed of white, thin bedded poorly indurated tuff containing a conformable basalt and perlite flow a few tens of feet in thickness. Neither the base nor the top of this unit are exposed. The dip of the basal unit is about 10 degrees west toward the mountains.

The basal unit is unconformably overlain by a thin white tuff deposit. The tuff is composed of glass shards with minor broken quartz and potash feldspar grains. It is generally well-bedded but

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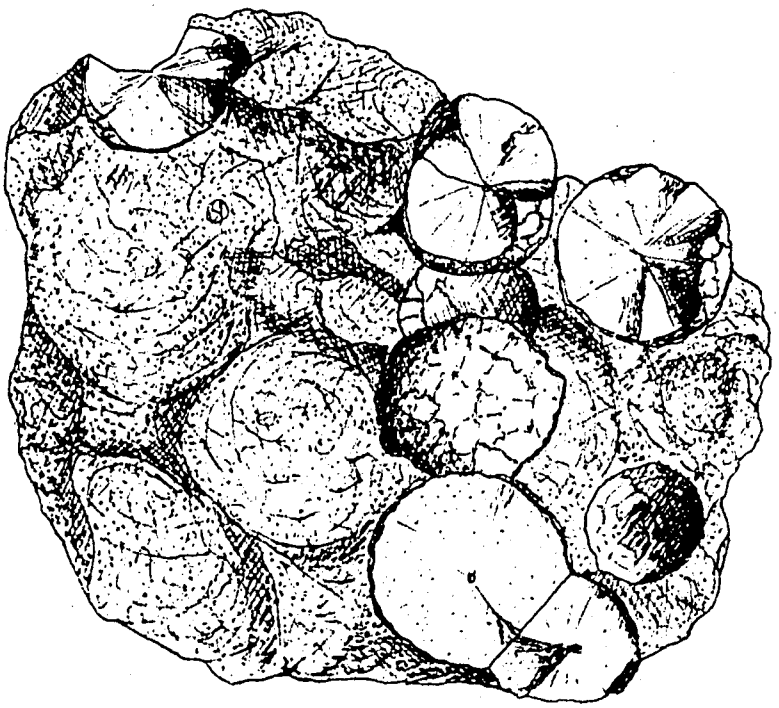

Figure 6. Spherulitic perlite from the Humboldt formation.

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poorly indurated. Individual beds are only a fraction of an inch to a few inches in thickness. This tuff was deposited on an uneven erosion surfact so thicknesses will vary at different localities, but the maximum thickness is probably less than 200 feet. The upper tuff beds are approximately horizontal or dipping slightly to the east, having been disturbed very little since their deposition. The tuff outcrop near the Delno campsite seems to correlate with this unit in both appearance and attitude. It is composed of white tuff similar to that east of the district. The beds in the camp area dip about 5 degrees northwest. The tuff here has been protected from erosion by a covering of landslide debris that had its origin on the slope above the Gold Note mine. The outcrop in the road cut is composed of conglomerate containing Paleozoic limestone and sandstone pebbles in a matrix of volcanic ash. The outcrop is separated from the Paleozoic sediments to the south by a small high angle fault, and laps on the Paleozoic sediments toward the east.

The upper unit of the Tertiary and Quaternary sediments is composed of conglomerate resting conformably on the middle tuff unit. It is made up of Paleozoic limestone, dolomite, and sandstone pebbles. Dips are gentle toward the east. The outcrop of this unit is found north of Sections 26 and 27. Southward the unit has been largely removed by erosion leaving only a thin scattering of gravel on the middle tuff unit. The ghickness of the conglomerate is probably less than 50 feet.

The fresh water limestone on Mill Creek is rather compact, a light creamy gray in color and very fine grained. It breaks with a rough layered fracture. A few poorly preserved fresh water snails have been recognized by J. Stewart Williams (1960) in this unit. One notable

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feature is that the limestone is only slightly displaced by the extensive faulting present in the surrounding rocks, and is thus younger than most of the fault movements.

Age and correlation

On the basis of field relationships and lithology the units are correlated as follows: The upper conglomerate unit appears to correspond with the upper Pliocene or Pleistocene conglomerate and gravels which are described by Van Houten (1956) and Sharp (1939) as the upper member of the Humboldt formation. Below the conglomerate and gravels the tuff member is correlated with Van Houten's vitric tuff of late Miocene to middle Pliocene age. The lower tuff and basalt unit probably represent deposition within the period from Eocene or Oligocene to middle Miocene. Van Houten describes tuff beds and basalt flows in the earlier Cenozoic rocks of eastern Nevada, as does Sharp. The beds vary in age from Eocene to middle Miocene and have been tilted and eroded prior to late Miocene when the overlying tuff was deposited. According to Van Houten the age of the lower unit on the basis of fossil evidence is Oligocene. The principal Cenozoic ash outbursts in the eastern part of Nevada and southern Idaho, according to Van Houten, were in the Oligocene, and waned toward the late Miocene. The basal Cenozoic unit in the Delno area is therefore assigned to the Oligocene or early Miocene.

Middle Pliocene faunas are recovered from the ash beds along Thousand Spring Valley according to Van Houten. The essentially undistrubed beds of the upper part of the younger unit in the Delno area are most likely of similar age. The Tertiary volcanic rocks therefore range from perhaps Oligicene to middle Pliocene. The conglomerate cover is Pliocene or Pleistocene. A thin cover of recent gravels is found in the bottom of the present drainage channels.

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IGNEOUS ROCKS

Extrusive Rocks

Two patches of flow rocks are noted in the Delno and Mill Creek areas. In the Delno area the outcrop, which is located in sections 26 and 36, T.44 N., R.68 E., is composed of basalt and perlite standing as a prominent hill 0.5 mile long above the surrounding tuff of the Humboldt formation. The basalt is conformable within the lower unit of the formation. The entire unit dips gently to the west. In hand specimen the basalt is black and dense, becoming slightly vesicular locally. Interbedded with the basalt is a medium gray perlite of rather limited amount. It contains the very typical perlitic cracks, and numerous spheroids of intergrown cristobalite amd argillized alkali feldspar alkali feldspar up to 1 inch in diameter.

The second area of flow rocks is located in sections 1 and 2 T.43 N., R.69 E. on the extreme southeast edge of the Mill Creek portion of the map (Plate 1). The flow is associated with a small outcrop of Humboldt tuff and may have the same relationship to it as the basalt described above has to the lower Hunboldt unit in sections 26 and 36 between the Delno and Granite Creek areas but appears to be younger. It is quite apparent that both the tuff and the basalt were deposited on an irregular relief surface quite similar to the present topography. The basalt is probably not much more extensive in total outcrop than is shown on the geologic map (Plate 1). In this small outcrop the basalt is seen to lap over all other rock units exposed in

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the area. It is somewhat higher in elevation than the basalt previously described. The elevation difference may be the result of different times of deposition or possibly as the result of late Tertiary or Quaternary movements on faults between the two units. The basalt in the Mill Creek area resembles the previous basalt except that no perlite is found at Mill Creek. It is quite possible that the flow at Mill Creek is younger than Oligocene or early Miocene.

Intrusive Rocks

Granite

Distribution. The granite pluton occurs as an irregular shaped mass 1.5 miles long with a maximum width of 1 mile located mainly in sections 3 and 10 in the southern part of the Delno district. The long axis of the outcrop has a northerly orientation conforming roughly with the axis of an anticline which has developed in the sedimentary rocks. Several small inliers of granite in the lowest sedimentary unit are found on the western and southern sides of the granite. The inliers are similar to the main granite except that sericite and muscovite are developed to a greater extent in the smaller units. The granite shows definite cross-cutting relations with the sediments.

Megascopic characteristics. In hand specimen the granite is dull white to gray in color near the edges of the pluton, darkening slightly to a medium gray toward the center of the body. Individual mineral grains are small and irregular. Quartz, especially, shows these characteristics. Most quartz grains are less than 1 millimeter in diameter and are clear and colorless. The feldspar grains are two or three times larger and are white in color. Dark minerals are

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minor and are composed primarily of biotite. The granite appears relatively higher in muscovite and lower in biotite near the contacts. Toward the center of the outcrop the muscovite rapidly gives way to biotite. The change in type of mica does not seem to be the result of hydrothermal alteration of the granite, but simply shows a distribution change in the original micas formed in the rock.

No aplite dikes or black xenoliths are noted in the granite except very near the south contact where a few small black masses of altered limestone are enclosed in the granite (Figure 8), and near the porphyritic granite mass (Plate 3), where a few small light-colored dikes are located. These changes in the granite are too small to be mapped without gross exaggeration.

The major departures from a uniform nature through the granite are the tactite shown near Indian Spring on the geologic map of the district (Plate 1), the porphyritic granite and granite porphyry (Plate 3) near the southern end of the granite, and a series of quartz masses up to 20 feet in diameter extending for a few hundred feet in a southwesterly direction in the hillside northwest of Mitch's Spring.

Microscopic characteristics. The microscopic texture of the granite near the contact is xenomorphic granular giving way to a hypautomorphic granular texture toward the central part of the outcrop. Near the contact are narrow zones of fine, brecciated quartz and feldspar imparting a local catclastic texture to the granite.

The average mode of the granite is estimated as follows on the basis of microscopic examination:

orthoclase and microcline	55 percent
quartz	20 to 30 percent
oligoclase (An 15 percent)	10 to 20 percent

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biotite and muscovite	1 to 5 percent
sphene, allanite, apatite, zircon, pyrite . . .	trace

Of the potash feldspars, orthoclase makes up about 65 percent and well-twinned microcline about 35 percent. A few percent of the orthoclase is perthitic and contains approximately 10 percent plagioclase as irregular patches. This estimate is based on differential weathering of the perthite. Orthoclase displays a more turbid appearance than the albite does in thin section. It may be that the combination of orthoclase and microcline represents disequilibrium. However the orthoclase identification may have been made on microcline crystals which did not show twinning.

Zoning in the plagioclase is not common, but occasional crystals of plagioclase are zoned, displaying a rim of oligoclase with inner zones becoming more calcic. Albite twinning is common. Carlsbad twinning is less common. Some of the larger plagioclase crystals show both Carlsbad and albite twins. Carlsbad twins are more common well within ghe granite outcrop. The lamellae in the albite twins are thin and distinct, giving extinction angles of from 6 to 8 degrees. These fragments have an index of refraction below 1.54. The index of refraction and extinction angles of the albite twins suggest an An content of about 15 percent. The feldspars are intimately intergrown with quartz grains. In most cases the grain boundaries are sutured. The feldspars may exhibit a poikilitic texture with quartz as the included mineral.

Quartz occurs uniformly through the granite as discrete, highly irregular grains generally less than 1 millimeter in diameter. The grains have sutured boundaries and are ordinarily broken and strained. The quartz ordinarily contains a few small apatite inclusions.

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Sphene, allanite, and pyrite are found as euhedral crystals disseminated sparsely through the granite. Zircon is found in a few scattered grains, mostly in biotite, where it is surrounded by pleochroic halos.

Chlorite occurs as an alteration product of biotite. It has anamalous blue interference colors and has been identified optically as penninite. In the northern part of the granite hornblende is found surrounding the biotite grains, and chlorite is rare.

One striking characteristic of the granite as seen in thin section is the change from a xenomorphic granular texture with a great variety of grain sizes near the contact to a uniform-grained hypautomorphic granular texture toward the center.

The exact nature of the contact between the granite and sediments is not known because of soil cover, but it appears that diopside, which is common in the skarn area surrounding the granite gives way abruptly to micas and feldspars. If the precise nature of this change were known it would probably shed some light on the development of the minerals in the granite. However, soil cover is such that continual observation and sampling from the sediments to the granite is not possible. The apparent sequence of changes is listed in the section on metamorphism but it is far from detailed or complete. Since diopside is no longer present in the rocks showing a high development of the micas and feldspars, especially plagioclase, it is assumed that the latter minerals formed at the expense of the diopside, a change involving removal of calcium and addition of potassium and aluminum.

Porphyritic granite

There is one small elliptical mass of porphyritic granite about 150 feet wide and 300 feet long toward the south end of the granite

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(Plate 3). It has indistinct boundaries and is similar to the main granite in all respects except that it contains abundant orthoclase phenocrysts. The phenocrysts vary up to 3 centimeters along the c crystallographic axis. They are mottled on the surface by small quartz and biotite inclusions.

Granite porphyry

Distribution. At the extreme south edge of the granite, cross-cutting both granite and sediments are two small, irregular granite porphyry dikes. Their size is difficult to determine because of soil cover, but the maximum width is probably 10 to 20 feet and the maximum length is probably less than 150 feet. A similar dike is found cross-cutting the granite-porphyritic granite contact (Plate 3). The porphyry is generally located in the field because it may stand out above the granite outcrop.

Megascopic characteristics. In outcrop the granite porphyry resembles the granite except on close examination. It is light in color, weathering slightly tan. On a fresh break the groundmass is light to medium gray with phenocrysts of white potash feldspar varying from 0.5 centimeter in diameter for the majority of the phenocrysts up to about 3 centimeters.

The rock weathers uniformly. The phenocrysts weather at the same rate as the groundmass, leaving a smooth flat surface exposed across the face of the rock.

Microscopic characteristics. In thin section the phenocrysts are found to be perthitic with an estimated plagioclase content of 30 to 50 percent. Many of the phenocrysts show growth banding. Between the outermost bands considerable muscovite may be found. Grains of

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quartz, orthoclase, microcline and oligoclase, in size between the larger phenocrysts and groundmass, make up about 60 percent of the granite porphyry. The average grain size is about 0.3 centimeter. Oligoclase and microcline are minor, accounting for about 5 or 6 percent of the rock. Quartz and orthoclase in the ratio of about 1:2 form subhedral to anhedral grains which are optically continuous with the quartz and orthoclase in the micropegmatitic groundmass. The groundmass makes up about 30 percent of the rock. Muscovite and sericite constitute 3 to 5 percent of the rock. Muscovite is generally scattered throughout the groundmass. Sericite is common along with clay in the central part of the medium-sized feldspar grains.

Biotite is found as small flakes 0.1 to 0.3 millimeters in length throughout the rock. It makes up 2 percent or less of the rock. About 10 percent of the biotite has altered to chlorite. Sphene, apatite, epidote and magnetite occur in euhedral crystals as accessory minerals in the rock.

It is suggested that the porphyry was injected as a crystal-fluid mush. It solidified and was then hydrothermally altered.

Rhyolite porphyry

Distribution. The main outcrop of the rhyolite porphyry is in the Granite Creek-Mill Creek area (Plate 1). It is roughly oval in shape with the major axis of the oval oriented about N.65° W. The outcrop extends from about 1.75 miles west of Granite Creek to about 1 mile east of Mill Creek, for a total length of 6.25 miles. The southern edge of the main body of porphyry is roughly parallel with a line oriented N.73° W. from the intersection of sections 33 and 34, T.44 N., R.69 E., and sections 3 and 4 T.43 N., R.69 E. The northern edge of the porphyry crops out in a westerly direction along the east-west

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Figure 7. Typical view of the rhyolite porphyry outcrop along Granite Creek.

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center line of T.44 N. The width of the outcrop is thus about 2.5 miles. The total area of the porphyry outcrop is calculated as 15.6 square miles.

The outcrop is very irregular. At its west edge the rhyolite porphyry is covered by Humboldt formation tuff and conglomerate and by quaternary gravel. A few small inliers of porphyry appear as hills in sections 25 and 36, T.44 N., R.68 E. The implication is that the porphyry actually extends west beneath the younger cover. This supposition is supported by the group of opalized porphyry dikes found in the southwest 1/4 of section 35, and by the silicified zone in section 34 about 1 mile southeast of the Cleveland mine.

The porphyry as seen on the south, east, and northeast edges is in contact with the upper unit of the Carboniferous sedimentary rocks. The contact is irregular, controlled to a great extent by faulting. The sedimentary rock is brecciated in large part and highly silicified. The northwest part of the porphyry is in intrusive (?) contact with the middle unit of the Carboniferous rocks. Alteration along this contact does not seem as extensive as it is on the northeastern edge where the contact of the porphyry is with the upper sedimentary unit.

Three large masses of sedimentary rocks are enclosed within the rhyolite porphyry. Extending north through almost the entire igneous mass, in the center of the intrusive rock outcrop, the western of these roof pendants is found. It is only 0.25 miles wide but is about 1.75 miles long. It is completely isolated from any other sedimentary unit and is tentatively called Carboniferous upper unit on the basis of lithology. The contact is apparently an intrusive one, but is poorly exposed so no certain determination of the nature of the contact can be made. The other two major enclosed sedimentary masses are about 1 mile east of the one described above. They are parallel to and controlled in their location by the strong northwesterly faults which

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are so common in the eastern half of the porphyry. The sediments are found in down-dropped fault blocks. The smaller of the two is only 1 mile long and a few hundred yards wide. The large one, however, completely bisects the porphyry on a line about N.20° W. Near its southern end the sedimentary rock wedge is only about 150 feet wide. It attains a maximum width of 0.75 mile near the center of the porphyry and tapers again to the north to a width of about 600 feet. The sedimentary mass splits in section 27 and one small sliver extends southeast in a direction parallel to the main mass. This small offshoot continues for about 1 mile along a fault line in the porphyry before it finally disappears.

Four other small sedimentary bodies are found in the porphyry. All are similar to those described above except for their very limited area, which is generally less than 1,500 square feet. In all cases the sedimentary pendants have been highly silicified. In sections 27 and 34 they have been brecciated as well. As mentioned above and as shown in structure section D-D' (Plate 2) these sedimentary units are apparently found as fault block remnants of roof pendants in the rhyolite porphyry.

North and east of the Barrell Springs fault there are several large outcrops of rhyolite porphyry. The exact contact relationships are difficult to establish since the entire outcrop area is highly silicified and in large part opalized and/or brecciated. Although the area was mapped only as far as the ridge top north of Granite Creek and Mill Creek it is apparent that the outcrop of porphyry continues to the northeast. Several small outcrops have been noted out of the map area both to the northwest and northeast. The narrow neck of rhyolite porphyry shown extending to the northeast in section 24, T.44 N., R.69 E. expands again down the slope to the northeast of the ridge top into

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Figure 8. Contact between rhyolite porphyry and sedimentary rocks.

Rhyolite porphyry (below line) in intrusive (?) contact with overlying brecciated, silicified sedimentary rocks along Mill Creek.

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another large porphyry mass similar to the Granite Creek-Mill Creek porphyry outcrop.

Megascopic characteristics. The main body of rhyolite porphyry has a tan to gray-weathering, slightly violet groundmass in which are enclosed abundant quartz and altered feldspar phenocrysts. Hydrothermal alteration has been of sufficient intensity to alter most of the feldspar phenocrysts to clay, probably kaolin. The rock, as a result of this alteration plus weathering, has become quite friable over most of its outcrop. Cracks which have developed as a result of weathering have become stained with iron oxide.

Near the contacts between the rhyolite porphyry and sedimentary rocks the porphyry becomes bleached in some instances and iron stained in others. As an example: The porphyry outcrop in section 25, T.44 N., R.69 E. is bright red to orange while the porphyry around the opalite outcrop in section 33 is creamy white. In both instances the porphyry is brecciated. This brecciation is noted in numerous places at or near the contact between porphyry and other rocks and is the result of either fracturing during injection of a partly crystallized magma, or of fracturing at the base of a viscous flow.

The quartz phenocrysts vary in size from a fraction of a millimeter to about 3 millimeters in diameter. Feldspar phenocrysts or rather relict feldspar phenocrysts are found in most of the porphyry. These vary up to 5 millimeters in diameter.

The most striking changes in the porphyry occur near the opalite zones in sections 22, 23, 24, 31, and 33, T.44 N., R.69 E. The porphyry changes gradually to a pearly white color (or, in the case of the outcrop in section 24, to a bright red, because of the high iron content) as the opalite zone is approached. The rock becomes vitreous-looking and

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changes over to white opalite with quartz phenocrysts.

From the contact zones toward the interior of the intrusive mass the porphyry becomes less broken and crushed, and the feldspar phenocrysts are less altered. Fracturing is still noted in both the feldspar and quartz phenocrysts, but the individual crystals have not been entirely broken and disrupted as they have nearer the contact. Jointing in the porphyry appears to be parallel to and dipping toward the contact between porphyry and sedimentary rocks.

Microscopic characteristics. In thin section the fresh rhyolite porphyry is seen to carry about 30 to 35 percent phenocrysts. Precise mineral ratios are difficult to establish because the fragmented crystals tend to pull out of the thin section during the grinding process. However, the ratio between quartz, orthoclase, and plagioclase seems to be about 1:2:1. The quartz phenocrysts are slightly embayed and rounded, while the feldspar phenocrysts exhibit sharp outlines and fine euhedral development.

Twinning is common in both feldspar types. Carlsbad twins are noted in both orthoclase and plagioclase. Albite twinning is common in the plagioclase crystals. An extinction angle of 12 degrees and an index above 1.54 indicate that the plagioclase has a composition near Ab 70, An 30.

Surrounding the phenocrysts is an irregular halo of very fine hematite (?) and clay. Commonly the amount of hematite decreases in the areas midway between phenocrysts and increases nearer the phenocryst. The hematite is normally extremely fine, with individual particles measuring much less than 0.01 millimeter in diameter. However, much of the iron oxide occurs as rudely branching feathery groups roughly oriented along flow (?) lines in the porphyry. The only other dark

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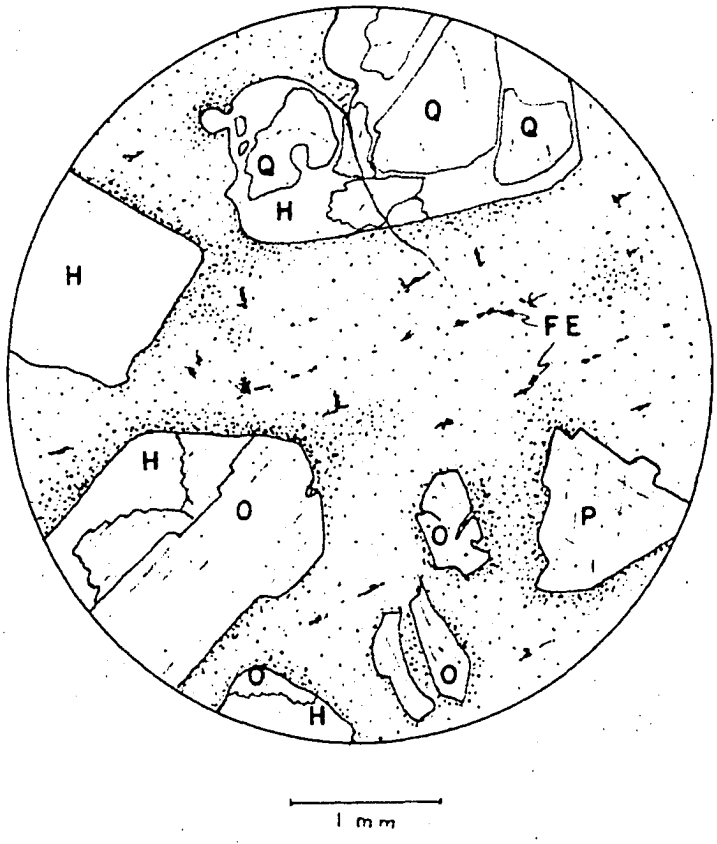

Figure 9. Thin section of rhyolite porphyry from Granite Creek.

Orthoclase (O), quartz (Q), and plagioclase (P) phenocrysts enclosed in argillized quartz and feldspar groundmass. The degree of argillation is shown by the density of stippling. Iron oxide (FE) plumes and specks (size exaggerated) are formed in roughly parallel lines in the groundmass. Holes (H) occur in the section where phenocrysts have broken out. Nicols uncrossed. Camera lucida drawing. 20X.

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mineral present is found as a very few small, highly corroded crystals of augite (?).

The groundmass consists of a mass of irregularly oriented crystals of quartz and feldspar from about 0.01 to 0.1 millimeter in diameter. The feldspar crystals, mainly orthoclase, are commonly enclosed in larger masses of quartz crystals. The groundmass has an overall turbid appearance because of clay developed from alteration of the feldspar. The fine iron oxide scattered throughout adds to this murky appearance and imparts a slight pinkish brown cast to the rock in thin section.

Throughout much of the porphyry body there has been considerable opal and chalcedony added to the rock, filling vugs and cracks. In more highly opalized areas near the intrusive contact the original feldspars are entirely replaced by an open network of opal and quartz veinlets. The cleavage planes of the feldspar have been preserved in the opal and quartz. This and the crystal outline are the only indication of the original nature of the phenocrysts.

Near the contact in several localities, especially at the northeastern contact the rock appears to have been mashed. Larger quartz crystals are badly broken and are surrounded by a growth of smaller quartz crystals as a narrow band. The groundmass consists of fine quartz and clay commonly stained with iron oxide. Several quartz phenocrysts present a rough zonal structure, giving the appearence of a second period of growth associated with the alteration of the rock.

Material which closely resembles the tin-bearing mineral found in the Delno district and in the sedimentary rocks about the contact area is found in thin sections of porphyry near the northern contact of the porphyry and sedimentary rocks. No analysis has been made of these rocks to date to demonstrate the validity of the identification.

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Basalt

A small basalt dike occurs in the Patsy fissure north of the Cleveland mine in section 28. The basalt is found only in the shallow workings in the north central part of the Cleveland #1 claim (Plate 4).

The basalt is thoroughly altered. Magnetite accounts for about 1 percent of the rock, calcite about 5 to 10 percent, quartz about 5 percent, and talc 2 percent. The remainder is clay and sericite. The original texture was apparently intergranular. The shape and position of the original feldspars is preserved in the clay and sericite which have replaced them. The dark minerals have altered to talc and iron oxide. The mere presence of calcite and quartz as well as their distribution in irregular patches and veins suggests a hydrothermal origin for these two minerals.

Although tin is found in the Patsy fissure, none is found in the basalt in the fissure, suggesting that the basalt is post-mineral in age, probably associated in time with the basalt flow in the Tertiary rocks east of the district.

Origin of the Igneous Rock

Larsen and Schmidt (1958) list six ways which granites are considered to form. These involve a primordial granitic crust, recrystallization with little chemical change, replacement with considerable chemical change, reaction of magma with wall rock, melting of a portion of the crust, and injection of a magma from depth. Of these, replacement with considerable chemical change seems to fit the Delno granite best.

A genetic classification of granites is suggested by Tuttle and Bowen (1958) which is based on the role of plagioclase in the rock as determined from phase studies of silicate melts. They divide granites

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Figure 10. Granite near the south end of the granite outcrop.

The granite (light) encloses dark irregular fragments of altered sediments.

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into two major groups, the hypersolvus granites, in which there is no plagioclase present except in perthite, and subsolvus granites, which contain plagioclase as free grains. The subsolvus granites are further divided on the basis of the plagioclase content of the perthite. If the perthite contains more than 30 percent Ab the granite may be considered magmatic in origin because it must have crystallized above 550 degrees centigrade at which temperature the plus 30 percent Ab perthite is stable. From 30 to 15 percent Ab is a transition zone. If the perthite contains less than 15 percent Ab the unmixing of the feldspars took place at a temperature below 300 degrees centigrade. In this instance the granite could have been formed either by recrystallization of a granite formed at higher temperatures or by metamorphism.

According to the above scheme, the granite porphyry dikes, which contain perthite with 30 to 50 percent Ab, must be of magmatic origin. This is borne out, of course, by the aphanitic groundmass of the dikes. The granite, on the other hand, with perthite containing 10 percent Ab could be either magmatic or metamorphic. Additional characteristics of the granite are useful in choosing which of the origins is most probable. Tuttle and Bowen suggest that biotite mica found without associated muscovite in a granite is suggestive of a magmatic origin. The Delno granite contains both biotite and muscovite thus suggesting a replacement origin. They also suggest that magmatic granites may contain soda pyroxene and amphibole. These minerals are not present in the Delno granite. As is shown on the geologic maps (Plate 1 and Plate 3) the granite shows cross-cutting relationships with the sediments, especially the lowest unit, without disturbing the beds. Alteration of the enclosing sediments is intense, and gradational contacts are noted. There is no brecciation or crushing at the contacts. In view of these factors the granite is considered metamorphic in origin. The granite porphyry in

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association with the granite suggests that the alteration may have been initiated by a deeper magma.

The rhyolite porphyry seems to be of intrusive origin. The sediments surrounding the porphyry were arched in a rough domal shape as evidenced by dips radially outward from the contact. Flow structures in the form of joints are in evidence throughout much of the mass. The joints appear oriented roughly parallel to the contact between porphyry and sedimentary rocks.

The most conclusive evidence of the intrusive nature of this rock is the relationship of the sediments to the igneous rock immediately around the periphery and especially in the roof pendants shown in structure section D-D' (Plate 2). These masses of brecciated, silicified sedimentary rocks are apparently in place on top of the invading porphyry mass. The contact may be followed on the northwest and southeast sides of the pendants. The other parts of the pendants are in fault contact with porphyry. The peripheral areas may or may not exhibit brecciation, but are, in practically every outcrop noted, intensely silicified. Here again it appears that the porphyry is intrusive. The opalized porphyry dikes, and the silicified brecciated zones near the Cotton Thomas fault lead us to the conclusion that the porphyry is not only intrusive into the Granite Creek-Mill Creek area, tut may underlie some of the northern part of the Delno district.

The author recognizes that the criteria for intrusion given above may also be interpreted to describe a flow rock surrounding resistant hills of sedimentary rock. However, such an interpretation would involve a number of assumptions that do not seem warranted concerning the topography on which the flow was deposited. The topography would have been extremely irregular, much more so than is indicated at present. This same topography would now be emerging from the covering and would

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be exposed only at the higher points. The present topography indicates that this is not the case. As an example: One narrow, high hill resembling a volcanic neck in outward appearance is located along Mill Creek in the northwest corner of section 3. At its top this hill has a small amount of brecciated and silicified limestone. The remainder of the hill, down the sides and around the base is all rhyolite porphyry. The most simple explanation is that the porphyry is intrusive into the sedimentary rocks. Other features such as brecciation and opalization of both units, and the great vertical extent of the mineralization associated with the porphyry seem to bear out the intrusive nature of the rock. The author prefers this interpretation to one in which the porphyry is a flow.

Age of the Igneous Rocks

In the Delno district the granite was probably emplaced after the folding of the Paleozoic sediments but before major elevation of the mountains was accomplished. Dating of the folding is a problem, since no Jurassic or Cretaceous rocks are found in the region. Triassic sediments are described by Clark (1957) near the Crittenden Ranch, a few miles to the southeast, but are absent in the Delno district. Permian sediments are shown probably conformable on the Pennsylvanian by Van Heise, et al. (1948) west of the Delno district. The area was thus one of deposition through the upper Paleozoic and Triassic. Folding and uplift of the area must have begun in the Jurassic or Cretaceous. If the intrusion post-dates folding of the sediments and pre-dates normal faulting which outlined and elevated the range (in a later section this is described as occurring in the early Cenozoic, probably late Eocene or early Oligocene) it must be Cretaceous or

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Eocene in age. This is in agreement with York (1944) who suggests an Eocene age for the eastern Nevada intrusives, and with Gottfried (1957) who dates the intrusives of central Nevada as early Tertiary on the basis of lead-alpha determinations.

The granite porphyry crosscuts both sediments and granite so is somewhat younger than the granite. Probably both granite and granite porphyry are the result of the same general chain of events and should be considered as essentially contemporaneous, the porphyry lagging behind the granite slightly. Emmons (1910) states that the porphyries in northeastern Nevada formed at the same general time as the granites they accompany. According to Gottfried, to York, and to Willden (1958) this would make them of an early Tertiary age. That the granite is at least in part pre-faulting is shown on structure section C-C' (Plate 2) where the granite is seen displaced by a reverse fault.

The problem of dating the rhyolite porphyry is essentially one of dating the normal faulting of the area. The rhyolite was intruded (?) prior to the elevation of the mountain block but after the development of the fault pattern and after some movement in the Paleozoic rocks. As shown later this would be between early Eocene and middle Miocene. The attitude of the opalized porphyry dikes in the valley between the Delno and Granite Creek areas suggests that they were intruded along some of the common northwesterly faults in the area, and therefore post-date formation of the fault pattern. Examination of the basal Tertiary rocks of the district shows a depositional contact between them and the rhyolite porphyry. Since the basal Tertiary unit is thought to be Oligocene in age the porphyry should be Middle to Upper Eocene in age, or very close to the age of the granite.

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CONTACT METAMORPHISM AND ALTERATION

Tactite

Two small tactite areas have developed in the southern part of the district. One is located in the sediments on the central west edge of the granite in the shaly limestone of the lower sedimentary unit. It is elliptical in shape and only a few tens of feet long. The second tactite is found within the granite near the sediment contact northeast of Indian Springs. It is smaller than the west tactite. Both tactite areas are mottled brown, green, and white in color, commonly with brown predominating. In thin section the tactites show a mixture of garnet, diopside, quartz, and sphene, in that order of abundance. Numerous actinolite crystals are found scattered through the quartz and surrounding the diopside. It appears to have replaced the diopside. The quartz contains numerous liquid inclusions and a few small apatite crystals. Scheelite has been reported in the tactites by the local miners, and a few small grains were found in a thin section of a quartz veinlet in the limestone near the tactite.

The texture varies considerably through the tactite. Most commonly the garnet shows the best crystal development. Diopside shows euhedral to subhedral crystals, as does sphene. Actinolite forms some perfect small crystals in the quartz, but is anhedral where it is in contact with and replacing diopside. Quartz in the tactite is completely anhedral.

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Skarn

Little remains of the original character of the lower sedimentary unit. Evidently it was originally a shaly, highly carbonaceous locally sandy limestone containing quartzite and conglomerate beds. Alteration has been intense immediately around the granite pluton and several zones of skarn have developed. These are shown on the geologic maps (Plate 1 and Plate 3). The most prominent skarn zone is at the southwest end of the granite where a silicated qone about 0.25 mile in width has developed. Within this zone and the other skarn zones shown on the maps there has been a marked development of diopside, wollastonite, and orthoclase. In parts of the southwest skarn zone the alteration is so intense that the sediments are not mappable separate from the granite. The detailed map of the south end of the granite (Plate 3) shows this area as one of "mixed rocks" containing both granite and altered sediments. The zones of greatest alteration are at the two ends of the granite and are aligned on the axis of an anticlinal fold in the sediments.

Away from the skarn zones the alteration effects are seen in recrystallization of the limestone, minor scattered diopside grains, and development of a schistose appearance in the carbonaceous portions of the rock.

A thin section of a quartzite unit near the west tactite shows about 20 percent diopside, 2 percent calcite as cement, abundant fine carbon surrounding the quartz grains, minor sphene, and considerable penninite as an alteration of diopside. The bulk of the rock, about 75 percent, is composed of fine equigranular quartz. The alteration of the quartzite is ordinarily seen in hand specimen as bleaching in the dark gray quartzite.

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Figure 11. Bleached quartzite from the south end of the Delno district.

These rocks occur in the skarn zone in the lower unit near its contact with the granite. The light streaks have a high diopside content. The darker streaks are composed of altered to unaltered quartzite. The darker shades indicate areas of less intense alteration.

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Changes noted in the sediments as the granite contact is approached are approximately as follows:

1. Quartzite and limestone are slightly silicated. The major change involves development of diopside and wollastonite.
2. Silicates increase until the sediments, especially the quartzite, are bleached.
3. Orthoclase crystals develop and diopside decreases. quartz is recrystallized.
4. Muscovite developes.
5. Quartz appears in larger grains.
6. Biotite and oligoclase develop.

Soil cover conceals most of the contact area. Because of this the above changes are probably not complete. The changes may take place over a distance of a few feet, but are common over most of the lower unit. Diopside crystals are found as much as 1 mile from the granite.

Oligoclase, garnet, epidote, and perthite occur with quartz and calcite veinlets at the southeast granite contact. The rock on the sediment side of the veinlets resembles a quartz, diopside, calcite schist. On the granite side of the veinlets is a mixture of muscovite granite and micropegmatite.

Silicification

South of the Cotton Thomas fault, as noted previously, there is some chloritization of the diopside and biotite. A small amount of actinolite is found with the diopside in the tactite. Small spots of clay are found in the sediments and in the feldspars of the granite

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near the contact with sediments. Sericite is found in a few specimens, but seems minor overall. The most important hydrothermal effect is silicification of the sediments. This appears to be rather minor south of the Cotton Thomas fault compared with the silication changes, locally making up as much as 50 percent but ordinarily only about 2 or 3 percent of the volume of the rock.

The alteration of the middle and upper units is very different from that in the lower unit. In the southern half of the district the alteration of the upper units consists mainly of weak silicification, and even this is absent over the greater part of the two units. North of the Cotton Thomas fault, however, silicification becomes more intense and is noticeable over much of the northern part of the district. Three small patches of the middle unit located just north of the Cotton Thomas fault in the eastern part of the district show extreme brecciation and silicification. The limestone in these three localities was fractured, then replaced by fine-grained quartz, and the interstices were filled with gray to white opal, tridymite fans and chalcedony veinlets. The rock closely resembles samples recovered at the limestone contact of the intrusive rhyolite porphyry about 4 miles east of the district. On this basis, and since outcrops of the porphyry dikes are seen just 1 mile to the east of the district it is suggested that the rhyolite may account for the silicification in the sedimentary rock units.

In the upper two units the silicification varies in intensity from traces to 100 percent and seems to be controlled by position with respect to the Cotton Thomas fault, and by the individual host rock. North of the Cotton Thomas fault silicification is more intense than to the south. Both dolomite and limestone beds are susceptible, but less

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so when pure than when mixed. Brecciated zones are still more susceptible. The silicification may take the form of silica cement in the sediments, of fine quartz replacing the carbonates, or massive jasper beds.

Silicification in the Delno area is apparently identical to that around the porphyry pluton in the Granite Creek area. The sedimentary units closely associated with the porphyry are in most instances almost completely silicified. In those samples of silicified sediments that are brecciated, the silicification is plainly post-brecciation in occurrence. The breccia fragments are altered in such a way that progressive bands of silicification are seen in individual fragments.

Both the middle and upper units are in contact with the porphyry. The middle unit, however, does not seem quite so intensely silicified as the upper unit. The silicification varies in intensity within each unit. Those areas in which the sedimentary rocks are essentially completely replaced by silica are shown on Plate 1. The contacts shown are only approximate and are intended only to indicate general areas of intense silicification.

In thin section the silicified sedimentary rocks are seen to be composed of quartz crystals varying in size from less than 0.002 millemeter to 0.05 millimeter in diameter. The tiny crystals are commonly oriented in rough planes corresponding to bedding in the original rock. Occasional larger quartz crystals are found, but these are not quantitatively important. Calcite and quartz veinlets cut through the rock in an apparently random fashion. Associated with the quartz veins, and disseminated through the silicified rock are tiny yellow grains of material similar to the tin mineral in the Cleveland tin vein. The fine yellow material is roughly arranged in disconnected

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stringers which lie parallel to the bedding. Only one tin analysis was performed on the silicified material in the Granite Creek area. This sample contained 0.1 percent tin. The sample, taken from the silicified outcrop north of the Barrell Spring fault, indicates a similarity between the mineralization of the Delno district and the Granite Creek-Mill Creek area, suggesting again that the porphyry is the cause of mineralization in both cases.

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STRUCTURAL GEOLOGY

Folds

In the northern part of the Delno district the structure is essentially homoclinal. In the immediate vicinity of the mines many local variations in attitude detract from the regional strike of about N. 5° W. and the westward dip of 15 to 50 degrees. The attitude of the sediments in the west half of the southern part of the district is essentially the same as in the northern part of the district. Dips average about 27 degrees to the west and the strike is about N. 5° W.

As previously noted, many small crenulations appear near the base of the middle unit of the upper Paleozoic sediments. These crenulations seem to be characteristic of that particular unit, probably the result of diagenetic processes, and not related to general regional deformation. Only two folds are found in the district which may be considered the result of regional deformation. The larger of these folds is an anticline whose axis is located approximately along the west edge of the granite pluton. The axis trends N. 10° to 15° E. and plunges from the granite to the northeast and southwest. The second fold, which is on and parallel to the west flank of the larger anticline, is a small overturned and thrust faulted anticline. The overturn and thrusting, which displaced the rock only a few feet, are to the east. North-south alignment of the folds and eastward movement on the thrust fault suggest compression in an east-west direction. The absence of radial and concentric features also indicate compression

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rather than vertical forces as the cause of folding.

The sedimentation record indicates there was no major deformation from Lower Pennsylvanian into the Triassic. The uplift and folding recorded here therefore represent either the Nevadan or the Laramide orogeny. Since no evidence is available in the Delno area on which to separate the two, we may only say that the folding took place in the Jurassic or Cretaceous.

In the Granite Creek-Mill Creek area the sedimentary rocks dip radially outward from the porphyry contact. Dips vary between 12 and 90 degrees. Along the south side of the porphyry in section 33 the dips change from 90 to 17 degrees going outward into the sedimentary rocks from the porphyry contact. This steepening of dips next to the intrusive and the dips radially outward from the intrusive suggest that the invading magma arched the sedimentary rocks. No other large folds are noted in the area.

Faults

Relation to topography

The mountains of the Delno district are formed by a series of fault blocks with the general dip of the faults toward the east. The east side of the range is the scarp of a north-striking normal fault which dips from 47 to 76 degrees east. Limited topographic control is exhibited by faults within the range. The Cotton Thomas fault may be traced by a series of low spots aligned on the ridges crossed by the fault. The low pass at the head of Cotton Thomas Canyon is apparently the result of a series of closely spaced northwesterly reverse faults. School House Canyon is controlled in its position by faulting. Finally, a fault scarp displaying sliken-sides is found in the canyon 0.5 mile

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Figure 12. A fault in the east side of Cotton Thomas Canyon.

The picture shows how faults may be recognized in the soils as a result of weathering processes.

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northeast of the Delno mine, suggesting structural control of that canyon.

In the vicinity of Mill Creek the major drainage patterns are almost normal to the fault pattern. However, between the faults or along the down-dropped blocks of the faults there has been a series of low passes formed connecting the drainages. The entire series of northwesterly valleys in the Mill Creek area is the result of normal faulting.

Most of the faults are poorly shown in the field. In mapping the district the faults were first found on aerial photographs and then field checked. The faults generally show as a dark line in the soil indicating an increase in soil moisture or a change in vegatation. Erosion has frequently been more rapid along faults, resulting in slight depressions. Abrupt changes in lithology along the strike of the strata also indicate faults in the district.

Kinds of faults

The majority of the faults in the Delno district are steep normal faults with a stratigraphic displacement of less than 60 feet. Dips are generally to the north and east and vary from 36 degrees to vertical, averaging about 70 degrees. Several of the normal faults have displacements considerably in excess of the above figure. For example: If we project the "ore bedding" at the Delno mine to intersect the Bracken fault between the Cleveland and Delno mines, a stratigraphic displacement of 1,200 to 1,300 feet is indicated for the fault. There is, however, another fault of unknown displacement between the Delno mine and the Bracken fault. In addition ore has been reported by Ala (1956) at a depth of 125 feet in a well drilled in the Delno campsite, and by

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Newman (1950) at the crest of the ridge just west of the Bracken fault. If this is the "ore bedding" of the Cleveland mine the stratigraphic displacement of the Bracken fault is 450 feet. The author does not recognize the "ore bedding" west of the Bracken fault and believes the displacement must be closer to the maximum value noted above (Structure A-A', Plate 2). The "ore" reported by Ala and Newman is probably the "tin bedding" recognized southeast of the Cleveland mine.

Movement on the Cotton Thomas fault must be in the order of several hundred feet. A stratigraphic displacement perhaps half as great as the thickness of the middle sedimentary unit, or 1,200 feet is indicated.

In the southern part of the Delno district are two strong northwesterly trending reverse faults, or fault zones. The reverse faults may be traced on the geologic map through sections 5, 6, 8, and 9 west of the granite, going at length into the major fault near the bottom of School House Canyon. Calculated stratigraphic displacement on the southern of the two reverse faults is about 1,100 feet. As this fault is traced toward School House Canyon the displacement increases to about 1,500 feet. The northern reverse fault probably has close to 800 feet displacement (Structure B-B', Plate 2). Occasional reverse faults of 10 to 50 feet offset are met in the mine workings. The pattern of the reverse faults is apparently the same as that of the normal faults, suggesting that the pattern was established in common for both, and subsequent movement has determined which shall be normal and which reverse. The fault which outlines the east edge of the Delno Range has experienced movement of the order of several thousand feet.

Structure sections A-A', B-B', and C-C' (Plate 2) show a series of steep east-dipping faults on which movement has been down on the eastern side of the faults toward the east side of the range and down

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on the western side of the fault toward the west side of the range. The faults on the west now appear as reverse faults and those on the east appear as normal faults because of westward tilting of the mountain block during Tertiary time after a great part of the movement on the faults was accomplished (Figure 13).

The original shears would have been close to vertical in attitude if formed with the major and minor axes of the stress ellipsoid in a horizontal plane. Tilting of the area would then give some of the former vertical faults apparent reverse movement and some apparent normal movement. Certainly the latest movement on the faults, where noted, has been normal.

At least one of the major faults in the area, the Cotton Thomas fault, shows evidence both normal and reverse movement in its history. Drag on the north side of the fault is downward, indicating that the north side went up. It is plain that the present displacement of the north side is downward. Thus, both normal and reverse movement are shown. Probably other faults of the region would show the same if they were well enough exposed for detailed study.

Because the relationships are constant between adjacent fault blocks along their entire length throughout the mountain mass it is not probable that the uplift of the range was caused by vertical uplift by intrusion of the granite. Subsidence of the sides of the range could have had the same effect; as could compression. Intrusion should have had a more local effect; one which changed outward from the intrusion and along the strike of the older (?) faults. This is not noted in the district. It is felt that the granite is in place as a permissive type intrusion, formed along the axis of the existing uplift and has had no effect in uplift of the range. The fold which seems to

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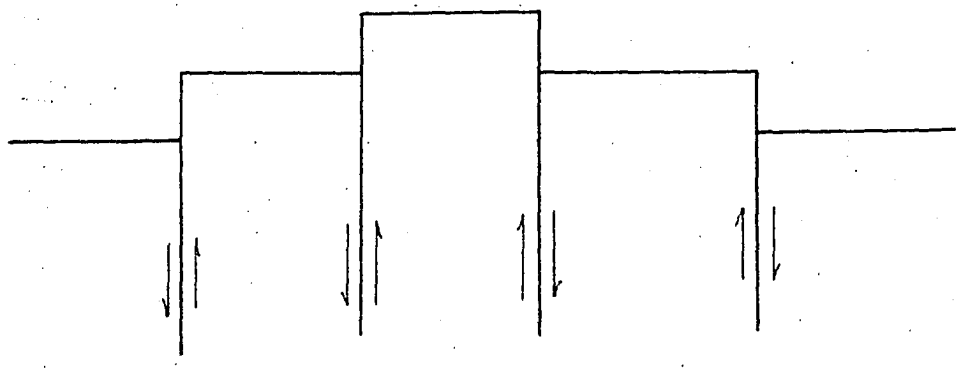
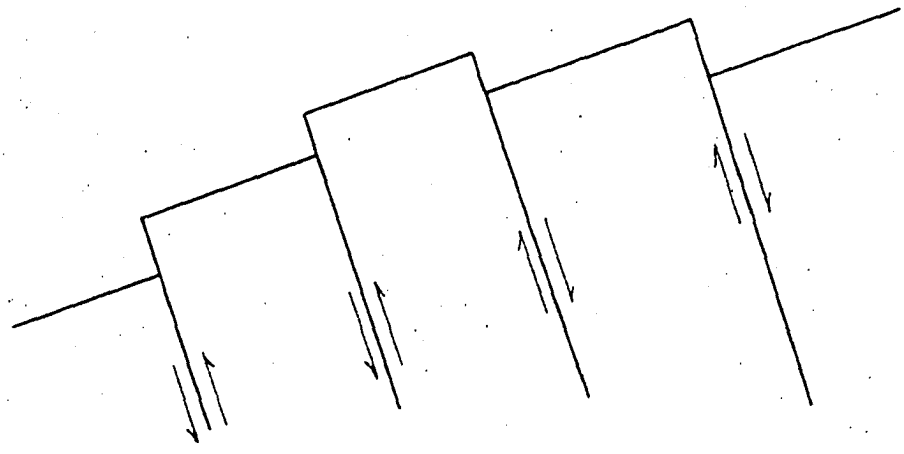


A. A series of vertical faults caused by uplift at the center or by subsidence of the sides.



B. The block above is tilted with the result that the two faults on the left appear as reverse faults and the two faults on the right appear as normal faults.

Figure 13. Possible development of reverse faults by rotation of the mountain block.

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control the position of the granite is formed across previously existing structures as a result of Laramide compression, and fracturing in the crest of the fold seems to be the factor controlling the location of the granite.

The faults of the Granite Creek-Mill Creek area are shown in structure sections D-D' and E-E' (Plate 2) as mainly vertical. In many instances there is no way of really knowing what the dip of the fault is. Since most of them are not deflected by topographic changes they are probably very steep. These faults have displacement of the order of 1,500 feet in sections 27 and 34. In the northeastern part of the map area it appears that the last two or three faults could have experienced some right lateral movement as well as a vertical component. The vertical component has been small, perhaps a maximum of 200 or 300 feet, and in some cases is reverse as shown by the fault in sections 22 and 26.

The Barrell Spring fault along the northern edge of the Granite Creek area terminates most of the faults of the area. No information is available concerning the continuation of these faults north of the Barrell Spring fault. This fault places the upper Carboniferous unit on the north in contact with the middle unit on the south of the fault. It is not known how great the displacement is along the fault, but it is assumed to be less than the combined displacement of the faults running into it from the southeast. Therefore these faults probably continue on the north side of the Barrell Spring fault, but have not been identified.

The northeasterly faults in general show very limited displacement, perhaps only a few feet. These faults are both normal and reverse in the Delno district and the same is assumed for them in the Granite Creek-Mill Creek area.

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Fault pattern

The fault pattern in the Delno district consists, in the main, of two sets of high angle faults; one with a strike of about N. 55° W. and the other north to a few degrees east of north (Figure 14). A few minor faults in the vicinity of the mines strike about N. 60° E. and dip steeply to the east. They are in the minority and seem to be of later origin than the major faults because they displace the latter.

The major departures from the general fault pattern occur in and near the granite. High angle faults in the granite strike N. 50° E. These faults possibly formed in the granite as a result of compressional forces in the early Tertiary. Adjustment of the normal faults on the east side of the range to the granite mass is suggestive of a buttressing effect by the granite.

There are three major trends shown by the faults in the Granite Creek-Mill Creek area. The majority of the larger faults have an average trend of about N. 34° W. The other major trend, shown by the Barrell Spring fault on the north side of the area, and by a minor thrust fault on the south edge of the district, is almost due west. The third trend is shown by numerous small faults in the porphyry itself, and varies from due north to N. 45° E. with an average strike of N. 15° E. The largest fault of this orientation cuts through the northwestern end of the porphyry, and like all others of the same system is confined to the porphyry itself. Only rarely do faults of this system extend into the sedimentary rocks, and then only for a very short distance.

The faults of the N. 34° W. system dip in general to the northeast. The amount of dip varies from 33° to vertical. No actual dips were observed for the Barrell Spring fault, but the trace of the fault is apparently not curved to fit topography, so the dip is assumed to be

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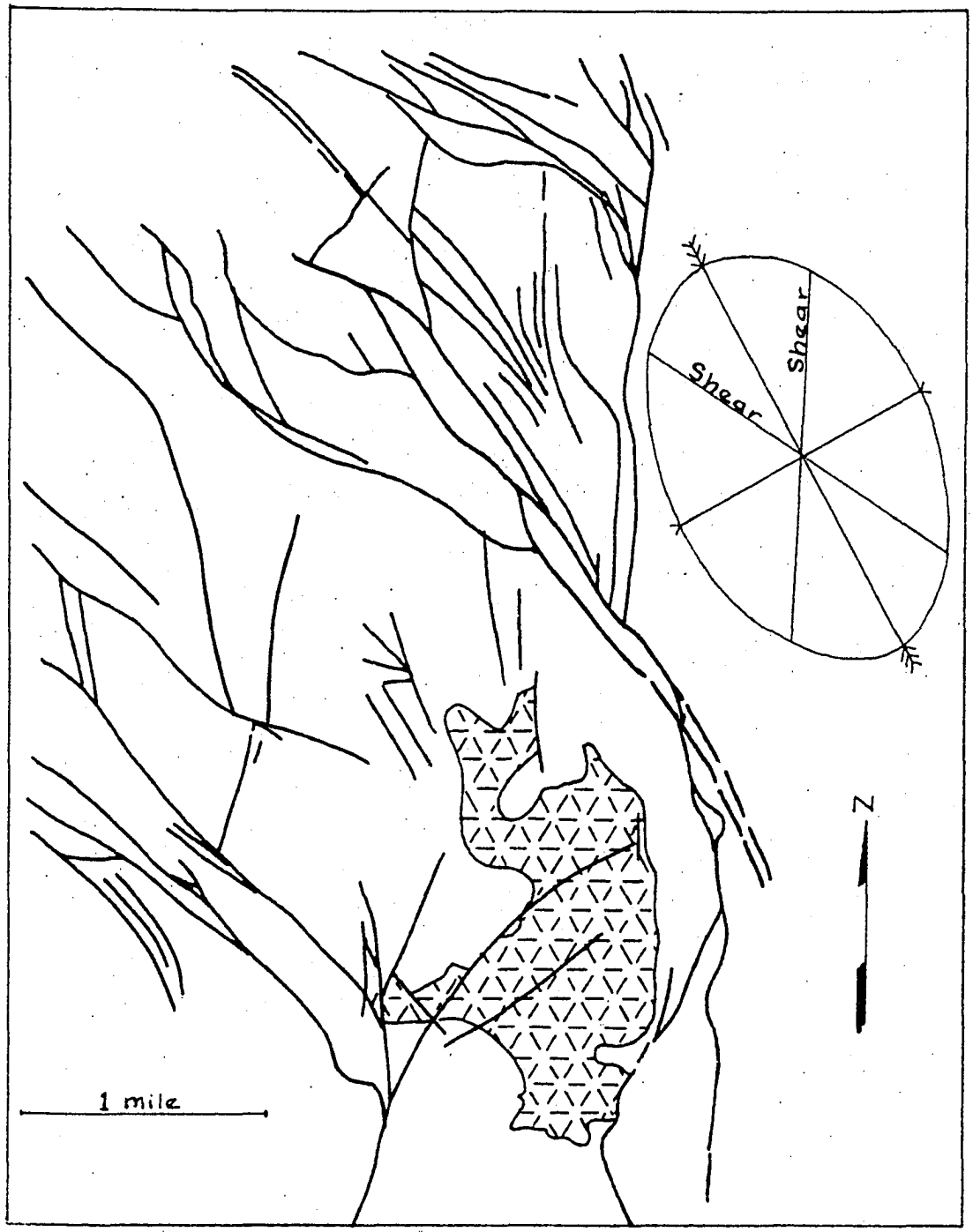

Figure 14. Fault pattern in the Delno district.

Stress diagram suggests that the maximum stress direction would be oriented about N. 25° W.

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close to vertical. The small thrust fault on the south side of the district dips about 25 degrees to the north.

The north-northeasterly fractures are generally quite steep. The dips vary from 41 to 77 degrees east, with most dips steeper than the mean. It is of interest to note that these latter faults are mostly isolated in areas not affected by northwesterly faulting, as if they were formed only where strain could not be relieved by movement on older faults.

The fault pattern in both the Delno and Granite Creek-Mill Creek areas fits the pattern for primary and secondary shears developed as a result of essentially north-south compression as described by Moody and Hill (1956). Moody and Hill suggest, however, that the fractures outlining the Basin and Range mountains in Nevada are the result of second order right lateral shears. The author feels that in this instance most of the fractures would correspond better to first order shears resulting from the same meridional forces described by Moody and Hill. In the case of the Delno district proper the maximum stress direction would have been oriented about N. 25° W. In the Granite Creek area it would have been oriented about N. 4° W. The difference is explained by rotation of one or both mountain blocks subsequent to initial shering. That the blocks have at least been tilted is reasonable to assume in view of the fact that the regional dip of the sedimentary rocks is west and the dip of the faults is to the northeast, rather than close to vertical as they should be if they were simple shears. If the faults were formed as shears with the major and minor axis of stress in a horizontal plane the dip of the plane of the faults should vary near 90 degrees. Since nearly all faults dip in the same northeasterly direction it is possible that the mountain blocks have rotated 20 or 30 degrees.

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In the Delno range the limiting fault on the east would have developed as a left lateral fault. The multitude of smaller northwesterly faults would have had their inception as right lateral faults. The small northeasterly faults such as those found in the Cleveland and Delno workings would then be explainable as second order shears complementary to the first order right lateral shears.

The northwesterly faults of the porphyry area may then be explainable as first order right lateral shears. This does not explain the easterly or the north-northeasterly faults of the area. The author feels that these can best be explained on the basis of east-west Laramide compression. They are found where the other faults are essentially absent, and they cut only the Laramide intrusive rocks, rather than the Paleozoic rocks. They would therefore appear to be younger than the northwesterly shears. Their orientation with a north-northeasterly compressive force would be second order shears.

A second possible method of developing the above pattern may be related to a stress couple. This will be explained briefly in the following discussion of the age of faulting in the district.

Age of faults

Relation of fault pattern to Mesozoic compression. The fault pattern in the area is suggestive of shears. The orientation of the faults, if they are shears, suggests two possible modes of origin; compression in a north or northwesterly direction, or a stress couple with the area north of the district moving toward the east.

If compression formed the shears the major stress axis calculated according to Billings (1954) would be oriented about N. 24° W. (Figure 14). This mode of origin does not seem probable from Mesozoic compression

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since the major stress axis would be oriented almost normal to the general direction of Laramide compression as described by Eardley (1951-Chapter 18).

The major stress axis required to develop the shears described here would be generally the same as the meridionally oriented stresses described by Moody and Hill (1956). The author finds this explanation quite satisfactory. The shears would, by this approach, need to be deep seated shears, perhaps reflecting Precambrian shears formed in the basement rocks. The older shears thus would have been perpetuated and it was along these shears that movement occurred during the Laramide orogeny. It is interesting to note that those areas where we have no shears to fit this pattern, as an example, the western third of the porphyry, are those places in which shears have formed with an orientation which would be required by an easterly or east-northeasterly compression.

In view of these facts it is suggested that the major shears are old, perhaps even Precambrian in age and have continued throughout the Paleozoic in successively younger rocks. Laramide compression, rather than developing a major group of shears, was relieved by movement on these older faults. Similar movement on older faults is described by Kupsch and Wild (1958) in Saskatchewan.

Butcher (1933) suggests that the Basin and Range faulting is the result of two independent processes, earlier fracturing from regional tensions, and later uplift by orogenic stresses. This is in accord with the present view, except that the second stage movements are seen as vertical adjustments on the older faults because of Laramide compression, which was diametrically opposed to the earlier northerly axis of compression. The author does not accept the Laramide compression as a result of continued stresses acting from the north as

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suggested by Moody and Hill, but feels that the two forces are separate and distinct in origin and action.

According to the above scheme the maximum age of the faults could well be Precambrian. The major movement, that which outlined the mountain ranges, as presently seen would be in or at the end of the Laramide orogeny. As will be noted later these movements have continued to the present.

The second of the two possibilities mentioned, a stress couple acting to the east on the northern edge of the Great Basin and west on the southern end, might in theory cause a shear pattern such as that found in the Delno region. The idea is presented with little discussion, but with the thought that further investigation may be warranted.

The couple may be explained if the Idaho batholith located north of the Delno district moved eastward as a mass. This is suggested as a possibility by Eardley (1951-Chapter 20). The Osburn fault zone north of the Idaho batholith suggests that the area north of the batholith moved eastward with respect to the batholith. However, the Lake Basin zone in Montana suggests that the batholith moved eastward with respect to the area north of the Lake Basin zone. Thrust faulting in eastern Idaho and western Wyoming likewise reflect eastward movement of the batholith. The problem is one of relative movement. Both above conditions could be satisfied if the north Idaho block moved eastward more than the batholith. The batholith could still have moved eastward with respect to southern Idaho and northern Nevada and Utah. The result would be a couple which would give in effect the same structural pattern as northwesterly compression (Figure 14), but would be in the same direction as the late Mesozoic compression.

The shear pattern formed by the couple would not be compatible with later direct compression and should be expected to resist deforma-

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tion. The compression, in this case, would have folded the strata before movement began on the faults, as indicated by truncation of the anticline in the south part of the district. However, folding in the area is very minor.

Postulated eastward movement in Idaho, beginning in late Mesozoic time could have caused the stress couple responsible for formation of the shear pattern. It could have been followed by eastward movement in Nevada, a wave progressing southward, causing reverse and/or normal movement on the shears. Termination or relaxation of the force could have brought about normal movement at the end of the Laramide orogeny, probably in late Eocene.

Relation of faulting to Tertiary and Quaternary sediments. To obtain a minimum age for the normal faulting it will be helpful to examine the relationship between the Tertiary and Quaternary sediments, present topography, and normal faults. The small outcrop of middle Humboldt tuff found in the Delno campsite rests at an elevation of about 6,350 feet. The middle Humboldt unit east of the district and on the opposite side of the fault outlining the range is at an elevation of about 6,300 feet. As previously suggested the total thickness of the unit is about 200 feet, so even if the tuff in the campsite represents the base of the unit, total elevation of the range since deposition of the middle Humboldt is no more than 250 feet, and is probably much less.

The Cotton Thomas fault may be seen cutting the middle Humboldt unit on the east side of the range and is traceable into the recent gravels capping the Humboldt. Displacement is apparently only a few feet in the tuff of the Humboldt formation, indicating minor movement on the fault since Upper Miocene. Near the northeastern corner of the

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range in section 27 another of the faults which cuts through and partially around the end of the range is similar to the Cotton Thomas fault in that it displaces very slightly the recent sediments. Activity on the faults has thus continued into the recent epoch, but was obviously greater before deposition of the middle Humboldt tuff.

The tuff in the campsite occupies the lower part of Cotton Thomas Canyon, so the canyon must have been formed prior to the deposition of the Humboldt formation. Van Houten (1956) recognizes that the Humboldt formation was deposited in isolated basins in a topography similar to that of the present. The deformation which caused tilting of the lower tuff and basalt unit of Oligocene age undoubtedly contributed to elevation of the mountains, but the mountains must have been in existance before the lower unit was deposited because the lower unit in adjacent areas contains a basal conglomerate of Paleozoic pebbles and was deposited in basins between the mountains. Since the lower Tertiary unit is Oligocene in age and since the normal faulting appears post-granite in age the elevation of the mountains must have occurred at the end of the Eocene.

Van Houten states that local structural basins had formed by Oligocene time and that one or more episodes of deformation occurred after the Eocene but before late Miocene. Two periods of uplift and vigorous erosion are recorded in the Tertiary rocks of the Delno district, one at the close of the Eocene and the other in the interval from Oligocene to late Miocene. Movement since that time has been minor.

Of the various ideas presented explaining the possible origin of faulting in the Delno region the author favors the continuation of old shears formed by a northward stress axis. Movement on those shears,

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and development of others, with minor associated folding took place during the Laramide orogeny and was the result of an easterly stress axis. Relief of Laramide compression has caused continued normal faulting on the same shears with some rotation of the fault blocks. Major normal movement took place at the close of the Eocene and before late Miocene. Movement has continued to the present time.

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ORE DEPOSITS

History and Production

Most of the history and production figures given here are taken from Granger (1957). Some notes were obtained by personal conversations with the present operators.

The district was probably discovered as early as 1890, but little ore was produced before 1918. Between 1918 and 1949 the district produced 53,340 tons of ore valued at $2,136,413. Of this amount approximately 50 percent of the value was in silver and 50 percent in lead. Small amounts of zinc, copper, and gold were recovered from the ore. A gravity mill of 50 tons per day capacity was installed in 1926, but was dismantled after operating for four years with minor success. No production record was obtained for the period following 1949. The operators report shipments of 40 to 50 tons every two weeks to a month with an average gross worth of $60 per ton.

During World War II the name was changed from Delno to Delano in recognition of the President of the United States, Franklin Delano Roosevelt. Local usage has again given Delno precedence as the name of the district. Following the war, one of the two major mines of the district, the Cleveland mine, ceased operating. The remaining mine of the district, the Delno has been in almost continual operation to the present time under lease from the owners, Delno Mining and Milling Company, and Panther Mines Company, by John Ala and Lucy Daz of Montello, Nevada. A small crew working on contract periodically ships ore from

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the rail head at Montello to the International Smelter at Tooele, Utah.

In addition to the work at the Delno mine the most recent activity in the district has consisted of sinking the Bracken shaft about 400 feet north-northwest of the Cleveland shaft and driving two exploration tunnels in the canyon walls above the Bracken shaft. This work was progressing at the time of the author's visits in 1959 and 1960.

At the time of the last visit to the property, some small-scale exploratory work was being done at the Gold Note mine south of the Delno mine. The history of the Gold Note and its sister property to the west, the "86", is not known. The miners stripped the oxidized ores from the outcroppings at these mines by a series of "gopher holes" and allowed the workings to cave when their operations were complete. Very likely they ceased operating because they came against the large fault cutting the south side of the properties.

Numerous old prospect pits are found throughout the district. Most of them show traces of mineralization in the form of jasper, iron oxide and/or copper carbonate stains, but none have proven productive.

The Cleveland mine has about 6,700 feet of workings exclusive of stoped areas. The shaft extends down the dip of the "ore bedding" about 450 feet. About 90 percent of the ore was mined at a depth of less than 300 feet. Near the surface the ore is reported to have been much higher grade than at depth. The Cleveland workings extend laterally about 670 feet. On the north they are terminated by a normal fault of about 40 feet displacement. Toward the south the ore beddings have been worked by numerous pits and tunnels and terminate in the South Cleveland workings against a series of normal faults with displacement of several hundred feet.

The ore beddings in the Cleveland mine are terminated on the west

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by the Bracken fault, and the ore is displaced upward toward the west. No surface evidence is found to indicate an outcropping of the ore between the Cleveland and Delno mines. However, Newman (1950) shows a possible ore outcrop in the hill 700 feet west of the Cleveland shaft, and ore was reported by Ala (1956) at a depth of 125 feet in a well drilled in the Delno camp. It may be that this horizon is the same as the tin-bearing bed situated about 1,800 feet southeast of the Cleveland shaft.

The Delno mine has about 6,200 feet of workings over a lateral distance of 125 feet and a down-dip distance of about 1,750 feet. The ore rakes about 65 degrees northwest, strikes almost due north, and dips 25 to 43 degrees west. The "upper ore bed" has been the most productive. It averages about 2.5 feet in thickness and varies from 2 to 6 feet thick.

As in the Cleveland mine, the ore at the Delno mine is terminated by northwesterly high angle faults on both the north and south. North of the mine the ore bed is found at the surface in several places although it has not been explored.

Mineralization

The ore-producing horizon in the district consists of two parallel beds within the upper Carboniferous unit, striking about north with an average dip of 42 degrees west in the Cleveland and 30 degrees west in the Delno mine. These beds, which are separated by a dark gray siliceous dolomite bed about 6 feet thick, average about 2.5 feet in thickness, varying from 1 to 4 feet in the Cleveland and from 2 to 6 feet in the Delno. The hanging wall of the ore zone is a light gray limestone becoming highly crinoidal a few feet above the ore beds. The footwall

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is a light brown sandy quartzite. The only alteration of the enclosing rocks is a slight silicification of the hanging wall extending a few inches from the ore.

The ore beds are highly siliceous and are stained from yellow to brown with iron oxide. They contain broken quartz and jasper in addition to the metallic minerals.

Mineralization in the northern part of the district is very much different from that in the southern part of the district. In the north the mineralization consists of lead and silver with minor zinc, copper, tin, and gold. Jasper, chalcedony, and opal are common in the ore veins. In the south the mineralization consists of very minor scheelite around and within the granite, minor tetrahedrite and its oxidation products and minor sphalerite with silver in isolated quartz veins around the edges of the granite. Lead, tin, jasper, chalcedony, and opal are notably absent in samples collected in the southern part of the district. The "ore bedding" in the southern end of the district contains only iron oxide.

Relation to faulting

A conjugate system of northwesterly faults and north-northeasterly faults displaces the ore beds. The movement on these faults is generally less than 65 feet. Most commonly the northwesterly faults dip toward the northeast and are normal faults. Occasionally reverse movement is encountered, especially in the southwest part of the district, but seems of less magnitude than the normal movement. The north-northeasterly faults dip toward the east and are also, in the main, normal faults. However, here too, occasional reverse movement of small magnitude is encountered. In descending through the Delno shaft a reverse fault displaces the ore downward 10 feet at a depth of 170 feet, a normal

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fault displaces it upward 35 feet at a depth of 300 feet, and another reverse fault displaces it downward about 5 feet at a depth of 810 feet. The north-northeasterly faults are much more numerous in the Cleveland shaft according to cross sections prepared by Newman (1950). Since the Cleveland shaft did not appear safe the author did not observe in person the fault conditions encountered there. In the Delno workings the beds are terminated on the north by normal faults, and on the south by smaller reverse (?) faults.

The ore bodies rake about 65 degrees to the northwest. This may be in part only apparent rake, seen because the workings follow and are limited by the northwesterly faults. It appears, however, from assays from the Delno mine that the rake is real. Since the rake follows the faults the most obvious explanation is that the mineralization was controlled by the faults.

In the case of the Cleveland mine the northern edge of the ore body in the upper levels of the mine is marked by a series of northwesterly-trending faults. The "ore bedding", on passing from the south side to the north side of these faults changes from a siliceous lead-silver ore to a calcareous iron oxide bedding. The change in mineralization is, no doubt, controlled by the fault. Where calcite is the dominant vein mineral the metallic minerals do not develop in economic amounts. Where silica, as quartz, chalcedony, opal, and jasper is present, the ore minerals may develop in mineable quantities. The calcite is controlled in its location by faulting and we may assume the same is true for quartz and the ore minerals. Thus, the faults must be pre-mineral in origin. Ore bodies develop where small northwesterly faults intersect the bedding. Thus the faults acted also as channelways for the ore solutions.

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There has been considerable post-mineral movement on some of the faults, as evidenced by drag ore in the fault plane. The faults have therefore had a threefold effect on the ore bodies. They controlled the original location of the ore by acting as limiting agents in the lateral movement of mineralizing solutions. They acted as channels for the ascending solutions to follow. They have displaced the ore after its deposition.

Relation to igneous rocks

Comparison of mineralization in the south and north parts of the district suggests two sources of mineralization. In the southern part of the district tungsten has developed in the tactite areas which formed as a result of emplacement of the granite. Copper, zinc, and silver have developed in quartz veins seemingly related in both space and time to the granite. Quartz veins around the granite contain or are enclosed in silicate minerals common to the alteration zone around the granite. This is in contrast with the area north of the Cotton Thomas fault where alteration is mainly siliceous. The gangue minerals in the north part of the district seem to be more closely related to the rhyolite porphyry and its strong silicification than to the granite. The tin occurrence in the north resembles other tin occurrences in Nevada associated with rhyolite rather than granite, such as those at Majuba Hill and near Battle Mountain described by Knopf (1916), Smith and Gianella (1942), and Fries (1942).

Mineralization in the Granite Creek area is very much like that in the Cleveland and Delno area in that the gangue minerals in the mines are represented mainly by varieties of silica found also in the rocks surrounding the porphyry. The resemblance is carried still further by the occurrence of tin in the silicified sedimentary rocks

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north of the porphyry. On this basis it appears that the porphyry and not the granite is the source of mineralization in the Delno district. This is in accord with conclusions regarding ore and igneous rock associations reached by Stringham (1958) in his statistical analysis of Basin and Range ore deposits.

Tin

Occurrence. According to the popular local story, tin was accidentally discovered in the district when a prospector making a test for uranium tipped some metallic zinc into an acid solution containing fragments of yellow-stained quartz. Metallic tin was deposited on the yellow material in the rock fragments. The author was unable to verify this by his own experiments on tin concentrates from the district and cannot vouch for its authenticity.

Tin was first found in a highly silicified bedding cropping out as a rounded knob about 1,800 feet southeast of the Cleveland shaft (Plate 4), between 800 and 1,000 feet stratigraphically below the "ore bedding" in the Cleveland mine. The bedding which contains the tin consists of an irregular iron-stained quartz breccia about 2 feet thick enclosed in layers of iron oxide 6 to 18 inches thick. The fractured quartz has been healed with chalcedony and opal, is highly jasperoid in part, and contains the tin-bearing mineral scattered randomly in thin yellow stringers and irregular yellow earthy spots. A channel cut across the 2-foot bedding contained 0.66 percent tin. The upper iron oxide layer contained 0.33 percent tin. Hand-picked samples have contained as much as 2 percent tin. The hanging wall of the bedding consists of yellow-stained, shaly limestone. A cut sample 4 feet long and 2 inches wide in the hanging wall contained

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less than 0.01 percent tin, the lower limit of the analytical method used. Across the iron oxide footwall a cut sample 1 foot long contained 0.66 percent tin.

Identification. One of the original problems encountered in the district was identification of the tin mineral. The United States Bureau of Mines at Salt Lake City, Utah reported that the tin occurred as the mineral arandisite, a tin silicate. Studies made at the Kennecott Research Center in Salt Lake City suggested that the tin occurred in a mixture of cassiterite and quartz. In September, 1958 a sample of the tin-bearing rock was submitted to Dr. W. F. Bradley of the Illinois State Geological Survey. Dr. Bradley (1958) suggested that the major constituent tin mineral should be considered cassiterite according to its x-ray diffraction pattern.

X-ray diffraction studies of the mineral do show cassiterite diffraction peaks at 2θ angles of 33.92 and 51.60 degrees using copper k alpha radiation, corresponding to d spacing values of 2.640 Å and 1.769 Å. The strongest cassiterite diffraction peak is at a 2θ of 26.60 degrees, or a d spacing of 3.348 Å. This line is masked in the sample by a strong quartz line. The two peaks shown are very low and broad, indicating perhaps only an incipient cassiterite crystallization in the sample, or perhaps a sample of cassiterite so fine that the x-ray pattern is partially destroyed.

Thus it appears that x-ray data are not sufficient to completely identify the tin-bearing material, and must be supplemented by other means. Palache, et al. (1944) indicate that artificial gels and sols of stannic oxide on aging give the x-ray diffraction pattern of cassiterite. This perhaps gives us some direction in searching for the mineral source of tin in the Delno district.

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Microscopic examination of the tin-bearing material gives results quite similar to the x-ray data. In the main, the yellow, earthy material appears amorphous and isotropic. Small isolated patches seem to be slightly anisotropic but on close examination these patches are seen to be mixed with quartz. A very few tiny highly birefringent elongated crystals showing parallel extinction are noted in the yellow, earthy material. These crystals have an index of refraction greater than 2.0 and are assumed to be cassiterite. Their small size, about 0.5 microns in diameter and 2.5 microns long, prohibit more detailed examination. The thin sections studied show many cubic molds filled with opal and chalcedony. Probably they represent sites of leached fluorite crystals.

Theoretical resolution of a 4 millimeter microscope objective lense of 0.85 N.A. in yellow light is 0.34 microns. With the above objective and a 10X ocular lens the earthy material appeared a pale yellow, unresolved, amorphous mass and showed the folded, mushy appearence of a gel. The index of refraction of this material varies between 1.66 and 1.80, averaging about 1.77.

Analysis of a heavy liquid concentrate of the tin-bearing rock using a Norelco x-ray diffractometer indicated only two constituents, quartz and tin oxide, in the proportion 64 percent quartz and 36 percent tin oxide. The specific gravity of the sample as determined with a pycnometer was 3.33. Since quartz has a specific gravity of 2.65 the specific gravity of the tin oxide portion of the sample may be calculated as follows:

$$.64 \times 2.65 + .36 \times X = 3.33$$

$$X = \frac{3.33 - .64 \times 2.65}{.36} = 4.53 = \text{specific gravity of tin mineral}$$

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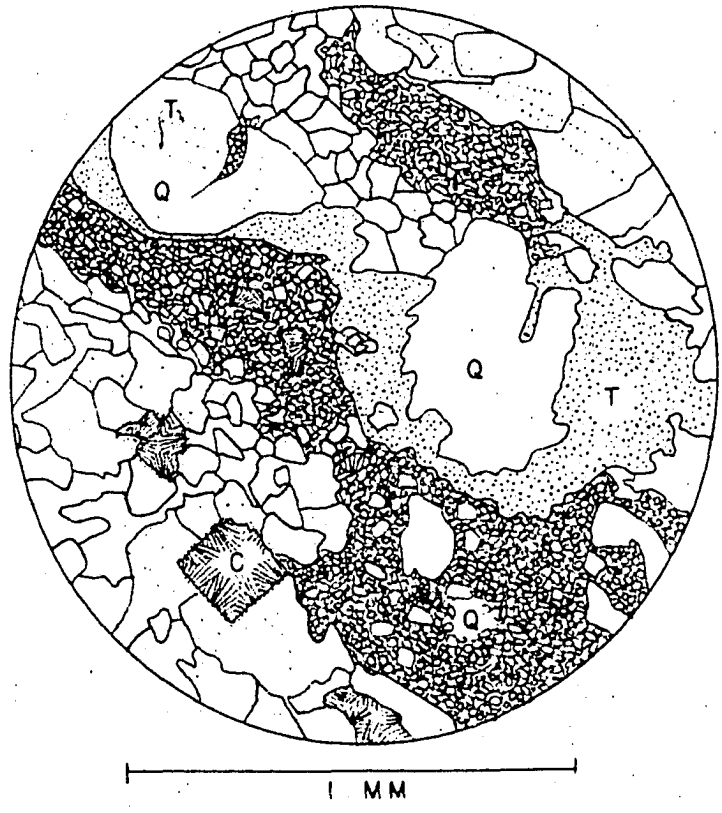

Figure 15. Thin section of tin-bearing quartz.

Stippled area (T) is tin mineral scattered through broken quartz crystals (Q) and fine quartz breccia in chalcedony matrix. Chalcedony (C) fills holes, perhaps fluorite molds, in rock. Camera lucida drawing. 60X.

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It is recognized that the x-ray method of determining the mode of the sample is not entirely satisfactory. Further work is necessary to establish a more accurate value for the specific gravity of the mineral. The value of the present system is in demonstrating that the specific gravity of the tin mineral is markedly less than that of cassiterity, which is in the range of 6.5 to 7.1.

The tin-bearing material is too fine-grained to show any structural or crystallographic features. The larger yellow patches have a hardness less than 2. The luster varies from dull to waxy.

A sample of the tin-bearing rock was analysed chemically and found to contain 1.58 percent tin. A similar sample, quartered from the first and ground to minus 200 mesh, was leached in 1:1 HCl for one hour at room temperature. The residue contained 0.88 percent tin. Thus about 49 percent of the tin was removed by leaching, a condition quite the opposite from that found with cassiterite, one of our most insoluble ore minerals. On the assumption the solubility could be caused by fine grain size a sample of chemically precipitated tin oxide was treated in the same manner. The tin oxide grain size should have been of the same order of magnitude as the tin material in the rock sample. Under the same conditions no measurable tin was removed in solution from the tin oxide precipitate. Solubility tests using alkalies show that the tin mineral from the Delno district is not soluble in alkalies.

Fink and Mantell (1924) performed extensive solubility tests on cassiterite and failed to find a metallurgical solvent. Collins (1910) on the other hand, states that wood tin is sometimes remarkably soluble in hydrochloric acid. Since wood tin is supposed to be precipitated as a colloid this points in the direction of increased solubility for

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cassiterite varieties with a decrease in grain size. This may be the explanation of the solubility of the sample even though laboratory reagents show no increase in solubility in extremely fine sizes. It may also be that some other factor not yet recognized is the cause of increased solubility in the sample from the Delno district.

Consideration was given to the possibility that water with the tin mineral structure could be the cause of both the poor x-ray diffraction pattern and the increased solubility. Infrared absorption patterns obtained from samples of tin-bearing heavy media concentrates show only very faint OH absorption bands. The water content of the mineral must therefore be negligible. This would rule out a gel or a sol of tin oxide as the form in which the tin was deposited unless it was quite effectively dehydrated. This is possible as shown by samples of wood tin, deposited as a colloid, which contain upon analysis only 0.25 percent water (Knopf, 1916). About one-half of this is surface water removed by gentle heating so only about 0.12 percent is water associated with the original colloidal deposition.

We are left, then, with a very fine tin oxide which lacks the optical, physical, or chemical characteristics of normal cassiterite, and to a lesser extent, of wood tin.

Newhouse and Buerger (1928) show that wood tin from Nevada was in some instances extremely fine-grained, almost to the extent that it was not resolvable with the microscope. Even then, however, the mineral was still anisotropic. There was some question whether the deposition of such a product was colloidal or if it should be considered a crystalline deposit. The present tin mineral may perhaps be considered as a still finer-grained variety with the same origin. It lacks the characteristic colloform structure and fibrous crystals

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characteristic of wood tin, but its mode of occurrence is quite similar. Opal, tridymite, and chalcedony are common associates of the tin mineral at Delno and also of wood tin.

There seem to be enough similar characteristics between wood tin and the Delno tin mineral to make naming a new species unwise. However, the differences are so pronounced that it becomes necessary to distinguish between them.

Further work is necessary, but at this point it seems quite possible that the mineral is a new variety of cassiterite. More precise specific gravity determinations and perhaps electron microscope viewing of the mineral should be of considerable aid in establishing whether the occurrence represents a new variety.

Conditions of formation. The conditions of formation of the tin mineral must have been governed by the proximity of the porphyry with the surface. The temperature gradient must have been steep, and the pressure low. Knopf (1916) states that the temperature of deposition in other Nevada tin deposits was between 70°C., and 360°C. The lower temperature is the minimum temperature at which tridymite has been deposited experimentally. The highest temperature is the greatest temperature at which opal has been made to form. The figures are probably quite reasonable for the Delno deposits. Probably in view of the great amount of alteration in the surrounding rocks a temperature near the maximum given would be a more accurate estimate than anything cooler.

The tin probably deposited as a colloid, or from a colloidal suspension. Presumably the steep temperature gradient and rapid cooling rate resulted in rapid nucleation and the resulting extremely fine grain size.

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Ore minerals

Lead minerals. The ore minerals produced in the district have been predominently secondary minerals formed in the zone of oxidation. The maximum depth of oxidation of the ore is not known except that it is below the 1,700 level of the Delno mine. Oxidation of the sulfides has been complete in most of the mine workings. The ore minerals have consisted mainly of cerussite and bindheimite with minor anglesite and massicot. Galena was rare in the upper levels of the Delno mine, but becomes quite common below the 1,300 level.

The secondary ore minerals occur as crusty, iron stained masses in a gangue of broken quartz and jasper. Cerussite is the most abundant ore mineral in the mines. It is seen in numerous specimens replacing galena. Yellow, earthy bindheimite is locally abundant and probably makes up a significant part of the ore. Its precise role is difficult to determine because the mineral is friable and easily lost in hand samples, and is masked by the abundant iron oxide in the ore. Bindheimite is generally found with jasper in the veins, probably because the jasper protects the earthy bindheimite.

Polished sections of galena from the 1,300 and 1,700 levels were examined microscopically by vertically reflected light. The sulfide is considerably broken. Cleavages have developed and replacement of galena by cerussite has progressed along most of the open cleavage planes. Lead minerals occupy the openings in the quartz and jasper, and were evidently deposited later than the quartz and jasper, but prior to the chalcedony and opal which fill cracks in the galena. The primary source of antimony for formation of bindheimite is not known except that chemical analysis of the galena shows 0.5 percent Sb.

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Silver minerals. Previous reports have not indicated the source of silver in the ore bodies of the district. Specific silver minerals are not known in the oxide zone. Efforts to locate the source of silver among the secondary minerals established that silver makes up 1.5 percent of the bindheimite. This is probably sufficient to account for the silver in the oxide ore.

Argentite in significant amounts is recognized microscopically in polished galena samples. The silver sulfide occurs as irregular stringers throughout the galena, but is more common near quartz-galena contacts. The argentite and galena were probably deposited contemporaneously. The average silver content of several samples of galena is shown by assay to be 208.8 ounces per ton.

Silver occurs with tin in the "tin bedding" east of the Cleveland mine. Assays of the tin-bearing quartz show from 0.4 to 1.99 ounces of silver per ton. The amount of silver, the source of which has not been recognized in the tin-bearing rock, varies directly with the tin.

Silver is also found in minor amounts in quartz veins around the granite. One north-striking fissure at the north end of the granite contained 8.08 ounces of silver per ton in a hand sample. No other significant metallization accompanies the silver in the vicinity of the granite.

Gold. Gold is minor in the district. There have been reports of small amounts of gold in abandoned workings west of Cotton Thomas Canyon. The Delno district produced only 190 ounces of gold up to 1949 (Granger, 1957). In the lower Delno workings a small amount of gold has been produced by recent mining. It is reported by Ala (1960) that the latest shipment netted about $0.88 per ton in gold, the first smelter payment for gold in many years. It does not appear likely that there

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will be any significant gold production from the district, even though there is an apparent increase in gold in the lower Delno workings.

Minor base metals. The source of the small amount of zinc in the ore has not been established, but the fact that the secondary ore contains considerable carbonate material suggests that the zinc may occur as smithsonite. Minor sphalerite occurs in the south end of the district, near the granite and the sulfide is very probably the ultimate source of zinc in the north end also.

Copper carbonate stains are found in veins throughout the district. Copper seems to be minor in the present workings, but was probably prominent in earlier workings. Production figures indicate that 108,227 pounds of copper have been recovered up to 1949. Copper in the form of tetrahedrite with minor chalcocite and copper carbonates occurs in quartz veins at the south end of the district. The copper minerals are sparsely scattered as spots up to 1 centimeter in diameter throughout the veins.

Tungsten occurs as specks scattered in the tactite and skarn areas in and around the granite pluton. Several small trenches have been opened in the tactite areas and at the west and southeast contacts of the granite with sedimentary rocks. Scheelite has been reported also to be found in the tunnel at Mitche's spring. The author was not able to verify this.

Gangue minerals

The gangue minerals are composed principally of various forms of silica. Quartz, jasper, chalcedony, opal, and tridymite, in that order of abundance are found throughout the "ore beddings" and veins in the district. The quartz and jasper are commonly fractured, and the

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fractures are healed by chalcedony and/or opal with very minor tridymite. The veins were apparently formed by bedding replacement of the country rock by quartz. The quartz was badly shattered and jasper and ore minerals filled the interstices between broken quartz fragments. Movement on the faults and beddings fractured the jasper. Ore minerals, chalcedony and finally opal healed, or partially healed the fractures. Throughout the district the quartzose veins and beddings show fractures with crusty coatings of opal. Commonly the fractures are still open, but opal has cemented the individual fragments of quartz or jasper very firmly together.

Jasper occurs as bedding replacements in the sedimentary rocks. Such a replacement body is found southeast of the Cleveland mine in the vicinity of the "tin bedding". It varies from 2 to 15 feet in thickness and is composed of dark brown dense jasper and quartz fragments. The whole mass dips westward with the enclosing rocks. Relict bedding planes of the original sedimentary rocks are recognizable in the jasper. The jasper of the "ore beddings" is commonly lighter yellow in color than the jasper of baren beds and fissures.

Calcite is found in the "ore beddings" and wherever it is found the tenor of the ore decreases. This may especially be noted in the north end of the Cleveland workings. The impression gained in examining the ore is that the calcite in the ore represents recrystallization of the original calcite of the rock. In order for mineable ore deposits to form the siliceous solutions were required to remove the recrystallized calcite from the bedding and replace it with the colloidal mixture of silica, fluorite (?), and tin oxide. In those instances where mineralization progressed only to the point of recrystallizing the limestone, but not to the point of actual removal of the crystalline calcite there

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was no space available for ore deposition. Hence ore values are lower in and around calcitic portions of the beddings.

Cubic molds in the tin-bearing rock have been filled with chalcedony and opal. They have been assumed to mark the sites of former fluorite crystals that have since been removed. The crystals were formed contemporaneously with the quartz, were leached away and the resulting mold was filled with opal and chalcedony. A fine halo of tin oxide surrounds most of these molds.

Iron oxide is universally present in the ore of the district. It occurs as friable masses of limonite and as staining in the other minerals. It has its origin in pyrite depostied with the ore sulfides. Pyrite is found with the ore in the lower Delno workings, but has been oxidized completely in the upper workings. The pyrite was deposited contemporaneous with or immediately following the quartz and just prior to the galena.

Summary

The ore deposits of the Delno district are in general thin, but of good grade and large areal extent. The relatively gentle dips and the thin cross section of the "ore beddings" make mining difficult. The difficulty of exploiting the deposits is increased by the parallel faults which frequently offset the ore and may be either normal or reverse faults. The district could probably support several small mining operations in times of reasonable lead prices, but could not support any large operations.

In view of our lack of domestic tin perhaps the greatest significance should be attached to the tin occurrence in the district. High specific gravity of the tin mineral and its solubility in dilute acid may offer easy means of recovery if the material could be found

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in sufficient quantities. The probability of locating economically recoverable amounts of tin in the district is not good. However, the mineral is scattered so widely over the Delno and Granite Creek-Mill Creek areas that a commercial deposit of tin in the area is certainly a possibility which should not be lightly dismissed.

No tin analyses were made in the porphyry, and only one in the sedimentary rocks near the porphyry. A detailed examination of the sediments themselves with this in mind may disclose other and perhaps better grade deposits.

Additional laboratory examination of the tin mineral is recommended. The specific gravity, although it likely varies, should be determined more precisely. More precise particle size and shape determinations are to be desired. Such information may be obtainable by means of the electron microscope. It may be possible that the isotropic nature of the mineral is simply the result of extremely small grain size, or the mineral may be isotropic because it is isometric rather than tetragonal as in normal cassiterite varieties. Solubility may be the result of grain size or of some factor not yet known about the mineral. Efforts might be directed toward obtaining samples of greater purity for x-ray examination and determination of physical and optical properties.

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EXPLANATION

SEDIMENTARY ROCKS

TERTIARY AND QUATERNARY

TQ / Tbp

Undifferentiated Humboldt formation and Quaternary sediments: tuff, conglomerate, alluvium: Tbp; basalt, perlite

CARBONIFEROUS

Cu

Upper unit; conglomerate, limestone, sandstone, dolomite

Cm

Middle unit; limestone, sandy limestone, sandstone, chert

UNCONFORMITY

Cl

Lower unit; carbonaceous limestone, sandstone, conglomerate

IGNEOUS ROCKS

QUATERNARY ?

Qb

basalt flows

TERTIARY

Tp

Rhyolite porphyry, intrusive

G

Granite and granite porphyry light-colored, fine-grained

ALTERATION TYPES

Tactite; garnet and diopside rock limited exposure in and near granite

Ts

Skarn; silicates, mainly diopside in sedimentary rocks around granite

Tsi

Silicification of sedimentary units, may be brecciated. Quartz, chalcedony, opal

Top

Opalite; dense, opaque white to transparent yellow. May contain considerable chalcedony

FAULT

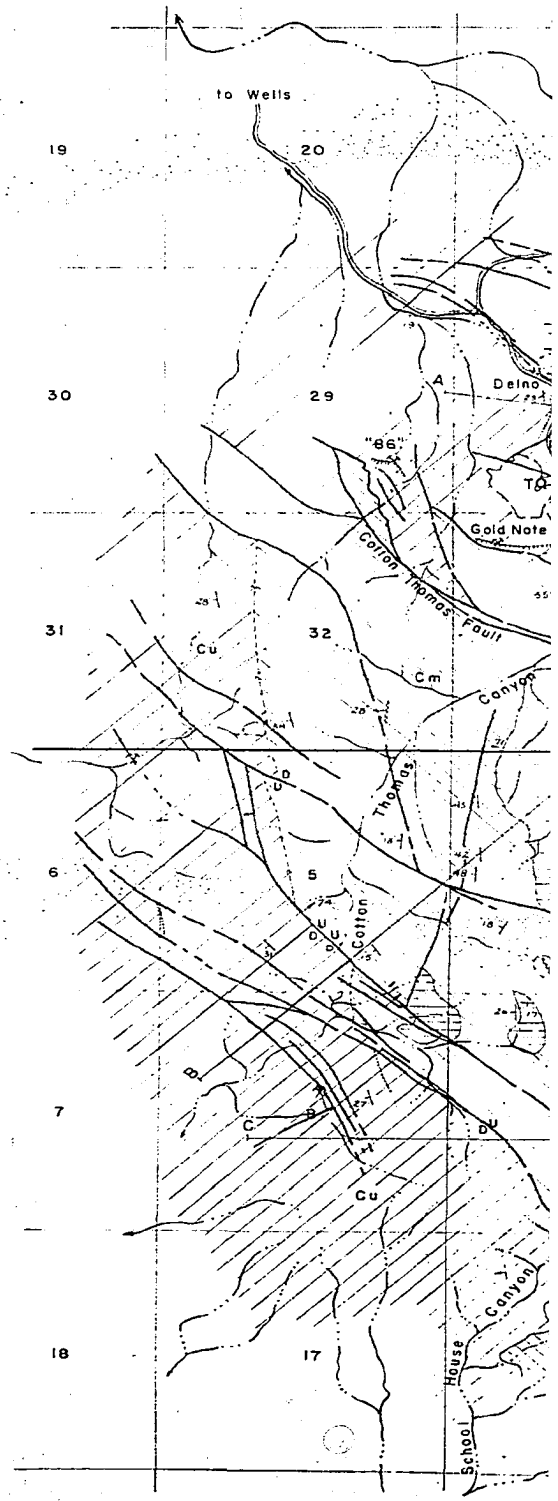
ORE BEDDING

STRIKE AND DIP OF BEDS

STRIKE AND DIP OF JOINTS

MINE OR PROSPECT

GENERALIZED STRIKE AND DIP



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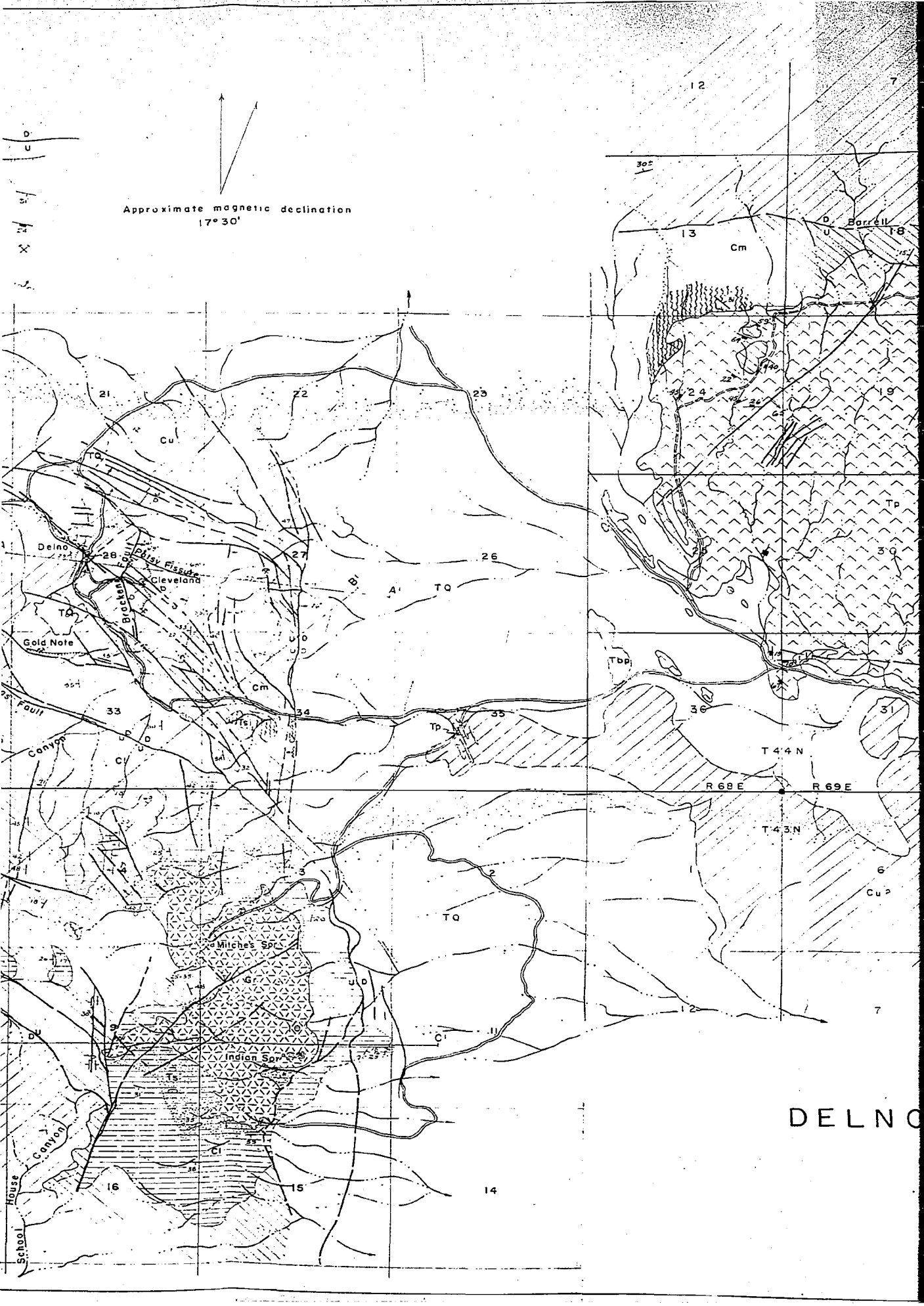

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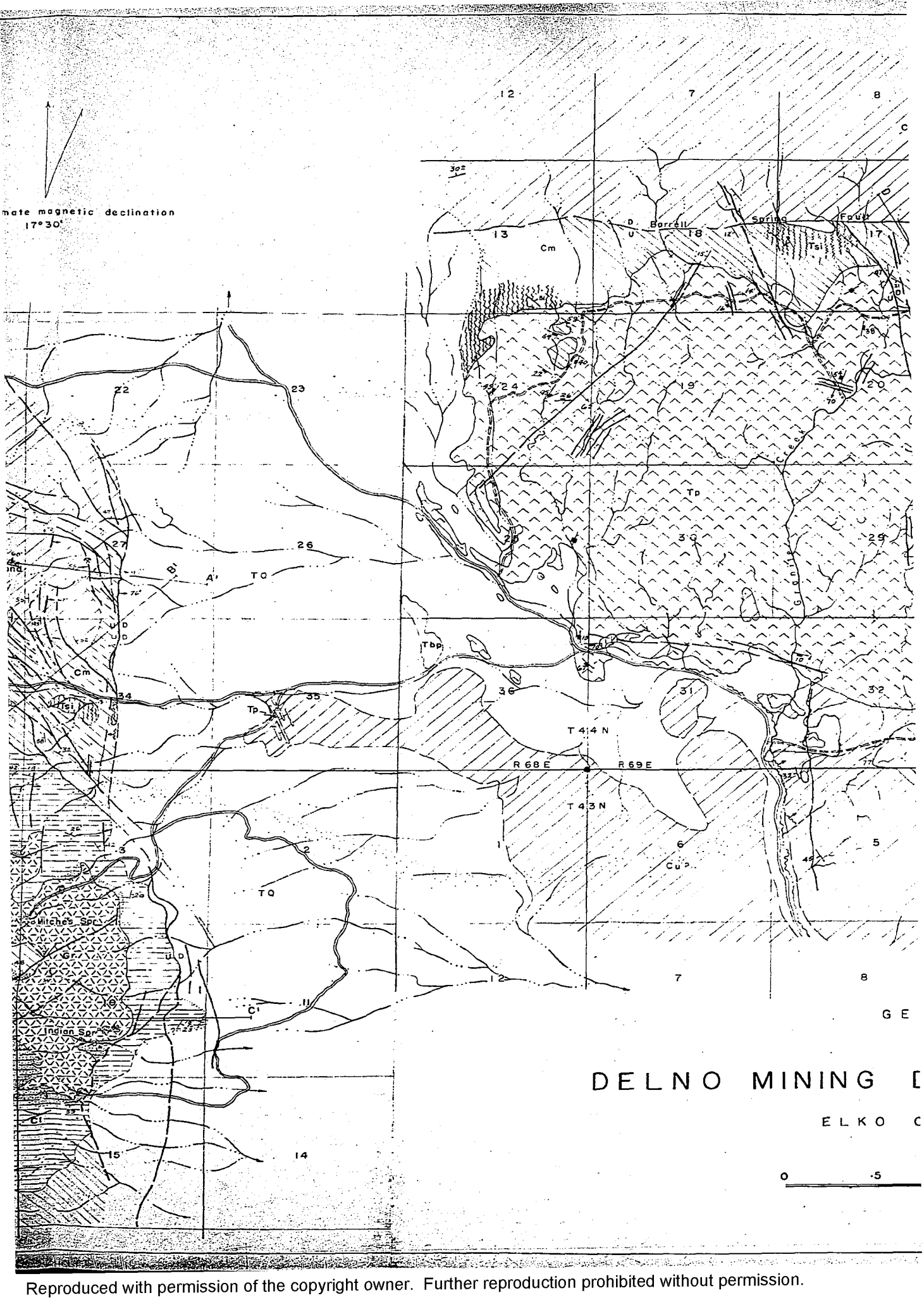

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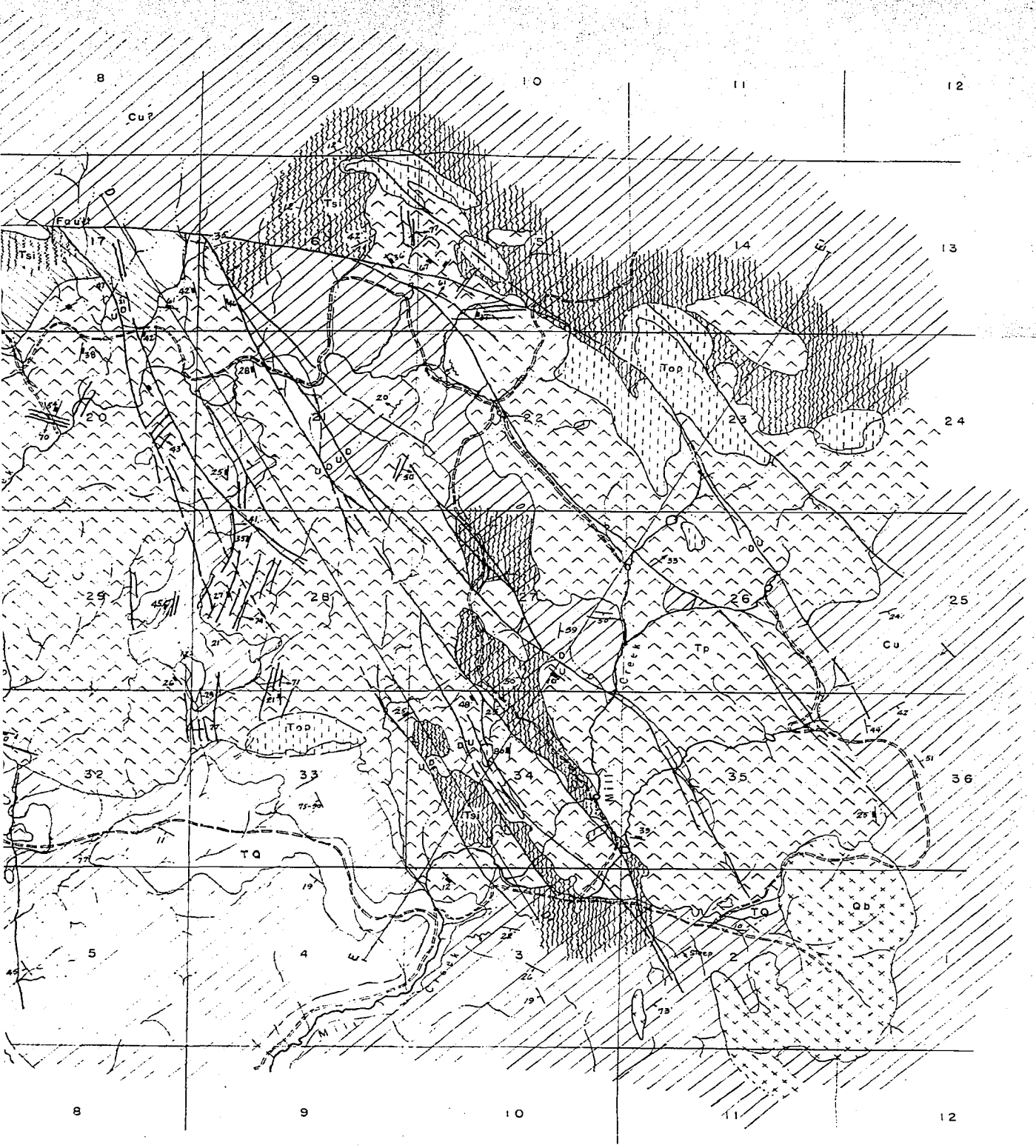

GEOLOGIC MAP

OF THE

NING DISTRICT AND VICINITY

ELKO COUNTY, NEVADA

·5 1·0 1·5 2·0 MILES

D·R·OLSEN APRIL, 1960

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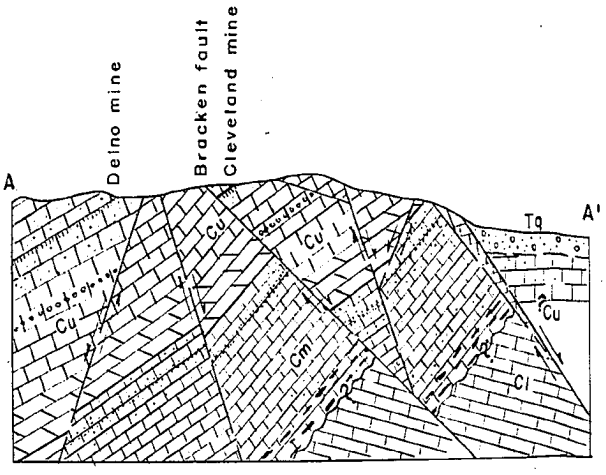

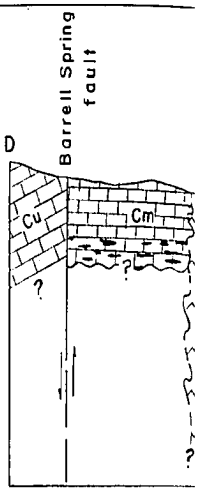

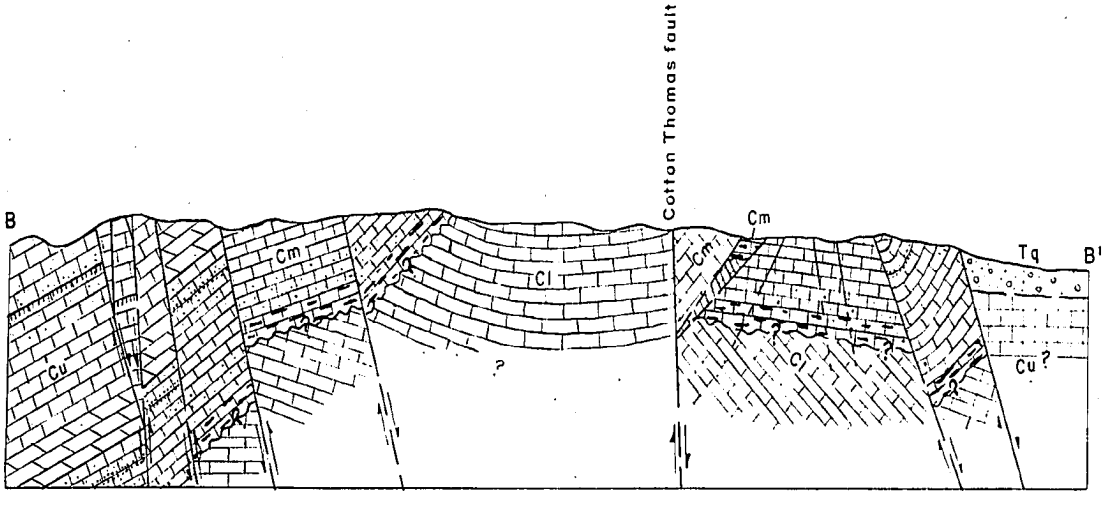

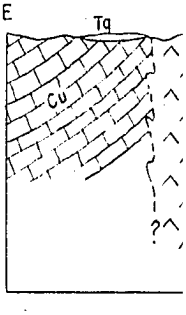

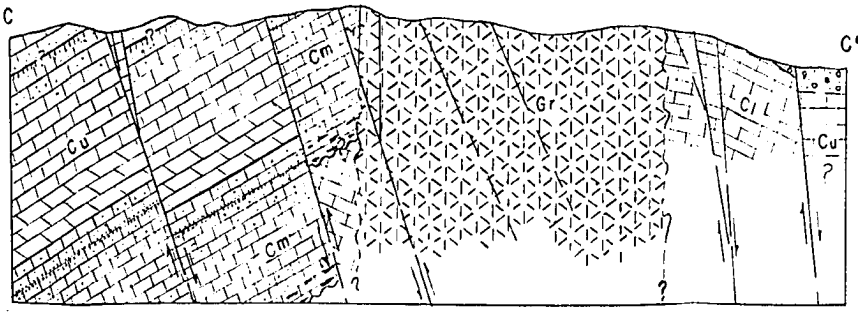

Tq, Tertiary-Quaternary

Gr, granite; Tp, rhyolite

"ore bedding"

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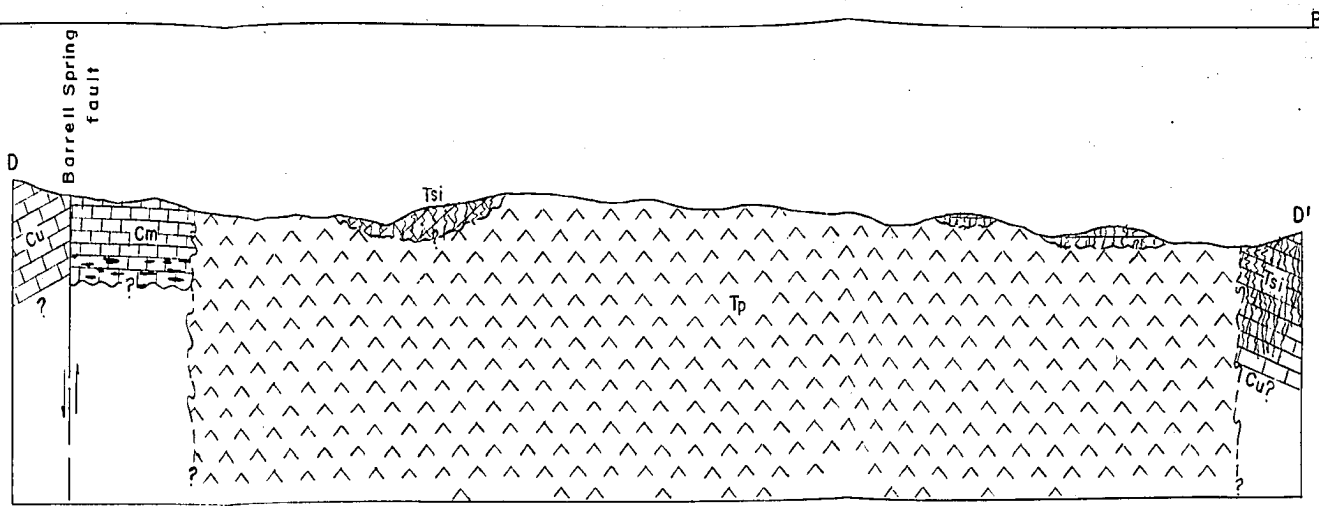

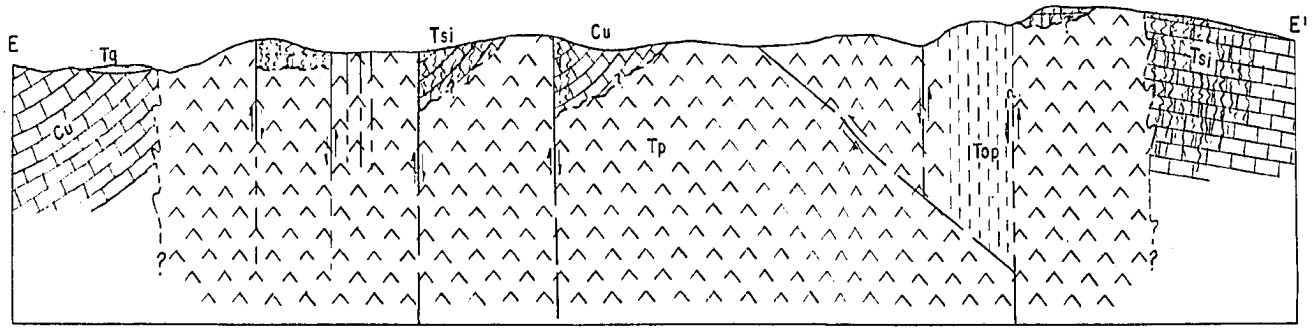

GEOLOGIC STRUCTURE SECTIONS

OF THE

DELNO MINING DISTRICT AND VICINITY

ELKO COUNTY, NEVADA

vertical scale not exaggerated topographic profile is only relative

1 Mile

ertiary-Quaternary undiff.; Cu, Carboniferous, upper unit; Cm, Carboniferous, middle unit; Cl, Carboniferous, lower unit

ranite; Tp, rhyolite porphyry, intrusive; Tsi, silicification zone; Top, opalite

edding" "tin bedding"

D·R·Olsen 1960

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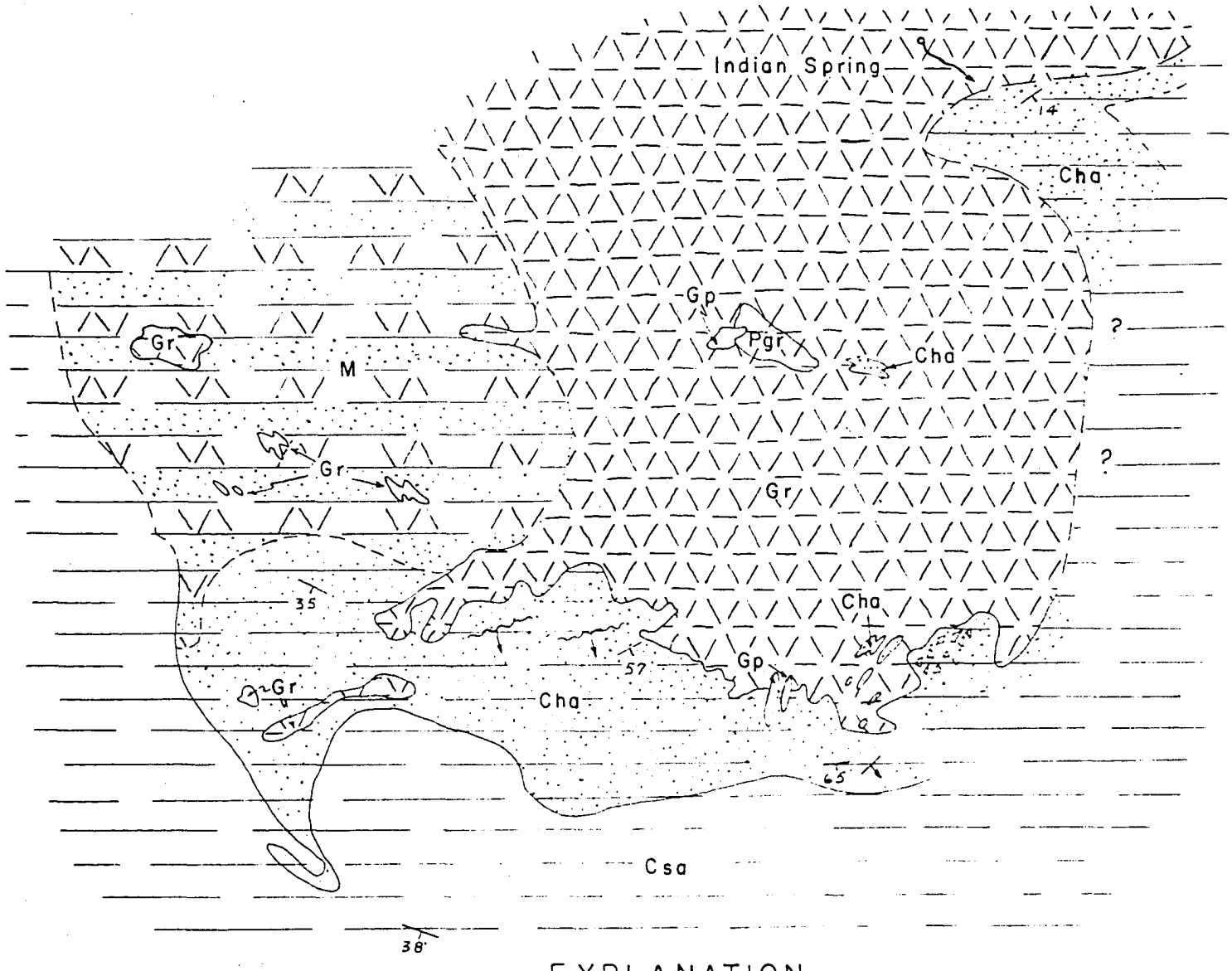

EXPLANATION

N

Granite	Gr
Porphyritic granite	Pg
Granite porphyry	Gp
Mixed granite and sedimentary rocks	M
Carboniferous sedimentary rocks	
Highly altered	Cha
Slightly altered	Csa

GEOLOGIC MAP

CONTACT ZONE SOUTH END OF GRANITE

Delno District, Nevada

0 500 1000 Feet

Geology by Donald R. Olsen, 1958

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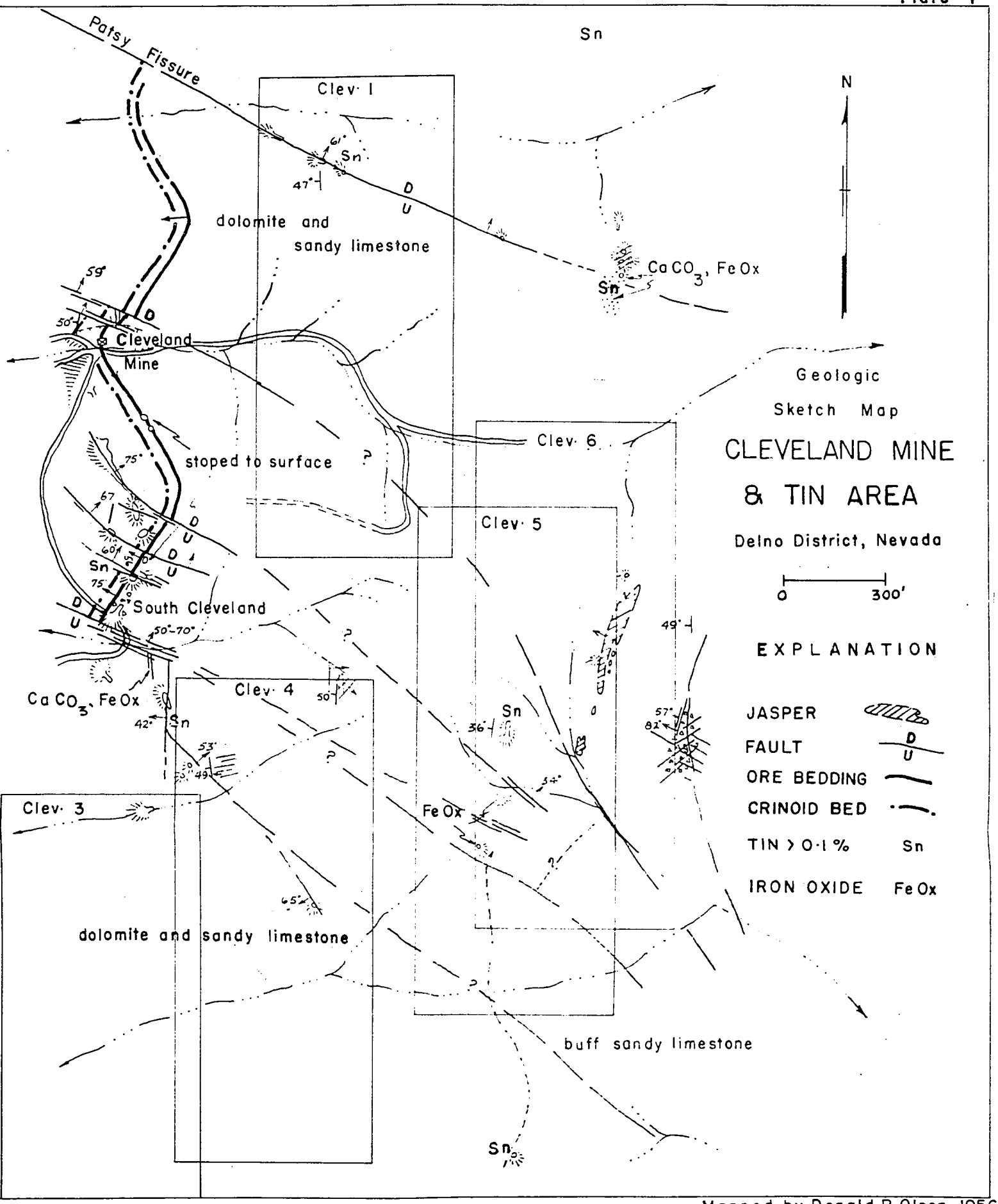

Mapped by Donald R. Olsen, 1956

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