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Jour. Research U.S. Geol. Survey
Vol. 6, No. 1, Jan.–Feb. 1978, p. 133–147

PLEISTOCENE RHYOLITE OF THE MINERAL MOUNTAINS, UTAH—GEOTHERMAL AND ARCHEOLOGICAL SIGNIFICANCE

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Abstract.—Little-eroded rhyolitic tuffs, flows, and domes extend over about 25 km^2 along the western side of the Mineral Mountains, southwestern Utah, which is along the eastern edge of the Roosevelt KGRA (Known Geothermal Resource Area). Initial eruptions resulted in two low-viscosity lava flows of nonporphyritic rhyolite. These were followed by bedded pumice falls and nonwelded ash flows. The youngest activity produced at least nine viscous domes and small lava flows of rhyolite that contain 1–5 percent phenocrysts of quartz, plagioclase, sodic sanidine, and biotite; distinction between domes and eroded flow segments locally is difficult.

Potassium-argon ages indicate that all the rhyolite of the Mineral Mountains was erupted between 0.8 and 0.5 m.y. ago. The rhyolite rests on dissected granite of the Mineral Mountains pluton, the largest intrusion in Utah, which has yielded published K-Ar ages of 9 and 15 m.y. A small older dissected rhyolite dome, about 8 m.y. old, occurs just west of the range front. Whether the young ages of the pluton represent time of intrusion or of later reheating, they, in conjunction with the Pleistocene rhyolite in the Mineral Mountains, do indicate a major late Cenozoic thermal anomaly, the size and age of which is significant to evaluation of the Roosevelt KGRA. The rhyolite is also the only known source of implement-grade obsidian in the southwest between eastern California and northern New Mexico.

As part of the U.S. Geological Survey's geothermal energy program, age, composition, and distribution data are being obtained for upper Cenozoic volcanoes in the western United States that have erupted significant amounts of silicic rocks. Such silicic rocks, mostly rhyolites, are considered possible indicators of the subsurface presence of shallow magma chambers still sufficiently hot to have potential for geothermal resources. A rationale for this approach is outlined by Smith and Shaw (1975).

Large volumes of rhyolite associated with known geothermal resources have been described from Yellowstone National Park (Allen and Day, 1935; Christiansen and Blank, 1972), in the Jemez Mountains in New Mexico (Smith, Bailey, and Ross, 1970), and in the Long Valley area, California (Bailey, Dalrymple, and Lanphere, 1976). Around the margins of the Colorado Plateau, small volumes of similar silicic rocks that also seem worthy of reconnaissance evaluation in terms of geothermal signifiance occur in the San Francisco Mountains volcanic field, Arizona (Robinson, 1913; Moore, Wolfe, and Ulrich, 1974), in the Mount Taylor and Taos Plateau volcanic fields of New Mexico (Hunt, 1938; Lambert, 1966), and in the Mineral Mountains, Utah.

In the Mineral Mountains, southwestern Utah, young rhyolite masses extend discontinuously for about 15 km along the range crest and cover an area of less than 25 km^2; these have been little studied and previously were interpreted as erosional remnants of a single large silicic volcano of late Tertiary age (Earll, 1957; Liese, 1957). This brief report presents new geologic data, including K-Ar ages which demonstrate that many separate lava domes, flows, and tuffs were erupted from vents along the range crest between 0.8 and 0.5 m.y. ago. Along one of the western range-front faults, about 2 km northwest of the nearest rhyolitic volcanic rocks, Roosevelt Hot Springs is located within a KGRA (Known Geothermal Resource Area) that is actively being developed for geothermal power production. The youthful silicic volcanism recorded by the rhyolite of the Mineral Mountains suggests the presence of a still-hot buried magma chamber that may be the heat source for the KGRA.

Acknowledgments.—Discussions with Glenn A. Izett and Irving Friedman, who examined the rhyolites, and Sr-Rb data on granite from the Mineral Mountains pluton by Carl E. Hedge aided the evolution of ideas on the rhyolite of the Mineral Mountains. We thank John S. Pallister and Alan Martz for assistance

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in the field and for making mineral separations for K-Ar dating and microprobe analyses, respectively. We also thank Gary L. Galyardt for information on the Roosevelt KGRA.

Research by authors from the University of Utah was supported by National Science Foundation Grant GI-43741 and U.S. Energy Research and Development Administration Contract no. EY-76-S-07-1601.

GENERAL GEOLOGIC SETTING

The Mineral Mountains, in west-central Utah (fig. 1), are a typical basin-range horst, which rises about 1 km above the adjacent alluviated basins, the Escalante Desert to the west and an unnamed valley to the east. The horst extends nearly 50 km in a northerly direction and is in general about 10 km wide.

On the western and northern sides of the range, metamorphic rocks of the Wildhorse Canyon Series of Condie (1960), of probable Precambrian age, are the dominant rocks, but on the southern, northern, and eastern sides of the range, Paleozoic and Mesozoic sedimentary rocks are exposed widely. These layered rocks are intruded by a distinctive body of granite, the Mineral Mountains pluton, which is the largest single exposed intrusive body in Utah, covering nearly 250 km². This granite and associated pegmatite and aplite may be as young as late Miocene, having yielded two K-Ar ages on feldspars of 15 and 9 m.y. from different sample sites (Park, 1968; Armstrong, 1970). These young apparent ages are supported in a general way by results of a Rb-Sr isotopic study. A Rb-Sr isochron, based on 11 analyses of whole-rock samples ranging in composition from diorite to aplite, shows exceptionally bad scatter but suggests that the age of the main batholith is about 35 m.y., with sizable chemical modification—especially Sr loss—having occurred 7–15 m.y. ago (C. E. Hedge, written commun., 1976).

Prior to the onset of late Cenozoic rhyolitic volcanism in the Mineral Mountains, the Mineral Mountains pluton and its country rocks were deeply dissected to form a rugged erosional topography with towering pinnacles rising above narrow usually dry valleys.

The Mineral Mountains are bounded on the west, and probably on the east side, by north-striking normal faults. The trend of the bounding faults on the west is marked locally in the Roosevelt KGRA by discontinuous elongate mounds of opaline sinter and other hot-spring deposits. Near the northern end of this trend is Roosevelt Hot Springs (Petersen, 1975). Water temperatures as high as 90°C have been recorded from Roosevelt Hot Springs, but sometime prior to 1966 the springs dried up (Mundorff, 1970). Phillips Petroleum Co., the successful bidder on the KGRA in 1974, is continuing exploration on the property. Numerous test wells so far drilled in the KGRA have documented the presence of a low-salinity liquid-dominated geothermal system (Berge, Crosby, and Lenzer, 1976; Greider, 1976). The thermal anomaly covers approximately 32 km², and reservoir temperatures exceed 250°C.

RHYOLITE OF THE MINERAL MOUNTAINS

Rhyolitic rocks in the Mineral Mountains include three stratigraphically distinct sequences. Lowermost are two nearly nonporphyritic obsidian-rich lava flows. These are overlain by a pyroclastic sequence, including both ash-fall and ash-flow tuffs. Stratigraphically highest are porphyritic rhyolite lava domes erupted from at least nine separate vents, most of which are along the range crest.

Flows of Bailey Ridge and Wildhorse Canyon

The oldest rhyolitic rocks in the Mineral Mountains are two lava flows of virtually nonporphyritic flow-layered rhyolite. One flow is exposed for about 3 km along Bailey Ridge and in Negro Mag Wash (fig. 2) northwest of Bearskin Mountain. The other is exposed for about 3.5 km along Wildhorse Canyon, west of Bearskin Mountain. Both flows were originally as much as 100 m thick and followed pre-existing valleys that drained the western side of the Mineral Mountains, with relief much like the present, and that were graded nearly to the present levels at valley fronts. Both flows are only slightly dissected, and much of their primary upper surfaces of frothy pumiceous perlitic rubble is preserved.

Where deeply dissected, both flows display similar cooling and crystallization zonations. The basal few meters of the flow, resting directly on medium- to coarse-grained Tertiary granite of the Mineral Mountains pluton, consists of dense black obsidian. The obsidian has well-developed flow lamination defined by alined microlites of feldspars and opaque oxides (fig. 3*A*). The basal obsidian zone grades upward within a meter or two into a well-layered zone, in which dark obsidian and light-gray or brown finely crystallized flow-layered lava alternate. The interior of the flow is as much as 10–30 m thick and consists of gray relatively structureless devitrified rhyolite, in places containing concentrations of ovoid gas cavities locally filled with vapor-phase crystallization products.

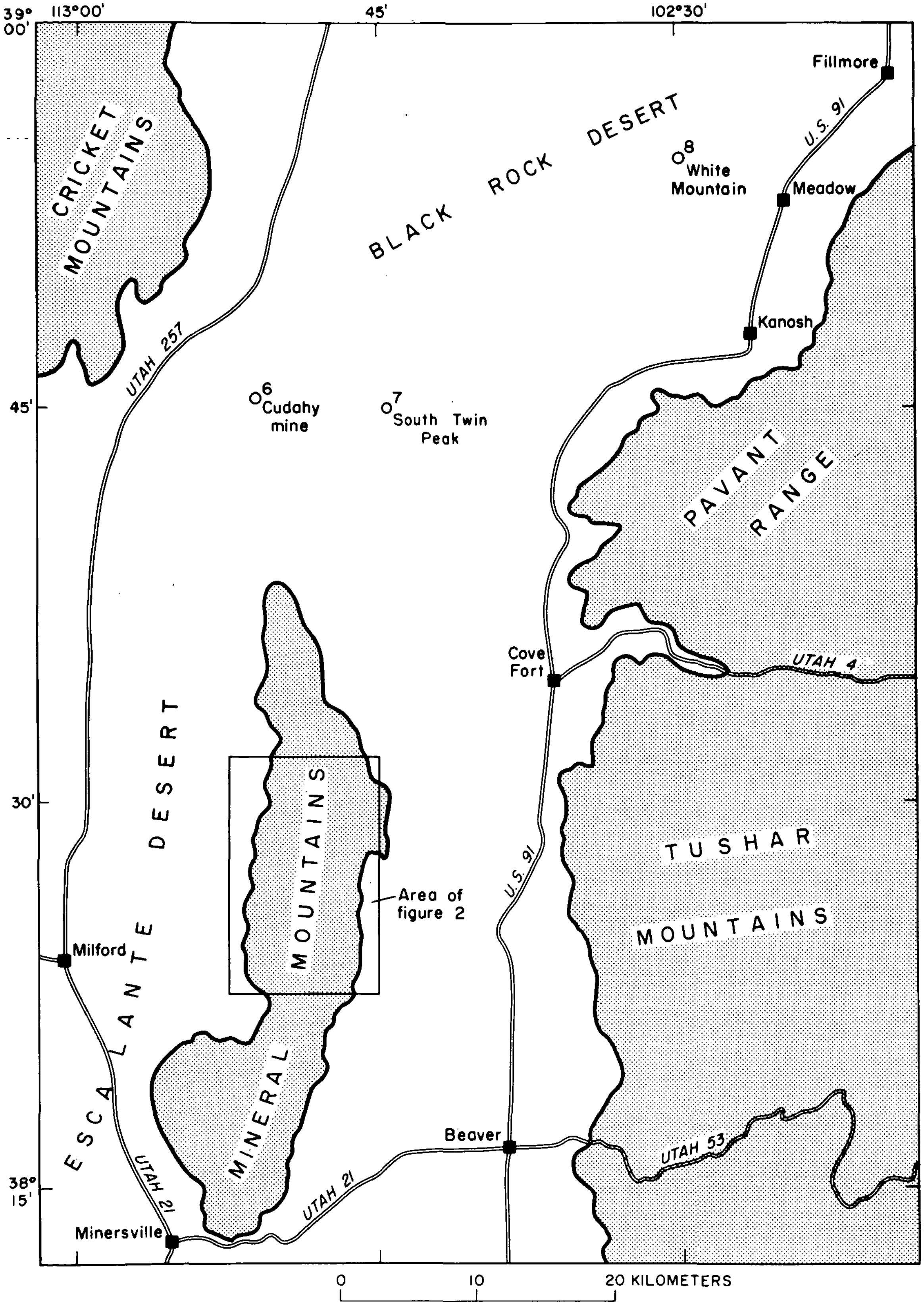


FIGURE 1.—Index map showing location of the Mineral Mountains and nearby areas, Utah. Numbers indicate locations of some dated samples (table 3); the others are shown on figure 2.

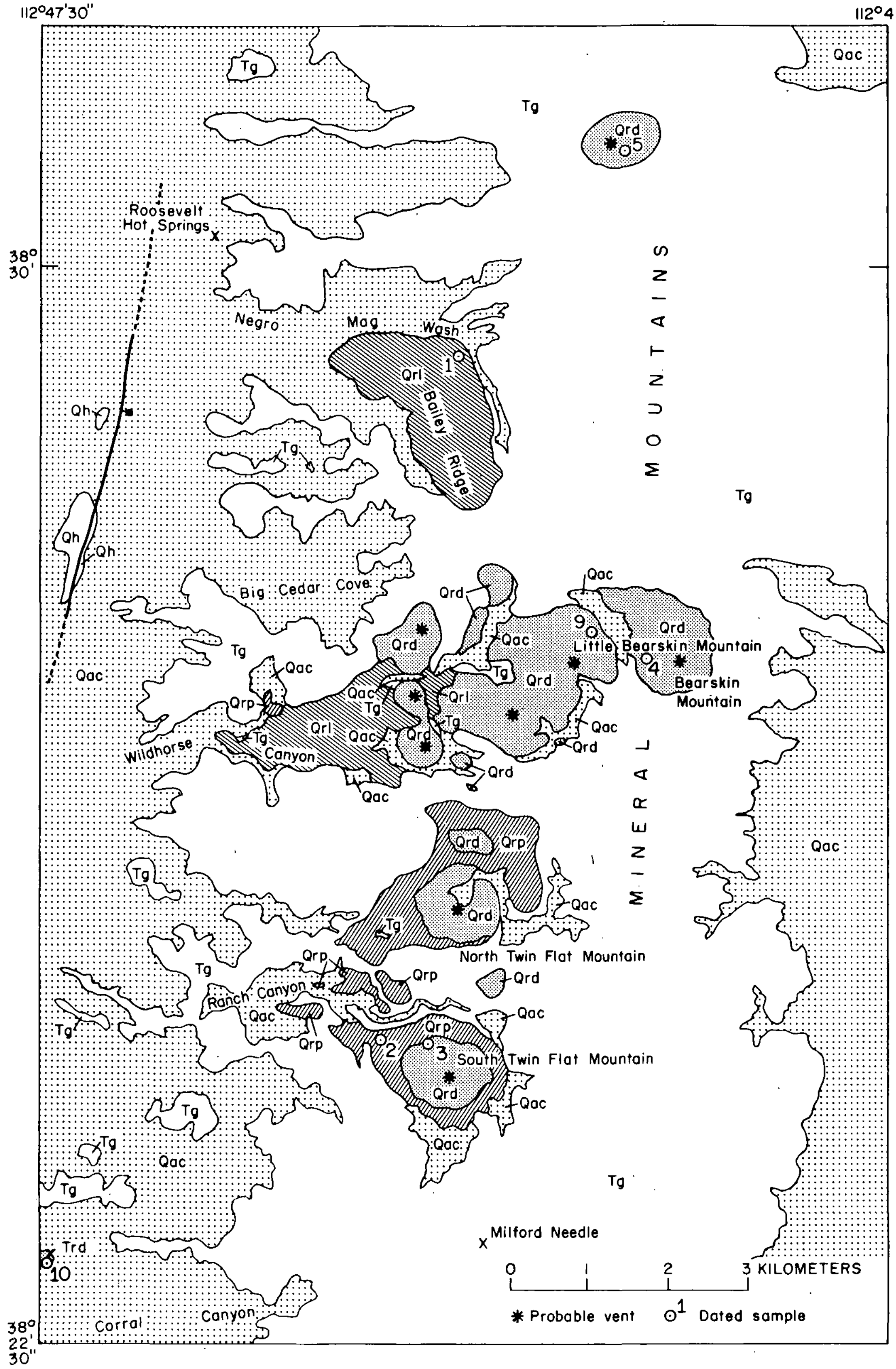
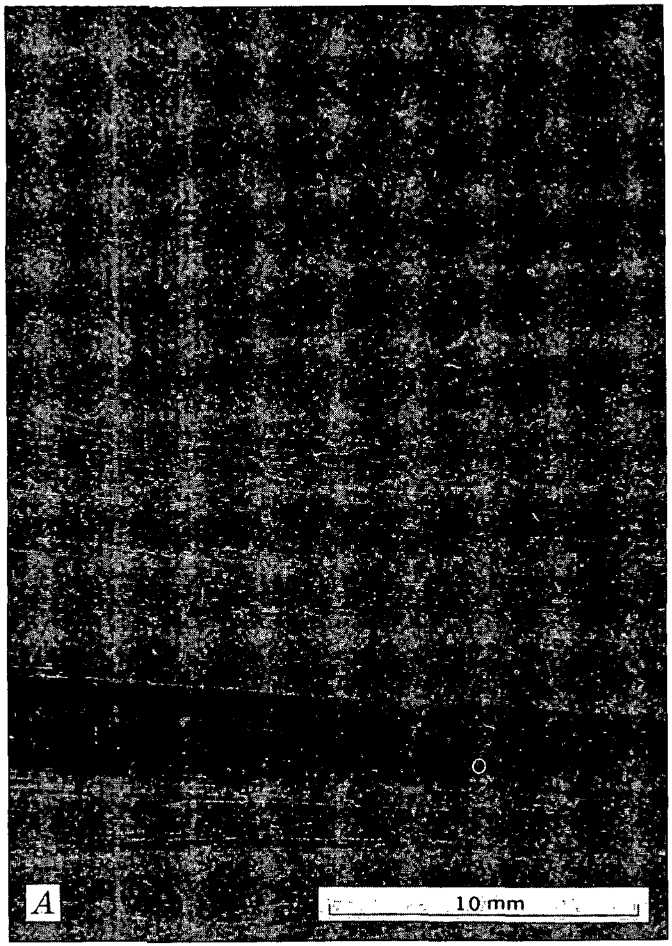


FIGURE 2.—Generalized geologic map of the central Mineral Mountains, Utah, showing distribution of Pleistocene rhyolitic rocks and locations of dated samples (table 3). Rock units, from oldest to youngest: **Tg**, Tertiary granite of Mineral Mountains; **Trd**, Tertiary rhyolite dome of Corral Canyon; **Qrl**, lava flows of Bailey Ridge and Wildhorse Canyon; **Qrp**, pyroclastic rocks; **Qrd**, lava domes; **Qac**, surficial deposits, primarily alluvium and colluvium; **Qh**, hot-spring deposits. Fault



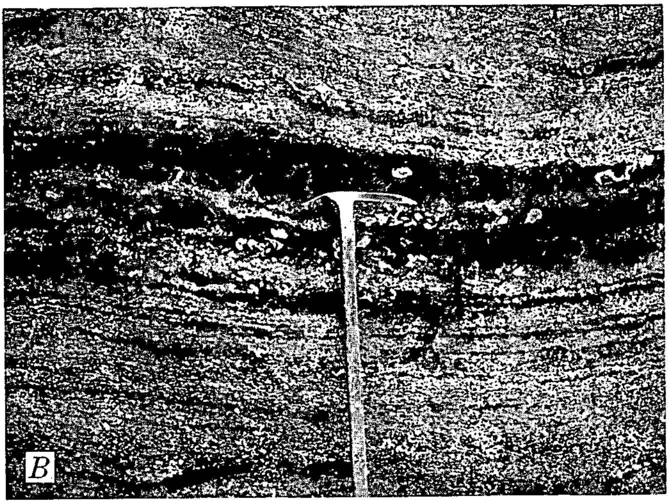


FIGURE 3.—Photographs of the Wildhorse Canyon flow. *A*, Photomicrograph showing recumbently folded flow lamination. Flow structures are defined by alined microlites. *B*, Alternating layers of obsidian and devitrified rhyolite in upper part of flow.

In upper parts of the flow a few meters of flow-layered obsidian are interlayered with devitrified rock (fig. 3*B*), passing upward into a more uniform dark glass zone or grading directly into a frothy rubbly breccia of tan perlitic pumice as much as 10 m thick at the top of the flow.

The flow layering and lamination in these rhyolitic lavas is remarkably planar and uncontorted as compared to the swirly internal structures typical of many rhyolitic lava flows. The "ramp structures" that occur commonly in upper parts of silicic flows (Christiansen and Lipman, 1966), are absent or poorly developed, and subhorizontal layering is typical throughout the Bailey Ridge and Wildhorse Canyon flows. The most common deviations from planar layering are small, typically rootless recumbent folds (fig. 3*A*), most limbs of which are less than 1 m long. These flowage features, as well as the relatively slight thickness of each lava flow as compared to its longitudinal extent, indicate that they were characterized by lower emplacement viscosities than many silicic lava flows.

Vents for these oldest flows of the Mineral Mountains have not been found. The Wildhorse Canyon flow appears to extend up drainage beneath younger lava domes in the upper part of the canyon, although exposures of the critical relations are poor because of cover by rubble. Probably the vent area for this flow is beneath the younger lavas to the east. If the Bailey Ridge flow vented from beneath its uppermost outcrop area, surface structures of this part of the flow give no indication of any concealed vent. This part of the flow is little dissected, however, and the vent area could be completely buried. Alternatively, the Bailey Ridge flow, and also the Wildhorse Canyon flow, might have come from higher on the slope, underneath the area now covered by the Bearskin and Little Bearskin Mountain lava domes. However, this would require that the upper portions of the flows be largely removed by erosion while the lower portions were left relatively undissected.

The Bailey Ridge and Wildhorse Canyon flows are petrographically similar. They contain less than 0.5 percent total phenocrysts, the majority of which are alkali feldspar (table 1). There are trace amounts of oligoclase, biotite, titanomagnetite, and ilmenite. The two flows are virtually identical in chemical composition (table 2). They are typical silicic rhyolites, containing about 76.5 percent SiO_2 and just over 9 percent total alkalis. The fresh obsidians contain more fluorine than water; secondarily hydrated pumice from the Bailey Ridge flow contains 2.4 percent total H_2O. The magmatic temperatures of these flows were about 750°C, as determined from compositions of iron-titanium oxides and coexisting plagioclase and alkali

TABLE 1.—*Modal compositions of radiometrically dated samples*

[Est., estimate; tr., trace; leaders (--), not present; *, microphenocrysts]

Field No.	Unit	Ground-mass	Plagio-clase	K-feldspar	Quartz	Biotite	Horn-blende	Clino-pyroxene	Opaques	Points counted
75L-17	Bailey Ridge flow, obsidian----------------	99.9	--	tr.	tr.	--	--	--	--	Est.
75L-15	Tuff of Ranch Canyon obsidian block---------	98.2	0.6	0.8	0.4	tr.	--	--	tr.	3,615
75L-16	South Twin Flat Mountain dome, obsidian with patchy devitrification-	92.6	1.2	3.9	2.3	tr.	--	--	tr.	3,034
75L-56	Bearskin Mountain, obsidian---------------	97.2	.3	1.2	1.2	0.1	--	--	tr.	4,725
75R-53	Little Bearskin Mountain dome, obsidian---------	96.0	.9	1.9	1.0	--	--	--	0.1	2,000
75L-18A	Northern dome, frothy perlite----------------	97.4	.4	1.3	.7	.1	--	--	.1	2,642
75L-19	Rhyolite of the Cudahy mine, obsidian---------	100	--	--	--	--	--	--	--	Est.
75L-21	Black Rock desert felsite plug-----------	91.2	5.8	1.2	--	tr.	--	1.2	.6	3,188
75L-23	Rhyolite of White Mountain, obsidian-----	94	--	--	--	--	*6	--	--	Est.

TABLE 2.—*Chemical analyses and CIPW norms of rhyolites of the Mineral Mountains*

[Analyses by S. H. Evans, Jr., by standard wet chemical techniques. Key to analyses; 74-3A, Obsidian, Bailey Ridge flow; 74-8, Obsidian, Wildhorse Canyon flow; 75-14, Obsidian, Little Bearskin Mountain dome; 75-20, Basal Obsidian, North Twin Flat Mountain dome. Leaders (---) not present; tr., trace]

Chemical Analyses				
	74-3A	74-8	75-14	75-20
SiO_2	76.52	76.51	76.42	76.45
TiO_2	.12	.12	.08	.08
Al_2O_3	12.29	12.29	12.79	12.79
Fe_2O_3	.31	.23	.20	.30
FeO	.46	.51	.38	.29
MnO	.05	.05	.09	.10
MgO	.08	.08	.11	.12
CaO	.64	.65	.44	.40
Na_2O	3.80	3.77	4.42	4.39
K_2O	5.24	5.28	4.72	4.73
P_2O_5	.02	.01	tr.	.06
H_2O+	.12	.06	.13	.10
H_2O-	.06	.06	.01	---
F	.16	.15	.42	.44
Sum	99.87	99.77	100.21	100.25
Less F=O	.07	.06	.18	.19
Total	99.80	99.71	100.03	100.06

CIPW Norms				
	74-3A	74-8	75-14	75-20
Q	33.40	33.28	33.22	32.48
c	---	.26	.41	.45
or	30.96	31.20	27.89	27.95
ab	32.15	31.90	37.40	37.15
an	1.00	1.02	---	---
di-wo	.37	.47	---	---
di-en	.11	.12	---	---
di-fs	.27	.38	---	---
hy-en	.09	.08	.27	.30
hy-fs	.21	.26	.57	.34
mt	.45	.33	.29	.43
il	.23	.23	.15	.15
ap	.05	.02	---	.14
fr	.33	.29	.61	.45
rest	.18	.12	.14	.10
Total	99.80	99.96	99.95	99.94

feldspar. The relatively low emplacement viscosities, indicated by the planar flow structures of these rhyolites, do not therefore seem related to exceptionally high emplacement temperatures.

A single K-Ar radiometric age determination of 0.79±0.08 m.y. (table 3, no. 1), from the toe of the Bailey Ridge flow, is the oldest age obtained from any rhyolite of the Mineral Mountains. The Bailey Ridge flow has a reversed paleomagnetic pole position (table 4) indicating, in conjunction with K-Ar data, that it was erupted toward the end of the Matuyama polarity epoch. The Wildhorse Canyon flow has not yet been dated radiometrically, but it also is characterized by a reversed polarity, which, in conjunction with morphological and chemical resemblance to the Bailey Ridge flow and its position beneath some of the pyroclastic rocks, suggests a similar age.

Pryoclastic rocks

South of Wildhorse Canyon, pyroclastic rocks of ash-fall and ash-flow origin are the lowest exposed rhyolitic rocks. The main area of pyroclastic rocks is in Ranch Canyon, where tuffs bury rugged paleotopography much like the present land surface.

The pyroclastic rocks are only weakly consolidated and are mostly poorly exposed, underlying alluviated slopes. All the pyroclastic deposits, both ash-fall and and ash-flow, are white to light tan. They occur over an altitude range from 1950 m in valley-bottom exposures in Ranch Canyon to as high as 2540 m on the surrounding slopes. They also occur in the Cove Fort area, where they are overlain by basalt lava flows (Nash and Smith, 1977). Much of the pyroclastic sequence has been removed by erosion in Ranch Canyon, and it is not clear to what extent this altitude range reflects an actual total thickness of the original deposit and to what extent the pyroclastic rocks were thinner but blanketed the preexisting topography. In Ranch Canyon these rocks are overlain by the large lava domes on North and South Twin Flat Mountains and by smaller masses of rhyolitic lava on adjacent ridges. Although contacts between these domes and the pyroclastic rocks are nowhere well exposed, this stratigraphic sequence is indicated by structural zones in the rhyolite domes of North and South Twin Flat Mountains. The lowest exposures are of a subhorizontal

TABLE 3.—K-Ar *age determinations on upper Cenozoic rhyolites of the Mineral Mountains, Utah, and adjacent areas*

[Constants: $K^{40}\lambda_{\epsilon} = 0.581 \times 10^{-10}$/yr, $\lambda_{\beta} = 4.963 \times 10^{-10}$/yr; atomic abundance: $K^{40}/K = 1.167 \times 10^{-4}$; *Radiogenic argon; Potassium determinations made with an Instrumentation Laboratories flame photometer with a Li internal standard. Figures 1 and 2 give sample locations. Ages of WM76-3 and MR76-26 determined by S. H. Evans, Jr., and F. H. Brown; other ages determined by H. H. Mehnert]

Sample	Field No.	Unit	Material dated	Location (Lat N Long W)	K_2O (percent)	*Ar^{40} (10^{-10}) (moles/gram)	*Ar^{40} (percent)	Age (m.y.±2σ)
1	75L-17	Bailey Ridge flow	Obsidian	38°29′, 112°49′	5.10, 5.10	0.058	25.8	0.79±0.08
2	75L-15	Tuff of Ranch Canyon	Obsidian block	38°25′, 112°50′	4.63, 4.66	.047	47.1	0.70±0.04
3	75L-16	South Twin Flat Mountain dome	Sanidine	38°25′, 112°49′	8.14, 8.08	.059	18.1	0.50±0.07
4	75L-56	Bearskin Mountain dome	Obsidian	38°27′, 112°47′	4.48, 4.49	.048	20.2	0.75±0.10
						.039	13.5	0.60±0.12
5	75L-18A	North Dome	Sanidine	38°31′, 112°47′	9.36, 9.35	.073	24.5	0.54±0.06
6	75L-19	Cudahy mine	Obsidian	38°45′, 112°51′	4.91, 4.93	.168	46.0	2.38±0.15
7	75L-21	South Twin Peak	Sanidine	38°45′, 112°47′	11.13, 11.12	.373	54.3	2.33±0.12
8	75L-23	White Mountain	Obsidian	38°55′, 112°30′	4.63, 4.70	.029	15.9	0.43±0.07
	WM76-3		Obsidian		5.23, 5.25	.030	21.5	0.39±0.02
9	75R-23	Little Bearskin Mountain dome	Sanidine	38°27′, 112°48′	9.31, 9.15 [1]9.26	.080	31.8	0.61±0.05
10	MR76-26	Corral Canyon dome	Biotite	38°24′, 112°53′	8.72, 8.75	1.011	61.6	7.90±0.30

[1] Isotope dilution determination

TABLE 4.—*Preliminary data on magnetic polarities of rhyolites of the Mineral Mountains*

Unit	Number of samples	Declination	Inclination	Standard error (percent)
Normal samples:				
Northern dome	9	350	62	3
Big Cedar Cove dome	4	23	67	4
Ranch Canyon dome	5	22	44	5
Corral Canyon dome	3	332	25	20
Ranch Canyon ash	2	356	46	29
Wildhorse Canyon ash	6	349	48	5
Reversed samples:				
Bailey Ridge flow	6	173	-63	6
Wildhorse Canyon flow	4	168	-61	2

zone of basal flow breccia below the basal obsidian zone; this is the typical zonation expectable at the base of a lava flow or dome and would be an improbable relation if the pyroclastic rocks had been plastered against older lava domes. Thus, the lava dome of South Twin Flat Mountain overlies pyroclastic rocks that are at least 60 m and probably as much as 180 m thick, and these figures suggest minimum thicknesses of the pyroclastic unit.

The lower pyroclastic rocks are beds of air-fall pumice and ash at least 10 m thick and probably much thicker. Individual beds are a few centimeters to about a meter thick. Variable dips indicate that the ash was deposited on the underlying granite, on a surface as rugged as the present one. The pumice and ash contain several percent of small phenocrysts of quartz, oligoclase, alkali feldspar, biotite, magnetite, ilmenite, sphene, and allanite. This mineral assemblage is generally characteristic of the youngest rhyolite flows as well. Associated with the pumice and ash are a few percent of rhyolitic lithic debris, including devitrified rhyolite, perlite, and sparse obsidian fragments. Phenocrysts in the lithic debris are sparse, generally similar to those in the flows of Bailey Ridge and Wildhorse Canyon.

Ash-flow deposits widely overlie the ash-fall beds in Ranch Canyon. The ash-flow deposits locally are at least 50 m thick; probably the total thickness is much greater, but accurate estimates are difficult because of the poor exposures. The ash-flow deposits are everywhere nonwelded and only weakly consolidated; they tend to weather to small conical hills. On especially

steep slopes the ash-flow deposits rest directly against granite, with no intervening ash-fall material (fig. 4). In exceptionally good exposures, several flow units —each a few meters thick—can be recognized in the ash-flow deposits, with partings between the flow units marked by local concentrations of pumice, lithic debris, or better sorted ash.

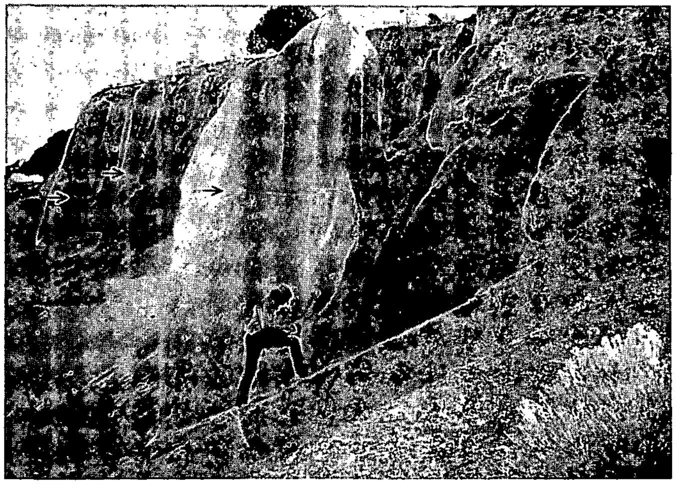


FIGURE 4.—Ash-flow tuff, resting on a rugged erosion surface cut on granite of the Mineral Mountains pluton. Arrows indicate faint parting between flow units of tuff. From northern side of Ranch Canyon at about 2105-m elevation.

On the northern side of lower Wildhorse Canyon, an isolated patch of pyroclastic material about 150 m across consists of finely laminated white fine-grained ash of lacustrine origin. These beds of water-reworked ash are younger than the Wildhorse Canyon flow and were deposited in a local basin dammed by the flow. The ash has a refractive index similar to that of the pyroclastic rocks in Ranch Canyon, one valley to the south, suggesting to us that it represents a reworked marginal facies of this deposit. In contrast, this patch of lacustrine tuff is interpreted by Glenn Izett (written commun., 1976) as airborne Bishop ash, from the Long Valley caldera in California, on the basis of small compositional differences with other rhyolites of the Mineral Mountains.

A single whole-rock K-Ar age on an obsidian clast from ash-flow tuff in Ranch Canyon yielded an age of 0.70±0.04 m.y. (table 3, no. 2), providing an older limit for the age of the pyroclastic rocks. The pyroclastic deposits in Ranch Canyon, as well as the local lake beds in Wildhorse Canyon. have normal magnetic polarities in contrast to the reverse polarities of Bailey Ridge and Wildhorse Canyon flows. Thus, the pyroclastic rocks have been deposited during the Brunhes polarity epoch.

Porphyritic lava domes

The stratigraphically highest part of the upper Cenozoic volcanic assemblage in the Mineral Mountains is a group of at least nine separate perlite-mantled lava domes and small flows of porphyritic rhyolite. The domes tend to occur along the crest of the range, discontinuously over a zone about 15 km long. These domes form some of the highest topographic points in the Mineral Mountains, including Bearskin Mountain with an elevation of 2772 m (9095 ft). Individual domes are as much as 1 km across at their bases and stand as much as 250 m high, although dimensions are difficult to determine precisely because of the irregular pre-existing topography and subsequent erosion. Small stubby flows extend out from some of the domes, and some small isolated patches of rhyolite (fig. 2) may represent either eroded flow remnants or small separate domes.

The larger domes, such as Bearskin and Little Bearskin Mountains, are little eroded, and surface exposures consist largely of blocks of tan perlitic glass that are slightly modified remnants of the original brecciated frothy carapaces of the domes. Scattered fragments of dense black obsidian, derived from beneath the perlitic breccia, occur about a third of the way above the base of these domes. Float of well-layered devitrified rhyolite is exposed locally just above the zone of obsidian fragments. Pumiceous material, that in places ravels out from below the level of the obsidian zone, may represent an initial pyroclastic fall that is not well exposed.

Other domes, such as those of North and South Twin Flat Mountains (fig. 5), have been more deeply dissected, in this case by the reexcavation of Ranch Canyon, and their internal structural and crystallization features are better exposed. The internal features of all these late domes are in general similar. A basal black vitrophyric zone is everywhere well developed, in places resting on lighter colored glassy basal flow breccia. The vitrophyre zone, which is as much as 5–10 m thick, grades upward into devitrified rock through a transition zone a few meters thick in which flow-layered obsidian alternates with devitrified rock that is commonly highly spherulitic. The devitrified interiors of the flows tend to be light gray and contain conspicuous spherulites. In places, gas cavities several centimeters across contain lithophysal fillings. The interiors of the flows tend to be crudely flow layered, with the layering subhorizontal just above the basal glass zone, but becoming steeper in upper parts of the lava dome. Near-vertical riblike masses of flow-layered devitrified rock are commonly exposed high on the

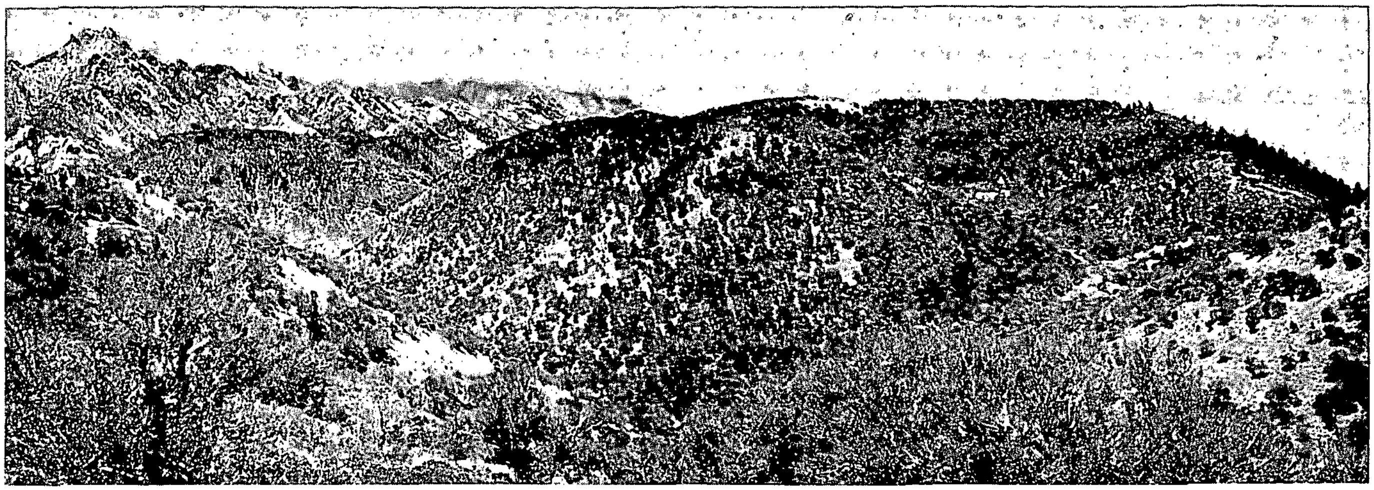


FIGURE 5.—Rhyolite domes of North and South Twin Flat Mountains. Rugged terrain in distance, including Milford Needle (elev. 2920 m) on the left side of the picture, is underlain by granite of the Mineral Mountains pluton. Photographed from ridge between Ranch and Wildhorse Canyons.

domes, where erosion has stripped away the surface mantle of frothy perlite. The steeply dipping flow layering and ramp structures of these domes thus are in contrast to structures in the older lava flows of Wildhorse Canyon and Bailey Ridge.

The porphyritic domes typically lack well-developed central craters (for example, the South Twin Flat Mountain dome) although several have slight central depressions that have been breached and accentuated by erosion. Breached depressions are especially evident for the unnamed northern dome, which is on the range crest northeast of Negro Mag Wash (fig. 2), Bearskin Mountain dome, and North Twin Flat Mountain dome (fig. 5).

All the domes contain several percent phenocrysts of quartz, oligoclase, alkali feldspar, biotite, and iron-titanium oxides (table 1). Trace amounts of sphene and allanite occur in some domes. Hornblende, zircon, and allanite are present in the Corral Canyon dome, the southernmost exposure of rhyolitic volcanic rocks. The North and South Twin Flat Mountain domes have 5–8 percent total phenocrysts, distinctly more than any of the others. The obsidian zones of these two domes appear even more phenocryst-rich, because of the presence of small "snowflake" devitrification spots. The flows in upper Wildhorse Canyon and to the north contain only 2–3 percent total phenocrysts.

Two analyzed samples of the porphyritic domes (table 2) are chemically similar silicic alkalic rhyolite. In comparison with the older flows of Bailey Ridge and Wildhorse Canyon, the domes are slightly but significantly higher in Na_2O and F; they are lower in K_2O and CaO.

Lack of continuity, and thus absence of contact relations, between the domes makes relative ages of the domes difficult to determine. On the basis of amount of dissection, North and South Twin Flat Mountains may be among the oldest, and Bearskin Mountain among the youngest of the domes. The K-Ar ages (table 1), petrographic and chemical similarities, and the generally similar degree of erosional dissection indicate that the domes are about the same age. Stratigraphic relations on the northern side of the North Twin Flat Mountain dome suggest that this dome is older than the unnamed ridge-capping flow 0.5 km north of it (fig. 2). Bearskin Mountain and the three domes extending southwest from it appear compositionally homogeneous, consisting of phenocryst-poor rhyolite similar to the rhyolite that overlies the North Twin Flat Mountain dome. The Bearskin Mountain dome has yielded K-Ar ages on obsidian of 0.60 ± 0.12 and 0.75 ± 0.10 m.y. (table 3, no. 4), and the Little Bearskin Mountain dome has an indicated sanidine age of 0.61 ± 0.05 m.y. (table 3, no. 9). Sanidines from obsidian of South Twin Flat Mountain and the unnamed northern dome have yielded K-Ar ages of 0.50 ± 0.07 and 0.54 ± 0.06 m.y. respectively (table 3, nos. 3, 5). Magnetic-polarity determinations for several domes of this group are normal (table 4) indicating, in conjunction with the K-Ar ages, that they were erupted during the Brunhes polarity epoch.

One small dome of mostly devitrified alkalic rhyolite and minor vitrophyre in Corral Canyon, shown as Trd in the lower left corner of figure 2, has been dated at 7.90 ± 0.30 m.y. (table 3, no. 10). These volcanic rocks appear to be unrelated to the young rhyolites higher in the Mineral Mountains; the rhyolite in Corral Canyon is more eroded and contains a different phenocryst assemblage than the other rhyolites. The thermal event about 8 m.y. ago, as represented by these lavas, may have been responsible for producing the anomalously young ages of 14 and 9 m.y. measured on the Mineral Mountains pluton.

DISCUSSION

The stratigraphic relations and K-Ar ages of rhyolites of the Mineral Mountains, newly reported here, indicate that these rocks were emplaced during a relatively brief period in the Pleistocene, between about 0.8 and 0.5 m.y. ago, but an older rhyolitic event occurred about 8 m.y. ago. The Mineral Mountains are flanked on the northern and eastern sides by upper Cenozoic basalt flows (Condie and Barsky, 1972; Hoover, 1974), roughly contemporaneous with and younger than the rhyolite of the Mineral Mountains, and this association of rhyolite and basalt constitutes a bimodal volcanic assemblage of a type that is being recognized widely in the western United States in upper Cenozoic volcanic sequences (Christiansen and Lipman, 1972).

A significant question is whether the thermal anomaly of the Roosevelt KGRA is due to proximity to the late Cenozoic volcanic centers in the Mineral Mountains. Roosevelt Hot Springs and other inactive hot springs are located along the mountain-front fault on the western side of the Mineral Mountains, about 2 km west of the nearest exposed rhyolite (fig. 2). The size and shape of the Pleistocene magmatic system underlying the Mineral Mountains cannot be determined with any precision from the surface distribution of rhyolite vents, yet the extent of the vents for 15 km along the crest of the range suggests the possibility of a sizable magmatic system at depth. The elongate trend of rhyolite vents might even mark a segment of a large evolving circular igneous structure, such as interpreted for the Coso rhyolite domes in California (Duffield, 1975). The rhyolites of the Mineral Mountains were extruded along the eroded core of the large Mineral Mountains pluton, itself a late Cenozoic intrusion of remarkably large size for so young an age. Proximity in space and time suggests that the rhyolite of the Mineral Mountains represents a late stage in the evolution of a complex magmatic system that earlier gave rise to the granite of the Mineral Mountains. Alternatively, the rhyolite volcanism might have evolved independently of the granite, but has been partly localized where the crust was still hot from an earlier plutonic event. It seems likely, though not provable, that this large complex magmatic system has also been the heat source for the Roosevelt KGRA, with the shallow thermal anomaly enhanced along the range front by deep fault-controlled convective circulation of hot water.

This interpretation of a complex shallow magmatic system is supported by limited available rare-earth element data (table 5), which indicate that the rhyolite of the Mineral Mountains had a magmatic residence time in a shallow environment for a sufficiently long time to undergo major low-pressure fractional

TABLE 5.—*Rare-earth element analyses of rhyolites of the Mineral Mountains*

[Analyses by J. S. Pallister and H. T. Millard by neutron activation, using a chemical concentration technique. (See Zielinski and Lipman, 1976.)]

	Bailey Ridge flow	Wildhorse Canyon flow	South Twin Flat Mountain dome	Bearskin Mountain dome
	(75L-17)	(75L-60A)	(75L-16)	(75L-56)
La------	43.5	44.3	24.9	25.0
Ce------	95.6	94.3	51.5	44.2
Nd------	27.0	25.5	9.6	7.5
Sm------	3.6	3.5	1.3	.90
Eu------	.42	.40	.037	.035
Gd------	2.8	2.5	1.3	.88
Tb------	.52	.49	.30	.20
Tm------	.38	.35	.47	.31
Yb------	2.9	2.9	4.2	3.0
Lu------	.52	.49	.79	.57

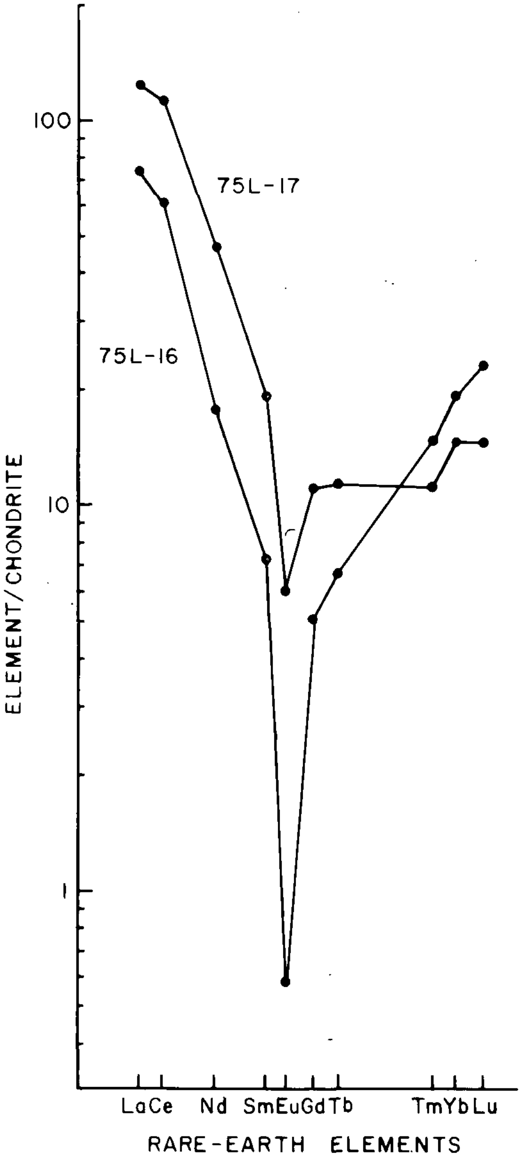


FIGURE 6.—Chrondite-normalized rare-earth-element plot for two rhyolites of the Mineral Mountains (75L–16 and 75L–17), showing negative Eu anomalies.

crystallization involving removal of feldspar. Chondrite-normalized analyses of two whole-rock samples show large negative Eu anomalies (fig. 6), indicative of major feldspar removal (Arth, 1976). This pattern contrasts with that of some other voluminous Cenozoic silicic rocks in the western United States (Zielinski and Lipman, 1976; P. W. Lipman, unpub. data, 1976) which show small or no Eu anomalies and appear to have developed their silicic compositions by processes not involving major feldspar fractionation, probably because the environment of differentiation was at pressures too high for feldspar to be stable.

Occurrences of upper Cenozoic alkalic rhyolite of possible geothermal significance in southwestern Utah are not restricted to the Mineral Mountains. We dated obsidian "Apache tears" from an eroded rhyolite flow at the Cudahy mine about 25 km north of the Mineral Mountains (fig. 1), as 2.38±0.15 m.y. (table 3, no. 6). A large rhyolite plug (South Twin Peak) in the Black Rock desert about 10 km east of the Cudahy mine yielded a similar K-Ar age of 2.33±0.12 m.y. (table 3, no. 7). Marginal obsidian from a small body of rhyolite at White Mountain, about 50 km northeast of the Mineral Mountains (fig. 1), yielded ages of 0.43±0.07 and 0.39±0.02 m.y. (table 3, no. 8), the youngest of any of our ages. The rhyolite at White Mountain contains inclusions of a distinctive dated basalt, indicating a maximum age for the dome of about 1 m.y. (Hoover, 1974). This rhyolite occurs less than 1 km from the nearest exposure of upper Pleistocene basalt of the Tabernacle volcanic field estimated to be 10 000–20 000 yr old (Hoover, 1974). Basalts of the Ice Springs volcanic field, 3 km north of White Mountain, are post-Lake Bonneville in age, that is, less than 12 000 yr old. These basaltic and rhyolitic rocks together offer another example of a bimodal basalt-rhyolite association in Utah. Thus, the potential for volcanic-related thermal anomalies in southwestern Utah is not confined to the Mineral Mountains. In fact, White Mountain is about 7 km north of Meadow and Hatton hot springs (Mundorff, 1970).

Another intriguing aspect of the rhyolites in the Mineral Mountains is their significance as a source of artifact obsidian. Implement-grade obsidian is relatively scarce in the southwestern United States, yet obsidian artifacts occur widely in archeological sites. Well-known sources of archeological obsidian include the Jemez Mountains in New Mexico, Coso Mountains and Long Valley areas in east-central California, Medicine Lake Highlands and associated rhyolitic centers in northeastern California, Newberry volcano and numerous small areas of rhyolite in eastern Oregon, and Yellowstone rhyolite plateau in Wyoming (fig. 7). The little known Mineral Mountains locality is in a region where high-quality obsidian is scarce, nearly equidistant from better known sources, yet it contains abundant obsidian suitable for implement manufacture. Individual blocks of nonporphyritic obsidian from the Bailey Ridge and Wildhorse Canyon flows are as much as 0.5 m across. Obsidian from the Mineral Mountains has recently been recognized in several archeological sites in southwestern Utah and adjacent parts of Nevada (Umshler, 1975), but how widely it has been distributed has yet to be established.

FIGURE 7.—Well-known sources for archeological obsidian in the western United States.

Available compositional data indicate that obsidian artifacts derived from the Mineral Mountains should be distinguishable, especially by minor-element compositions, from those of most of the better known obsidian sites.

Fission-track age dating, by G. A. Izett and C. W. Naeser, and obsidian-hydration age dating, by Irving Friedman, were conducted—independently of our study—on selected samples of rhyolite from the Mineral Mountains. The ages determined by these two other techniques provide a cross-check on the ages presented above that were determined by the K-Ar isotope method. Comparisons of the results of the three techniques are presented separately, in the sections that follow.

FISSION-TRACK DATING

By G. A. Izett and C. W. Naeser

Fission-track age determinations were made on samples of obsidian from the Bailey Ridge flow and the Bearskin Mountain dome. The fission-track age of the Bailey Ridge obsidian is in fair agreement with the K-Ar age of the obsidian, but the fission-track age of the Bearskin Mountain obsidian is anomalously younger than the K-Ar age. Th sample we dated of the Bearskin Mountain obsidian contains no fossil fission tracks; however, the age can be estimated by assuming the presence of one fossil track as shown in the table below. The anomalously young fission-track age of the Bearskin Mountain obsidian probably is due to the annealing of fossil tracks from a recent thermal event. The fission-track analytical data follow:

Fission-track analytical data

[Fission tracks etched for about 10 seconds in 48 percent hydrofluoric acid; ± 1 sigma about the mean. $\lambda f = 6.85 \times 10^{-17} yr^{-1}$]

Locality	ϕ (neutrons cm^{-2})	ρ_s (tracks cm^{-2})	ρ_i (tracks cm^{-2})	Fission track glass age x 10^6 years	K-Ar glass age x 10^6 years[1]
Bearskin Mountain dome	8.72×10^{14}	$<3.37 \times 10^1$(1)	1.25×10^5(309)	<0.02	0.75 ± 0.1 0.60 ± 0.12
Bailey Ridge flow	0.5×10^{15}	7.89×10^2(3)	4.40×10^4(213)	0.55 ± 0.30	0.79 ± 0.08

[1] See table 3.

OBSIDIAN-HYDRATION DATING

By *Irving Friedman*

Four rhyolite lava flows or domes from the Mineral Mountains, Utah, were dated by the obsidian-hydration technique. Most of the results agree with K-Ar and fission-track dates of the same flows.

Obsidian-hydration dating depends upon the fact that a newly formed surface on obsidian, such as a cooling crack, adsorbs water from the atmosphere. This adsorbed water slowly diffuses into the obsidian, and the depth of penetration of the water can be measured under the microscope in a thin section cut normal to the surface (Friedman and Smith, 1960). The rate at which the water diffuses into the obsidian is dependent upon temperature and glass composition (Friedman and Long, 1976).

The thickness of the hydrated layer (in micrometers) for the rhyolite units is tabulated below. Also listed is the expected rate of hydration (in $\mu m^2/10^3$ yr) for each flow, calculated for an estimated effective hydration temperature of 8°C and from the chemical composition of the obsidian. (See Friedman and Long, 1976.) The calculated obsidian-hydration age is also given, as is the K-Ar age.

Although the effective hydration temperature is assumed to be the same for all the flows sampled, the differing whole-rock chemistry of the obsidian gives different calculated hydration rates. Compositions of two of the obsidians are from table 2 in this paper; the analysis of the Bearskin Mountain dome is from S. H. Evans (written commun., 1976). No analysis is available for the South Twin Flat Mountain dome. An analysis for the North Twin Flat Mountains (table 2) was used instead; the hydration rate and calculated age are accordingly uncertain.

The calculated hydration rates vary by a factor of 2.5, owing mainly to differences in the amount of $CaO+MgO$. The chemical analyses were on whole-rock samples, but the hydration-rate calculation should be based on glass compositions. The Wildhorse Canyon and the Bailey Ridge glasses are almost free of phenocrysts, but the Bearskin Mountain and particularly the

Rhyolite	Thickness of hydration µm (± 1 µm)	Chemical index	Calculated hydration rate $\mu m^2/10^3$ yrs	Calculated age 10^6 yrs	Corrected age	K/Ar age
Wildhorse Canyon flow------------	41	42.5	2	0.85	0.85	([1])
Bailey Ridge flow------------	40	41.7	2	.80	.80	0.79
Bearskin Mountain dome------------	31	47.4	4	.24	.48	.75 .60
South Twin Flat Mountain dome---	22	51.1(?)	5(?)	.10(?)	.25	.50

[1] No determination

South Twin Flat Mountain glasses are porphyritic. Obsidian from Wildhorse Canyon, Bailey Ridge, and South Twin Flat Mountain all have refractive indices of 1.4847 ± 0.0005, whereas Bearskin Mountain dome has a slightly higher index, 1.4856 ± 0.0005. The similarity in index of all four glasses makes any assumption of greatly differing hydration rates for these samples unrealistic. If we assume that the chemical compositions of the glass phase of all four samples are similar, then the hydration rates also will be similar and the dates shown in the column "Corrected age" should apply.

The corrected ages agree with the K-Ar dates, except for the date for the South Twin Flat Mountain dome, where the hydration date is about half that derived by K-Ar dating. The reasons for this discrepancy are not known, but we may not have sampled sufficiently to find an original surface on the samples from this site. Alternatively, the discrepancy may be due to some inherited argon in the sanidine used for K-Ar dating.

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PLEISTOCENE RHYOLITE OF THE MINERAL MOUNTAINS, UTAH—GEOTHERMAL AND ARCHEOLOGICAL SIGNIFICANCE

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With sections by G. A. IZETT and C. W. NAESER
and by IRVING FRIEDMAN, Denver, Colo.

Abstract.—Little-eroded rhyolitic tuffs, flows, and domes extend over about 25 km² along the western side of the Mineral Mountains, southwestern Utah, which is along the eastern edge of the Roosevelt KGRA (Known Geothermal Resource Area). Initial eruptions resulted in two low-viscosity lava flows of nonporphyritic rhyolite. These were followed by bedded pumice falls and nonwelded ash flows. The youngest activity produced at least nine viscous domes and small lava flows of rhyolite that contain 1–5 percent phenocrysts of quartz, plagioclase, sodic sanidine, and biotite; distinction between domes and eroded flow segments locally is difficult.

Potassium-argon ages indicate that all the rhyolite of the Mineral Mountains was erupted between 0.8 and 0.5 m.y. ago. The rhyolite rests on dissected granite of the Mineral Mountains pluton, the largest intrusion in Utah, which has yielded published K-Ar ages of 9 and 15 m.y. A small older dissected rhyolite dome, about 8 m.y. old, occurs just west of the range front. Whether the young ages of the pluton represent time of intrusion or of later reheating, they, in conjunction with the Pleistocene rhyolite in the Mineral Mountains, do indicate a major late Cenozoic thermal anomaly, the size and age of which is significant to evaluation of the Roosevelt KGRA. The rhyolite is also the only known source of implement-grade obsidian in the southwest between eastern California and northern New Mexico.

As part of the U.S. Geological Survey's geothermal energy program, age, composition, and distribution data are being obtained for upper Cenozoic volcanoes in the western United States that have erupted significant amounts of silicic rocks. Such silicic rocks, mostly rhyolites, are considered possible indicators of the subsurface presence of shallow magma chambers still sufficiently hot to have potential for geothermal resources. A rationale for this approach is outlined by Smith and Shaw (1975).

Large volumes of rhyolite associated with known geothermal resources have been described from Yellowstone National Park (Allen and Day, 1935; Christiansen and Blank, 1972), in the Jemez Mountains in New Mexico (Smith, Bailey, and Ross, 1970), and in the Long Valley area, California (Bailey, Dalrymple, and Lanphere, 1976). Around the margins of the Colorado Plateau, small volumes of similar silicic rocks that also seem worthy of reconnaissance evaluation in terms of geothermal signifiance occur in the San Francisco Mountains volcanic field, Arizona (Robinson, 1913; Moore, Wolfe, and Ulrich, 1974), in the Mount Taylor and Taos Plateau volcanic fields of New Mexico (Hunt, 1938; Lambert, 1966), and in the Mineral Mountains, Utah.

In the Mineral Mountains, southwestern Utah, young rhyolite masses extend discontinuously for about 15 km along the range crest and cover an area of less than 25 km²; these have been little studied and previously were interpreted as erosional remnants of a single large silicic volcano of late Tertiary age (Earll, 1957; Liese, 1957). This brief report presents new geologic data, including K-Ar ages which demonstrate that many separate lava domes, flows, and tuffs were erupted from vents along the range crest between 0.8 and 0.5 m.y. ago. Along one of the western range-front faults, about 2 km northwest of the nearest rhyolitic volcanic rocks, Roosevelt Hot Springs is located within a KGRA (Known Geothermal Resource Area) that is actively being developed for geothermal power production. The youthful silicic volcanism recorded by the rhyolite of the Mineral Mountains suggests the presence of a still-hot buried magma chamber that may be the heat source for the KGRA.

Acknowledgments.—Discussions with Glenn A. Izett and Irving Friedman, who examined the rhyolites, and Sr-Rb data on granite from the Mineral Mountains pluton by Carl E. Hedge aided the evolution of ideas on the rhyolite of the Mineral Mountains. We thank John S. Pallister and Alan Martz for assistance

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Ar dating and microprobe analyses, respectively. We also thank Gary L. Galyardt for information on the Roosevelt KGRA.

Research by authors from the University of Utah was supported by National Science Foundation Grant GI–43741 and U.S. Energy Research and Development Administration Contract no. EY–76–S–07–1601.

GENERAL GEOLOGIC SETTING

The Mineral Mountains, in west-central Utah (fig. 1), are a typical basin-range horst, which rises about 1 km above the adjacent alluviated basins, the Escalante Desert to the west and an unnamed valley to the east. The horst extends nearly 50 km in a northerly direction and is in general about 10 km wide.

On the western and northern sides of the range, metamorphic rocks of the Wildhorse Canyon Series of Condie (1960), of probable Precambrian age, are the dominant rocks, but on the southern, northern, and eastern sides of the range, Paleozoic and Mesozoic sedimentary rocks are exposed widely. These layered rocks are intruded by a distinctive body of granite, the Mineral Mountains pluton, which is the largest single exposed intrusive body in Utah, covering nearly 250 km². This granite and associated pegmatite and aplite may be as young as late Miocene, having yielded two K-Ar ages on feldspars of 15 and 9 m.y. from different sample sites (Park, 1968; Armstrong, 1970). These young apparent ages are supported in a general way by results of a Rb-Sr isotopic study. A Rb-Sr isochron, based on 11 analyses of whole-rock samples ranging in composition from diorite to aplite, shows exceptionally bad scatter but suggests that the age of the main batholith is about 35 m.y., with sizable chemical modification—especially Sr loss—having occurred 7–15 m.y. ago (C. E. Hedge, written commun., 1976).

Prior to the onset of late Cenozoic rhyolitic volcanism in the Mineral Mountains, the Mineral Mountains pluton and its country rocks were deeply dissected to form a rugged erosional topography with towering pinnacles rising above narrow usually dry valleys.

The Mineral Mountains are bounded on the west, and probably on the east side, by north-striking normal faults. The trend of the bounding faults on the west is marked locally in the Roosevelt KGRA by discontinuous elongate mounds of opaline sinter and other hot-spring deposits. Near the northern end of this trend is Roosevelt Hot Springs (Petersen, 1975). Water temperatures as high as 90°C have been re-

Phillips Petroleum Co., the successful bidder on the KGRA in 1974, is continuing exploration on the property. Numerous test wells so far drilled in the KGRA have documented the presence of a low-salinity liquid-dominated geothermal system (Berge, Crosby, and Lenzer, 1976; Greider, 1976). The thermal anomaly covers approximately 32 km², and reservoir temperatures exceed 250°C.

RHYOLITE OF THE MINERAL MOUNTAINS

Rhyolitic rocks in the Mineral Mountains include three stratigraphically distinct sequences. Lowermost are two nearly nonporphyritic obsidian-rich lava flows. These are overlain by a pyroclastic sequence, including both ash-fall and ash-flow tuffs. Stratigraphically highest are porphyritic rhyolite lava domes erupted from at least nine separate vents, most of which are along the range crest.

Flows of Bailey Ridge and Wildhorse Canyon

The oldest rhyolitic rocks in the Mineral Mountains are two lava flows of virtually nonporphyritic flow-layered rhyolite. One flow is exposed for about 3 km along Bailey Ridge and in Negro Mag Wash (fig. 2) northwest of Bearskin Mountain. The other is exposed for about 3.5 km along Wildhorse Canyon, west of Bearskin Mountain. Both flows were originally as much as 100 m thick and followed pre-existing valleys that drained the western side of the Mineral Mountains, with relief much like the present, and that were graded nearly to the present levels at valley fronts. Both flows are only slightly dissected, and much of their primary upper surfaces of frothy pumiceous perlitic rubble is preserved.

Where deeply dissected, both flows display similar cooling and crystallization zonations. The basal few meters of the flow, resting directly on medium- to coarse-grained Tertiary granite of the Mineral Mountains pluton, consists of dense black obsidian. The obsidian has well-developed flow lamination defined by alined microlites of feldspars and opaque oxides (fig. 3*A*). The basal obsidian zone grades upward within a meter or two into a well-layered zone, in which dark obsidian and light-gray or brown finely crystallized flow-layered lava alternate. The interior of the flow is as much as 10–30 m thick and consists of gray relatively structureless devitrified rhyolite, in places containing concentrations of ovoid gas cavities locally filled with vapor-phase crystallization products.

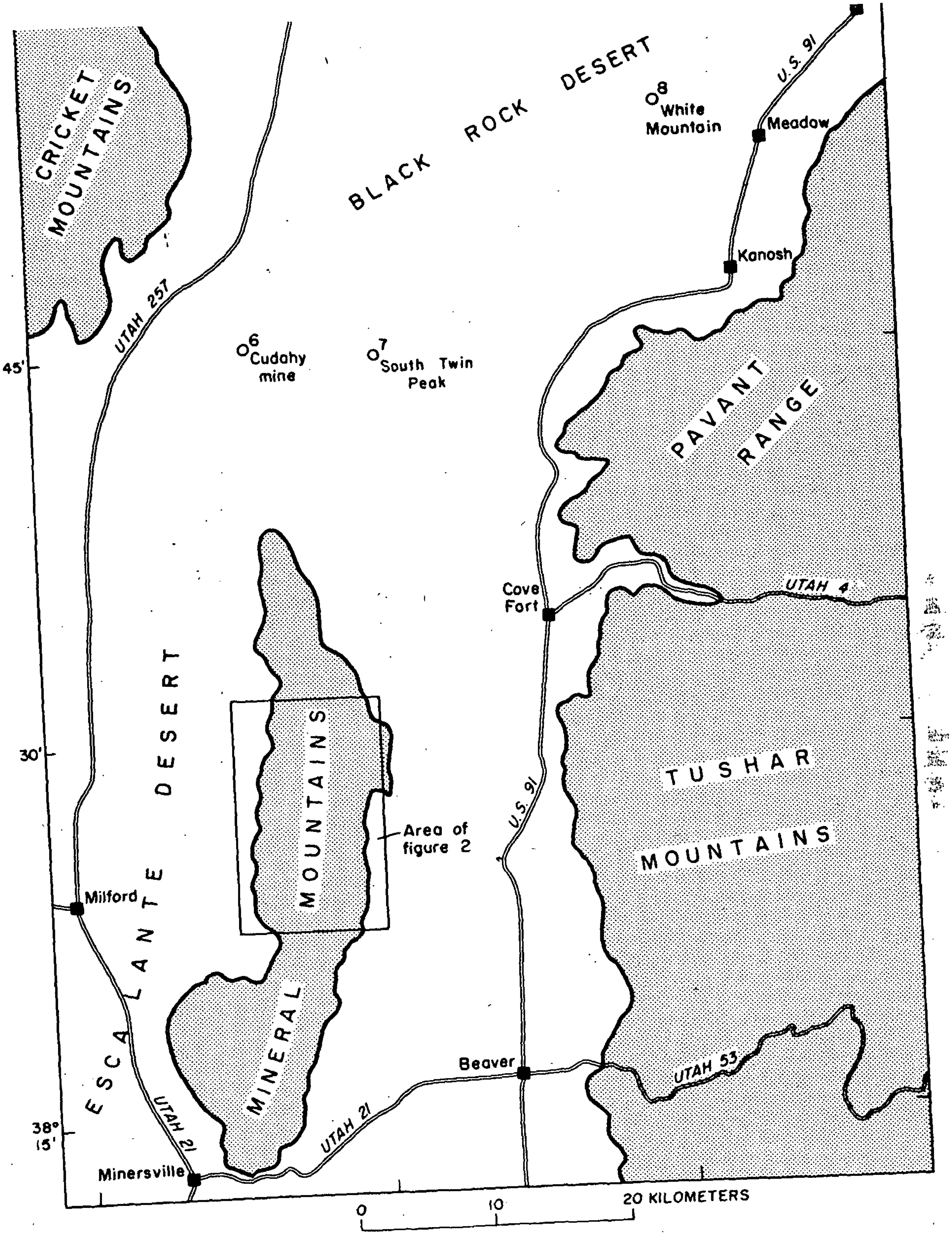


FIGURE 1.—Index map showing location of the Mineral Mountains and nearby areas, Utah. Numbers indicate locations of some dated samples (table 3); the others are shown on figure 2.

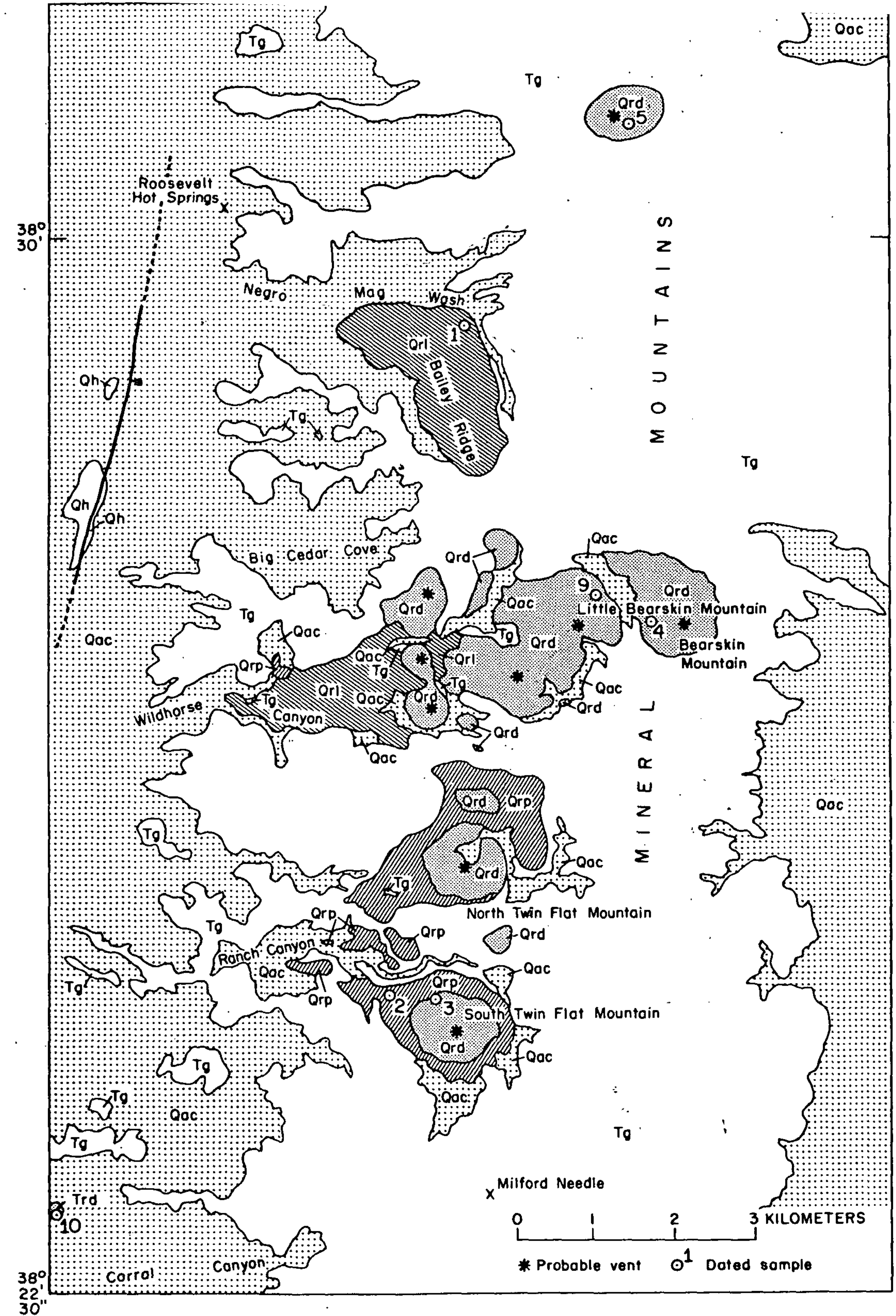
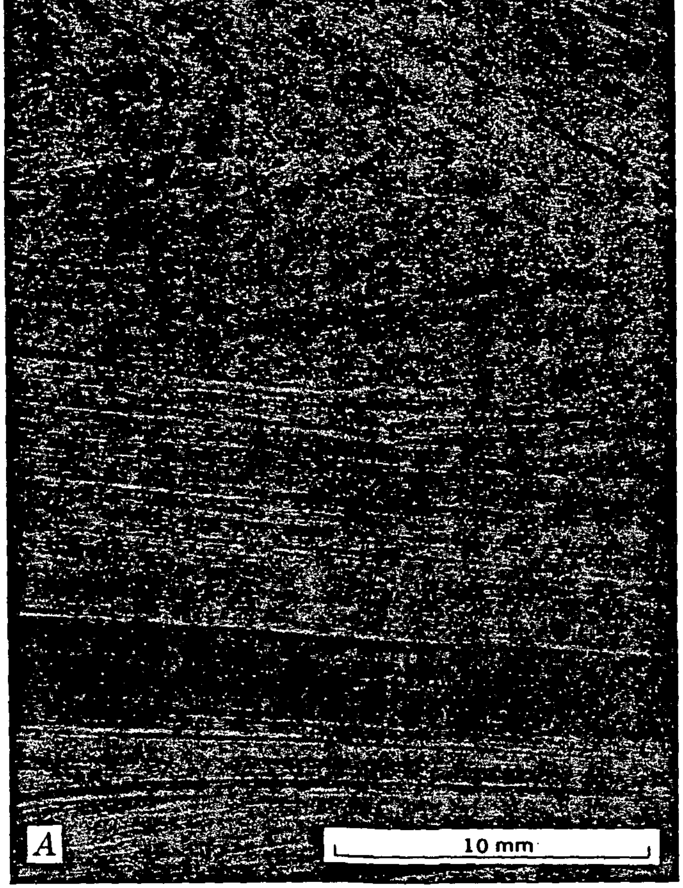


FIGURE 2.—Generalized geologic map of the central Mineral Mountains, Utah, showing distribution of Pleistocene rhyolitic rocks and locations of dated samples (table 3). Rock units, from oldest to youngest: Tg, Tertiary granite of Mineral Mountains; Trd, Tertiary rhyolite dome of Corral Canyon; Qrl, lava flows of Bailey Ridge and Wildhorse Canyon; Qrp, pyroclastic rocks; Qrd, lava domes; Qac, surficial deposits, primarily alluvium and colluvium; Qh, hot-spring deposits. Fault shown (bar and ball on downthrown side), named the Dome fault by Petersen (1975), is only one of many along the



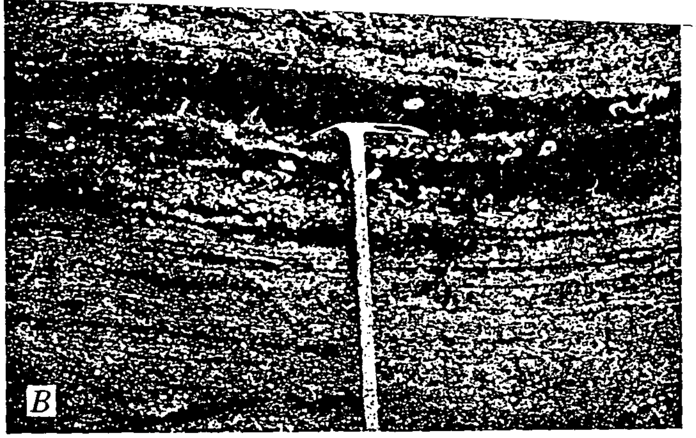


FIGURE 3.—Photographs of the Wildhorse Canyon flow. *A*, Photomicrograph showing recumbently folded flow lamination. Flow structures are defined by alined microlites. *B*, Alternating layers of obsidian and devitrified rhyolite in upper part of flow.

In upper parts of the flow a few meters of flow-layered obsidian are interlayered with devitrified rock (fig. 3*B*), passing upward into a more uniform dark glass zone or grading directly into a frothy rubbly breccia of tan perlitic pumice as much as 10 m thick at the top of the flow.

The flow layering and lamination in these rhyolitic lavas is remarkably planar and uncontorted as compared to the swirly internal structures typical of many rhyolitic lava flows. The "ramp structures" that occur commonly in upper parts of silicic flows (Christiansen and Lipman, 1966), are absent or poorly developed, and subhorizontal layering is typical throughout the Bailey Ridge and Wildhorse Canyon flows. The most common deviations from planar layering are small, typically rootless recumbent folds (fig. 3*A*), most limbs of which are less than 1 m long. These flowage features, as well as the relatively slight thickness of each lava flow as compared to its longitudinal extent, indicate that they were characterized by lower emplacement viscosities than many silicic lava flows.

Vents for these oldest flows of the Mineral Mountains have not been found. The Wildhorse Canyon flow appears to extend up drainage beneath younger lava domes in the upper part of the canyon, although exposures of the critical relations are poor because of cover by rubble. Probably the vent area for this flow is beneath the younger lavas to the east. If the Bailey Ridge flow vented from beneath its uppermost outcrop area, surface structures of this part of the flow give no indication of any concealed vent. This part of the flow is little dissected, however, and the vent area could be completely buried. Alternatively, the Bailey Ridge flow, and also the Wildhorse Canyon flow, might have come from higher on the slope, underneath the area now covered by the Bearskin and Little Bearskin Mountain lava domes. However, this would require that the upper portions of the flows be largely removed by erosion while the lower portions were left relatively undissected.

The Bailey Ridge and Wildhorse Canyon flows are petrographically similar. They contain less than 0.5 percent total phenocrysts, the majority of which are alkali feldspar (table 1). There are trace amounts of oligoclase, biotite, titanomagnetite, and ilmenite. The two flows are virtually identical in chemical composition (table 2). They are typical silicic rhyolites, containing about 76.5 percent SiO_2 and just over 9 percent total alkalis. The fresh obsidians contain more fluorine than water; secondarily hydrated pumice from the Bailey Ridge flow contains 2.4 percent total H_2O. The magmatic temperatures of these flows were about 750°C, as determined from compositions of iron-titanium oxides and coexisting plagioclase and alkali

TABLE 1.—*Modal compositions of radiometrically dated samples*

[Est., estimate; tr., trace; leaders (--), not present; *, microphenocrysts]

Field No.	Unit	Ground-mass	Plagio-clase	K-feldspar	Quartz	Biotite	Horn-blende	Clino-pyroxene	Opaques	Point counte
75L-17	Bailey Ridge flow, obsidian---------------	99.9	--	tr.	tr.	--	--	--	--	Est.
75L-15	Tuff of Ranch Canyon obsidian block---------	98.2	0.6	0.8	0.4	tr.	--	--	tr.	3,615
75L-16	South Twin Flat Mountain dome, obsidian with patchy devitrification-	92.6	1.2	3.9	2.3	tr.	--	--	tr.	3,034
75L-56	Bearskin Mountain, obsidian---------------	97.2	.3	1.2	1.2	0.1	--	--	tr.	4,725
75R-53	Little Bearskin Mountain dome, obsidian---------	96.0	.9	1.9	1.0	--	--	--	0.1	2,000
75L-18A	Northern dome, frothy perlite----------------	97.4	.4	1.3	.7	.1	--	--	.1	2,642
75L-19	Rhyolite of the Cudahy mine, obsidian---------	100	--	--	--	--	--	--	--	Est.
75L-21	Black Rock desert felsite plug-----------	91.2	5.8	1.2	--	tr.	--	1.2	.6	3,188
75L-23	Rhyolite of White Mountain, obsidian-----	94	--	--	--	--	*6	--	--	Est.

74-3A, Obsidian, Bailey Ridge flow; 74-8, Obsidian, Wildhorse Canyon flow; 75-14, Obsidian, Little Bearskin Mountain dome; 75-20, Basal Obsidian, North Twin Flat Mountain dome. Leaders (---) not present; tr., trace]

Chemical Analyses	74-3A	74-8	75-14	75-20
SiO_2-------	76.52	76.51	76.42	76.45
TiO_2-------	.12	.12	.08	.08
Al_2O_3------	12.29	12.29	12.79	12.79
Fe_2O_3------	.31	.23	.20	.30
FeO--------	.46	.51	.38	.29
MnO--------	.05	.05	.09	.10
MgO--------	.08	.08	.11	.12
CaO--------	.64	.65	.44	.40
Na_2O-------	3.80	3.77	4.42	4.39
K_2O--------	5.24	5.28	4.72	4.73
P_2O_5-------	.02	.01	tr.	.06
H_2O+ ------	.12	.06	.13	.10
H_2O- ------	.06	.06	.01	---
F----------	.16	.15	.42	.44
Sum-----	99.87	99.77	100.21	100.25
Less F=O-	.07	.06	.18	.19
Total----	99.80	99.71	100.03	100.06

CIPW Norms	74-3A	74-8	75-14	75-20
Q--------	33.40	33.28	33.22	32.48
c---------	---	.26	.41	.45
or-------	30.96	31.20	27.89	27.95
ab-------	32.15	31.90	37.40	37.15
an-------	1.00	1.02	---	---
di-wo----	.37	.47	---	---
di-en----	.11	.12	---	---
di-fs----	.27	.38	---	---
hy-en----	.09	.08	.27	.30
hy-fs----	.21	.26	.57	.34
mt-------	.45	.33	.29	.43
il-------	.23	.23	.15	.15
ap-------	.05	.02	---	.14
fr-------	.33	.29	.61	.45
rest-----	.18	.12	.14	.10
Total--	99.80	99.96	99.95	99.94

feldspar. The relatively low emplacement viscosities, indicated by the planar flow structures of these rhyolites, do not therefore seem related to exceptionally high emplacement temperatures.

A single K-Ar radiometric age determination of 0.79±0.08 m.y. (table 3, no. 1), from the toe of the Bailey Ridge flow, is the oldest age obtained from any rhyolite of the Mineral Mountains. The Bailey Ridge flow has a reversed paleomagnetic pole position (table 4) indicating, in conjunction with K-Ar data, that it was erupted toward the end of the Matuyama polarity epoch. The Wildhorse Canyon flow has not yet been dated radiometrically, but it also is characterized by a reversed polarity, which, in conjunction with morphological and chemical resemblance to the Bailey Ridge flow and its position beneath some of the pyroclastic rocks, suggests a similar age.

Pryoclastic rocks

South of Wildhorse Canyon, pyroclastic rocks of ash-fall and ash-flow origin are the lowest exposed rhyolitic rocks. The main area of pyroclastic rocks is in Ranch Canyon, where tuffs bury rugged paleotopography much like the present land surface.

The pyroclastic rocks are only weakly consolidated and are mostly poorly exposed, underlying alluviated slopes. All the pyroclastic deposits, both ash-fall and and ash-flow, are white to light tan. They occur over an altitude range from 1950 m in valley-bottom exposures in Ranch Canyon to as high as 2540 m on the surrounding slopes. They also occur in the Cove Fort area, where they are overlain by basalt lava flows (Nash and Smith, 1977). Much of the pyroclastic sequence has been removed by erosion in Ranch Canyon, and it is not clear to what extent this altitude range reflects an actual total thickness of the original deposit and to what extent the pyroclastic rocks were thinner but blanketed the preexisting topography. In Ranch Canyon these rocks are overlain by the large lava domes on North and South Twin Flat Mountains and by smaller masses of rhyolitic lava on adjacent ridges. Although contacts between these domes and the pyroclastic rocks are nowhere well exposed, this stratigraphic sequence is indicated by structural zones in the rhyolite domes of North and South Twin Flat Mountains. The lowest exposures are of a subhorizontal

[Constants: $K^{40}\lambda_{\varepsilon} = 0.581 \times 10^{-10}$/yr, $\lambda_{\beta} = 4.963 \times 10^{-10}$/yr; atomic abundance: $K^{40}/K = 1.167 \times 10^{-4}$; *Radiogenic argon; Potassium determinations made with an Instrumentation Laboratories flame photometer with a Li internal standard. Figures 1 and 2 give sample locations. Ages of WM76-3 and MR76-26 determined by S. H. Evans, Jr., and F. H. Brown; other ages determined by H. H. Mehnert]

Sample	Field No.	Unit	Material dated	Location (Lat N Long W)	K_2O (percent)	$*Ar^{40}$ (10^{-10}) (moles/gram)	$*Ar^{40}$ (percent)	Age (m.y.±2σ)
1	75L-17	Bailey Ridge flow-------	Obsidian--------	38°29′, 112°49′	5.10, 5.10	0.058	25.8	0.79±0.08
2	75L-15	Tuff of Ranch Canyon----	Obsidian block--	38°25′, 112°50′	4.63, 4.66	.047	47.1	0.70±0.04
3	75L-16	South Twin Flat Mountain dome---------	Sanidine--------	38°25′, 112°49′	8.14, 8.08	.059	18.1	0.50±0.07
4	75L-56	Bearskin Mountain dome--	Obsidian--------	38°27′, 112°47′	4.48, 4.49	.048	20.2	0.75±0.10
						.039	13.5	0.60±0.12
5	75L-18A	North Dome--------------	Sanidine--------	38°31′, 112°47′	9.36, 9.35	.073	24.5	0.54±0.06
6	75L-19	Cudahy mine-------------	Obsidian--------	38°45′, 112°51′	4.91, 4.93	.168	46.0	2.38±0.15
7	75L-21	South Twin Peak---------	Sanidine--------	38°45′, 112°47′	11.13, 11.12	.373	54.3	2.33±0.12
8	75L-23	White Mountain----------	Obsidian--------	38°55′, 112°30′	4.63, 4.70	.029	15.9	0.43±0.07
	WM76-3		Obsidian--------		5.23, 5.25	.030	21.5	0.39±0.02
9	75R-23	Little Bearskin Mountain dome---------	Sanidine--------	38°27′, 112°48′	9.31, 9.15 [1]9.26	.080	31.8	0.61±0.05
10	MR76-26	Corral Canyon dome------	Biotite---------	38°24′, 112°53′	8.72, 8.75	1.011	61.6	7.90±0.30

[1] Isotope dilution determination

TABLE 4.—*Preliminary data on magnetic polarities of rhyolites of the Mineral Mountains*

Unit	Number of samples	Declination	Inclination	Standard error (percent)
Normal samples:				
Northern dome-------------	9	350	62	3
Big Cedar Cove dome------	4	23	67	4
Ranch Canyon dome---------	5	22	44	5
Corral Canyon dome--------	3	332	25	20
Ranch Canyon ash----------	2	356	46	29
Wildhorse Canyon ash-----	6	349	48	5
Reversed samples:				
Bailey Ridge flow---------	6	173	-63	6
Wildhorse Canyon flow----	4	168	-61	2

zone of basal flow breccia below the basal obsidian zone; this is the typical zonation expectable at the base of a lava flow or dome and would be an improbable relation if the pyroclastic rocks had been plastered against older lava domes. Thus, the lava dome of South Twin Flat Mountain overlies pyroclastic rocks that are at least 60 m and probably as much as 180 m thick, and these figures suggest minimum thicknesses of the pyroclastic unit.

The lower pyroclastic rocks are beds of air-fall pumice and ash at least 10 m thick and probably much thicker. Individual beds are a few centimeters to about a meter thick. Variable dips indicate that the ash was deposited on the underlying granite, on a surface as rugged as the present one. The pumice and ash contain several percent of small phenocrysts of quartz, oligoclase, alkali feldspar, biotite, magnetite, ilmenite, sphene, and allanite. This mineral assemblage is generally characteristic of the youngest rhyolite flows as well. Associated with the pumice and ash are a few percent of rhyolitic lithic debris, including devitrified rhyolite, perlite, and sparse obsidian fragments. Phenocrysts in the lithic debris are sparse, generally similar to those in the flows of Bailey Ridge and Wildhorse Canyon.

Ash-flow deposits widely overlie the ash-fall beds in Ranch Canyon. The ash-flow deposits locally are at least 50 m thick; probably the total thickness is much greater, but accurate estimates are difficult because of the poor exposures. The ash-flow deposits are everywhere nonwelded and only weakly consolidated; they tend to weather to small conical hills. On especially

4). In exceptionally good exposures, several flow units—each a few meters thick—can be recognized in the ash-flow deposits, with partings between the flow units marked by local concentrations of pumice, lithic debris, or better sorted ash.

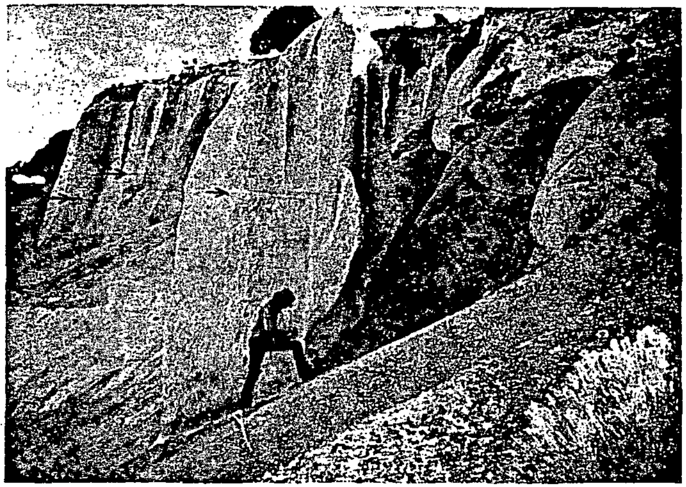


FIGURE 4.—Ash-flow tuff, resting on a rugged erosion surface cut on granite of the Mineral Mountains pluton. Arrows indicate faint parting between flow units of tuff. From northern side of Ranch Canyon at about 2105-m elevation.

On the northern side of lower Wildhorse Canyon, an isolated patch of pyroclastic material about 150 m across consists of finely laminated white fine-grained ash of lacustrine origin. These beds of water-reworked ash are younger than the Wildhorse Canyon flow and were deposited in a local basin dammed by the flow. The ash has a refractive index similar to that of the pyroclastic rocks in Ranch Canyon, one valley to the south, suggesting to us that it represents a reworked marginal facies of this deposit. In contrast, this patch of lacustrine tuff is interpreted by Glenn Izett (written commun., 1976), as airborne Bishop ash, from the Long Valley caldera in California, on the basis of small compositional differences with other rhyolites of the Mineral Mountains.

A single whole-rock K-Ar age on an obsidian clast from ash-flow tuff in Ranch Canyon yielded an age of 0.70 ± 0.04 m.y. (table 3, no. 2), providing an older limit for the age of the pyroclastic rocks. The pyroclastic deposits in Ranch Canyon, as well as the local lake beds in Wildhorse Canyon, have normal magnetic polarities in contrast to the reverse polarities of Bailey Ridge and Wildhorse Canyon flows. Thus, the pyroclastic rocks have been deposited during the Brunhes polarity epoch.

The stratigraphically highest part of the upper Cenozoic volcanic assemblage in the Mineral Mountains is a group of at least nine separate perlite-mantled lava domes and small flows of porphyritic rhyolite. The domes tend to occur along the crest of the range, discontinuously over a zone about 15 km long. These domes form some of the highest topographic points in the Mineral Mountains, including Bearskin Mountain with an elevation of 2772 m (9095 ft). Individual domes are as much as 1 km across at their bases and stand as much as 250 m high, although dimensions are difficult to determine precisely because of the irregular pre-existing topography and subsequent erosion. Small stubby flows extend out from some of the domes, and some small isolated patches of rhyolite (fig. 2) may represent either eroded flow remnants or small separate domes.

The larger domes, such as Bearskin and Little Bearskin Mountains, are little eroded, and surface exposures consist largely of blocks of tan perlitic glass that are slightly modified remnants of the original brecciated frothy carapaces of the domes. Scattered fragments of dense black obsidian, derived from beneath the perlitic breccia, occur about a third of the way above the base of these domes. Float of well-layered devitrified rhyolite is exposed locally just above the zone of obsidian fragments. Pumiceous material, that in places ravels out from below the level of the obsidian zone, may represent an initial pyroclastic fall that is not well exposed.

Other domes, such as those of North and South Twin Flat Mountains (fig. 5), have been more deeply dissected, in this case by the reexcavation of Ranch Canyon, and their internal structural and crystallization features are better exposed. The internal features of all these late domes are in general similar. A basal black vitrophyric zone is everywhere well developed, in places resting on lighter colored glassy basal flow breccia. The vitrophyre zone, which is as much as 5–10 m thick, grades upward into devitrified rock through a transition zone a few meters thick in which flow-layered obsidian alternates with devitrified rock that is commonly highly spherulitic. The devitrified interiors of the flows tend to be light gray and contain conspicuous spherulites. In places, gas cavities several centimeters across contain lithophysal fillings. The interiors of the flows tend to be crudely flow layered, with the layering subhorizontal just above the basal glass zone, but becoming steeper in upper parts of the lava dome. Near-vertical riblike masses of flow-layered devitrified rock are commonly exposed high on the

FIGURE 5.—Rhyolite domes of North and South Twin Flat Mountains. Rugged terrain in distance, including Milford Needle (elev. 2920 m) on the left side of the picture, is underlain by granite of the Mineral Mountains pluton. Photographed from ridge between Ranch and Wildhorse Canyons.

domes, where erosion has stripped away the surface mantle of frothy perlite. The steeply dipping flow layering and ramp structures of these domes thus are in contrast to structures in the older lava flows of Wildhorse Canyon and Bailey Ridge.

The porphyritic domes typically lack well-developed central craters (for example, the South Twin Flat Mountain dome) although several have slight central depressions that have been breached and accentuated by erosion. Breached depressions are especially evident for the unnamed northern dome, which is on the range crest northeast of Negro Mag Wash (fig. 2), Bearskin Mountain dome, and North Twin Flat Mountain dome (fig. 5).

All the domes contain several percent phenocrysts of quartz, oligoclase, alkali feldspar, biotite, and iron-titanium oxides (table 1). Trace amounts of sphene and allanite occur in some domes. Hornblende, zircon, and allanite are present in the Corral Canyon dome, the southernmost exposure of rhyolitic volcanic rocks. The North and South Twin Flat Mountain domes have 5–8 percent total phenocrysts, distinctly more than any of the others. The obsidian zones of these two domes appear even more phenocryst-rich, because of the presence of small "snowflake" devitrification spots. The flows in upper Wildhorse Canyon and to the north contain only 2–3 percent total phenocrysts.

Two analyzed samples of the porphyritic domes (table 2) are chemically similar silicic alkalic rhyolite. In comparison with the older flows of Bailey Ridge and Wildhorse Canyon, the domes are slightly but significantly higher in Na_2O and F; they are lower in K_2O and CaO.

Lack of continuity, and thus absence of contact relations, between the domes makes relative ages of the domes difficult to determine. On the basis of amount of dissection, North and South Twin Flat Mountains may be among the oldest, and Bearskin Mountain among the youngest of the domes. The K-Ar ages (table 1), petrographic and chemical similarities, and the generally similar degree of erosional dissection indicate that the domes are about the same age. Stratigraphic relations on the northern side of the North Twin Flat Mountain dome suggest that this dome is older than the unnamed ridge-capping flow 0.5 km north of it (fig. 2). Bearskin Mountain and the three domes extending southwest from it appear compositionally homogeneous, consisting of phenocryst-poor rhyolite similar to the rhyolite that overlies the North Twin Flat Mountain dome. The Bearskin Mountain dome has yielded K-Ar ages on obsidian of 0.60±0.12 and 0.75±0.10 m.y. (table 3, no. 4), and the Little Bearskin Mountain dome has an indicated sanidine age of 0.61±0.05 m.y. (table 3, no. 9). Sanidines from obsidian of South Twin Flat Mountain and the unnamed northern dome have yielded K-Ar ages of 0.50 ±0.07 and 0.54±0.06 m.y. respectively (table 3, nos. 3, 5). Magnetic-polarity determinations for several domes of this group are normal (table 4) indicating, in conjunction with the K-Ar ages, that they were erupted during the Brunhes polarity epoch.

One small dome of mostly devitrified alkalic rhyolite and minor vitrophyre in Corral Canyon, shown as Trd in the lower left corner of figure 2, has been dated at 7.90±0.30 m.y. (table 3, no. 10). These volcanic rocks appear to be unrelated to the young rhyolites higher in the Mineral Mountains; the rhyolite in Corral Canyon is more eroded and contains a different lavas, may have been responsible for producing the anomalously young ages of 14 and 9 m.y. measured on the Mineral Mountains pluton.

DISCUSSION

The stratigraphic relations and K-Ar ages of rhyolites of the Mineral Mountains, newly reported here, indicate that these rocks were emplaced during a relatively brief period in the Pleistocene, between about 0.8 and 0.5 m.y. ago, but an older rhyolitic event occurred about 8 m.y. ago. The Mineral Mountains are flanked on the northern and eastern sides by upper Cenozoic basalt flows (Condie and Barsky, 1972; Hoover, 1974), roughly contemporaneous with and younger than the rhyolite of the Mineral Mountains, and this association of rhyolite and basalt constitutes a bimodal volcanic assemblage of a type that is being recognized widely in the western United States in upper Cenozoic volcanic sequences (Christiansen and Lipman, 1972).

A significant question is whether the thermal anomaly of the Roosevelt KGRA is due to proximity to the late Cenozoic volcanic centers in the Mineral Mountains. Roosevelt Hot Springs and other inactive hot springs are located along the mountain-front fault on the western side of the Mineral Mountains, about 2 km west of the nearest exposed rhyolite (fig. 2). The size and shape of the Pleistocene magmatic system tion of rhyolite vents, yet the extent of the vents for 15 km along the crest of the range suggests the possibility of a sizable magmatic system at depth. The elongate trend of rhyolite vents might even mark a segment of a large evolving circular igneous structure, such as interpreted for the Coso rhyolite domes in California (Duffield, 1975). The rhyolites of the Mineral Mountains were extruded along the eroded core of the large Mineral Mountains pluton, itself a late Cenozoic intrusion of remarkably large size for so young an age. Proximity in space and time suggests that the rhyolite of the Mineral Mountains represents a late stage in the evolution of a complex magmatic system that earlier gave rise to the granite of the Mineral Mountains. Alternatively, the rhyolite volcanism might have evolved independently of the granite, but has been partly localized where the crust was still hot from an earlier plutonic event. It seems likely, though not provable, that this large complex magmatic system has also been the heat source for the Roosevelt KGRA, with the shallow thermal anomaly enhanced along the range front by deep fault-controlled convective circulation of hot water.

This interpretation of a complex shallow magmatic system is supported by limited available rare-earth element data (table 5), which indicate that the rhyolite of the Mineral Mountains had a magmatic residence time in a shallow environment for a sufficiently long time to undergo major low-pressure fractional

TABLE 5.—*Rare-earth element analyses of rhyolites of the Mineral Mountains*

[Analyses by J. S. Pallister and H. T. Millard by neutron activation, using a chemical concentration technique. (See Zielinski and Lipman, 1976.)]

	Bailey Ridge flow	Wildhorse Canyon flow	South Twin Flat Mountain dome	Bearskin Mountain dome
	(75L-17)	(75L-60A)	(75L-16)	(75L-56)
La------	43.5	44.3	24.9	25.0
Ce------	95.6	94.3	51.5	44.2
Nd------	27.0	25.5	9.6	7.5
Sm------	3.6	3.5	1.3	.90
Eu------	.42	.40	.037	.035
Gd------	2.8	2.5	1.3	.88
Tb------	.52	.49	.30	.20
Tm------	.38	.35	.47	.31
Yb------	2.9	2.9	4.2	3.0
Lu------	.52	.49	.79	.57

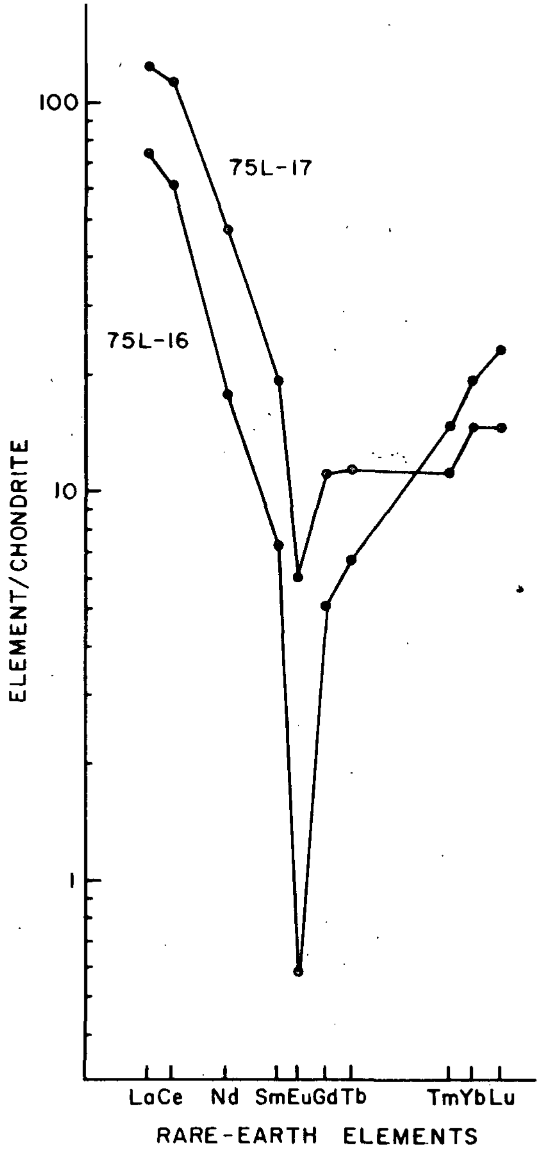


Figure 6.—Chrondite-normalized rare-earth-element plot for two rhyolites of the Mineral Mountains (75L–16 and 75L–17), showing negative Eu anomalies.

crystallization involving removal of feldspar. Chondrite-normalized analyses of two whole-rock samples show large negative Eu anomalies (fig. 6), indicative of major feldspar removal (Arth, 1976). This pattern contrasts with that of some other voluminous Cenozoic silicic rocks in the western United States (Zielinski and Lipman, 1976; P. W. Lipman, unpub. data, 1976) which show small or no Eu anomalies and appear to have developed their silicic compositions by processes not involving major feldspar fractionation, probably because the environment of differentiation was at pressures too high for feldspar to be stable.

possible geothermal significance in southwestern Utah are not restricted to the Mineral Mountains. We dated obsidian "Apache tears" from an eroded rhyolite flow at the Cudahy mine about 25 km north of the Mineral Mountains (fig. 1), as 2.38±0.15 m.y. (table 3, no. 6). A large rhyolite plug (South Twin Peak) in the Black Rock desert about 10 km east of the Cudahy mine yielded a similar K-Ar age of 2.33±0.12 m.y. (table 3, no. 7). Marginal obsidian from a small body of rhyolite at White Mountain, about 50 km northeast of the Mineral Mountains (fig. 1), yielded ages of 0.43±0.07 and 0.39±0.02 m.y. (table 3, no. 8), the youngest of any of our ages. The rhyolite at White Mountain contains inclusions of a distinctive dated basalt, indicating a maximum age for the dome of about 1 m.y. (Hoover, 1974). This rhyolite occurs less than 1 km from the nearest exposure of upper Pleistocene basalt of the Tabernacle volcanic field estimated to be 10 000–20 000 yr old (Hoover, 1974). Basalts of the Ice Springs volcanic field, 3 km north of White Mountain, are post-Lake Bonneville in age, that is, less than 12 000 yr old. These basaltic and rhyolitic rocks together offer another example of a bimodal basalt-rhyolite association in Utah. Thus, the potential for volcanic-related thermal anomalies in southwestern Utah is not confined to the Mineral Mountains. In fact, White Mountain is about 7 km north of Meadow and Hatton hot springs (Mundorff, 1970).

Another intriguing aspect of the rhyolites in the Mineral Mountains is their significance as a source of artifact obsidian. Implement-grade obsidian is relatively scarce in the southwestern United States, yet obsidian artifacts occur widely in archeological sites. Well-known sources of archeological obsidian include the Jemez Mountains in New Mexico, Coso Mountains and Long Valley areas in east-central California, Medicine Lake Highlands and associated rhyolitic centers in northeastern California, Newberry volcano and numerous small areas of rhyolite in eastern Oregon, and Yellowstone rhyolite plateau in Wyoming (fig. 7). The little known Mineral Mountains locality is in a region where high-quality obsidian is scarce, nearly equidistant from better known sources, yet it contains abundant obsidian suitable for implement manufacture. Individual blocks of nonporphyritic obsidian from the Bailey Ridge and Wildhorse Canyon flows are as much as 0.5 m across. Obsidian from the Mineral Mountains has recently been recognized in several archeological sites in southwestern Utah and adjacent parts of Nevada (Umshler, 1975), but how widely it has been distributed has yet to be established.

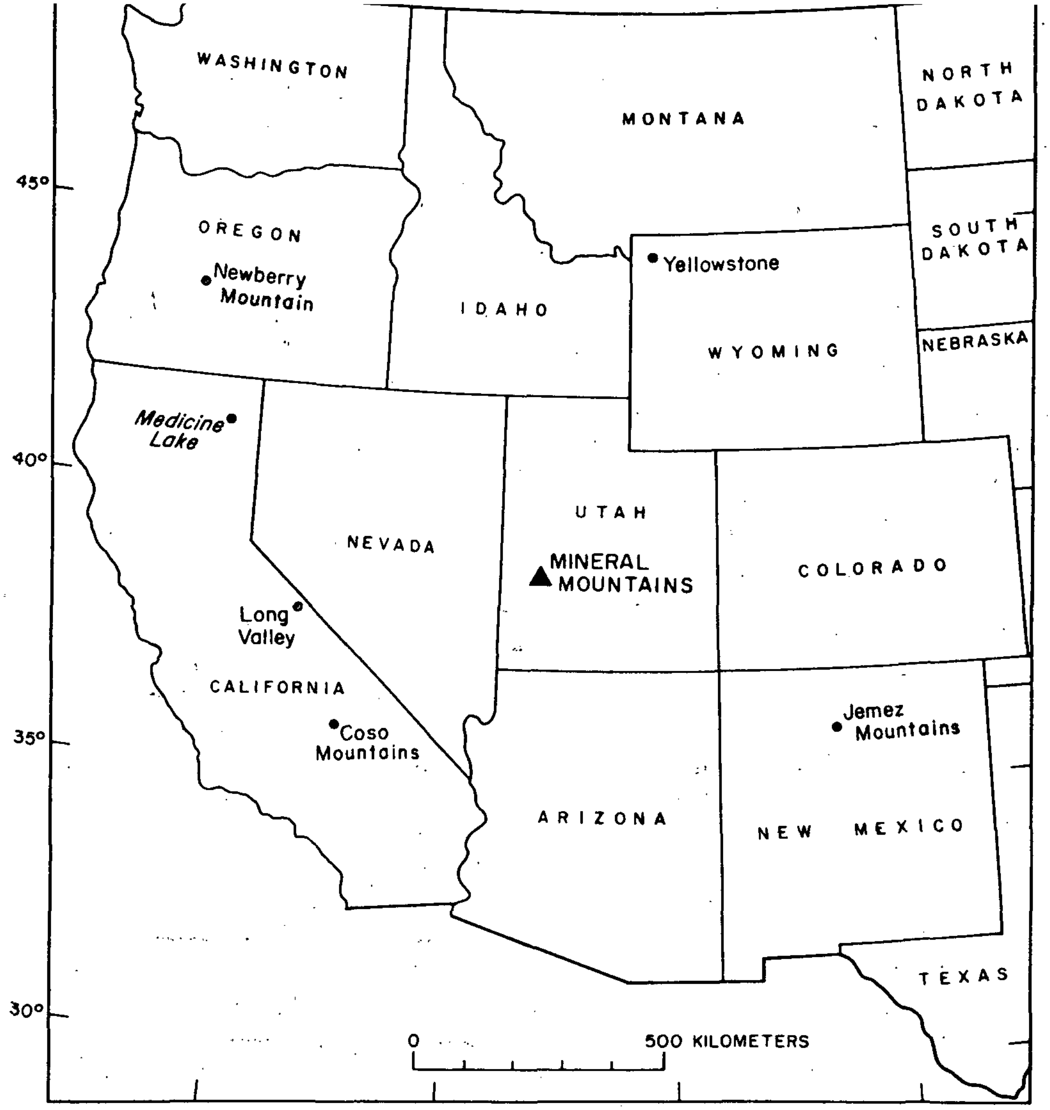


Figure 7.—Well-known sources for archeological obsidian in the western United States.

Available compositional data indicate that obsidian artifacts derived from the Mineral Mountains should be distinguishable, especially by minor-element compositions, from those of most of the better known obsidian sites.

Fission-track age dating, by G. A. Izett and C. W. Naeser, and obsidian-hydration age dating, by Irving Friedman, were conducted—independently of our study—on selected samples of rhyolite from the Mineral Mountains. The ages determined by these two other techniques provide a cross-check on the ages presented above that were determined by the K-Ar isotope method. Comparisons of the results of the three techniques are presented separately, in the sections that follow.

FISSION-TRACK DATING

By G. A. Izett and C. W. Naeser

Fission-track age determinations were made on samples of obsidian from the Bailey Ridge flow and the Bearskin Mountain dome. The fission-track age of the Bailey Ridge obsidian is in fair agreement with the K-Ar age of the obsidian, but the fission-track age of the Bearskin Mountain obsidian is anomalously younger than the K-Ar age. Th sample we dated of the Bearskin Mountain obsidian contains no fossil fission tracks; however, the age can be estimated by assuming the presence of one fossil track as shown in the table below. The anomalously young fission-track age of the Bearskin Mountain obsidian probably is due to the annealing of fossil tracks from a recent thermal event. The fission-track analytical data follow:

[Fission tracks etched for about 10 seconds in 48 percent hydrofluoric acid; ± 1 sigma about the mean. $\lambda f = 6.85 \times 10^{-17} yr^{-1}$]

Locality	ϕ (neutrons cm^{-2})	ρ_s (tracks cm^{-2})	ρ_i (tracks cm^{-2})	Fission track glass age x 10^6 years	K-Ar glass age x 10^6 years[1]
Bearskin Mountain dome	8.72×10^{14}	$<3.37 \times 10^1$(1)	1.25×10^5(309)	<0.02	0.75 ± 0.1 0.60 ± 0.12
Bailey Ridge flow	0.5×10^{15}	7.89×10^2(3)	4.40×10^4(213)	0.55 ± 0.30	0.79 ± 0.08

[1] See table 3.

OBSIDIAN-HYDRATION DATING

By Irving Friedman

Four rhyolite lava flows or domes from the Mineral Mountains, Utah, were dated by the obsidian-hydration technique. Most of the results agree with K-Ar and fission-track dates of the same flows.

Obsidian-hydration dating depends upon the fact that a newly formed surface on obsidian, such as a cooling crack, adsorbs water from the atmosphere. This adsorbed water slowly diffuses into the obsidian, and the depth of penetration of the water can be measured under the microscope in a thin section cut normal to the surface (Friedman and Smith, 1960). The rate at which the water diffuses into the obsidian is dependent upon temperature and glass composition (Friedman and Long, 1976).

The thickness of the hydrated layer (in micrometers) for the rhyolite units is tabulated below. Also listed is the expected rate of hydration (in $\mu m^2/10^3$ yr) for each flow, calculated for an estimated effective hydration temperature of 8°C and from the chemical composition of the obsidian. (See Friedman and Long, 1976.) The calculated obsidian-hydration age is also given, as is the K-Ar age.

Although the effective hydration temperature is assumed to be the same for all the flows sampled, the differing whole-rock chemistry of the obsidian gives different calculated hydration rates. Compositions of two of the obsidians are from table 2 in this paper; the analysis of the Bearskin Mountain dome is from S. H. Evans (written commun., 1976). No analysis is available for the South Twin Flat Mountain dome. An analysis for the North Twin Flat Mountains (table 2) was used instead; the hydration rate and calculated age are accordingly uncertain.

The calculated hydration rates vary by a factor of 2.5, owing mainly to differences in the amount of CaO+MgO. The chemical analyses were on whole-rock samples, but the hydration-rate calculation should be based on glass compositions. The Wildhorse Canyon and the Bailey Ridge glasses are almost free of phenocrysts, but the Bearskin Mountain and particularly the

Rhyolite	Thickness of hydration µm (± 1 µm)	Chemical index	Calculated hydration rate $\mu m^2/10^3$ yrs	Calculated age 10^6 yrs	Corrected age	K/Ar age
Wildhorse Canyon flow------------	41	42.5	2	0.85	0.85	([1])
Bailey Ridge flow------------	40	41.7	2	.80	.80	0.79
Bearskin Mountain dome------------	31	47.4	4	.24	.48	.75 .60
South Twin Flat Mountain dome---	22	51.1(?)	5(?)	.10(?)	.25	.50

[1] No determination

South Twin Flat Mountain all have refractive indices of 1.4847±0.0005, whereas Bearskin Mountain dome has a slightly higher index, 1.4856±0.0005. The similarity in index of all four glasses makes any assumption of greatly differing hydration rates for these samples unrealistic. If we assume that the chemical compositions of the glass phase of all four samples are similar, then the hydration rates also will be similar and the dates shown in the column "Corrected age" should apply.

The corrected ages agree with the K-Ar dates, except for the date for the South Twin Flat Mountain dome, where the hydration date is about half that derived by K-Ar dating. The reasons for this discrepancy are not known, but we may not have sampled sufficiently to find an original surface on the samples from this site. Alternatively, the discrepancy may be due to some inherited argon in the sanidine used for K-Ar dating.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1977--261-198/1

Vol. 6, No. 1, Jan.–Feb. 1978, p. 133–141

PLEISTOCENE RHYOLITE OF THE MINERAL MOUNTAINS, UTAH—GEOTHERMAL AND ARCHEOLOGICAL SIGNIFICANCE

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With sections by G. A. IZETT and C. W. NAESER
and by IRVING FRIEDMAN, Denver, Colo.

Abstract.—Little-eroded rhyolitic tuffs, flows, and domes extend over about 25 km^2 along the western side of the Mineral Mountains, southwestern Utah, which is along the eastern edge of the Roosevelt KGRA (Known Geothermal Resource Area). Initial eruptions resulted in two low-viscosity lava flows of nonporphyritic rhyolite. These were followed by bedded pumice falls and nonwelded ash flows. The youngest activity produced at least nine viscous domes and small lava flows of rhyolite that contain 1–5 percent phenocrysts of quartz, plagioclase, sodic sanidine, and biotite; distinction between domes and eroded flow segments locally is difficult.

Potassium-argon ages indicate that all the rhyolite of the Mineral Mountains was erupted between 0.8 and 0.5 m.y. ago. The rhyolite rests on dissected granite of the Mineral Mountains pluton, the largest intrusion in Utah, which has yielded published K-Ar ages of 9 and 15 m.y. A small older dissected rhyolite dome, about 8 m.y. old, occurs just west of the range front. Whether the young ages of the pluton represent time of intrusion or of later reheating, they, in conjunction with the Pleistocene rhyolite in the Mineral Mountains, do indicate a major late Cenozoic thermal anomaly, the size and age of which is significant to evaluation of the Roosevelt KGRA. The rhyolite is also the only known source of implement-grade obsidian in the southwest between eastern California and northern New Mexico.

As part of the U.S. Geological Survey's geothermal energy program, age, composition, and distribution data are being obtained for upper Cenozoic volcanoes in the western United States that have erupted significant amounts of silicic rocks. Such silicic rocks, mostly rhyolites, are considered possible indicators of the subsurface presence of shallow magma chambers still sufficiently hot to have potential for geothermal resources. A rationale for this approach is outlined by Smith and Shaw (1975).

Large volumes of rhyolite associated with known geothermal resources have been described from Yellowstone National Park (Allen and Day, 1935; Christiansen and Blank, 1972), in the Jemez Mountains in New Mexico (Smith, Bailey, and Ross, 1970), and in the Long Valley area, California (Bailey, Dalrymple, and Lanphere, 1976). Around the margins of the Colorado Plateau, small volumes of similar silicic rocks that also seem worthy of reconnaissance evaluation in terms of geothermal signifiance occur in the San Francisco Mountains volcanic field, Arizona (Robinson, 1913; Moore, Wolfe, and Ulrich, 1974), in the Mount Taylor and Taos Plateau volcanic fields of New Mexico (Hunt, 1938; Lambert, 1966), and in the Mineral Mountains, Utah.

In the Mineral Mountains, southwestern Utah, young rhyolite masses extend discontinuously for about 15 km along the range crest and cover an area of less than 25 km^2; these have been little studied and previously were interpreted as erosional remnants of a single large silicic volcano of late Tertiary age (Earll, 1957; Liese, 1957). This brief report presents new geologic data, including K-Ar ages which demonstrate that many separate lava domes, flows, and tuffs were erupted from vents along the range crest between 0.8 and 0.5 m.y. ago. Along one of the western range-front faults, about 2 km northwest of the nearest rhyolitic volcanic rocks, Roosevelt Hot Springs is located within a KGRA (Known Geothermal Resource Area) that is actively being developed for geothermal power production. The youthful silicic volcanism recorded by the rhyolite of the Mineral Mountains suggests the presence of a still-hot buried magma chamber that may be the heat source for the KGRA.

Acknowledgments.—Discussions with Glenn A. Izett and Irving Friedman, who examined the rhyolites, and Sr-Rb data on granite from the Mineral Mountains pluton by Carl E. Hedge aided the evolution of ideas on the rhyolite of the Mineral Mountains. We thank John S. Pallister and Alan Martz for assistance

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also thank Gary L. Galyardt for information on the Roosevelt KGRA.

Research by authors from the University of Utah was supported by National Science Foundation Grant GI–43741 and U.S. Energy Research and Development Administration Contract no. EY–76–S–07–1601.

GENERAL GEOLOGIC SETTING

The Mineral Mountains, in west-central Utah (fig. 1), are a typical basin-range horst, which rises about 1 km above the adjacent alluviated basins, the Escalante Desert to the west and an unnamed valley to the east. The horst extends nearly 50 km in a northerly direction and is in general about 10 km wide.

On the western and northern sides of the range, metamorphic rocks of the Wildhorse Canyon Series of Condie (1960), of probable Precambrian age, are the dominant rocks, but on the southern, northern, and eastern sides of the range, Paleozoic and Mesozoic sedimentary rocks are exposed widely. These layered rocks are intruded by a distinctive body of granite, the Mineral Mountains pluton, which is the largest single exposed intrusive body in Utah, covering nearly 250 km². This granite and associated pegmatite and aplite may be as young as late Miocene, having yielded two K-Ar ages on feldspars of 15 and 9 m.y. from different sample sites (Park, 1968; Armstrong, 1970). These young apparent ages are supported in a general way by results of a Rb-Sr isotopic study. A Rb-Sr isochron, based on 11 analyses of whole-rock samples ranging in composition from diorite to aplite, shows exceptionally bad scatter but suggests that the age of the main batholith is about 35 m.y., with sizable chemical modification—especially Sr loss—having occurred 7–15 m.y. ago (C. E. Hedge, written commun., 1976).

Prior to the onset of late Cenozoic rhyolitic volcanism in the Mineral Mountains, the Mineral Mountains pluton and its country rocks were deeply dissected to form a rugged erosional topography with towering pinnacles rising above narrow usually dry valleys.

The Mineral Mountains are bounded on the west, and probably on the east side, by north-striking normal faults. The trend of the bounding faults on the west is marked locally in the Roosevelt KGRA by discontinuous elongate mounds of opaline sinter and other hot-spring deposits. Near the northern end of this trend is Roosevelt Hot Springs (Petersen, 1975). Water temperatures as high as 90°C have been reported. Phillips Petroleum Co., the successful bidder on the KGRA in 1974, is continuing exploration on the property. Numerous test wells so far drilled in the KGRA have documented the presence of a low-salinity liquid-dominated geothermal system (Berge, Crosby, and Lenzer, 1976; Greider, 1976). The thermal anomaly covers approximately 32 km², and reservoir temperatures exceed 250°C.

RHYOLITE OF THE MINERAL MOUNTAINS

Rhyolitic rocks in the Mineral Mountains include three stratigraphically distinct sequences. Lowermost are two nearly nonporphyritic obsidian-rich lava flows. These are overlain by a pyroclastic sequence, including both ash-fall and ash-flow tuffs. Stratigraphically highest are porphyritic rhyolite lava domes erupted from at least nine separate vents, most of which are along the range crest.

Flows of Bailey Ridge and Wildhorse Canyon

The oldest rhyolitic rocks in the Mineral Mountains are two lava flows of virtually nonporphyritic flow-layered rhyolite. One flow is exposed for about 3 km along Bailey Ridge and in Negro Mag Wash (fig. 2) northwest of Bearskin Mountain. The other is exposed for about 3.5 km along Wildhorse Canyon, west of Bearskin Mountain. Both flows were originally as much as 100 m thick and followed pre-existing valleys that drained the western side of the Mineral Mountains, with relief much like the present, and that were graded nearly to the present levels at valley fronts. Both flows are only slightly dissected, and much of their primary upper surfaces of frothy pumiceous perlitic rubble is preserved.

Where deeply dissected, both flows display similar cooling and crystallization zonations. The basal few meters of the flow, resting directly on medium- to coarse-grained Tertiary granite of the Mineral Mountains pluton, consists of dense black obsidian. The obsidian has well-developed flow lamination defined by alined microlites of feldspars and opaque oxides (fig. 3*A*). The basal obsidian zone grades upward within a meter or two into a well-layered zone, in which dark obsidian and light-gray or brown finely crystallized flow-layered lava alternate. The interior of the flow is as much as 10–30 m thick and consists of gray relatively structureless devitrified rhyolite, in places containing concentrations of ovoid gas cavities locally filled with vapor-phase crystallization products.

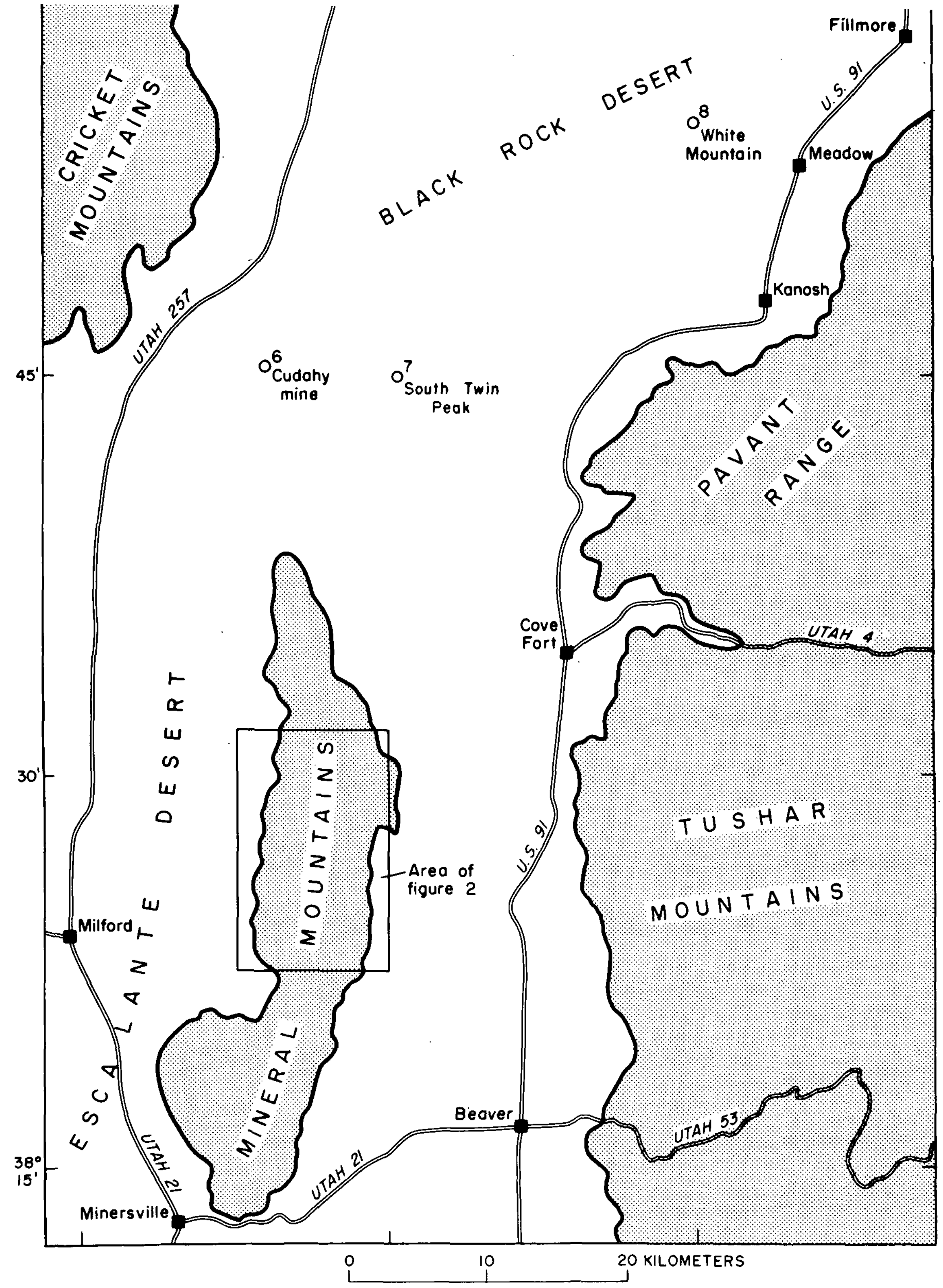

FIGURE 1.—Index map showing location of the Mineral Mountains and nearby areas, Utah. Numbers indicate locations of some dated samples (table 3); the others are shown on figure 2.

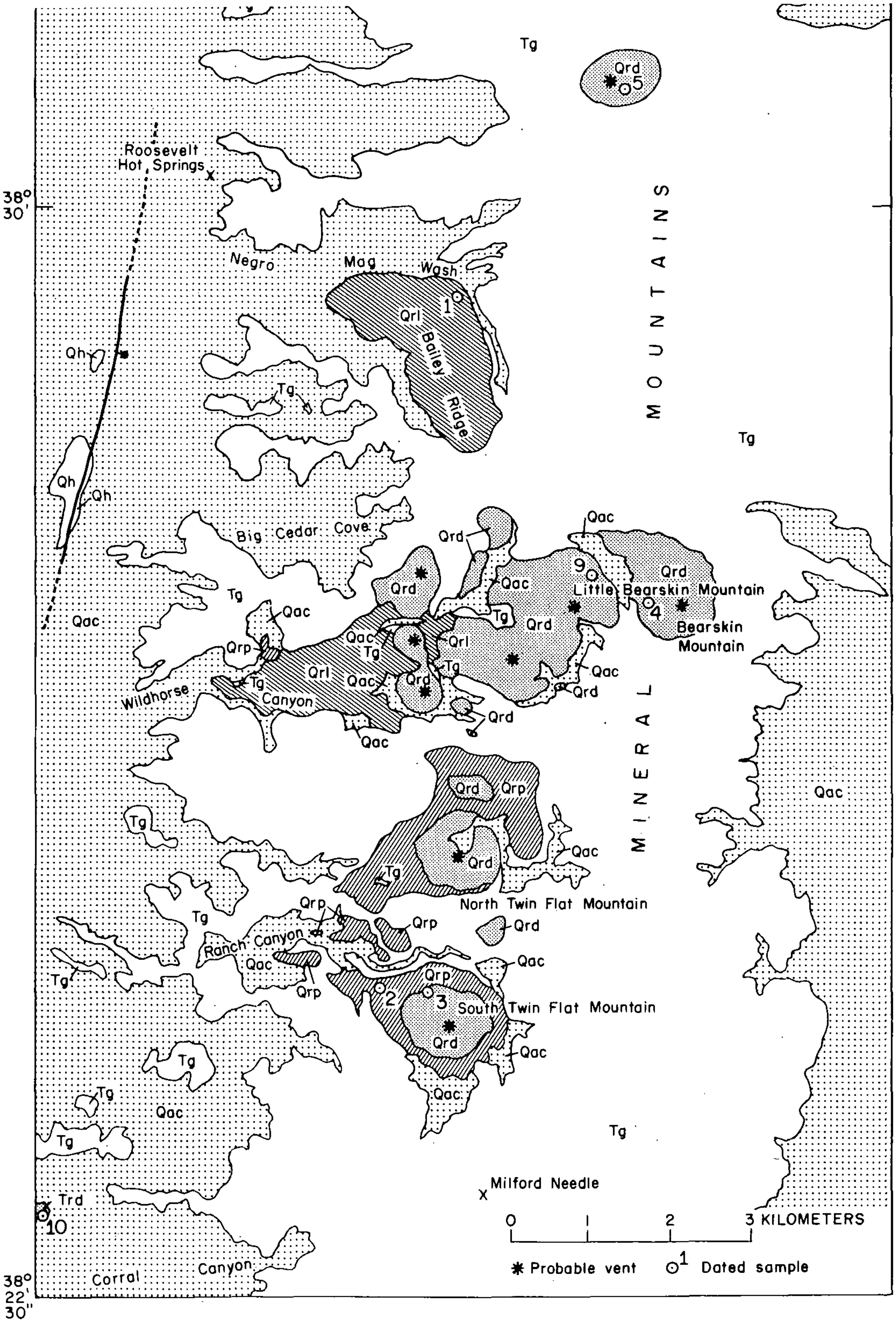

FIGURE 2.—Generalized geologic map of the central Mineral Mountains, Utah, showing distribution of Pleistocene rhyolitic rocks and locations of dated samples (table 3). Rock units, from oldest to youngest: Tg, Tertiary granite of Mineral Mountains; **Trd**, Tertiary rhyolite dome of Corral Canyon; **Qrl**, lava flows of Bailey Ridge and Wildhorse Canyon; **Qrp**, pyroclastic rocks; **Qrd**, lava domes; **Qac**, surficial deposits, primarily alluvium and colluvium; **Qh**, hot-spring deposits. Fault shown (bar and ball on downthrown side), named the Dome fault by Petersen (1975), is only one of many along the western range front.

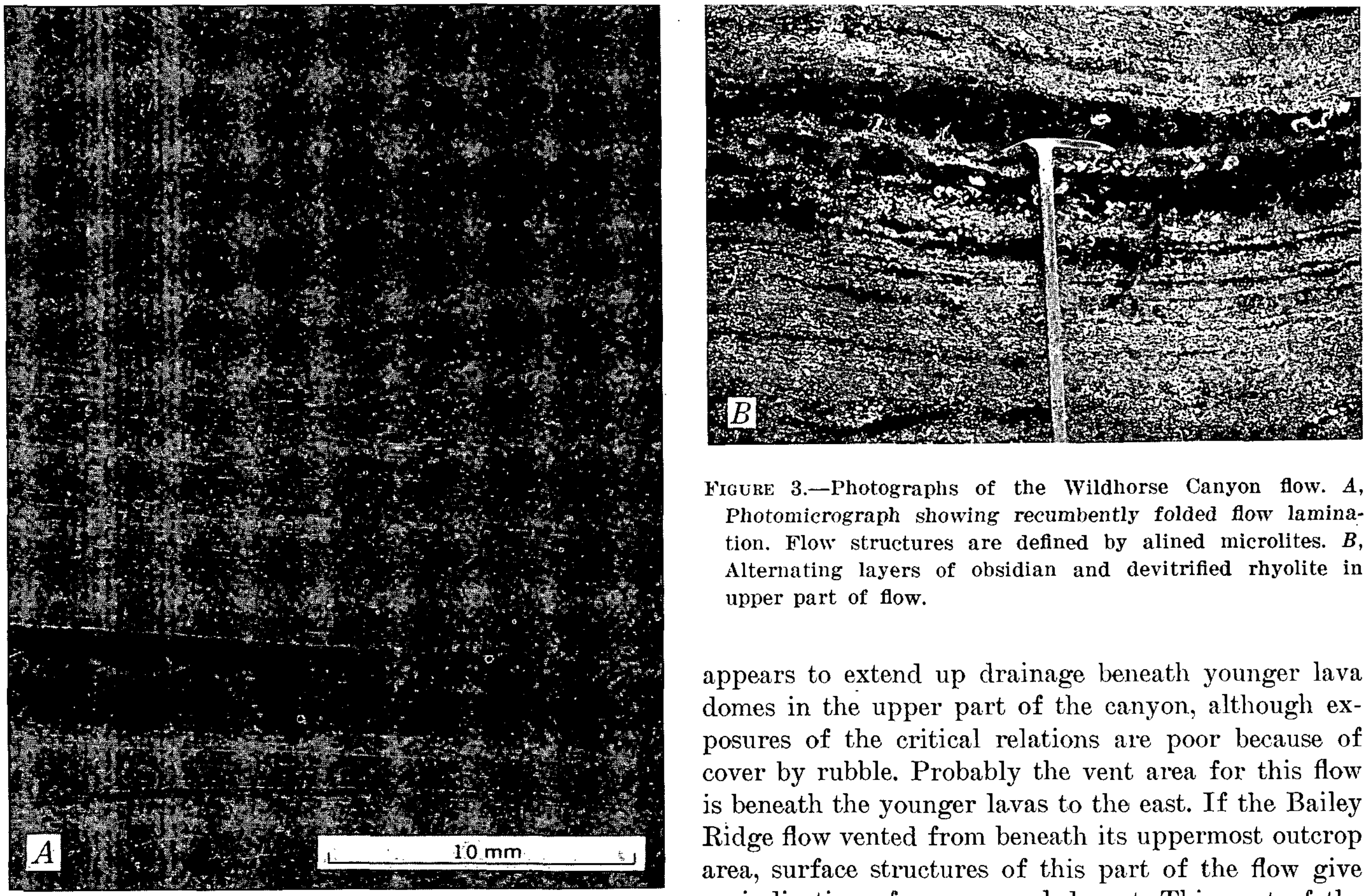

FIGURE 3.—Photographs of the Wildhorse Canyon flow. *A*, Photomicrograph showing recumbently folded flow lamination. Flow structures are defined by alined microlites. *B*, Alternating layers of obsidian and devitrified rhyolite in upper part of flow.

In upper parts of the flow a few meters of flow-layered obsidian are interlayered with devitrified rock (fig. 3*B*), passing upward into a more uniform dark glass zone or grading directly into a frothy rubbly breccia of tan perlitic pumice as much as 10 m thick at the top of the flow.

The flow layering and lamination in these rhyolitic lavas is remarkably planar and uncontorted as compared to the swirly internal structures typical of many rhyolitic lava flows. The "ramp structures" that occur commonly in upper parts of silicic flows (Christiansen and Lipman, 1966), are absent or poorly developed, and subhorizontal layering is typical throughout the Bailey Ridge and Wildhorse Canyon flows. The most common deviations from planar layering are small, typically rootless recumbent folds (fig. 3*A*), most limbs of which are less than 1 m long. These flowage features, as well as the relatively slight thickness of each lava flow as compared to its longitudinal extent, indicate that they were characterized by lower emplacement viscosities than many silicic lava flows.

Vents for these oldest flows of the Mineral Mountains have not been found. The Wildhorse Canyon flow appears to extend up drainage beneath younger lava domes in the upper part of the canyon, although exposures of the critical relations are poor because of cover by rubble. Probably the vent area for this flow is beneath the younger lavas to the east. If the Bailey Ridge flow vented from beneath its uppermost outcrop area, surface structures of this part of the flow give no indication of any concealed vent. This part of the flow is little dissected, however, and the vent area could be completely buried. Alternatively, the Bailey Ridge flow, and also the Wildhorse Canyon flow, might have come from higher on the slope, underneath the area now covered by the Bearskin and Little Bearskin Mountain lava domes. However, this would require that the upper portions of the flows be largely removed by erosion while the lower portions were left relatively undissected.

The Bailey Ridge and Wildhorse Canyon flows are petrographically similar. They contain less than 0.5 percent total phenocrysts, the majority of which are alkali feldspar (table 1). There are trace amounts of oligoclase, biotite, titanomagnetite, and ilmenite. The two flows are virtually identical in chemical composition (table 2). They are typical silicic rhyolites, containing about 76.5 percent SiO_2 and just over 9 percent total alkalis. The fresh obsidians contain more fluorine than water; secondarily hydrated pumice from the Bailey Ridge flow contains 2.4 percent total H_2O. The magmatic temperatures of these flows were about 750°C, as determined from compositions of iron-titanium oxides and coexisting plagioclase and alkali

TABLE 1.—*Modal compositions of radiometrically dated samples*

[Est., estimate; tr., trace; leaders (--), not present; *, microphenocrysts]

Field No.	Unit	Ground-mass	Plagio-clase	K-feldspar	Quartz	Biotite	Horn-blende	Clino-pyroxene	Opaques	Poi cou
75L-17	Bailey Ridge flow, obsidian----------------	99.9	--	tr.	tr.	--	--	--	--	Es
75L-15	Tuff of Ranch Canyon obsidian block---------	98.2	0.6	0.8	0.4	tr.	--	--	tr.	3,
75L-16	South Twin Flat Mountain dome, obsidian with patchy devitrification-	92.6	1.2	3.9	2.3	tr.	--	--	tr.	3,
75L-56	Bearskin Mountain, obsidian---------------	97.2	.3	1.2	1.2	0.1	--	--	tr.	4,
75R-53	Little Bearskin Mountain dome, obsidian---------	96.0	.9	1.9	1.0	--	--	--	0.1	2,
75L-18A	Northern dome, frothy perlite----------------	97.4	.4	1.3	.7	.1	--	--	.1	2,
75L-19	Rhyolite of the Cudahy mine, obsidian---------	100	--	--	--	--	--	--	--	Est
75L-21	Black Rock desert felsite plug-----------	91.2	5.8	1.2	--	tr.	--	1.2	.6	3,1
75L-23	Rhyolite of White Mountain, obsidian-----	94	--	--	--	--	*6	--	--	Est

[Analyses by J. H. Evans, Jr., by standard wet chemical techniques. Key to analyses, 74-3A, Obsidian, Bailey Ridge flow; 74-8, Obsidian, Wildhorse Canyon flow; 75-14, Obsidian, Little Bearskin Mountain dome; 75-20, Basal Obsidian, North Twin Flat Mountain dome. Leaders (---) not present; tr., trace]

Chemical Analyses				
	74-3A	74-8	75-14	75-20
SiO_2	76.52	76.51	76.42	76.45
TiO_2	.12	.12	.08	.08
Al_2O_3	12.29	12.29	12.79	12.79
Fe_2O_3	.31	.23	.20	.30
FeO	.46	.51	.38	.29
MnO	.05	.05	.09	.10
MgO	.08	.08	.11	.12
CaO	.64	.65	.44	.40
Na_2O	3.80	3.77	4.42	4.39
K_2O	5.24	5.28	4.72	4.73
P_2O_5	.02	.01	tr.	.06
H_2O+	.12	.06	.13	.10
H_2O-	.06	.06	.01	---
F	.16	.15	.42	.44
Sum	99.87	99.77	100.21	100.25
Less F=O	.07	.06	.18	.19
Total	99.80	99.71	100.03	100.06

CIPW Norms				
	74-3A	74-8	75-14	75-20
Q	33.40	33.28	33.22	32.48
c	---	.26	.41	.45
or	30.96	31.20	27.89	27.95
ab	32.15	31.90	37.40	37.15
an	1.00	1.02	---	---
di-wo	.37	.47	---	---
di-en	.11	.12	---	---
di-fs	.27	.38	---	---
hy-en	.09	.08	.27	.30
hy-fs	.21	.26	.57	.34
mt	.45	.33	.29	.43
il	.23	.23	.15	.15
ap	.05	.02	---	.14
fr	.33	.29	.61	.45
rest	.18	.12	.14	.10
Total	99.80	99.96	99.95	99.94

feldspar. The relatively low emplacement viscosities, indicated by the planar flow structures of these rhyolites, do not therefore seem related to exceptionally high emplacement temperatures.

A single K-Ar radiometric age determination of 0.79±0.08 m.y. (table 3, no. 1), from the toe of the Bailey Ridge flow, is the oldest age obtained from any rhyolite of the Mineral Mountains. The Bailey Ridge flow has a reversed paleomagnetic pole position (table 4) indicating, in conjunction with K-Ar data, that it was erupted toward the end of the Matuyama polarity epoch. The Wildhorse Canyon flow has not yet been dated radiometrically, but it also is characterized by a reversed polarity, which, in conjunction with morphological and chemical resemblance to the Bailey Ridge flow and its position beneath some of the pyroclastic rocks, suggests a similar age.

Pryoclastic rocks

South of Wildhorse Canyon, pyroclastic rocks of ash-fall and ash-flow origin are the lowest exposed rhyolitic rocks. The main area of pyroclastic rocks is in Ranch Canyon, where tuffs bury rugged paleotopography much like the present land surface.

The pyroclastic rocks are only weakly consolidated and are mostly poorly exposed, underlying alluviated slopes. All the pyroclastic deposits, both ash-fall and and ash-flow, are white to light tan. They occur over an altitude range from 1950 m in valley-bottom exposures in Ranch Canyon to as high as 2540 m on the surrounding slopes. They also occur in the Cove Fort area, where they are overlain by basalt lava flows (Nash and Smith, 1977). Much of the pyroclastic sequence has been removed by erosion in Ranch Canyon, and it is not clear to what extent this altitude range reflects an actual total thickness of the original deposit and to what extent the pyroclastic rocks were thinner but blanketed the preexisting topography. In Ranch Canyon these rocks are overlain by the large lava domes on North and South Twin Flat Mountains and by smaller masses of rhyolitic lava on adjacent ridges. Although contacts between these domes and the pyroclastic rocks are nowhere well exposed, this stratigraphic sequence is indicated by structural zones in the rhyolite domes of North and South Twin Flat Mountains. The lowest exposures are of a subhorizontal

sample locations. Ages of WM76-3 and MR76-26 determined by S. H. Evans, Jr., and F. H. Brown; other ages determined by H. H. Mehnert]

Sample	Field No.	Unit	Material dated	Location (Lat N Long W)	K$_2$O (percent)	*Ar^{40} (10^{-10}) (moles/gram)	*Ar^{40} (percent)	Age (m.y.$\pm 2\sigma$)
1	75L-17	Bailey Ridge flow-------	Obsidian--------	38°29′, 112°49′	5.10, 5.10	0.058	25.8	0.79±0.08
2	75L-15	Tuff of Ranch Canyon----	Obsidian block--	38°25′, 112°50′	4.63, 4.66	.047	47.1	0.70±0.04
3	75L-16	South Twin Flat Mountain dome---------	Sanidine--------	38°25′, 112°49′	8.14, 8.08	.059	18.1	0.50±0.07
4	75L-56	Bearskin Mountain dome--	Obsidian--------	38°27′, 112°47′	4.48, 4.49	.048	20.2	0.75±0.10
						.039	13.5	0.60±0.12
5	75L-18A	North Dome-------------	Sanidine--------	38°31′, 112°47′	9.36, 9.35	.073	24.5	0.54±0.06
6	75L-19	Cudahy mine------------	Obsidian--------	38°45′, 112°51′	4.91, 4.93	.168	46.0	2.38±0.15
7	75L-21	South Twin Peak---------	Sanidine--------	38°45′, 112°47′	11.13, 11.12	.373	54.3	2.33±0.12
8	75L-23	White Mountain----------	Obsidian--------	38°55′, 112°30′	4.63, 4.70	.029	15.9	0.43±0.07
	WM76-3		Obsidian--------		5.23, 5.25	.030	21.5	0.39±0.02
9	75R-23	Little Bearskin Mountain dome---------	Sanidine--------	38°27′, 112°48′	9.31, 9.15 [1]9.26	.080	31.8	0.61±0.05
10	MR76-26	Corral Canyon dome------	Biotite---------	38°24′, 112°53′	8.72, 8.75	1.011	61.6	7.90±0.30

[1] Isotope dilution determination

TABLE 4.—*Preliminary data on magnetic polarities of rhyolites of the Mineral Mountains*

Unit	Number of samples	Declination	Inclination	Standard error (percent)
Normal samples:				
Northern dome------------	9	350	62	3
Big Cedar Cove dome------	4	23	67	4
Ranch Canyon dome--------	5	22	44	5
Corral Canyon dome-------	3	332	25	20
Ranch Canyon ash---------	2	356	46	29
Wildhorse Canyon ash-----	6	349	48	5
Reversed samples:				
Bailey Ridge flow--------	6	173	-63	6
Wildhorse Canyon flow----	4	168	-61	2

zone of basal flow breccia below the basal obsidian zone; this is the typical zonation expectable at the base of a lava flow or dome and would be an improbable relation if the pyroclastic rocks had been plastered against older lava domes. Thus, the lava dome of South Twin Flat Mountain overlies pyroclastic rocks that are at least 60 m and probably as much as 180 m thick, and these figures suggest minimum thicknesses of the pyroclastic unit.

The lower pyroclastic rocks are beds of air-fall pumice and ash at least 10 m thick and probably much thicker. Individual beds are a few centimeters to about a meter thick. Variable dips indicate that the ash was deposited on the underlying granite, on a surface as rugged as the present one. The pumice and ash contain several percent of small phenocrysts of quartz, oligoclase, alkali feldspar, biotite, magnetite, ilmenite, sphene, and allanite. This mineral assemblage is generally characteristic of the youngest rhyolite flows as well. Associated with the pumice and ash are a few percent of rhyolitic lithic debris, including devitrified rhyolite, perlite, and sparse obsidian fragments. Phenocrysts in the lithic debris are sparse, generally similar to those in the flows of Bailey Ridge and Wildhorse Canyon.

Ash-flow deposits widely overlie the ash-fall beds in Ranch Canyon. The ash-flow deposits locally are at least 50 m thick; probably the total thickness is much greater, but accurate estimates are difficult because of the poor exposures. The ash-flow deposits are everywhere nonwelded and only weakly consolidated; they tend to weather to small conical hills. On especially

4). In exceptionally good exposures, several flow units —each a few meters thick—can be recognized in the ash-flow deposits, with partings between the flow units marked by local concentrations of pumice, lithic debris, or better sorted ash.

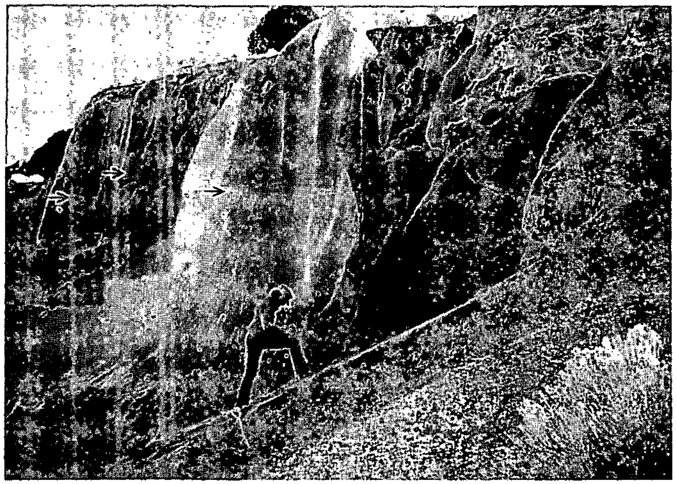

FIGURE 4.—Ash-flow tuff, resting on a rugged erosion surface cut on granite of the Mineral Mountains pluton. Arrows indicate faint parting between flow units of tuff. From northern side of Ranch Canyon at about 2105-m elevation.

On the northern side of lower Wildhorse Canyon, an isolated patch of pyroclastic material about 150 m across consists of finely laminated white fine-grained ash of lacustrine origin. These beds of water-reworked ash are younger than the Wildhorse Canyon flow and were deposited in a local basin dammed by the flow. The ash has a refractive index similar to that of the pyroclastic rocks in Ranch Canyon, one valley to the south, suggesting to us that it represents a reworked marginal facies of this deposit. In contrast, this patch of lacustrine tuff is interpreted by Glenn Izett (written commun., 1976) as airborne Bishop ash, from the Long Valley caldera in California, on the basis of small compositional differences with other rhyolites of the Mineral Mountains.

A single whole-rock K-Ar age on an obsidian clast from ash-flow tuff in Ranch Canyon yielded an age of 0.70±0.04 m.y. (table 3, no. 2), providing an older limit for the age of the pyroclastic rocks. The pyroclastic deposits in Ranch Canyon, as well as the local lake beds in Wildhorse Canyon. have normal magnetic polarities in contrast to the reverse polarities of Bailey Ridge and Wildhorse Canyon flows. Thus, the pyroclastic rocks have been deposited during the Brunhes polarity epoch.

The stratigraphically highest part of the upper Cenozoic volcanic assemblage in the Mineral Mountains is a group of at least nine separate perlite-mantled lava domes and small flows of porphyritic rhyolite. The domes tend to occur along the crest of the range, discontinuously over a zone about 15 km long. These domes form some of the highest topographic points in the Mineral Mountains, including Bearskin Mountain with an elevation of 2772 m (9095 ft). Individual domes are as much as 1 km across at their bases and stand as much as 250 m high, although dimensions are difficult to determine precisely because of the irregular pre-existing topography and subsequent erosion. Small stubby flows extend out from some of the domes, and some small isolated patches of rhyolite (fig. 2) may represent either eroded flow remnants or small separate domes.

The larger domes, such as Bearskin and Little Bearskin Mountains, are little eroded, and surface exposures consist largely of blocks of tan perlitic glass that are slightly modified remnants of the original brecciated frothy carapaces of the domes. Scattered fragments of dense black obsidian, derived from beneath the perlitic breccia, occur about a third of the way above the base of these domes. Float of well-layered devitrified rhyolite is exposed locally just above the zone of obsidian fragments. Pumiceous material, that in places ravels out from below the level of the obsidian zone, may represent an initial pyroclastic fall that is not well exposed.

Other domes, such as those of North and South Twin Flat Mountains (fig. 5), have been more deeply dissected, in this case by the reexcavation of Ranch Canyon, and their internal structural and crystallization features are better exposed. The internal features of all these late domes are in general similar. A basal black vitrophyric zone is everywhere well developed, in places resting on lighter colored glassy basal flow breccia. The vitrophyre zone, which is as much as 5–10 m thick, grades upward into devitrified rock through a transition zone a few meters thick in which flow-layered obsidian alternates with devitrified rock that is commonly highly spherulitic. The devitrified interiors of the flows tend to be light gray and contain conspicuous spherulites. In places, gas cavities several centimeters across contain lithophysal fillings. The interiors of the flows tend to be crudely flow layered, with the layering subhorizontal just above the basal glass zone, but becoming steeper in upper parts of the lava dome. Near-vertical riblike masses of flow-layered devitrified rock are commonly exposed high on the

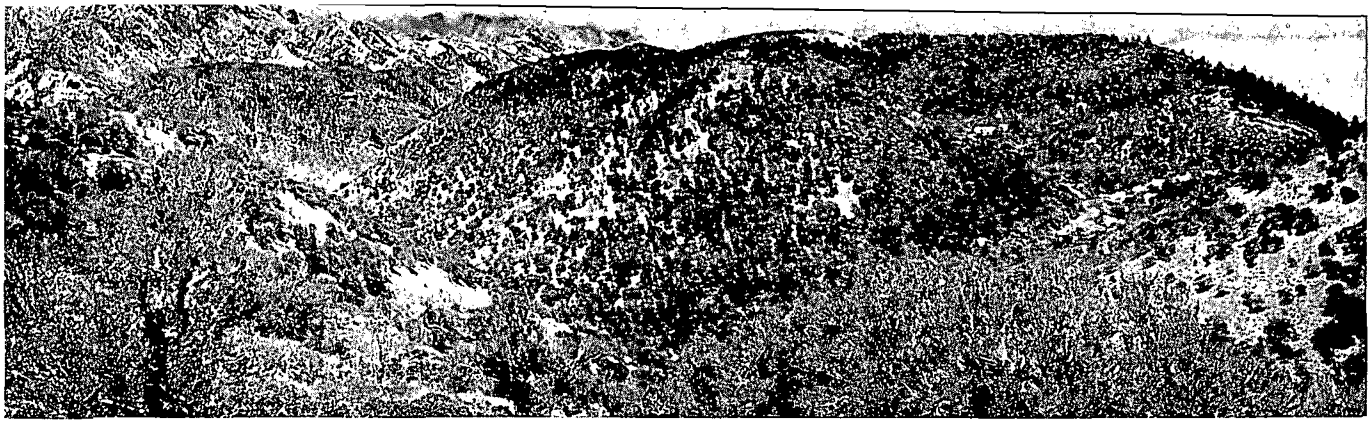

FIGURE 5.—Rhyolite domes of North and South Twin Flat Mountains. Rugged terrain in distance, including Milford Needle (elev. 2920 m) on the left side of the picture, is underlain by granite of the Mineral Mountains pluton. Photographed from ridge between Ranch and Wildhorse Canyons.

domes, where erosion has stripped away the surface mantle of frothy perlite. The steeply dipping flow layering and ramp structures of these domes thus are in contrast to structures in the older lava flows of Wildhorse Canyon and Bailey Ridge.

The porphyritic domes typically lack well-developed central craters (for example, the South Twin Flat Mountain dome) although several have slight central depressions that have been breached and accentuated by erosion. Breached depressions are especially evident for the unnamed northern dome, which is on the range crest northeast of Negro Mag Wash (fig. 2), Bearskin Mountain dome, and North Twin Flat Mountain dome (fig. 5).

All the domes contain several percent phenocrysts of quartz, oligoclase, alkali feldspar, biotite, and iron-titanium oxides (table 1). Trace amounts of sphene and allanite occur in some domes. Hornblende, zircon, and allanite are present in the Corral Canyon dome, the southernmost exposure of rhyolitic volcanic rocks. The North and South Twin Flat Mountain domes have 5–8 percent total phenocrysts, distinctly more than any of the others. The obsidian zones of these two domes appear even more phenocryst-rich, because of the presence of small "snowflake" devitrification spots. The flows in upper Wildhorse Canyon and to the north contain only 2–3 percent total phenocrysts.

Two analyzed samples of the porphyritic domes (table 2) are chemically similar silicic alkalic rhyolite. In comparison with the older flows of Bailey Ridge and Wildhorse Canyon, the domes are slightly but significantly higher in Na_2O and F; they are lower in K_2O and CaO.

Lack of continuity, and thus absence of contact relations, between the domes makes relative ages of the domes difficult to determine. On the basis of amount of dissection, North and South Twin Flat Mountains may be among the oldest, and Bearskin Mountain among the youngest of the domes. The K-Ar ages (table 1), petrographic and chemical similarities, and the generally similar degree of erosional dissection indicate that the domes are about the same age. Stratigraphic relations on the northern side of the North Twin Flat Mountain dome suggest that this dome is older than the unnamed ridge-capping flow 0.5 km north of it (fig. 2). Bearskin Mountain and the three domes extending southwest from it appear compositionally homogeneous, consisting of phenocryst-poor rhyolite similar to the rhyolite that overlies the North Twin Flat Mountain dome. The Bearskin Mountain dome has yielded K-Ar ages on obsidian of 0.60±0.12 and 0.75±0.10 m.y. (table 3, no. 4), and the Little Bearskin Mountain dome has an indicated sanidine age of 0.61±0.05 m.y. (table 3, no. 9). Sanidines from obsidian of South Twin Flat Mountain and the unnamed northern dome have yielded K-Ar ages of 0.50 ±0.07 and 0.54±0.06 m.y. respectively (table 3, nos. 3, 5). Magnetic-polarity determinations for several domes of this group are normal (table 4) indicating, in conjunction with the K-Ar ages, that they were erupted during the Brunhes polarity epoch.

One small dome of mostly devitrified alkalic rhyolite and minor vitrophyre in Corral Canyon, shown as Trd in the lower left corner of figure 2, has been dated at 7.90±0.30 m.y. (table 3, no. 10). These volcanic rocks appear to be unrelated to the young rhyolites higher in the Mineral Mountains; the rhyolite in Corral Canyon is more eroded and contains a different lavas, may have been responsible for producing the anomalously young ages of 14 and 9 m.y. measured on the Mineral Mountains pluton.

DISCUSSION

The stratigraphic relations and K-Ar ages of rhyolites of the Mineral Mountains, newly reported here, indicate that these rocks were emplaced during a relatively brief period in the Pleistocene, between about 0.8 and 0.5 m.y. ago, but an older rhyolitic event occurred about 8 m.y. ago. The Mineral Mountains are flanked on the northern and eastern sides by upper Cenozoic basalt flows (Condie and Barsky, 1972; Hoover, 1974), roughly contemporaneous with and younger than the rhyolite of the Mineral Mountains, and this association of rhyolite and basalt constitutes a bimodal volcanic assemblage of a type that is being recognized widely in the western United States in upper Cenozoic volcanic sequences (Christiansen and Lipman, 1972).

A significant question is whether the thermal anomaly of the Roosevelt KGRA is due to proximity to the late Cenozoic volcanic centers in the Mineral Mountains. Roosevelt Hot Springs and other inactive hot springs are located along the mountain-front fault on the western side of the Mineral Mountains, about 2 km west of the nearest exposed rhyolite (fig. 2). The size and shape of the Pleistocene magmatic system tion of rhyolite vents, yet the extent of the vents for 15 km along the crest of the range suggests the possibility of a sizable magmatic system at depth. The elongate trend of rhyolite vents might even mark a segment of a large evolving circular igneous structure, such as interpreted for the Coso rhyolite domes in California (Duffield, 1975). The rhyolites of the Mineral Mountains were extruded along the eroded core of the large Mineral Mountains pluton, itself a late Cenozoic intrusion of remarkably large size for so young an age. Proximity in space and time suggests that the rhyolite of the Mineral Mountains represents a late stage in the evolution of a complex magmatic system that earlier gave rise to the granite of the Mineral Mountains. Alternatively, the rhyolite volcanism might have evolved independently of the granite, but has been partly localized where the crust was still hot from an earlier plutonic event. It seems likely, though not provable, that this large complex magmatic system has also been the heat source for the Roosevelt KGRA, with the shallow thermal anomaly enhanced along the range front by deep fault-controlled convective circulation of hot water.

This interpretation of a complex shallow magmatic system is supported by limited available rare-earth element data (table 5), which indicate that the rhyolite of the Mineral Mountains had a magmatic residence time in a shallow environment for a sufficiently long time to undergo major low-pressure fractional

TABLE 5.—*Rare-earth element analyses of rhyolites of the Mineral Mountains*

[Analyses by J. S. Pallister and H. T. Millard by neutron activation, using a chemical concentration technique. (See Zielinski and Lipman, 1976.)]

	Bailey Ridge flow	Wildhorse Canyon flow	South Twin Flat Mountain dome	Bearskin Mountain dome
	(75L-17)	(75L-60A)	(75L-16)	(75L-56)
La------	43.5	44.3	24.9	25.0
Ce------	95.6	94.3	51.5	44.2
Nd------	27.0	25.5	9.6	7.5
Sm------	3.6	3.5	1.3	.90
Eu------	.42	.40	.037	.035
Gd------	2.8	2.5	1.3	.88
Tb------	.52	.49	.30	.20
Tm------	.38	.35	.47	.31
Yb------	2.9	2.9	4.2	3.0
Lu------	.52	.49	.79	.57

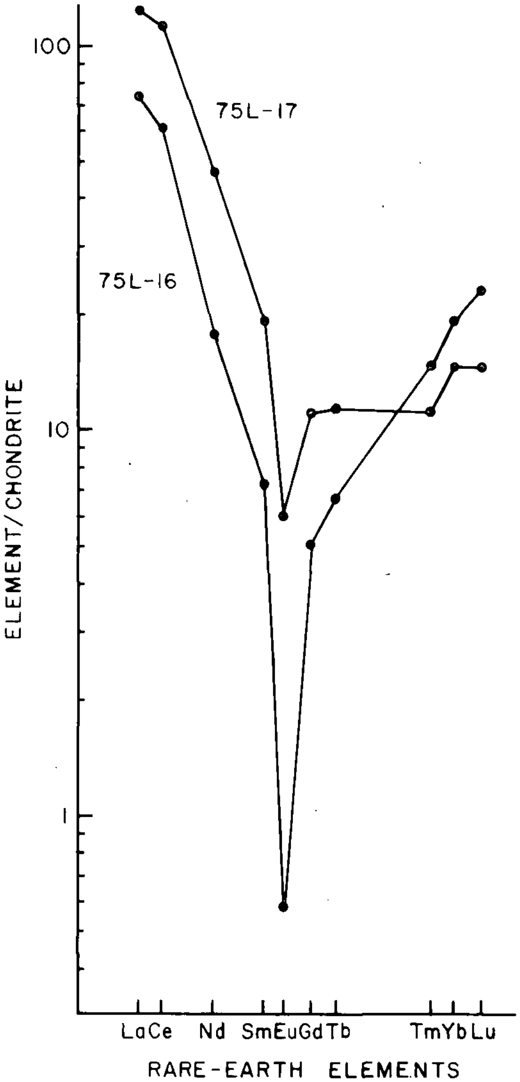

Figure 6.—Chrondite-normalized rare-earth-element plot for two rhyolites of the Mineral Mountains (75L–16 and 75L–17), showing negative Eu anomalies.

crystallization involving removal of feldspar. Chondrite-normalized analyses of two whole-rock samples show large negative Eu anomalies (fig. 6), indicative of major feldspar removal (Arth, 1976). This pattern contrasts with that of some other voluminous Cenozoic silicic rocks in the western United States (Zielinski and Lipman, 1976; P. W. Lipman, unpub. data, 1976) which show small or no Eu anomalies and appear to have developed their silicic compositions by processes not involving major feldspar fractionation, probably because the environment of differentiation was at pressures too high for feldspar to be stable.

are not restricted to the Mineral Mountains. We dated obsidian "Apache tears" from an eroded rhyolite flow at the Cudahy mine about 25 km north of the Mineral Mountains (fig. 1), as 2.38±0.15 m.y. (table 3, no. 6). A large rhyolite plug (South Twin Peak) in the Black Rock desert about 10 km east of the Cudahy mine yielded a similar K-Ar age of 2.33±0.12 m.y. (table 3, no. 7). Marginal obsidian from a small body of rhyolite at White Mountain, about 50 km northeast of the Mineral Mountains (fig. 1), yielded ages of 0.43±0.07 and 0.39±0.02 m.y. (table 3, no. 8), the youngest of any of our ages. The rhyolite at White Mountain contains inclusions of a distinctive dated basalt, indicating a maximum age for the dome of about 1 m.y. (Hoover, 1974). This rhyolite occurs less than 1 km from the nearest exposure of upper Pleistocene basalt of the Tabernacle volcanic field estimated to be 10 000–20 000 yr old (Hoover, 1974). Basalts of the Ice Springs volcanic field, 3 km north of White Mountain, are post-Lake Bonneville in age, that is, less than 12 000 yr old. These basaltic and rhyolitic rocks together offer another example of a bimodal basalt-rhyolite association in Utah. Thus, the potential for volcanic-related thermal anomalies in southwestern Utah is not confined to the Mineral Mountains. In fact, White Mountain is about 7 km north of Meadow and Hatton hot springs (Mundorff, 1970).

Another intriguing aspect of the rhyolites in the Mineral Mountains is their significance as a source of artifact obsidian. Implement-grade obsidian is relatively scarce in the southwestern United States, yet obsidian artifacts occur widely in archeological sites. Well-known sources of archeological obsidian include the Jemez Mountains in New Mexico, Coso Mountains and Long Valley areas in east-central California, Medicine Lake Highlands and associated rhyolitic centers in northeastern California, Newberry volcano and numerous small areas of rhyolite in eastern Oregon, and Yellowstone rhyolite plateau in Wyoming (fig. 7). The little known Mineral Mountains locality is in a region where high-quality obsidian is scarce, nearly equidistant from better known sources, yet it contains abundant obsidian suitable for implement manufacture. Individual blocks of nonporphyritic obsidian from the Bailey Ridge and Wildhorse Canyon flows are as much as 0.5 m across. Obsidian from the Mineral Mountains has recently been recognized in several archeological sites in southwestern Utah and adjacent parts of Nevada (Umshler, 1975), but how widely it has been distributed has yet to be established.

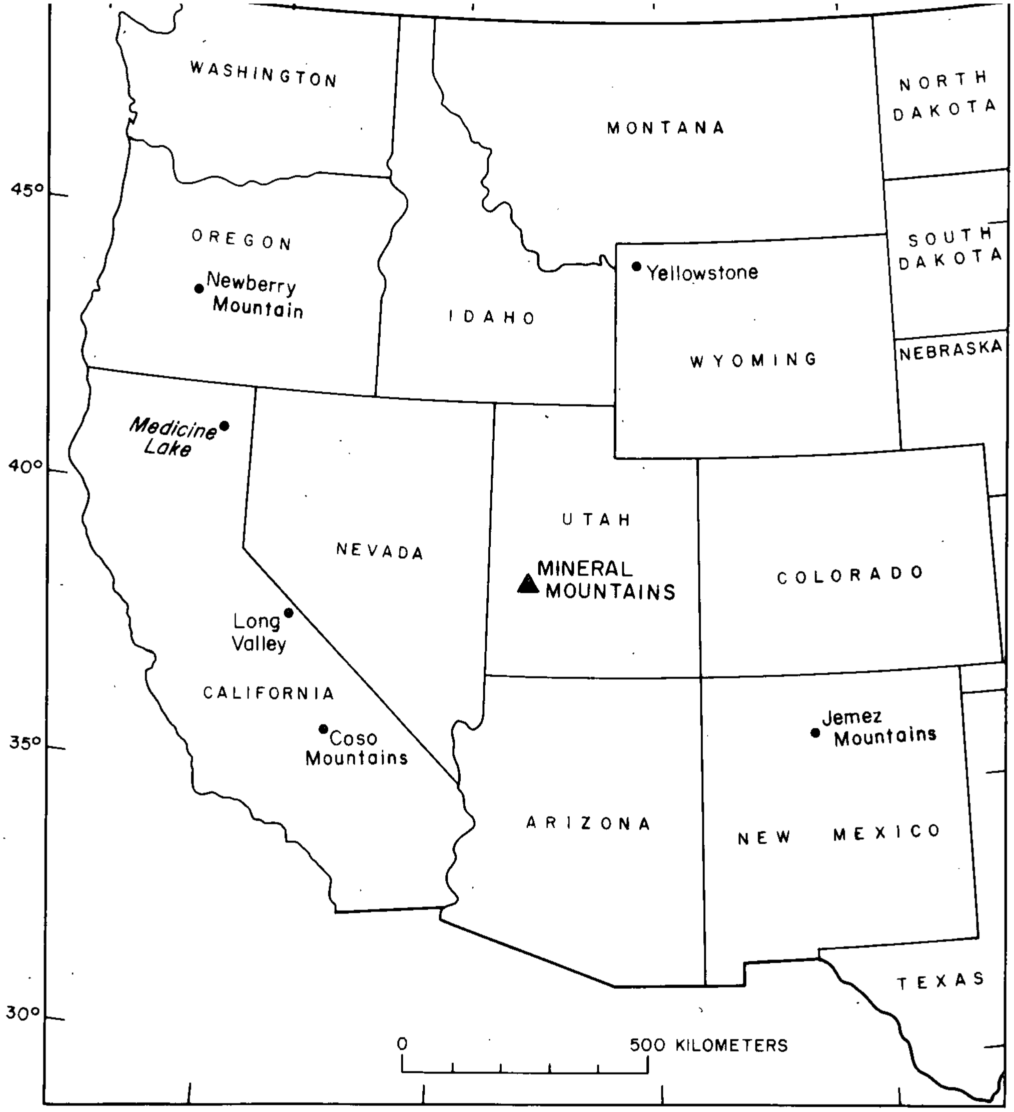

FIGURE 7.—Well-known sources for archeological obsidian in the western United States.

Available compositional data indicate that obsidian artifacts derived from the Mineral Mountains should be distinguishable, especially by minor-element compositions, from those of most of the better known obsidian sites.

Fission-track age dating, by G. A. Izett and C. W. Naeser, and obsidian-hydration age dating, by Irving Friedman, were conducted—independently of our study—on selected samples of rhyolite from the Mineral Mountains. The ages determined by these two other techniques provide a cross-check on the ages presented above that were determined by the K-Ar isotope method. Comparisons of the results of the three techniques are presented separately, in the sections that follow.

FISSION-TRACK DATING

By G. A. Izett and C. W. Naeser

Fission-track age determinations were made on samples of obsidian from the Bailey Ridge flow and the Bearskin Mountain dome. The fission-track age of the Bailey Ridge obsidian is in fair agreement with the K-Ar age of the obsidian, but the fission-track age of the Bearskin Mountain obsidian is anomalously younger than the K-Ar age. Th sample we dated of the Bearskin Mountain obsidian contains no fossil fission tracks; however, the age can be estimated by assuming the presence of one fossil track as shown in the table below. The anomalously young fission-track age of the Bearskin Mountain obsidian probably is due to the annealing of fossil tracks from a recent thermal event. The fission-track analytical data follow:

± 1 sigma about the mean. λf = 6.85 x 10 yr]

Locality	ϕ (neutrons cm^{-2})	ρ_s (tracks cm^{-2})	ρ_i (tracks cm^{-2})	Fission track glass age x 10^6 years	K-Ar glass age x 10^6 years[1]
Bearskin Mountain dome	8.72×10^{14}	$<3.37 \times 10^1$(1)	1.25×10^5(309)	<0.02	0.75 ± 0.1 0.60 ± 0.12
Bailey Ridge flow	0.5×10^{15}	7.89×10^2(3)	4.40×10^4(213)	0.55 ± 0.30	0.79 ± 0.08

[1] See table 3.

OBSIDIAN-HYDRATION DATING

By Irving Friedman

Four rhyolite lava flows or domes from the Mineral Mountains, Utah, were dated by the obsidian-hydration technique. Most of the results agree with K-Ar and fission-track dates of the same flows.

Obsidian-hydration dating depends upon the fact that a newly formed surface on obsidian, such as a cooling crack, adsorbs water from the atmosphere. This adsorbed water slowly diffuses into the obsidian, and the depth of penetration of the water can be measured under the microscope in a thin section cut normal to the surface (Friedman and Smith, 1960). The rate at which the water diffuses into the obsidian is dependent upon temperature and glass composition (Friedman and Long, 1976).

The thickness of the hydrated layer (in micrometers) for the rhyolite units is tabulated below. Also listed is the expected rate of hydration (in $\mu m^2/10^3$ yr) for each flow, calculated for an estimated effective hydration temperature of 8°C and from the chemical composition of the obsidian. (See Friedman and Long, 1976.) The calculated obsidian-hydration age is also given, as is the K-Ar age.

Although the effective hydration temperature is assumed to be the same for all the flows sampled, the differing whole-rock chemistry of the obsidian gives different calculated hydration rates. Compositions of two of the obsidians are from table 2 in this paper; the analysis of the Bearskin Mountain dome is from S. H. Evans (written commun., 1976). No analysis is available for the South Twin Flat Mountain dome. An analysis for the North Twin Flat Mountains (table 2) was used instead; the hydration rate and calculated age are accordingly uncertain.

The calculated hydration rates vary by a factor of 2.5, owing mainly to differences in the amount of CaO + MgO. The chemical analyses were on whole-rock samples, but the hydration-rate calculation should be based on glass compositions. The Wildhorse Canyon and the Bailey Ridge glasses are almost free of phenocrysts, but the Bearskin Mountain and particularly the

Rhyolite	Thickness of hydration µm (± 1 µm)	Chemical index	Calculated hydration rate $\mu m^2/10^3$ yrs	Calculated age 10^6 yrs	Corrected age	K/Ar age
Wildhorse Canyon flow------------	41	42.5	2	0.85	0.85	([1])
Bailey Ridge flow------------	40	41.7	2	.80	.80	0.79
Bearskin Mountain dome------------	31	47.4	4	.24	.48	.75 .60
South Twin Flat Mountain dome---	22	51.1(?)	5(?)	.10(?)	.25	.50

[1] No determination

South Twin Flat Mountain all have refractive indices of 1.4847 ± 0.0005, whereas Bearskin Mountain dome has a slightly higher index, 1.4856 ± 0.0005. The similarity in index of all four glasses makes any assumption of greatly differing hydration rates for these samples unrealistic. If we assume that the chemical compositions of the glass phase of all four samples are similar, then the hydration rates also will be similar and the dates shown in the column "Corrected age" should apply.

The corrected ages agree with the K-Ar dates, except for the date for the South Twin Flat Mountain dome, where the hydration date is about half that derived by K-Ar dating. The reasons for this discrepancy are not known, but we may not have sampled sufficiently to find an original surface on the samples from this site. Alternatively, the discrepancy may be due to some inherited argon in the sanidine used for K-Ar dating.

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BULLETIN OF THE UNIVERSITY OF UTAH
Vol. 35 June, 1945 No. 15

BULLETIN No. 25
of the
DEPARTMENT OF MINING AND METALLURGICAL RESEARCH
(UTAH ENGINEERING EXPERIMENT STATION)
IN COOPERATION WITH THE
STATE DEPARTMENT OF PUBLICITY AND INDUSTRIAL DEVELOPMENT

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Tungsten Deposits of the Mineral Range, Beaver County, Utah

With a Discussion of

The General Geology

BY

ARTHUR L. CRAWFORD
ALFRED M. BURANEK

Salt Lake City, Utah

Price 50 Cents

FOREWORD

This paper was started and drafted under a cooperative agreement between the Utah State Department of Publicity and Industrial Development and the Mining and Metallurgical Research Department (Engineering Experiment Station) of the University of Utah.

Mr. Crawford was granted a leave of absence by the University in September, 1944, for the school year to work at the Geneva Steel Plant. Mr. Buranek joined the United States Armed Forces in February, 1945.

Mr. Earl B. Young was most cooperative in assisting me thereafter in preparing the draft as a bulletin for publication.

ARTHUR A. CENTER, Head
Department of Mining and
Metallurgical Research,
University of Utah.

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Tungsten Deposits of the Mineral Range Beaver County, Utah

ABSTRACT

With the outbreak of World War II in 1939 tungsten became a strategic material. An intensive search for tungsten deposits was instituted throughout the United States. In September, 1940, prospects of promise were discovered in the San Francisco District of Beaver County, Utah, and in October tungsten showings were found along the southeast flank of the adjacent Mineral Range. The October showings and later observations by the writers yielded the results which form the body of this bulletin.

The granite intrusive which is responsible for the tungsten mineralization is prominently exposed over an elongated northeast-southwest belt approximately five by fifteen miles. Extensive contact metamorphic deposits occur around the periphery of the intrusive. Many of them are known to carry tungsten in the form of disseminated scheelite. Conspicuous limestone roof pendants along the southeast flank of the range north of Pass Canyon have been mineralized, and along certain bands entirely replaced by contact silicates. It is in these bands that the most extensive and promising ore bodies occur.

The mineralization, where the contact is comparatively regular, seems to have followed a consistent pattern. Going outward from the intrusive toward the unaltered limestone the following facies of rocks appear showing progressively a diminishing grade of metamorphism: (1) normal granite, through (2) marginal granite rich in green contact silicates, (3) a somewhat brecciated zone, containing hydrothermal minerals and occasionally sulphides, (4) garnetite, (5) garnet-vesuvianite-epidote tactite, (6) clinozoisite tactite, (7) tremolite-wollastonite-calcite rock grading into (8) crystalline marble. The scheelite may be found in any of these zones but is characteristically best developed in the garnetite near the brecciated zone.

The conclusion is reached that further development may prove the existence of large low-grade tungsten deposits which, under the stress of a national emergency, would be a strategic reserve of considerable value. Furthermore, smaller higher grade bodies, that might be worked at a profit have been found and it is possible that others will be discovered.

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ILLUSTRATIONS

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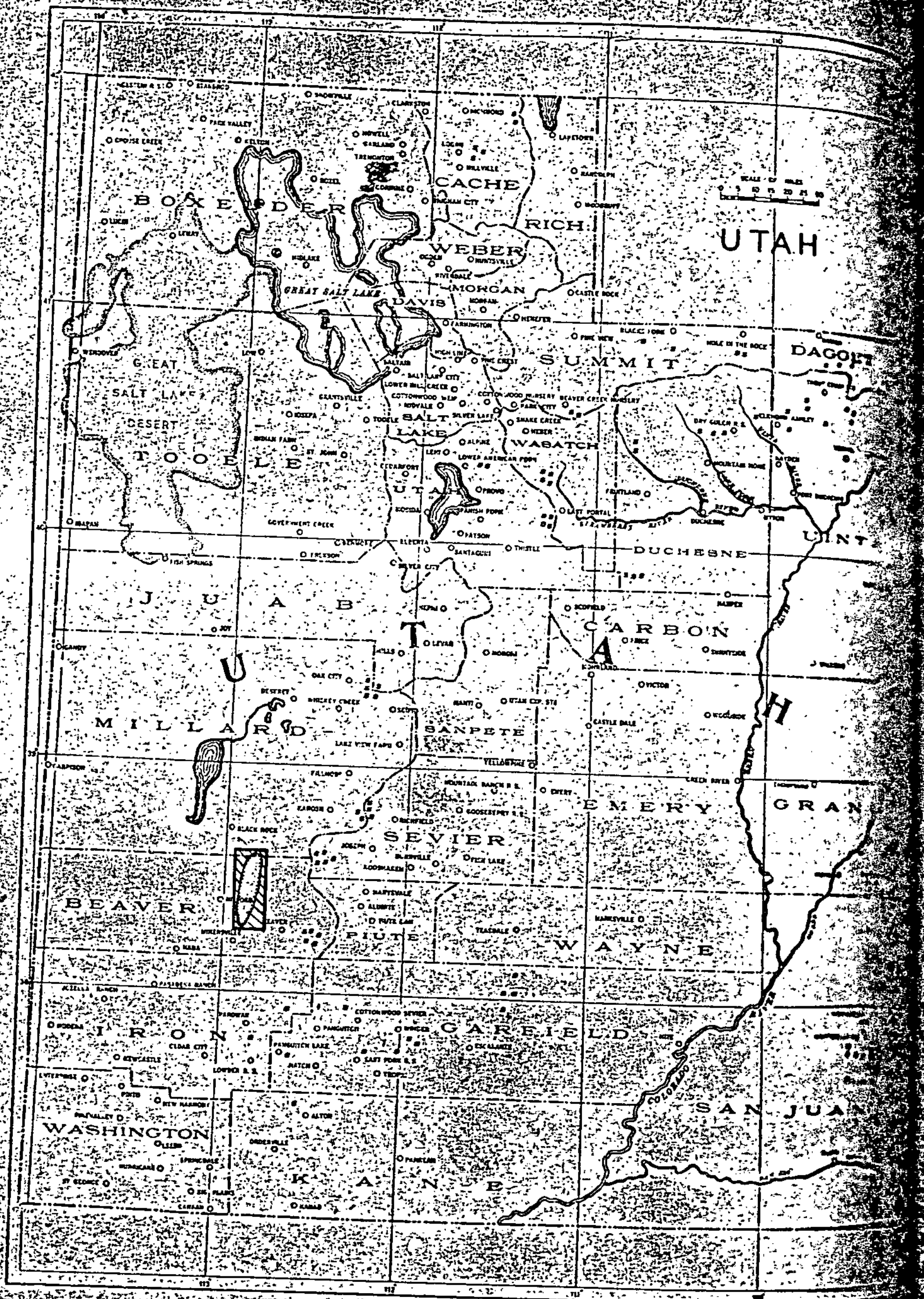

FIGURE I. INDEX MAP OF UTAH SHOWING LOCATION OF THE MINERAL RANGE

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Tungsten Deposits of the Mineral Range
Beaver County, Utah

WITH A DISCUSSION OF

The General Geology

By

ARTHUR L. CRAWFORD[1] ALFRED M. BURANEK[2]

INTRODUCTION

When the present World War restricted international trade and threatened to cut off our supply of oriental tungsten, a vigorous search was begun for more adequate domestic supplies of this strategic metal. In September, 1940, prospects of promise were discovered in the San Francisco district of Beaver County, Utah, and in October[3] of the same year tungsten showings were also found on the Oak Claim in Little Well Canyon along the foot-hill belt forming the southeast flank of the Mineral Range between the towns of Milford and Beaver. See Figures 1 and 2.

The San Francisco District has received a great deal of attention from the U. S. Geological Survey, the U. S. Bureau of Mines, and important domestic tungsten producers. Much exploratory effort has been expended in this neighboring district resulting in substantial production from the Old Hickory mine and other less important properties in the vicinity.

The investigation here reported indicates that the Mineral Range also has greater tungsten possibilities than has been generally appreciated. Tungsteniferous rocks were observed in areas from the ravine of Burnt Hollow, about midway along the eastern flank, south to Pass Canyon; north from Minersville, at the south end of the range; and south of the Pass Canyon road at the southwest portion of the range. (See Figure 2.) All of the known tungsten deposits are strikingly similar in character. All occur in zones of pronounced contact metamorphic alteration associated with intrusive igneous rocks. Consequently, it is logical to hunt for the presence of tungsten in other unprospected areas where limestones abut against the intrusive. One such tungsten occurrence, located near the summit of the range in the proximity of Pinnacle Pass, has been reported to the writers, but not visited by them. That the Mineral Range intrusion of granitic rocks was accompanied by tungsten-bearing solutions is apparent by the existence of so large a tungsten-bearing zone. However, as to be expected, valuable accumulations of scheelite, the calcium tungstate, ($CaWO_4$), are limited to such areas where physico-chemical and structural factors favorably controlled deposition of tungsten. Most of the tungsten-bearing tactite beds contain small amounts of scheelite, that is, insofar as local concentrations are

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[1] Geologist and Mineral Technologist, Department of Mining and Metallurgical Research, University of Utah, Salt Lake City, Utah.

[2] Geologist, Utah State Department of Publicity and Industrial Development, Salt Lake City, Utah.

[3] Verbal communication of Ambrose McGarry.

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rned. Marginal ore-bodies having from 0.15 to 0.50 percent content are relatively abundant and widespread, but such its could not be mined profitably during the war period even he premium prices paid for tungsten. If a custom mill to treat grade ores could have been established at one of the more ising mines or at some other locality favorable to the district, ubtedly a greater yield of tungsten would have resulted since discoveries. Unfortunately, this was not done and as a conse- ce only higher grade ores were utilized.

Tungsten production resulted from but a few of the properties in described, and tonnages of similar ore can still be obtained market for low-grade ores were available. The outlook for the future for the small tungsten producer is rather unfavorable. y concentrates can be sold to a market dependent upon the uating needs of their respective purchasers. Although the domes- tungsten consumption trend is believed by many to be on the the fact that only concentrates can be marketed automatically inates the small producer of the type so prevalent during the period. The possibility remains, however, that the owners of more promising tungsten deposits may erect a privately financed l in the area to produce scheelite concentrates. With this in view, viding the \$24.00 per unit WO_3 continues, sufficient mill-grade ore sts within the district to anticipate a longlivity of operation. uld this not take place, the tungsten deposits of the Mineral nge will remain as reserves from which large tonnages of tungsten- ring tactite can be obtained to satisfy the needs of future emer- cies.

roduction of Tungsten Ore, Mineral Range, Beaver County, Utah 1941 to 1944[1]

Mine	Total Short Tons shipped (dry)	Average WO_3 Content	Total Units	Gross Value	Net Value
rategic Metals, Inc. (Big Pass Group)	278.648	0.789	214.48	\$ 6,434.40	\$5,233.53
ly Metal Mines, Inc. (Garnet Group)	634.265	0.6402	406.1445	\$12,184.33	\$7,331.48
B's Property	70.0	0.58	40.60	\$ 1,218.00	
eole Mine	200.0	0.70			

Other Tungsten Localities. Utah is fortunate in possessing a ber of tungsten localities similar in character to the Mineral ge. The more important may be enumerated as follows: (1) The p Creek Range, (2) The Wasatch Range, (3) The West Tintic ge, (4) The House Range, (5) The Grouse Creek Range, and The San Francisco and adjacent ranges. In other words, the amorphosed calcareous rocks adjacent to many of the intrusive ies of our Great Basin and Range Province contain to a lesser greater degree tungsten in the form of scheelite. Accordingly, a

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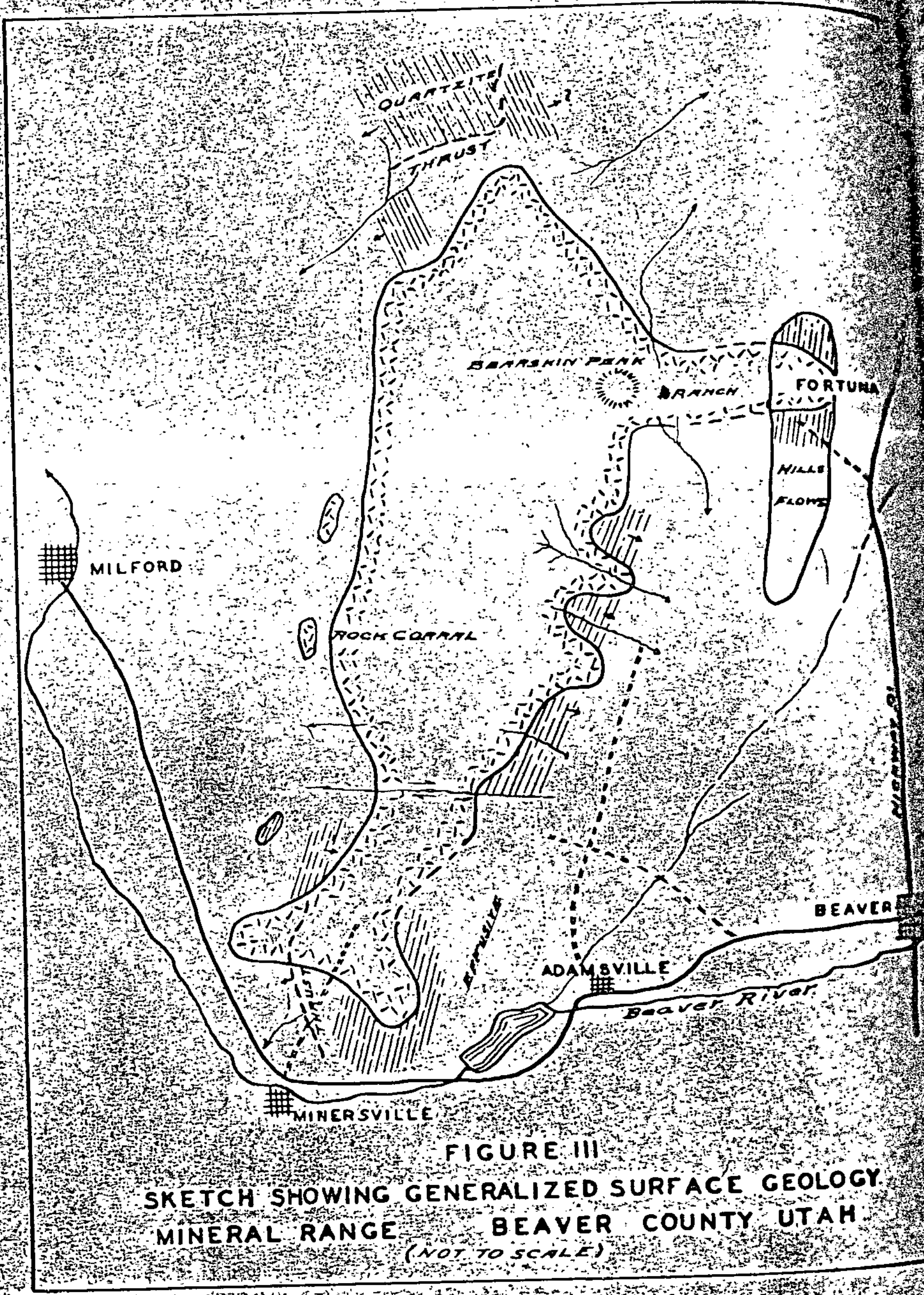

FIGURE III

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of Utah, Vol. 2, No. 2, p. 7,

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eralized statement can be made,—that with few exceptions the rusive bodies of the Basin and Range Province of Utah contained ngsten as one of the primary constituents of the magma. Interpretation of tungsten deposition indicates that it was under the uence of, or associated with molybdenum, fluorine, boron, and in me instances beryllium.[1] As a detailed description of the isomorphus tionship between molybdenum and tungsten minerals formed in presence of strong mineralizers has been presented by the writers a recently published paper[2], a discussion of these affinities will t be made here. Those who may be interested are referred to this port.

Previous work on the Mineral Range has been confined to cursory examinations in connection with studies of adjacent districts, or to confidential unpublished engineering reports withheld from general circulation. For many years it has been known that the range contained the contact metamorphic zones so frequently associated with tungsten deposits. Butler[3] mentions these zones but does not elaborate upon them. Lee[4], Thomas[5], and Dennis[6], have studied the ground water problems of the adjacent valleys, and other U. S. Geological Survey men, U. S. Bureau of Mines Engineers, and U. S. Reconstruction Finance Corporation Engineers, have made examinations for access roads and development loans for particular properties seeking federal aid to develop strategic minerals. Likewise, Baker and Hall of the U. S. Vanadium Corporation and other engineers representing private and Federal agencies have visited the area, but any reports they may have made are not available to the public. No comprehensive treatment of the geology of the Mineral Range has been published. In 1941, Crawford suggested[7] prospecting for tungsten in this area. In 1942, Crawford and Buranek examined and described[8] the great tremolite contact metamorphic zone on the northwest flank of the Mineral Range, and early in 1943 they made a hurried inspection of some of the scheelite prospects on the southwest flank of the range (See Figure 2).

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[1] A tungsten property near Trout Creek, Tooele County, Utah, contained scheelite intimately associated with fluorite and slender colorless prisms of beryl.

[2] Crawford, A. L., Buranek, A. M., Tungsten Reserves Discovered in the Cottonwood-American Fork mining districts, Utah, with a discussion of the Influence of Scheelite on the Character of Secondary Molybdenum Minerals, Bull. No. 24, Department of Mining and Metallurgical Research, University of Utah, Dec., 1944.

[3] Butler, B. S., "The Ore Deposits of Utah", U. S. Geologic Survey, Professional Paper 111.

[4] Lee, W. T., "Water Resources of Beaver Valley, Utah", U. S. Geologic Survey Water Supply Paper 217 (1908).

[5] Thomas, Harold E., "Possibility of Artificial Recharge to the Milford Pumping District, Utah", Unpublished manuscript read before the October, 1941, meeting of the Utah Academy of Sciences, Arts, and Letters.

[6] Dennis, P. Eldon, "Shore Lines of the Escalante Bay of Lake Bonneville", Unpublished manuscript read before the May, 1943, meeting of the Utah Academy of Sciences, Arts, and Letters.

[7] "Strategic Minerals of Utah", by Arthur L. Crawford; Bulletin of the Mineralogical Society of Utah, Vol. 2, No. 2, p. 7, December, 1941.

[8] "Tremolite Deposits of the Mineral Range, Millard County, Utah", Circular No. 2 (Sept. 1942) of the Utah State Department of Publicity and Industrial Development in cooperation with the Mining and Metallurgical Research Department, University of Utah.

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The present report is a revision of a preliminary study[1] (the authors) made at the request of Senator Abe Murdock (D., Utah) and under the sponsorship of the Utah State Department of Publicity and Industrial Development, in cooperation with the Mining and Metallurgical Research Department of the University of Utah. The preliminary study summarized briefly pertinent facts on the scheelite occurrences between the Pass Canyon road and the region known as the Oak Basin—on the southeast flank of the Mineral Range. The presentation includes deposits to the south and the west of those originally described as well as a more detailed discussion on the areas covered in the preliminary study. The purpose is to release the data thus far assembled in a form and manner that will make the information available to all who are interested. Although the writers have made many trips to the Mineral Range since their first visit to the north end, their primary objective was to investigate tungsten occurrences. Consequently, a detailed study of the entire range was not possible. From what is known about the geology and ore deposits associated with this most interesting granitic core, a detailed study is justified from both an economic and academic standpoint. It is hoped that sufficient interest can be aroused by the following to make such a study become a future actuality.

GEOLOGY

The granite intrusive, responsible for the tungsten mineralization, is prominently exposed over an elongated northeast-southwest belt approximately 5 by 15 miles. Due to the bold outcrops and jagged peaks of this intrusive, forming the central portions and highest summits, the name "Granite Mountains" often has been applied to the range. The granite peaks reach an elevation of over 10,000 feet. Typical facies show a light gray, medium-grained rock composed chiefly of feldspar and quartz. Ferromagnesian minerals are inconspicuous in all facies observed with the exception of certain dolerite dikes in Robinson Canyon and vicinity injected in parallel position with vertical beds of marbleized limestones. The altered strata here form the broad conspicuous white (roof pendant) band above the foothills along the southeast flank of the range northeast of Pass Canyon.

East of the divide the higher reaches of the granite constitute a very rugged topography. In contrast, the sheer boss-like eminences of the west side have been sculptured into smooth, rounded and much furrowed cliffs. This latter weathering, so different from ordinary granite disintegration, probably is due to the interplay of several erosive factors. Increased precipitation on the west side, the greater amount of granite exposed, and the influence of prevailing southwesterly winds—blowing almost continually over the desert—are believed to be the factors most important. Such an area of erosion embraces a small picnic site utilized by the people of local towns, known as the Rock Corral, because of its corral-like appearance.

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[1] Certain Tungsten Deposits of the Mineral Range, Beaver County, Utah: Cir. No. 26,

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There is valid reason for believing the intrusive to be much larger than is at first suspicioned. The west, and much of the east slopes, flanking the central portion of the range, apparently consist of a granite pediment thinly mantled by alluvium. On the west side, the pediment is covered by decomposed granite throughout which "windows" of granite are exposed for a distance of about four miles from the range proper. Inliers of limestone were also noted in the area of detritus, but generally westward from the granite outcrops. These obscure exposures can be observed adjacent to the "Rock Corral" road and other roads leading to the range south of this point. Scheelite bearing altered limestone is reported by Reese Griffith to crop out low on the piedmont alluvial plain, south of the Pass Canyon road.

On the east side of the range, from Pass Canyon to Bearskin Peak (a smooth, well-rounded granite peak west of the Cunningham Ranch), tongues of granite extend eastward from the main mass, cutting the highly inclined north-eastward striking sedimentary strata. (See Figure 3). The regularity of the granite tongues is striking, suggesting a series of parallel fault blocks, the main components of which would be about east-west, movement being to the east. However, even though locally the sedimentary beds are at times highly crushed and disturbed, the persistence of the prevailing N. 35° E. strike and southeasterly dip of the strata is more indicative of unequal assimilation of certain east-west sedimentary zones by the invading magma. From Bearskin Peak, the granite extends eastward for at least two miles, and possibly much more. It is reported[1] that the Fortuna Mining District, some five miles east of Bearskin Peak, is located chiefly along the contact of a granitic intrusive with sedimentary rocks, and that the granite can be traced from the Fortuna District westward to Bearskin Peak. Unfortunately, this area is quite heavily wooded, rugged in relief, and inaccessible to the modern automobile. Thus, only that region north and south of Bearskin Peak, and eastward for not more than two miles, was traversed. Even so, from observation, it appears that an east-west granitic highland does extend from Bearskin Peak to the Fortuna district. An abrupt change in the strike of the range is evident from Bearskin Peak northward. South of this area, a general north-eastward trend prevails, reflected most pronouncedly in the N. 35° E. strike of the sedimentary strata. North of this area, the range trends nearly north-south, the granite being exposed to the region adjacent to Pinnacle Peak. The sedimentary beds strike in an arc-like manner around the north end of the range. Although the granite does not crop out at the north end, its proximity to the surface can be inferred by the presence of a great zone of tremolitized limestone.[2]

The Pass Canyon delineates the southern boundary of the main granite mass, although various related bodies of granite have intruded the sedimentary series south of Pass Canyon. These granitic masses

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[1] Personal communication with Ambrose McGarry.

[2] Crawford, A. L., Buranek, A. M., Tremolite Deposits of the Mineral Range, Millard County, Utah. Cir. No. 2 (Sept. 1942), of the Utah State Department of Publicity and Industrial Development in Cooperation with the Mining and Metallurgical Research Dept., University of Utah.

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are exposed in several areas of the southwest portion of the r One of the large bodies is that near the Cave Mine. Between area and that of the Creole and Lincoln Mines, the granite crops at various intervals, being separated by either alluvium or con dated sedimentaries. Another large unroofed mass is in the proxi of the Creole Mine, some four miles north of Minersville. Con metamorphic alteration of intervening limestones indicate a n surface relationship of these granite bodies, and by inference, th are probably connected with the main intrusive north of Pass Can

Pegmatite lenses are relatively abundant in certain portions the granite. Those observed have formed as pipe-like bodies at t intersection of joint planes, the most common systems being N. 1 to 20° W. and N. 80° W. to nearly east-west. "Pockety" phases the more coarsely crystallized pegmatites contain euhedral minera typical of pegmatitic deposits. Well-developed crystals of qua (both colorless and smokey) and feldspar (varities—orthocla microcline and albite), are generally the principal minerals pres in the cavities. More rarely other minerals are associated. Appro imately 2,000 feet north of the Rock Corral campsite, splend crystals of titanite, epidote, and garnet were found with quartz an feldspar in a small pegmatite pocket. The titanite crystals ar brownish in color, typically rhombic in cross-section, roughly on quarter of an inch in greatest width, and are embedded in a matri of small, but well-formed albite crystals, possibly of the variet clevelandite. The garnets are rich cinnamon red in color, dodecahedr in form, and smaller than the titanite. The epidote crystals consis of yellow-green elongated prisms less than one-half inch in length. Subhedral beryl crystals of a very pleasing sky-blue color were found firmly embedded in quartz on the Garnet Claims, and in pegmatit of Beaumont Basin. The beryl crystals are small, less than one-hal inch in length, translucent, and rare in occurrence. Subhedral, cry talline masses of opaque topaz, pinkish colored with blue crystal cores, were found on the Ward Claims of the Beaumont Basin area. They were not observed in place, however, and consequently littl is known of their mineralogic setting. Graphic granite, the cuneiform appearing intergrowths of quartz and feldspar, is relatively abundant in pegmatitic bodies of the "pocket" type. The general absence of muscovite and tourmaline in the observed pegmatites is a feature somewhat unusual to deposits of this kind, although, perhaps, muscovite should not be expected as it is almost lacking in the parent intrusive. Sericite mica, probably the result of feldspar alteration, was abundant in a small pegmatite pocket between Pass Canyon and the Rock Corral.

Some fine quality quartz crystals have been obtained from the west side of the range. The writers visited a quartz crystal property from which some transparent and flawless quartz had been mined. Unfortunately, as the pocket was limited to a spherical cavity about two feet in diameter, the quantity of clear quartz was small. Only a few of the locally reported quartz crystal areas of the range were visited, principally because of the inaccessibility of the regions and

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to the lack of importance of this mineral to the problem on hand. Although it is not believed that large quantities of piezoelectric grade quartz are likely to be discovered, the prospector should bear in mind the importance of flawless and transparent quartz to today's mechanized world. Quartz crystals of this type are saleable, and if found, may be submitted to the Mining and Metallurgical Research Department, University of Utah, Salt Lake City, the U. S. Bureau of Mines, or the U. S. Geological Survey, Washington, D. C. for quality determination.

At the base of the granite cliffs, forming the ramparts of Robinson Canyon, there is a fifteen-foot pegmatite marking the boundary between the large medium-grained granite intrusive body to the northwest and a parallel fine-grained border facies to the south-east. The same type of pegmatite was also observed on the Big Pass property in Pass Canyon, representing its apparent continuation several thousand feet along the strike to the southwest. The pegmatite, consisting chiefly of quartz and feldspar crystals up to five inches across, has been brecciated and recemented with an aplitic matrix. The strike of the pegmatite and the dominant shearing in the granite is N. 35° E. with a dip of 67° to the northwest. The pegmatite seems to have formed as a parallel border facies of the parent intrusive and then to have been brecciated and intruded by still later material forming the aplites in parallel position to the south-east.

In Robinson Canyon and Barton Hollow, northeast of Pass Canyon, there are several fine-grained aplitic dikes injected between the brecciated pegmatite and the nearly vertical marble beds of the above-mentioned roof pendant. They not only form irregular bands between the crystalline limestones and the pegmatite-breccia zone separating them from the main granite mass, making up the central portion of the range, but they are also injected into and between parallel beds of the marble roof pendant. These bands follow a direction of N. 35° E. paralleling the strike of the beds in the roof pendant and usually show a dominant joint system parallel to this strike and have a steep dip northwestward into the range.

These aplitic border facies are, like the parent intrusive, gray in color, but in some cases they show a pinkish cast due to the presence of some microscopic constituent suspected as being zoisite, clinozoisite, or possibly piedmontite, derived from the impure limestones assimilated by the invading magma. Others are distinctly greenish due to the color of a similar microscopic constituent the identification of which must await petrographic studies. All gradations can be found between these "off-color" aplites and the fine-grained "micro-tactites" developed as contact phenomena from the metasomatic replacement of the limestones.

Approximately five miles northeast of the aplites, mentioned as occurring along the southeast flank of the mountain face northeast of Pass Canyon, is a similar border facies of still finer-grained rock which is tentatively regarded as a rhyolite intrusive connected with the larger granite body. It forms a relatively large apophysis with the elongated direction of its outcrops nearly at right angles to the range.

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It is well exposed near the portal of the tunnel of the old King-of-the-Hills Mine situated in Oak Leaf Canyon, a rugged ravine etched in point of the prominent spur forming the angle at the northeast end of that portion of the range (between Pass Canyon and Oak Basin) which has a comparatively straight southeast front and in which the dominant structure strikes N. 35° E. Beyond this angle the trend of the mountain front and the strike of the beds veer to the north and lose the regularity characteristic of the segment under discussion.

The Oak Leaf Canyon rhyolitic apophysis has a variable width. Its outline was not traced in detail, but its width locally is believed to exceed 100 feet and it is estimated to have a length in excess of a thousand feet. The ravine in which the King-of-the-Hills Mine is located trends N. 65° W. (approximately the strike of the dike-like apophysis), having been eroded in most part along the contact between the dike and the adjacent crystalline limestones. This direction is roughly parallel to a fairly prominent plane of shearing and jointing in this part of the range—the most important structural plane, however, being approximately N. 35° E.

The Oak Leaf Canyon dike is very fine-grained and is so uniformly hard and dense that its individual constituents cannot be differentiated with the unaided eye except in the case of quartz microphenocrysts, about one-half millimeter in size. In some weathered facies they can be detected by their glassy appearance in the otherwise uniformly porcelain-like material. This dike rock is nearly white and must be viewed at close range to distinguish it from the fine-grained marbleized limestones into which it is injected. Like the aplites, paralleling the southeast face of the main intrusive in Robinson Canyon and Barton Hollow, the Oak Leaf Canyon rhyolite dike is apparently associated with a large roof pendant of limestone which has been bleached and recrystallized through the metamorphic action of the intruding magma. Conversely, the invading dikes have been affected by the presence of the limestones. The latter appears to have chilled the magma so as to retard crystal growth, thus producing an aplitic or even rhyolitic texture rather than that of a typical granite.

Still another border intrusive extends from the granite southwestward down the south ridge of Oak Canyon, upon which are located the most northern scheelite occurrences, the Oak Basin group. The injection of this intrusive (more coarsely crystalline than the Oak Leaf Canyon rhyolite) is believed to have been responsible for the lead-silver-tungsten mineralization of the adjacent sedimentary rocks. Other similar dikes are present in the area under discussion. A northward trending dike, more subsilicic in character and at least fifty feet in width, cuts the sedimentary strata covered by the Ward claims. Micaceous hematite, locally abundant, and minor amounts of scheelite and malachite, were observed to be associated with the intrusive. Although none of the dike rocks themselves were observed to be mineralized, the association of ore minerals in the adjacent intruded rocks(usually footwall side) to the dikes is significant, as is likewise, the similar ore-body relation-

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[1] Dennis, Verbal Communication.

[2] Lee, W. T., "Water Resources of
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of the sedimentary strata to the parent intrusive. Dennis[1] has ped a number of dikes of variable composition in an area south east of the Creole Mine, north of Minersville. As the writers not examined the dikes of this area, little is known of the ore ral association to them.

Extrusive rocks flank the range at several points on all sides. nt volcanic vents at the northeast end near Cove Fort have red out basaltic floods that streamed down Wild Cat and Indian ks along the southeast flank of the range in the direction of msville. Basalt also poured around the north end of the range the Blackrock Desert. At the southern end, near the Minersville dge, agglomerates, tuffs, and poorly sorted stream gravels of canic origin, are well exposed. Lee[2] describes the effusives east Minersville as follows:

"The oldest of the lavas covering the red beds and the overlying con- merate are dark-colored andesites. These are most conveniently seen in the Beaver region in the canyon east of Minersville. They consist of flow sheets, tuffs, and volcanic breccias and occur also as boulders in the under- lying conglomerate.

"Above the andesites are extensive masses of light-ink to white rhyolite. These are especially large in the Tushar Mountains, where they occur as flow sheets, tuffs, and breccias, constituting a large part of the range. The rhyo- lites are best known locally as the soft pink rock found near the mouth of Beaver Canyon and elsewhere, that is used for building purposes. It is a fine-grained, consolidated rhyolitic tuff which, on account of its softness, is easily quarried and dressed, but which is resistant enough to make good building stone. In many places masses of this tuff are not well consolidated and resemble beds of light-colored sand and clay.

"After some, at least, and probably after all of the rhyolites of this region had been extruded they were extensively eroded, as shown by the occurrence of beds of conglomerate made up largely of pebbles and boulders of rhyolite. These conglomerates of rhyolite occur in Beaver Canyon at Minersville, in Bakers Canyon, 5 miles east of Beaver, and elsewhere. At Minersville they are well stratified, but consist mainly of angular fragments of rhyolite. In Bakers Canyon they are several hundred feet thick and made up of well-rounded pebbles and boulders of many kinds of rock, the largest boulders consisting of rhyolite.

"Basalt overlies the rhyolitic rocks and rests in some places upon the conglomerates and in others upon the tuffs and breccias. The basalt is the black rock used to a considerable extent as a building stone in Beaver Valley. It occurs in sheets near the mouth of Beaver Canyon, in the canyon east of Minersville, in Black Mountain north of Beaver, and elsewhere. It also forms the volcanic cones, one of which is located 13 miles north of Beaver and another 20 miles north of Beaver near the Cove Creek sulphur beds."

Beds of tuffaceous pumice occur near Adamsville that have een utilized locally to a small extent for abrasive purposes. A light ight, gray colored, extremely vesiculated pumice makes the rounded oll between Bearskin Peak and the Cunningham Ranch, where it antles the granite over a circular area of at least 300 feet in diam- ar. The Bald Hills to the east are, in most part, made up of extru- ve rocks. On the western face of the range, northeast of Milford, a fty-foot bed of beautiful black obsidian, remarkably free from devit- fication, is said to be well preserved. The obsidian was not seen

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[1] Dennis, Verbal Communication.

[2] Lee, W. T., "Water Resources of Beaver Valley, Utah", U. S. Geologic Survey Water Supply Paper 217 (1908).

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in place, but was examined in many float samples collected at the foot of the range northeast of Milford. Similar material of mottled and banded reds, browns, gray-greens and blacks, some of which contain christobalite inclusions, crop out north and east of Black Rock and east of Pumice. The obsidian is known locally as flint and was widely used by the Indians as a source of material for arrowheads and other primitive artifacts.

The origin of the volcanic glass of the Mineral Range is not known, but is believed to represent remnants of the great rhyolite and similar silicic flows that originated in the region north of Black Rock, rather than related to the flows of the Cove Fort area. The rhyolitic Twin Peaks, for example, of Millard County, are the remnants considered to be at or near the orifice of eruption of at least one of these more acid phases of vulcanism, and further, probably have a common genetic affinity to the pumice, obsidinn, and tuffs of that section of the Sevier Desert.

The sedimentary rocks are predominantly Paleozoic limestones, sandstones, and quartzites, with minor amounts of shales and impure varieties representing transitional phases of sedimentation. Fossils are absent in much of the strata, but there is reason to believe that the rocks belong to the same sequence as those found in the San Francisco District to the west where Butler[1] has described rocks ranging in age from the Grampian limestone of lower Cambrian, to the Harrington shale of Triassic Age. The Mesozoic rocks of the Mineral Range, *thus far recognized*, are those of the south end where Dennis[2] has mapped a Mesozoic section up to and including the Carmel (Jurassic) limestone. Small patches of the Wasatch formation of Tertiary Age have been noted by Dennis.

Paleozoic rocks. Judging from the lithologic character of the rocks exposed near the tremolite deposits, at the northwest portion of the range,[3] the writers feel safe in assigning the quartzites to the Tintic quartzite of basal or lower Cambrian age, and the limestones to the lower Paleozoic of probable Cambrian or Ordivician Age. The quartzites are fine grained, compact, massive, and pink to gray in color. The limestones are massive bedded, dolomitic in part, siliceous near the top, and blue to gray in color.

The exposed portion of the quartzite is estimated to have a thickness of 1,000 feet, and from the cursory examination of the writers, it appeared comparatively uniform throughout. Much of the limestone is also quite uniform, some showing a thin-bedded character with mottled impurities characteristic of the Cambrian and Ordivician limestones and dolomites of the Wasatch and Basin Ranges. Other variations in texture noted were associated with faulting and mineralized areas and thus have no direct bearing upon the original

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[1] Butler, B. S., Geology and Ore Deposits of the San Francisco and Adjacent Districts, Utah: U. S. Geol. Survey Prof. Paper 80, 1913.

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nature of the beds. The uppermost strata of the limestone are siliceous, containing lenses of chert up to twelve inches in length. The thickness of the limestone series was estimated to be well over 1000 feet and is tentatively regarded as 1500 feet.

The beds strike north to northwest with gentle dips to the west and southwest, whereas, immediately to the east on the northeastern slopes the strata are more eastwardly inclined with strikes to the north and northeast, indicating a gentle anticlinal structure. In part, the limestones and quartzites have been affected by the intrusion of the granite, and although it is not unroofed in this area, its proximity to the surface can be inferred by the strong tremolitization of the limestone. The superjacent Paleozoic and Mesozoic formations are missing, possibly because erosion has stripped the less resistant beds down to the more durable quartzites.

Butler,[1] in his detailed description of the San Francisco Region, but a few miles to the west, describes a similar series of limestone and quartzite as being Cambrian, Ordivician, and Silurian in age. By fossil evidence, he has assigned the siliceous and arenaceous members near the top of the limestone series to basal Ordivician, and by inference, has suggested the great thickness of underlying limestones as Ordivician and possibly Cambrian. Further, because the quartzite, which he designates the Morehouse Quartzite, rests upon the limestone, he suggests that it is the Ordivician and Silurian in age, representing a normal sequence of deposition, the quartzite being younger than the limestone. Assuming that the so-called Morehouse Quartzite is in fact the Tintic Quartzite over-thrust upon the limestone, then the description given by Butler of the San Francisco Range limestone-quartzite sequence correlates with the sedimentary series exposed at the northern end of the Mineral Range.

On the east flank of the range, in the region embracing the Oak Basin and canyons north thereof to about Bearskin Peak, the writers have had occasion to examine various outcrops of the sedimentary rocks in conjunction with investigations of certain ore deposits. Here, the strata strike northeastward with dips to the southeast. The quartzite (Tintic?) exposed is similar to that described at the north end, except that it apparently underlies the limestone and overlies the granite, thereby being in normal sequence. The thickness of the quartzite is approximately that given for the north end exposures, although it may be greater. The limestones have undergone severe metamorphic alteration, due to the intrusion of the main granite mass, and to a lesser degree, from the injection of "offshoot" silicic dikes. As a consequence, the limestones now exist as selectively replaced beds of crystalline limestone, garnetite, epidosite, and other high silica-bearing rocks. Age limits cannot be assigned these strata because of too little knowledge concerning them, but by comparison with beds exposed both to the south and the north, they probably represent rocks ranging from Cambrian to Mississippian—the members becoming progressively younger eastward from the range front.

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[1] Butler, B. S., opt. cit.

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From Pass Canyon northward to Oak Basin, a very conspic band of more or less altered sedimentary rocks flanks the intru The contact is by no means regular with respect to the bedd but on the contrary, is very irregular with eastward projec of the granite embayed into the sedimentary beds at intervals. P haps the largest of these eastward apophyses is the granite to of Beaumont Basin, which extends far beyond the limits of exposed sedimentary formations. Other similar granite masses dikes separate the once continuous band of sedimentaries. Unqu tionably, the lithologic affinities of the sedimentary beds are co plex. Little is known of sequential deposition and this, together w granitic assimilation and severe post-intrusive crushing and faulti make the interpretation of these rocks remain obscure until such time when detailed mapping is instituted.

The low-lying ridge south of Oak Leaf Canyon contains siliferous limestone. Samples obtained from an outcrop appro mately 200 feet west of the Mineral Range Access Road definit relate these rocks to the Mississippian. The formations consist of thick series of bluish gray limestones, which weather to a pal color than that of a fresh fracture. Interbedded are occasional th members of shale. The strike of the strata is N. 35° E. with var ing, although not too steep, dips to the southeast. This strike pr vails, with only minor variations, for a distance of nearly one-thi the length of the range, and is remarkable for its consistency. Ev the rocks which are now completely altered, such as those wh make up the contact metamorphic band from Pass Canyon nort ward for several miles, and those of the Oak, Garnet, and Conta claims, hold true to this trend. Close parting and mineral comp sition of some of the altered sedimentary strata indicate that or nally a number of intercalated shale members were present. Sou were dominantly fissile in character. No evidence of quartzite ha been observed in this section of the range.

On the west side of the range and south of the Pass Canyo Road, a roof-pendant block of sedimentaries caps a ridge-like kno upon which is located the 2R's tungsten property. The sedimenta formations consist of limestone, shale, and quartzite that have general strike of N. 30° E. and dip to the southeast. The granite has extended irregularly from below into the inclined beds. At the contact occurs a zone of garnet,epidote, and other contact silicat Because of the thinness of the quartzite, its physical dissimilarit to the quartzite of the north end of the range, and its apparent conformable nature to the underlying limestones it is believed that this sedimentary block is not basal-Paleozoic but rather mid-Pale zoic, perhaps Carboniferous in Age.

The geology of the sedimentary rocks of the south end of the range is extremely complex. In general, the formations become pro gressively younger from west to east, although faulting has repeated the series, that no continuous section from old to youn rocks can be observed.[1] The prevailing strike of the strata is north

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[1] Verbal communication with Eldon Dennis, U. S. Geological Survey who has mapped the portion of the range in conjunction with a study of the ground water problem, and to the writers are indebted for his many helpful suggestions on the stratigraphy of the

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south with easterly dips. The faults also have a north-south trend and eastward dip, but generally are more highly inclined as they obliquely cut across the sedimentary beds. Butler[1] assigns the limestones in the vicinity of the Cave Mine, about six or seven miles north from Minersville, to the Carboniferous. The lithologic similarity of these rocks to those immediately to the north, in the area of the 2 R's holdings, suggest that a more or less continuous belt of Carboniferous formations extend from the Cave Mine area to the Pass Canyon road. Permo-Carboniferous rocks crop out easterly from the Cave Mine to the area of the Lincoln Mine. They consist of limestones, quartzites, and shales. At the Creole Mine, believed to be in the metamorphosed sediments of the Kaibab formation, the strata strike N. 20° W. and dip to the northeast. Granitic intrusives, ramifying off-shoot dikes, apophyses, and sills, have altered to a high degree much of the sedimentary rocks to zones of contact metamorphism in which most of the metalliferous ore bodies have been formed. Such is the "home" or host-rock of the Cave, Lincoln, Creole, and other mines of the region.

Mesozoic rocks are exposed at the south end of the range from the area of the Creole Mine eastward to where the sedimentary rocks are buried by the recent flow sheets, tuffs, and volcanic breccias, and northward to Pass Canyon. They include: the variegated shales and intercalated limestones of the Moenkopi; the sandy conglomerates of the Shinarump; the variegated shales and sandy shales of the Chinle; the typical cross-bedded massive sandstone of the Navajo; and the finely crystalline limestones of the Carmel. The measured members are much thinner than those present in the type localities of southern Utah. This is particularly true for the Chinle and Navajo formations.

East of Minersville, the Triassic Red Bed formations (chiefly Moenkopi) cross the Beaver-Milford Highway. The north-south ridge immediately to the west of the reddish shales and sandstones is the basal limestone of the Moenkopi. In general, the strata are inclined to the east at a comparatively low angle and strike dominantly to the north or northeast.

The Big Pass property (Strategic Metals, Inc.) is tentatively thought to be in Permo-Triassic rocks. Approximately one-quarter of a mile east from the main tungsten workings, reddish to chocolate colored shales cross the Big Pass road. Because of the abundance of cherty nodules in the shale, so common to the Moenkopi and Chinle horizons of southern Utah, the writers feel safe in assigning these rocks to the Triassic. Whether the shale represents a portion of the Moenkopi or the basal Chinle is not known. The Shinarump conglomerate, the usual marker of distinguishing between these two members, was not observed in the Big Pass area, although farther south the conglomerate is exposed at several places. Should this shale be the Moenkopi, then the altered limestone (white marble)

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[1] Butler, B. S. and others, Ore Deposits of Utah: U. S. Geological Survey Prof. Paper 111, p. 535, 1920.

in which the gold prospects have been driven, is an interbedded phase. The severely crushed nature of the limestone, however, indicates movement of more than minor faulting. The low angle of the fault contact plus the considered direction of movement suggests thrustal rather than normal fault displacement, and may be related, in part at least, to the imbricate structure of the sedimentary block south of the Pass Canyon road as recognized by Denni
The altered limestones, sandstones and shales of the main workings of the Big Pass property are possibly Permian, as the strike and dip indicate that they underlie the shale. The north-south fault which terminates the eastward extension of tungsten ore, could be of sufficient magnitude to abut older rocks, perhaps Carboniferous, against the Triassic, and consequently this possibility should not be precluded. The rugged expression of the topography, plus the complex faulting of the strata, makes reconnaissance geology difficult. The shale and sandstone phases of the "Red Beds," near the gold prospect, however, represent the northernmost extension of Jura-triassic rocks known to the writers, although inconspicuous remnants of these beds may extend several miles northward along the east flank of the range. Several pieces of reddish sandstone, lithologically resembling the Navajo sandstone of the south end of the range, were found as float approximately three miles north of the Pass Canyon Road near the head of Cottonwood Canyon in the locale of the old Bismuth prospect and immediately south of the Oak group of tungsten claims. A search was made to locate the sandstone member in place, but it was not found. Should Jura-Triassic formations exist in the higher reaches at the head of ? Cottonwood Canyon, then the thrust faulting displayed elsewhere may have extended at least to this point and perhaps farther along the east side of the range. This explanation is tentatively suggested because of the southeastward dipping Mississippian rocks (determined by fossil evidence) outcropping less than one-half of a mile to the east near the mouth of the canyon.

Structure and Faults. The Mineral Range may be classed as a typical Basin and Range mountainous highland—its long direction oriented approximately north-south and its shorter axis nearly east-west—covering an area roughly 25 by 7 miles. Most of the range is homoclinal in structure, that is, from the region of Bearskin Peak southward. Over this portion of the range but few exceptions of the north or northeast strike and easterly dip of the strata were observed. The north end of the range, however, loses its consistent easterly dip. Here the beds are gently arched into an anticline, the limbs of which are inclined at low angles to the west, northwest, and northeast, respectively.

The west and east flanks of the range are interpreted as being bounded by steep-appearing faults that have elevated the range several thousand feet above the adjacent lowlands. Although no direct evidence has been found thus far, with respect to the delineation of this faulting, the relatively steep and straight range front strongly impresses the geologist of displacement on far more than

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minor scale. Butler[1] is also of the opinion that "The front of the range is determined by a strong north-south fault with downthrow to the west." The presence of hot springs along the west flank as described by Lee,[2] suggests that either frictional tension forces still interplay along the fault zone, or that residual heat from effusive rocks is still being emanated,[3] East-west faults cross the range in Pass Canyon, and at the south end in Beaver Canyon. Butler mentions the latter fault but does not elaborate upon it. Other major transverse breaks are suspected. The abrupt change in the range trend from Bearskin Peak northward and the eastward projecting granite tongue from this peak toward the Fortuna Mining District in the Bald Hills, are indicative of another important east-west fault.

The relationship of the granite intrusive to the major uplift is obscure, but there is valid reason to believe that the two phenomena were affected by each other, and that mountain building forces were during or immediately subsequent to the intrusion. However, at least three important epochs of faulting have been recognized. They are subdivided as follows: (1) pre-intrusive faulting (2) faulting during or immediately subsequent to the intrusion, and (3) post-intrusive faulting.

Pre-intrusive movement has been noted at both the north and south portions of the range. The great thrust block of Tintic quartzite of the north end, in the vicinity of the tremolite deposits, is arched to a slight degree by the near-surface granitic intrusive. Further, the thrust plane consists of a breccia zone approximately 10 feet in thickness which has been mineralized by solutions rich in barium, sulphur, and lead. Several prospects along the fault contained galena crystals embedded within a gangue of brecciated limestone, quartzite and interstitial barite. Accordingly, the writers feel safe in assigning this fault as pre-intrusive—perhaps related to the great Laramide orogeny of late Cretaceous time that affected so much of the Basin and Range Province of Utah. In this connection it is of interest to note the Laramide thrusting as mapped by Maxey and Dennis[4] in the Pavant Range, east of Fillmore and Kanosh where Tintic quartzite is faulted against Navajo sandstone. Immediately to the north of this area at the south end of the Canyon Range (locally called the Oak Creek Range) observations of the writers indicate that the Tintic quartzite here too overrides well over one thousand feet of younger Paleozoics. The quartzite block makes the "capping" or upper reaches of the range and is plainly visible from U. S. Highway 91 a few miles north of Holden. Further, the flanking foothills of the southwest portion of the Canyon Range (northwest of Holden) show similarly faulted conditions,

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[1] Butler, B. S., and others, the Ore Deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 533 (1917).

[2] Lee, W. T., Water Resources of Beaver Valley, Utah: U. S. Geol. Survey Water Supply Paper 217 (1908).

[3] Of the two thermal producing criteria, the writers are inclined to favor the emission of heat from extrusive igneous rocks, as the hot spring zone extends far to the south into the Escalante Desert Lowlands. Thermo, a station on the Los Angeles-Salt Lake Railroad, was so named because of the presence of hot springs. On the other hand, the recency of some of the crustal disturbances, also reflects the possibility of present adjustments along the range front fault, which undoubtedly would generate heat.

[4] Personal Communication—G. B. Maxey and E. P. Dennis, U. S. Geol. Survey.

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and like the Mineral Range north-end thrust, the low-angle zone was mineralized—subjected to apparently weak solutions copper, silver, and iron over certain areas. Many authors h contributed to the literature on the regional Laramide deform of late Cretaceous or early Tertiary time with respect to its upon Basin and Range structure, but mention of them and works is purposely omitted because of their wide recognition. above citations are brought forth because they pertain to a sec of Utah which until recently was not recognized as having un gone severe thrustal adjustments.

As previously described, the sedimentary strata south of P Canyon are offset by a number of overlapping faults that cause imbricate repetition of the beds at least three times. These faults ha a general north-south strike with an average dip of approxima 45° to the east, are more highly inclined than the strata, and li the north-end thrust are believed to have resulted from west compressive stresses during Laramide times. Since then, the strat graphic units have been tilted to the east, perhaps due to the gra itic uplift. Other pre-intrusive faults may exist, but as yet correla tion is undetermined.

Faulting during or immediately subsequent to the intrusion is difficult to interpret. Determinative criteria which form the bas for such a classification are: relationship to known pre-intrusive movement, effect of the intrusion upon believed contemporaneous displacement, and structural and mineralogic setting for faulted roof-pendant units. The first of the above factors can be expressed with a fair degree of certainty. The other two factors are tentative although suggested by field evidence.

Two and possibly more normal faults cut across the thrust of the north end, the downthrow blocks being to the west in each case. These faults strike approximately north-south with steep dips to the west and roughly parallel the range front. Moreover, in part at least, they acted as ascension channels for mineral-laden solutions expelled from the invading magma as both the normal and the thrust faults show some degree of ore deposition. Compounds of silver, lead, copper and zinc are present in and adjacent to the fault zones. Since the mineralized areas are considered a product of magmatic differentiation and since the normal faults displace the thrust, the time assignment of this movement is placed as contemporaneous with the intrusion, although it is acknowledged that the faulting may be pre-intrusive—the result of relaxational adjustments after the cessation of the Laramide thrustal compressive forces.

It was noted that many of the roof-pendant tungsten ore-bodies are considerably faulted, folded and crushed. Typical examples are the Oak, Big Pass, and Oak Basin properties. In no case was the faulting traceable outward into the intrusive. Consequently, it must be related either to the intrusion or pre-intrusive movement. Of the two factors, the writers favor the former, and believe the inter-roof pendant movement is the direct result of uplift of the sedimentary segment and perhaps equally important, the result of forces exerted upon the pendant by the crystallizing magma.

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Post-intrusive faulting is apparent at various places in the range and is more easily recognized than either that considered contemporaneous with or prior to the intrusion. One of the prominent faults of this group is the low-angle thrust (of granite upon granite), as mapped by Dennis,[1] of Minersville. The fault is plainly visible from the Beaver-Milford Highway approximately five miles northwesterly from Minersville. The east-west fault of Pass Canyon is also post-intrusive. Near the mid-section of Pass Canyon granite is faulted against limestone. Topographic expression near the divide is suggestive of another related fault that veers to the northwest from the east-west fault of Pass Canyon, although field evidence as yet is not conclusive. On a less pretentious scale, post-intrusive movement is evident in many of the prospects of the range, indicated by "slickensides" in ore-bodies, along the contact of the granite and sedimentary beds and their presence in joint fractures of the granite. A fault scarp in the extrusive rocks of the southeast portion of the range west of Adamsville is evidence of very recent movement.

The Contact Zone in the vicinity of the chief tungsten properties strikes approximately north 35° east parallel to the general trend of the mid-south portion of the range. On the east flank it is associated with the large roof pendant which occupies the foothill belt at the base of the mountain slope and which, particularly in the area between Pass Canyon and Barton Hollow, is conspicuously visible from the Milford road a few miles west of Beaver City. From the Milford road the wide band of white marbleized limestone flanking the mountains northeast of Pass Canyon strongly impresses the geologist with the strength and character of the contact metamorphism caused by the intrusion, and prepares his mind to expect the garnetites, epidosites, and other tactive bodies which are found between the marble and the intrusive. North from Minersville and also in the vicinity of the 2 R's property, the contact zone is more irregular as the intrusive has generally embayed and replaced the sedimentary strata across rather than parallel to their strike. Nevertheless, a definite garnet, crystalline limestone zoning of the sedimentary rocks is evident.

The Tactite Bodies vary from thick, dark brown, hard, massive garnet lenses, usually on the inner side next to the granite, to thin, relatively even-banded zones of pale yellowish-green epidotized and zoisitized marble beds within the crystalline limestones in the outer contact zone next to the marble and away from the igneous intrusive. Where these tactite zones have been subjected to sulphide mineralization, the oxidation of the sulphide minerals, causes a general decomposition of the more soluble constituents of the usually tough compact rock, resulting in a softer, brownish-yellow to black mass containing small amounts of copper, lead, zinc, gold, and silver along with the usual small amounts of tungsten. A typical

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[1] Verbal Communication.

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occurrence is shown in the plan view of a portion of the property known as the Garnet group of Claims being operated by the D Metal Mines Incorporated shown herewith as Figure 5.

The Mineralization, where the contact is comparatively regular as in Figure 5, and where the ore channels have not been deflected and complicated by too many faults, seems to have followed a consistent pattern. The zonal arrangement going outward from the intrusive indicates (with irregularities and exceptions) a sequence of tactite beds (commonly called dikes by the prospector) showing progressively a diminishing grade of metamorphism. The pattern may be idealized as follows:

(1) Normal granite.

(2) An irregular band consisting of a marginal facies of the granite usually marked by the absence of biotite and the relative abundance of pyroxenes, amphiboles and minerals of the epidote-clinozoisite group.

(3) A narrow, more or less crushed, zone, occasionally marked with selvage, giving evidence of pneumatolitic and hydrothermal alteration, and characterized by such minerals as fluorite, muscovite, tourmaline, scheelite, and molybdenite along with later hydrothermal minerals such as chlorite, damourite, pyrite, chalcopyrite and galena, which seem to have followed older channels of escape of the mobile constituents distilled from the crystallizing magma.

(4) Garnetite often massive and hard if composed of garnet alone or intergrown with quartz, epidote, *etc.*, but sometimes soft and crumbly due to weak or partially dissolved interstitial cementing minerals, such as calcite, chlorite and biotite. Diopside is a prominent associate near the intrusive and epidote near the limestone.

(5) Calcite-wollastonite marble, occasionally with fibrous tremolite.

(6) Garnet-vesuvianite-epidote tactite band.

(7) Crystalline limestone.

(8) Epidote-clinozoisite tactite band.

(9) Crystalline limestone.

The number of tactite bands is highly variable. Instead of only three bands as shown in Figure 5, there are, as in the case at the Big Pass Property, often several. On the other hand, there may be only one. The intervening crystalline limestone beds are then missing so as not to separate the different facies of tactite into differentiated bands. When, as was observed in one case in Well Canyon, the tactite zone is thus telescoped into a narrow band of transition from the inner intrusive to the outer limestone country rock, the relative positions of the contact silicates with reference to the intrusion may, in general, follow the same pattern within the single band as described for the successive bands provided the complexities created by interlacing "escape" channels of the mineralizers

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The scheelite ore is found to a greater or lesser degree throughout the successive facies of the contact zone. Characteristically, however, it is best developed in Zones 3 and 4. It is often in high-grade streaks in Zone 3 where it is concentrated along channels that appear to have been feeders for pneumatolitic tungsten which often became impounded or entrapped within the confines of wider zones along with garnet masses forming disseminated intergrowths of fine-grained scheelite within the garnetite, or even (less characteristically) within the epidosite of Zones 6 or 8. On Dutch Mountain in the Gold Hill District the writers have observed high-grade masses of pure scheelite isolated within marble roof pendants a considerable distance from any garnet or other contact silicates. However, no such examples were found in the Mineral Range even though the relationship of the roof pendants to the tactite zone and the intrusive body is otherwise very similar. Prospecting with the fluorescent lamp may yet reveal in the Mineral Range the existence of such high-grade "pockets."

The tungsten deposits of the Mineral Range are strikingly similar in both the characteristics of the scheelite (the only tungsten-bearing mineral noted) and the manner in which the scheelite occurs. All of the deposits examined are located in contact metamorphic rocks adjacent to the granitic intrusive. Nearly all of the scheelite occurs in tactite as small disseminated crystals that fluoresce cream to yellow in color under the ultraviolet ray of the "Mineralight," indicating the presence of molybdenum isomorphously replacing part of the tungsten in the scheelite. Pure scheelite which fluoresces blue-white and occurs in large euhedral crystals is present in relative abundance on some of the claims, but this variety is rare when the deposits are considered as a whole.

Because of the presence of scheelite in most of the tactite zones examined, it is not unreasonable to assume that pneumatolitic solutions containing tungsten were expelled along the periphery of the granitic intrusive and that wherever physico-chemical conditions were favorable, scheelite was deposited. Thus the possibility exists that scheelite also may be present in other contact rocks of the north, east, south, and west flanks of the range.

DESCRIPTION OF INDIVIDUAL TUNGSTEN PROPERTIES OF THE MINERAL RANGE

The tungsten occurrences of the Mineral Range are by no means restricted to one or two properties, and no doubt tungsten deposits are present other than described in this report. Time did not permit an exhaustive study of each deposit, nor was there opportunity to even visit all of them. The original assignment was to make preliminary examinations of the Big Pass, the Garnet and the Contact properties. However, because of the close relationship of these three deposits in geography, structure, mineral association, and genesis to others in the immediate vicinity, it seemed advisable to include a brief summary of such facts as are known regarding the adjacent deposits. Further incentive was to gain a better perspective of the deposits in question with relation to the mineralization as a whole.

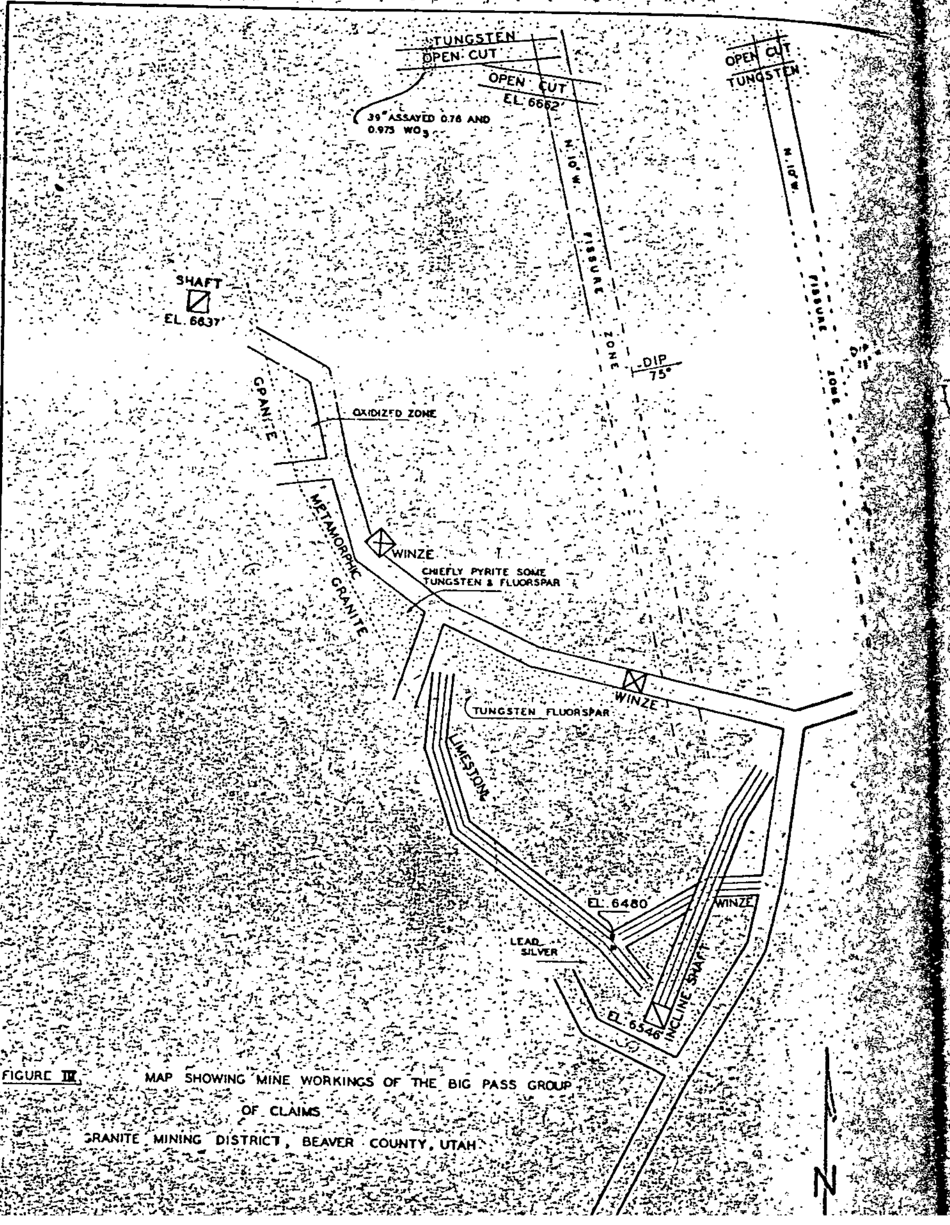

FIGURE III. MAP SHOWING MINE WORKINGS OF THE BIG PASS GROUP OF CLAIMS GRANITE MINING DISTRICT, BEAVER COUNTY, UTAH

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BIG PASS GROUP

The location of the Big Pass group, consisting of twenty overlapping unpatented claims, is on the north side of East Pass Canyon. This is near the southern end of the Mineral Range east of where two prominent canyons draining in opposite directions have by headward erosion formed a low pass in the mountains over which ore and supplies were once freighted with teams between Beaver and Milford. The town of Beaver lies approximately ten miles to the east of the property. See Figure 2 for location of the Pass Canyon Road and Claims.

Ownership of the Big Pass group was, until recently, very involved. People interested in three overlapping groups of claims were in litigation. In order of the chronology of their location these groups were: the Hope Chest group of three claims, the Contact group[1] of twelve claims, and the Lucky Lu group of five claims. Consolidated as they now are they comprise approximately the equivalent of eight full claims.

The property is not a newly discovered mineralized area. Prior to 1900 Claim No. 5 of the Contact group was worked for lead, silver and some gold. A large portion of the underground workings shown on Figure 4 was developed during this early activity. However, with the cessation of the original mining operations, the property was idle until 1937 when the Lessing family of Beaver County operated a certain section of the property for gold which occurred in high grade but "spotty" pockets along the contact zone in a white crystalline limestone. After the discovery of scheelite on the property three sets of claimants asserted their alleged rights and became involved in a lawsuit for ownership. By stipulation, it was agreed to end the suit by compromise so that the three contesting groups of parties shared in the legal title. As a result, a comparatively large number of persons now own fractional interests in what is tentatively agreed shall be known as the Big Pass group of claims. Mr. Ambrose McGarry has recently acquired a ten-year lease on the property.

The ore deposits of the Big Pass group of claims consist of typical "contact metamorphic" deposits, together with some later fissure-replacement deposits containing gold, silver, lead, copper, zinc, and manganese. In many respects these ore bodies are similar to the ore-bodies of the Garnet and Contact properties (to be described later). The values occur in zones of tactite varying in composition and texture from those composed chiefly of garnet (either the tough, fresh variety or the altered, more friable type) to those which consist primarily of epidote, wollastonite, tremolite, fluorite, pyrite, and calcite. All contain scheelite in variable amounts.

Tongues from the main mass of granite extend irregularly into metamorphosed sedimentary rocks which in this vicinity form what is believed to be a large roof pendant on the flank of the main intru-

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[1] This "Contact" group of claims should not be confused with the "Contact Group" or the "Contact Fraction", discussed under the captions, "Contact Group" and "Garnet Group", respectively.

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sive. It is near the contact of the intrusive rocks with the sedimentary formations, that the tactite zones were formed extending laterally and upward along favorable beds as metasomatic replacement deposits. No promising mineralization was noted in the granite proper. Dikes and sills of pegmatite, aplite, and a dark green-appearing rock (rich in ferromagnesian minerals) are not uncommon as apophyses of the parent igneous body, and occasionally they carry small amounts of ore minerals.

On the east side of a ridge between the old gold workings of the Lessing family and the area where most of the tungsten development is now being carried on is a prominent zone of contact metamorphism. Here the original sedimentary rocks have been changed to an area of beautifully colored (predominately green, yellow, and brown) serpentine, ophicalcite, and finely crystalline marbles containing wollastonite and short-fiber chrysotile (asbestos). This area was "lamped" during the investigation, but no scheelite was found.

Prospecting of the surface by a number of trenches which crosscut the tactite bodies has exposed scheelite in every instance. The tenor of the ore, however, is variable from place to place. Most of the ore exposed in these trenches will average less than 0.50 per cent WO_3, but it is not uncommon to get small, higher grade streaks carrying from 1.0 to 2.0 per cent. Using fluorescence as a criterion to estimate quality, it seems apparent that much of the ore in the open pits and trenches can be classified as a good grade mill ore. Although the geology of these tactite zones has not been worked out in detail, there apparently exists a considerable tonnage of this type of material. The majority of these tactite zones strike north 30° east and dip steeply to the southeast, although a lesser number strike west of north and dip (75°) to the northeast. Their average thickness is approximately twenty feet.

Because of the difference in mineral composition, the tactite zones vary considerably in appearance. Some, containing large quantities of iron, 1 originally as pyrite, have been oxidized and weathered to a brownish yellow porous rock, while others composed chiefly of 2 tremolite, fluorite, scheelite, and calcite, are more massive. A third type, a brown to 3 greenish-brown garnetite, is even more massive and resistant to weathering, forming bold dike-like outcrops and ridges. All, however, represent metasomatically replaced impure limestones and most of them contain tungsten in the form of scheelite.

Development was originally carried on, as mentioned previously, in search of gold, silver, lead, and copper. Figure No. 4 shows the workings of the largest of these operations. The main tunnel prospected a fissure carrying the silver-lead ore. Stopes and winzes further prospected the ore trends. Hand specimens taken in a stope approximately 100 feet from the portal of the main adit, consisted of malachite, aurichalcite, galena, cerussite, and jarosite

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From the character of the exposures examined and from the facts gleaned concerning the history of the deposits, it is evident that certain of these gold, silver, lead, and copper stopes were very high grade. However, as in similar contact zones, they proved "spotty" and unreliable. As indicated in Figure No. 4, a lateral drift to the west contains considerable amounts of pyrite associated with fluorite and scheelite. One such body is exposed in this drift for approximately 50 feet and the scheelite showings are among the best exposed on the property. Grab samples (not taken by the writers) assayed 3.65, 2.75, and 2.46 per cent WO_3. The limestone penetrated by this drift is completely marbleized and highly shattered. Adjacent to the high-grade zone, sections of the limestone are extremely crushed and broken, some of which contain small crisscross fissure systems filled with limonite. These veinlets occasionally contain isolated blue-fluorescing scheelite crystals. Evidence of faulting, chiefly parallel to the ore-drift (also parallel to the granite contact) is indicated by the slickensided "hanging wall" exposed by the drift into the ore zone. Other minor fault zones are also exposed, most of which strike with the drift, but vary in dip from steep to gentle in a southerly direction.

During a night investigation with an ultraviolet lamp, the writers located the source of scheelite "float" found on the west side of the prominent ridge some 500 feet east of the nearest tungsten workings. This newly discovered outcrop was prospected and now exposes in a short open cut and a shaft 50 feet in depth a very promising blue-fluorescing scheelite ore zone which it is believed will carry in excess of 2.0 per cent WO_3. The scheelite occurs as coarse white crystals embedded in green, lime-rich contact rock, adjacent to a white crystalline marble bed which parallels the ridge. The better grade scheelite ore is invariably associated with fluorite, the latter mineral often surrounding the scheelite crystals.

Production of tungsten ore consists of 50 tons of scheelite-bearing tactite which was hand-sorted, sacked, and stored on the property ready for shipment when road facilities can be provided.

Transportation facilities are good. Approximately 3500 feet of road from the Pass Canyon road to the main workings were constructed under the auspices of the U. S. Grazing Service during 1943. Heretofore, the property has been inaccessible because most of the development has been confined to an area roughly 500 feet above the Pass Canyon road. Ultimately, if the ore-bodies now exposed at the higher elevations prove of economic importance, sinking must necessarily be done to follow the steep pitching ore zones. At such time it might be wise to drive a tunnel in a northerly direction from a suitable site at the base of the hill, preferably on one of the tactite zones, into and under the ore-bodies now exposed. Such a project would have a twofold advantage, for it would not only develop ore at depth, permitting stoping methods of mining to be utilized, but it would have an additional advantage of serving haulage laterals at depth which could intersect each tactite (northeast-southwest) zone apparent on the property.

THE MOLLY GROUP

The location of the Molly group of claims is on some low-lying foothills drained by the intermittent stream of Little Well Canyon. The claims are immediately southwest of the Oak group. See Figure 2. The property is covered by three unpatented claims controlled by Joe Fotheringham of Minersville and associates.

Occurrence of the scheelite is confined to tactite zones in metamorphosed limestones near the main intrusive. It is typical of the tungsten deposits of the region. The limestones of Little Well Canyon have been subjected to varying degrees of metamorphism. On the spur southwest of the wash and below the old lime kiln, the limestones have been little changed and some of them contain Paleozoic fossils. At and near the lime kiln, and farther up the canyon in the vicinity of the scheelite-bearing tactite, much of the limestone has been recrystallized into a snow-white marble. The largest tactite body observed is located several hundred feet northwest of the lime kiln and is exposed by surface trenching and a shallow shaft. It consists of a vertical band of massive, brownish garnet approximately eight feet in thickness which strikes to the northeast. Small vugs in the massive garnet are lined with brilliant euhedral and subhedral crystals. Green "contact silicates" were noted as accessory minerals, but they comprise only a minor percentage of the rock mass. The garnet body was offset by a small fault which may have permitted some post-garnet mineralization. Sulphides, chiefly pyrite, and their oxidation products, were noted in this zone. The work on the garnet body undoubtedly was done (years ago) in a search for gold, silver, copper, etc., suggested by the partially oxidized sulphide mineralization exposed in surface outcrops.

Grab samples collected during the daylight examination were subsequently "lamped" under ultraviolet light and showed appreciable amounts of scheelite. Although the samples were not assayed, the fluorescence of some specimens indicated approximately 0.75 per cent WO_3.

One hundred feet to the northeast, across a small ravine, a tactite body is exposed on a low-ridge. It consists chiefly of a greenish-yellow mass of silicate minerals tentatively identified as tremolite, vesuvienite, and epidote, in a ground-mass of quartz and calcite. The trend of this tactite was similar to the garnet body previously described, i.e., the strike being northeast with a steep (almost vertical) dip. Because of insufficient exposures, the thickness of the tactite could not be accurately determined above a minimum of four feet. Grab samples taken were negative under the ultraviolet ray, but this does not mean that the whole zone necessarily is barren. The nearness of this tactite body to the garnetite zone which has fairly strong concentrations of scheelite, suggests that the former should be thoroughly "lamped."

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A short distance to the west of the garnet body, an old shaft as been sunk on a highly oxidized fissure-vein, approximately ghteen inches in thickness, composed almost entirely of limonite, he brown hydrous oxide of iron. According to Ambrose McGarry, ome high-grade lead-silver ore was encountered in this shaft.

Further investigation is justified. It seems apparent that the ungsten-bearing garnetite exposed on the Molly group of claims, s an extension of the tungsteniferous tactite zone now being developed on the Oak, Garnet, and Contact groups, respectively.

OAK GROUP

The location of the Oak group of claims is immediately northeast of the drainage channel of Little Well Canyon. To the southwest lies the Molly group and to the northeast the Garnet group of claims. See Figures 2 and 5. The Oak group comprises two full unpatented claims side by side with the long direction northeast-southwest. The northeast claim is the Oak and the southwest is the Oak No. 1.

Ownership is in the name of Collis Huntington, James W. Fotheringham and Ambrose McGarry, who have given a ten-year lease to the Beaver Tungsten Mines Incorporated. The company, consisting of James C. McGarry and California associates, is now prospecting the property for commercial quantities of tungsten ore.

The ore deposits have been developed by three shafts and a number of surface trenches. The exact relationship between the granite and the sedimentary rocks is not known, but there is reason to believe that the sedimentary series now being prospected are a roof-pendant sliver of rather narrow width but of considerable length, the long direction being northeast-southwest, the apparent dip being to the southeast. The sedimentary rocks now existing, as tactites and coarsely crystal marbles, have been impregnated with tungsten-bearing solutions and have been subjected to rather severe stresses. This is well exemplified in the underground workings where it was noticed that the sedimentary rocks vary considerably in dip even over short distances and in places have been subjected to crushing and faulting.

Scheelite is exposed in most of the workings, both underground and surface, occurring as fine disseminated grains in a light buff-colored garnetite. This tactite is locally known as the "upper garnet body" and although its strike is consistent with the strike of the tactite present on the Garnet group of claims, it lies stratigraphically parallel and several hundred feet west of where the southwest extension of the tactite of the Garnet group of claims outcrops on the property. Thus far the latter zone has not been prospected here.

The main workings consists of a ninety-foot vertical shaft with drifts, exposing but little ore, and a new shaft, located a short distance to the west, now being developed. Thus far the latter been sunk to a depth of thirty-five feet at which point an eastw drift was run following a garnet ore-bearing zone. On the thi five-foot level of the new workings the ore body, although l grade, appears promising. Structurally, however, the ore zone un ates, changing from a gentle southeastward to a steep N. 63° dip with a northwesterly strike. Because of this fact, a winze h been started at the face of the drift on the thirty-five-foot le following the ore. If a continuity in strike and dip of the ore zon being followed downward by the winze should be proven wi further development, then the downward extension of this zo could be intersected on the ninety-foot level of the old workings short distance in an eastward direction from the face of the mos eastward trending drift. Naturally accurate surveys should be ma before any contemplated development of this type should progr also because of the "rolling" nature of the ore zone thus far dev oped, enough work should first be done in the winze in the n shaft to assure a continuance of dip at a consistent angle. Caref consideration must be given these points.

On the ninety-foot level of the old workings a tongue of th *granite* has been exposed. The *granite mass, friable* and *somewh* decomposed, has a porphyrytic texture with large phenocrysts o reddish feldspar. The two main drifts on this level have been ru in a southeast and south direction respectively. Here again struc tural variations of the sedimentary rocks are apparent. Measurements taken showed a strike of N. 10° E. with a dip of 30° to the southeast. Between the shaft and the face of the southeast drift there is evidence of the beds being overturned, the latter bein adjacent to a distinct faulted area. Fault gouge containing sericitized chlorite, white to greenish-colored slickensided surfaces, and flattened pellets of serpentine, are prevalent in the fault zone approximately twelve inches in thickness.

The south drift encountered only non-tungsten-bearing marbleized limestone. It is interesting to note that if a downward extension of the ore-bearing tactite exposed in the winze of the new workings does exist at depths, the southeast and south *trending* drifts of the old workings have actually been extended away from the ore-bearing tactite. On the other hand, if the sedimentary rock series do not continue stratigraphically eastward over a great enough distance, the ore-bearing zone could be bottomed before reaching the ninety-foot level.

A short distance southwesterly from the main workings, a shallow shaft and open-cut have also exposed tungsten-bearing tactite. The open-cut is approximately one hundred feet in length extending in a S. 55° E. direction from the portal of the shaft. The first forty feet, composed chiefly of garnetite, averages 0.28 per cent WO which is followed by an interbedded resistant limestone and shale

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The geologic setting is indeed interesting and very complex. Apparently the complexity and change in structure is due to heavy drag stresses during the intrusion and possibly post-mineralization faulting of the roof-pendant sedimentary block. To what distance the sedimentary series may extend can only be proved by further development. However, it is well to bear in mind that they may be bottomed at comparatively shallow depths. However, this could also be an advantage, for the ore-bearing tactite may exist over a shallow but relatively rich lateral zone. The original ore-bearing solutions permeate favorable areas for mineralization resulting in relatively confined but rich ore deposition. The ore, as observed under the ultraviolet lamp and assays made on that exposed in the open trench, indicate rather large thicknesses of mill-grade ore. Only local high-grade bunches, however, observed by the writer, could be considered shipping ore, thus the ore-body as a whole should undoubtedly be classified as marginal.

THE GARNET GROUP

The location of the Garnet group of claims is on the eastern flank of the Mineral Range and is three miles north of the intersection of the Pass Canyon Road with the new access road on the east side of the range. See Figures 1 and 2. The group derives its name from the abundance of the mineral garnet existing in the contact metamorphic rocks of the area. The group consists of three unpatented claims, Garnet No. 1, Garnet, and Contact Fraction, in approximate tandem position, from southwest to northeast, respectively. The Garnet is a full claim, 600 feet by 1500 feet. The Contact Fraction is a short claim of only 177 feet in length but having a full claim width of 600 feet. Garnet No. 1 is also a fractional claim. Its southeast corner is in common with the southwest corner of the Garnet claim. However, it is wedge-shaped, being less than 800 feet in length and about 500 feet wide at the northeast end and approximately 300 feet wide at the southwest end.

The owners, Ambrose McGarry and Ezra Barton of Beaver, and Dr. Hartley G. Dewey of Los Angeles, have leased the claims for a period of 20 years to the Daily Metal Mines Incorporated. F. L. Daily, an attorney of Chicago, is president. Ernest C. McGarry, Salt Lake City, is vice-president. R. H. Barton, Salt Lake City, is secretary-treasurer and manager. Robert B. Harper, vice-president of the Peoples Gas and Electric Co. of Chicago, is a substantial stockholder and director, as is also John C. Wood of the J. C. Wood Investment Co. of Chicago. John Bestelmeyer is mine superintendent. The company was granted a $15,000.00 loan by the Reconstruction Finance Corporation in 1943 to assist in the development of the tungsten ore bodies on the Garnet group of claims.

The ore deposits of the Garnet claims consist of a number of parallel northeast-southwest, nearly vertical scheelite-bearing tactite zones which have been prospected on the surface by a number of northwest-southeast shallow trenches. Because of the nearly flat surface of the topography, two vertical shafts have been sunk to prove the ore-bodies at depth. The new shaft, now in use, has been sunk on the middle garnet zone to a depth of 100 feet with lateral drifts on the 40 and 100-foot levels. Figure 5 shows a surface plan view of a portion of the claims with the workings of the 40-foot level superimposed.

On the 40-foot level the scheelite-bearing garnet contains two types of scheelite deposits: (1) a finely disseminated scheelite in garnet, which has thus far yielded two cars of 0.70 per cent WO_3 and (2) a richer but much more spotted vein-type of scheelite, which apparently deposited in shear zones and joint planes of the tactite host rock. Both types of ore fluoresce yellow to cream under the ultraviolet ray indicating the presence of molybdenum. The shear zones have a general northwest strike, with steep almost vertical dips. A less prominent system strikes N. 25° to 30° E., paralleling the dominant trend of the sedimentary beds in this vicinity. The high-grade occurs along these breaks with disseminated coarse scheelite crystals penetrating approximately one-half inch into the adjacent wall rock. Whether or not these high-grade streaks represent a second phase of mineralization is not definitely known. It was noticed that the finely disseminated type of ore was usually confined to a softer and more altered garnet rock than the tougher less friable rock adjacent to the high-grade streaks. This may indicate that the disseminated scheelite was associated with pyrite which later oxidized, liberating sulphuric acid that corroded and weakened the rock. On the other hand, it may mean that the scheelite was later than the deposition of the first metamorphic silicates, and that the scheelite-bearing solutions were better able to permeate and replace the interstitial calcite of certain tactites, consisting of garnet with calcite than to replace the tougher type which consisted almost wholly of relatively insoluble silicates. It is assumed that these contact silicates were not replaceable to an appreciable extent beyond the joint and fracture planes which now contain the high-grade streaks.

The main drift on a 100-foot level exposes scheelite-bearing garnetite of the disseminated scheelite type at the face. The vertical continuation of the ore zone present on the 40-foot level has been encountered on the left side of the main drift on the 100-foot level. Three cars shipped (133,208 tons) from this zone assayed 1.05, 0.80, 0.70 per cent WO_3, respectively. Some sulphide (iron pyrite) and reddish fluorescent calcite is associated with the ore. Minor amounts of copper, gold and silver are also reported present. Malachite-stained garnet rock containing fluorite was observed on the 100-foot level. Scheelite was also noted at the southern end of the main drift on this level; but as thus far developed, occurs as a body too low in grade to be considered ore. According to Bestelmeyer, samples taken assayed 0.30 per cent WO_3. This zone, however, is rather large and appears promising. Northwest and southeast laterals from the main drift have

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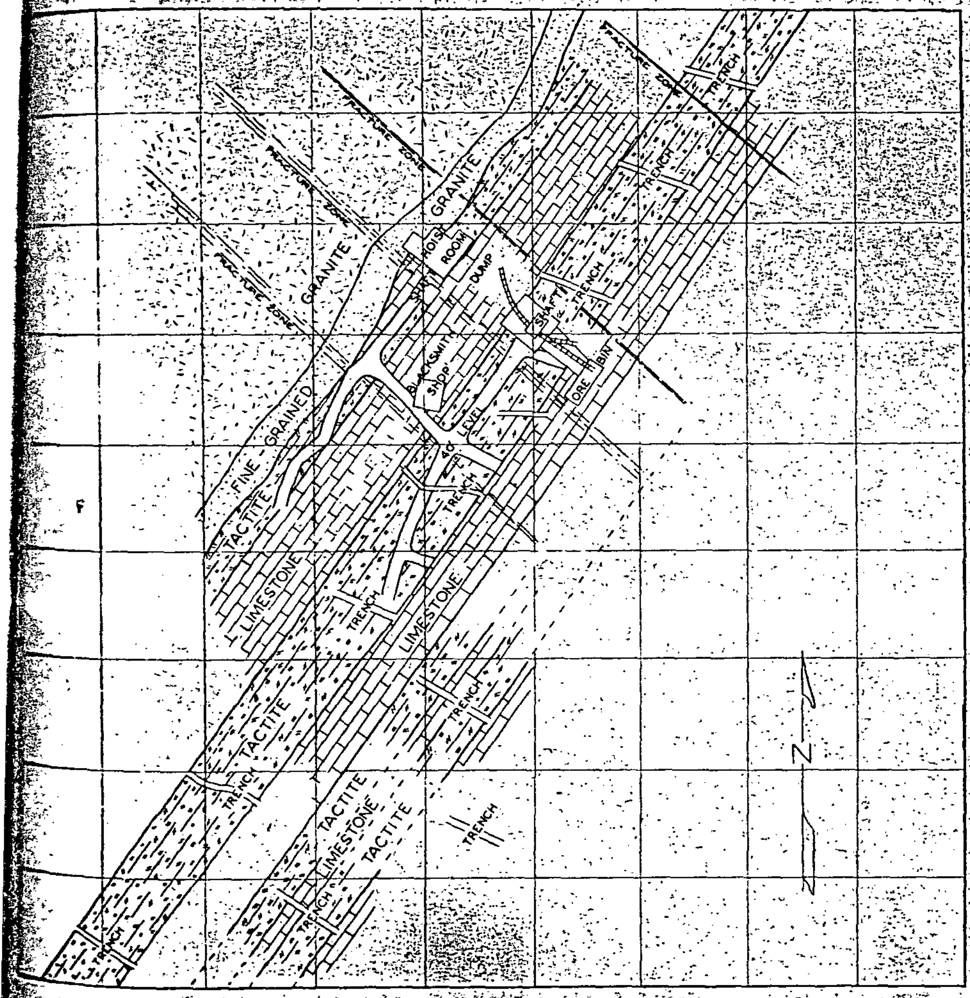

FIGURE V
PLAN VIEW OF PORTION OF GARNET NO. I
SCHEELITE ORE-BODY OF DAILY MINES CORPORATION
MINERAL RANGE, BEAVER COUNTY, UTAH

SCALE
0 10 20 30 40 50

ADAPTED FROM MAP BY
JOHN BESTELMEYER

Four such garnet-epidote (tactite) zones roughly parallel each other and all are tungsteniferous. The third and fourth zones are separated by only a few feet of marbleized limestone and are sometimes considered as a single zone. See Figure 5. Thus far, the main development has been concentrated on the middle zone, although the west zone (adjacent to the granite) has been prospected to some extent by the U. S. Vanadium Corporation, the previous lessee of the property. It was the latter company that sunk the west shaft which is not now in use.

The future possibilities of developing large low-grade ore-bodies appear promising. If what has been found on the surface (exposed by the trenches) and in the underground workings, can be a criterion for what may be expected of further development, a longevity of mining operations seems promising when 1943 tungsten prices prevail. However, if large tonnages are contemplated, the average grade of tungsten ore is low, and less than 0.50 per cent WO_3 should be assumed. Thus the deposit as a whole should be considered marginal under normal economic conditions. Much of the ore present in the garnet bodies cannot be profitably mined and shipped at present, but if sufficient tonnages of the lower grade ore can be blocked out during the mining of the higher grade bodies, the erection of a mill at the property might well be justified in order that these lower grade ore-bodies can also be utilized.

THE CONTACT GROUP

The location of the Contact group of claims is immediately to the northeast of the Garnet group of the Daily Metal Mines Incorporated. See Figure 2. The group consists of "two unpatented claims and three fractions known as Contact Lode Mining Claim, Contact No. 1 Lode Mining Claim, and (three?) Contact Fraction Lode Mining Claims."

The owners are Ambrose McGarry, Ezra Barton, Dr. Hartley G. Dewey and associates, who are prospecting the tungsten-bearing tactite for bodies of commercial grade. Previously these claims were owned by Arch Fotheringham, Ray Morgan, and others who prospected the ground, chiefly for gold. Since the present owners have taken over the property for tungsten development, three shafts have been sunk and an open cut made along the strike of the ore-bearing zone. Several open cuts also have been made adjacent to this zone to prospect the surrounding area.

Ore deposits and development are described briefly from the showings along the proved ore zone. For convenience, they are described as Shaft No. 1, the surface trench, Shaft No. 2 and Shaft

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mplex, seven feet of a greenish ferromagnesian rock was encoun-
ed containing hematite, pyrite, small amounts of chalcopyrite, and
sibly bornite. The pyrite is tarnished yellow resembling chalco-
rite and consequently the hand specimen appears much richer in
pper than is shown by the analysis below. Fluorite and quartz
re noted in the hand specimen as accessory minerals. Below the
riferous zone the shaft has penetrated a porphyritic granite con-
ning occasional quartz veins. In addition to the quartz, these
ins contain small amounts of molybdenite, forming rosettes one-
lf inch across. A lateral drift to the southeast has left the granite
d encountered the copper-bearing ferromagnesian rock. Further
velopment to the southeast should intersect the downward exten-
on of the tungsten-bearing tactite.

An analysis made by Black and Deason, Salt Lake City, Utah,
a 20-pound composite sample of the green copper-bearing ferro-
gnesian rock showed the following:

Copper per cent	Silver Oz. per ton	Gold Oz. per ton	Iron per cent	Lead per cent
0.75	0.2	Trace	20.8	None

Approximately 100 feet to the northeast of Shaft No. 1, the
en-cut has apparently exposed 20 feet of the same garnet-epidote
ngsten-bearing tactite encountered in Shaft No. 1. The central
rtion of the tactite consists of a fresh massive brownish garnetite,
hile the garnet-epidote margins on either side of the massive zone
re thin-banded, partially decomposed, and more friable. Certain
rtions of the tactite exposed in the trench which have been assayed
re reported to carry from 1 to 2 per cent WO_3.

Approximately 75 feet northeast of the open-cut, Shaft No. 2
has been sunk to a depth of 40 feet. Apparently most of the sinking
was in coarsely crystalline marbleized limestone as the dump con-
sts almost entirely of this material.

Some 40 feet northeast of Shaft No. 2, Shaft No. 3 has been
nk to a depth of 80 feet. This shaft penetrated limestone, tactite,
d granite. The tactite, similar to that described in the open-cut,
arries disseminated scheelite throughout and according to Ambrose
McGarry a 26-inch section assays better than 1 per cent WO_3.

At the time of the examination, development was confined to
Shaft No. 1. This work consisted of extending the southeast drift
n the 100-foot level to encounter the downward extension of the
ngsten-bearing tactite.

The ore bodies of the Contact group and of the Garnet group
re strikingly similar. Both properties have developed tungsten ore
tactite (garnet-epidote rock) which strikes and dips generally
the same. The character of the tactite bodies are also similar in
both their structural makeup and in the manner in which the scheelite
occurs. The chief difference between these properties is that the
Garnet group has three tactite zones whereas the Contact group
evelopment has thus far encountered only one. Whether the tactite
one of the latter is an extension of one of the three zones exposed
n the Garnet group is not definitely known, but there is reason to
trongly suspect such a correlation.

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THE SCHEELITE GROUP

The location of the Scheelite group of claims is between the Contact group on the south-southwest and the Burnt Hollow group on the north-northeast. The Scheelite group is twelve claims (18,000 feet) long and two claims (1200 feet) wide and has been surveyed as a N. 35° E. extension of the tactite zone exposed on the Contact group of claims. However, except for granite knobs, quartz veins, and resistant pegmatite outcrops few exposures can be found on the scheelite group. The elongated plan of these claims extends like a chord across the arc of the Beaumont Basin embayment of the mountain front. Beaumont Basin is a partially covered pediment which, judging from the outcrops available is eroded chiefly in granite. The Scheelite group was apparently located in the belief that the scheelite-bearing tactite zone extended northeastward with the same consistency exhibited to the southwest in the Contact, Garnet, Oak, and Molly groups, respectively. The limited exploration beneath the soil mantle, however, has failed to find such tactite bodies and there is some doubt as to whether they have been offset by faulting in this vicinity or may have followed a different trend being deflected by a change in strike or an irregularity in the margin of the granite intrusive.

The Scheelite group is here discussed because it acts as a key to help tie in a number of claims which extend in a northerly direction from the Contact group to the Oak Basin group.

To the northwest of the Scheelite group are located the Ward, Rattler, King-of-the-Hills, and Oak Basin groups, from south to north, respectively. The Epidote, Barton, Wild Bill and Big Two are other groups of claims which have been located southeast of the Scheelite group.

The owners of the Scheelite claims, Ezra C. Barton and Ambrose McGarry, have leased their holdings to the New Majestic Mining Company.

Development consists of two shafts, located approximately one mile north of the Contact group in the mouth of Beaumont Basin. They were sunk to a depth of 68 and 80 feet, respectively, by the New Majestic Mining Company. Neither shaft encountered anything but sand and decomposed granite. Knolls of resistant granite and pegmatites are exposed near the shafts. One pegmatite observed (in Section 20, T. 28 S., R. 8 W., S. L. B. & M.) contained small (one-half inch) euhedral crystals of pale sky-blue beryl, a complex silicate of beryllium and aluminum. This mineral is reported to occur as crystals up to four inches in length on the Mahogany claims located a short distance to the west of the shafts.

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THE WARD GROUP

The location of the Ward group is in Porcupine Canyon to the rtheast beyond Beaumont Basin. The claims lie to the northwest the Scheelite group about midway along the length of the latter group. Hence, the Ward group is northeast of the Contact group, rthwest of the Scheelite group and southwest of the Major Fault d the Rattler groups, respectively. See Figure No. 2.

The owners of the claims are Mrs. M. M. Ward and daughter, Miss E. E. Ward, of California. The property was not visited by the writers, but they have been informed[1] that it is similar in tungsten mineralization to other properties in the district already discussed.

The ore occurs in tactite zones which strike N. 35° E. and dip 75° to the southeast. The character of these zones is probably very similar to those present on the adjacent Major Fault and Rattler groups, respectively.

RATTLER GROUP

The location of the Rattler group of claims is on the east end of a small spur extending eastwardly from the main range south of Oak Leaf Canyon. See Figure 2. This is the spur in which is found the rhyolite apophysis of the main granite intrusion described on page 12 of this report. No doubt metamorphism of the limestones along the southern boundary of this rhyolite body has made the rocks in this vicinity more resistant to erosion and thus accounts for the existence of this ridge south of the Oak Leaf Canyon, which latter, in turn, has been eroded along the axis of the rhyolite apophysis It is believed that the extension of the King-of-the-Hills rhyolite is present as far east as the Rattler group of claims, for the intrusive dike rock exposed in the shaft is similar in character and can be aligned with the latter. West of the Rattler group in a ravine draining the south slope of this spur are the Major Fault groups, and over the saddle to the north is Oak Leaf Canyon, at the head of which is the King-of-the-Hills mine. Eastward from the workings on the Rattler claims, the spur merges with a gentle dip into the alluvium covered (pediment?) slope which carries far out into the valley southeast of the range proper.

Location no certain,
in Sec. 20, NE or
Sec. 17, SE ?

The owners of the Rattler group are Ambrose McGarry, Ezra Barton and James E. Robinson who contemplate development of tungsten ore in the near future. The ground controlled by these men consists of two full claims and three fractions.

Development of the property consists of a shallow inclined shaft approximately 30 feet in depth which exposes a green, epidote-rich tactite containing scheelite. The tactite strikes N. 35° E. and dips 75° to the northwest. The inclined shaft has been sunk at the contact of the intrusive rhyolite with the metamorphosed sedimentary rocks.

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[1] Verbal communication with H. M. Fay, Supervising Engineer, Mining Section, R. F. C. Salt Lake City Office.

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The ore deposits are similar in most respects to those occur elsewhere in the district. The scheelite occurs as disseminated gr throughout the greenish epidotized contact rock which varies f the tough massive to the more friable, crumbly varieties; the l type usually being associated with the better ore. Occasionally scheelite occurs in lenticular masses which are so oriented that long direction follows the dip of the tactite zone. During a m investigation of the property it was noted, by means of the ul violet light, that the best ore remaining in a shallow incline present near the bottom of the workings. The scheelite fluore a cream color and occasionally is associated with a pink to fluorescing calcite. Although local high-grade areas are present, tenor of the over-all ore body exposed is rather lean.

THE MAJOR FAULT GROUP

The location of the Major Fault claims is adjacent to, and west of, the Rattler group. Reese Griffith and associates control the clai designated as Major Fault No. 1 and Major Fault No. 2 and th other claims, comprising a group of five. The principal developm work has been carried on near the floor of a small, southeast drain ravine which empties into the broad mouth of Beaumont Basin short distance to the south.

The country rock of the area consists of limestones exhibit metamorphism varying from limestones which are slightly altered those which are highly so. Tactite zones have been formed chi parallel to the bedding planes. Several hundred feet down the cany from the main workings is the remains of an old lime kiln wh apparently utilized local white and gray marbleized limestones the production of quicklime. Intrusive rocks are not exposed n the workings, but the rhyolitic apophysis ~~outcrops~~ crops out near the sad at the head of the ravine along the road to the King-of-the-Hi Mine.

The tactite bodies comprise a zone roughly twenty-four feet thickness separated by several feet of shaly limestones. No typi garnet was apparent in the tactite bodies, which are best descri as greenish epidotized limestones, similar to the tactite of the Ratt claims. On either side of the mineralized zone, the country-r consists of a gray to nearly black compact limestone. The gene strike of the beds is N. 28° E. with dips from 55° to 65° to th southeast. One small tactite zone was observed to strike southe northwest roughly parallel to the rhyolite apophysis, but contrary the general trend of the tactite zones previously described.

Development consists of a shaft approximately fifty feet in de (with lateral drifts ?), one hundred feet of track, including du extensions, an inclined shaft some fifty feet in length (which follo the tactite in a northeast direction), and a shallow open pit loca some one hundred feet to the northeast of the main shaft. Ot prospect pits were also observed nearby. No development was be carried on at the time of the writers' investigation and consequ no examination was made of the underground workings. Howe

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THE KING-OF-THE-HILLS GROUP

The location of the King-of-the-Hills Mine is at the head of Oak Leaf Canyon, immediately north of the Major Fault group of claims. See Figure 2.

The owners, Roy Harris, Tom Harris, Collis A. Huntington, and associates, control 22 claims known as the King-of-the-Hills group.

Development of the property during World War I had been extensive. Approximately 3000 feet of underground workings are present, of which a portion is still accessible by means of the adit entering at the bottom of the steep face of the hill at the head of Oak Leaf Canyon. The early development was done by A. T. Burton and R. H. Strickland in search of copper, gold and silver. It is reported[1] that although high assays were often obtained, the ore was too "spotty" to justify commercial shipments. During the mine's activity, tungsten was not recognized in the ore, but the presence of scheelite in boulders on the dump has been recently discovered in such amounts as to indicate the possibility of commercial ore.

The present owners contemplate reopening the mine and exploring the old workings for tungsten ore-bodies.

The country rock in the vicinity of the mine differs but little from that of other parts of the range already discussed, being limestones metamorphosed by the intrusive. However, no prominent tactite zones were observed by the writers such as are present on adjoining properties previously described. The dominant structures strike north 35° east and dip steeply to the southeast. A fine-grained intrusive, tentatively regarded as a rhyolite, extends as a tongue-like apophysis to the southeast, from the main east granite body to the west, cutting the sedimentary series.

The structure is significant. The apophysis, almost at right angles to the main intrusive, appears to have formed a sharp angle along which mineralizing solutions ascended north of the rhyolite dike and locally replaced the adjacent limestones. The strength of the mineralization, however, seems to have been insufficient to develop a large commercial copper deposit. Whether the solutions were stronger in tungsten remains to be proved by further development.

The scheelite is apparently associated with the copper ore zone and also a hematite-rich ferro-magnesian rock which was noted in abundance on the dumps and is reported to occur in considerable quantities underground.

THE OAK BASIN GROUP

The location of the Oak Basin group of claims is in Oak Basin, the next drainage channel north of Oak Leaf Canyon. See Figure 2. The property is covered by four unpatented claims owned by Ambrose McGarry and Mason B. McLaughlin, who leased the property to

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[1] Verbal communication with A. T. Burton, Salt Lake City, Utah.

Hartley G. Dewey. Because the property was not visited by writers, no definite statements can be made regarding the tun occurrence. As scheelite is reported in tactite zones, it is assum that the property does not differ in mineralogic character from th previously described. Reportedly, good ore has been exposed on surface, assaying from 0.68 to 1.34 per cent WO_3. A tunnel has b started below the surface exposures to intersect the ore-zone at de

THE BURNT HOLLOW GROUP

The location of the Burnt Hollow group is high on the nor eastern slopes of the Mineral Range. The main workings are confi to the ridge immediately south of the ravine of Burnt Hollow, east draining canyon a short distance north of Oak Basin. Th property is accessible by means of a dirt road which intersects th Mineral Range Access Road approximately ten miles north of th Pass Canyon road. See Figure 2.

The group consists of five full claims and two fractions, wh are owned by Ambrose McGarry, Mason B. McLaughlin, and Hartl G. Dewey, who have recently leased the property to H. J. Pott S. C. McBride, and S. S. Kitching.

The geologic setting of the Burnt Hollow group is in many wa similar to that at the King-of-the-Hills area. An intrusive rhyoli dike approximately sixty feet in thickness has invaded the sedimentar rocks in a northwest-southeast direction, (Strike N. 40° W. with a almost vertical dip). The intrusive being more resistant to eros factors than the adjacent country rock has resulted in a ridge o spur which extends down the eastern slope of the range separati Burnt Hollow on the north from Oak Basin on the south. Th sedimentary rocks of the immediate vicinity are limestones, in par metamorphosed. The tactite zones, consisting chiefly of the greeni contact minerals, roughly parallel the bedding of the limeston striking N. 20° to 25° E. with steep almost vertical dips. The clo relationship between the tungsten-bearing ore zones and the intrus body suggests that the latter was responsible for the mineralizatio and undoubtedly controlled deposition to a large extent.

Numerous float samples of quartzite are present in the tal mantel covering the ridge upon which the property is located, and reportedly the quartzite outcrops to the west in the higher portion of the range. In the hand specimen this quartzite appears simila to the material assigned by the writers as Tintic Quartzite of Cambrian age occurring in abundance on the western flank of the north end of the Mineral Range. There the quartzite is present as part of wha seems to be a large overthrust block which apparently rode ov Paleozoic limestones from a southwesterly direction. Because of the nearness of this area to that of known overthrusting, and also becaus of the stratigraphic position occupied by this quartzite with respe to the limestone members, there is strong indication that here too exist thrust conditions similar to those apparent on the northw quartzite may belong [illegible] thrust block

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The ore zone of the Burnt Hollow group is associated with the
rusive dike previously described under the caption "Geologic
ing". The upper shaft of the Burnt Hollow group has been sunk
acent to the dike. On the 100-foot level of the shaft considerable
elite is present in a tactite zone adjacent to the intrusive. On
150-foot level, scheelite is exposed in several drifts. The most
mising ore zone, however, is one which apparently parallels the
present on the 100-foot level.
Extensive underground development was performed (years ago)
quest of lead-silver ores. Reportedly the property had consider-
production in the above mentioned metals, but only recently
scheelite been found. The tungsten showings are the disseminated
of ore, fluorescing as small cream-colored scheelite grains embed-
in a somewhat limonitized tactite zone comprised chiefly of the
nish contact minerals.
The sedimentary rocks adjacent to the dike show evidence of
vement, in some cases severe, as fault breccia, gouge and slicken-
surfaces are not uncommon. Where the metamorphosed lime-
ne has been disturbed, open "water courses" containing stalag-
aragonite are present. The latter mineral fluoresces a light blue
or and is strongly phosphorescent. On the 100-foot level a strong
of cold air issued from one of these open channels. Apparently
close relationship exists between the silver-lead ore bodies and the
fissures for usually the latter contain limonite and occasionally
matite and possibly magnetite. The writers were informed that these
es contained varying amounts of silver and lead. Close inspection
hand specimens indicate that whatever silver-lead minerals are
sent, most of them exist in a highly oxidized form. Galena, the
sulphide has been found.
Another shaft some fifty feet in depth, located southeasterly
the above described shaft, also contains scheelite. It was not
mined by the writers. Because the upper shaft is located on the
of a ridge, a tunnel was driven to intersect the silver-lead ores
depth. The original work progressed to approximately 100 feet.
this point, the present owners plan to continue development
the tungsten-bearing ore-zone is encountered. By such a pro-
re, the adit will intersect the upper shaft at the 150-foot level,
eby eliminating hoisting costs. The ore may be classed as
ginal, as is usual in deposits of this type, but inasmuch as the
promising showings appear to be continuous from the 100- to
150-foot levels, indicating that the ore zone has definite trends
ch, under the contemplated method of mining can be opened
not too great a cost, further development is justified.

2 R's GROUP

The location of the 2R's group is on the apex of a prominent
southeast 3.8 miles by road from the Pass Canyon road on the
side of the Mineral Range. See Figure 2. The dirt road from
Pass Canyon road to the 2 R's claims is locally known as the
Boy road. It also serves other mining prospects nearby. The

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town of Milford lies approximately ten miles by road to the northw from the property.

Ownership of the 2 R's group is invested in Reese Griffiths Ralph Meyers of Minersville. The property controlled consists of f full unpatented claims: 2 R's, 2 R's No. 1, 2 R's No. 2, and 2 R's No. so arranged as to completely cover the ridge containing the tungs deposits. The block of ground is 1200 feet wide and 3,000 feet lo with the long direction approximately east-west. The property w discovered and located by Reese Griffith in 1940 and production date amounts to seventy tons of ore shipped to the Segerstr mill at Milford in the summer of 1942. The shipment averaged 0.5 WO_3.

The rocks in the immediate vicinity consist of both igneous and sedimentary varieties. From the information obtained by the writ during the inspection of the property, the sedimentary strata exist a roof-pendant in the Mineral Range granite. The contact betw the sedimentary rocks and the intrusive is well exposed on the property at several points, and may be traced over an irregul pattern from the open-pit down the ridge to the south and al along the ridge to the east. The limestones which have been litt affected by the intrusion of the granite body are bluish in color and weather to a drab gray. Several hundred feet to the east of the open pit a small outcrop of reddish quartzite was observed. Its stratigrap position with reference to the limestones was not positively dete mined, in fact, the age of the limestones can only tentatively be co sidered as Paleozoic. A careful search for fossils was made, but no were observed. Because several remnants of limestone exist near the property at a much lower elevation, minor faulting may be present or an irregular assimilation of the sedimentary rocks by the granit mass may have occurred.

Development of the property consists of several open-pits and a series of trenches. The largest open-pit, approximately 20x10x1 feet in length, width and depth respectively, is located on the north side of the ridge and has yielded the seventy tons of ore, thus far produced. A short distance to the north and at an elevation som fifty feet below the open-pit is a short tunnel which also contains some scheelite.

The ore deposits of the 2 R's claims consists of soft decompos tactite rock varying from green to brown in color. Some of the tactit is a hard massive variety; especially that out-cropping to the south from the main open-pit. The scheelite occurs as small crysta disseminated throughout the tactite. Under the ultra-violet ray they fluoresce a cream color. The tactite exposed in the open-pit was "lamped" exhibiting scheelite crystals as described above. Consider ing this area from the standpoint of an ore body, the tenor of the ore would probably be marginal but consistent for the scheelit crystals are distributed very uniformly throughout the rock mass Associated minerals in minor amounts consist of fluorite, malachite and serpentine.

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Limestones, immediately above the open-pit, strike N. 30° E. and dip 60° and less to the southeast. The tactite zone has an apparent parallel position with reference to the roof of the intrusive and oblique in reference to the sedimentary beds. In most instances, the tactite zones examined thus far in the Mineral Range have paralleled or roughly paralleled sedimentary bedding planes. A number of incipient joint planes, some of which show movement and are filled with reddish gouge material, strike almost east-west and dip at varying degrees to the south. These measurements were taken in the open-pit and apparently the tactite zone follows the slope of the periphery of the intrusive. The dip, as measured here however, may not remain consistent, for if the tactite zone does exist under such conditions, it may vary considerably even in limited local areas. In general, however, there is evidence to confirm the southward dip of the tactite body as both the tactite zone and the intrusive can be traced dipping in this general direction from the north side of the ridge at a high elevation to the south side at a much lower elevation.

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CREOLE MINE

The location of the Creole Mine is approximately five miles to the northeast from Minersville, Beaver County, Utah. The property is situated on the south slope of a resistant knoll which is part of the southern foot-hill extension of the range proper. To the west is the drainage channel of this area, heading almost to the Pass Canyon region to the north. A short distance to the southwest is the old Lincoln Mine, one of the first developed mineral deposits in the State of Utah. During the early Mormon settlement of Beaver County lead ore was obtained from the Lincoln Mine and some bullion utilized in the making of bullets.

A dirt road in good condition, connects the Creole Mine with Minersville.

Ownership of the Creole Mine is invested in the Croff Mining Company which has had control for many years. The Nevada-Massachusetts Company acquired a lease on the property in 1942 for the purpose of developing tungsten ore, but activity ceased in the summer of 1943.

The property was located by Ben L. Croff prior to 1900, at which time the quest was for lead-silver ore. Later the mine was worked chiefly for copper. Although the tenor of the ore obtained by the early operators is not known, a large tonnage of material must have been mined and shipped, as indicated by the extensive underground workings and comparatively small amount of "dump".

The geologic formations in the immediate vicinity consist of metamorphosed limestones and shales, and intrusive granite rocks. The localized but main granite mass lies southerly from the main workings although a portion of the granite is exposed in the main adit near the portal. Contact metamorphism resulting from the intrusion of the granite has resulted in a huge contact zone. Although the bedding strikes approximately N. 20° W. and dips 40° to the northeast, the prominent, mineralized belt exposed on the surfa follows the east-west contact of the granite, with replacement ore-bearing minerals to the north along the sedimentary series. short distance to the east of the main workings a tongue of grani extends at approximately right angles to the north from the ma intrusive. This sill has been injected between the limestone strat is approximately fifty feet in thickness, and is flanked on either si by a hard resistant non-tungsteniferous garnetite. The age of t sedimentary rocks, according to Dennis[1], is Kaibab. To the east short distance is metamorphosed Moenkopi.

The mineralization of the Creole Mine is extremely interestin because of both the intensity and varied mineral content. Garne hematite, magnetite, limonite, pyrite, chalcopyrite, bornite, malachite, azurite, copper pitch, chrysocolla, scheelite, cerussite, galena, dendriti manganese, and manganiferous materials suspected to be wad, ar minerals present in the dumps and underground workings. Othe minerals associated with those listed above, obtainable in fine hand specimens, are opal, quartz, calcite, vesuvianite, tremolite, and green yellow, brown to black garnets.

The scheelite occurrence is confined to a limonitized contac rock, in many cases altered to a yellow gossan material, located approximately 100 feet easterly from the portal of the adit of th main workings. The scheelite occurs as (1) spotty high-grade "bunches" with individual crystals measuring an inch or more across and (2) disseminated small crystals following definite feeder channels. Measurements taken of the oxidized tungsteniferous tactite showed the ore zone to be variable in strike and dip, but the general trend approximates a strike of North 10° W. and dip 45° to the northeast. The latter being a rough equivalent of the sedimentary series. The fluorescence of the scheelite is cream in color and although a careful lamping investigation was made no blue fluorescent scheelite was observed.

From observation, the scheelite ore body is confined to a relatively narrow zone and may possibly be in the form of a pipe-like body or kidney.[2] The area immediately to the east of the tungsten workings contained no scheelite with the exception of a trace noted in a shallow open-cut several hundred feet away. This is also true of the extensive underground workings located immediately to the west. Several hours were spent lamping this maze of drifts, stopes, etc., and even though most of this area is composed of mineralized tactite no trace of scheelite was observed.

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[1] Verbal communication with Eldon P. Dennis of the U. S. Geological Survey Ground Wate Division.

[2] Written communication from Nevada-Massachusetts Co.

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THE AMERICAN MINERALOGIST, VOL. 47, MARCH-APRIL, 1962

MINERALOGICAL NOTES

HELVITE NEAR BEAVER, UTAH[1]

C. L. SAINSBURY, *U. S. Geological Survey, Menlo Park, Calif.*

INTRODUCTION

Helvite [$(Mn, Fe, Zn)_4Be_3Si_3O_{12}S$] from the Miller mine was identified in 1956 by John Miller, a prospector from Beaver. In 1957 the writer mapped the workings from which the helvite was obtained. Further work on the specimens was deferred until 1960, and as no description of the deposit has yet appeared, it seems worthwhile to record briefly the geologic setting of the deposit and the *x*-ray data on the helvite. Very few published *x*-ray data for helvite are available.

LOCATION AND REGIONAL GEOLOGY

The Miller mine is about 14 miles from Beaver, Utah, on the west side of the Mineral Range. The property originally had been prospected for silver, and two shafts were sunk. Beryllium mineralization was recognized in the old workings by John Miller, who leased the property to interests in Los Angeles. During the work that followed, one of the old shafts was deepened and relagged, and a few trenches were excavated in alluvium nearby.

The country rock at the property consists of marble and tactite, both of which are intruded by granite dikes. Granite of the Mineral Range crops out a short distance east and continues eastward to form the core of the central Mineral Range (Earll, 1957). The shafts are sunk near the footwall of a granite dike, and drifts from the shafts penetrate the dike and several thin tactite bands.

The freshest dike rock consists of about 50 per cent quartz, 30 to 35 per cent orthoclase, and 5 to 10 per cent oligoclase; the remainder is a highly-birefringent mica, pleochroic in shades of greenish gray, and minor chlorite. The minor accessory minerals include magnetite, fluorite, and allanite(?). The dike and enclosing rocks have been irregularly argillized.

GENERAL OCCURRENCE OF BERYLLIUM MINERALS

Helvite and beryl occur in close proximity both in altered dike rock and in sugary-textured marble. Neither has been identified by the writer in tactite, although three samples of tactite gave strong beryllium lines with the flame spectrometer. The largest helvite fragments were ob-

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[1] Publication authorized by the Director, U. S. Geological Survey.

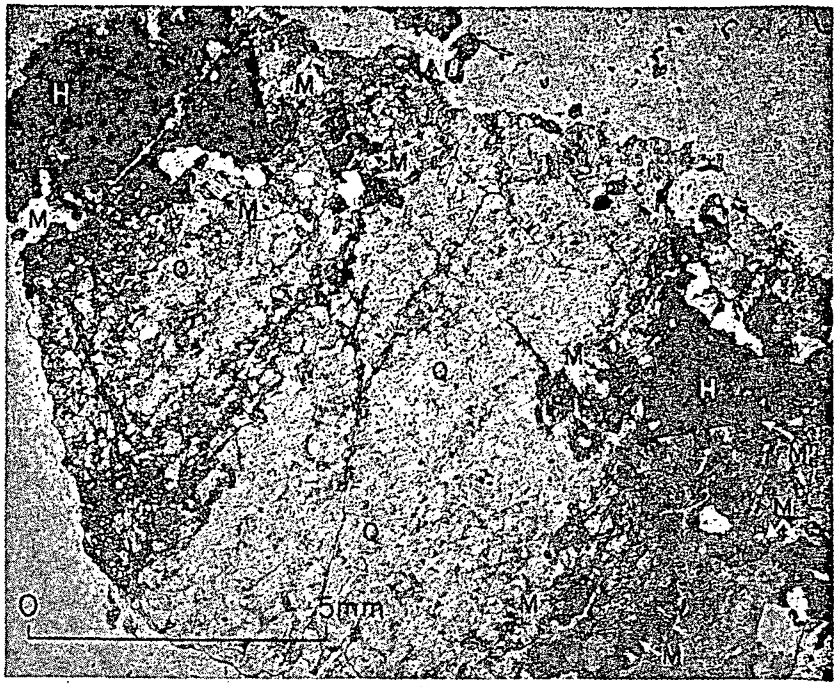

FIG. 1. Photomicrograph of helvite (H) in altered granite. Associated minerals are quartz (Q), and a highly birefringent green mica (M). Section also contains specks of galena, pyrite, magnetite, and fluorite, which are not marked.

tained from brecciated marble on the footwall of the dike, and beryl was found in close association. Helvite was obtained also from altered dike rock on the lowest level of the northerly shaft. The helvite is in parts of the dike that contain abnormal amounts of mica, a black uranium mineral, and such sulfide minerals as sphalerite, galena, and chalcopyrite.

Fluorite is common and at places constitutes several per cent of the rock. Topaz was identified in several thin sections, and magnetite locally is relatively abundant. Carbonate minerals are abundant throughout the altered dike. Secondary uranium minerals coat the fractures in the dike at several places. Argillic alteration is sporadic in both dike rock and limestone and has no readily apparent relation to the ore.

HELVITE

The helvite occurs as anhedral to subhedral masses as much as 1 inch long in both dike rock and in fractured marble. Vugs in the fractured marble contain minute grains of helvite. The helvite in altered dike rock exhibits a distinct preference for dark-green mica in replacement (Fig. 1).

TABLE 1. OPTICAL AND X-RAY DATA OF HELVITE FROM MILLER MINE

Optical properties: isotropic, n variable 1.72 to 1.75; absorption—none; pleochroism—none
x-ray diffractometer data (main lines)

d (Å)	I
9.935	4
3.678	4
3.363	100
2.60	12
2.20	15
1.94	30
1.68	3
1.455	4
1.415	2
1.373	3
1.272	4
1.124	3
Other lines too weak to be positively identified	

In one specimen of altered dike rock, helvite replaces carbonate formed from altered feldspar, and hence it appears that the helvite is later than the general alteration of the dike. The helvite is tawny-colored and the luster vitreous. It contains small grains of a black, opaque mineral, possibly magnetite, and locally small grains of glassy topaz.

OPTICAL AND X-RAY DATA

The pertinent optical and x-ray data of the helvite are shown in Table 1. The x-ray diffractometer pattern of this helvite is very similar to that shown by Neumann *et al.* (1957). The patterns of helvite from Iron Mountain, New Mexico (U. S. National Museum No. 104,724), and from Saxony were compared with that of the Utah helvite and found to be almost identical.

Several specimens of the Utah helvite were examined by x-ray fluorescence spectrometry; all gave strong peaks for iron, manganese, and zinc, indicating that it contains some of each of the three end members of the helvite group (Glass, *et al.* 1944).

CONCLUSIONS

The occurrence of helvite and beryl in a geologic environment similar to that of known deposits of beryllium minerals is of mineralogic and perhaps economic interest. Tactite and marble are extensively developed on the west side of the Mineral Range in this area, and beryl has been found in small amounts in both granite and small pegmatite dikes in the granite at scattered localities. The area seems to have escaped investigation in recent comprehensive surveys of beryllium (Warner *et al.*, 1959) and might warrant detailed examination to assess its beryllium potential.

ACKNOWLEDGMENTS

The writer is indebted to John Miller for his courteous help during the examination of the property and for his permission to publish this paper. Jewell J. Glass kindly furnished a specimen of helvite from Iron Mountain for *x*-ray study, and Professor Paul F. Kerr and George Megrue of Columbia University furnished a diffractometer pattern of helvite from Saxony for comparison. Their courtesy and help are gratefully acknowledged.

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THE AMERICAN MINERALOGIST, VOL. 47, MARCH-APRIL, 1962

JEŽEKITE IS MORINITE

D. JEROME FISHER, *Rosenwald Hall, University of Chicago.*

It is stated by Frondel (1947) that *x*-ray and optical study of morinite (presumably from Montebras, France) showed it to be identical with ježekite. This was confirmed by Fisher and Runner (1958), who however considered that the name ježekite should be dropped, since morinite has priority.

I have recently completed a detailed optical study of the two minerals, together with the Black Hills morinite, on the temperature-controlled spindle stage (Fisher, 1962); the results are given in Table 1. Precession *x*-ray pictures were also taken of the French morinite and of ježekite from the type locality, samples of both of which were supplied me by F. Čech of the Mineralogical Institute of Charles University (Prague)

CACTUS MINE DRILL CORE
BEAVER COUNTY, UTAH

MEMORANDUM TO FILES

Location: The Cactus Mine drill holes, a former porphyry Mo-Cu prospect of AMAX, are located in Sec. 3, 4, 10, T.27S, R13W. This is about 15 miles west of Milford Utah and about 24 miles due West from Roosevelt Hot Springs, Utah, in the southern end of the San Francisco Mountains.

Drill Core: Drill core from four drill holes totaled about 9,000 ft. The AMAX project ended in 1973. Mr. Harry Olson, Vice President Steam Reserve Corporation and former AMAX Geothermal Manager, Transferred the drill core to the Earth Science Laboratory, UURI, through the efforts of P. Mike Wright, in 1985. The drill core was picked up by David Langton, UURI, in September 1985, and maintained in the ESL/UURI - EGI Geothermal Sample Library until June 1999.

Drill Core Transfer to Utah Geological Survey: This drill core was transferred to the UGS on June 2, 1999, with one (original) set of supporting documentation, a copy of which is provided here.

Howard P. Ross 06/10/99

Howard P. Ross
Research Professor/Senior Geophysicist

October 8, 1985

Mr. Phillip M. Wright
University of Utah Research Institute
Earth Science Laboratory
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108

Re: Cactus Data
Beaver County, Utah

Dear Mike:

Sorry about the delay in getting this drill data from the Cactus Mine area for the core that I gave you last June.

As I mentioned, the Cactus files were never completed and as a project discontinued in 1973 and were dumped in dead storage.

I managed to find a map giving the locations of each of the four holes drilled. Holes DDH 520-1,2, and 3 were spudded in with a diamond drill. Hole DDH 520-4 was spudded in with a rotary rig using a 5 inch hammer to a depth of 355 feet. From that depth of the total depth the hole was drilled with a diamond core rig. DDH 520-3 is an angle hole drilled with a bearing of S78°W and a dip of -58° from the horizontal. All the other holes are vertical. Total drilled depth of the holes are as follows:

Hole	Total Depth in Feet
520-1	2975
520-2	2454
520-3	2777 (angle depth)
520-4	875

I couldn't find the lith logs for the holes but did find 100 foot assay composits for all four wells and 100 foot alteration composit diagrams for holes 520-1,2, and 3. As I remember, all four holes were drilled in the Cactus stock which is a Tertiary 39± mybp quartz monzonite (?).

Again I am sorry that I couldn't find more of the data, but I hope this will be of some use.

Hope to see you at one of the geothermal functions shortly.

Best regards.

Sincerely,

STEAM RESERVE CORPORATION

Larry

H. J. Olson
Vice President and Operations Manager

HJO/c

attachment

P.S. Mike I did find a lith log of DDH 520-4 which I am enclosing.

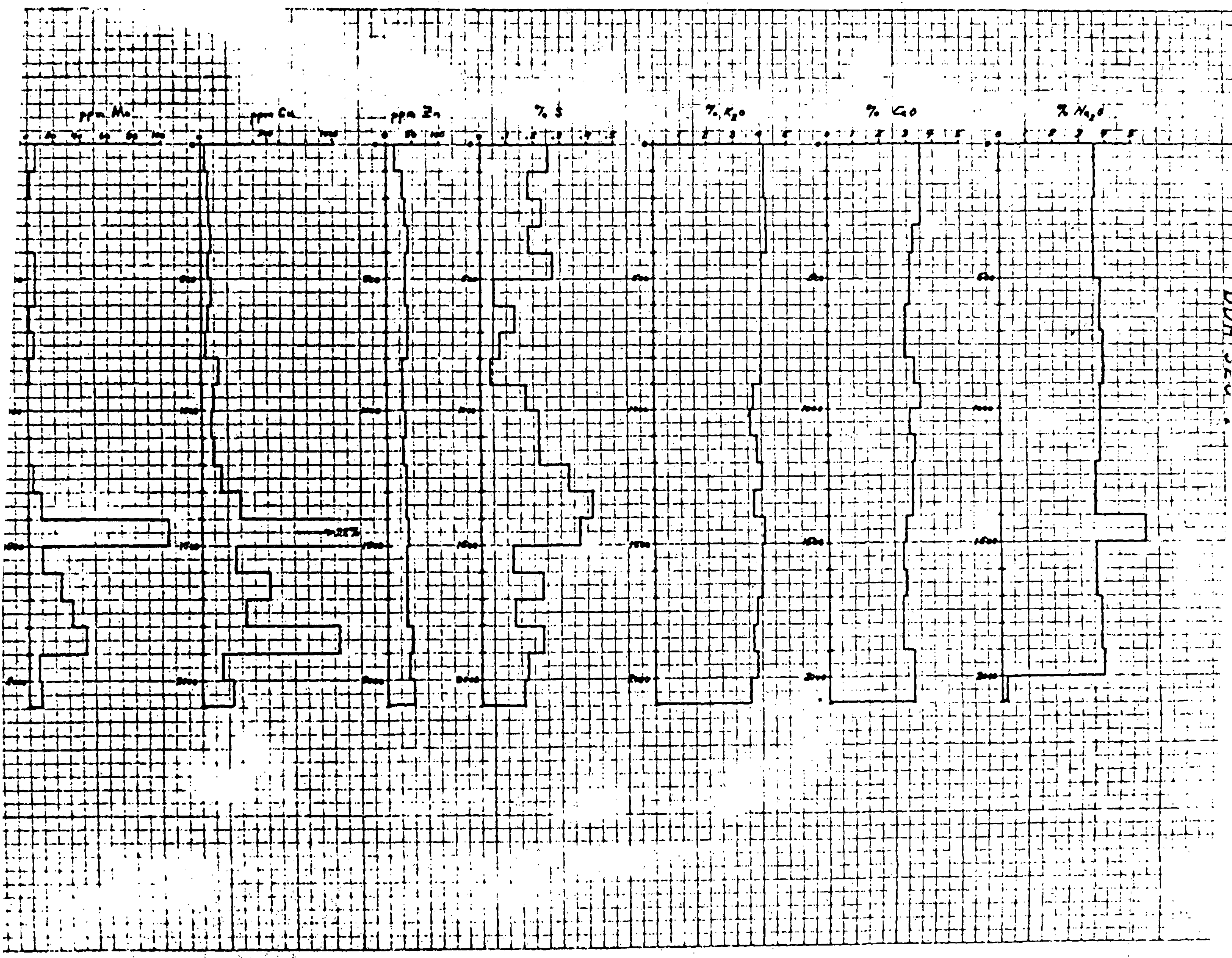
Cactus Peak Project

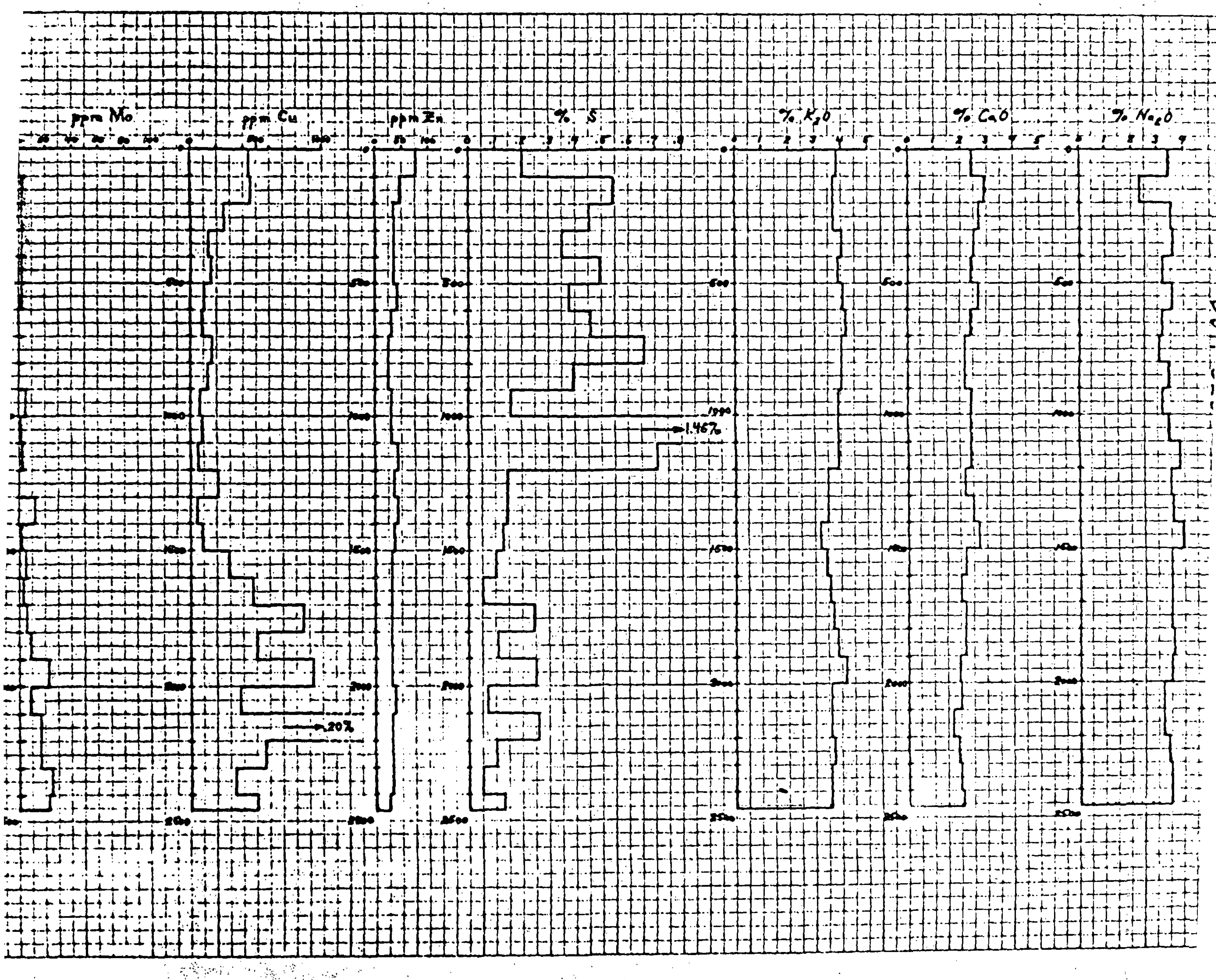
e Name	County	Location	Footage	Drill
20-1	Beaver, Co.	Sec. 3/T27S/R13W	0-2975 Core	Amo
0-2	Beaver, Co.	Sec. 10/T27S/R13W	0-2454 Core	Ama,
0-3	Beaver, Co.	Sec. 3/T27S/R13W	0-2777 Core	Amay
0-4	Beaver Co.	Sec. 4/T27S/R13W	0-875 Core	Amax

NOTE. These Sample were involved in a spill, That Lost all Sample Contents

	Footage
#80	713'-723'
81	723'-732'
82	732'-740'
84	748.5'-757'
85	757'-765'
87	773'-781'
89	788'-798'
91	807-815'
92	815'-824'
93	824'-833'
94	833'-842'
96	850'-859'
98	868'-878'
99	878'-887'
100	887'-896'
102	905'-915'
103	915'-924'
106	942.5'-951'
109	969'-978'
110	978'-988'
112	997'-1006'
113	1006'-1015'
114	1015'-1024'
115	1024'-1032'

Box Number	Footage
#117	1042'-1051
118	1051'-1060'
120	1069'-1078'
123	1096'-1105'
124	1105'-1113'
125	1113'-1122'
127	1132'-1141'
128	1141'-1150'
129	1150'-1159'


ppm Mo
0
20
40
60
80
100
ppm Cu
0
500
1000
ppm Zn
0
50
100
% S
0
.1
.2
.3
.4
.5
% K2O
0
1
2
3
4
5
% CaO
0
1
2
3
4
5
% Na2O
0
1
2
3
4
5
500
1000
1500
2000
0.25%


ppm Mo
20
40
60
80
100
ppm Cu
0
500
1000
ppm Zn
0
50
100
% S
0
.1
.2
.3
.4
.5
.6
.7
.8
% K2O
0
1
2
3
4
5
% CaO
0
1
2
3
4
5
% Na2O
0
1
2
3
4
500
1000
1500
2000
2500
1.46%
.20%


ppm Mo
0 20 40 60 80 100
ppm Cu
0 500 1000
ppm Zn
0 50 100
% S
0 .1 .2 .3 .4 .5 .6 .7 .8
% K2O
0 1 2 3 4 5
% CaO
0 1 2 3 4 5
% Na2O
0 1 2 3 4
500
1000
1500
2000
.11%

by M.H. Wesley & R.T. Klein

for Core Logging (DDH's 520-1, 2, & 3)

Alteration

+ = trace

++ = moderately abundant

+++ = very "

Vein Py, Mag & Tl

+ = < 1%

++ = 1-3 %

+++ = > 3 %

Dissem. Py, Cp, Mag, & mo

Tr = < 0.1%

For amounts greater than 0.1%, give estimated percent.

Vein Cp & Mo (molybdenite)

+ = < 1/2 %

++ = 1/2-1 %

+++ = > 1%

Items added by KPR during logging

1) Cp/Py ratio = estimates given as ratios : <1/10, ≤1/10, (≤1/7), ≤1/5, ≤1/3, ≤1/2, ~1 ≥1, ≥ 2, ≥ 3, ≥5, (≥ 7), ≥ 10.

2) Estimated total-sulfide content :

Low 0.0X%

" → mod "

mod → high "

High 0.0X → Low 0.X%

Low 0.X%

" → mod 0.X%

mod → high 0.X%

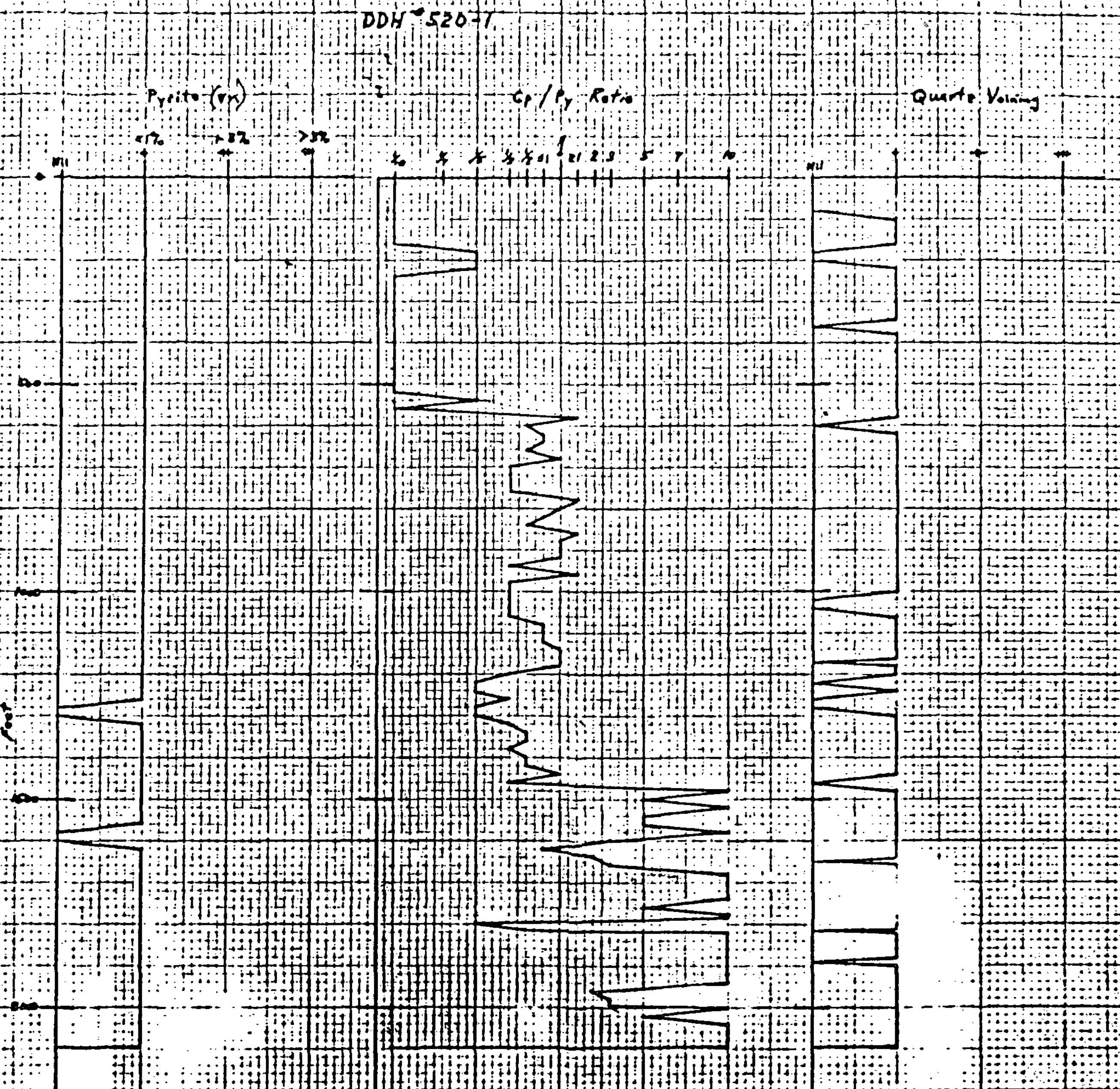
Values above high 0.X% as percent.

3) Qual → semi-quant estimate of breaking — refers to open fractures, strongly broken/clayey zones, and tourmalinized zones (± brec. also).

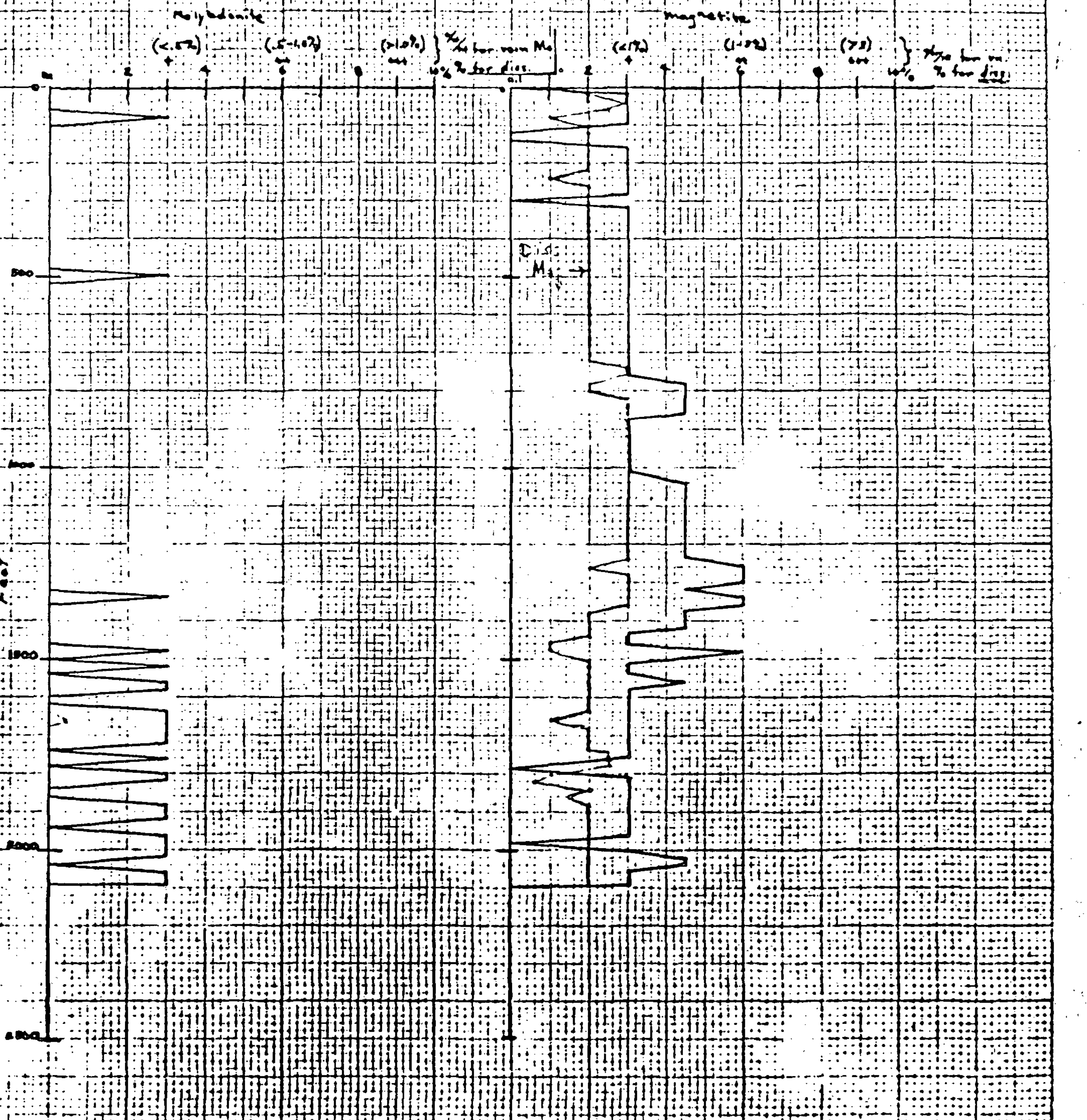
Sl → mod broken – sparse fracturing & jointing; est. < 3/ft or [illegible] 0.3 ft. avg.

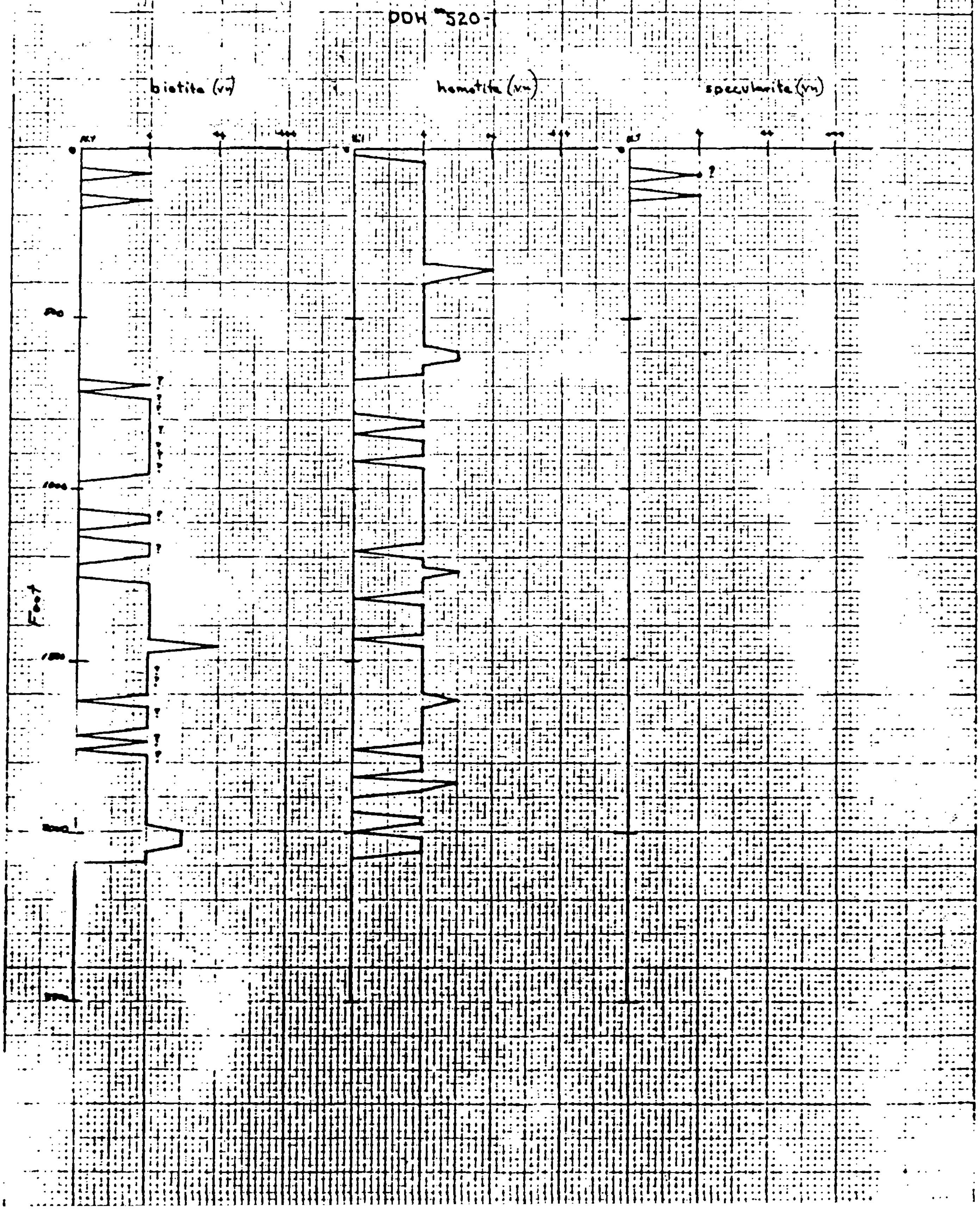
Mod → strongly " – est. 3-5 fract/ft

Strongly " – " 5-10 "

DDH #520-1
Pyrite (vx)
Cp/Py Ratio
Quartz Veining
Nil
<1%
+3%
>3%
1/10
1/5
1/3
1/2
1
2
3
5
7
10
Nil
+
++
+++
200
400
600
800
Feet

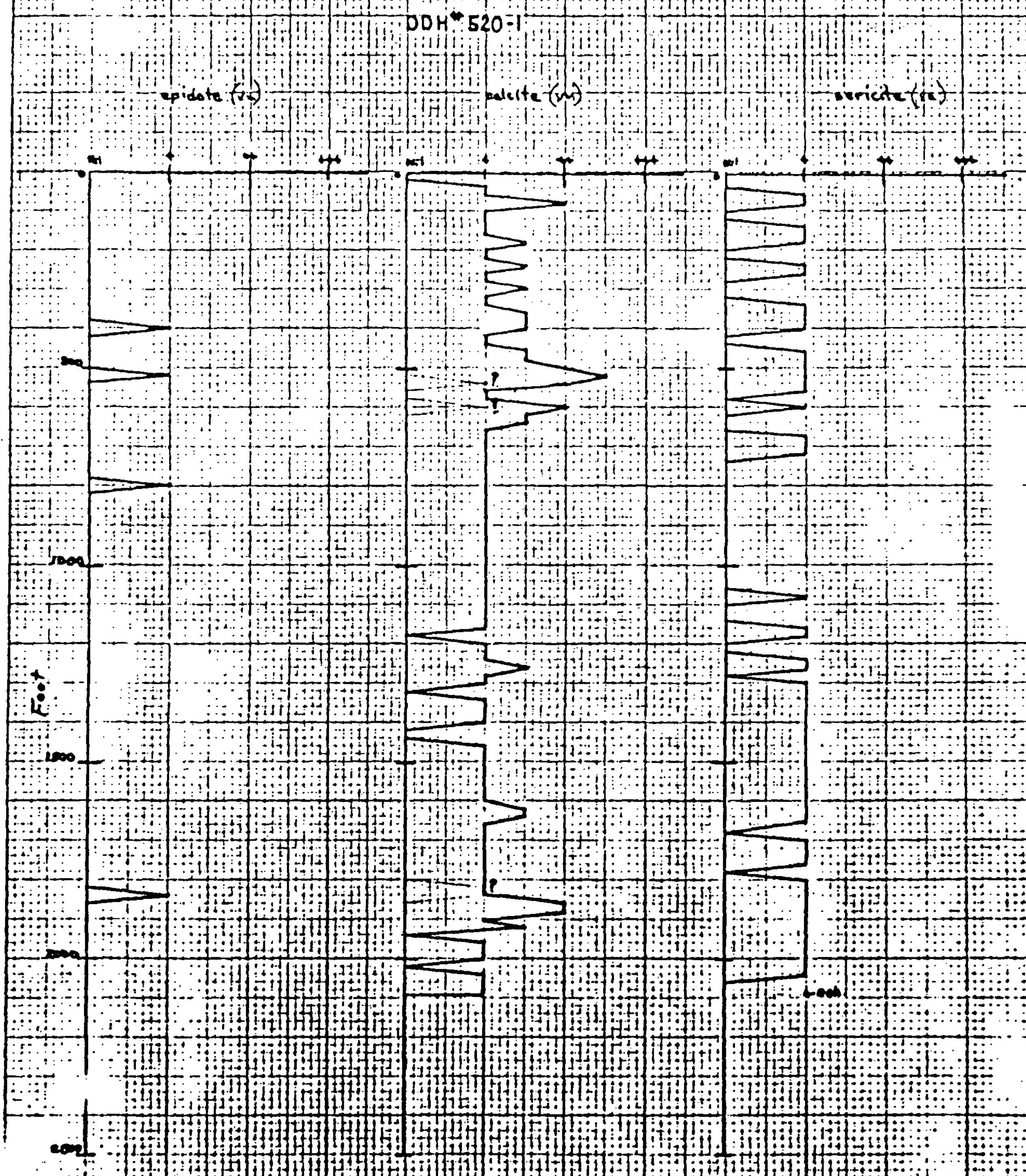
DDH # 520-1

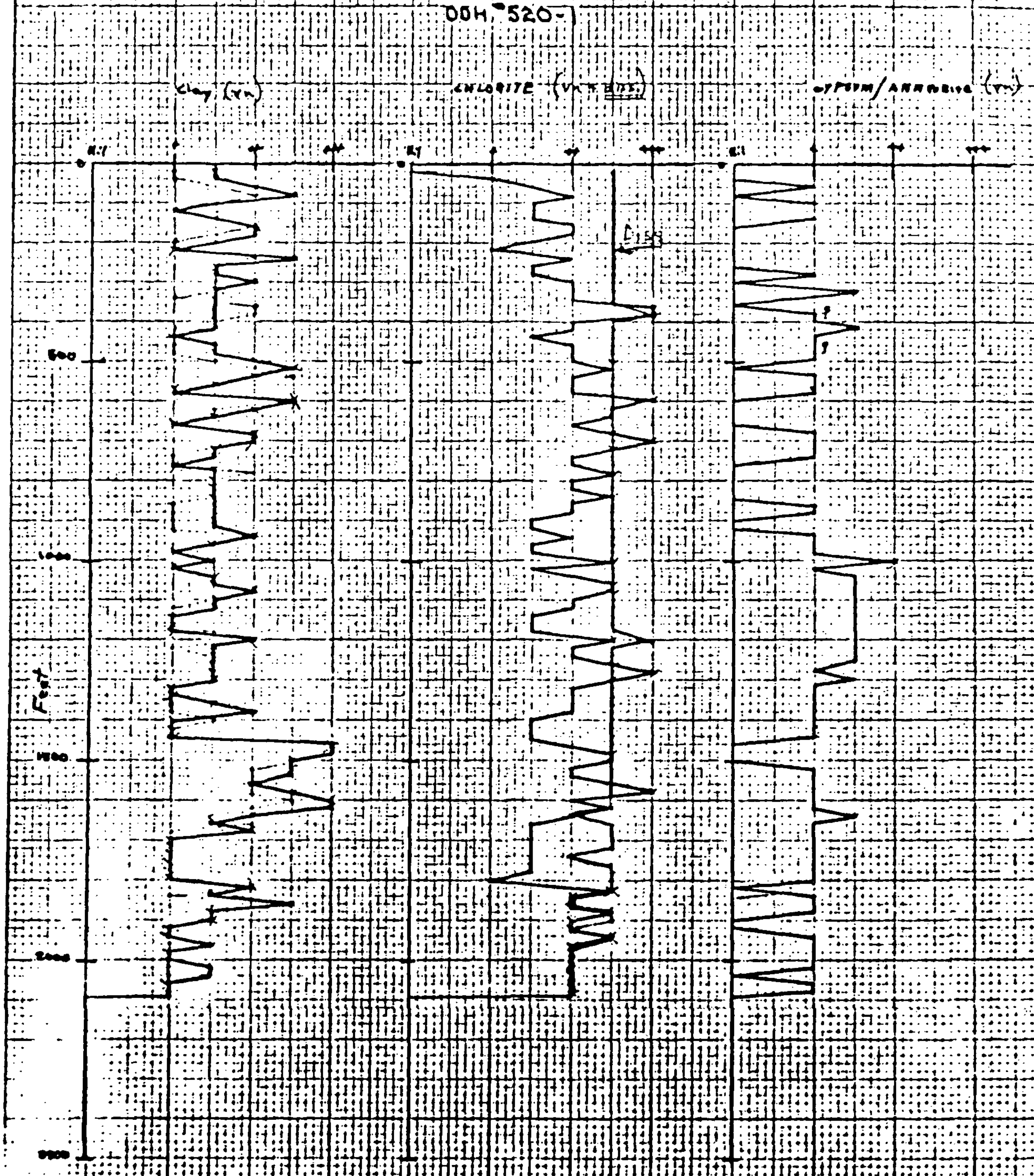

Molybdenite
(<.5%)
(.5-1.0%)
(>1.0%)
% for vein Mo
% for diss.
0.1
Magnetite
(<1%)
(1-5%)
(>5)
% for vn
% for diss.
0
2
4
6
8
10%
Diss.
Mt
Feet
0
500
1000
1500
2000
2500

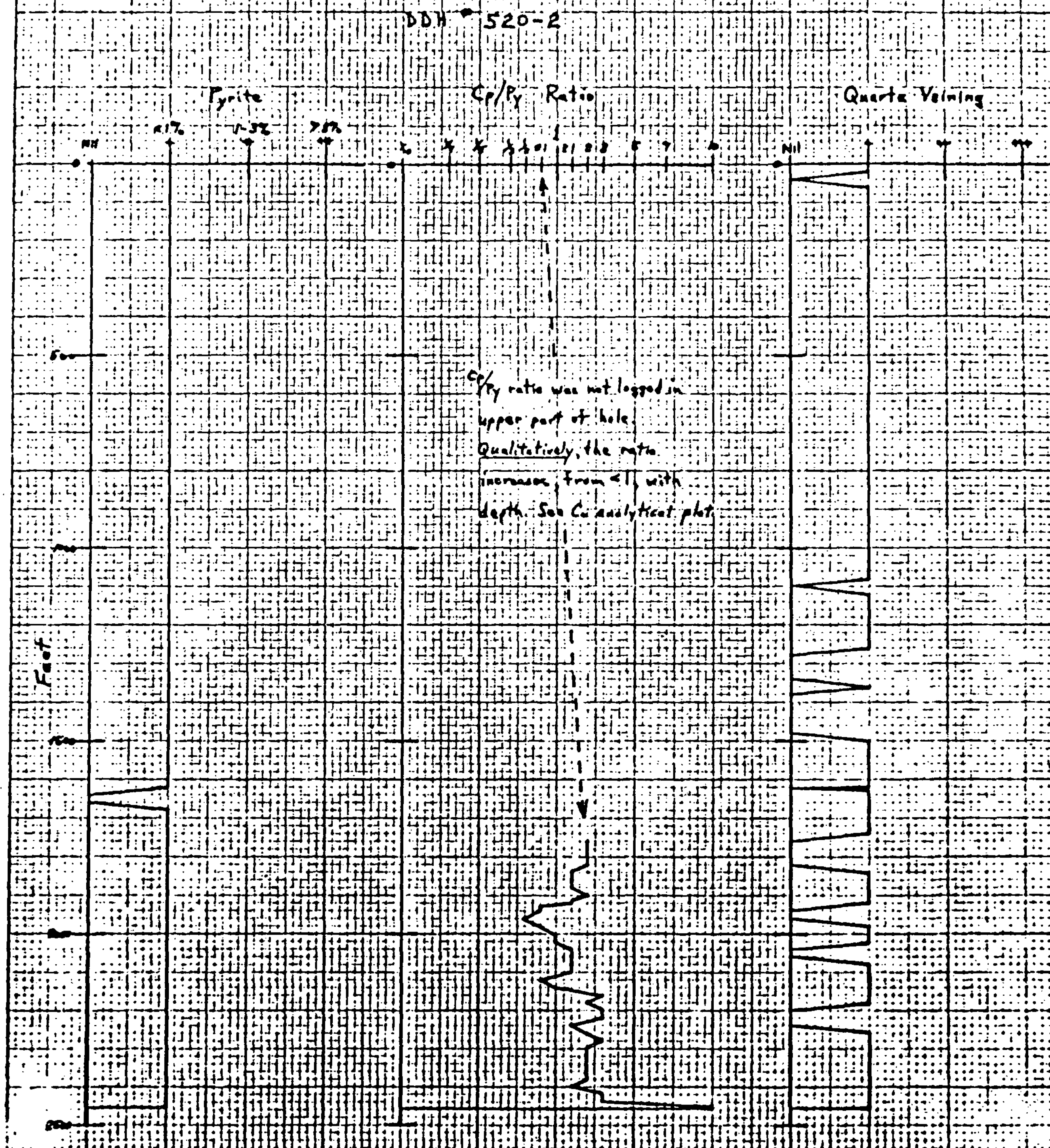


DDH #520-1

biotite (vn)
hematite (vn)
specularite (vn)
+
++
+++
?
500
1000
1500
2000
2500
Feet

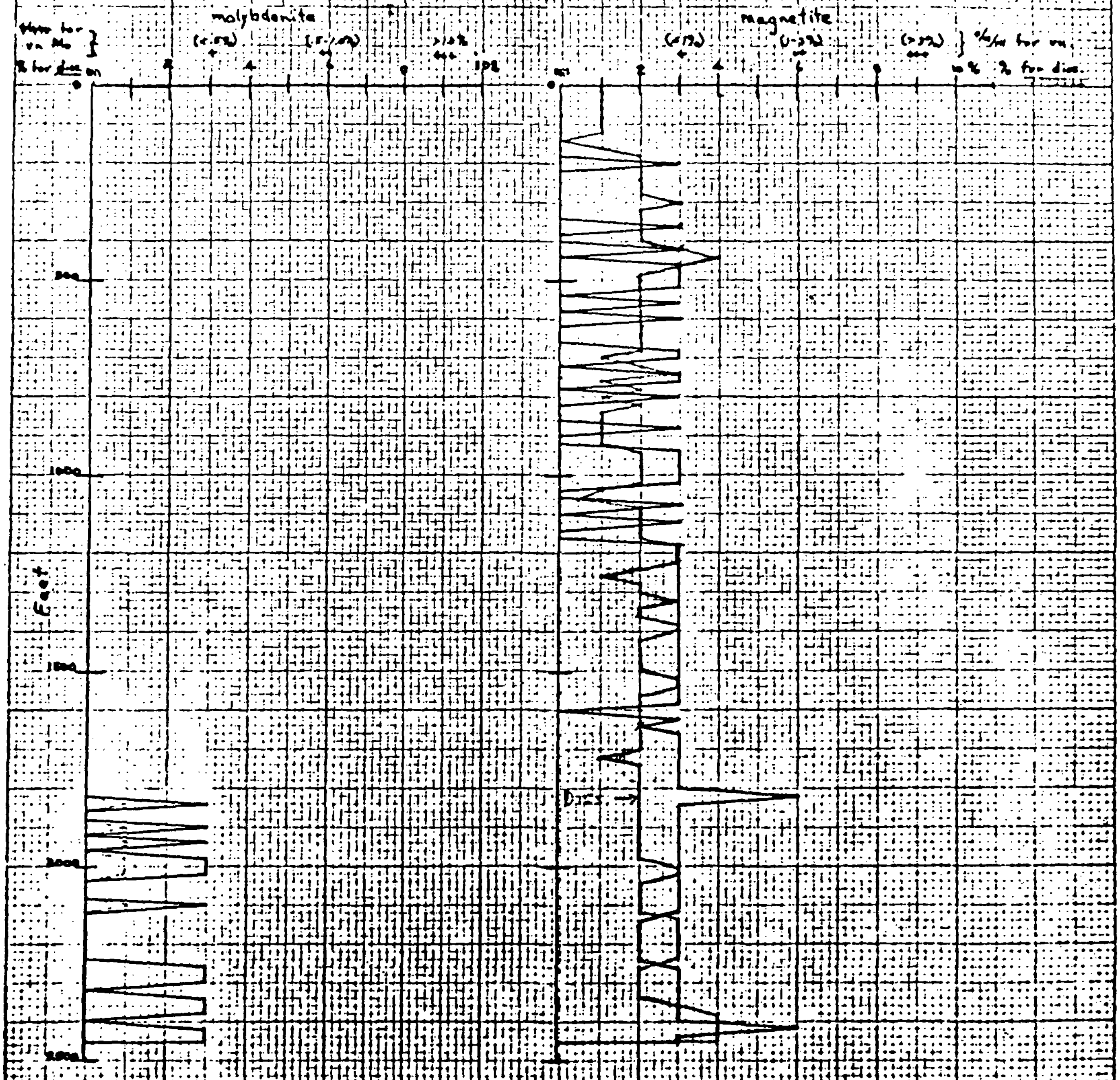

DDH# 520-1
epidote (vt)
calcite (vn)
sericite (ss)
nil
+
++
+++
500
1000
1500
2000
2500
Feet
?
?
?
e.o.h

DDH-520-1
Clay (Vn)
CHLORITE (Vn x 20%)
GYPSUM/ANHYDRITE (Vn)
tr
+
++
+++
Diss
500
1000
1500
2000
2500
Feet

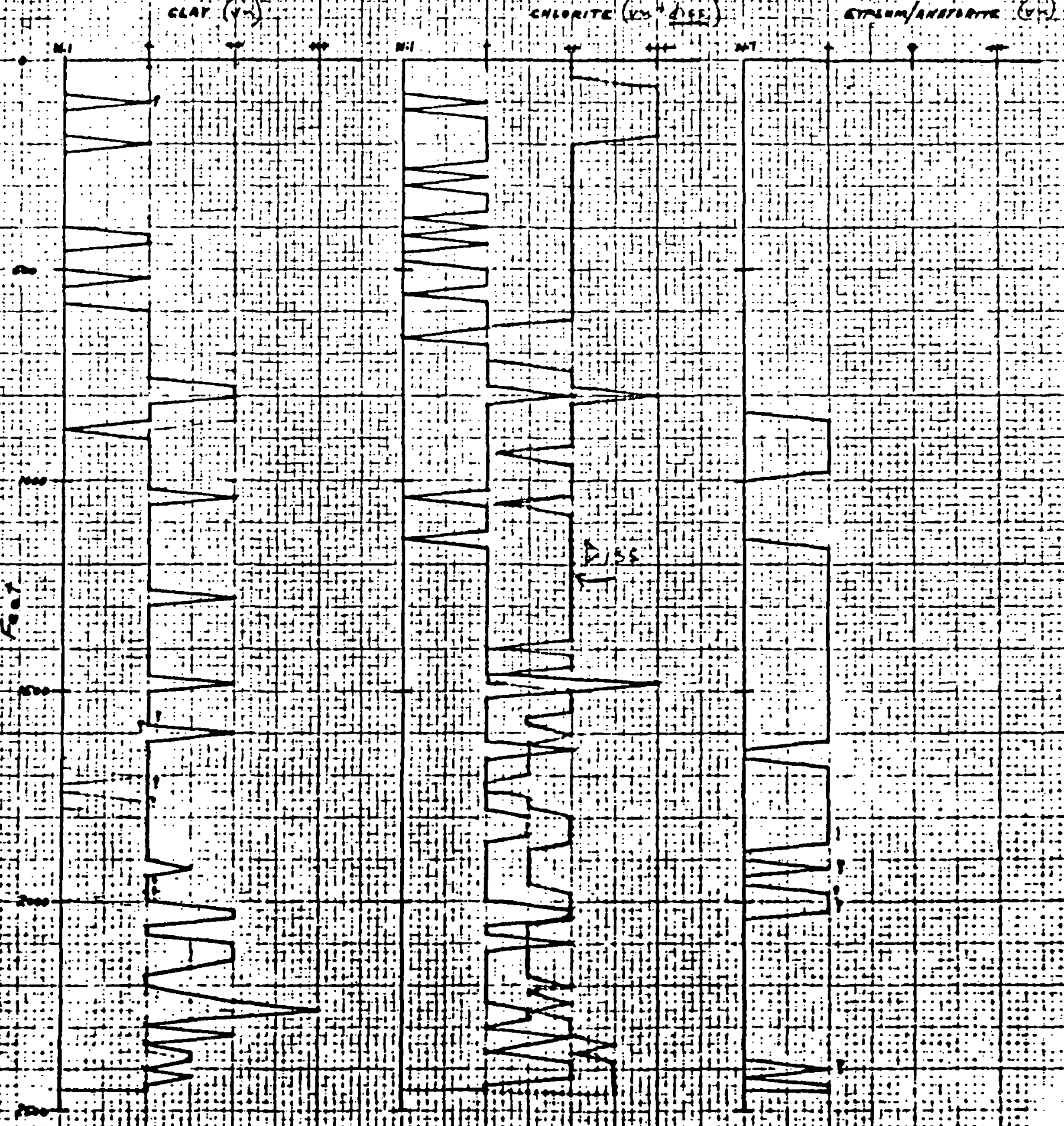

DDH # 520-2

Cp/Py ratio was not logged in upper part of hole. Qualitatively, the ratio increases, from <1, with depth. See Cu analytical plot.

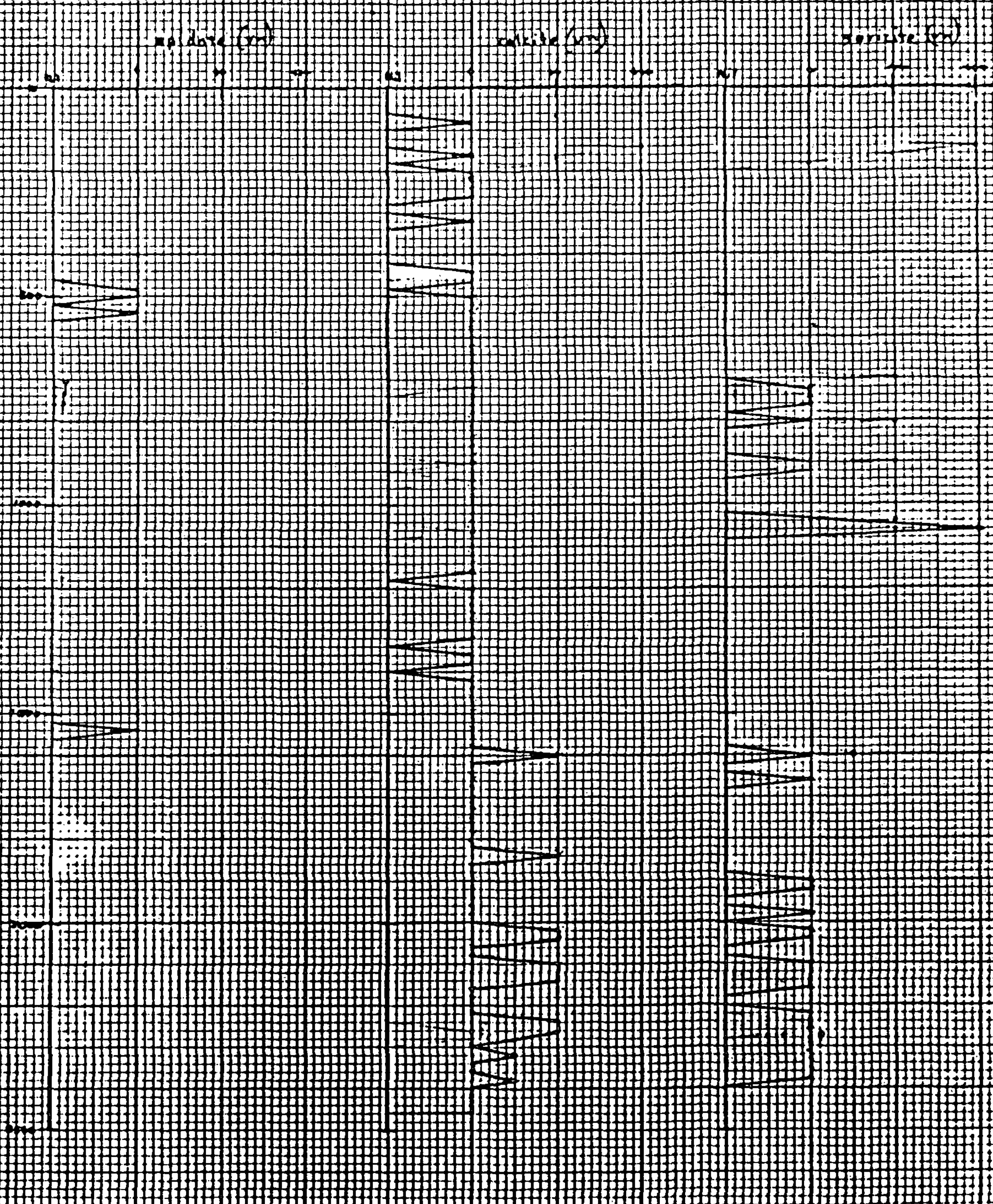
DDH - 520-2

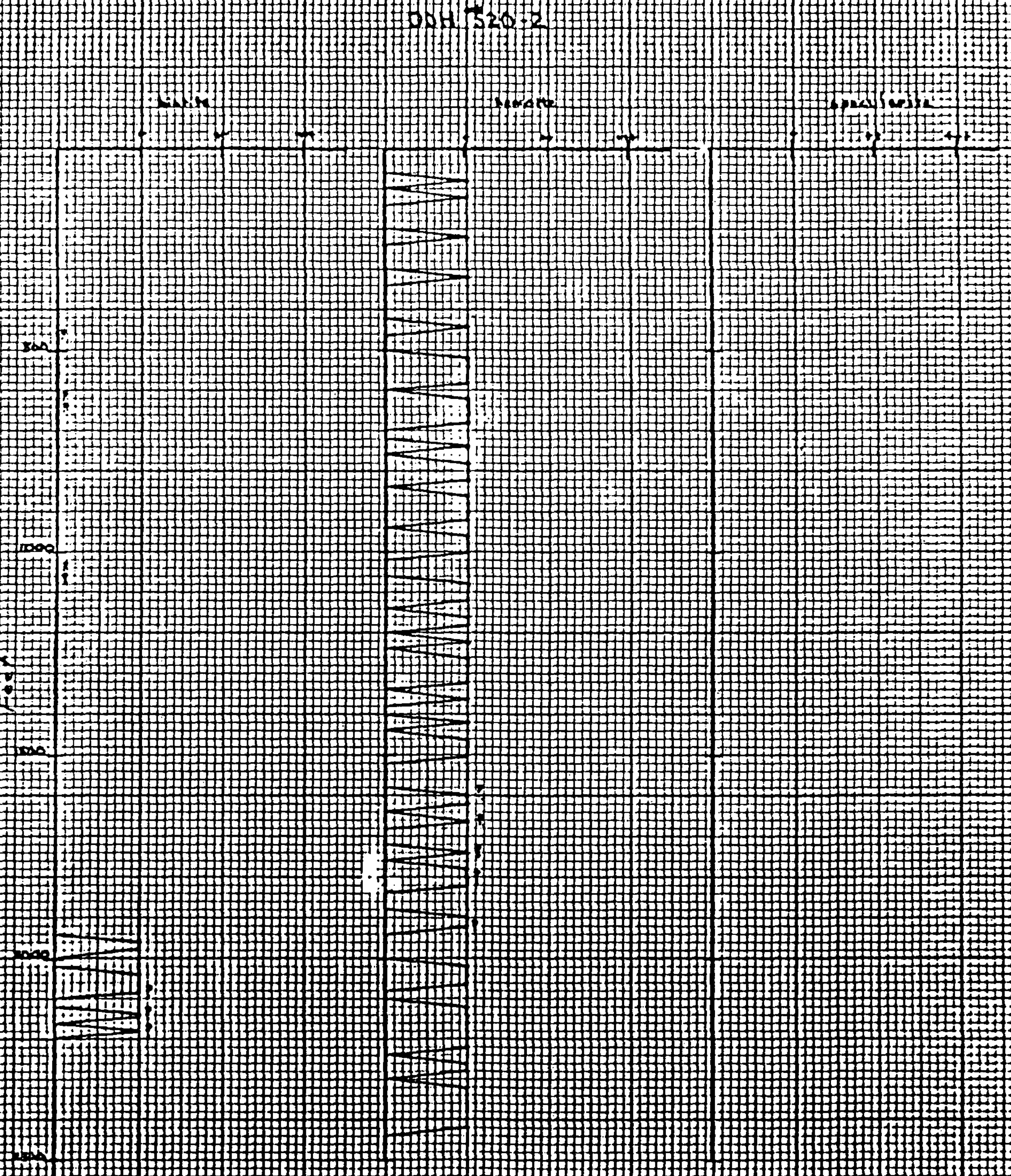

molybdenite
(<.5%)
(.5-1.0%)
>1.0%
[illegible] for
[illegible] Mo
% for diss. on
2
4
6
8
10%
magnetite
(<1%)
(1-3%)
(>3%)
% for [illegible]
10%
% for diss.
Feet
500
1000
1500
2000
2500
Diss

DDH # 520-2

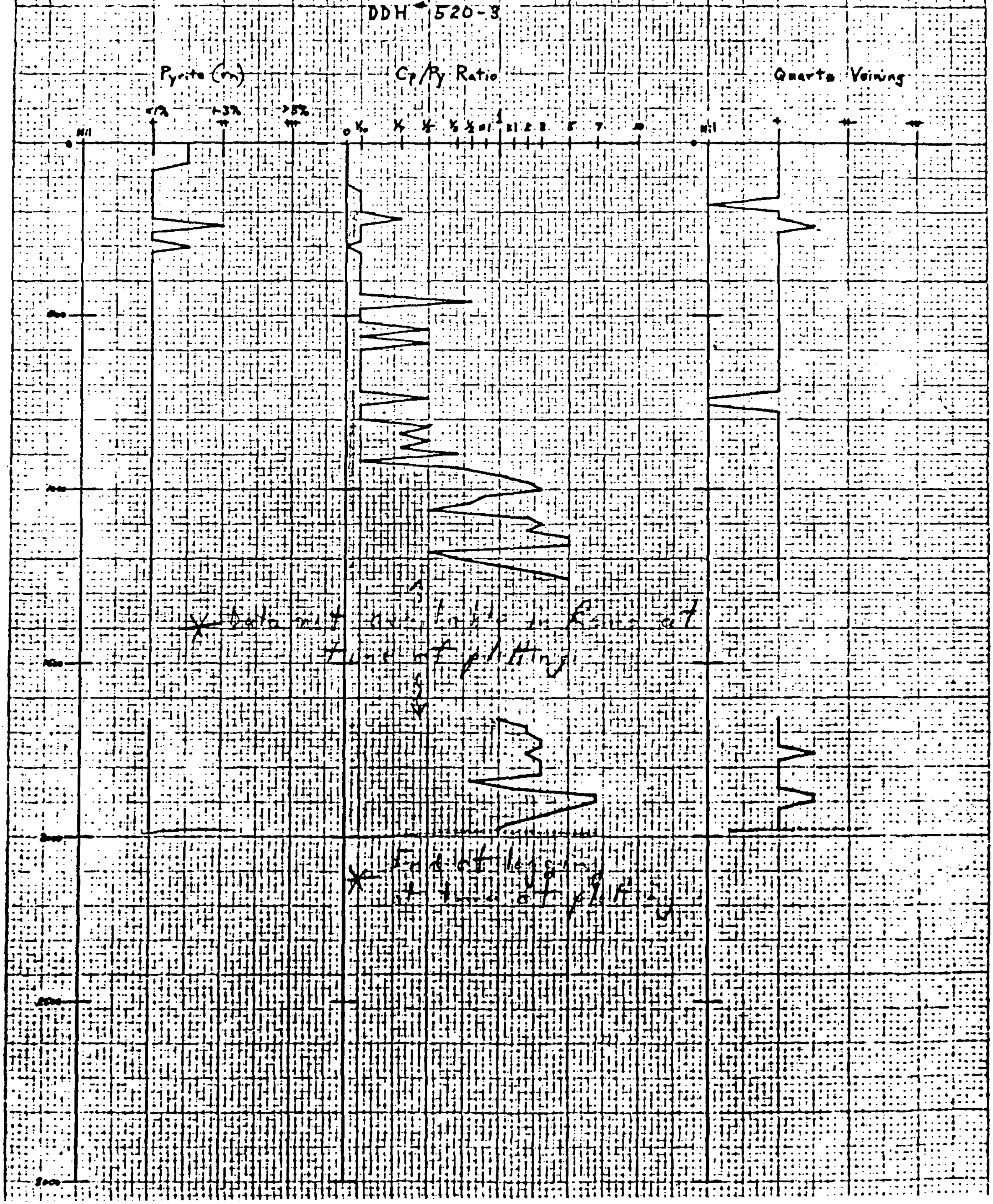

CLAY (VN)
CHLORITE (VN + DISS)
GYPSUM/ANHYDRITE (VN)
Nil
+
++
+++
Nil
+
++
+++
Nil
+
++
+++
0
500
1000
1500
2000
2500
Feet
Diss

DDH #520.2




DDH 520.2
500
1000
1500
2000
2500
Feet

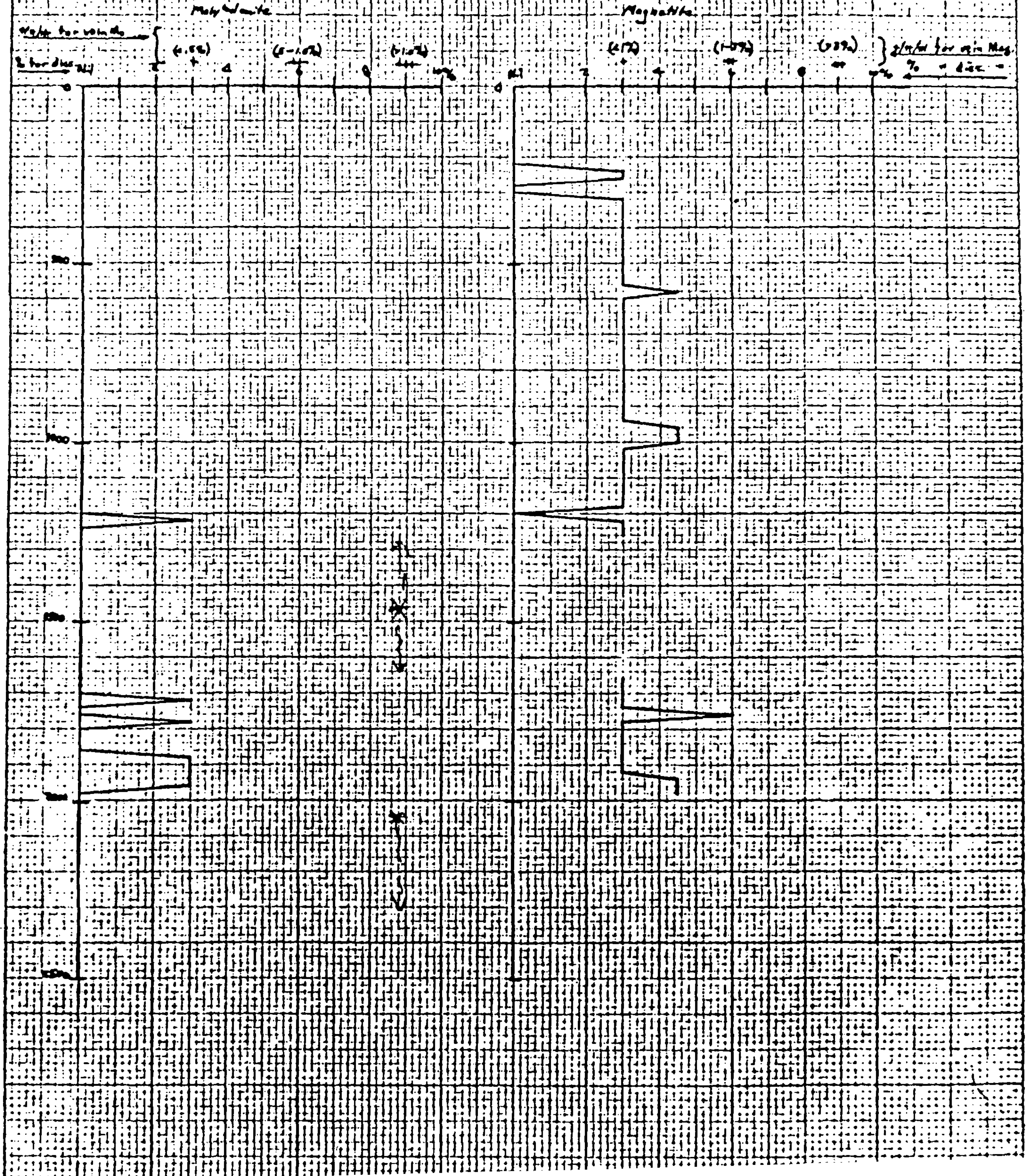
DDH 520-3



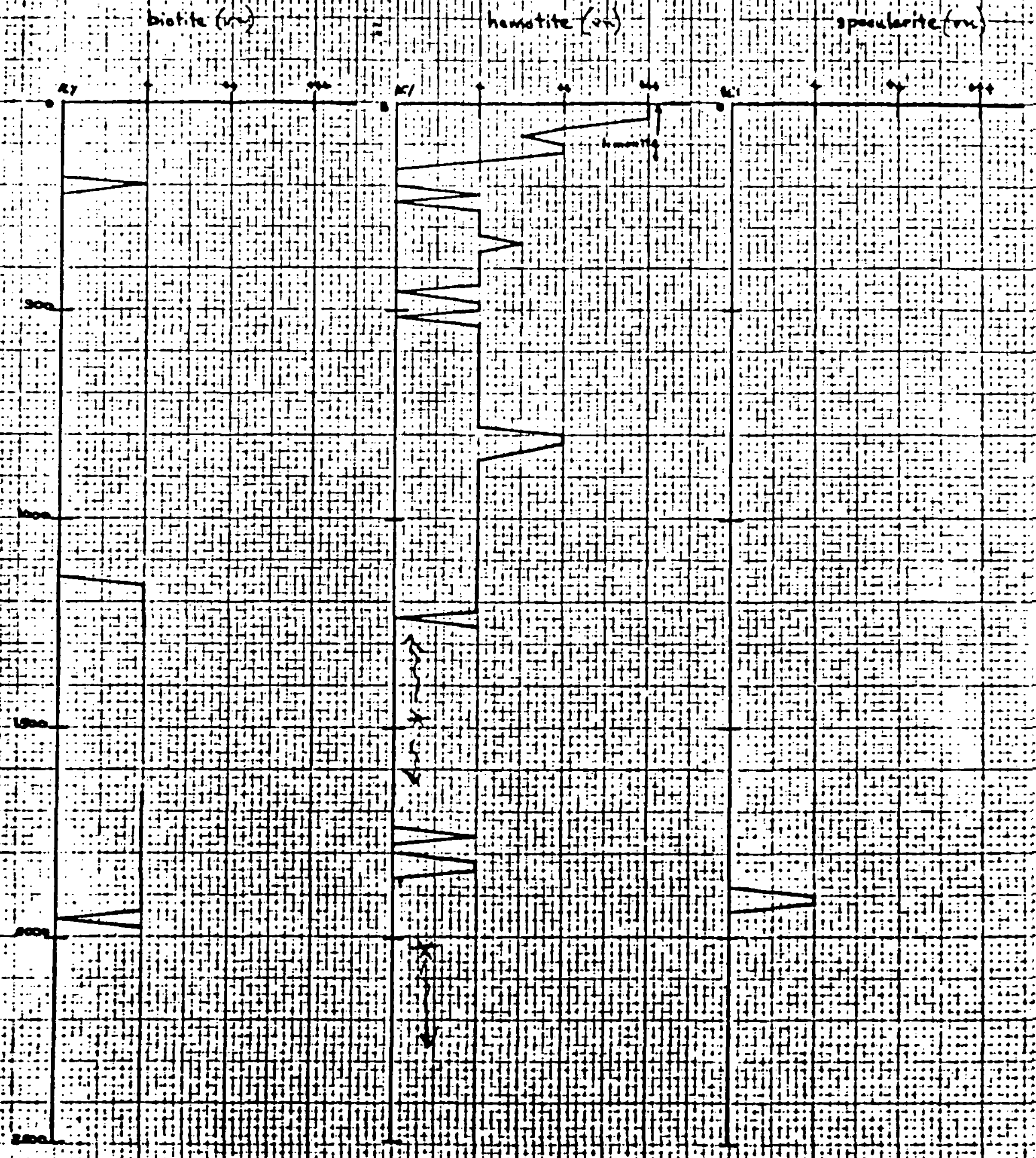
* Data not available at time of plotting

* End of logging at time of plotting

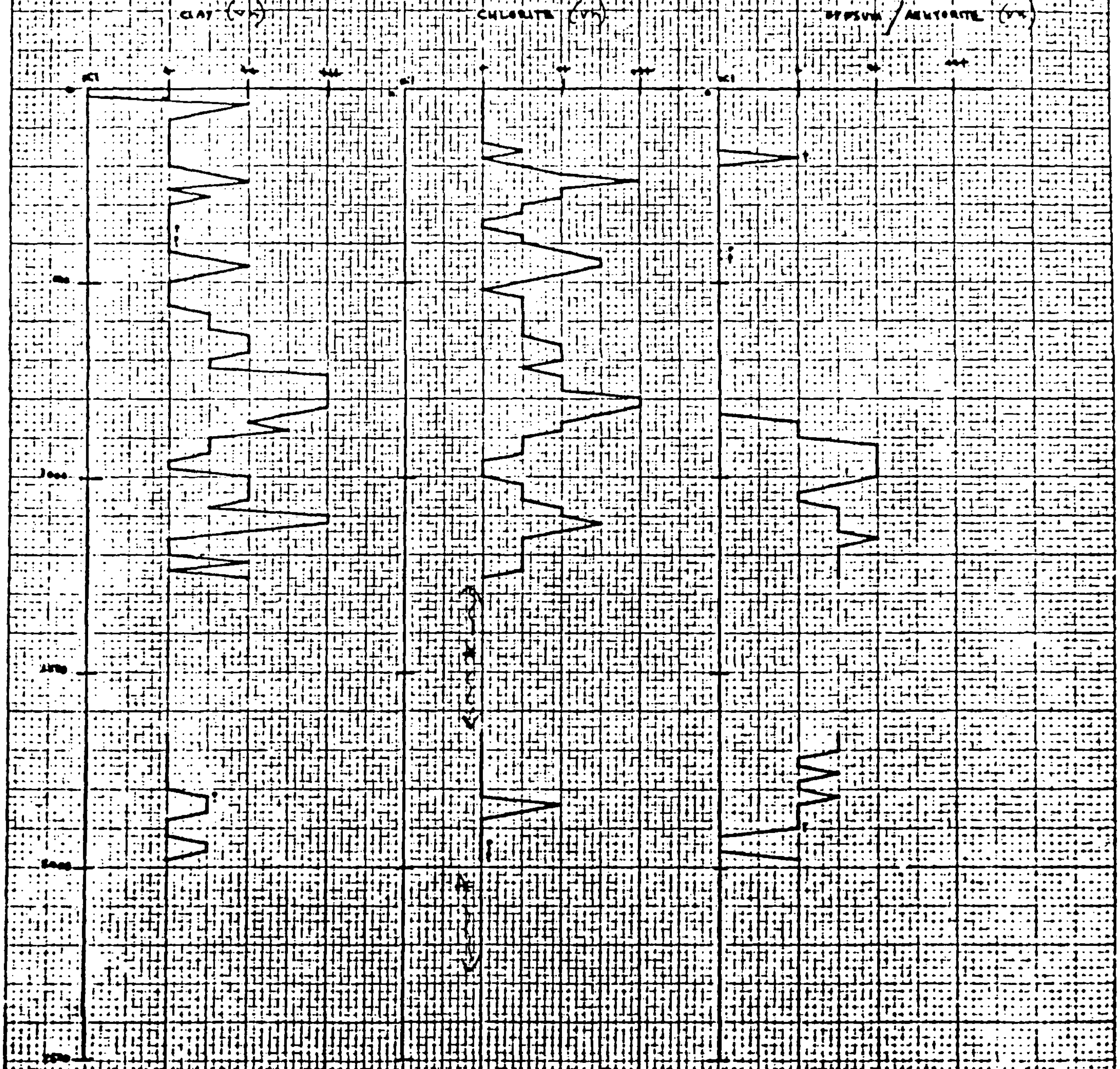
DDH # 520-3


Molybdenite
Magnetite
Visible for veinlets
% for diss. Nil
(<.5%)
(.5-1.0%)
(>1.0%)
0
2
4
6
8
10%
Nil
(<1%)
(1-3%)
(>3%)
Visible for min Mag.
% = diss. =
0
500
1000
1500
2000
2500

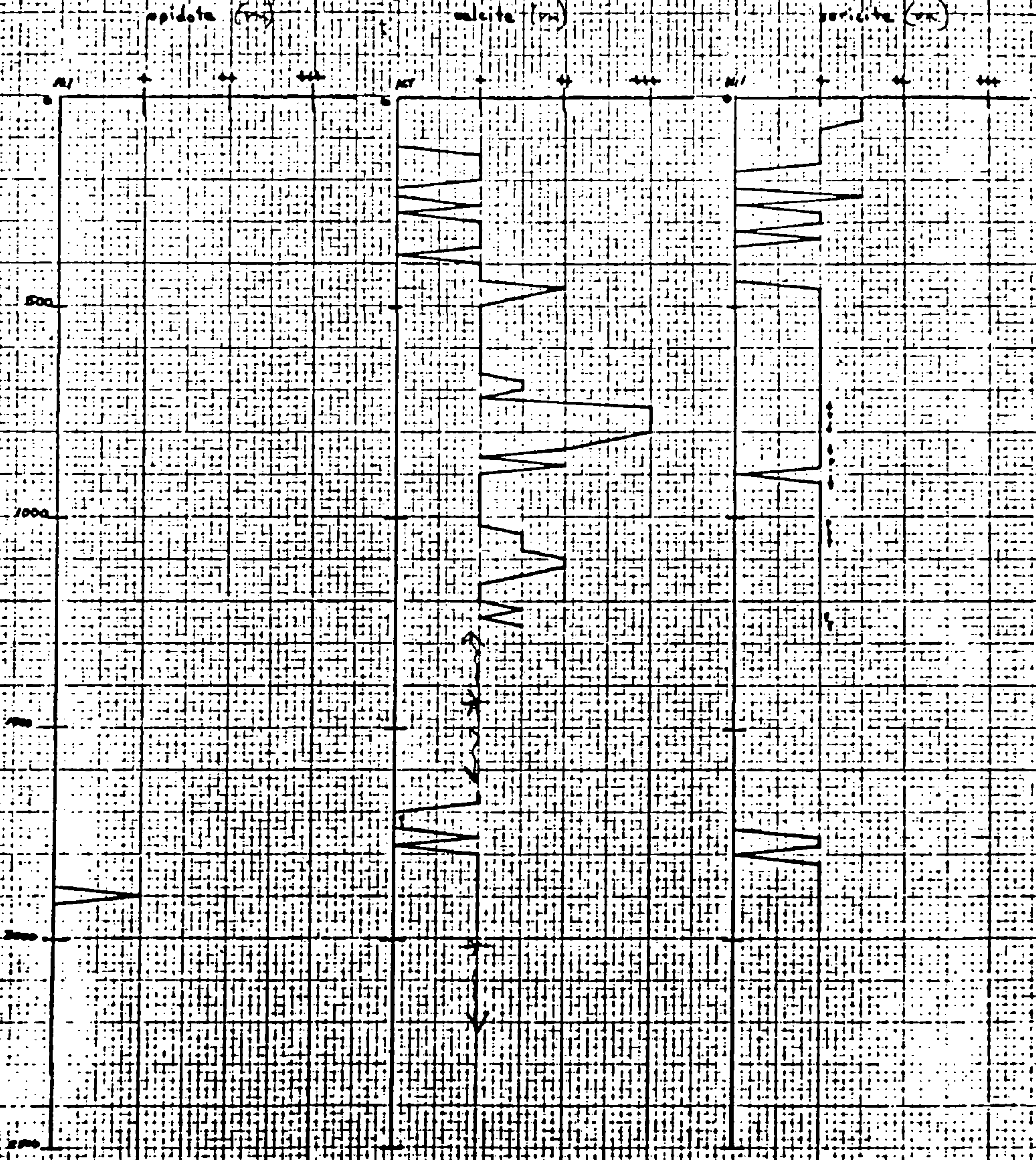
DDH # 520-3

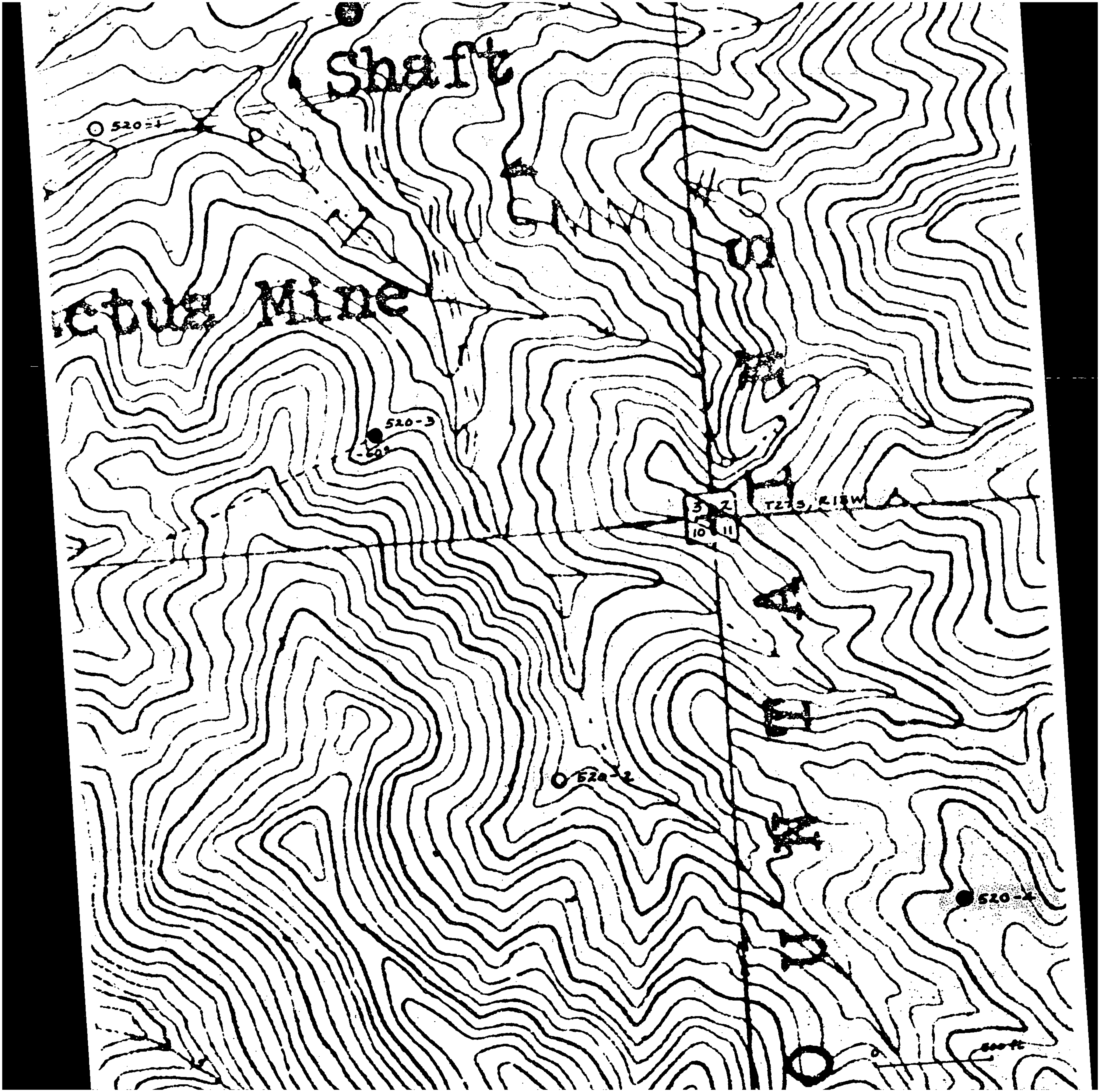

biotite (vn)
hematite (vn)
specularite (vn)
tr
+
++
+++
hematite
500
1000
1500
2000
2500
X
X

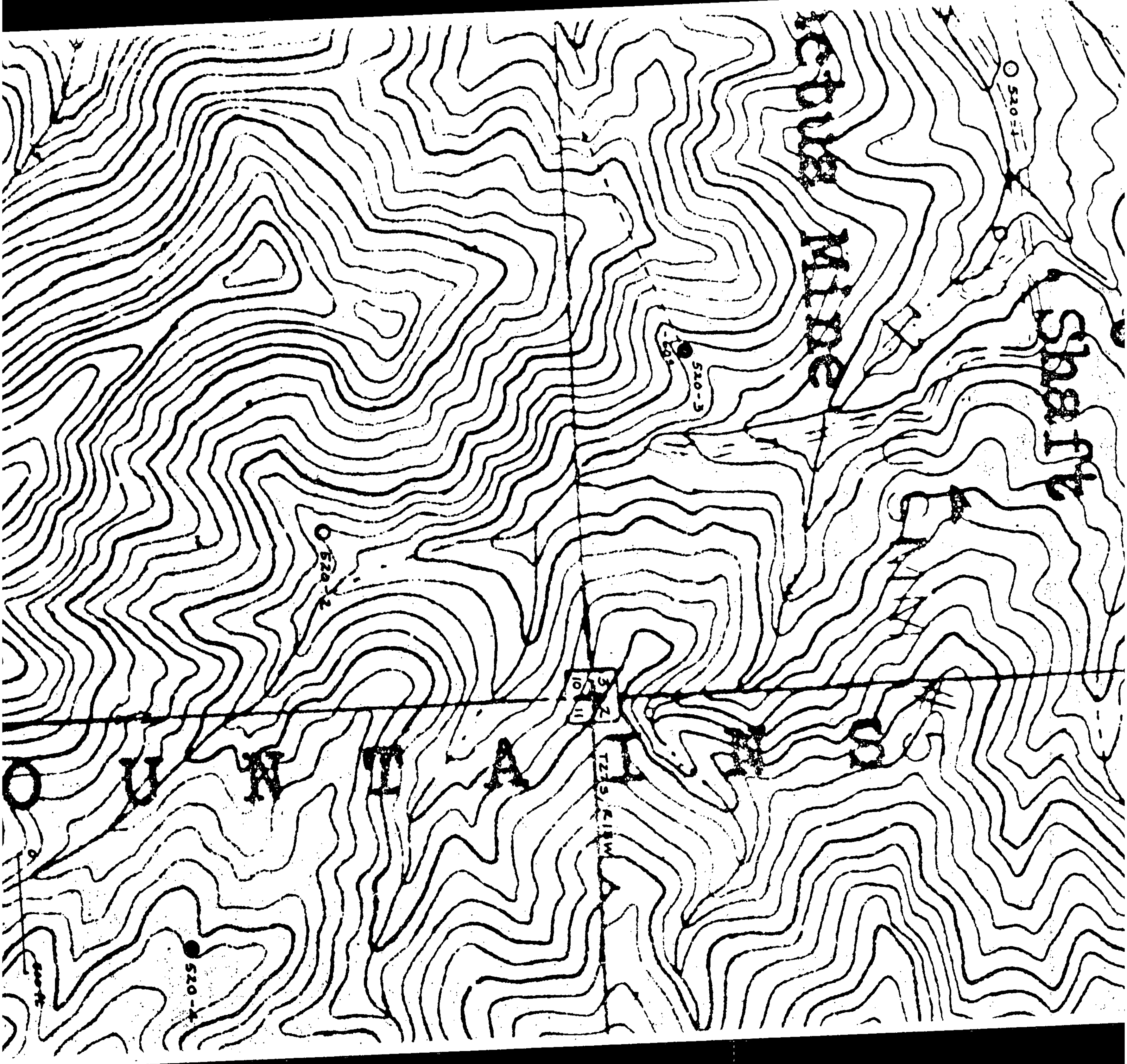
DOH #520-3


CLAY (V%)
CHLORITE (V%)
GYPSUM / ANHYDRITE (V%)
<1
+
++
+++
500
1000
1500
2000
2500

DDH#520-3


epidote (vn)
calcite (vn)
sericite (vn)
nil
+
++
+++
nil
+
++
+++
nil
+
++
+++
500
1000
1500
2000
2500


Shaft
520-1
ctus Mine
520-3
3
2
10
11
T27S, R15W
520-2
520-4


OUNTAINS
T27S, R18W
3
2
10
11
520-4
520-2
520-3
520-1
ctus Mine
Shaft

Beaver Co.
Utah

1 OF

SAMPLE NO.	INTERVAL		CORE REC.	% CORE	PPM			%				
					Mo	Cu	Zn	K$_2$O	CaO	Na$_2$O	S	
B7860-64	9.5	100	✓		6	30	15	4.1	3.5	3.6	.26	
B7865-69	100	200	✓		2	60	30	4.1	3.5	3.6	.18	
B7870-74	200	300	✓		<1	65	35	4.2	3.5	3.5	.23	
B7875-79	300	400	✓		<1	75	40	4.2	3.2	3.5	.18	
B7880-84	400	500	✓		6	55	35	4.0	3.1	3.5	.27	
B7885-89	500	600	✓		6	80	35	4.0	3.1	3.8	.05	
B7890-94	600	700	✓		1	40	40	4.0	2.9	3.8	.13	
B7895-99	700	800	✓		5	30	40	4.0	2.9	3.9	.07	
B7900-04	800	900	✓		1	130	30	4.0	3.3	3.9	.04	
B7905-09	900	1000	✓		<1	90	30	3.7	3.5	3.8	.17	
B7910-14	1000	1100	✓		<1	80	35	3.6	3.1	3.8	.22	
B7915-19	1100	1200	✓		<1	90	30	3.8	3.3	3.8	.22	
B7920-24	1200	1300	✓		3	145						
B7925-29	1300	1400	✓		10	295						
B7930-34	1400	1500	✓		105	.22%						
B7935-39	1500	1600	✓		10	250						
B7940-42,44 46-48	1600	1700	✓		23	510						
B7949-53 55	1700	1800	✓		32	325						
B7957, (59) 61 63-67	1800	1900	✓	7959	MISSING	1035						
B7968-72	1900	2000	✓		80	155						
B-7973-77	2000	2096	✓		9	225						
B-8371-75	2100	2200	✓		17	395						
B-8376-80	2200	2300	✓		10	175						
B-8381-85	2300	2400	✓		10	300						
B-8386-90	2400	2500	✓		20	60						
B-8391-95	2500	2600	✓		16	340						
8396-99 B 8500	2600	2700	✓		14	140						
B8601-05	2700	2800	✓		9	55				3.8	.05	
B 8606-10	2800	2900	✓		1	25	30	3.6	2.6	3.8	.03	
B8611-14	2900	2978	✓		2	25	25	3.6	2.6	3.6	.07	
B8370	2095	2100										
B7943 45	In the 1600-1700 Interval		bx with ign mat 7959			720	30	4.0	2.4	4.0	.35	
B7954,56,58 60,62	In the 1900-1800 Interval		aphanitic	dike	185	900	45	5.4	1.4	3.5	.19	
B-7954	1785.3	1790.7		"	150	1300						
56	1791.5	1802		"	240	1300						
58	1805	1808.5		"	700	800						
60	1809	1814		"	100	700						
62	1817.2	1817.9		"	30	425						

MISSING

7959

#520
Beaver Co.
Utah

1 OF

Angle LAB S78W@-58° METHOD

SAMPLE NO.	INTERVAL		CORE REC.	% CORE	PPM			%				
					Mo	Cu	Zn	K_2O	Na_2O	CaO	S	
B7978-82	10	100	✓	7979 MISSING		440	75	3.8	3.4	2.4	.20	.14
B7983-87	100	200	✓		2	450	45	3.7	2.3	2.9	.54	
B7988-92	200	300	✓		2	240	35	3.7	3.5	2.7	.45	
B7993-97	300	400	✓		2	130	35	4.0	3.6	2.5	.35	
B7998-8002	400	500	✓		2	155	35	3.9	3.2	2.4	.49	
B8003-07	500	600	✓		2	100	40	4.1	3.6	2.7	.38	
B8008 B8010-13	600	700	✓		<1	90	30	4.2	3.2	2.4	.46	
B8014-18	700	800	✓		<1	170	25	4.0	3.1	2.2	.66	
B8019-23	800	900	✓		<1	125	25	4.0	3.4	2.2	.39	43
B8024-28	900	1000	✓		5	80	30	3.9	3.2	2.4	.16	
B8029-33	1000	1100	✓		1	90	30	3.9	3.4	2.4	1.46	
B8034-38	1100	1200	✓		2	60	40	3.9	3.8	2.4	.71	
B8039-43	1200	1300	✓		<1	205	35	3.5	3.5	2.2	.14	
B8044-48	1300	1400	✓		12	40	40	3.5	3.6	2.5	.14	
B8049-53	1400	1500	✓		1	90	35	3.2	3.9	2.7	.13	
B8054-58	1500	1600	8057 MISSING		5	290	30	3.4	3.5	2.2	.10	.12
B8059-63	1600	1700	✓		3	480	30	3.6	3.5	2.0	.05	
B8064-68	1700	1800	✓		6	855	30	3.7	3.5	2.2	.24	
B8069-73	1800	1900	✓		9	500	30	3.8	3.6	2.2	.11	.12
B8074,75 77-80	1900	2000	✓		22	925	30	4.3	3.5	1.9	.25	
B8081-85	2000	2100	✓		9	375	35	3.6	3.2	2.0	.07	
B8086-90	2100	2200	✓		17	.20%	30	3.6	2.2	1.7	.26	.25
B8091-95	2200	2300	✓		17	565	30	3.7	3.4	1.9	.10	
B8096-99- 8200	2300	2400	✓		25	330	30	3.6	3.5	2.0	.05	
B8201-03	2400	2454	✓		22	500	25	3.6	3.5	2.1	.13	
B8039✓	1200	1220			5	385	35					
B8040✓	1220	1240			3	120	55					
B8041✓	1240	1260			9	65	15					
B8009✓	620.5	622.2	Aplite	dike	3	15	15	5.9	2.6	.66	.40	
B8076✓	1928	1930	"	"								

Cactus Project
#520
Beaver Co.
Utah

1 OF

MISSING

COLLAR
LAB METHOD
Vertical

SAMPLE NO.	INTERVAL		CORE REC.	% CORE	PPM			%			
					Mo	Cu	Zn	K_2O	CaO	Na_2O	S
B8204-08	10	100	✓	8207,9	Miss 5	55	30	3.6	2.2	3.1	.23
B8209-13	100	200	✓		6	110	40	4.0	3.0	3.5	.10
B8214-18	200	300	✓		5	170	40	4.0	2.5	3.2	.41
B8219-23	300	400	✓		5	80	25	3.7	2.9	3.4	.15
B8224-28	400	500	✓		3	95	25	4.0	2.5	3.5	.42
B8229-33	500	600	✓		5	80	25	3.8	2.5	3.4	.24
B8234-38	600	700	✓		3	75	20	3.8	2.2	3.2	.20
B8239-43	700	800	✓	8241	Miss 20	50	40	3.6	2.6	3.2	.19
B8244-48	800	900	✓		4	345	35	3.8	2.6	3.4	.18
~~B8249,60~~ B8120-22	900	1000	✓		1	540	30	3.7	2.9	3.5	.29
B8123-27	1000	1100	✓		1	355	35	3.7	2.8	3.6	.12
B8128-32	1100	1200	✓		3	390	30	3.5	2.7	3.4	.14
B8133-37	1200	1300	✓		14	530	25	4.1	2.5	3.5	.11
B8251-55	1300	1400	✓		2	485	30	3.8	2.5	3.9	.09
B8256-60	1400	1600	✓		26	480	25	3.7	2.6	3.7	.09
B8261-65	1500	1600	✓		2	275	25	3.6	2.3	3.6	.10
B8266-70	1600	1700	✓		5	216	25	3.7	2.4	3.5	.13
B8271-75	1700	1800	✓		10	420	25	3.6	2.4	3.5	.24
B8276-80	1800	1900	✓		17	.11	25	3.5	2.1	3.5	.19
B8281-85	1900	2000	✓		9	950	25	3.7	2.1	3.8	.21
B8287-91	2000	2100	✓		31	320	30				.09
B8292-96	2100	2200	✓		36	425	30				
B8297-8301	2200	2300	✓		142	325	30	5.0	2.2	3.9	.25
B8302-06	2300	2400	✓		154	310	35	5.0	2.2	3.8	.03
B8307-11	2400	2500	✓		34	90	30	4.8	2.4	3.9	.01
B-8312-16	2500	2600	✓		29	145	40	4.1	2.1	3.5	.03
B8317-21	2600	2700	✓		115	320	40	4.0	2.1	3.6	.04
B8322-25	2700	2777	✓		70	560	40	4.1	1.9	3.4	.05

CACTUS
#520
Beaver Co.
Utah

1 OF

COLLAR 7040
LAB METHOD
Vertical

SAMPLE NO.	INTERVAL		CORE REC.	% CORE	PPM			%				
					Mo	Cu	Zn	K_2O	CaO	Na_2O	S	
B8400-18	0	105	✓		1	80	120	4.8	2.0	3.3	<.01	
B8419-28	105	200	✓	8420	Miss'g 1	75	90	4.8	2.4	3.7	.08	
B8429-38	200	300	✓	8433	" 17	235	175	4.4	2.6	3.8	1.68	
B8439-44	300	354 Td R	Rotary ✓	8434	" 23	250	230	4.4	2.5	3.3	1.53	
B8445-47	355	400	✓	8447	4	85	75					
B8448-52	400	500	✓	8443	4	80	120					
B8453-57	500	600	✓	8453	<1	75	95					
B8458-62	600	700	✓		60	75	1					
B8463-68	700	800	✓		215	125	17					
B8469-72	800	825	✓		190	85	2					
B8465	740	760	✓		255	105	41					

Rotary Drill hole 520-4
0'-354'
Diamond - 354'-875'

Geologic Log

Pg 1 of 5

Interval (Ft)	Mineralization									Rock Type			Alteration																				Vein Thickness (in)				Vein Angle				Remarks	
	Py		Ccp		Mo		Mag		Π				Clay		Chl		Anh		Ep		Calc		Qtz		Ser		K-spar		Bio		Hem	spec	<.1	.1-.5	.5-1.0	>1.0	0-30	30-60	60-90			
Rotary Cuttings Fm. 0' to 354' - Diamond Drlg. 354' to TD	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn		Lith	Color	Tex	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn										Ccp/Py		
0'-5'	—	—	—	—	—	—	+	—	—	1(?)	FeOx	Med Grain	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	No sulfides - FeOx.	
5'-10'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	
10'-15'	—	—	—	—	—	—	+	—	—	"	"	"	+	—	—	—	—	—	—	—	—	—	—	—	+(?)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	Tgmc(:) strongly FeOx
15'-20'	—	—	—	—	—	—	+	—	—	"	"	"	++	—	—	—	—	—	—	—	—	—	—	—	+(?)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	" " " "
20-25'	—	—	—	—	—	—	++	—	—	"	"	"	+	—	+	—	—	—	—	—	—	—	—	—	+(?)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	" Mod. "
25-30'	—	—	—	—	—	—	++	—	—	"	"	"	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	" Mod "
30'-35'	—	—	—	—	—	—	++	—	—	"	"	"	++	—	—	—	—	—	—	—	—	—	—	—	+(?)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	Tgmc. strongly FeOx
35'-40'	—	—	—	—	—	—	++	—	—	"	"	"	++	—	+/++	—	—	—	—	—	—	—	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	" mod. "
40'-45'	—	—	—	—	—	—	+	—	—	"	"	"	++	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	+	+	—	—	—	—	—	—	—	—	" "	- Tgmc-wk "
45'-50'	—	—	—	—	—	—	+	—	—	"	FeOx/Lt Pink	"	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	+	—	—	—	—	—	—	—	—	No Sulfides	" " "
50'-55'	—	—	—	—	—	—	+	—	—	"	"	"	+	+	+	—	—	—	—	—	—	—	—	—	+	—	—	—	—	—	—	+	—	—	—	—	—	—	—	—	" "	" mod. FeOx
55-60'	—	—	—	—	—	—	+	—	—	1	Pink & Grey	Med Grain	—/+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	" wk. to fsh.
60'-65'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	"	Tgmc. pred. fsh.
65'-70'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	+	—	—	—	—	—	—	—	—	" "	" " "
70-75'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	" " "
75'-80'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	" " "
80'-85'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	" " "
85'-~~85'~~ 95'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	" " "
95'-105'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	" " "
105-110'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	" " "
110'-120'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	
120-130'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	
130'-140'	+	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	<1	Very low sulf 0.x% - py diss. w/ Fe-Mgs.	
140'-150'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	No sulfides -	
150'-160'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	
160'-170'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	" "	
170'-180'	+	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	<1	" Cu Sulfides	
180'-190'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	N	
190-200'	—	—	—	—	—	—	+	—	—	"	"	"	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—									
200-210'	++	—	—	—	—	—	+	—	—	"	"	"	—	—	++	—	—	—	+	—	—	—	—	—	+	—	—															

Pg 2 of 5

Interval	Mineralization									Rock Type			Alteration																				Vein Thickness (in)				Vein Angle				Remarks
	Py		Ccp		Mo		Mag		Tl				Clay		Chl		GYP Anh		Bp		Calc		Qtz		Ser		K-spar		Bio		Hem	Spec	<.1	.1-.5	.5-1.0	>1.0	0-30	30-60	60-90		
	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn		Lth	Color	Tex	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn	Diss	Vn										ccp/py	
200'-210'	+	—	+	—	—	—	+	—	—	1(?)	Pink & Grey	MOD Grain	—	—	+	—	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≥1	Very low sulf 0.x%
210-220'	+	—	+	—	—	—	—	—	—	"	"	"	—	—	++	—	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≤1	" " " " - rock may be more gray: than pink-
220'-230'	++	—	—	—	—	—	—	—	—	"	"	"	—	—	++	—	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≤1	Very low sulf 0.x% — rock as abv.
230'-240'	+	—	—	—	—	—	—	—	—	"	"	"	—	—	++	—	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≤1	" " " " — " " "
240'-250'	—	—	—	—	—	—	—	—	—	"	"	"	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	No sulf 0.x% — " " "
250'-260'	+	—	—	—	—	—	—	—	—	"	"	"	—	—	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≤1	Very low sulf 0.x% — " " "
260'-270'	++	—	—/+	—	—	—	—	—	—	"	"	"	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≤1	" " " " - pink cast more prevo
270'-280'	++	—	—	—	—	—	—	—	—	"	"	"	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≤1	" " " " — " " " "
280-290	++	—	+(?)	—	—	—	—	—	—	"	"	"	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≤1	" " " " - encountered H_2O
290-300'	++	—	+(?)	—	—	—	—	—	—	"	"	"	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≤1	" " " " - sample very fine py/ccp(?) tumbled-
300-310'	+	—	+(?)	—	—	—	—	—	—	"	"	"	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≤1	Very low sulf 0.x%
310-320'	+	—	+	+	—	—	—	—	—	"	"	"	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	+	—	—	—	—	—	—	—	—	≤1	" " " "
320-330'	++	—	+(?)	—	—	—	—	—	—	GREY FELDSPAR DIKE			—	+	++	—	—	—	—	—	—	—	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≤1	Low to mod Sulf 0.x% - py pred - rx med. to fine. pink-grey feld. dike - not porph.
330-340'	++	—	+(?)	—	—	—	—	—	—	"	"	"	—	—	++	—	—	—	—	—	—	—	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≤1	As Abv.
340'-350'	+	—	—	—	—	—	—	—	—	1(?)	Pink & Grey	Med. Grain	—	—	++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	≤1	Very low sulf 0.x%
BTM ROTARY 350'-354'	++	+	+	—	—	—	—	—	—	"	"	"	—	—	++	+	—	—	—	—	—	—	—	+	+	—	—	—	—	—	—	—	—	1	—	—	—	—	—	≤1	" " " "

ASSAY SEPARATELY (320-330', 330-340')

11/28/72

	Interval (Ft)	Mineralization									Rock Type			Alteration																				Vein Thickness (in)				Vein Angle °				Remarks
		Py		Cp		Mo		Mag		Ti				Clay		Chl		Anh/Gyp		Epi		Calc		Qtz		Ser		K-Spar		Bio		Hem	Spec									
		D	V	D	V	D	V	D	V		Lith	Color	Tex	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V			<.1	.1-.5	.5-1.0	>1.0	0-30	30-60	60-90	Cp/Py	
3445-47	355-360	-	+	-	-	-	-	++	+	-	lfg	Gray	fg	-	-	-	+	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	6	-	-	-	2	2	2	α	Low sulf .x% confined to vns, abundant vert fracts, several ks vns w/ py, qtz, chl alteration, bleached, rock fresh, dark gray-mottled gray & pink
	360-380	-	++	-	-	-	-	++	-	-	"	Gray Pink	"	-	-	-	+	-	-	-	+	-	+	-	+	-	-	-	+	-	-	-	-	14	-	-	-	1	3	10	α	Mod sulf ~1%, thin indistinct qtz-K-spar vns @ 368-70, strong vert fracts w/py & minor qtz-chl
	380-400	-	++	-	+	-	-	++	+	-	"	"	"	-	-	+	+	-	-	-	+	-	+	-	+	-	-	-	+	-	-	+ fracts	-	11	-	-	-	4	2	5	1/100	Mod sulf ~.5% indistinct qtz-K-spar bleached vns, py on fracts, rock essentially unalt
3448-52	400-420	-	++	-	-	-	-	++	+	-	"	"	"	-	-	+	+	-	-	+	+	-	+	-	+	-	-	-	+	-	+	-	-	13	-	-	-	4	2	7	α	Mod sulf ~.5% highly chl w/diss Kspar @ 411-14, bn bio @ 418, rock becomes grayish
	420-440	-	++	-	-	-	-	++	+	-	"	"	"	-	-	+	+	-	-	+	+	-	+	-	+	-	-	-	+	-	+	+ fracts	-	10	-	-	-	3	1	6	α	Mod sulf ~1%, rock grays 425-435 highly broken @ 435-39, highly chl gouge, K-spar, becomes cg w/some large py xtls, normal gray-pink, fg rock below 439
	440-460	-	++	-	-	-	-	++	+	-	"	"	"	-	++	+	++	-	-	+	+	+	++	-	+	-	-	-	+	-	-	+ fracts	-	27	-	-	-	6	5	16	α	Mod sulf ~1%, highly fract-gouge @ 445-48 w/blk clay-py zone w/ closely spaced chl-py vns, calc plated on fracts
	460-480	+	++	-	-	-	-	++	?	+	"	"	"	-	+	+	+	-	-	+	+	+	++	-	+	-	-	-	+	-	-	-	-	24	-	-	-	6	4	14	α	Mod sulf ~1.5%, pyritohedrons common, py in fracts & matrix, broken zone @ 464-67, thin vert aplite dike w/py @ 460, noticely pinker below 475
	480-500	-	++	-	-	-	-	++	-	+	"	"	mfg	+	-	+	+	-	-	-	+	+	+	-	+	-	-	-	+	-	-	+	-	16	-	-	-	2	3	11	α	Mod sulf ~2%, heavy py on some fracts, strong vert fracts @ 488 & 498-500, narrow aplite dike .1-.2 wide (vert) @ 494-96, Tl associated w/K-spr. and bleaching
453-57	500-520	-	++	-	-	-	-	++	-	+	"	"	"	+	-	+	+	-	-	-	+	+	++	-	-	-	-	-	+	-	?	-	-	16	-	-	-	6	3	7	α	Mod sulf ~2%, strong vert fracts w/ py @ 501, 503-4, 508, 510, 511-12, narrow aplite dike w/minor dism py @ 515-17
	520-540	+	++	-	-	-	-	++	-	-	"	"	"	++	++	+	++	-	-	+	+	+	++	-	+	-	-	-	+	-	+	-	-	14	-	-	-	5	2	7	α	Mod sulf ~1%, strong arg-gouge zone @ 533-35, 537-38, local abundant clay, chl & py on fracts
	540-560	-	++	-	-	-	-	++	-	-	" Aplite	" Pink	" fg	+	+	-	++	-	-	+	++	+	++	-	+	-	-	-	+	-	+	-	-	20	-	-	-	8	3	9	α	Mod sulf ~1% locally abundant on fracts, pink aplite dike w/dism py fracts @ 540-49, contact may be gradational w/fg l (becomes porph) strong chl-epi on fracts below 553
	560-580	-	++	-	-	-	-	++	+	-	lfg	Pink Gray	mfg	-	+	-	++	-	-	-	++	-	++	-	+	-	-	-	+	-	-	+	-	19	-	-	-	3	6	8	α	Mod sulf ~1.5%, calc, chl epi & py on fracts, otherwise relatively unalt, @ 576 two .1" qtz vns w/p in middle & bio on fringe

	…terval (ft)	Mineralization									Rock Type			Alteration																				Thickness (in)				Angle °				Remarks
		Py		Cp		Mo		Mag		Tl				Clay		Chl		Anh/Gyp		Epi		Calc		Qtz		Ser		K-Spar		Bio		Hem	Spec									
		D	V	D	V	D	V	D	V		Lith	Color	Tex	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V			<.1	.1-.5	.5-1.0	>1.0	0-30	30-60	60-90	Cp/Py	
											vfg l	Gray	vfg																													@576 vfg l, gray, fg white feld & dark brown laths bio, abundant d & vn py
	580 - 600	++	+	-	-	-	-	+	-	-	〃	Light Gray	〃	-	-	+	+	-	-	-	-	-	+	-	+	-	-	-	+	-	??	-	-	12	-	-	-	2	4	6	α	Mod sulf ~ 2.5% dism & fracts, abruptly grades into lfg @584 & a 585, locally dism mag, laths of dk bio locally → chl, may be silicifi zone
	600 - 620	+	+	-	-	-	-	++	-	-	〃 lfg	〃 Pink-Gray	〃 mfg	-	-	-	+	-	-	-	+	-	+	-	+	-	-	-	+	-	?	+ fract	-	14	-	-	-	4	3	7	α	Mod sulf ~1% dism & vns in vfg light rock, along fracts only in lfg vfg facies grades into lfg @ 604 flat qtz-K-spar vns (.01-.1 thick) common in interval w/ lfg
	620 - 640	+	+	-	-	-	-	++	-	-	〃	〃	〃	-	-	-	+	-	-	-	+	-	+	-	+	-	-	-	+	-	-	++ fracts	-	13	-	-	-	2	4	7	α	Mod sulf ~ 1%, blocky fracts @ 34, 637-39 w/ calc vns, qtz - K-spar - p vns common - thin (<.1), thin vfg zon
38458-62	640 - 660	+	+	-	-	-	-	++	+	-	〃	〃	〃	+	-	+	++	-	++	+	++	+	++	-	+	-	-	-	+	-	-	++ fracts	-	8	-	-	-	2	4	2	α	Mod sulf ~1.5%, blocky fracts common, mag vn @ 643, gyp vns common below 651, rock bleach from 652-59, K-spar vns not common altho bleached rock h dism K-spar, locally plag → sa (green clay)
	660 - 680	+	+	-	-	-	-	++	-	-	〃	〃	〃	-	-	-	+	-	++	-	+	-	-	-	-	-	-	-	+	-	-	+ fract	-	9	-	-	-	2	5	2	α	Low sulf <.5%, gyp vns (.01w10 common, rock relatively unalte py dism in gyp vns
	680 - 700	-	+	-	-	-	-	++	-	-	〃	〃	〃	-	-	-	+	-	++	-	+	-	+	-	+	-	-	-	+	-	-	+ fract	-	8	-	-	-	3	2	3	α	Low sulf <.5%
	700 - 720	-	+	-	-	-	-	++	+	-	〃 Qtz Monz Porph	〃 Pink	〃 fg Porph	-	-	-	+	-	+	-	+	-	+	-	-	-	-	-	+	-	-	-	-	5	-	-	-	1	2	2	α	Low sulf <.5%, fg pink qtz monz porph @ 705.5-07.5 & 712-14, matrix, indistinct white feld phenos, blk bio, & dism py
	720 - 740	++	+	-	-	-	-	+	-	-	lfg Qtz Monz Porph	Pink-Gray Pink	mfg fg Porph	-	-	-	+	-	++	+	-	-	+	-	-	-	-	-	-	-	-	+ dism	-	10	-	-	-	4	2	4	α	Mod sulf ~ 2.5%, pink qtz mo porph @ 721.5, fg pink matrix, indistinct white feld phenos, brn bio flak mag clots, py & epi, gyp vns common - mo flat lying - thin, occasional steep chl-vn, interval relatively unalt.
38463-68	740 - 760	++	+	-	-	-	-	+	-	-	〃	〃	〃	-	-	+	+	-	++	+	-	-	+	-	-	-	-	-	-	-	-	+ dism	-	7	-	-	-	5	1	1	α	Mod sulf ~2%, calc vn @ 759.5, 756 rock bleached light gray, all mafics → chl
	760 - 780	+	+	-	+	-	-	+	-	-	lfg Qtz Monz Porph	Pink-Gray Pink	mfg fg Porph	-	-	+	+	-	++	-	-	-	+	-	+	-	-	-	+	-	-	-	-	5	-	-	-	3	1	1	1/100	Mod sulf ~1%, @767 pink qtz m porph as above, cp xal in K-spar v 761.5, flat & vert gyp vns, qtz ± chl vns (flat) in porph
	780 - 800	+	+	+	-	-	-	+	+	-	〃 vfg l	〃 Light Gray	〃 vfg	-	-	-	+	-	++	-	+	+	-	-	+	-	-	-	-	-	-	+ dism	-	6	-	-	-	4	1	1	1/10	Mod sulf ~1%, cp blebs w/py, m calc & chl @ 783, 784, & 791, @ 794 lvfg, unaltered

Srfs

	Interval (ft)	Mineralization									Rock Type			Alteration																				Vein Thickness (in)				Vein Angle °				Remarks
		Py		Cp		Mo		Mag		Tl				Clay		Chl		Anh/Gyp		Epi		Calc		Qtz		Ser		K-Spar		Bio		Hem	Spec									
		D	V	D	V	D	V	D	V		Lith	Color	Tex	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V			<.1	.1-.5	.5-1.0	>1.0	0-30	30-60	60-90	Cp/Py	
169-72	800-820	+	+	+	—	—	—	+	—	—	vfg / Qtz Monz Porph vfg /	Light Gray Pink Light Pink-Gray	vfg fg Porph vfg	—	—	+	+	—	++	+	—	—	+	—	+	—	—	—	—	—	—	—	—	4	—	1	—	3	1	1	1/100	Mod sulf ~1%, lvfg becomes pink w/depth, @ 809.5 qtz monz porph, cp blebs @ 811, grades into pinkish gray lvfg w/indistinct white feld phenos, @ 813, 0.1 qtz-py vn (45°) @ 807, .05 qtz vn (50°) w/chl @ 810
	820-840	+	+	—	—	—	—	+	—	—	" Qtz Dorite	" Dark Gray	" fg	—	—	+	+	—	+	—	+	—	+	—	—	—	—	—	—	—	—	—	—	7	—	—	—	5	2	0	α	Low sulf <.5%, rock becomes less altered w/depth, gyp vns common but less than above, @ 835 fg qtz diorite w/ vert gyp vns & minor epi
	840-860	+	+	—	—	—	—	+	—	—	"	"	"	—	—	—	+	—	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	9	—	—	—	1	5	3	α	Low sulf ~.2% qtz diorite, equigran fg, white plag & ho-horn (?) minor chl-epi on fracts, dism fg py
	860-875	+	+	—	—	—	—	+	—	—	"	"	"	—	—	—	+	—	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	6	—	—	—	1	1	4	α	Low sulf ~.2%

UTAH cont.

Area/Hole Name	Location		Footage	Driller
ROOSEVELT				
TPC-14-2	Beaver Co.	Sec. 2 T26S R9W	Chips 0-6100	Thermal Power
Cactus 520-1	Beaver Co.	Sec. 3 T27S R13W ✓	Core 0-2975	AMAX
Cactus 520-2	Beaver Co.	Sec. 10 T27S R13W	Core 0-2454	AMAX
Cactus 520-3	Beaver Co.	Sec. 3 T27S R13W	Core 0-2777	AMAX
Cactus 520-4	Beaver Co.	Sec. 4 T27S R13W	Core 0-875	AMAX
Diamond #1	Beaver Co.	Sec. 34 T26S R9W	Core 10.8-201.8	
Diamond #1A	Beaver Co.	Sec. 3 T27S R9W	Core 20-217	
Diamond #1B	Beaver Co.	Sec. 4 T27S R9W	Core 133-231	
Ryan Springs	Beaver Co.	Sec. 4 T27S R8W	Core 215-331	
UT State 24-36	Beaver Co.		Chips 0-5600	Thermal Power
KGRA 9-1	Beaver Co.	Sec. 9 T27S R9W	Chips 0-6883	Phillips
HF1	Beaver Co.	Sec. 8 T27S R8W	Core 101.7-503.9	
HF3	Beaver Co.	Sec. 25 T26S R9W	Core 29.0-489.3	
HF3b	Beaver Co.	Sec. 2 T24S R9W	Core 17.4-498.3	
TG 0	Beaver Co.	Sec. 16 T26S R9W	Chips 15-245	Univ of Utah

~15,000 ft core

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