

FIG. 1. Geologic map of the southwestern part of the Picuris Range, New Mexico.

# GEOCHEMISTRY OF TANTALUM IN THE HARDING PEGMATITE, TAOS COUNTY, NEW MEXICO\*

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## ABSTRACT

The notable tantalum enrichment in the Harding pegmatite, in northern New Mexico, is believed due to (1) a parental tantalum-rich granite, (2) a uniquely favorable environment, (3) specific absence of tantalum-bearing sphene from all adjacent granite, (4) long-continued deformation acting upon crystallizing granite and pegmatite.

A more indirect factor, affecting the type of tantalum mineralogy peculiar to this pegmatite and perhaps responsible for a vertical mineralogical zoning, is believed to have been a chemical control exerted by pegmatite assimilation of country rock.

A complex series of geochemical events, all affecting each other, seems necessary for any such rare-element concentration.

## INTRODUCTION

The Harding pegmatite is in north-central New Mexico, mid-way between Santa Fe and Taos and 5 miles due east of Dixon. It lies 20 miles from Taos, in the far southwest corner of the Picuris Range, a 16-mile-long spur projecting from the main north-south Sangre de Cristo Range. It was worked extensively in the 1920's for lepidolite, became the only important domestic source of tantalum during World War II, and now is one of the country's foremost beryl producers. The mineralogy of this pegmatite has been studied by Schaller and Henderson (1926), Jahns (*U.S. Geol. Survey report* in preparation) who mapped the deposit in 1942, and in greater detail in connection with drilling exploration by the U. S. Bureau of Mines in 1943 (*U.S. Bur. Mines*, 1943, 1944, 1946, 1949), and Montgomery (1950) who has done the operating for tantalum and beryl. The author owes his introduction to the Harding Mine to Prof. E. S. Larsen, Jr., who originally suggested to him that tantalum might be found there in quantity.

The pegmatite has intruded amphibolites and quartz-muscovite schists which form the major part of a younger pre-Cambrian rock group occupying the southern half of the Picuris Range. An older metasedimentary rock group occupies the northern half. The Dixon† granite (Just, 1937, pp. 24-25) borders the southern group along the southwest and southern range boundaries, also occupies the far-eastern end of the range. Pegmatites and quartz veins genetically related to the granite intrude granite and all older pre-Cambrian rocks. The granite lies only a half-mile south and west of the Harding pegmatite; to the west it cuts across bedding of schists and amphibolites.

\* Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 318.

† This name has been changed to *Embudo*. In addition to this change, the name *Harding formation* should be changed to *Vadito formation* in Fig. 2.

## DESCRIPTION OF THE PEGMATITE

The main pegmatite mass is an almost flat-lying lens that dips gently to the southwest, with an axial dip length of 1,000 feet, a strike width of 500 to 600 feet, and an average thickness of about 60 feet.

From the largest central mass exposed in the quarry, drilling has explored the pegmatite down-dip along its axial length for a distance of 900 feet. All of this part of the pegmatite is hidden beneath overlying amphibolites which increase in thickness from 10 to 20 feet at the quarry to more than 100 feet at the holes drilled furthest to the southwest. Drilling 700 feet southwest of the quarry has shown the pegmatite there to be a narrowing pipe-like mass roughly 70 feet thick and 70 feet wide; further southwest it thins rapidly and may pinch out in that direction beyond 900 feet. Several holes 50 to 100 feet to the southeast show the pipe-like mass narrowed down to a 15 foot thick dike dipping 45 degrees southeast and nearly parallel to foliation in the amphibolites.

Out around the dumps by the quarry the northwest part of the pegmatite thins abruptly; only a few portions of it remain uneroded in that area. Southeast of the quarry the pegmatite is hidden beneath amphibolites.

The well-exposed eastern extension is very irregular, thinning and passing beneath the North Knob and narrowing southeastward from there to a thin, branching dike following steep bedding and foliation (N60E, 60-70SE); then, 800 feet from the quarry, it swells to a thick mass, before thinning again and continuing another 1,000 feet down into the Southeast Gulch. Gulch outcrops represent a 2 to 10 foot thick dike ascending from below. Exposures here show an irregular step-like pattern as the dike successively follows bedding and crosscuts it in a tortuous ascent from an elevation of 7,200 to 7,400 feet at the mine. Near the mine the horizontal crosscutting process became paramount resulting in the great flat-lying Harding mass. This is not bedding control, for various beds of amphibolite, schist and quartzite are crosscut. The northern, much-eroded part of the pegmatite chiefly crosscuts quartz-muscovite schist; the central mass and southern parts cut across dark amphibolites.

## INTERNAL STRUCTURE AND MINERALOGY

The internal structure shows a horizontal layering, with a topmost 2 foot thick wall zone of coarsely-intergrown quartz and muscovite with fist-size spots of white beryl and patches of albitized microcline. Large crystals of blue apatite and columbite-tantalite (averaging 45%  $Ta_2O_5$ ), also some coarse lepidolite, occur sparingly. Where beryl is now being mined at the quarry's west end, a solid, almost pure, 2 to 5 foot thickness

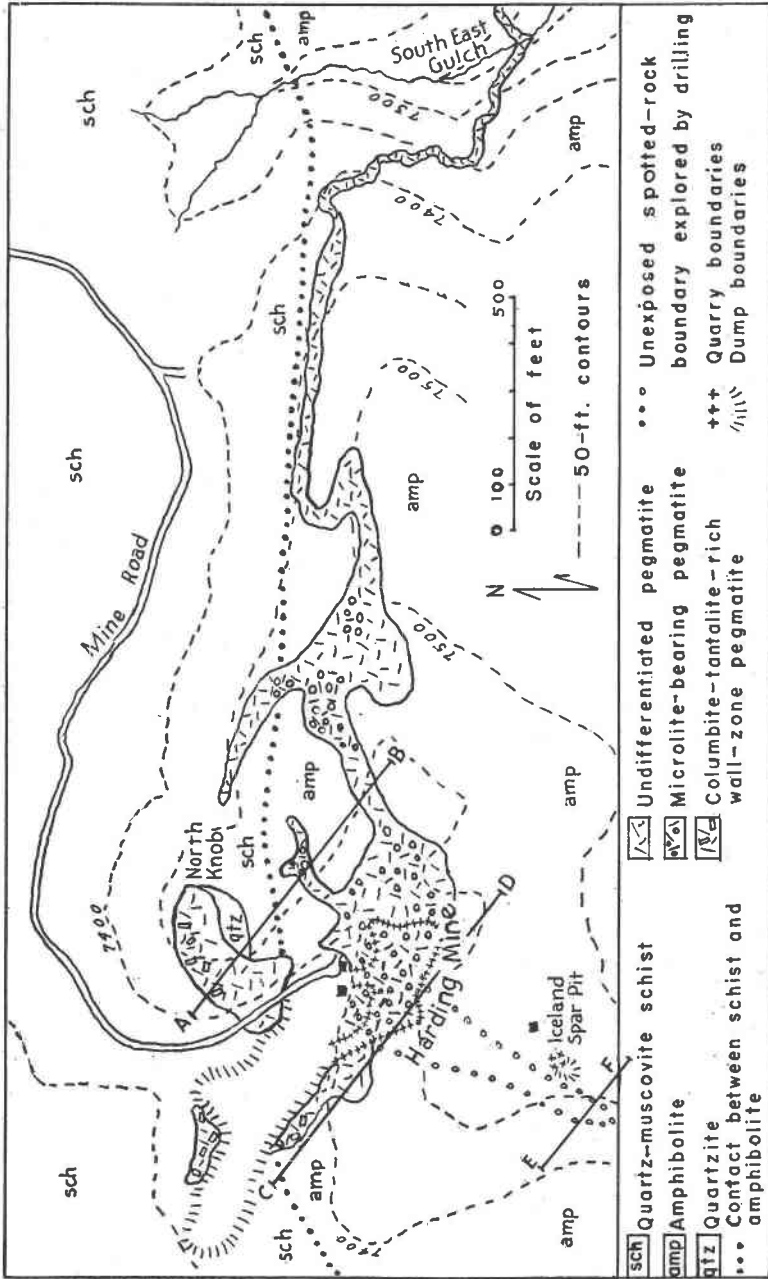


Fig. 2. Geologic map of the Harding pegmatite (based in part on mapping by U. S. Geological Survey).

of beryl occurs as the topmost layer; an albite-rich stringer in places comes down out of the amphibolite above to lie directly on top of the beryl as a thin border-zone layer. A 6 foot thickness of nearly pure quartz underlies the wall zone. Below this in the central quarry section is a 30 foot thick core zone of coarsely crystallized microcline, small rounded spodumene crystals, finely crystalline muscovite and lepidolite, and abundant minute crystals of columbite-tantalite and brownish-black microlite. At

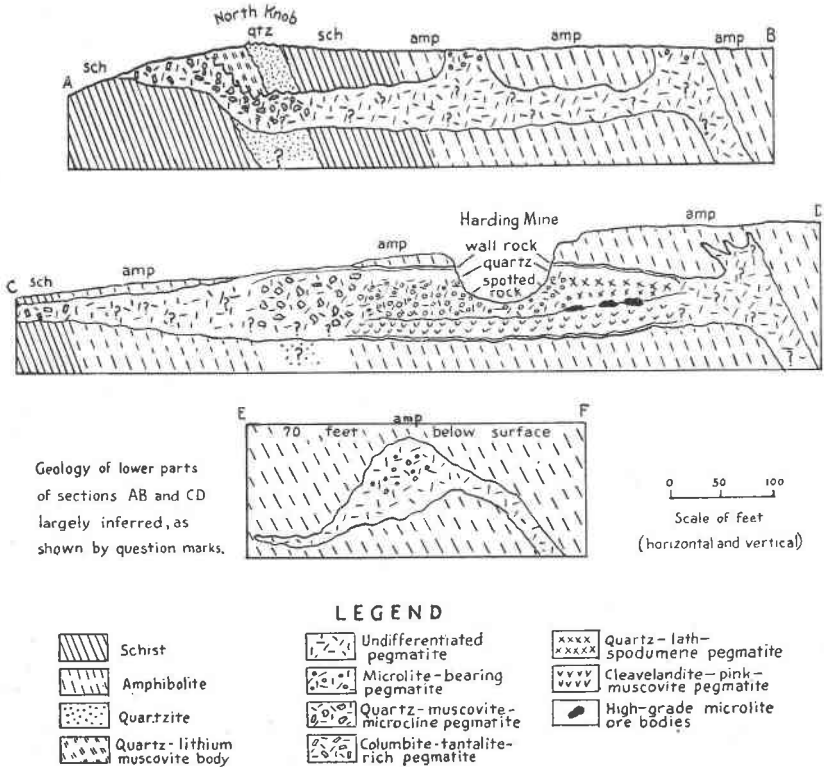


FIG. 3. Structure sections of the Harding pegmatite along AB, CD, and EF.

the top of this zone is a layer of rich lepidolite and coarse spodumene. This central spodumene-rich zone, called "spotted-rock" by Jahns, is the low-grade tantalum ore body developed down-dip for 650 feet by drilling. This zone ends abruptly southward against a southeasterly quartz zone 20 feet thick, full of huge, flat spodumene crystals crisscrossing each other like jackstraws and standing at steep angles to the horizontal. At the foot of this zone occur rich concentrations of spodumene and smoky

quartz, associated with large lepidolite lenses commonly averaging 10% in tiny yellow microlite crystals. This latest microlite ore mineralization is structurally controlled by fracturing and shearing. Below this ore mineralization is 20 to 30 feet of white cleavelandite with pink muscovite, largely hidden beneath the quarry floor but continuing northeastward under the "spotted rock" zone. The "spotted rock" ends abruptly northward at the northwest quarry portal against very coarse quartz-rich pegmatite containing blocky partly-albitized microcline and veined by patchy streaks of muscovite, gray lepidolite and smoky quartz. No spodumene or microlite occur in this distinctive northwest zone, but columbite-tantalite in coarse crystals becomes abundant in the overlying (largely-eroded) wall zone. Many hundreds of pounds of columbite-tantalite have been picked up in northern gulch placers. No microlite has been observed in these placers, either as loose grains or as inclusions in water-worn pieces of lepidolite.

The mineral paragenesis appears to show a long-continued hydrothermal history with later tantalum-lithium mineralization largely structurally controlled. Pre-mineral and post-mineral deformation are much in evidence.

A northwest-southeast cross-section through the pegmatite (Fig. 3, C-D) shows, then, not only a horizontal layering in part conforming to the expected internal structure of a flat-lying lens, but also a three-fold, vertical mineralogical zoning difficult to explain in terms of such structure.

#### WALL-ROCK CONTROL OF MINERAL ZONING

A possible explanation can be found for the vertical zoning if two factors which the author believes fundamental in the formation of this pegmatite are considered: (1) replacement of a large body of country rock, and (2) wall-rock control exerted by the different types of replaced country rock upon adjacent parts of the replacing, crystallizing pegmatite. Evidence for such a hypothesis comes from a study of the manner of occurrence of tantalum in this pegmatite.

On the North Knob above the quarry, prospect cuts have exposed a large body of fine-grained muscovite, lithium muscovite and quartz. This grades northward, and vertically downward also, into blocky quartz-microcline pegmatite similar to that at the northwest quarry portal. It grades southward into a mass of almost pure quartzite. All gradations may be seen in this area between quartzite or quartz schist and apparent pegmatite replacement of these. Possible replacement of unexposed quartzite might help to explain likewise the very coarse quartz-rich character of the northwest quarry-portal zone. A further significant fact is

the abundance of calcium-free columbite-tantalite (and absence of calcium-rich microlite) in pegmatite adjacent to this zone; also the quartzite and quartz-muscovite schist replaced by most of this part of the pegmatite are free of calcium-bearing minerals.

The central and southeast pegmatite zones largely crosscut calcium-rich amphibolites; in these zones microlite occurs in great quantity and almost entirely takes the place of columbite-tantalite. The calcium from the assimilated amphibolites would go to make up the calcium tantalum oxide, microlite,  $[(\text{Na}, \text{Ca})_2\text{Ta}_2\text{O}_6(\text{O}, \text{OH}, \text{F})]$ . The quartz-rich character of the southeast zone could depend in part also on replacement of quartzite, since quartzite lenses outcrop in amphibolite along the southeastern pegmatite border. All of this is possible evidence favoring country rock control on tantalum mineralization of the pegmatite. Further possible evidence that calcium might have been set free in large quantity by pegmatite replacement of amphibolite derives from the rich iceland-spar occurrence (Kelley, 1940) 400 feet south of the quarry. A number of iceland-spar veins found elsewhere in the range all occur close to amphibolites much intruded by pegmatite.

In the Southern Rockies of New Mexico and Colorado are two other microlite-rich pegmatites, the Pidlite (Jahns, 1946) 40 miles south of the Harding Mine near Rociada and the Brown Derby (Hanley, 1946) 150 miles northward near Ohio City. Both occurrences have dark calcium-bearing wall rocks, amphibolite and meta-diorite. This is not to suggest that all microlite occurrences require calcium-rich wall rock, but the two remarkably similar regional occurrences mentioned at least do not disagree with the hypothesis advanced for the Harding pegmatite.

#### GEOCHEMISTRY OF TANTALUM IN THE PEGMATITE

*Problems to be solved.*—Why is there such a notable concentration of tantalum in the Harding pegmatite? Mining and drilling have proved a minimum total of 150 tons of the pure element. Together with the Brown Derby and Pidlite deposits, these three lithium-rich pegmatites are unique in this country for abundance of tantalum and manner of its occurrence in the rare tantalum mineral, microlite. One geochemical reason has already been suggested for the character and distribution of the tantalum minerals in the Harding; the still more fundamental problems relating to the source of this tantalum and the cause for its extreme concentration in this particular pegmatite will now be considered.

*The Dixon granite a tantalum-rich granite.*—Landes (1935) has described small regional pegmatite areas as characterized by distinctive rare-element or hydrothermal-mineral phases. A similar geochemical rare-element characterization applies over very great regional areas; ore-

vein occurrences confirm this. Southern California pegmatites are thus boron-rich; in the same region are found many other boron minerals as axinite, dumortierite and borates. In the same way pegmatites over much of the eastern Southern Rockies are distinctly characterized by fluorine, the rare earths and their common associates, columbium and tantalum. From Denver southward pegmatite areas noted for such minerals as cerite, monazite, pyrochlore, bastnäsite, fergusonite, samarskite, columbite, etc., are legion. Monazite-rich pegmatites occur near Petaca, 30 miles northwest of the Harding Mine, and in the Pidlite pegmatite area 40 miles southward. Picuris pegmatites mostly lack such minerals, except for traces of tiny columbite crystals in some of them and the Harding columbite-tantalite and microlite.

From such evidence it seems valid to assume that in general "younger"<sup>1</sup> granitic magmas of the eastern Southern Rockies have been tantalum-rich. The Dixon granite, genetically related to the Harding pegmatite by field relations and by petrologic and mineralogical evidence,<sup>2</sup> represents one of these geochemically-related magmas.

*The Harding pegmatite geochemical environment favorable for tantalum enrichment.*—Rankama's (1944) classic research on Ta geochemistry shows that (1) this element is a typical associate of Cb and the rare earths, (2) in minerals it replaces most easily tetravalent Ti, Zr, Sn and W, and less easily, trivalent Cr and Mn, (3) at high temperatures it is most easily incorporated into the minerals, sphene, rutile, anatase, brookite, columbian rutile, cassiterite, wolframite, zircon, thorite, monazite and tourmaline, (4) it least easily enters the structures of apatite, garnet, beryl, iron oxides, sulfides, quartz and silicates in general (excluding titaniferous types, as biotite), (5) granites are far richer in it than other rocks, (6) it possesses a high energy of ionic migration, or high E-value (Wickman, 1944, p. 373), (7) it is not found in concentrations (as tantalum minerals) in early crystallized igneous rocks, but in those of late-magmatic stage, as pegmatites.

Points (6) and (7) appear to be anomalous, for with high energy necessary for ionic migration tantalum should be able to enter structures of high-temperature-formed minerals of early magmatic stage. Wickman (1944, p. 388) has answered this by suggesting that the minerals most apt to incorporate Ta at high temperature are so rare in early magmatic igneous rocks, that there is no favorable resting place for the element during that stage. It is thus left over for late-stage concentration. A normal granite with the usual high-temperature accessories, sphene, zircon and rutile, would house Ta in these minerals. If a crystallizing

<sup>1</sup> Late pre-Cambrian or younger.

<sup>2</sup> Discussed under *Dixon granite* and *Pegmatites* in Montgomery (1950).



granite largely lacked such accessories, were also lean in biotite, and had been originally Ta-rich, then Ta conceivably might be left mostly free for abnormal concentration in later-formed genetically-related pegmatites. Such concentration would be further enhanced by a tendency for tantalum to form independent Ta-rich minerals alone, rather than to be dispersed as traces among other pegmatite minerals. This would be particularly true if such Ta-receptive hosts as monazite, titanium and rare-earth minerals, cassiterite, rutile, tourmaline, etc., were lacking in the pegmatite. Bray's (1942, p. 797) geochemical investigation of rocks of the Jamestown area, Colorado, found that pegmatite minerals there typically contained less of almost every rare element than the same minerals of related parent granites. His explanation was that the structures of the pegmatite minerals would be less open and less tolerant to rare-element substitution at their lower crystallization temperatures. In such a hypothetical case as outlined above, Ta might be left free in great quantity at a late stage of pegmatitic consolidation and be more or less forced to form crystallized compounds in its own right, provided the appropriate environment with a sufficiency of requisite chemical elements were available.

The Ta geochemistry and mineral paragenesis of the Harding pegmatite perfectly fit the hypothetical case above. No Ta-receptive minerals are present in the pegmatite other than the independent Ta-rich minerals, columbite-tantalite and microlite. All the granite that borders the pegmatite on the south and west is unusually lean in sphene, zircon and rutile, and biotite is not abundant. Abundant Ca would have been available for late-stage microlite formation from pegmatitic replacement of amphibolite. Spectrochemical analysis shows the latest-formed, structurally controlled yellow microlite of the southeast zone to be purer and far richer in Ta than the earlier-formed black microlite and columbite-tantalite of the central and northeast mineral zones.

*The immediate tantalum source during pegmatite formation.*—The two sections above have brought out evidence for an original Ta-rich granitic magma in the Harding area and for that special geochemical environment favoring an exceptional Ta-enrichment in the Harding pegmatite. The final section deals with the most fundamental problem of all; namely, the reasons for the great and specific Ta source which must have been immediately available for this particular crystallizing pegmatite.

This study began three years ago when it was realized that significant geochemical clues bearing on the problem would depend on detailed geologic mapping backed by accurate spectrochemical analyses. Since then the geology of the area has been mapped (Montgomery, 1950) and the background lithology clarified; special attention was given to

the Dixon granite. Dr. Harold C. Harrison, now at Rhode Island State College, cooperated in the study by setting up Ta standards and making many spectrochemical analyses. Much of the result depends upon his work.

Field work and spectrochemical research together were able to give both Rankama and Bray several highly significant geochemical correlations between certain rare-element-bearing pegmatites and quartz veins and genetically-related igneous rocks. Rankama (1944, p. 67) found in the Tammella, Finland, pre-Cambrian igneous complex that only the youngest granite contained Ta, and that it was this particular rock alone which could be related by field evidence to tantalum pegmatites of the area. Bray (1942, pp. 786-87) found in the Jamestown, Colorado, igneous complex that a cerium-rich granite could be related to cerite-bearing pegmatites of the area and that a vanadium-rich granodiorite probably was related to certain pyritic veins of the area containing the vanadium mica, roscoelite. It was hoped in the present study to find similar geochemical clues, especially since there was only one possible related igneous rock, the Dixon granite.

It was thought that the Dixon granite might contain sufficient Ta to be detectable by Harrison's spectrochemical analysis. Rankama (1944, p. 54) found an average Ta content of about .0004% for all granites investigated by him, and .0007% for the Ta-bearing younger ones. Several Ta-rich granites contained more than .001% Ta (Rankama, 1944, p. 36). The Dixon granite is a "younger" granite and has been dated in terms of the Harding pegmatite at about 800 million years (Ahrens, 1949, p. 252), or late pre-Cambrian.

Rankama's determinations of minute percentages of Ta depended upon  $\alpha$ -ray spectrography and chemical pre-enrichment. Without such means, using the Harvard optical 2-meter grating spectrograph and a modified cathode-layer excitation technique, and finding the 2714 Å line to be the most sensitive, Harrison was unable to detect Ta in any Dixon granite samples. He was able to verify qualitative Ta estimates on sphene as low as .001-.002%. Sphene was selected because it had been found in quantity in certain parts of the Dixon granite. A number of sphenes from well-known localities had already been analyzed for Ta by Rankama (1944, p. 30) and von Hevesy (1929, p. 95). Sphenes in the Harvard mineral collection from identical localities were run by Harrison, and the tabulated results show good agreement (see Table 1). Sphene collected from Dixon granite several miles east of the Hardiny Mine showed a clearly detectable tantalum content of approximately .003%. Although the range of sensitivity used was too low for detection of Ta below .001%, this very fact minimized contamination problems

and strengthened authenticity of results. Tantalum was sought in appreciable quantity, or not at all.

A study of the Dixon granite brought out two facts of great interest: all observed granite outcrops south and west of the mine contain traces of sphene and zircon, and no rutile; all observed granite outcrops from 2 miles southeast of the Harding Mine and for 6 miles eastward past the Picuris Pueblo show similar traces of zircon and no rutile, but also abundant sphene in the form of thinly disseminated flat crystals of average 1–3 mm. length. These last may be outlined by white leucoxene, and are easily seen with a hand lens. The sphene-bearing granite contains a minimum average of .3% sphene; in some areas it contains

TABLE 1. Ta CONTENT OF TITANIUM MINERALS

	Rankama Ta <sub>2</sub> O <sub>5</sub> %	von Hevesy Ta <sub>2</sub> O <sub>5</sub> %	Harrison Ta %
Sphene, Eganville, Ontario	.001	.007	.001 (SiO <sub>2</sub> removed)
Sphene, Arendal, Norway		.003	.003–.005
Sphene (95% pure), Dixon granite, New Mexico			.003
Yttrotitanite, Kragerö, Norway		.01	.05–.08
Perovskite, Magnet Cove, Ark.	.01		(undetected)
Perovskite, Achmatowsk, Urals	.002	.0015	.001–.002

up to 4%. In this paper the darker biotite-rich sphene-bearing Dixon granite will be called the *Peñasco granite*, and the more metamorphosed, sphene-free Dixon granite south and west of the Harding Mine, the *Harding granite*. A third type of Dixon granite occurs further north-eastward in the range, almost lacking in dark minerals, and is a leucogranite. The Peñasco granite is fresher and darker than the Harding granite. Study of the Dixon granite (Montgomery, 1950) shows this rock to be everywhere microcline-rich and of quartz monzonite character. It is high in silica and alkalis, and low in MgO and CaO. In most thin sections albite-oligoclase slightly exceeds microcline; orthoclase is absent. Porphyritic phases, with 10–20% of large microcline phenocrysts, occur near the Picuris Pueblo and west of the mine. Some of the more altered granite near the mine shows a small amount of muscovite of hydrothermal origin instead of biotite. Chemical analyses show the Peñasco granite to carry slightly more TiO<sub>2</sub> than the average Harding granite, as well as more Fe, Mg, Ca, but less silica. Differences appear largely due to differential assimilation effects. The importance of such assimilation is not known, but xenoliths of an inferred original dacitic

type are numerous all through the western area of the darker Peñasco granite; assimilation of such rock is believed responsible for the slightly more mafic character of the Peñasco granite. West of the Harding pegmatite most of the granite has cut across muscovite schists, and a few schistose inclusions have been found in it; assimilation of such rocks is believed partly responsible for its more felsic composition, lighter color and porphyritic character, although more severe metamorphism has also affected the resulting rock. Where amphibolites 1 mile southwest of the mine have been crosscut by granite, the granite ceases to be porphyritic and becomes much darker and biotite-rich; but it contains no sphene. Much meta-rhyolite and meta-quartz-latitude are believed to have been assimilated by large masses of Harding granite which now appears as strongly metamorphosed granite, either light-colored or biotite-bearing, south of the mine and the Rio Pueblo.

Although differential assimilation effects thus furnish very important geochemical clues, they may not be responsible for the varying sphene content of the Harding and Peñasco granites. Darker biotite-rich granite southwest of the mine does not contain sphene. Comparison of chemical analyses of Peñasco and Harding granites (Montgomery, 1950) shows slightly less  $\text{TiO}_2$  in the latter (.30% in the Harding granite (3 analyses), as against .46% for the Peñasco (2 analyses)). This difference is not believed sufficient to explain the absence of abundant sphene in the Harding granite; the difference is more likely related to the smaller biotite content of most of the Harding granite. Analysis of the darker biotite-rich Harding granite (not included in the  $\text{TiO}_2$  percentages above) shows .55%  $\text{TiO}_2$ . It is possible that sphene crystallization in the Harding granite may have been prevented because of the more severe metamorphism suffered by it, perhaps during early stages of consolidation. This portion of the Dixon granite was more exposed to deformation and metamorphism because it apparently represents the earliest-crystallized, quickest-cooled outer shell of the intrusive. The sphene-bearing Peñasco granite is believed to represent a deeper-level, more protected portion of the intrusive.

Two points have been demonstrated: that it is all the same granite, and that near the mine the granite is sphene-free as compared to the sphene-rich Peñasco granite some distance removed. Assuming the Ta content to have been constant for the granitic magma giving rise to both Peñasco and Harding granite types, the absence of this sphene in the crystallizing Harding granite is believed to have left free the amount of Ta proved by spectrographic analysis as present in the sphene alone of the Peñasco granite. It would not require a very large body of crystallizing granite magma *without the sphene* to supply sufficient Ta from this

one unlocked source for all the great tonnage of Ta minerals found within the Harding pegmatite. Based on the spectrochemical analyses, a square-mile of the Peñasco granite 1,000 feet thick contains 200 tons of Ta in its sphene alone.

#### ADDITIONAL FACTORS NEEDING CONSIDERATION

Rankama found .004% as an average Ta content for all Ta-bearing granites investigated by him. Only a tenth of this amount can be accounted for in the average Peñasco granite in terms of likely Ta contents for individual minerals present. The following rough estimates are largely based on Rankama's (1944, pp. 25-32) findings for the minerals concerned:

TABLE 2. ESTIMATED TOTAL Ta IN PEÑASCO GRANITE

	% of mineral in granite	Ta content of mineral in %	Ta content of granite in %
Coarse sphene (Harrison)	> .3	.003	.00001
Zircon, allanite, sphene, rutile (?), apatite	.01- .1	< .01	.00001
Magnetite, ilmenite (?), pyrite	.1 - .5	< .0001	.0000005
Epidote, sericite, kaolin	.5 - 1.0	< .00001	.0000001
Biotite (Harrison: <.001% Ta), muscovite (minor)	6.0 -10.0	< .0001	.00001
Albite-oligoclase	31.0	< .00001	.0000031
Microcline	26.0	< .00001	.0000026
Quartz	32.0	< .00001	.0000032
Total Ta in granite			.0000395%

The discrepancy is large, even though it has been suggested (Rankama, *priv. comm.*, 1950) that much of it may be due to large local variations of Ta content to be expected in granitic minerals. Rankama (1944, p. 52) anticipated some such possible anomalies by suggesting that some Ta might occur in Ta-rich rocks in the form of alkali tantalates as included substances. A small amount of undetectable Ta might be so dispersed but the relatively large quantity, which this study suggests may be missing, surely would be observable, recoverable and detectable regardless of its chemical state. The only way to clear up such a possible discrepancy would be to take such a Ta-rich granite as the Dixon granite is believed to be and, by means of  $x$ -ray spectrography and chemical pre-enrichment, to check and recheck the over-all Ta content, then to analyze for Ta each separated and purified mineral constituent in turn. In this way the whereabouts of any missing Ta should be discovered.

A final vital question must be answered: could the Harding Ta concentration be due to greatly increased volume of pegmatite alone? Rough estimates based on a careful mineralogical study of columbite-bearing Picuris pegmatites, and comparing one of the latter of typical outcrop size (200 feet long by 2 feet thick) and allowing for 1 inch of depth as surely exposed by weathered and broken pieces all along the outcrop, do not bear this out. Allowing for several ounces of columbite in the rock so exposed, a liberal allowance in terms of the very few minute columbites ever exposed along the whole of such an outcrop, a ratio of 1 lb. of Ta to 50-100 tons of pegmatite is the result. Mining and drilling have proved for the main present mass of the Harding pegmatite a minimum ratio of 1 pound of Ta to 8 tons of pegmatite. To explain the Harding Ta concentration, there would have to be nearly a ten-fold Ta increase above the maximum Ta content observed in columbite-bearing pegmatites of the area. A similar increase would be necessary for Be; for Li the increase would be fantastic. Why should the Harding body carry an extra abundance of these rare elements, far above all other Picuris pegmatites of similar and related type, because of greatly increased size alone? It is not necessary for a pegmatite rich in rare elements to have large size. Would not the simplest explanation be that the exceptional rare-element concentration found in the Harding depended upon an open system, fed during pegmatite consolidation by some sort of granitic or pegmatitic magma below? Much evidence explains the bulk of the Harding Ta-Be-Li enrichment as due to a long-continued process in which hydrothermal solutions from granitic magma below successively invaded a large partly-consolidated pegmatite mass undergoing severe structural deformation.

#### CONCLUSIONS

The exceptional Ta enrichment in the Harding pegmatite is believed due to these factors:

- (1) a genetically related Ta-rich granite;
- (2) some indirect wall-rock control which, during pegmatitic replacement of amphibolite, supplied to adjacent and replacing pegmatite the Ca needed for abundant formation of the rare Ta mineral, microlite;
- (3) a uniquely favorable environment in which the parental crystallizing granite lacked the usual Ta-receptive minerals, and consolidating pegmatite itself lacked such minerals;
- (4) specific absence of abundant Ta-bearing sphene, present in the same granite elsewhere, from all pegmatite-adjacent granite, which during crystallization of that granite may have freed, or left free, sufficient Ta from this source alone to supply the entire Harding enrichment;

- (5) a long-continued process of deformation acting upon the consolidating pegmatite, fracturing it and keeping it open and accessible to successive invasions of hydrothermal solutions from granitic magma below which was under stress and being squeezed of its pegmatitic juices by great regional forces.

## ACKNOWLEDGMENTS

Sincere thanks go to Drs. Clifford Frondel, C. S. Hurlbut, Jr., R. H. Jahns and Kalervo Rankama for critical reading of the manuscript and many helpful suggestions. Grateful acknowledgment is made for the spectrochemical research carried out by Dr. Harold C. Harrison, and for the preparation of several chemically-enriched samples by Mr. F. A. Gonyer. Dr. Ping Hsi Chang first suggested one of the principal ideas developed in this paper.

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