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## THE HARDING PEGMATITE: SUMMARY OF RECENT RESEARCH

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## INTRODUCTION

The Harding pegmatite, located in the western part of the Picuris Range about 30 km southwest of Taos, lies 7 km southeast of the Rio Grande Canyon at an altitude of 2,260 m (sec. 29, T23N, R11 E) and is readily accessible from a nearby point on State Highway 75 about 10 km east of Dixon (fig. 1). The locality is unique because it has yielded commercial quantities of beryl, lepidolite, spodumene and microlite over a period of a half a century. It also has become a widely known source of handsome mineral specimens, a provocative locality for scientific studies, and a mine noted for its spectacular exposures of pegmatite. The pegmatite itself is a classic locality and point of controversy for those workers who have addressed the question of the origin of pegmatites (Burnham, 1967; Gresens, 1967; Jahns and Burnham, 1957, 1969).

In 1974, Dr. Arthur Montgomery approached the University of New Mexico with an offer to donate the property to the University so that it might be preserved as one of the State's unusual natural assets. Since that time, the University has leased the property from Dr. Montgomery until the transfer of title could be completed. During the past five years, the University has done the yearly assessment work, modified the mine to insure the safety of the public, retained a caretaker for the mine property, designed and completed a walking tour of the mine's surface workings, established museum and research collections of pegmatite specimens, and supported faculty and students in research programs concerning the pegmatite. The Harding pegmatite is now an integral part of the teaching and research program at the University of New Mexico.

The mine property includes both patented and unpatented claims so that the transfer of the title has required the transfer of federal lands to state lands. The transfer literally has reguired an "Act of Congress" (Senate Bill 1403). The bill was signed by the President as part of Public Law 95-550 on October 30, 1978. The law requires that: (1) the University make application for conveyance, (2) that the conveyance be made "at the fair market value" of the land, (3) that the University provide satisfactory assurances to the Secretary of Interior that no other valid mining claims exist on the transferred lands, and (4) that necessary land surveys be completed. Even with the transfer of title, the United States retains the right to mine strategic minerals should it become necessary for the security of the United States. All royalties from such mining would go to the United States. The faculty of the Department of Geology are indebted to Dr. Montgomery and to the University of New Mexico for their time, resources and patience during this complicated process.

The University plans to make this classic locality continually available for public inspection, study and mineral collect-

#### Present Address:

ing on a modest scale. During the summer of 1978, well over 500 visitors from over twenty universities and colleges visited the mine. Anyone with an interest in visiting the property should contact the Chairman, Department of Geology, University of New Mexico, 87131 to obtain permission. A splendid collection of representative Harding minerals, donated by Dr. Montgomery, can be viewed in the University's Geology Museum.

This paper is a brief summary of the work of students and faculty of the Geology Department at the University of New Mexico. A more extended discussion of this work may be found in the indicated references. For a detailed discussion of the geology, mineralogy and mining history of the Harding pegmatite see Jahns and Ewing (1976, 1977).

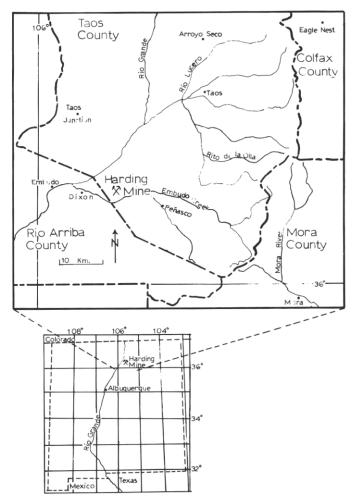


Figure 1. Index map showing location of the Harding mine (Cook, 1979).

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#### **GEOCHRONOLOGY**

Ahrens (1949) reported a Rb-Sr age of 800 m.y. for the Harding pegmatite. Aldrich and others (1958) reported K-Ar and Rb-Sr ages of 1,260 m.y. for a Harding lepidolite. Fullagar (unpublished) reported Rb-Sr model ages of 1,449 and 1,476 m.y. for potassium feldspars in the pegmatite. He also reported model ages of 1,655 and 1,416 m.y. for a fine-grained phase; however, the zone from which the sample was collected is unknown. Gresens (1975) reported a K-Ar age of 1,335 m.y. for a muscovite from an unnamed pegmatite in the Picuris Range.

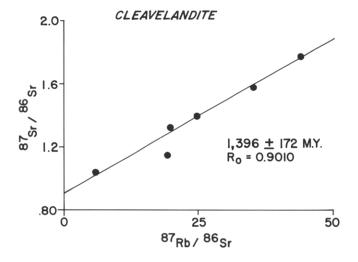
The forty-two samples analyzed in this study consist of whole rocks and mineral separates. Whole-rock samples are defined to be at least ten times larger than the coarsest grains or perthitic component; this insures a representative sample. Four whole-rock samples were collected from the "spotted rock" unit which is fine-grained enough to allow such sampling. Mineral separates were handpicked in the field, and later carefully cleaned of impurities in the laboratory to insure 99 percent purity. Rubidium and strontium concentrations were determined by standard isotope ,dilution techniques using 87 Rb and 84 Sr spikes. The 85 Rb/87 Rb ratio was taken to be 2.591, and the decay constant for 87 Rb was taken as 1.42 x  $_{10}$ -4  $\boldsymbol{y}$  Analyses of Eimer and Amend standard SrCO $_{3}$  give an average normalized 87 Sr/86 Sr ratio of 0.7080 with a standard deviation of 0.0003. All Rb-Sr ages and initial 87 Sr/86 Sr ratios have been calculated using the least-squares cubicregression method of York (1969). One-standard-deviation experimental errors of 0.05 percent and 1 percent have been assigned to  $(^{87} Sr/^{86}Sr)_N$  and  $^{87} Rb/^{86} Sr$ , respectively.

The linear fit to the Rb-Sr data for five wall-zone muscovites yields an age of 1,529  $\pm$  42 m.y. and an indicated  $^8$  7 Sr/ $^8$  6 Sr initial ratio of  $-3.6064 \pm 1.3264$ . The initial ratios on this and some of the other isochrons are meaningless due to the extrapolation from such high x, y data to the y-axis (Register, 1979). The age of these muscovites is slightly older than what might be considered to be the age of the pegmatite (i.e. reflected by the age of the pegmatite whole-rocks). This may be a result of mixing between the surrounding older country rock and the wall zone during injection. Jahns and Ewing (1976) report that the border rind has a different composition from the rest of the pegmatite, the former being richer in Na<sub>2</sub>0, poorer in K<sub>2</sub>0 and Si0<sub>2</sub>. These data suggest exchange of cations.

The linear fit of the Rb-Sr data for cleavelandites from the cleavelandite-quartz zone yields an age of 1,396  $\pm$  172 m.y. and an indicated  $^{87}$ Sr/ $^{86}$ Sr initial ratio of 0.9010  $\pm$  0.0339 (fig. 2). The data for whole rocks from the "spotted rock" unit yield an age of 1,336  $\pm$  73 m.y. (fig. 2). The average of these two ages, 1,366 m.y., may be taken to be the average age of the pegmatite, as sample selection and linearity of the data suggest little if any mixing or resetting of ages due to subsequent thermal events.

Lepidolite and rose muscovite are considered to be late in the paragenesis of the pegmatite, and are typical minerals in replacement textures. Lepidolite data yield an age of 1,246  $\pm$  40 m.y.; and rose muscovite, 1,264  $\pm$  128 m.y. These younger ages may indicate that replacement mineralization by lepidolite and rose muscovite occurred during the final stages of pegmatite crystallization.

Data for perthites from the blocky perthite zone yield an age of 1,121  $\pm$  6 m.y. and an indicated  $^{87}$  Sr/ $^{86}$  Sr initial ratio of 3.6492  $\pm$  0.0497. Whether this anomalously young age is due



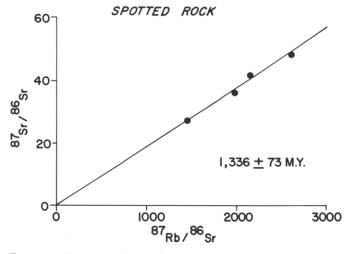


Figure 2. Rb-Sr isochrons for cleavelandite and the "spotted rock" unit (Register, 1979).

to the lack of data or to a loss of radiogenic strontium from the perthite is indeterminable. Rare-earth element data (Register, 1979) indicate a late-stage origin for the perthite with a positive europium anomaly. This is consistent with the younger age; however, fluid inclusion and stable isotope data (Cook, 1979), coupled with field evidence, suggest early stage formation. Thus, loss of radiogenic strontium may be a plausible explanation for the anomalously young age.

Perthitic microcline occurring as remnants of the blocky perthite zone in the replacement mass of the cleavelandite-quartz unit yield an anomalously young age of 718 m.y. and an indicated \$^5Sr/\$^5Sr initial ratio of 5.3356. The least-squares fit for a straight line was not employed on this iso-chron due to the high degree of scatter of the data. A best-fit line yields a 0.64 correlation coefficient. This scatter may be responsible for the dramatic deviation in age or it may be due to loss of radiogenic strontium from the microcline. As with the microcline, a best-fit line was used for the sugary albite data, with a correlation coefficient of 0.85. The linear fit yields an anomalously old age of 5,253 m.y. and an indicated \$^7 Sr/\$^6 Sr initial ratio of 0.7981. If radiogenic strontium was lost from the early stage perthite and microcline phases, the

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Table 1. Summary of Pegmatite Rb-Sr Age Dates

Sample	Age (x 10 <sup>6</sup> m.y.)
Wall-Zone Muscovites	1,529
Cleavelandites	1,396
"Spotted Rock" (whole rock)	1,336
Rose Muscovites	1,264
Lepidolites	1,246
Perthites	1,121
*Microclines	718
*Sugary Albites	5,253

<sup>\*</sup>best-fit line instead of least-squared regression for the isochron

sugary albite may have acted as a sink for the strontium, resulting in the anomalously old age.

The summary of the determined ages and initial ratios for the lithologic units of the Harding pegmatite is presented in Table 1. Within the pegmatite itself, the wall zone was the first to crystallize with some exchange with surrounding country rock, followed by the perthite and the microcline. These two phases probably lost radiogenic 87 Sr during the early stages of crystallization, as reflected by their apparently young ages. The massive quartz zone probably crystallized at about the same time as the perthite and microcline, or perhaps afterwards, as suggested by fluid inclusion data (Cook, 1979). Cleavelandite replaced most of the microcline, followed by the formation of the "spotted rock" unit, or the core. The radiogenic 87 Sr lost from the perthite and the microcline may have been picked up at a later time, during the formation of the sugary albite. Replacement mineralization by lepidolite and rose muscovite probably occurred during the final stages of pegmatite crystallization. This sequence is generally consistent with field evidence, rare-earth element data (Register, 1979) and fluid inclusion work by Cook (1979).

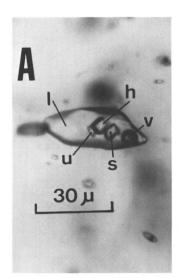
### FLUID INCLUSIONS

As minerals crystallize in the presence of a fluid medium, they trap small quantities of the fluid. These entrapped fluids, or fluid inclusions, occur along growth irregularities and, under certain conditions, are actually preserved "samples" of the fluid present at the time of mineral growth. These primary fluid inclusions provide information about the conditions of host-mineral formation. Fluid inclusions also occur as isolated or interconnected pockets of fluid wetting the surfaces of fractures or cracks in minerals. Fluids trapped in re-sealed fractures after the crystallization of the host mineral form secondary fluid inclusions. Fluid inclusion diameters from 1.0 cm to 10<sup>-7</sup> mm are known, but they are usually less than 0.01 mm in diameter. The large number of microscopic fluid inclusions (> 109 inclusions/cm3) gives quartz its milky appearance, though the total volume of inclusions may be only a few tenths of 1 percent. The entrapped fluid is normally an aqueous solution. Roedder (1962, 1967, 1972) and Smith (1953) provide excellent reviews and summaries of the basic tenants of fluid-inclusion research. A detailed discussion of special considerations applicable to pegmatite studies is given in Cook (1979).

Fluid inclusions in mineral specimens from the Harding pegmatite were investigated in order to determine the following: (1) the temperature of crystallization of the host minerals, (2) the salinity and approximate chemical composition of the fluid at the time of host-mineral growth, and (3) the fluid pressure. A total of 62 samples representing all the lithologic units was collected from surface and underground workings. From these samples, approximately 150 optically polished plates were prepared. In all, more than 500 fluid inclusions were examined, with detailed measurements on 454.

A number of inclusion types was observed (fig. 3). Primary fluid inclusions contain  $CO_2$ -rich aqueous fluids or are essentially pure  $CO_2$ . Daughter minerals (solutes originally in solution at elevated temperature of entrapment) are not typical of these inclusions. Secondary fluid inclusions are either  $CO_2$ -rich or aqueous saline fluids  $\pm$  daughter minerals. Single-phase  $CO_2$  secondary inclusions also were observed. Of particular interest is the occurrence of silicate melt (glass) inclusions in early zones of the pegmatite. Fluid inclusions are present in all phases but are best suited for detailed study in quartz and beryl. Detailed descriptions of all fluid-inclusion types, and numerous photomicrographs are presented in Cook (1979).

Temperatures are obtained from fluid inclusions by assuming that the entrapped fluid was originally a single-phase fluid at some elevated temperature. Upon cooling to ambient temperature, the fluid separated into a liquid and a vapor bubble. By heating the host mineral chip in a heating stage mounted on a microscope while observing the fluid inclusion, the temperature at which the two-phase inclusion homogenizes to a single phase fluid is recorded. This is a minimum temperature of entrapment. A bimodal distribution of homogenization temperatures is readily apparent for inclusions from the wall zone, massive quartz zone, and quartz-lath spodumene zone (fig. 4). Primary inclusions from the massive quartz zone homogenize at lower temperatures, 301° to 325°C; saline secondary inclusions, 76° to 100°C. Primary inclusions from the quartz-rich spodumene zone homogenize at temperatures of 301' to 325°C; and saline secondary inclusions, 76' to 100°C. Temperatures from the "spotted rock" zone indicate temperatures of homogenization from 275° to 300°C.



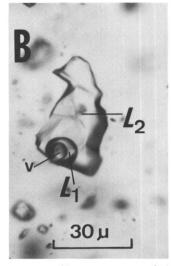


Figure 3. (A) Fluid inclusion with liquid (I), vapor bubble (V) and daughter minerals, halite (H), sylvite (S) and unknown (U). (B) Fluid inclusion with two immiscible liquids, aqueous  $(L_1)$ ,  $CO_2$  liquid  $(L_2)$  and vapor (V).

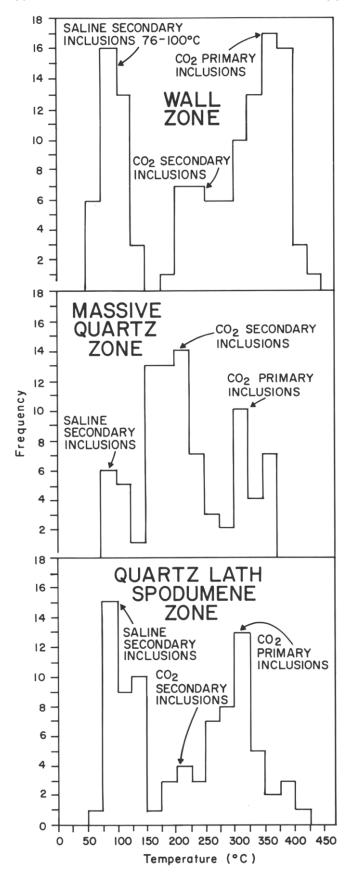


Figure 4. Histograms of homogenization temperatures of the wall zone, massive quartz zone and quartz-lath spodumene

An estimate of inclusion fluid salinity is obtained by measuring the freezing point depression of the entrapped fluid while observing the fluid inclusion on a freezing stage. A total of 350 measurements was made on 74 samples. A histogram of salinity as equivalent weight-percent NaCI for all data from the wall zone, massive quartz zone and quartz-lath spodumene zone is presented in Figure 5. Saline secondary-fluid inclusions have a consistent salinity of 28 to 30 weight percent NaCI. Primary inclusions average 14 to 16 weight percent NaCI. The salinity measurements for all primary inclusions are variable, but are not related to the CO<sub>2</sub> content of the inclusions. No systematic variations between zones have been identified.

An estimate of fluid pressure was made by use of combined oxygen-isotope data, and the NaCI and  $CO_2$  content of fluids in the inclusions. Geometry and textural relations of Harding pegmatite minerals suggest that the lithostatic pressure could not have been significantly greater than the fluid pressure. By three independent methods, the fluid pressure is estimated to be approximately 2.0 to 2.5 kbar (6.0 to 7.5 km depth). This pressure range requires a correction to the measured homogenization temperatures of as much as  $\pm$  175°C.

### MICROLITE MINERALOGY

Microlite belongs to the pyrochlore group, a complex group of cubic Nb-Ta-Ti oxides with the general formula A2- $_{\scriptscriptstyle \parallel}$  B206 (0,0H, F), • pH $_{\scriptscriptstyle 2}$ 0 (A = Na, Mg, K, Ca, Mn, Fe $^{\scriptscriptstyle 2+}$ , Sr, Sn, Sb,

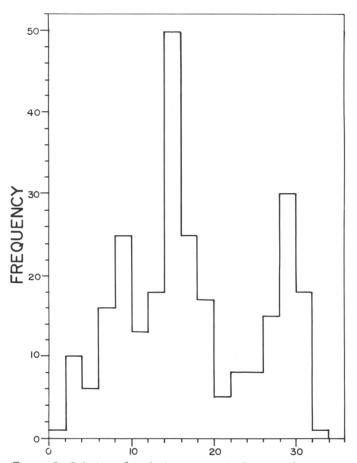


Figure 5. Salinity of inclusions as equivalent weight-percent NaCl for the wall zone, massive quartz zone and quartz-lath spodumene zone.

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Ba, Pb, Bi, REE, Th,  $U^{\text{s-}}$ ,  $U^{\text{s-}}$ ; B = Ta, Nb, Ti,  $Fe^{\text{3-}}$ ; m = 0 to 1, n = 0 to 1, p = 0 to ?). The Harding pegmatite is noteworthy because it has produced the largest amount of microlite in the world. During the five-year period, 1942-1947, the pegmatite yielded over 10,000 kg of Nb-Ta concentrate. Baker (1945) described the pegmatite as the world's largest deposit. Additional blocked-out reserves of low-grade ore remain in place (Berliner, 1949; Soule", 1946).

Hirschi (1928) first described microlite as occurring in the base of the quartz-lath spodumene zone. Page (1950) and Jahns (1953) reported hatchettolite, both referring to the dark mineral in 1.0 mm-size crystals dispersed in the "spotted rock." Jahns and Ewing (1976, 1977) note that this common reference is incorrect; the mineral is a uranian microlite. Suchomel (1976) gives an incomplete occurrence description. This report is a condensation of the occurrence description and x-ray diffraction study made by Chakoumakos (1978).

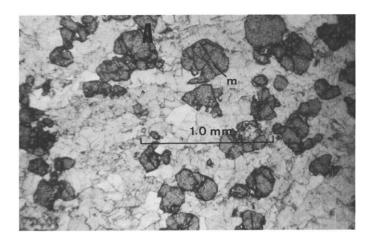
Microlite is a common accessory in three of the eight lithologic units, in replacement masses in the wall zones, and in core units of the eastern extensions of the dike system. Samples display a large range of physical properties due to alteration, metamictization and variable chemistry (fig. 6). Anhedral to euhedral crystals range from 0.1 to 25 mm in size, most commonly 0.5 to 3 mm. Crystals occur dispersed and isolated, intergrown with one another or as dense aggregates. Modified octahedral and dodecahedral forms, with rough and bloated faces, are observed. Dull, vitreous and highly glassy lusters are displayed on uneven to broad conchoidal fractures. Color is extremely variable: nearly white or colorless, straw yellow, honey yellow, yellow-brown, bronze-brown, dark maroon, dark brown, chocolate brown and almost black. Color-zoned crystals are common, generally with thin dark rinds around light-colored cores. The reverse is rare. Crystal exteriors typically are mottled. Cleavelandite, quartz and microcline are the common host minerals, and less commonly, spodumene and beryl. Inclusions of albite, quartz, lepidolite and microcline are common. Microlite occurs intergrown with and included in columbite-tantalite and zircon.

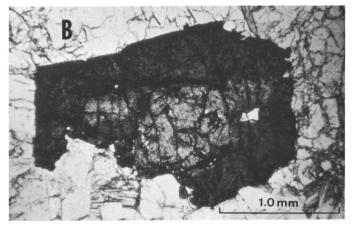
The microlite varies from completely crystalline to completely metamict. Typically, the metamict samples are microfractured and show fraCture-controlled alteration; the perimeters of the grains are affected most. Host minerals commonly are stained rusty brown where in contact with microlite. The adjacent quartz matrix is typically smoky, the result of radiation damage.

Microlite occurs late in the paragenesis of the pegmatite. Most of the wall zones were consolidated prior to the first crystallization of microlite. In the thick western portion of the main dike, microlite began crystallizing in the quartz-lath spodumene zone. Most of the spodumene crystallized to form a jackstraw mesh of large crystals. Quartz ± lepidolite ± microlite then crystallized to form the interstitial matrix. Microlite continued crystallizing during the formation of core units. The major segregation resulted as dispersed crystals within the microcline of the "spotted rock." Core units in the eastern extensions of the dike system contain microlite as a principal accessory. Microlite accompanied much of the late-stage replacement and some fracture fillings. Microlite continued crystallizing until the final stages of the pegmatite crystallization as indicated by: (1) microlite embedded in euhedral microcline protruding into open cavities along the crest of the "spotted rock," (2) euhedral microlite included in cleave

landite pseudomorphs after spodumene in portions of the quartz-lath spodumene zone, and (3) microlite in fracture-controlled replacement bodies within wall zones.

Thirty located samples, three high-grade ore samples and two analyzed samples have been examined by x-ray powder diffraction (Debye-Scherrer camera, 114.6 mm; Cu/Ni radiation). X-ray patterns were corrected for shrinkage and indexed on a face-centered cubic unit cell (a 10 A). Unit-cell dimensions were calculated using a least-squares program (Appleman and Evans, 1973). The samples ranged from completely crys-





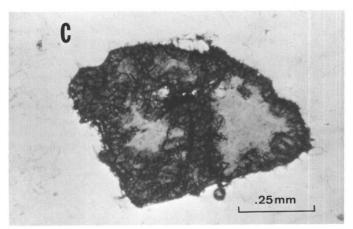


Figure 6. Transmitted-light photomicrographs of microlite: (A) subhedral crystals (m) in lepidolite-cleavelandite matrix; (B) typical zoned crystal; (C) highly altered and microfractured rim surrounding the intact core.

talline to completely metamict. No relationship between lithologic unit and degree of crystallinity was noted. The patterns of crystalline samples showed sharp back reflections and separation of the  $K_{\rm a}$  doublet. Patterns of metamict samples showed few, if any, diffuse reflections. The (222) reflection, one of the three most intense, was the most persistent in the metamict samples. The mean unit-cell volume for 19 unheated microlites is 1131.4  $\mbox{\ensuremath{A}}^3$ .

Samples were recrystallized in air for 10 hours at 1000°C, air quenched and re-examined by x-ray diffraction. After heating, the metamict samples produced patterns with more and sharper reflections. The major recrystallized phase in all the samples was microlite. Most samples were originally crystalline or only partially metamict, so that domains of microlite provided nucleation sites during recrystallization. For the samples that were metamict prior to heating, the resulting patterns had numerous reflections that could not be indexed. These additional reflections probably correspond to other Nb-Ta oxides. The mean unit cell volume for 35 heated microlites is 1121.8 A<sup>3</sup>.

Three microlites (crystalline, partially metamict and metamict) were heated in  $100\,^\circ\text{C}$  intervals for 1 hour in air over the range  $300\,^\circ$  to  $1000\,^\circ\text{C}$ . The samples were air-quenched at each temperature interval and examined by x-ray diffraction. All samples recrystallized microlite at all intervals and showed decreasing unit-cell size with increasing temperature. The metamict sample began recrystallizing between  $300\,^\circ$  and  $400\,^\circ\text{C}$ , and the partially metamict sample between  $400\,^\circ$  and  $500\,^\circ\text{C}$ .

Two microlites (crystalline and metamict) subjected to differential thermal analysis (DTA, air ignition, heating rate =  $25\,^{\circ}$ C/min) show similar peaks. Both DTA curves have endotherms between  $150\,^{\circ}$  and  $300\,^{\circ}$ C, corresponding to dehydration. The endotherm for the metamict sample is at a lower temperature and more pronounced. The metamict sample exhibits a major exotherm at  $535\,^{\circ}$ C, corresponding to recrystallization. The crystalline sample lacks this exotherm.

The few analyses of Harding microlites (5, Jahns and Ewing, 1976; 30, Suchomel, 1976) indicate a range of Ta<sub>2</sub>O<sub>5</sub> concentrations of between 59 and 75 weight percent. All analyzed samples belong to the microlite subgroup of the pyrochlores because the weight percent  $Ta_2O_5 > Nb_2O_5$ . The dominant A-site cations are sodium and calcium. Thus, these specimens must be assigned to the microlite species (Hogarth, 1977). Uranium is sometimes an important constituent, approaching 5 percent of the A-site cations, particularly in the metamict samples. Fluorine and water contents are related inversely to one another. The range from light to dark colors is correlated with decreasing Ta + Nb content and Ta/Nb ratio; with increasing OH/F ratio; and with increasing U, Ti and Mn contents. The ratio Ta205/(Ta205 Nb<sub>2</sub>O<sub>5</sub>) ranges from 0.84 to 0.95. The analyses by Jahns and Ewing (1976) correspond well with the general formula and exhibit only slight A-site deficiencies.

The physical properties of the Harding microlite vary greatly due to alteration, metamictization and variable chemistry. Dark color, broad conchoidal fracture, glassy luster and microfracturing are properties characteristic of the metamict samples. Pronounced "radiohaloes" and rusty staining are additional effects in adjacent grains. In some grains, highly altered and microfractured perimeters around intact cores suggest an uneven distribution of uranium and thorium or external alteration by hydrothermal fluids.

#### **CONCLUSIONS**

The following conclusions may be drawn from the various lines of evidence provided by field observations, Rb/Sr age dating, fluid inclusion geobarometry and chemistry, stable isotope geothermometry and detailed mineralogic studies:

- (1) The "average age" of the pegmatite is 1,336  $\pm$  30 m.y. There was exchange between the wall zone and the surrounding country rock during injection, as evidenced by a high age (1,529  $\pm$  42 m.y.) of formation for early muscovite. Replacement masses of rose muscovite and lepidolite formed at a later time. Redistribution of radiogenic <sup>8 7</sup> Sr occurred, with apparent loss from perthite and microcline compensated for by a gain in the late-stage sugary albite (Register, 1979).
- (2) The pegmatite was injected as a volatile-rich magma at temperatures near 600 °C. Based on fluid inclusion data, the depth of emplacement was 6.0 to 7.5 km (2.0 to 2.5 kb). Primary pegmatite zones crystallized under closed-system conditions within the temperature range of 525 °to 425 °C  $\pm$  50 °C. A separate CO2-H20 volatile-rich fluid was present in the pegmatite system throughout initial crystallization of the primary pegmatite zones. Immiscibility of CO2 in the fluid phase was probable during crystallization. Sugary albite units formed from a residual Na-rich magma as a late-stage event in response to pressure release. Corrosive saline brines caused lepidolite replacement at temperatures of 265  $^{\circ}$   $\pm$  25 °C. The final stage of mineralization was the formation of small pocket minerals of quartz, feldspar and microlite (Cook, 1979).
- (3) Metamict and nonmetamict microlite occurs in three late-stage lithologic core units and replacement masses. The chemical and physical properties of the microlite are complicated by variations in chemistry, degree of metamictization and degree of alteration (Chakoumakos, 1978).

All of the above conclusions are consistent with the model of Jahns and Burnham (1969) for the crystallization of granitic pegmatites and the model for the petrogenesis of the Harding pegmatite proposed by Jahns and Ewing (1976).

## **REFERENCES**

Ahrens, L. H., 1949, Measuring geologic time by the strontium method: Geological Society of America Bulletin, v. 60, p. 253-255.

Aldrich, L. T., Wetherill, G. W., Davis, G. L. and Tilton, G. R., 1958, Radioactive ages of micas from granitic rocks by Rb-Sr and K-Ar methods: American Geophysical Union Transactions, v. 39, p. 1124-1134.

Appleman, D. E. and Evans, H. T., Jr., 1973, Indexing and least-squares refinement of powder diffraction data: U.S. National Technical Information Service Pb-216 188, 62 p.

Baker, J. S., 1945, World survey of tantalum ore: U.S. Bureau of Mines Information Circular 7319, 48 p.

Berliner, M. H., 1949, Investigation of the Harding tantalum-lithium deposits, Taos County, New Mexico: U.S. Bureau of Mines Report of Investigations 4607, 7 p.

Burnham, C. W., 1967, Hydrothermal fluids at the magmatic stage, *in* Barnes, H. L., ed., Geochemistry of hydrothermal ore deposits: Holt, Rinehart and Winston, Inc., New York, p. 34-76.

Chakoumakos, B., 1978, Microlite, the Harding pegmatite, Taos County, New Mexico (B.S. honors thesis): University of New Mexico, Albuquerque, 111 p.

Cook, C. W., 1979, Fluid inclusions and petrogenesis of the Harding pegmatite, Taos County, New Mexico (M.S. thesis): University of New Mexico, Albuquerque, 143 p.

Gresens, R. L., 1967, Tectonic-hydrothermal pegmatites, I: Contributions to Mineralogy and Petrology, v. 15, p. 345-355.

----, 1975, Geochronology of Precambrian metamorphic rocks, north-central New Mexico: Geological Society of America Bulletin, v. 86, p. 1444-1448. THE HARDING PEGMATITE 133

- Hirschi, H., 1928, Thormineral aus lithiumpegmatit von camp Harding bei Embudo, New Mexico: Schweizerische Mineralogie and Petrographic Mitteilung, v. 8, p. 260-261.
- graphic Mitteilung, v. 8, p. 260-261. Hogarth, D. D., 1977, Classification and nomenclature of the pyrochlore group: American Mineralogist, v. 62, p. 403-410.
- Jahns, R. H., 1953, Distribution of rare elements within granites and granitic pegmatites: Geological Society of America Bulletin, v. 64, p. 1440.
- Jahns, R. H. and Burnham, C. W., 1957, Preliminary results from the experimental melting and crystallization of Harding, New Mexico, pegmatite: Geological Society of America Bulletin, v. 68, p. 1751-1752.
- ----, 1969, Experimental studies of pegmatite genesis: I. a model for the derivation and recrystallization of granitic pegmatites: Economic Geology, v. 64, p. 843-864.
- Jahns, R. H. and Ewing, R. C., 1976, The Harding mine, Taos County, New Mexico: New Mexico Geological Society Guidebook 27, p. 263-276.
- ----, 1977, The Harding mine, Taos County, New Mexico: Mineralogical Record, v. 8, p. 115-126.
- Page, L. R., 1950, Uranium in pegmatites: Economic Geology, v. 45, p. 12-34

- Register, M. E., 1979, Geochemistry and geochronology of the Harding pegmatite, Taos County, New Mexico (M.S. thesis): University of New Mexico, Albuquerque, 145 p.
- Roedder, E., 1962, Ancient fluids in crystals: Scientific American, v. 207, p. 38-47.
- ---, 1967, Fluid inclusions as samples of ore fluids, in Barnes, H. L., ed., Geochemistry of hydrothermal ore deposits: Holt, Rinehart and Winston, Inc., New York, p. 515-574.
- ---, 1972, Composition of fluid inclusions (Chapter J J, Data of Geochemistry 6th edition): U.S. Geological Survey Professional Paper 440, 164 p.
- Smith, F. G., 1953, Historical development of inclusion thermometry: University of Toronto Press, Toronto, 149 p.
- Soulé, J. H., 1946, Exploration of the Harding tantalum-lithium deposits, Taos County, New Mexico: U.S. Bureau of Mines Report of Investigations 3986, 10 p.
- Suchomel, T. J., 1976, Geology and mineralogy of the Harding pegmatite, Taos County, New Mexico (M.S. thesis): University of Illinois, Urbana-Champaign, 88 p.
- York, D., 1969, Least-squares fitting of a straight line with correlated errors: Earth and Planetary Science Letters, v. 5, p. 320-324.

