



NEW MEXICO MINERAL SYMPOSIUM

November 11 & 12, 1989



NMIMT Campus, Socorro, New Mexico

Welcome to

THE TENTH ANNUAL

NEW MEXICO MINERAL SYMPOSIUM

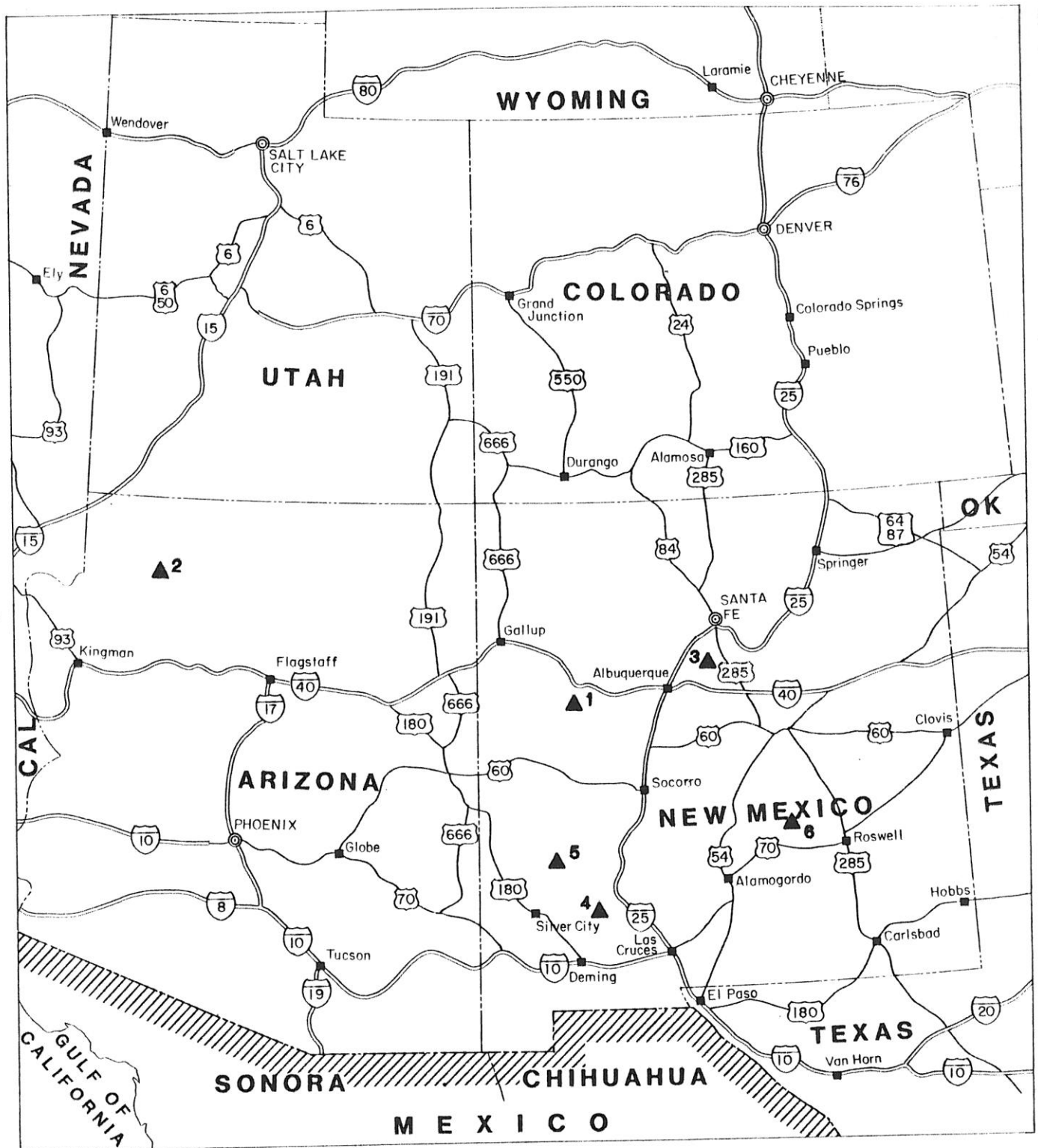
November 11 and 12, 1989

Macey Center Auditorium
New Mexico Institute of Mining and Technology
Socorro, New Mexico

sponsored by
New Mexico Bureau of Mines and Mineral Resources
Albuquerque Gem and Mineral Club
Los Alamos Geological Society
New Mexico Geological Society

The purpose of the New Mexico Mineral Symposium is to bring together for an exchange of ideas both professionals and amateurs interested in mineralogy. The sponsors hope that the Tenth New Mexico Mineral Symposium will give both groups a forum to present their cumulative knowledge of mineral occurrences in the state. In addition to the formal papers, informal discussions among mineralogists, geologists, and hobbyists should benefit all.

Cover--MINERALS OF THE FOUR-CORNERS STATES. Scepter quartz from Kingston, New Mexico; rhodochrosite from Silverton, Colorado; topaz from the Thomas Mountains, Utah; and barite from Superior, Arizona represent the four-corners states in the cover design by Teresa Mueller.



Geographic Index Map
10th New Mexico Mineral Symposium

SCHEDULE

Numbers in parentheses refer to geographic location on index map.

Friday, November 10

6:00 pm Informal tailgating and social hour, individual rooms, El Camino Motel

Saturday, November 11

- 8:00 am Registration; coffee and donuts
- 9:00 Opening remarks
- 9:10 Some recent developments in mineralogy--Cornelius Klein
- 10:10 (1) Minerals and rock forms in lava tubes of El Malpais National Monument, Cibola County, New Mexico--Kent Carleton and Chris McKee
- 10:35 Coffee break
- 10:55 (2) Minerals in breccia pipes of the Grand Canyon region, Arizona--Karen J. Wenrich and Hoyt B. Sutphin
- 11:30 (3) Minerals of the Carnahan mine, Santa Fe County, New Mexico--Ramon S. DeMark and Judith L. DeMark
- 12:00 Lunch
- 1:30 pm Use of fluid inclusions in the study of mineral deposits--Andrew Campbell
- 2:05 Microminerals from the four-corners states--Patrick E. Haynes
- 2:40 Coffee break
- 3:00 (4) Lake Valley's famed Bridal Chamber, "a beautifully large and solid looking streak--Robert W. Eveleth
- 3:30 (5) Minerals of the Black Range and vicinity, southwestern New Mexico--Allen V. Heyl
- 5:30 Sarsaparilla and suds: cocktail party, Garcia Opera House
- 6:30 Dinner, Garcia Opera House, with keynote address, Adventures in the Sierra Madre, Batopilas, Chihuahua, by Philip C. Goodell and Kathryn Evans Goodell and an auction to benefit the New Mexico Mineral Symposium.

Sunday, November 12

- 9:00 am Silver distribution in ore minerals of New Mexico--Peter
J. Modreski
- 9:40 Electron microprobe x-ray analysis: what can it tell us
about minerals?--Paul F. Hlava
- 10:20 Coffee break
- 10:45 Rare-earth minerals of New Mexico--Virginia T. McLemore
- 11:15 (6) Mineralogy and geochemistry of veins in the Capitan
Mountains, central New Mexico--Randall S. Phillips and
Virginia T. McLemore
- 12:00 Lunch
- 1:15 pm Silent auction, upper lobby, Macey Center, sponsored by
-3:00 the Albuquerque Gem and Mineral Club

SOME RECENT DEVELOPMENTS IN MINERALOGY

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Many of the research advances in mineralogy since the early 1960's can be related to the advent of new types of instrumentation such as the electron microprobe, the scanning and transmission electron microscopes, and the computer-controlled single-crystal x-ray diffractometer. Many of these new and sophisticated tools allow us to look at minerals on a very fine scale. Quantitative chemical analyses with the electron microprobe can be achieved on areas only a few microns in size. Scanning electron microscopes (SEM) produce magnifications with resolutions of 100 Angstroms or better. Transmission, especially high-resolution transmission electron microscopy (HRTEM), provides us structural images with a resolution of a few Angstroms. Complete crystal-structure determinations are now obtained routinely by computer-controlled single-crystal x-ray diffractometers on crystals with volumes of about 0.003 mm^3 . Investigations involving one, or several of the above techniques in combination, demonstrate that a homogeneous mineral is a very rare species. What was once considered a homogeneous single phase is now often recognized as a difficult to interpret composite.

Examples of major advances in our understanding of structural and chemical aspects of common minerals are: opal, which is now known to consist of spheres in a size range of 1,500 to 3,000 Å that are arranged in some regular scheme of closest packing (Darragh et al., 1976); and plagioclase feldspar, which is not a continuous solid-solution series at low temperature but contains several miscibility gaps, as expressed by the occurrence of fine lamellar structures in "moonstone," in labradorite, and in a compositional region between An_{50} and An_{85} (Smith, 1974).

Evaluation of the exsolution lamellae inside a single metamorphic pyroxene has led Robinson et al. (1977) to a quantitative assessment of its cooling history.

The invention of the diamond-anvil pressure cell has made possible studies of the changes in crystalline materials as a function of high to very high pressure. Such studies should help in an evaluation of the deep mantle region of the earth.

High-resolution transmission microscopy (Veblen et al., 1977) has proven the existence of new types of crystal structures that are closely related to those of biotite, pyroxenes, and amphiboles ("biopyriboles").

And the measurement of strontium isotope ratios in a single

rotated garnet crystal from a metamorphic rock has allowed for the first quantitative determination of a crystal growth rate (Christensen et al., 1989).

References

- Christensen, J. M., Rosenfeld, J. L., and DePaolo, D. J., 1989, Rates of tectonometamorphic processes from rubidium and strontium isotopes in garnet: *Science*, v. 244, pp. 1465-1469.
- Darragh, P. J., Gaskin, J. J., and Sanders, J. V., 1976, Opals: *Scientific American*, v. 234, no. 4, pp. 84-95.
- Robinson, P., Ross, M., Nord, G. L., Smyth, J. R., and Jaffe, H. W., 1977, Exsolution lamellae in augite and pigeonite-- fossil indicators of lattice parameters at high temperature and pressure: *American Mineralogist*, v. 62, pp. 857-874.
- Smith, J. V., 1974, Feldspar minerals, v. 1 and v. 2: Springer-Verlag, New York.
- Veblen, D. R., Buseck, P. R., and Burnham, C. W., 1977, Asbestiform chain silicates--new minerals and structural groups: *Science*, v. 198, no. 4315, pp. 359-365.

**MINERALS AND ROCK FORMS IN LAVA TUBES OF
EL MALPAIS NATIONAL MONUMENT
Cibola County, New Mexico**

(Location 1 on index map)

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El Malpais National Monument was established recently by Congress. One of the outstanding features of the monument is its lava-tube systems. The concentration of tubes is so high here that Hatheway and Herring (1970) chose El Malpais as a terrestrial analog to what are believed to be similar structures called "rills" that occur on the moon.

The El Malpais tubes are also significant because of the length of many of the systems. For example, one tube system within the monument is reported to be 17.9 mi (28.6 km) long by Elston and Wohletz (1987). Such a considerable length is not believed to be typical of lava tubes in other locales. Further, the intact (cave) portions of El Malpais lava tubes are often noteworthy relative to tube lengths observed elsewhere. Four lava caves within the monument exceed one kilometer in length and one is two kilometers. Finally, the size of many of the El Malpais tubes appears to be uncommonly large. Tubes that exceed 50 ft in height and 60 ft in width are not uncommon.

Kent Carlton collected cave minerals during a 1988 lava-tube inventory and submitted them to New Mexico Institute of Mining and Technology for identification.

Chris McKee analyzed the samples by x-ray diffraction. The samples contain quartz, feldspar, calcite, thenardite, gypsum, trona, and burkeite.

References

Hatheway, A. W., and Herring, A. K., 1970, Bandera lava tubes of New Mexico, and lunar implications: *Ariz. Univ., Communications of the Lunar and Planetary Laboratory*, v. 8, part 4, pp. 298-327.

Elston, W. E., and Wohletz, K. H., 1987, Quaternary basalt fields of west-central New Mexico--McCarty's pahoehoe flow, Zuni Canyon as flow, Zuni ice cave, Bandera crater and Zuni Salt Lake maar; in Beus, S. S. (ed.), *Rocky Mountain Section of the Geological Society of America: Geological Society of America, Centennial Field Guide*, v. 2, pp. 431-436.

MINERALS IN BRECCIA PIPES OF THE GRAND CANYON REGION, ARIZONA

(Location 2 on index map)

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Solution-collapse breccia pipes in northwestern Arizona provided excellent conduits for fluid movement and sites for the precipitation of minerals containing Ag, Co, Cu, Mo, Ni, Pb, V, U, and Zn. Colorful minerals of the oxidized zones of breccia pipes have caught the attention of prospectors and mineral collectors for more than 100 years; recorded mining claims in breccia pipes of the Grand Canyon date back to the late 1860's (G. H. Billingsley, written communication 1989). In fact, the Grandview mine has long been known for its beautiful sprays of cyanotrichite. It was not until 1956, when uranium was first produced from the Orphan Lode breccia pipe, that interest peaked for minerals in the primary (unoxidized) ore zones; access to these minerals, however, is only available from underground workings, commonly from shafts as deep as 1200 ft below the Kaibab or Coconino plateau surfaces. Both the oxidized and primary minerals occur in the quartz-sand matrix of the breccia, with minor amounts occurring in clasts of Paleozoic or Triassic sandstone and little to none in the limestone or shale clasts. Unfortunately, most of the 104 minerals listed below that occur in these solution-collapse breccia pipes are so extremely fine grained (generally less than 1 mm) that they do not even lend themselves to photography, other than with the SEM, let alone to macro-specimen mineral collecting.

Most of the minerals listed below were precipitated from fluids that were cooler than 173½ C; fluid-inclusion studies suggest that sphalerite, dolomite, and calcite were formed from saline brines having more than 18 wt % NaCl equivalent at temperatures between 80½C and 173½C. The uranium mineralization occurred approximately 200 million years ago (Ludwig, 1988) and was preceded first by a stage of Co-Ni-As-Fe sulfide deposition and then by a Cu-Fe-Zn-Pb sulfide stage.

The breccia pipes in this region began to form at the close of the Mississippian after extensive karst development in the Redwall Limestone. Many of the pipes penetrate as much as 3,000 ft upward into overlying Pennsylvanian, Permian, and Triassic strata. No volcanic rock is associated with them. The pipes are less than 500 ft in diameter and contain strata that have been downdropped as much as 700 ft. The bottoms of small breccia pipes can be observed on the ceilings in Redwall Limestone caves. On the walls of one such pipe, in a Redwall Limestone cave, are speleothems and oncrustations formed from secondary minerals containing Mo, U, As, and Cu--all elements that are commonly enriched in primary breccia-pipe ore. These minerals include powellite, carnotite, conichalcite, talmessite, and hoernesite.

Neither talmessite nor hoernesite have been reported previously from the United States.

Colorado Plateau-type breccia pipes also exist in the Basin and Range Province of southern Utah, Nevada, and California. The breccia-pipe host rocks extend into the Beaver Dam Mountains of southwestern Utah where a solution-collapse breccia pipe hosts the Ge and Ga ore of the Apex mine. The Apex minerals are almost totally oxidized, and the mine contains 24 of the minerals listed below that have been identified in the Colorado Plateau pipes. In addition the Apex contains: adamite, allophane, cobaltoan adamite, duftite, plattnerite, plumbojarosite, rosasite, and svanbergite.

More than 1000 breccia pipes have been located in northwestern Arizona; all contain similar mineralogy and geochemistry. They are a species collector's paradise, but it is unlikely that many large showy crystals will ever surface from these pipes.

<u>URANIUM</u>	<u>VANADIUM</u>	<u>COPPER</u>	<u>IRON</u>
uraninite*	hewettite	chalcocite	pyrite*
tyuyamunite	vesignieite	djurleite	marcasite*
metatyuyamunite	volborthite	digenite	arsenopyrite*
zippeite	calciovolborthite	covellite	siderite*
zeunerite	roscoelite	enargite*	scorodite
metazeunerite		chalcopyrite*	melanterite
metatorbernite	<u>NICKEL</u>	lautite*	limonite
uranophane	nickeline*	bornite	hematite
bayleyite	rammelsbergite*	tennantite*	goethite
uranospinite	pararammelsbergite*	tetrahedrite*	siderotil
carnotite	gersdorffite*	cuprite	coquimbite
	bravoite*	tenorite	jarosite
<u>ZINC</u>	siegenite*	chrysocolla	
sphalerite*	vaesite*	azurite	<u>MISCELLANEOUS</u>
smithsonite	millerite*	malachite	quartz*
aurichalcite		olivenite	chalcedony*
hemimorphite	<u>COBALT</u>	chalcanthite	ttpyrobitumenhl*
adamite	skutterudite*	brochantite	celadonite
	erythrite	cyanotrichite	illite
<u>LEAD</u>	cobaltoan gers-	chalcoalumite	kaolinite*
galena*	dorffite*	langite	chlorite
cerussite	bieberite	antlerite	fluorite*
wulfenite	linnaeite*	devilline	calcite*
anglesite		conichalcite	dolomite*
	<u>ANTIMONY</u>	luzonite	ankerite*
<u>MANGANESE</u>	stibnite*	nukundamite	anhydrite*
rhodochrosite			gypsum
	<u>MOLYBDENUM</u>	<u>SILVER</u>	hexahydrate
<u>BARIUM</u>	ilsemannite	acanthite	leonhardtite
barite*	powellite	naumannite	gold
	molybdenite*	proustite	halloysite
			hoernesite
			talmessite

Minerals marked * are primary ore or gangue minerals; the remainder are slightly oxidized or supergene minerals (secondary). Minerals in bold print were recognized during this study; others are compiled from Kofford (1969), Gornitz and Kerr (1970), and Leicht (1971). In addition, four unknown minerals containing the following elements have been collected:

1) Pb-As-S, 2) Co-O, 3) Cu-V-As, and 4) U-Ca-P.

References

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- Kofford, M. E., 1969, The Orphan mine: Four Corners Geological Society, Guidebook to 5th Field Conference, pp. 190-194.
- Leicht, W. C., 1979, Minerals of the Grandview mine: *Mineralogical Record*, Sept./Oct. edition, pp. 215-221.
- Ludwig, K. R., and Simmons, K. R., 1988, Progress in U/Pb isotope studies of collapse-breccia pipes in the Grand Canyon region, northern Arizona (abs.): *Geological Society of America, Abstracts with Programs*, v. 20, no. 7, p. A139.

**MINERALS OF THE CARNAHAN MINE
SANTA FE COUNTY, NEW MEXICO**

(Location 3 on index map)

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The Carnahan mine, located in the San Pedro Mountains (New Placers district) of Santa Fe County, New Mexico, has not been a major ore producer. Nonetheless, it has had a long, but intermittent, record of production of lead-silver, zinc, and manganese ores. Since 1968, the mine has been owned by the San Pedro Mining Corporation (Patrick Freeman, personal communication 1989).

The mine workings consist predominantly of an inclined tunnel (5-20°) trending N75 E to N90 E with minor drifts and some stoping. Near the end of this tunnel another north-trending inclined tunnel proceeds approximately 500 ft before intercepting the water table.

The geology and mineralogy of the Carnahan mine was looked at most extensively in 1903 (Yung and McCaffery). More recent studies have, in most cases, cited the mineralogical findings of Yung and McCaffery in reporting occurrences of specific minerals. Northrop (1959), crediting Dale Carson, cited a number of oxidized minerals including anglesite, cerussite, botryoidal hematite, limonite, possibly minium, pyrolusite, and native silver.

Since 1985, however, a number of new species have been identified from the Carnahan mine, species that were either overlooked by earlier investigators or possibly misidentified. With the help of microprobe (Paul Hlava, personal communications 1989) and x-ray diffraction/SEM (Peter Modreski, personal communications 1989) analyses, 20 species new to the Carnahan mine have been confirmed. Two of the species (adamite and hetaerolite) are the first reported occurrences of these minerals in New Mexico.

The new minerals are all secondary minerals resulting from the oxidation of primary iron, copper, zinc, and manganese sulphides. They include one native element (copper), oxides, carbonates, sulfates, arsenates, a molybdate (wulfenite), and silicates. Although galena and pyrite have been found in the oxidized zone, the predominant occurrence of primary sulphides is reputed by Atkinson (1961) to occur below the ground-water level approximately 400 ft below the surface.

Most of the secondary copper minerals were found in a very restricted zone substantially down the tunnel. The arsenates, adamite, and agardite-(Y) were found in association with cuprite octahedrons that were partially or completely altered to rosasite,

malachite, and chrysocolla. Native copper commonly occurs in the cores of the less altered cuprite octahedrons. Adamite most often occurs as transparent green spheres, but crystal morphology is evident on some of the balls. This adamite is cuprian, which accounts for the green color. Some individual colorless crystals to 0.5 mm are very low in copper content (Hlava, personal communication 1989). None of the Carnahan mine adamite is fluorescent. Aurichalcite and azurite, although scarce, were also found in association. Agardite-(Y) occurs in very fine acicular sprays and tufts. Linarite occurs as sky-blue, bladed crystals about 0.1 mm long and also as fine sprays of crystals about 0.3 mm across. They are found in association with pyrite, galena, and green spheres that appear to be a mixture of malachite and brochantite (Hlava, personal communication 1989). The pyrite in some cases is coated with a dark-purple to black layer of drusy covellite that is argentiferous.

Gibbsite, opal (hyaline), and allophane are also found in the same area. Gibbsite occurs as white spheres and irregular masses often coated with hyaline opal while the allophane is in blue, transparent to opaque bands. Wulfenite is surprisingly sparse. It was only found in a very restricted horizon near the end of the main tunnel in association with cerussite.

The uncommon zinc manganese oxide, hetaerolite, is found in many areas throughout the mine, often in fine splendant tetragonal dipyrramids about 1 mm in size. Chalcophanite, cerussite, and hemimorphite are ubiquitous throughout the mine. The habit and forms of chalcophanite at the Carnahan mine are varied. It may be in lustrous black, brown, or red pseudo-hexagonal crystals that resemble hematite or goethite or more commonly as reniform, botryoidal, vermiform, or stalagmitic masses. Plattnerite is restricted in occurrence (one site) and was found on reniform chalcophanite in lustrous, black, prismatic crystals. A manganoan variety of smithsonite has been identified in association with secondary copper minerals. It has a dark-brown color and glassy luster on cleavages. The crystals have the typical rice-grain habit. Calcite is common throughout the mine and may be in papier-spath crystals or in transparent colorless rhombs, or in prisms. Botryoidal and cave-type forms are also found. As mineral investigations are continued, additional species are expected to be added to the current list.

ACCESS TO THE CARNAHAN MINE IS STRICTLY PROHIBITED AND ILLEGAL WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE SAN PEDRO MINING CORPORATION, P.O. BOX 1670, TRUTH OR CONSEQUENCES, NEW MEXICO 87901.

MINERALS OF THE CARNAHAN MINE

Native Elements

+ Silver	Ag
* Copper	Cu

Sulfides

+ Acanthite	Ag ₂ S
+ Alabandite	MnS
+ Chalcopyrite	CuFeS ₂
* Covellite	CuS
Galena	PbS
+ Marcasite	FeS ₂
Pyrite	FeS ₂
+ Sphalerite	(Zn, Fe) S

Oxides

* Chalcophanite	(Zn, Fe ⁺² , Mn ⁺²) Mn ₃ ⁺⁴ O ₇ • 3H ₂ O
* Coronadite	Pb (Mn ⁺⁴ , Mn ⁺²) ₈ O ₁₆
* Cuprite	Cu ₂ O
* Gibbsite	Al (OH) ₃
+ Hematite	Fe ₂ O ₃
* Hetaerolite	ZnMn ₂ ⁺³ O ₄
+ Minium(?)	Pb ₂ ⁺² Pb ⁺⁴ O ₄
* Plattnerite	PbO ₂
+ Pyrolusite	MnO ₂

Carbonates

* Aurichalcite	(Zn, Cu) ₅ (CO ₃) ₂ (OH) ₆
* Azurite	Cu ₃ (CO ₃) ₂ (OH) ₂
Calcite	CaCO ₃
Cerussite	PbCO ₃
* Malachite	Cu ₂ (CO ₃) (OH) ₂

Carbonates (cont'd)

* Rosasite	$(\text{Cu}, \text{Zn})_2(\text{CO}_3)(\text{OH})_2$
+ Siderite	$\text{Fe}^{+2}\text{CO}_3$
Smithsonite	ZnCO_3

Sulfates

Anglesite	PbSO_4
* Brochantite(?)	$\text{Cu}_4(\text{SO}_4)(\text{OH})_6$
* Linarite	$\text{PbCu}(\text{SO}_4)(\text{OH})_2$

Arsenates

* Adamite	$\text{Zn}_2(\text{AsO}_4)(\text{OH})$
* Agardite-(Y)	$(\text{Y}, \text{Ca})\text{Cu}_6(\text{AsO}_4)_3(\text{OH})_6 \cdot 3\text{H}_2\text{O}$

Molybdates

* Wulfenite	PbMoO_4
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Silicates

* Allophane	Hyd. Aluminum Silicate
* Chrysocolla	$(\text{Cu}, \text{Al})_2\text{H}_2\text{Si}_2\text{O}_5(\text{OH})_4 \cdot n\text{H}_2\text{O}$
Hemimorphite	$\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH})_2 \cdot \text{H}_2\text{O}$
Koolinite	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
* Opal (hyaline)	$\text{SiO}_2 \cdot n\text{H}_2\text{O}$
Quartz	SiO_2

* Reported for first time

+ Reported but not observed by authors

References

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- Northrop, S. A., 1959, *Minerals of New Mexico*: University of New Mexico Press, 665 p.
- Yung, M. B., and McCaffery, R. S., 1903, The ore deposits of the San Pedro district; in *American Institute of Mining and Engineering, Transactions Volume 33*, p. 350-362; abs. in *Engineering and Mining Journal*, v. 75, p. 297-299.

Suggested reading

- Lasky, S. G., and Wootton, T. G., 1933, *The metal resources of New Mexico and their economic features*: New Mexico Bureau of Mines and Mineral Resources, Bulletin 7, 178 p.
- Wells, E. G., 1918, *Manganese in New Mexico*: New Mexico Bureau of Mines and Mineral Resources, Bulletin 2, 85 p.

USE OF FLUID INCLUSIONS IN THE STUDY OF MINERAL DEPOSITS

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Fluid inclusions are pockets of fluid trapped during the growth of a crystal from a hydrothermal fluid. They represent the only remaining sample of the mineralizing fluid and therefore can provide valuable information about the conditions of formation of the minerals.

The inclusions typically consist of one or two liquid phases, a gas phase, and one or more solid phases. The relationship between these phases and their behavior during cooling and heating experiments can be used to determine the temperature at which the fluid inclusion was trapped by the growing crystal and the salinity of the mineralizing fluid. Other techniques can also be applied to obtain a more complete chemical and isotopic analysis of the fluid.

The data obtained from fluid inclusions are very valuable in ore-deposit studies to determine the origin of fluids, temperature of mineralization, fluid salinity, and mechanisms of deposition. Fluid inclusions have been studied at these sites among others in New Mexico: Hansonburg Pb-F deposit, Helen Rae Au deposit, Victorio Mts. W deposit, Capitan rare-earth-element quartz veins, and the Zn deposits of the Kelly district.

MICROMINERALS FROM THE FOUR CORNERS STATES

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with microphotography by
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This visual presentation shows some microminerals from Colorado, Utah, Arizona, and New Mexico, collectively known as the four-corners states. The specimens shown will be limited to those collected personally from about 30 localities.

**LAKE VALLEY'S FAMED BRIDAL CHAMBER
"A BEAUTIFULLY LARGE AND SOLID LOOKING STREAK!"**

(Location 4 on index map)

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The famous vug known as the Bridal Chamber, discovered at Lake Valley during the early 1880's, is so well known that it has entered oral tradition and become part of New Mexico's folklore. Contrary to popular belief, the bonanza deposits did not lead to long-term profits. The Sierra Grande Company of Lake Valley in fact had its hands full contending with sudden wealth, sudden fame, and sudden failure.

**MINERALS OF THE BLACK RANGE AND VICINITY,
SOUTHWEST NEW MEXICO**

(Location 5 on index map)

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Many mines and mineral localities are along the Rio Grande trench in south-central and southwestern New Mexico. Many of the best localities are along the Black Range, particularly south of Alamosa Creek. (The well-known tin deposits on the west side of the range are not discussed here because many recent papers have described them.) The best-known mineral locality is the Iron Mountain deposit in the Sierra Cuchillo, east of the main Black Range, about 2 mi east of the junction of the road to Dusty and NM-52. Many minerals have been reported in the iron manganese skarn at Iron Mountain, including helvite, danalite, fluorescent fluorite, and fluorescent molybdenum-bearing sheelite (Richard Jahns and J. J. Glass, U.S. Geological Survey, Bulletin 945). Manganoan calcite that fluoresces red and hypogene pale-yellow granular willemite that fluoresces bright yellow-green (similar to that at Franklin, N.J.) are also common in the main tunnel workings and at the adjacent large ore bin. Both minerals are intergrown with banded andradite garnet, magnetite, and inconspicuous danalite. Nonfluorescent supergene grayish-pink transparent willemite crystals occur in vugs. The helvite occurs in yellow-brown tetrahedrons; the danalite, where present as euhedral crystals, has a similar habit but is pale brown to pink.

South of NM-52, 1.2 miles into the Black Range, a mine road leads southward to the Great Republic mine in a branch of Poverty Creek, where large open pits expose gold-quartz veins. The veins contain beautiful coarse amethyst crystals that are suitable for slabbing, bands of silver-copper minerals, sparse grains of gold, and pale-green chlorargyrite. A rocky point of andesite, adjacent to the north side of the Winston-Chise road, 7 mi south of Winston, contains crystals of heulandite, stilbite, and uncommon natrolite. Along the same road 6.1 miles south of Winston, Cuchillo Negro Creek is joined by a valley from the south that becomes Coyote Canyon. South 1.1 miles, on a 4-wheel-drive road up the canyon, along the northwest side of the road, are outcrops of semiprecious white opal. West of Chloride, about 14 miles up Chloride Creek on a 4-wheel drive road, are the dumps of the Silver Monument mine. The dumps contain beautifully colored massive bornite and much nearly microscopic native silver. South of NM-152, 2.5 mi east of Hillsboro, a passable road extends down Ready Pay Gulch to the east end of Percha Creek Box. Here old vanadium mines have well-formed pale-yellow crystals of endlichite (arsenian vanadinite), orange vanadinite, wulfenite, and yellow-brown descloizite. Far to the south of the Black Range, 2.3 mi due south of Deming and 10 mi south on NM-517, are the old silver-lead mines of the Mahoney mining area that are at the foot of the

northwest corner of the Tres Hermanas Mountains. These mines and their dumps have well-formed supergene crystals of willemite and smithsonite, masses of cerussite, pale-green fornacite $(\text{Pb,Cu})_3[(\text{Cr,As})\text{O}_4]_2(\text{OH})$, wollastonite, hyrozincite, malachite, and hemimorphite.

SILVER DISTRIBUTION IN ORE MINERALS OF NEW MEXICO

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The precious metal, silver, may occur in a variety of mineralogical forms within base metal, gold, or silver ores, including:

- native silver
- silver sulfide (argentite/acanthite)
- silver halides (chlorargyrite/bromargyrite)
- alloyed with gold (electrum)
- gold-silver tellurides
- silver sulfosalts (proustite, polybasite, etc.)
- substituting in other sulfosalts (tetrahedrite, etc.)
- substituting in galena
- substituting in other sulfide minerals
- in supergene minerals (Mn-oxides, jarosite, other sulfates, and carbonates)

Of the primary (hypogene) silver-bearing minerals, aside from those sulfosalts that contain essential silver (proustite-pyrargyrite, pearceite-polybasite, stephanite, matildite, miargyrite, etc.), a major host for silver is the tennantite-tetrahedrite-freibergite series. This solid-solution series of isometric "gray copper ores" can be characterized by the general

formula $(\text{Cu, Fe, Ag})_{12} (\text{As, Sb})_4\text{S}_{13}$, or more accurately as

$(\text{Cu, Ag})_{10} (\text{Fe, Zn, Cd, Hg, Cu})_2 (\text{As, Sb, Bi})_4\text{S}_{13}$. A complete series extends from tennantite, ideally $\text{Cu}_{10} (\text{Fe, Zn})_2\text{As}_4\text{S}_{13}$, to tetrahedrite, $\text{Cu}_{10} (\text{Fe, Zn})_2\text{Sb}_4\text{S}_{13}$. From this binary series, solid solution extends part way to freibergite, $(\text{Ag, Cu})_{10} (\text{Fe, Zn})_2 (\text{Sb, As})_4\text{S}_{13}$, and to the recently (1988) described argentotennantite,

$(\text{Ag, Cu})_{10} (\text{Zn, Fe})_2 (\text{As, Sb})_4\text{S}_{13}$. Silver-bearing

members are more common in the tetrahedrite (Sb-rich) members of the group. True freibergites are rare; silver contents in tetrahedrites commonly range from <0.1 to approximately 15-20 wt % Ag (equivalent to approximately 25-35 mole % freibergite).

Silver enters galena through a coupled substitution with either bismuth or antimony: $\text{Ag} + \text{Bi} = 2 \text{Pb}$ or $\text{Ag} + \text{Sb} = 2 \text{Pb}$. Thus, in the absence of these semi-metals, synthesis experiments have produced not more than about 0.4 wt % Ag in galena. Galenas containing Bi or Sb, however, can contain as much as 10 wt % Ag. Low-silver galena (less than a few percent Ag) may be homogenous,

but high-silver galenas (>5% Ag) usually contain exsolved silver-bearing sulfosalts, such as tetrahedrite or matildite. Estimates of the average or typical concentration of silver in galena worldwide are on the order of 0.1 wt % Ag (= 1000 ppm, = 29.16 oz/ton of galena), but this may range from <0.005% to 1% or more in different types of ore deposits.

Silver contents in other sulfide and sulfosalt minerals worldwide, reported in the literature plus some analyzed by the author via KEVEX semiquantitative energy-dispersive x-ray spectrometry, fall into the following (all highly variable) ranges:

chalcopyrite	<1 - 20,000 ppm	(median = 55-300, mean = 90-550)
sphalerite	<1 - 8,000 ppm	(median = 55-110, mean = 110-535)
enargite	<100 - 6000 ppm	
bornite	80 - 4000 ppm	
pyrrhotite	10 - 1600 ppm	(median = <10-15, mean = 15-25)
arsenopyrite	100 ppm	
pyrite	<10 - 300 ppm	(median = <10-30, mean = 15-70)
marcasite	2 ppm	

The higher values reported for some of these minerals probably represent bulk admixture of native silver or other silver-rich minerals.

Few accurate analytical data exist for tetrahedrite-tennantites from New Mexico. Galenas from the Hansonburg and other districts of lead-zinc-barite-fluorite replacement deposits are quite low in silver (<0.01 to 0.02 wt % Ag), a feature they have in common with the Mississippi Valley-type ore deposits they resemble. Some galena from other deposits in the state, probably higher temperature and more closely igneous-related ore deposits, shows higher silver values (one sample from the Groundhog mine, Grant County, contains 0.25 wt % Ag); Northrop (1959) quoted eight analyses of galena, ranging from 0.02 to 0.17 wt % Ag. A specimen of coarsely bladed enargite (Denver Mus. Nat. Hist. #2334) from New Mexico, locality unknown, contains 0.03 wt % Ag. Analyses by Burnham (1959) showed a range from 1 to 20,000 ppm Ag in chalcopyrite from New Mexico mines (median = 65 ppm; n = 36), and 2 to 1000 ppm Ag in sphalerite (median = 50 ppm; n = 42). Two analyses, by this author, of New Mexico sphalerite show 0.00 (Groundhog mine) and 0.02 (Mason Tunnel, Hanover district, Grant County) wt % Ag. More analyses are in progress and new results will be reported at the symposium.

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**ELECTRON MICROPROBE X-RAY ANALYSIS:
WHAT CAN IT TELL US ABOUT MINERALS?***

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Electron microprobe analysis is one of the most important techniques, if not the major one, used in mineral research today. It is the only technique that combines the desirable qualities of being quantitative, being micro (having high spatial resolution), and being nondestructive to the material analyzed. Like any technique, it does have some distinct limitations. In this talk I want to discuss the kinds of information (signals) we can obtain from a microprobe and how they are produced. These include secondary electron, back-scattered electron, and x-ray information. I will also discuss many of the shortcomings, disadvantages, and limitations of microprobe analysis.

Secondary electrons (SE) are produced when primary electrons, those that have been accelerated down the column of the instrument toward the sample, "collide" with electrons in the shells forming the outer portions of atoms and knock them out of orbit. Prodigious numbers of these low-energy, secondary electrons are produced, and they are attracted to the secondary-electron detector by a charged grid. Because the energy of these electrons is very weak (a few 10's of volts at best), the efficiency with which they travel is highly affected by the topography of the sample. Contrast between high- and low-efficiency areas gives rise to the secondary electron image, which is a faithful rendering of the sample topography.

Back-scattered electrons (BSE) are produced when primary electrons "bounce" or "reflect" off the surface of the sample. In fact, the primary electrons occasionally try to collide with nuclei of the atoms in the sample, but tremendous nuclear forces repel the electrons and they are scattered back elastically. This is much like the case of a billiard ball--the electrons have almost the same energy or speed as before but they are going in a different direction. The back-scatter coefficient of a material is related mainly to its average atomic number. Minerals that contain even modest amounts of lead or rare-earth elements would be very bright on a BSE photograph, as compared to normal silicates, while graphite or diamond would be very dark. With modern detectors it is easy to detect the compositional differences between such similar materials as olivine, orthopyroxene, and clinopyroxene or even zoning within a crystal.

X-rays are produced on those rare occasions when primary electrons knock inner-shell electrons out of their orbits. Electron vacancies in the inner shells are very unstable, and the atoms will respond immediately to remedy the situation. This is accomplished by the transfer of an electron from the next higher shell of the atom. Because the electron has to have more energy

to be in a higher shell, it must lose energy to go to the lower shell. It can do this by producing a photon (a particle of electromagnetic energy) that is, in most cases, part of the x-ray spectrum. Because the energy differences between electron shells are constant and well known for all elements, it is possible to determine the composition of a sample by examining all of the x-rays (the x-ray spectrum) coming from the material. Quantitation can be accomplished by counting under constant conditions, comparing with suitable standards, and mathematically correcting for the effects that the elements in the mineral have on the x-rays produced.

Microprobe analysis is an important and powerful technique, but like all analytical techniques it has limitations. Electron microprobes cannot detect hydrogen, helium, or lithium and have great problems with most elements lighter than sodium. Probe analysis is an elemental technique; it doesn't tell how the elements are combined, their valences, or the structure of the mineral. Pyrite, marcasite, pyrrhotite, troilite, melanterite, etc., would all show lots of iron and sulfur. It requires careful technique to distinguish pyrite/marcasite from the rest, but there is no probe technique available that will distinguish pyrite from marcasite. Heat is generated in the mineral by the electron beam. Some delicate minerals can be damaged or destroyed by this heat, and even when the effect is slight, the probe analysis may be perturbed. Further damage to mineral samples occurs during preparation. Quantitative analyses require a flat and polished surface. In most cases that means the mineral is embedded in epoxy, and a flat surface is ground and polished through the sample (good-bye world-class specimen!). Probe analyses use electrons, which are electrically charged particles. The excess electrons have to be drained from the surface being analyzed or the area will charge up and repulse the electron beam. Which all means that most minerals being electrical insulators, have to be coated with carbon and that pretty much destroys the sample's beautiful colors and appearance. Some might consider cost a limitation (a modern, fully automated microprobe with all the whistles and bells costs a tad more than a Hastings triplet). And there are other problems. But, all things considered, probe analysis is still one of the most powerful analytical techniques for looking at minerals.

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RARE-EARTH MINERALS OF NEW MEXICO

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The rare-earth elements (REE) include a group of 15 chemically similar elements called the lanthanide group (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu). Yttrium (Y) is included in this group because it has chemical properties similar to the REE and it typically occurs with them. REE are found in more than 100 minerals, but significant concentrations are rare.

Five types and examples of REE deposits recognized in New Mexico are: 1) veins and breccias (Laughlin Peak, Colfax County), 2) pegmatites (Harding Pegmatite, Taos County), 3) carbonatites and alkalic rocks (Lemitar Mountains, Socorro County), 4) Cretaceous heavy-mineral, beach-placer deposits (Sanostee, San Juan County), and 5) Recent stream-placer deposits. REE minerals also are found in numerous other types of deposits and host rocks but not in economic concentrations. Economically, the most significant deposits in the state are found in veins and breccias; however, REE-bearing minerals can be found in any of the deposit types. The only production of REE from New Mexico, although not significant, has come from pegmatites and from the Gallinas Mountains, Lincoln County. However, Molycorp, Inc. recently announced it will develop the Pajarito Mountain deposit, Otero County, and mine eudialyte for Y and Zr; eudialyte occurs in Precambrian nepheline syenite. Other favorable areas for development include Laughlin Peak, Colfax County, and the Gallinas Mountains, Lincoln County, both vein and breccia deposits.

Some of the REE minerals form attractive specimens and are collected by mineral collectors. Point of Rocks Mesa, Colfax County, although not an REE deposit, has yielded micromounts of eudialyte, mosandrite, steenstrupine, and tundrite. No doubt other REE-bearing minerals will be collected from this locality. Bastnaesite from the Gallinas Mountains, Lincoln County, is well known to collectors. Many of the pegmatites in New Mexico have yielded REE minerals such as betafite, zircon (cyrtolite), euxenite, senotime, and others. Zircon, monazite, and garnet are common in Recent stream-placer deposits. A list, complete for New Mexico, of REE minerals and minerals that may contain REE as impurities are:

(*species reported new to New Mexico since Northrop, 1959)

aeschnite	(Ce, Ca, Nd, Y, Fe, Th) (Ti, Nb) ₂ (O, OH) ₆
*agardite	(Y, Ca) Cu ₆ (AsO ₄) ₃ (OH) ₆ •3H ₂ O
allanite	(Ce, Ca, Y) ₂ (Al, Fe ⁺³) ₃ (SiO ₄) ₃ (OH)
apatite group	Ca ₅ (PO ₄) ₃ (F, Cl, (OH)) ± REE

bastnaesite (Ce, La) (CO₃) F ± U, Th
 betafite (Ca, Na, U)₂ (Ti, Nb, Ta)₂ O₆ (OH) ± Fe, REE
 brannerite (U, Ca, Ce, Y) (Ti, Fe)₂ O₆
 *brockite (Ca, Th, Ce) (PO₄) • H₂O
 *chernovite-(Y) YAsO₄
 *chevkinite (Ce, Ca, Th)₄ (Fe⁺², Mg)₂ (Ti, Fe⁺³)₃ Si₄ O₂₂
 *crandalite CaAl₃ (PO₄)₂ (OH)₅ • H₂O
 eudialyte Na₄ (Ca, Ce)₂ (Fe, Mn, Y) ZrSi₈ O₂₂ (OH, Cl)₂ ± REE
 euxenite-(Y) (Y, Ca, Ce, U, Th) (Nb, Ta, Ti)₂ O₆
 fergusonite (Y, La, Ce, Nd) (Nb, Ta) O₄
 fluorite CaF₂ ± REE
 gadolinite-(Y) Y₂ Fe⁺² Be₂ Si₂ O₁₀
 garnet
 (Ca, Fe⁺², Mg, Mn⁺²)₃ (Al, Cr⁺³, Fe⁺³, Mn⁺³, Si, Ti, V⁺³, Zr) (SiO₄)₃
 *gasparite CeAsO₄
 monazite (Ce, La, Nd, Th) PO₄
 *mosandrite (rinkite) (Na, Ca, Ce)₃ Ti (SiO₄)₂ F
 samarskite-(Y) (Y, Ce, U, Fe)₃ (Nb, Ta, Ti)₅ O₁₆
 *steenstrupine-(Ce) Na₁₄ Ce₆ Mn⁺² Mn⁺³ Fe₅⁺²
 (Zr, Th) (SO₁₈)₂ (PO₄)₇ • 3H₂O
 *thorbastnaesite Th (Ca, Ce) (CO₃)₂ F₂ • 3H₂O
 Titanite CaTiSiO₅
 *tundrite-(Nd)
 Na₃ (Nd, La)₄ (Ti, Nb)₂ (SiO₄)₂ (CO₃)₃ O₄ (OH) • 2H₂O
 uraninite UO₂ ± REE, Th, Y, Pb
 *xenotime-(Y) YPO₄
 yttrotantalite-(Y)
 (Fe⁺², Y, U) (Nb, Ta) O₄
 zircon (cyrtolite) ZrSiO₄
 *zirkelite (Ca, Th, Ce) Zr (Ti, Nb)₂ O₇

MINERALOGY AND GEOCHEMISTRY OF VEINS IN THE CAPITAN MOUNTAINS, CENTRAL NEW MEXICO

(Location 6 on index map)

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The Capitan Mountains, northeast of Capitan, Lincoln County, range in elevation from 5,800 to 10,200 ft. The Capitan Mountains are composed of an east-west-trending Tertiary (26.5 Ma, K/Arbiotite; Allen, 1988) alaskite stock that intrudes the Permian Yeso and San Andres Formations. The alaskite stock, the largest Tertiary intrusive in New Mexico, is 23 mi long, 3.5-5.0 mi wide, and is aligned along the east-west-trending Capitan lineament (Chapin et al., 1978). The alaskite is cut by several faults and many small brecciated zones.

The mineral deposits of the Capitan Mountains consist of five types: 1) quartz veins with rare-earth elements (REE); 2) thorium-uranium-REE quartz veins; 3) feldspar; 4) magnetite skarns near limestone-alaskite contacts; 5) manganese veins. Some iron and manganese were produced but exact production figures are unknown. Extensive prospecting for radioactive ore deposits was conducted during the 1950's, which resulted in the discovery of a number of thorium and uranium anomalies. A thorium mill was constructed during the 1950's by the New Mexico Thorium Company, but no ore was ever processed. At present, only veins containing mineral specimens are being developed in the Capitan Mountains.

The alaskite hosting the mineralized veins can be classified chemically as an alkali granite according to de la Roche et al. (1980). It exhibits the following chemical composition: SiO₂ 70.75%, TiO₂ 0.1-0.2%, Al₂O₃ 13-14%, Fe₂O₃ 1.5-1.9%, MgO 0.2-0.3%, CaO <0.5%, Na₂O <5%.

The mineralized zones occur as fillings in brecciated veins and as joint or fracture fillings in the alaskite. The mineralogy of the quartz veins is of two types. The first type is quartz veins with REE, characteristic of the Mina Tiro Estrella (MTE) quartz prospect. The minerals consist of quartz, allanite, titanite, adularia, chlorite, and clay minerals. Quartz occurs as massive, somewhat transparent, vein-filling material; as clear, single crystals as large as 3 cm filling open spaces; as the famous, clear to smoky, Japanese Law twinned crystals, averaging 1-2 cm. Allanite, host mineral for REE, occurs as black tabular crystals as large as 3 cm, averaging 5 mm. Titanite crystals are

reddish brown, wedge shaped, and range from less than 1 mm to 1 cm. Adularia is pink to white and commonly occurs as massive intergrowths with quartz. Chlorite has been observed as needle-like inclusions within single quartz crystals and as part of the clay gangue. Clay minerals are present within the vein material and may be related to the alteration of the feldspars. The second type is thorium-uranium-REE quartz veins, characteristic of most of the vein occurrences in the Capitan Mountains. The minerals consist of quartz, fluorite, adularia, hematite, calcite, magnetite, allanite(?), and thorite(?). Quartz ranges from smoky to clear and occurs as massive, vein-filling material and as euhedral crystals filling open spaces. Fluorite occurs as subhedral to euhedral, colorless to yellow to purple cubes, as long as 1 cm. Hematite occurs as cements and coatings on brecciated vein material. Adularia generally forms small, pink euhedral crystals. Calcite occurs as small veinlets in brecciated vein material. Most of the mineralized zones appear to be the result of cracking of the stock during cooling, followed by injection of the mineralizing fluids into fractures and brecciated zones.

The unique feature of quartz from the Capitan Mountains is their abundance of fluid inclusions, from which we can tell a great deal about the mineralizing fluids. The quartz from the MTE quartz prospect is an excellent example. The inclusions, ranging from less than 1 micron to 40 microns long, consist of a multiphase system composed of 5 to 20% vapor, 20 to 30% liquid, and 50 to 70% solids (daughter minerals). The daughter minerals consist of halite, sylvite, hematite, titanite, and possibly Ca-Fe-Mg chloride salts, anhydrite, barite, and other identifiable minerals. From optical microscopy and fluid-inclusion microthermometry of 50 inclusions, the MTE quartz vein possibly was derived from fluids that: 1) were of high temperature, vapor homogenization, and halite-dissolution temperatures averaging 550 to 600 C; 2) were of high salinity, to 72 eq. wt% NaCl; 3) were of high densities, approximately 1.3 to 1.5 g/cm³; 4) were complex, with the inclusion fluid containing between 6 to 15 daughter minerals; 5) were emplaced at pressures of 0.4 kbar and depths of 1.5 km; and 6) exhibited a single fluid population that showed a simple cooling trend.

Stable isotope data from the inclusion fluid and quartz of the MTE vein has δD values from inclusion fluid of -56 / ∞ to -58 / ∞ and $\delta^{18}O$ values from quartz of 8.6 / ∞ to 8.9 / ∞ , corresponding to water values of 7.6 / ∞ to 7.9 / ∞ .

Field relationships and petrographic and geochemical data suggest that the mineralization fluids are of magmatic origin and were derived from the alaskite stock that hosts the MTE quartz vein. Future work will concentrate on other veins in the Capitan Mountains to determine their fluid origin.

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