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FLUORITE–BASTNAESITE DEPOSITS OF THE GALLINAS MOUNTAINS, NEW MEXICO AND BASTNAESITE PARAGENESIS[1]

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Abstract

Many early reports on the occurrence of bastnaesite indicate that the mineral crystallized under a high-temperature environment. The Gallinas Mountain (New Mexico) bastnaesite deposits, however, occur as epithermal veins and breccia fillings in unaltered Permian sandstone in proximity to early Tertiary alkalic hypabyssal intrusives. The low temperature of formation is indicated by the predominance of open-space fillings, little replacement, extensive crustification, and lack of wall rock alteration. In addition, a geothermometric fluid inclusion study indicated a temperature of formation of 175–185° C.

This re-examination of a previously-known deposit and a study of other bastnaesite occurrences shows that the mineral is generally indicative of mineralization of alkalic derivation. Bastnaesite, however, is not a critical mineral diagnostic of any particular geological environment or temperature of formation. Bastnaesite occurs in magmatic, hydrothermal, contact metasomatic, and carbonatite deposits. It is both a primary and secondary mineral.

INTRODUCTION

During a recent investigation of the geology of the Gallinas Mountains in central New Mexico, the writers studied the fluorite-bastnaesite deposits of the area. The rare-earth mineral occurs in epithermal copper sulfide-fluorite veins and breccia fillings in sandstones overlying alkalic trachytic hypabyssal intrusives. Glass and Smalley (8), who described these deposits briefly, also attempted to define the general paragenesis of this relatively rare mineral. They concluded that bastnaesite was a mineral diagnostic of high-temperature environments. Our studies of the Gallinas deposits, as well as studies of other bastnaesite occurences, are not in accord with this conclusion. The purpose of this paper is, therefore, twofold: 1. to describe the geology and mineralogy of the Gallinas bastnaesite deposits and to classify them genetically, and 2. to summarize information on bastnaesite paragenesis.

GEOLOGY OF THE GALLINAS MOUNTAINS

Much of the high plateau of central New Mexico is underlain by nearly-horizontal Permian strata that were locally arched. In Lincoln County this arching was accompanied by Late Cretaceous or early Tertiary intrusion of a

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variety of subsilicic and alkalic hypabyssals and stocks (15, 25). The Gallinas Mountains, the northernmost of these domal uplifts, are in northern Lincoln County, about 40 miles north of Carrizozo. The range covers about 50 square miles, reaches an elevation of nearly 9,000 feet, and thus forms a prominent topographic feature rising nearly 3,000 feet above the surrounding semi-arid plateau.

The Gallinas Mountains have a core of Precambrian granite overlain by a nearly 2,000-feet section of lower Permian sedimentary rocks into which were intruded two alkalic laccoliths, consisting of porphyritic trachyte and porphyritic leuco-rhyolite. In addition to the two laccoliths, numerous dikes and one small stock also are exposed. The alkalic nature of these intrusives is indicated by their chemical composition (about 14% $K_2O + Na_2O$), the presence of riebeckite, aegirine-augite, titaniferous aegirine, extremely sodic plagioclase, albitized orthoclase, and the associated bastnaesite mineralization. The sedimentary sequence is typically transgressive, grading upwards from continental arkosic conglomerates (Abo Formation), through feldspathic sandstone (Yeso Formation), into near-shore quartzose sandstone (Glorietta Formation).

The range is a faulted, double domal uplift resulting from the intrusion of the two laccoliths. The dome is somewhat elliptical in plan, with the major axis trending northwest. The domed overlying sedimentary strata were extensively faulted (high angle normal faults) and jointed, resulting in a pronounced northwest and northeast fracture pattern. It is along these fractures and attendant breccia zones that the fluorite-bastnaesite mineralization was localized.

MINERAL DEPOSITS

General

Numerous small mineral deposits occur in the eastern part of the Gallinas Mountains, particularly within an area of about one square mile; the Red Cloud district. These deposits have been mined intermittently for iron, lead, copper, silver, gold, fluorite, and bastnaesite. Altogether 29 mines or prospects were worked or developed in the district; four were for copper, five for iron, and the remaining twenty were for fluorite and/or bastnaesite. Lead, silver, and gold were generally recovered as by-products to copper mining.

The mineral deposits are of two general types: iron deposits and copper-fluorite deposits, bastnaesite occurring as a ubiquitous accessory in the latter. Copper and fluorite deposits differ chiefly in the proportions of copper minerals and fluorite.

The mineral deposits were known as early as 1885. Little mining was done, however, until World War II, when the increased mineral demand spurred prospecting that resulted in the discovery of most of the major deposits in the district. It was during this period of intense prospecting that bastnaesite was recognized in the Red Cloud Fluorite mine.

About 10,000 tons of iron were mined in 1942 and 1943, and nearly 4,000 tons of copper ores were produced between 1920 and 1949. Between 1942 and 1955, fluorite was shipped from three mines (3, 10, 15). From 1953 to 1955, fluorite ore was mined from the Red Cloud Fluorite mine primarily for its bastnaesite content. The total fluorspar production from the district probably did not exceed 2,000 tons, from which about 60 tons of bastnaesite concentrate were produced.

Geology

Except for two deposits occurring in prophyritic trachyte, all fluorite-copper sulfide-bastnaesite deposits are in Yeso sandstones and siltstones, although locally an adajcent trachyte dike or sill is mineralized. The majority of deposits is in breccia zones associated with faults. Because of the brittle nature of the Yeso sandstones, most faults in this area are bordered by breccia zones ranging in width from a few inches to as much as 30 feet, and in length from a few feet to as much as 1,500 feet. The extent of the brecciation is apparently a function of both the magnitude of faulting and of the number of closely-spaced parallel faults in a particular zone. Not only does mineralization occur in breccia zones parallel with faults, but also in pipe-like breccia bodies formed along the intersection of two or more faults, which may serve as boundaries for the pipe.

Mineralization occurs as open-space fillings in the breccia. Commonly veinlets are less than an inch thick and rarely exceed a few inches in length. Ore minerals also occur along bedding planes and joint surfaces within the fracture zone. Only in areas of intense mineralization has the sandstone been replaced. Typical ore specimens thus consist of a porous mass of fluorite and bastnaesite (± copper minerals) and as tiny veinlets crisscrossing a highly brecciated rock.

Little wall rock alteration accompanies the deposits. Locally small veinlets of fluorite, quartz, or calcite extend from the breccia zones into the adjacent wall rock for a few inches. At only one or two deposits, minor silicification appears to have affected the Yeso sandstones adjacent to a vein or breccia zone. Small amounts of pyrite also occur in the wall rock as much as three or four inches away from the veins.

The most important bastnaesite deposit is at the Red Cloud Fluorite mine. It was here, in 1943, that the third occurrence of bastnaesite in the United States was discovered. The workings, which are along the steep eastern wall of Red Cloud Canyon (NE$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 25, T. 1 S., R. 11 E.), consist of an open cut, over 800 feet of underground exploratory and development workings, and open stopes. The major ore shoot contained about 11,000 tons of 50 percent fluorite ore, of which nearly 6,500 tons were mined between 1943 and 1955.

This deposit (Fig. 1) is localized along an intensely brecciated zone of Yeso sandstones and siltstones, the zone being bounded on three sides by major faults, one having a stratigraphic throw exceeding 400 feet. This breccia zone, nearly rectangular in plan, covers about 7,500 square feet and extends to a depth of at least 140 feet, as determined by diamond drilling. Kelley (27, p. 108) tentatively suggested that the zone may be a breccia pipe formed

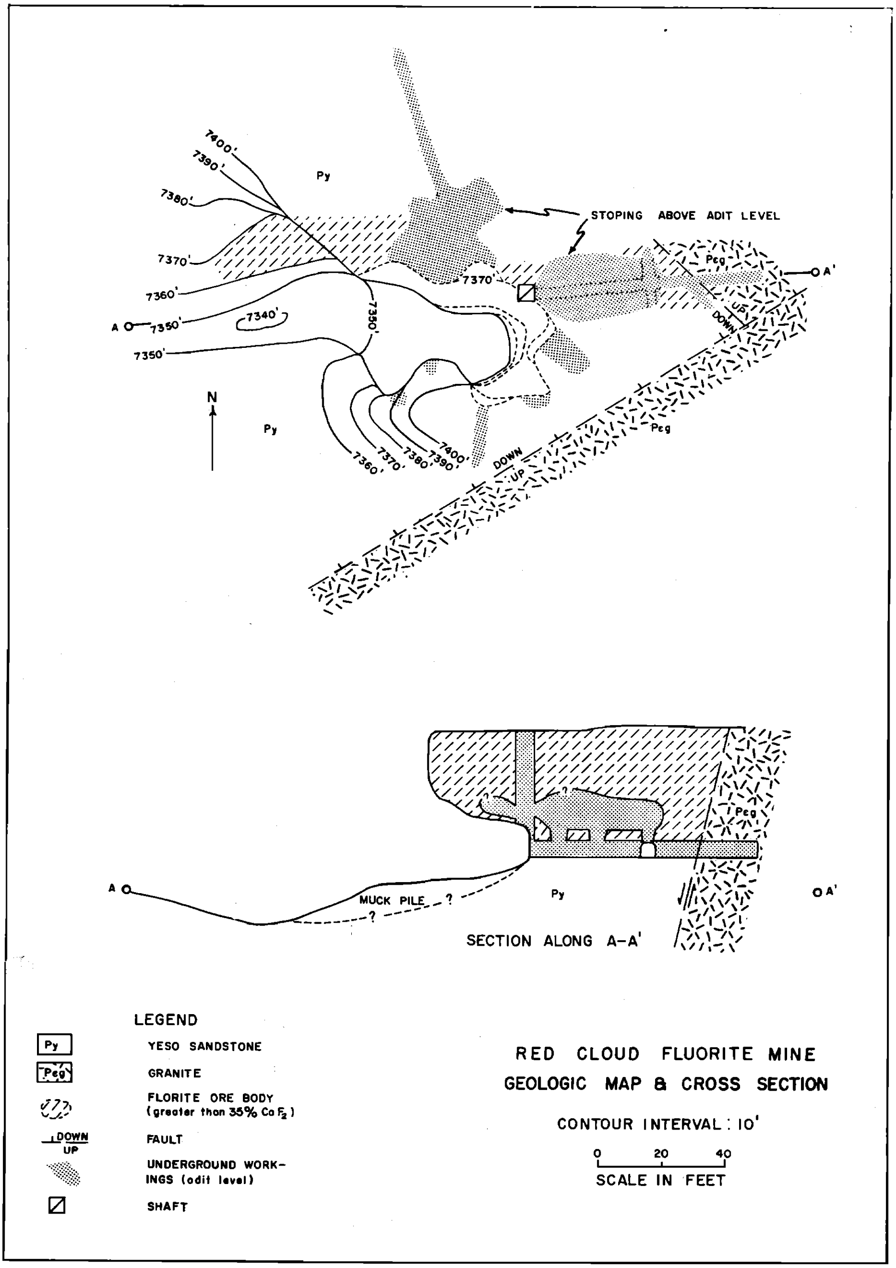
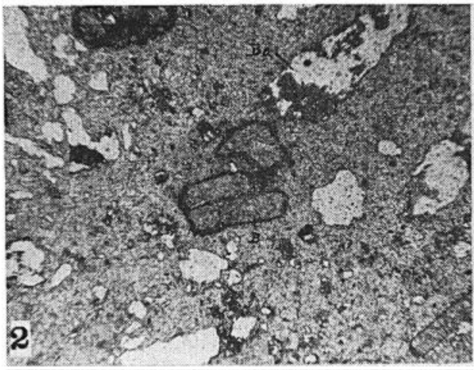


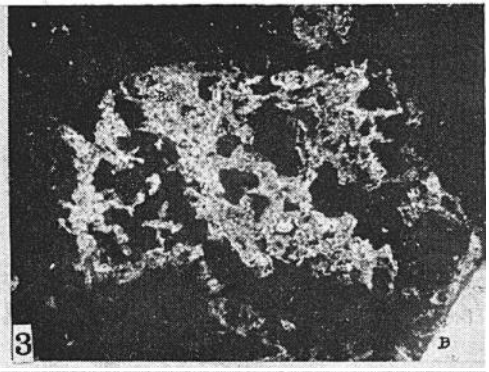
FIG. 1. Geologic map, Red Cloud Fluorite mine.

by explosive action of magmatic gases. The writers believe, however, that it is tectonic in origin.

Mineralogy

Hypogene Minerals.—The mineralogy of the deposits is summarized in Table 1. Modal analyses of specimens from some of the deposits are given in Table 2. The thin sections from which the compositions were determined are from high-grade specimens, hence the modes are not necessarily representative of the overall grade.





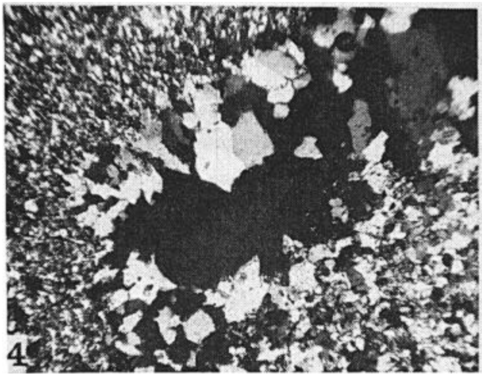


FIG. 2. Photomicrograph of porous fluorite ore showing skeletal barite (Ba) crystals and dark halos around bastnaesite (B) crystals. Clear areas are voids. Plane polarized light, × 35.

FIG. 3. Photomicrograph of skeletal crystal of barite (Ba) crystal partly embayed by fluorite (black) and bastnaesite (B). ×-nicols, × 40.

FIG. 4. Photomicrograph of fracture (in Yeso sandstone) lined with quartz and filled with fluorite (black). ×-nicols, × 35.

FIG. 5. Brecciated Yeso sandstone. Fluorite (dark-colored) occurs in the fractures between the light-colored angular fragments.

Flourite is the most abundant mineral, even in those deposits mined primarily for copper. It occurs typically as fine-grained aggregates filling open spaces. Although pale green and white crystals were noted, nearly all fluorite is medium to dark purple. Despite the dark color, its radioactivity rarely exceed twice background. Where bastnaesite is present, dark purple halos in fluorite surround the bastnaesite crystals (Fig. 2). Both the specific gravity (3.3) and the index of refraction (1.440) are slightly higher than for

Table 1: Mineralogy of the Fluorite-Copper Deposits

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Fluorite	X	x	x	x	X	x	x	X	x	X	x	x	x	x	x	x	x
Quartz	M	tr	m	m	m	m	tr	m	M	m	m	tr	m	m	x	m	m
Barite	x	x	tr	m	M	M	M	M	m	M	m	m	m	m	m	M	m
Bastnaesite	m			tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
Calcite	tr	tr	tr	tr						tr	M	tr	m		m	tr	
Chalcedony													tr		tr		
Pyrite	tr	tr	tr	m	tr	tr	m	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
Galena		m	tr			tr						tr	m			m	
Bornite		tr	tr		tr								tr				
Chalcocite		m	M		tr							tr	tr				
Limonite	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
Hematite	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
Pyromorphite		tr	tr								tr		tr		tr		
Cerrusite		?											m		tr		
Anglesite			tr										tr			tr	
Chrysocolla		m	m		tr						tr	tr	tr		tr		
Malachite		tr	tr		tr						tr	tr	tr		tr		
Azurite		tr	tr								tr	tr	tr				

X = greater than 50%
x = 25 - 50%
M = 10 - 25%
m = 5 - 10%
tr= less than 5%

Deposits

1. Red Cloud Fluorite
2. Red Cloud Copper and Deadwood
3. Little Wonder
4. Last Chance
5. Eagle Nest
6. Bottleneck
7. Congress
8. Conqueror No. 4 and Hilltop
9. Summit
10. Hoosier Girl North
11. Hoosier Girl South
12. Eureka
13. Rio Tinto
14. All American
15. Sky High
16. Pride No. 2
17. M and E No. 13

Table 2: Modes of Specimens From Fluorite-Copper Deposits

	1	2	3	4	5	6	7	8	9
Fluorite	82.8	71.1	66.8	68.2	84.9	83.9	53.8	86.3	61.7
Barite	13.2	5.3	20.1	15.8	8.5	10.4	4.3	6.3	9.5
Quartz	0.2	3.9	4.8	1.3	1.8	0.3	tr	0.3	6.5
Pyrite	0.5	6.7	2.6	9.7	3.4	2.9	2.8	0.1	1.2
Bastnaesite	3.3	1.2	2.1	5.0	1.5	2.4	0.2	2.4	4.7
Calcite		tr	3.6		tr		28.4	tr	
Cu minerals		tr	tr				0.9	4.7	
Galena			tr					tr	12.7
Albite									3.7
Yeso fragments	tr	11.8					8.1		
	100.0	100.0	100.0	100.0	100.1	99.9	100.1	100.1	100.0

Sample Locations

1. Red Cloud Fluorite
2. Last Chance
3. Bottleneck
4. Congress
5. Conqueror No. 4 and Hilltop
6. Hoosier Girl North
7. Hoosier Girl South
8. Eureka
9. Pride No. 2

pure CaF_2; this may be due to the presence of trace elements in the structure of the mineral or to microscopic inclusions. The fluorite does not fluoresce, but Glass and Smalley (8) report thermoluminescence in shades of very pale yellow.

Galena, chalcocite, and bornite generally occur in minor amounts; however, in some deposits these sulfides are economically significant. Like pyrite, cubes of galena (up to 10 mm) occur randomly distributed throughout the ore, commonly as individual crystals rather than aggregates. Chalcocite is by far the most abundant copper sulfide; bornite occurs only in small amounts. Both copper minerals occur as fine-grained masses. Bornite is randomly distributed, whereas chalcocite replaces galena and bornite.

Pyrite, one of the minerals found in every deposit, ranges from traces up to 7 or 8 percent, and averages about 1½ percent. It forms tiny euhedra (up to 5 mm in size): cubes and pyrithohedra, both with modifying forms.

In most deposits barite is the second most abundant mineral, ranging from traces to as much as 35 percent; most specimens contain 7–8 percent. The mineral typically occurs as subhedral prismatic crystals, up to 15 mm in length, intimately intergrown with fluorite or occurring in small cavities within fluorite. The crystals are most commonly white and opaque (or pink where iron stained), but transparent colorless individuals also occur. Much barite has been dissolved leaving skeletal crystals which produce a "honeycomb" ore (Fig. 3).

Quartz is ubiquitous; the amount varies from traces to about 20 percent. Most ore contains about 5 percent. Generally quartz has an especially irregular distribution throughout an ore zone. It occurs both as irregular anhedral grains and as euhedral prismatic crystals. Well-developed terminated crystals commonly line the walls of fractures or cavities (Fig. 4), thereby indicating its early paragenetic position.

Minor calcite is present in many deposits. The mineral occurs as extremely fine-grain masses filling open spaces in the mineralized rock. Calcite may be absent, or, rarely, may make up as much as 28 percent of the rock. Generally, the calcite content does not exceed 2 or 3 percent.

Bastnaesite.—Bastnaesite has been found in nearly every one of the fluorite-copper deposits in the Gallinas Mountains. It typically occurs as thin hexagonal plates. In addition, a prismatic habit with well-developed pyramidal faces is relatively common. The platy grains range from 2 to 7 mm in diameter with a thickness rarely exceeding 2 mm. The prismatic crystals may attain a length of 10 mm. Although prismatic cleavage $(10\bar{1}0)$ is poorly developed, the mineral possesses a distinct basal parting (0001) which can easily be mistaken for true cleavage. This parting was originally thought to be a cleavage, and was so reported by Glass and Smalley (8, p. 605), but specimens without (0001) "cleavage" have been reported (2, p. 393; 16, p. 354; 21, p. 298).

The bastnaesite is pale yellow, transparent to translucent. The streak is colorless, luster waxy, rarely vitreous. Hardness is 4.5. The specific gravity, as determined by M. Fleischer of the U. S. Geological Survey, is 4.99. In thin section, the mineral is colorless or very pale yellow with very weak pleochroism. Bastnaesite is optically positive; indices of refraction are: $e = 1.819$, $w = 1.718$; birefringence $= 0.101$. In hand specimen, the mineral is easily recognized by the platy habit, pale yellow color, and hardness of less than five.

Supergene Minerals.—A relatively large number of supergene minerals are present because of wide spread oxidation of the ore. Pyrite is always partly altered to limonite and hematite, in many instances pseudomorphously, which occur as fine-grained disseminated aggregates that impart a brownish color to the ore. The most common alteration products of the copper sulfides are chrysocolla, malachite, and azurite respectively. Galena is not as markedly altered as the copper sulfides. Pyromorphite and cerrusite are the most common supergene lead minerals; tiny anglesite crystals occur rarely.

PARAGENESIS AND ORIGIN

Most of the Gallinas Mountain fluorite-copper-bastnaesite deposits show evidence of at least two periods of hypogene mineralization, the two being separated by a period of fracturing due to additional movement along the faults. The first phase includes deposition of quartz, barite, sulfide minerals, fluorite, bastnaesite, and perhaps minor calcite, probably in that general order. This is evidenced by such textural features as quartz-lined fractures, fluorite deposition in etched barite crystals, and bastnaesite crystallization along fluorite cleavage and fracture planes. The sequence of introduction of ions, therefore, was $(SiO_4)^{4-}$, $(SO_4)^{2-}$, S^{2-}, F^-, and $(CO_3)^{2-}$. Following the initial phase of mineralization, the deposits were refractured. This is apparent from the number of early-formed minerals that are fractured, bent, or microfaulted. During the second period of mineralization mainly barite, fluorite, and locally abundant calcite were precipitated. Only at one deposit were two generations of quartz noted. In addition, at a few prospects, minor late silica occurs as chalcedony lining tiny cavities in the ore. Supergene alteration was the final phase in the formation of the deposits.

Throughout the central New Mexico intrusive belt, epigenetic mineral deposits are commonly and typically found in the sedimentary rocks overlying the numerous hypabyssal intrusives (10, 15, 26). This relationship is particularly notable in the Gallinas Mountains where both contact-metasomatic replacement iron lodes in limestone and fluorite-copper-bastnaesite veins in sandstone occur. The proximity of the bastnaesite deposits to the intrusive bodies and the confinement of mineralization to sandstone immediately adjacent to the trachyte leave little doubt of a magmatic derivation of the ores. Apparently, tension resulting from doming produced extensive faults, joints, and breccia zones along which the hydrothermal mineralizing fluids emanating from the crystallizing alkalic trachytic magma could percolate. That the trachyte was nearly or totally solidified is indicated by the presence of minor mineralization in the fractured roof zone of the intrusive itself.

The temperatures at which the fluorite-copper-bastnaesite deposits formed cannot be determined simply from the mineralogy of the veins; no critical or diagnostic minerals or assemblages are present. That these deposits were formed relatively near the surface and at a low temperature is evidenced, among other things, by their general textures. Although variable replacement occurs, the ore bodies are prominently fracture-controlled, and mineralization is limited to fissure and breccia zones and their margins. Fracture-filling was the predominant type of deposition. Abundant open spaces, comb structure, crustification, and the presence of many short and irregular veinlets all indicate low pressure and temperature conditions. Structural and stratigraphic studies indicate that the sedimentary cover probably did not exceed 1,500 feet at the time of mineralization. The lack of wallrock alteration and the presence of chalcedony also suggest a relatively low temperature for the ore-forming fluid. These deposits bear all the textural characteristics of such classic epithermal areas as those of Goldfield and Tonapah, for example.

In an attempt to obtain quantitative information on the formational temperatures, a study of fluid inclusions was made using the geothermometric method suggested by Ingerson (14). Usable fluid inclusions were found in some bastnaesite crystals. The sections, approximately 1 mm thick, were heated on an electrical heating stage, the temperature being controlled by a double Variac. Temperature was read directly from a thermometer mounted in the stage in direct contact with the section. Repeated runs showed disappearance of the vapor bubble in the inclusions over the range of 175–185° C. Complete decrepitation occurred at about 205° C. Inasmuch as mineralization occurred at shallow depth, the pressure correction is small, probably less than 15 degrees. It seems safe to conclude, therefore, that the bastnaesite formed at temperatures less than 200° C. From textural relations, most of the fluorite, quartz, and barite are pre-bastnaesite, hence the initial temperatures were probably slightly higher.

Glass and Smalley (8, p. 613) originally considered the Gallinas bastnaesite deposits to be contact metamorphic. Many deposits do occur relatively close to trachyte-Yeso contacts, hence they might be considered "contact" because of this distribution. Texturally, structurally, and mineralogically, however, they are entirely different from typical contact-metasomatic ores. Rather than occurring as replacements associated with contact metamorphism, i.e., in or near skarns or tactites, these deposits are the result of open-space fillings in unaltered sandstone (Fig. 5). Texturally, the ores are not unlike the epithermal Goldfield or Tonapah ores. On the basis, therefore, of texture, structure, mineralogy, and temperature of formation, the Gallinas Mountain bastnaesite deposits may be classed as epithermal veins.

PARAGENETIC SIGNIFICANCE OF BASTNAESITE

Glass and Smalley (8) previously attempted to define the paragenesis of bastnaesite. They report (p. 613), for example, that ". . . the most frequent and most abundant deposits . . . are in contact metamorphic zones. . . ." Actually, the only true contact occurrences are in Sweden and possibly in the Soviet Union (Table 3). Admittedly, at the time of their writing, the largest bastnaesite deposit was the contact ore at Bastnäs, but the recently discovered carbonatite occurrence at Mountain Pass, California (23) is now the greatest bastnaesite deposit in the world. On the basis, therefore, of several more recently described major occurrences of bastnaesite and on re-examination of the Gallinas deposit, a much more complete and detailed definition can now be prepared.

Twenty-seven bastnaesite occurrences are reported in the literature. These are listed in Table 3, plus a Nyassaland occurrence not previously reported (Heinrich, personal observation). The deposits are classified genetically, and for each deposit, the specific occurrence (if known) and the significant or abundant associated minerals are also listed. The table does show that the Gallinas deposit is unique in two respects: it is the only definite low-temperature occurrence of bastnaesite, and it is probably the only deposit in which only one rare earth mineral occurs.

The most numerous occurrences of bastnaesite are magmatic, particularly if the probable magmatic occurrences are included. In this class, bastnaesite occurs as an accessory in granite and syenite (or their pegmatitic equivalents), most of which are alkalic. Allanite is a common associated mineral. In most instances, the bastnaesite appears to have crystallized late in the paragenetic sequence.

Although magmatic occurrences are the most numerous, the most abundant deposits are associated with carbonatites. All carbonatite occurrences are associated with alkalic complexes. Also, many different rare earth minerals commonly occur in the deposit. To this extent, the carbonatite and contact-metasomatic deposits are similar. Both are intimately associated with alkalic rocks and both contain a great variety of rare earth minerals.

The hydrothermal occurrences are typified more by differences than similarities. The host consists of sedimentary, metamorphic, and igneous rocks. Mineralogy differs from one deposit to another. Temperature of formation apparently covers a wide range. Perhaps the only similarity is that the bastnaesite occurs in metalliferous veins.

In recent years, a number of secondary alteration occurrences of bastnaesite have been discovered.[1] At every locality, the mineral occurs in a granite (or pegmatite) as an alteration of accessory allanite or fluocerite. These occurrences are not unlike the magmatic occurrences except for the presence of bastnaesite as an alteration product rather than as an accessory mineral.

This study of bastnaesite occurrences shows that:

1. Bastnaesite is generally an indicator of mineralization of alkalic or subalkalic derivation.
2. Bastnaesite is not a diagnostic or critical mineral whose presence, per se, can be used to define, even qualitatively, the intensity environment under which the deposit was formed.

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[1] In addition to the increasing number of occurrences of *secondary* bastnaesite that are being reported, an occurrence of presumably *secondary, supergene* bastnaesite also has recently been described (E. I. Semenov, A. P. Khomyakov, and A. V. Bykova, Trudy Mineral. Mazeya, Akad. Nauk SSR, 1961, No. 11, 202–204; Chem. Abs. 55, 20799i, 1961). At an unspecified Russian deposit, bastnaesite occurs in the zone of weathering, finely dispersed in an argillaceous mass with limonite, pyrolusite, ferrihalloysite and other supergene species. The bastnaesite is considered to form from parisite by removal of calcium and partial hydration.

TABLE 3: SELECTED BASTNAESITE OCCURRENCES

Location	Occurrence	Associated Minerals	Reference
HYDROTHERMAL OCCURRENCES			
Gallinas Mountains, N. Mex., U. S. A.	Epithermal veins in sandstone	Fluorite, barite, bornite, quartz, galena, pyrite	Glass and Smalley, 1945
Karonge district, Gakara, Urundi	Mesothermal (?) quartz veins in schist	Monazite, barite, pyrite, quartz	Thoreau et al., 1958
Beiyin Obo, Suiyuan, China	Fluorite veins in iron deposit	Fluorite, barite, magnetite, oborite	Ho, 1935
Tuva, U. S. S. R.	Veins (?) in alkalic granite	No information	Semenov and Barinskii, 1958
Potgietersrus, U. of So. Africa	Veins and pipes in granite	Parasite, fluocerite, tourmaline, cassiterite	McDonald, 1912; Strauss, 1954
CONTACT METASOMATIC OCCURRENCES			
Riddarhyattan district, Bastnäs, Sweden	Replacement bands in skarns	Allanite, törneböhmite, cerite, magnetite	Hisinger, 1838; Geijer, 1920
Norberg district, Sweden	Replacement bands in skarns	Cerite, orthite, fluorite törneböhmite	Geijer, 1961
Kychtym, Urals, U. S. S. R.	Bands in granite gneiss near alkalic syenite contact	Allanite, cerite, törneböhmite	Silberminz, 1929
MAGMATIC DEPOSITS			
Ambositra, Madagascar	Alkalic syenite pegmatite	Torendrikite, chevkinite, riebeckite	Lacroix, 1912, 1913, 1915, 1920, 1922
Laondany, Madagascar	Alkalic syenite pegmatite	Probably same as Ambositra	Lacroix, 1922
Karonge district, Murambi, Urundi	Granite pegmatite	No information	Thoreau et al., 1958
Jamestown, Colo., U. S. A.	Granite pegmatite and aplite	Cerite, allanite, fluorite, uraninite	Goddard and Glass, 1940
Mt. Rosa area, Colo., U. S. A.	Alkalic granite		Gross, 1962
Bancroft, Ont., Canada	Granite	Thorite, uraninite, pyrochlore	Satterly, 1957

TABLE 3 (continued)

PROBABLE MAGMATIC OCCURRENCES			
Pocos de Caldas, Brazil	Nepheline syenite	Allanite, cerianite, thorogummite	Frondel and Marvin, 1959
Westerly, R. I., U. S. A.	Granite	Monazite, sphene	Smith and Cisney, 1956
Agusta County, Va., U. S. A.	Alkalic dike rocks	No information	U. S. Geol. Survey, 1962
Langesundsfjord, Norway	Nepheline syenite pegmatite	Analcite, zircon, aegirite	Sverdrup et al., 1959
Anst-Agder County, Norway	Pegmatite	Monazite, xenotime, allanite	Sverdrup et al., 1959
CARBONATITE OCCURRENCES			
Mountain Pass, Calif., U. S. A.	Carbonatite associated with alkalic intrusives	Cerite, parasite, monazite, fluorite	Olson et al., 1954
Powderhorn district, Colo., U. S. A.	Carbonatite veins in pyroxenite	Synchisite, cerite (?)	Olson and Wallace, 1956
Tundula area, Nyassaland. E. Africa	Carbonatite in alkalic complex	Ankerite	Heinrich, personal observation
SECONDARY ALTERATION OCCURRENCES			
Österby, Sweden	Alteration of fluocerite in granite pegmatite	Fluocerite, lanthanite (?)	Geijer, 1921
Cheyenne Mountain, Colo., U. S. A.	Alteration of fluocerite in pegmatite	Fluocerite	Allan and Comstock, 1880; Hillebrand, 1899
Elberton area, Georgia, U. S. A.	Alteration of allanite in granite	Allanite	Silver and Grunenfelder, 1957
Jefferson County, Colo., U. S. A.	Alteration of allanite in Pikes Peak granite	Allanite, monazite	Adams and Young, 1961
Vest-Agder County, Norway	Alteration of allanite in granite pegmatite	Allanite	Sverdrup et al., 1959
Drag in Tysfjord, Norway	Alteration of allanite	Allanite, fluorite, zircon	Sverdrup et al., 1959

Semenov and Barinskii (29) have summarized the variation in rare earth elements in bastnaesite for available analyses. The rare earth assemblage is very restricted, comprising only Ce (dominant), La, Pr, Nd, Sm, and very minor Gd. The ratio $Ce_2O_3/\Sigma RE_2O_3$ is very similar in all; the major variations are in La and Nd. It may well be, therefore, that the specific rare earth content will reflect, at least in part, the type of geological environment in which the bastnaesite crystallized. This, of course, can be determined only after a sufficient number of bastnaesites from a wide variety of deposits have been analyzed for their individual rare earth element contents.

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