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FORBESITE — A MIXTURE OF COBALTOAN ANNABERGITE AND ARSENOLITE

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ABSTRACT

Examination of a topotype specimen of forbesite from "Atacama, Chile" by X-ray powder techniques, scanning electron microscopy, and infrared analysis indicates that this material is an intimate mixture of cobaltoan annabergite, $(Ni,Co)_3(AsO_4)_2 \cdot 8H_2O$, and arsenolite, As_2O_3. Rose-pink aggregates on a specimen of cobaltoan annabergite from Cobalt, Ontario, were also found to contain arsenolite. Interpretation of two analyses of unidentified earthy cobaltous blooms from Schneeberg and Annaberg, Germany (Kersten 1843), assuming that the As_2O_3 in each analysis represented admixed arsenolite, led to the empirical erythrite formula, $Co_3(AsO_4)_2 \cdot 8H_2O$.

SOMMAIRE

L'étude d'un échantillon topotype de forbésite d'Atacama (Chili), effectuée aux rayons-X par la méthode des poudres, au microscope électronique à balayage et par analyse à l'infrarouge, indique que ce matériau est un mélange intime d'annabergite cobaltifère $(Ni,Co)_3(AsO_4)_2 \cdot 8H_2O$ et d'arsénolite As_2O_3. Les agrégats rosés observés sur un échantillon d'annabergite cobaltifère provenant de Cobalt, Ontario, contiennent aussi de l'arsénolite. Deux analyses de "fleurs de cobalt" terreuses non-identifiées, provenant de Schneeberg et d'Annaberg (Allemagne) (Kersten 1843), interprétées en supposant que l'As_2O_3 provient d'une admixture d'arsénolite, donnent la formule emprique de l'érythrine $Co_3(AsO_4)_2 \cdot 8H_2O$.

(Traduit par la Rédaction)

INTRODUCTION

In connection with a mineralogical investigation of several unidentified nickel-cobalt arsenate minerals, an effort was made to obtain and authenticate specimens of the rare mineral forbesite, presumed to have the formula $H_2(Ni,Co)_2(AsO_4)_2 \cdot 7H_2O$ (Fleischer 1971). No powder data for forbesite have been reported in the literature.

Forbesite, the name given by Kenngott (1868) to a hydrated arsenate of nickel and cobalt, was originally described by Forbes (1863) as a new unnamed mineral that he found in veins in a semidecomposed mafic rock at a mine in the locality where the Potrerillos mine is now located in the Atacama Desert, Chile, about 100 km east of the port of Flamenco (Fig. 1).

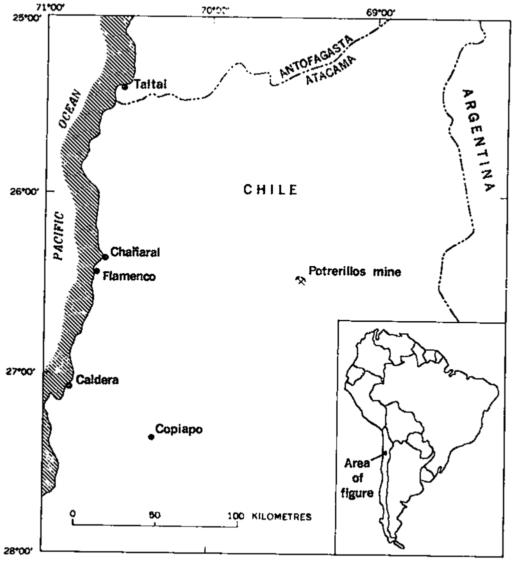

FIG. 1. Index map showing the location of the Potrerillos copper mine near the locality where forbesite was discovered.

Forbes reported that the new mineral occurred in abundance in the upper part of the veins but that a few yards below the surface, it gave way to chloanthite, $(Ni,Co)As_{3-x}$, from which the forbesite was considered to have been derived. This is the only recorded occurrence of forbesite.

Unfortunately, Forbes gave no description of hand specimens of forbesite. The physical properties of the new mineral, determined by Forbes (1863), are summarized in Table 1. The chemical analysis (see Table 4) led Forbes (1863) to postulate the formula $(NiO+CoO)_2 + As_2O_5 + 8H_2O$ [$= (Ni,Co)_2(AsO_4)_2 \cdot 8H_2O$] for his new mineral. He noted that this formula was anal-

TABLE 1. PHYSICAL PROPERTIES OF FORBESITE AND ANNABERGITE

Reference	Forbesite Forbes (1863)	Annabergite Palache *et al.* (1951, p. 746-750)
Habit	Fibro-crystalline masses; radial fibrous crusts	Radial or stellate crystal aggregates; globular or reniform masses with columnar or coarse-fibrous structure
Color	Colorless or grayish white	Pale rose or pink at Co:Ni = 1:1, becoming white or gray, pale green, and fine apple green in the nickel-rich variety
Luster	Dull to silky or resinous	Weakly adamantine, pearly on (010); also, dull and earthy
Hardness	2-1/2	1-1/2 to 2-1/2
Specific gravity	3.086*	3.07 (Laurium, Greece)

* The average of measurements from three different specimens: 3.054, 3.069, and 3.134.

ogous to the then-assigned formula of pharmacolite, $2CaO \cdot As_2O_5 + 6H_2O$, presently $CaH(AsO_4) \cdot 2H_2O$, wherein the nickel and cobalt in forbesite substitute for the calcium in pharmacolite; however, the formula differed in having eight instead of only six molecules of water. Forbes noted also that in this last respect the formula of the new mineral resembled those of the arsenates of nickel, cobalt, and zinc, respectively: annabergite, $Ni_3(AsO_4)_2 \cdot 8H_2O$; erythrite, $Co_3(AsO_4)_2 \cdot 8H_2O$; and köttigite, $Zn_3(AsO_4)_2 \cdot 8H_2O$. Later, Dana (1892, p. 834) reinterpreted Forbes' analysis to give a new formula, $H_2(Ni,Co)_2(AsO_4)_2 \cdot 8H_2O$. More recently, Palache *et al.* (1951, p. 711) proposed that forbesite is a hydrated arsenate of nickel and cobalt of uncertain formula, perhaps $H(Ni,Co)(AsO_4) \cdot 3\frac{1}{2}H_2O$, with Ni:Co=2:1. Fleischer (1971) recast this formula as $H_2(Ni,Co)_2(AsO_4)_2 \cdot 7H_2O$.

We have not been able to locate a type specimen of forbesite in any of the mineralogical collections of the major museums in the United States, Canada, and Europe: Iron and Steel Institute of London (now The Metals Society), U.S. National Museum of Natural History (Washington, D.C.), Harvard Mineralogical Museum (Cambridge, Massachusetts), The American Museum of Natural History (New York City, N.Y.), and the Royal Ontario Museum (Toronto, Canada). Neither of the two catalogues — *An Index to the Systematic Collection of Minerals in the British Museum (Natural History)* (British Museum, 1965) and *Collection de Minéralogie* which had been compiled by Lacroix (1931) for specimens in the Muséum National d'Histoire Naturelle in Paris, France — listed forbesite in its index. A specimen labeled forbesite, now in the study collection of the U.S. National Museum of Natural History, Washington, D.C. ("Atacama, Chile"; USNM R5551), was originally acquired by the late Col. Washington Roebling. It is a fragment approximately 6x5x3½ cm, consisting of a trellised network of a silvery-grey metallic mineral, in a groundmass of diorite, encrusted with finely crystalline, soft, greyish white, locally pale greenish white, material (~0.25 mm thick). The museum does not have any information about Col. Roebling's acquisition of this specimen. Consequently, this specimen, labeled forbesite (USNM R5551), can only be considered a topotype of the mineral, as defined by Embrey & Hey (1970).

X-RAY STUDIES

We attempted to ascertain whether Roebling's specimen of forbesite (USNM R5551) represented material from the type locality. X-ray powder patterns, therefore, were taken of the silver-grey metallic mineral to find out whether it corresponded to the so-called chloanthite of Forbes (1863) and whether the soft greyish white mineral encrusting it might be identified with Forbes' description of forbesite. The X-ray powder pattern gave data identical with those reported in the literature for rammelsbergite, $(Ni,Co)As_2$. A semiquantitative microprobe analysis of several fragments of this rammelsbergite shows Co, Ni, and As as the major constituents, and traces of Fe. Semiquantitative microprobe analyses of altered rammelsbergite seen in the fragments show an increase in cobalt and iron content and a decrease in nickel content; the arsenic content is about the same in altered and unaltered areas.

The X-ray powder diffraction patterns of the greyish white and very pale greenish white encrusting material (assumed to be "forbesite") are identical. They, in turn, are identical, except for a few additional lines, with patterns of minerals in the annabergite-erythrite series, $A_3(AsO_4)_2 \cdot 8H_2O$ (where A is Ni or Co). The d-values, however, indicated that this phase is annabergite, the nickel-rich member of the series. The additional lines in these X-ray patterns are those of arsenolite, As_2O_3; identification of the arsenolite in the diffraction pattern was hampered by the superposition of its strongest line with that of the strongest line of annabergite (~3.20Å). Arsenolite occurs as a secondary mineral with erythrite at Joachimstal in Bohemia (Palache *et al.* 1951, p. 543), but it has never been reported, to our knowledge, as an admixture with either erythrite or annabergite.

To confirm the presence of arsenolite as a separate phase in the Roebling specimen, heating tests were made of this material and of samples of the bright green aggregates of anna-

TABLE 2. X-RAY IDENTIFICATION OF QUENCHED PRODUCTS OBTAINED AFTER HEATING SAMPLES OF ANNABERGITE, ARSENOLITE, AND FORBESITE

Temp. (°C)	Annabergite* (Cobalt, Ontario; USNM 95741)	Arsenolite (Hunan, China; USNM 93432)	Forbesite ("Atacama, Chile"; USNM R5551)
150	annabergite	arsenolite	annabergite + arsenolite
180	amorphous	arsenolite	arsenolite
200	amorphous	-------†	amorphous

* Bright-green aggregates
† Arsenolite sublimes at 193°C (Weast, 1971-1972, p. B-69)

bergite (Cobalt, Ontario; USNM 95741) and arsenolite (Hunan, China; USNM 93432). Fragments of these specimens were heated simultaneously for 30 minutes in an oven at 150°, 180°, and 200°C, and X-ray powder patterns (Cu*Kα* radiation) were made of their quenched products (Table 2). The X-ray powder patterns of the heat-treated annabergite and arsenolite (Table 2) served as a guide in interpreting the patterns of the heat-treated "forbesite". The pattern of the "forbesite" heated to 150°C was identical with that taken of the untreated material; the sample heated to 180°C showed only lines of arsenolite, indicating that at that temperature the annabergite phase in "forbesite" is amorphous; no lines appeared on the powder pattern of the "forbesite" heated at 200°C, indicating that at that temperature the arsenolite phase had completely sublimed.

SCANNING ELECTRON MICROSCOPY

The scanning electron microscope (SEM) provided further evidence that forbesite is a mixture of two minerals. The SEM micrographs at magnification 1400× show fragments of forbesite to consist of two morphologically distinct species: 1) bladed rosettes; and 2) well-developed octahedra (Fig. 2). A qualitative scan, using the energy-dispersive X-ray (EDX) system, showed the rosettes to contain major amounts of Ni and As and only minor amounts of Co (=cobaltoan annabergite), whereas the octahedra showed the presence of As (=arsenolite) and only a trace of Ni, which probably is present as surface contamination by cobaltoan annabergite (see Fig. 2).

A SEM examination likewise was made of rose-pink aggregates of annabergite from Cobalt, Ontario (USNM 95741), a material that gave a powder pattern virtually identical with that obtained for Roebling's forbesite. This material is characterized by intergrowths of octahedra and bladed rosettes, as is the forbesite. A qualitative scan with the energy-dispersive X-ray detector in the SEM showed that the rosettes contain slightly more Ni than Co in addition to As (=cobaltoan annabergite), whereas the octahedra contain major As (=arsenolite) and traces of Co and Ni (possibly from cobaltoan annabergite coating on crystal faces).

With reference to the color of forbesite,

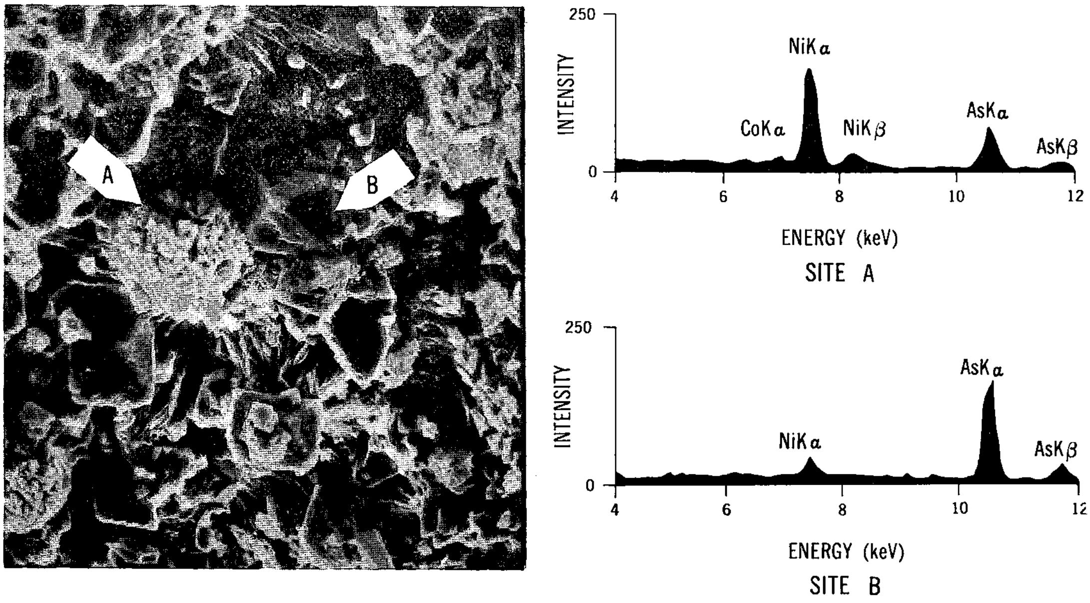

FIG. 2. Scanning electron photomicrograph (1400X) and qualitative energy-dispersive X-ray analysis of forbesite ("Atacama, Chile"; USNM R5551); rosettes (site A) = cobaltoan annabergite; octahedra (site B) = arsenolite. Intensity: counts for 80 seconds.

Forbes (1863, p. 104) stated, "It is remarkable that this mineral is colourless notwithstanding its containing so large a proportion of the protoxides of nickel and cobalt, the combinations of which are so generally distinguished by their more or less promising tints." Many years later, Walker & Parsons (1924) also noted that the analysis of the white bloom from the LaRose vein at Cobalt, Ontario, shows five times as much nickel as cobalt, and that even when the nickel is 10 times as abundant as the cobalt, the bloom is still nearly white. In our study, the Ni-Co content of aggregates of different color (white, greenish white, bright green, and rose-pink — all of which gave an annabergite-type X-ray diffraction pattern) found on a single specimen from Cobalt, Ontario, was determined by the EDX system. The energy-dispersive X-ray spectrum for each material of contrasting color is shown in Figure 3, for the energy

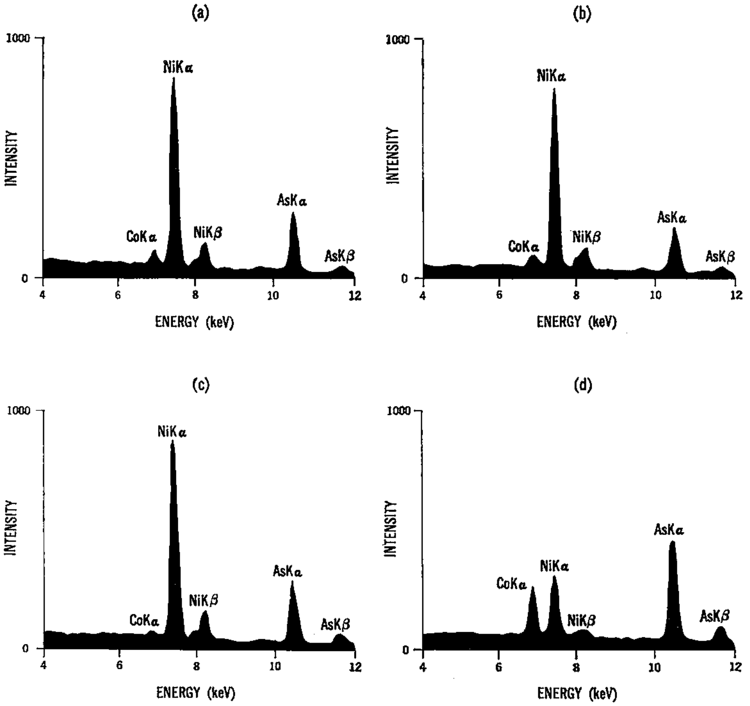

FIG. 3. Traces showing relative Ni-Co X-ray intensity (counts for 85 seconds) in four differently colored fragments of cobaltoan annabergite from a specimen from Cobalt, Ontario (USNM 95741): *(a)* white, *(b)* greenish white, *(c)* bright green, and *(d)* rose-pink (note that the AsK peaks are enhanced in this trace because of the presence of arsenolite, which is intimately admixed with the cobaltoan annabergite).

TABLE 3. COMPARISON OF Ni-Co CONTENT OF VARIOUSLY COLORED BLOOMS FROM THE COBALT, ONTARIO, AREA

	This study		Walker & Parsons (1924)			
	Cobalt, Ontario, specimen; USNM 95741		Cobalt-area mines, Ontario			
	Energy dispersive analysis (EDX)	Identification	Chemical analysis (wt. %)		Locality	Identification
			NiO	CoO		
White	Ni>Co	cobaltoan annabergite	29.30	6.43	LaRose vein	cobaltoan annabergite
Greenish white	Ni>Co	cobaltoan annabergite	33.82	3.40	Unspecified	cobaltoan annabergite
Bright green	Ni>Co	cobaltoan annabergite	---	---	---	---
Rose-pink	Ni>Co (~1)	cobaltoan annabergite	---	---	---	---
Pale rose	---	---	17.37	16.33	Kilpatrick claim	cobaltoan annabergite
Deep peach-blossom	---	---	0.52	34.11	O'Brien mine	erythrite

TABLE 4. POSSIBLE INTERPRETATIONS OF THE CHEMICAL ANALYSIS OF FORBESITE

	Forbesite			Theoretical composition for cobaltoan annabergite		Forbesite = cobaltoan annabergite + arsenolite		
	Forbes (1863)		Present Study					
Oxides	(1) Wt. %	(2) Atoms	(3) Atoms	(4) Wt. %	(5) Atoms	(6) Wt. %	(7) Recalc. to 100	(8) Atoms
NiO	19.71	2.02	3.00	25.47	3.00	19.71	25.69	3.03
CoO	9.24			12.02		9.24	12.04	
As_2O_3	---			---		21.20*		
As_2O_5	44.05	2.00	2.97	38.42	2.00	29.37	38.27	2.00
H_2O	26.98	15.62	23.22	24.09	16.00	18.42	24.00	16.00
Total	99.98			100.00		97.94	100.00	
Formula (empirical)	$(Ni,Co)_2(AsO_4)_2.8H_2O$		$(Ni,Co)_3(AsO_4)_3.12H_2O$	$(Ni,Co)_3(AsO_4)_2.8H_2O$, with Ni:Co = 0.68:0.32		$(Ni,Co)_3(AsO_4)_2.8H_2O + As_2O_3$		

* Summation of the two values for As_2O_3 (12.64% + 8.56%) derived by conversion of the arsenic atom and the four water molecules (in column 3) that are in excess of that required by the annabergite formula.

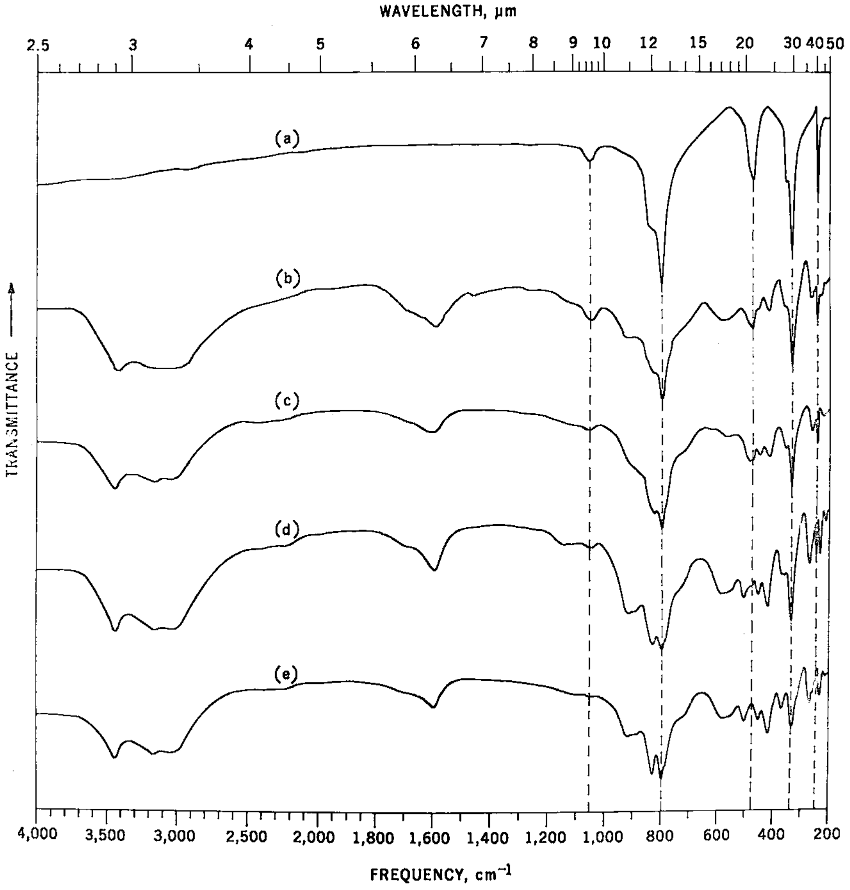

FIG. 4. Infrared spectra of arsenic oxide minerals: (a) arsenolite (Hunan, China; USNM 93432); (b) forbesite ("Atacama, Chile"; USNM R5551); (c) cobaltoan annabergite (rose-pink) with admixed arsenolite (Cobalt, Ontario; USNM 95741); (d) simulated forbesite — a mixture of cobaltoan annabergite (USNM 95741; bright green) + 21% arsenolite (USNM 93432); (e) cobaltoan annabergite (Cobalt, Ontario; USNM 95741; bright green).

range 4-12 keV. Table 3 shows the relative Ni and Co content of the variously-colored blooms from the above specimen from Cobalt, Ontario, and the NiO-CoO content of four other analyzed blooms of variable color from mines in the Cobalt area (Walker & Parsons 1924). The white, greenish white, and bright green aggregates of annabergite from Cobalt, Ontario (USNM 95741), were found to contain considerably more nickel than cobalt; the rose-pink aggregates on the same specimen, however, contained almost as much cobalt as nickel (Fig. 3 and Table 3). The high nickel content obtained in our study for the white aggregates of annabergite confirms the observations of Forbes (1863) for his forbesite from the Atacama Desert, Chile (Table 4), and of Walker & Parsons (1924) for the white bloom from the LaRose vein at Cobalt, Ontario (Table 3).

INFRARED SPECTROSCOPY

The infrared absorption spectra in this study were taken using a Perkin-Elmer Model 621 grating spectrophotometer.* Except for forbesite, infrared macropellets were prepared by the standard techniques of mixing 500 mg of powdered cesium iodide and 1 mg of the preground sample for 5 minutes in a mullite mortar.

Special ultra-microsampling techniques were devised to isolate sufficient forbesite for preparation of an infrared micropellet from this material. Forbesite was repeatedly scraped from three different areas of the surface of a small fragment of Roebling's specimen. Material from each scraping was loaded directly into the cavity (1.5 mm diameter) of a Perkin-Elmer ultramicrodie, already half-filled with tamped cesium iodide matrix powder (~5 mg). After an estimated 5μg of forbesite had thus been loaded into the cavity, additional cesium iodide powder (~ 5 mg) was placed on top of it and tamped to form a "sandwich" micropellet. The usual step of blending sample with matrix was omitted because of the extremely small sample of forbesite. A micropellet was then prepared in this microdie according to the procedure described by Estep *et al.* (1973).

The infrared spectrum of forbesite is shown as curve b in Figure 4, where it can be compared with spectra of arsenolite from Hunan, China (curve a), cobaltoan annabergites from Cobalt, Ontario (curves c and e), and a synthetic mixture of annabergite and arsenolite (=simulated forbesite; curve d). Our infrared spectra obtained for the samples of arsenolite and annabergite agree well with those of Sadtler Research Laboratories (1972; arsenolite) and Moenke (1962; annabergite), suggesting that the samples were pure. In Figure 4, the predominant absorption bands for arsenolite at 1050 (weak; unique), 795 (strong), 472 (medium), 333 (strong), and 244 (medium) cm^{-1} can be identified by frequencies, band shapes, and band-intensity agreement in the spectrum for forbesite (curve b). These same five absorption bands can be identified in spectra of the rose-pink annabergite and the mixture of annabergite and arsenolite (Fig. 4c, d).

INTERPRETATION OF THE CHEMICAL ANALYSIS

An interpretation of the chemical analysis of forbesite (Forbes 1863), assuming that this material is a mixture of two minerals, is shown in Table 4. In our interpretation (Table 4), we initially assumed that water was determined by loss on ignition, as this method prevailed in the 1860s, but we recognized that the method is not precise and that the presence of volatile constituents introduces a possible source of error. Hence, the water content reported for forbesite (26.98%) probably includes some, if not all, of the arsenolite, which is reported to sublimate at 193°C (Weast 1971-1972). In column 3 (Table 4), the analysis has been recalculated assuming (Ni,Co)=3.00, as required by the formula of cobaltoan annabergite. It is apparent that this interpretation results in an extra arsenic atom and approximately four extra water molecules, thereby suggesting that the part of the sample on which the arsenic determination (As_2O_5) was made also contained arsenolite and that the water value (26.98%) was obtained by ignition of a separate part of the analysis sample at a temperature higher than 193°C and thus includes loss of water and As_2O_3, from arsenolite. In column 6 (Table 4), we have recast the original forbesite analysis on the basis of the assumptions made above. Here the arsenic atom in excess of 2.00 (column 3, Table 4) first was converted to As_2O_5 (=14.68%) and then to As_2O_3 (12.64%); the water in excess of that required for assignment to the cobaltoan annabergite formula (8.56%) was accepted as representing the As_2O_3 that volatilized during ignition. If this represents a correct interpretation of Forbes' analysis, then it may be concluded that the analyzed sample contained 21.20% (12.64% + 8.56%) arsenolite. We are unable to offer a satisfactory explanation for the discrepancy between the two

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*Equipment is named in this report for identification only and does not necessarily imply endorsement by the U.S. Geological Survey or the U.S. Bureau of Mines.

values for As_2O_3 (12.64% and 8.56%) that we derived by conversion of the arsenic atom and the water molecules in excess of that demanded by the annabergite formula. After deducting the arsenolite as impurity and recalculating to 100, the results cited in column 7 in Table 4 permit allocation of the atoms (column 8) to the formula for cobaltoan annabergite, $(Ni,Co)_3(AsO_4)_2 \cdot 8H_2O$, and can be compared with the theoretical composition for cobaltoan annabergite, with Ni:Co=0.68:0.32 (Table 4).

COMPARISON OF FORBESITE WITH ANNABERGITE–ERYTHRITE SPECIMENS FROM OTHER LOCALITIES

A specimen of annabergite (Cobalt, Ontario; USNM 95741) was made available for use in heating experiments in conjunction with our study of forbesite. Material on this specimen consisted of an admixture of white, greenish white, pale pink, rose-pink, and bright green globular to earthy aggregates. Except for the rose-pink aggregates, all gave an X-ray powder diffraction pattern characteristic of annabergite, empirically $Ni_3(AsO_4)_2 \cdot 8H_2O$; the pattern of the rose-pink material, however, was identical with that obtained for forbesite (USNM R5551)= cobaltoan annabergite+arsenolite.

Museum records did not indicate a specific mine in the Cobalt area from which this specimen of annabergite (USNM 95741) was collected. Walker & Parsons (1924), in their study of the cobalt and nickel arsenates from the silver-bearing veins in the O'Brien mine, Kilpatrick claim, and LaRose vein at Cobalt, Ontario, suspected that some of the arsenic in their specimens might be present in a lower state of oxidation (As^{3+}), as previously reported by Kersten (1843) for two samples of earthy cobalt bloom from the Wolfgang Maafsen mine in Schneeberg, and from the Markus Röhling mine in Annaberg, Germany. They reported, however, that this was not the case in any of the bloom (deep peach-blossom, pale rose, earthy white, greenish white) examined by them from the northern Ontario localities. Kersten (1843) offered no explanation for the two states of oxidation for the arsenic (As^{3+} and As^{5+}) that he found in his earthy cobalt blooms (Table 5), nor did he attempt to identify his results with a formula. On the basis of our study of forbesite from "Atacama, Chile" (USNM R5551), and the rose-pink aggregates from Cobalt, Ontario (USNM 95741), we have interpreted Kersten's two analyses of earthy cobalt bloom from Schneeberg and from Annaberg (Table 5), assuming that both contained admixed arsenolite, As_2O_3. After deducting As_2O_3 from each of the two analyses and recalculating to 100, we found that both analyses led to an erythrite formula. The Schneeberg bloom represents a mixture of ferroan erythrite, $(Co,Fe)_3(AsO_4)_2 \cdot 8H_2O$, and arsenolite; the Annaberg bloom represents a mixture of near end-member erythrite, $Co_3(AsO_4)_2 \cdot 8H_2O$, and arsenolite.

TABLE 5. INTERPRETATION OF THE CHEMICAL ANALYSES OF EARTHY COBALT BLOOMS CONTAINING As^{+3} AND As^{+5} (from Kersten 1843)

	Wolfgang Maafsen mine, Schneeberg (Germany)			Markus Röhling mine, Annaberg (Germany)		
Oxides	Wt. %	Recalc. to 100*	Atoms	Wt. %	Recalc. to 100*	Atoms
CaO	---	---		tr.	---	
NiO	tr.	---		tr.	---	
CoO	16.60	33.40	3.02	18.30	36.29	3.00
FeO	2.10	4.23		---	---	
As_2O_3	51.00	---		48.10	---	
As_2O_5	19.10	38.43	2.00	20.00	39.66	2.14
H_2O	11.90	23.94	15.89	12.13	24.05	16.54
H_2SO_4	tr.	---		tr.	---	
	$100.70^{\dagger}$	100.00		$98.53^{\dagger\dagger}$	100.00	
Formula (empirical)	$(Co,Fe)_3(AsO_4)_2.8H_2O$ = ferroan erythrite			$Co_3(AsO_4)_2.8H_2O$ = erythrite		

* Recalculated to 100 by the present authors after deducting As_2O_3

† Reported as 99.80 by Kersten (1843, p. 264)

††Reported as 99.63 by Kersten (1843, p. 264)

CONCLUSIONS

Our investigations indicate that forbesite is a mixture of cobaltoan annabergite and arsenolite, and we have recommended that the name forbesite be added to the list of discredited mineral names. This recommendation was approved by the Commission on New Minerals and Mineral Names, IMA (M. Fleischer, Chairman of the Commission, written commun., 1974).

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REFERENCES

BRITISH MUSEUM (1965): *An Index to the Systematic Collection of Minerals in the British Museum (Natural History)*, 28th ed. London, Trustees of the British Museum (Natural History).

DANA, E. S. (1892): *The System of Mineralogy*, 6th ed. John Wiley & Sons, New York.

EMBREY, P. G. & HEY, M. H. (1970): "Type" specimens in mineralogy. *Mineral. Record* **1**, 102-104.

ESTEP, P. A., KOVACH, J. J. & KARR, C., JR. (1973): Microsampling techniques for infrared spectroscopic analysis for lunar and terrestrial minerals. *In* Analytical Methods Developed for Application to Lunar Samples Analyses. *Amer. Soc. Testing Mat.*, Philadelphia, Pa., 80-99.

FLEISCHER, M. (1971): *Glossary of Mineral Species 1971.* Mineral. Record, Inc., Bowie, Md.

FORBES, D. (1863): On the chemical composition of some Chilean minerals. *Philos. Mag.* **25**, 103-114.

KENNGOTT, A. (1868): Forbesit. *Uebersicht der Resultate Mineralogischer Forschungen in den Jahren 1862-1865.* Leipzig, Germany, 46-47.

KERSTEN, C. (1843): Ueber die chemische Zusammensetzung der Producte der Freiwillingen Zersetzung der Kobalt - und Nickelerze. *Ann. Physik Chemie* **60**, 251-271.

LACROIX, A., (1931): *Collection de Minéralogie du Muséum National d'Histoire Naturelle.* Masson et Cie, Paris.

MOENKE, H. (1962): *Mineralspectren.* Akademie-Verlag, Berlin; 42 pp. and Card Collection.

PALACHE, C., BERMAN, H., & FRONDEL, C. (1951): *The System of Mineralogy* **2**, 7th ed. John Wiley & Sons, New York.

SADTLER RESEARCH LABORATORIES (1972): *Special Collection — Inorganics.* Sadtler Research Laboratories, Inc., Philadelphia, Pa., 1300 Infrared Grating Spectra.

WALKER, T.L. & PARSONS, A.L. (1924): The arsenates of cobalt, nickel, and iron observed in the silver-bearing veins of Cobalt, Ontario. *Univ. Toronto Studies, Geol. Ser.*, No. 17, 13-17.

WEAST, R.D. (ED.-IN-CHIEF), (1971-1972): *Handbook of Chemistry and Physics,* 52nd ed. The Chemical Rubber Co., Cleveland, Ohio.

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