THE MINERAGRAPHY AND *X*-RAY ANALYSIS OF STAINIERITE FROM THE SWANSEA MINE, GOODSPRINGS, NEVADA[1]

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INTRODUCTION

In conjunction with flotation tests on a cobalt ore from the Swansea mine, Goodsprings, Nev., polished sections were made of the ore and of the concentration products. As the cobalt occurred as hydrated oxide, which is uncommon, its mineragraphic characteristics and *x*-ray diffraction pattern were determined. The crude ore contained 1.23 per cent of cobalt, and the interlocking between the cobalt mineral and the gangue persisted to finer than 400-mesh. Nevertheless, by grinding the ore through 200-mesh, a flotation concentrate was prepared which contained 39.3 per cent of cobalt. The work was done at the Mississippi Valley Experiment Station of the United States Bureau of Mines in cooperation with the Missouri School of Mines and Metallurgy, Rolla, Mo.

DESCRIPTION OF ORE

The naturally occurring hydrated cobalt oxides have been poorly described in the literature, and only recently has a satisfactory nomenclature been proposed.

The geology and mineralogy of the Goodsprings quadrangle have been described by Hewett.[3] On the basis of the usual mineralogical blow-pipe tests, the black cobalt-bearing mineral is referred to by him as heterogenite. In the *x*-ray diffraction study, described later in this paper, the writers have concluded that the mineral is stainierite, and henceforth it will be referred to by that name.

Heterogenite is referred to by Dana[4] and Doelter[5] as an amorphous mineral, the composition being given as $CoO \cdot 2Co_2O_3 \cdot 6H_2O$.

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[3] Hewett, D. F., Geology and Ore Deposits of the Goodsprings Quadrangle, Nevada: *U. S. Geol. Survey*, Prof. Paper **162**, 1931.

[4] Dana, E. S., *A System of Mineralogy*, 6th ed., New York, **1892**, p. 259.

[5] Doelter, C., *Handbuch der Mineral-Chemie:* Bd. **III**, Heft 2, Dresden, 1926, p. 976.

Schneiderhohn and Ramdohr[6] state that an analysis by Benrath gave approximately the composition $Co_2O_3 \cdot 2H_2O$, probably mixed with a little CoO. Schneiderhohn determined the mineral to be optically uniaxial and probably to belong to the hexagonal system. He noted the occurrence of two varieties of the mineral, one crystalline and anisotropic, the other nodular and vitreous, and he refers to both as heterogenite.

Cuvelier,[7] Schoep and Cuvelier,[8] de Jong,[9] and Schoep[10] recently named two varieties of hydrated cobalt oxide on the basis of *x*-ray diffraction studies. One, giving a definite *x*-ray diffraction pattern, was named "stainierite"; the other, a vitreous variety giving no *x*-ray diffraction pattern, retained the name "heterogenite." Cuvelier gives the formula for stainierite as $(Fe, Co, Al)_2O_3 \cdot H_2O$.

Hand samples from the Swansea mine consist essentially of stainierite scattered in a matrix of rhombohedral carbonates. An analysis of a representative sample gave 1.23 per cent of cobalt. The carbonates range from pure white to earthy red and from gray to a light shade of purple. The stainierite occurs as small black specks in the gray and purple carbonate, as larger masses, and as veinlets traversing the reddish carbonate. As a rule the higher the cobalt content the redder and more "rotten" and porous the ore. Occasionally the stainierite occurs as a sooty covering on the carbonates.

The stainierite is black and dull, although a fresh fracture may occasionally appear bright. The rich flotation froth is as black as jet. In no case were macroscopic crystals developed.

Mineralogy and Mineragraphy of the Ore

Gangue Minerals. A sample of the ore was crushed through 14-mesh and the 14- to 20-mesh material was separated with acetylene

[6] Schneiderhohn, H., and Ramdohr, P., *Lehrbuch der Erzmikroskopie*, Berlin, vol. **2**, 1931, pp. 558–59.

[7] Cuvelier, V., Analyse van Enkele Zuivere Stoffen, Technische Produkten en Kobaltmineralien: *Natuurwetenschappelijk Tijdschrift*, Antwerpen, vol. **11**, 1929, pp. 170–79.

[8] Schoep, A., and Cuvelier, V., Sur la Stainierite (un Hydroxide Cobaltique), nouveau mineral: *Bull. Soc. Belge Geol. Pal. Hydrol.*, vol. **39**, 1930 (for 1929), pp. 74–82.

[9] de Jong, W. F., Over Goethiet, Stainieriet, Diaspoor en Heterogeniet: *Natuurwetenschappelijk Tijdschrift*, Antwerpen, vol. **12**, 1930, pp. 69–72.

[10] Schoep, A., Sur la Stainierite et sur un Nouveau Gisement de ce Mineral: *Ann. Service Mines*, Katanga, vol. **1**, 1930, pp. 55–58.

tetrabromide of 2.95 specific gravity. The product lighter than 2.95 specific gravity consisted of carbonates with very little adhering stainierite. Hand-picking under a low-power microscope effected a separation into four products corresponding to the colored materials mentioned above. Petrographic examination of these products showed that the white mineral was calcite and that the "rotten" reddish material and that having a purplish hue were calcite stained by goethite. The gray carbonate possessed higher refractive indices than calcite, dissolved slowly in cold concentrated hydrochloric acid, and gave a strong microchemical test for magnesium and a weak test for iron. It was identified as dolomite. A small amount of quartz occurred locked with the dolomite. The material heavier than specific gravity 2.95 contained the major portion of the ore minerals.

Ore Minerals. Samples heavier than 2.95 specific gravity and samples of the natural ore were briquetted in bakelite and polished on a modified Vanderwilt polishing machine. Two apparently different opaque cobalt minerals were distinguished in these polished sections. With the exception of a small amount of goethite they were the only opaque minerals observed. The more abundant of the two polished brilliantly, showed strong anisotropism in polarized reflected light, and possessed to a marked degree the property characterized by Schneiderhohn as "reflection pleochroism." In other words, the mineral was markedly anisotropic when no nicols were used. This property is shown in figure 4. In nearly crossed nicols the colors ranged from brown to first order gray. The second mineral was closely associated with the anisotropic variety but polished with a dull mat surface. Some grains showed weak anisotropism; others were quite isotropic.

Microchemical tests of the strongly anisotropic mineral indicated cobalt, a trace of nickel and iron but no manganese. It occurs as:

(1) Irregular veinlets in the carbonates, frequently separated from them by a thin border of the isotropic mineral described above. The surrounding ground mass of carbonates is often replaced by filaments of stainierite. These features are shown in figure 1.

(2) A replacement between individual grains of the carbonates in the ground mass of the ore, as in figure 2. This occurrence is quite common.

(3) A replacement of carbonate along the rhombohedral cleavage, as in figure 3. An example of regular replacement is shown in figure 4, the stainierite occurring as a fretwork between a vein and the matrix.

That the stainierite was originally deposited as colloidal material is fully evident from the sections examined. Figure 5 shows a typical colloform structure.

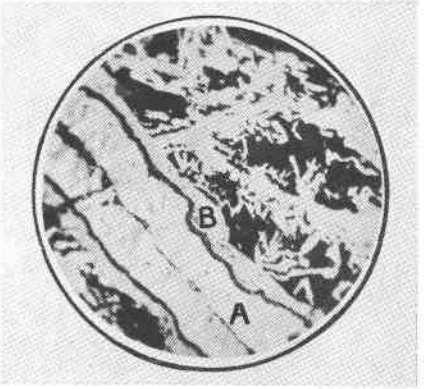

FIG. 1. Veinlet of anisotropic stainierite (A), and filaments of the same in calcite (black). Isotropic stainierite (B). Polished section, vertical illumination, ×200.

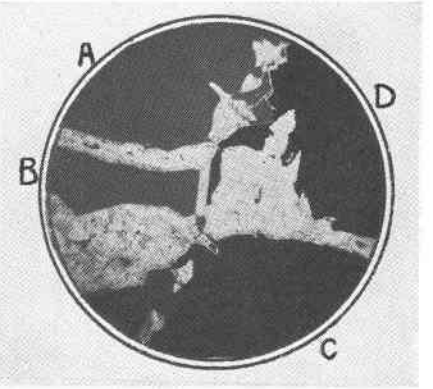

FIG. 2. Anisotropic stainierite (white) replacing carbonates along the grain boundaries. A, B, C, D, rhombohedral carbonate grains. Polished section, crossed nicols, ×200.

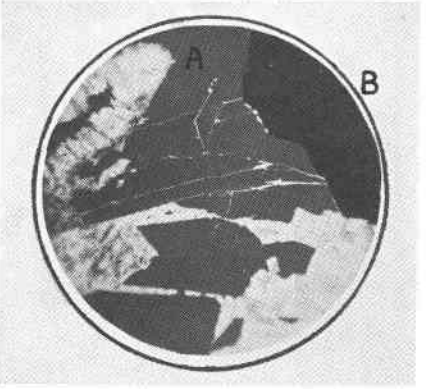

FIG. 3. Stainierite replacing calcite along the rhombohedral cleavages. A, B, individual calcite grains. Polished section, ×200.

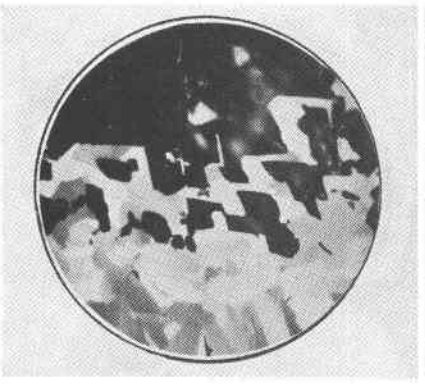

FIG. 4. Regular replacement of calcite by stainierite. Polished section, ×1100.

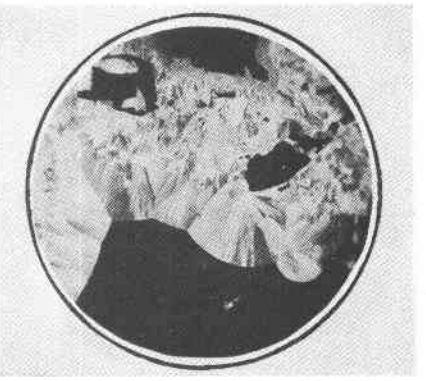

FIG. 5. Colloform stainierite in rhombohedral carbonate (black). Polished section, nicols nearly crossed, ×200.

The second opaque mineral examined was also colloform. Microchemical tests indicated a high cobalt content, a trace of iron, but no manganese or copper. In all probability it is a cryptocrystalline variety of stainierite.

TABLE 1.—MINERAGRAPHIC CHARACTERISTICS OF STAINIERITE

	Etch tests	Color in Reflected Light	Streak	Reflection Pleochroism	Microhardness
Anisotropic variety	Negative to HNO_3, KCN, KOH, $HgCl_2$, $SnCl_2$, H_2O_2. Dissolves slowly in cold HCl with slight tarnish. Dissolves slowly in aqua regia.	Creamy white, yellower than hematite, close to magnetite in color. Brighter than goethite.	Iron gray	Very strong	830 = Talmage E
Isotropic variety	Ditto; no tarnish in HCl.	Dull white.	Dark yellow brown.	—	420 = Talmage D

The various properties of the two microscopically different forms of stainierite are summarized in table 1. Neither variety exhibited any tendency to be attracted by a high-intensity electromagnet. Reducing gases convert the stainierite to metallic cobalt at temperatures about 600° C.

X-ray Diffraction Study

X-ray examinations of a flotation concentrate containing 39.3 per cent of cobalt and of a micro-drill sample of the cryptocrystalline cobalt mineral were made. A modified Siegbahn hot-filament-type *x*-ray tube was used and operated at approximately 25 kilovolts and 10 milliamperes. Hull-Debye-Scherrer photograms were made of the samples by means of a cylindrical camera of 3.929 cm. radius. The radiation used was the K alpha doublet for iron (wave length, 1.934 Angstrom units).

Both fine-grained diffraction lines and spotted lines appeared on the photogram of the flotation concentrate. By direct comparison with standard photograms the spotted lines were shown to be due to rhombohedral carbonates.

The photogram for the micro-drill sample of the cryptocrystalline mineral showed lines which corresponded to the fine-grained pattern of the flotation concentrate. It was thus concluded that both these microscopically different minerals were in reality the same substance, also that the fine-grained pattern was due to the cobalt mineral.

According to de Jong[11] heterogenite is black $Co_2O_3 \cdot H_2O$ and is the amorphous variety of the crystalline material, $Co_2O_3 \cdot H_2O$. This crystalline mineral has been named stainierite. The *x*-ray study thus eliminates heterogenite.

Table 2 gives the *x*-ray diffraction data for the mineral in question.

De Jong's[12] patterns are reproduced diagramatically and do not lend themselves to accurate comparison. However, the above data correspond to those of the mineral stainierite, provided two excess lines which appear in de Jong's pattern are attributed to goethite. The other lines due to goethite correspond approximately to a portion of the stainierite pattern. This assumption seems justified, since de Jong's material contained iron.

[11] *Op. cit.*, p. 72.
[12] *Op. cit.*, p. 71.

The mineral in question is, therefore, identified as stainierite, $Co_2O_3 \cdot H_2O$, the crystalline form of heterogenite.

TABLE 2.—*X*-RAY DIFFRACTION DATA FOR STAINIERITE

Line	Intensity (1–5)	Sin θ	$d_{hkl/n}$
1	2	0.1928	5.02
2	5	.2128	4.55
3	1	.3703	2.61
4	1	.3897	2.48
5	5	.4094	2.36
6	2	.4769	2.03
7	3	.5257	1.84
8	1	.6051	1.60
9	2	.6327	1.53
10	4	.6689	1.45
11	3	.7032	1.38
12	2	.7875	1.22_8
13	1	.7978	1.21_2
14	1	.8171	1.19_6
15	1	.8551	1.13_1

SUMMARY

The occurrence of cobalt in an ore from the Swansea mine, Goodsprings, Nev., is of considerable metallurgical importance, for few cobalt deposits of commercial value are known in the United States and domestic production has been far below the demand.

The cobalt in this ore is present as stainierite, or hydrated cobalt oxide, the crystalline equivalent of heterogenite, with which it has sometimes been confused. The stainierite was identified by *x*-ray diffraction studies.

Microscopically, the stainierite occurs as two varieties, one crystalline and anisotropic and the other cryptocrystalline and isotropic. *X*-ray diffraction studies showed no essential differences between the two.

The mineragraphic properties and *x*-ray diffraction pattern of the stainierite have been determined and are presented in tabular form in this paper.