

THE UM SAMIUKI VOLCANOGENIC Zn–Cu–Pb–Ag DEPOSIT, EASTERN DESERT, EGYPT: A POSSIBLE NEW OCCURRENCE OF CERVELLEITE

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ABSTRACT

A cervelleite-like mineral has been recorded in the Precambrian Ag-rich volcanogenic Zn–Cu–Pb deposits of Um Samiuki, Eastern Desert, Egypt. The optical properties, mineral associations and chemical composition of the mineral are described. The associated hypogene minerals comprise sphalerite, pyrite, chalcocopyrite, galena, bornite, tetrahedrite–tennantite, hessite and electrum, whereas the supergene minerals comprise covellite and mckinstryite. The cervelleite-like mineral has been observed in two textural positions, a) as small (15–40 μm) subhedral crystals close to margins of hessite and galena grains, and b) as inclusions in sphalerite, where it is associated with silver-rich bornite, chalcocopyrite and hessite. Compositionally, two varieties of the cervelleite-like mineral are recognized, Cu-rich (up to 6.0 wt.%) and Cu-poor (<0.25 wt.%). Silver shows well-defined reciprocal variation with Cu. The chemical composition of the mineral (calculated formula approaching Ag_4TeS) depends on the mineral association and bulk composition. The mode of occurrence of the cervelleite-like mineral suggests a hypogene origin. The mineral forms in an environment of very high Ag activity, and the minimum $f(\text{Te}_2)$ values required to stabilize silver tellurides.

Keywords: cervelleite, silver minerals, chemical composition, tellurium activity, hypogene, volcanogenic deposit, Um Samiuki, Egypt.

SOMMAIRE

Un minéral rappelant la cervelléite a été trouvé dans les gisements précambriens volcanogéniques argentifères de Zn–Cu–Pb à Um Samiuki, Désert Oriental, en Egypte. On décrit ses propriétés optiques, les associations de minéraux et sa composition chimique ici. Parmi les minéraux hypogènes associés, on trouve sphalérite, pyrite, chalcocopyrite, galène, bornite, tétraédrite–tennantite, hessite et électrum, tandis que covellite et mckinstryite sont les minéraux supergènes. Le minéral de type cervelléite occupe deux positions texturales: a) en petits (15–40 μm) cristaux sub-idiomorphes près de la bordure des grains de hessite et de galène, et b) en inclusions dans la sphalérite, en association avec bornite argentifère, chalcocopyrite et hessite. Il y a aussi deux champs de composition de cette phase, soit riche en Cu (jusqu'à 6.0% en poids) et pauvre en Cu (<0.25%). La teneur en argent montre une variation réciproque bien définie avec celle du cuivre. La composition du minéral, qui est voisine de Ag_4TeS , dépend de l'association de minéraux et de la composition globale du minerai. La distribution de ce minéral fait penser à une origine hypogène. Sa présence requiert une activité de Ag très élevée et la fugacité minimale de Te_2 pour stabiliser les tellurures d'argent.

(Traduit par la Rédaction)

Mots-clés: cervelléite, minéraux d'argent, composition chimique, activité du tellure, hypogène, Um Samiuki, Egypte.

INTRODUCTION

The importance of tellurides arises from the fact that they, among other ligands, are the main carriers of precious metals (Au, Ag, PGE, platinum-group elements) in a wide variety of geological environments. They form minor or trace components in vein mineralizations (*e.g.*, Spry *et al.* 1997), magmatic ultramafic–mafic complexes (*e.g.*, Garuti & Rinaldi 1986, Helmy *et al.* 1995) and massive sulfides. Silver tellurides (*e.g.*, hessite

Ag_2Te , empressite AgTe , stützite $\text{Ag}_{5-x}\text{Te}_3$) were described from several cases of massive sulfide mineralization (*e.g.*, Sabir 1981, Craig & Vokes 1992). One silver sulfotelluride mineral, benleonardite [$\text{Ag}_8(\text{Sb,As})\text{Te}_2\text{S}_3$] is known (Stanley *et al.* 1986). Experimental evidence on the stability of precious metal tellurides was given by Kracek *et al.* (1966).

Cervelleite, Ag_4TeS , was first discovered by Criddle *et al.* (1989) at the Bambolla mine, Moctezuma, Sonora (Mexico), as fracture fillings in a highly altered silicified

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rhyolite. At the Bambolla mine, cervelleite occurs as a thin (30 μm) rim surrounding irregular inclusions of finely granular acanthite in hessite and as vermiciform inclusions in the latter. Other associated minerals are native silver, pyrite and sphalerite. Recently, a phase similar to cervelleite was described by Spry & Thiebn (1996) from the Mayflower mine, Montana. The present study focusses on the occurrence of a Ag–Te–S mineral in the Um Samiuki volcanogenic Zn–Cu–Pb–Ag mineralization. This mineral has optical properties and chemical composition close to those of cervelleite from the Bambolla mine (Criddle *et al.* 1989). As X-ray-diffraction analysis could not be carried out, the term “cervellite-like mineral” is used. On the basis of mineral association, the approximate conditions of formation of this mineral are discussed.

UM SAMIUKI Zn–Cu–Pb–Ag MINERALIZATION

The Late Precambrian (~710 Ma) Shadli Metavolcanic Belt of the southeastern Desert, in Egypt, contains some polymetallic massive sulfide deposits, *e.g.*, El Atshan, Egat, Derhib, Abu Gurdi, Helgate, Maqaal and Um Samiuki. These deposits are distributed over the whole metavolcanic belt, which extends for more than 80 km in a WNW direction, with an average width of 25 km. The Shadli metavolcanic suite is a thick pile of bimodal volcanic rocks that were erupted in two magmatic cycles: the Um Samiuki volcanic sequence (stratigraphically lower), and the Hamamid Group (Searle *et al.* 1978, Hafez & Shalaby 1983, Stern *et al.* 1991). Each cycle commenced with the eruption of basic lavas and terminated by the eruption of felsic volcanic rocks. Geochemical studies (Stern *et al.* 1991) indicate that the Shadli metavolcanic suite is bimodal and calc-alkaline; they proposed that it erupted in a rift. The geological framework of the Shadli Metavolcanic Belt suggests that most of the polymetallic massive sulfide deposits were formed over a fairly narrow stratigraphic interval within a group of felsic metavolcanic rocks.

The Um Samiuki Zn–Cu–Pb–Ag prospect (latitude 24°16'N, longitude 34°51'E) is hosted by felsic volcanic rocks (Fig. 1). The Um Samiuki area is the type locality of the Shadli metavolcanic suite, where it consists of weakly metamorphosed rhyolite, andesite, basalt and volcanoclastic rocks (Shukri & Mansour 1980). Two volcanic vents are present in the area (Searle *et al.* 1978). A pipe-like zone of alteration, with a variable thickness, was syngenetically formed (Rasmy *et al.* 1983). This alteration zone exhibits gradational contacts with the ore horizon; it was formed by the circulation of seawater within the felsic volcanic rocks (Rasmy *et al.* 1983). Structurally, the area is characterized by the presence of two large faults, the Samiuki fault and the Helgate fault. A detailed geological map of the Um Samiuki mine area is given in Figure 2.

Two lenticular ore zones (the Western and Eastern mines) of massive and disseminated mineralization occur at the top of rhyolitic breccias (footwall) and are overlain by banded and graded fine lapilli tuff (hanging wall). The contact between the ore zones and the hanging-wall rocks is sharply defined, whereas with the footwall rocks, it is not. These ore zones follow the general structures of the host rocks, with dips ranging from 60 to 70°. Massive sulfide mineralization with more than 70% sulfides dominates the upper six meters of the ore zone at the Western mine. The massive mineralization grades vertically and laterally into a semimassive sulfide mineralization (~30% sulfides) and then into the disseminated sulfide halo. Within the massive ore, there is no zoning, but barite and Mn minerals are common in the upper part of the lenses. Small-scale shearing and faulting are common in the massive ore.

Figure 3 illustrates the variation of Cu, Zn, Pb and Ag in a vertical cross-section of the ore zone in the Western mine. At Um Samiuki, Ag is more strongly correlated with Cu than with Pb (Fig. 3). Ore reserves were estimated at slightly less than 300,000 tonnes (Searle *et al.* 1978) containing 11.5% Zn, 1.15% Cu, 1.1% Pb and 250 ppm Ag. Sphalerite, chalcopyrite, pyrite, galena, bornite, and tetrahedrite–tennantite are the major constituents of the massive ore, and arsenopyrite, pyrrotite, and molybdenite are accessory minerals. Covellite and digenite are common supergene minerals, whereas magnetite also is common. Pyrite and sphalerite are the major constituents of the semimassive and disseminated types of ore. Relevant studies on the mineralogy of the Um Samiuki mineralization include those of El Aref *et al.* (1985), Helmy (1995) and Helmy & Shalaby (1996).

Careful examination of high-quality polished blocks supported by an extensive program of electron-microprobe analyses led to the identification of seven silver-bearing minerals at Um Samiuki, hessite, acanthite, freibergite, electrum, stephanite, native silver (Ag) and mckinstryite (Helmy & Shalaby 1996). These minerals occur mainly in the massive sulfide ore and are closely associated with bornite, galena and chalcopyrite. Hessite occurs as subhedral inclusions (250 μm) in galena and chalcopyrite, and shows lamellar twinning. Native silver, electrum and freibergite form intergrowths with pyrite and sphalerite, whereas mckinstryite replaces bornite and galena in covellite-bearing samples.

METHODS OF INVESTIGATION

During a previous investigation of the Um Samiuki Zn–Cu–Pb–Ag mineralization (Helmy 1995), a few small grains (<5 μm) of the cervelleite-like mineral were observed microscopically, but the grains were found to be too small to perform any chemical analyses. During the 1996 field season, resampling focused on the area in which the mineral was previously identified.

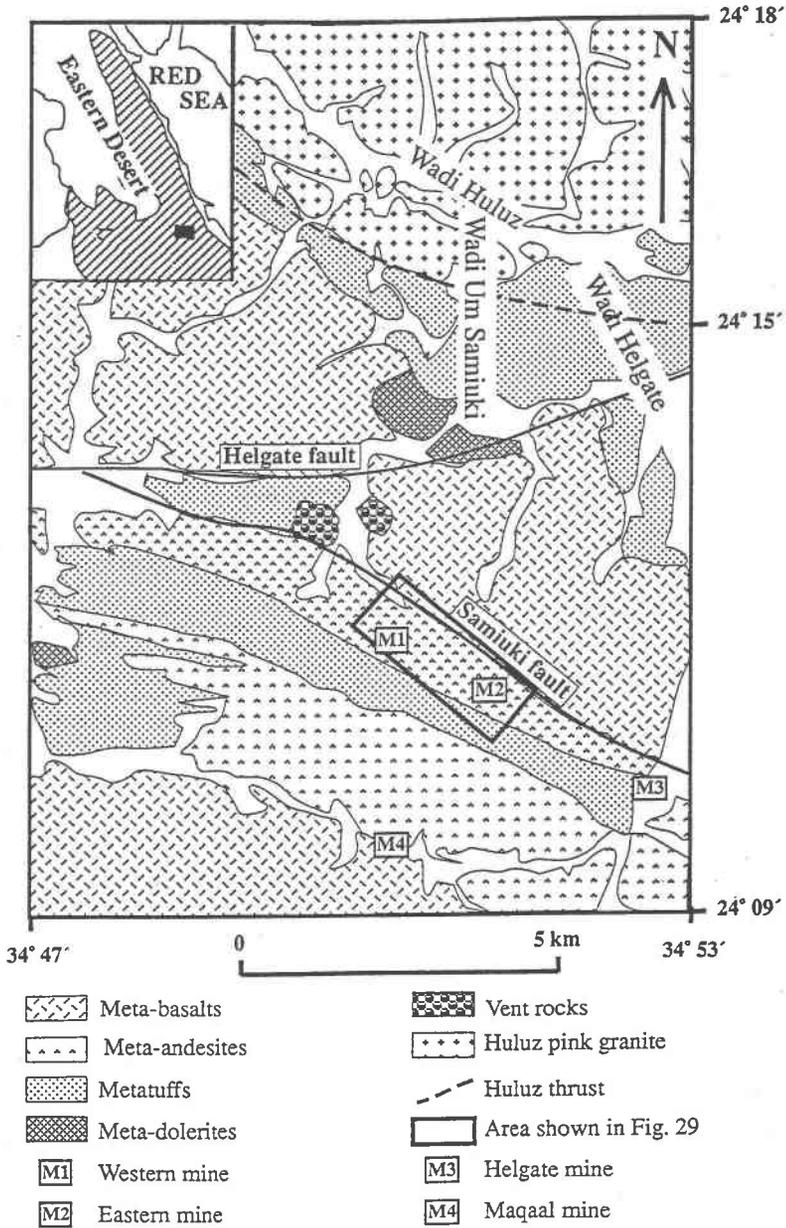


FIG. 1. Geological map of the Um Samiuki area from Helmy (1995).

Twenty-seven new samples of massive sulfides were examined, and the cervelleite-like mineral was recorded and confirmed by electron-microprobe analysis. The observed grains are, however, too small to perform X-ray-diffraction analysis or to measure reflectivity. Chemical analyses of the mineral were obtained by wavelength-dispersion methods using an ARL-SEM

electron microprobe at the Institute of Mineralogy and Petrology, Mining University of Leoben, and the Institute of Mineralogy-Crystallography and Petrology, Karl-Franzens University, Graz, Austria. The accelerating voltage was 20 kV, the beam current was 15 nA, and the counting time, 10 seconds. The following standards were used: native silver and gold for Ag and Au,

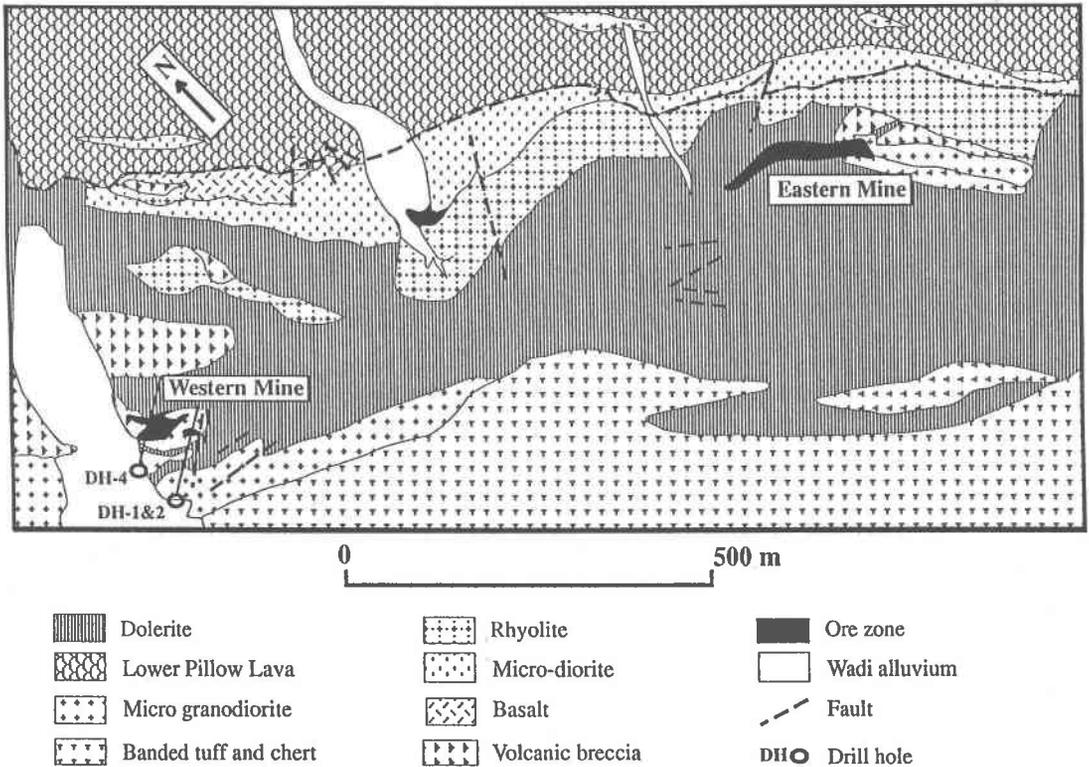


FIG. 2. Geological map of the Um Samiuki mine area, modified from Searle *et al.* (1978).

altaite for Te and Pb, tetrahedrite for Cu, Sb and S, and sphalerite for Zn and Fe. Matrix effects were corrected according to Bence & Albee (1968). Back-scattered electron images were initially used to confirm that there was no contamination from other admixed minerals during analysis and that the analyzed crystals are homogeneous. More than two microprobe analyses were made on individual grains to check for any zoning.

MINERAL ASSOCIATIONS AND TEXTURAL FEATURES

From a total of 27 samples, the cervelleite-like mineral has been found in nine samples of massive sulfides: UC3, UC20, UCX, UCY, UC6, UC29, UC29-2, UC29-3 and UC30. These samples were collected from the middle and upper parts of the massive sulfide lens of the Western mine (Fig. 2). The sulfides and other minerals were identified microscopically and confirmed by electron-microprobe analyses. Results of the electron-microprobe analyses of silver-bearing minerals are listed in Table 1. A full description of the samples containing the cervelleite-like mineral follows.

Recrystallized massive sulfide ore UC20 is composed of idiomorphic crystals of pyrite, galena,

chalcopyrite and sphalerite (average of 2.7 mole % FeS) as major constituents, and minor arsenopyrite and pyrrhotite. Large (0.5 mm) crystals of pyrite contain numerous inclusions of galena, sphalerite and hessite. Pyrrhotite occurs as anhedral grains closely associated with pyrite or arsenopyrite (or both), which may indicate that it was formed by decomposition of the latter minerals (Carpenter 1974). Silver-bearing minerals in this sample comprise hessite, electrum and freibergite. Hessite and electrum ($\text{Ag}_{70}\text{Au}_{30}$) occur at the pyrite surfaces, whereas freibergite usually forms small (2–20 μm) inclusions in pyrrhotite. The cervelleite-like mineral occurs as small subhedral grains together with hessite at the margins of galena grains (Figs. 4a, b).

Sulfide minerals in UC3 constitute about 30% of one polished section, whereas barite, rhodonite, tephroite, rhodochrosite and calcite constitute the remainder. Galena, sphalerite, and chalcopyrite are the common sulfides, whereas bornite and tetrahedrite-tennantite are minor. The various minerals form small (<200 μm) grains. Alteration of bornite to covellite and mckinstryite is common. Tetrahedrite-tennantite, bornite and covellite from this sample are, as in samples UC29, UC29-2, UC29-3 and UC30, Ag-rich (Table 1). Silver-

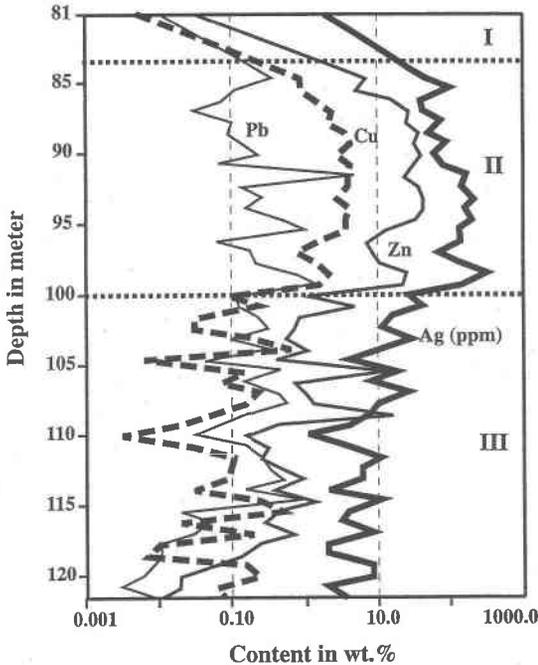


FIG. 3. A cross-section of the ore zone in the Western mine, Um Samiuki prospect, showing the variation of Zn, Cu, Pb and Ag. I: hanging-wall tuff, II: massive sulfide zone, III: the alteration zone. Adapted from Helmy (1995), with data from Searle *et al.* (1978).

bearing minerals comprise minor hessite, mckinstyrite and the cervelleite-like mineral. The latter is present as small subhedral crystals at the margin of galena and hessite grains.

Ore samples UCY and UCX contain massive, fine-grained sphalerite with cross-cutting veinlets of galena, chalcopyrite and tetrahedrite-tennantite. Small euhedral crystals of magnetite occur as inclusions in sphalerite. Hessite is the only silver mineral, other than the cervelleite-like phase. Hessite forms large (100–200 μm) euhedral crystals included in chalcopyrite and galena. Two distinct forms of the cervelleite-like mineral were observed in this sample: small (15–20 μm) subhedral inclusions in hessite and galena (close to margins), and thin rims (25 μm) replacing hessite. The subhedral inclusions show well-developed crystal outlines against hessite, which exhibits lamellar twinning. Small vermiform inclusions of the cervelleite-like mineral were also encountered in hessite and chalcopyrite.

Samples UC6, UC29, UC29-2, UC29-3 and UC30 consist of massive sphalerite (average 0.7 mole % FeS), bornite, chalcopyrite and minor galena and minerals of the tetrahedrite-tennantite series. Small crystals of molybdenite are common. Covellite is a major constituent of samples UC29, UC29-2, UC29-3 and UC30; it occurs in fractures and replaces bornite, chalcopyrite and tetrahedrite-tennantite. Bornite and covellite are unusually rich in Ag (average 0.57 and 0.83 wt %, respectively) (Table 1). The minerals of the tetrahedrite-tennantite series exhibit a compositional range extending from $(\text{Cu}_{9.43}\text{Fe}_{1.32}\text{Zn}_{0.61}\text{Ag}_{0.18})_{\Sigma 11.54}(\text{Sb}_{0.27}\text{As}_{3.87})_{\Sigma 4.14}\text{S}_{13.32}$ to $(\text{Cu}_{10.60}\text{Fe}_{0.05}\text{Zn}_{1.92}\text{Ag}_{0.11})_{\Sigma 12.68}(\text{Sb}_{3.87}\text{As}_{0.34})_{\Sigma 4.21}\text{S}_{12.11}$. Native silver forms small (<20 μm) inclusions in electrum. Hessite is not common, whereas electrum is more abundant. The cervelleite-like mineral

TABLE 1. ELECTRON-MICROPROBE DATA ON SILVER- AND SILVER-BEARING MINERALS FROM THE SAMPLES THAT CONTAIN THE CERVELLEITE-LIKE MINERAL, UM SAMIUKI, EGYPT

Element	Electrum		Tennantite		Tetrahedrite		Bornite		Chalcopyrite	Covellite		
	UC29	UC20	UC29	UC29	UCX	UCY	UC20	UC29	UC30*	UC29	UC3	
Fe	0.03	0.28	4.33	0.90	0.83	4.29	6.31	10.79	10.08	28.01	0.17	0.14
Cu	0.16	0.04	39.92	41.50	37.42	39.54	12.33	60.98	57.94	33.07	66.61	66.46
S	0	0	27.95	27.13	25.13	28.77	19.48	26.54	25.56	35.05	32.13	29.54
Sb	0	0	4.06	11.73	26.53	2.31	24.09	0	0	0	0	0
Te	0	0.38	0	0	0	0	0	0	0	0	0.04	0
Zn	0.56	0	2.84	6.90	5.25	3.98	0	0	1.65	1.82	0	0
As	0	0	17.13	11.89	2.75	19.15	0	0	0	0	0	0
Ag	50.29	68.95	3.13	0.11	0.51	1.08	39.93	0.57	4.02	1.20	0.83	2.92
Au	48.60	29.97	0	0	0	0	0	0	0	0	0	0
Total	99.64	19.02	99.36	100.16	98.42	99.12	102.14	98.88	99.25	99.15	99.78	99.06
Atomic proportions												
Fe	0.14	0.63	4.08	0.85	0.87	3.96	7.62	9.72	9.27	23.31	0.15	0.15
Cu	0.41	0.12	32.85	34.79	34.09	32.03	13.08	48.34	46.72	24.14	50.70	52.38
S	0	0	45.61	45.07	45.37	46.19	40.98	41.69	40.83	50.74	48.77	46.12
Sb	0	0	1.73	5.12	12.62	0.98	13.35	0	0	0	0	0
Te	0	0.38	0	0	0	0	0	0	0	0	0	0
Zn	1.24	0	2.25	5.65	4.63	3.14	0	0	1.28	1.30	0	0
As	0	0	11.98	8.47	2.14	13.18	0	0	0	0	0	0
Ag	64.19	79.88	1.52	0.05	0.29	0.51	24.97	0.25	1.90	0.51	0.39	1.35
Au	34.02	19.00	0	0	0	0	0	0	0	0	0	0

* For bornite and covellite, an average of at least five analyses. Bornite and chalcopyrite from sample UC30 (one analysis for each) coexist with the cervelleite-like mineral (Fig. 4C). Electrum: one analysis. In the case of tennantite, the compositions of the two end-members. The electron-microprobe data are reported in weight %.

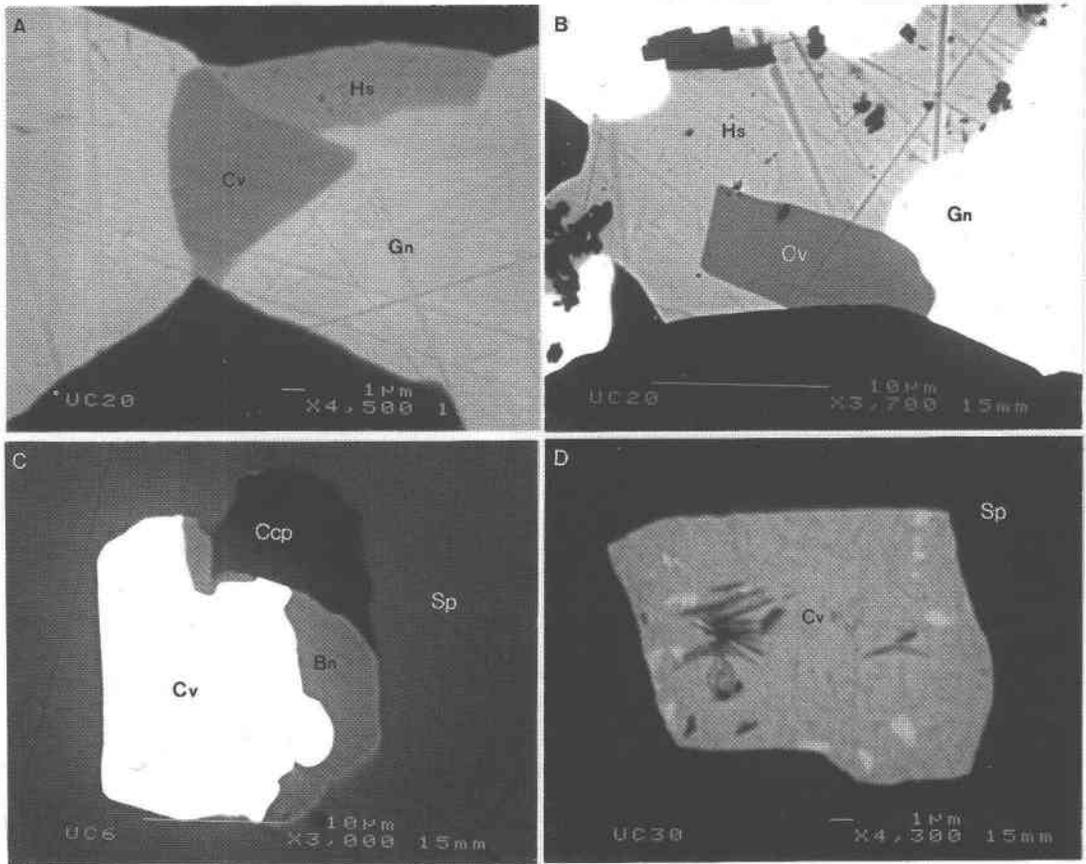


FIG. 4. Back-scattered electron images showing the various textures of the cervelleite-like mineral (Cv). A and B. Euhedral cervelleite-like mineral grains with hessite (Hs) close to galena (Gn) crystal margin, sample UC20. C. The cervelleite-like mineral associated with bornite (Bn) and chalcopyrite (Ccp), all included in sphalerite (Sp). D. Euhedral grain of the cervelleite-like mineral included in sphalerite (Sp); note the small inclusions of hessite (white) and covellite (black lamellae).

occurs as euhedral to subhedral grains included in sphalerite, where it is commonly associated with Ag-rich bornite, chalcopyrite and hessite (Fig. 4c). Bornite and chalcopyrite coexisting with the cervelleite-like mineral are Ag-rich (up to 13.0, 4.6 wt.% Ag, respectively). The cervelleite-like mineral also forms small euhedral crystals (Fig. 4d), and generally replaces hessite (Fig. 5). Small crystals of covellite are commonly developed inside and at the contact between hessite and the cervelleite-like mineral (Fig. 5).

In summary, the cervelleite-like mineral is associated with two sulfide parageneses, *i.e.*, chalcopyrite + bornite + tetrahedrite-tennantite + sphalerite and pyrite + sphalerite + galena + chalcopyrite. The cervelleite-like mineral and the sulfides of these parageneses are considered to define an equilibrium assemblage. Although metamorphic textures (like recrystallization)

were observed, primary banding and textures (chalcopyrite-diseased sphalerite) are still preserved. Deformation caused mobilization and plastic flow of ductile sulfides such as chalcopyrite and galena, to form small veins crossing the massive ore. On the basis of textural relations, the paragenetic sequence of sulfide and silver-bearing minerals is given in Figure 6. In all the investigated samples, sphalerite has a unimodal FeS content ranging from 0.7 to 2.7 mole %. No silver was detected in galena, and no Te was detected in sulfides or the tetrahedrite-tennantite series. The latter have a composition covering the whole range from tetrahedrite to tennantite, with Ag contents ranging from 0.1 to 2.0 at.%. Electrum is generally Ag-rich, ranging from $Ag_{0.80}Au_{0.20}$ to $Ag_{0.64}Au_{0.34}$, with minor Cu (up to 0.41 wt.%), Zn (up to 1.26 wt.%) and Fe (up to 0.63 wt.%).

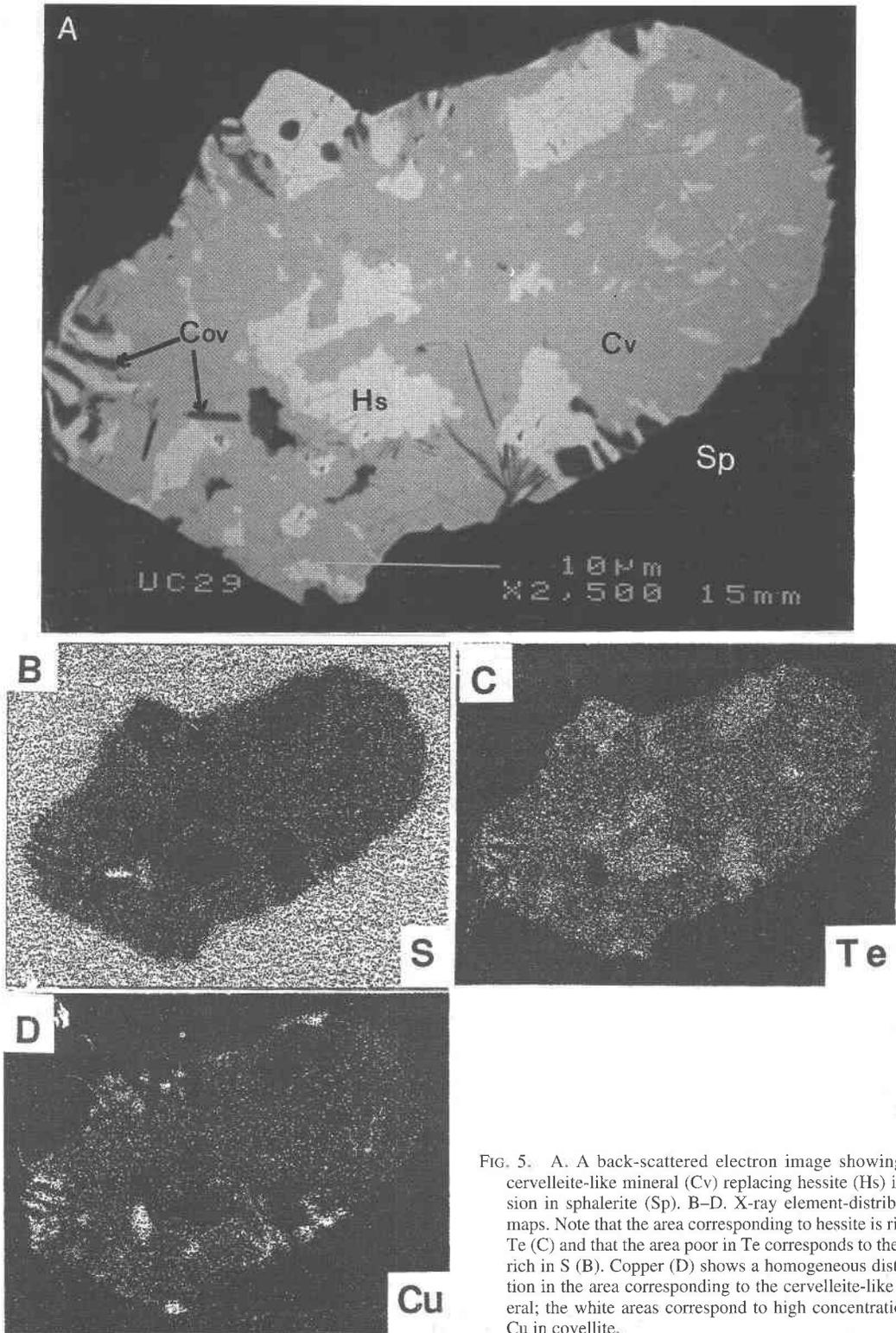


FIG. 5. A. A back-scattered electron image showing the cervelleite-like mineral (Cv) replacing hessite (Hs) inclusion in sphalerite (Sp). B–D. X-ray element-distribution maps. Note that the area corresponding to hessite is rich in Te (C) and that the area poor in Te corresponds to the area rich in S (B). Copper (D) shows a homogeneous distribution in the area corresponding to the cervelleite-like mineral; the white areas correspond to high concentration of Cu in covellite.

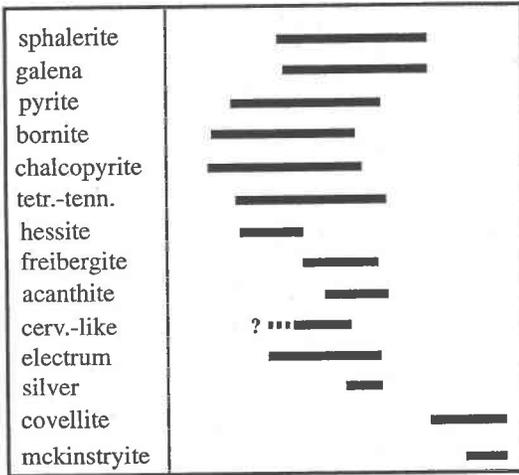


FIG. 6. Suggested paragenetic sequence of the Um Samiuki sulfides and silver minerals.

Optical properties

In plane-polarized reflected light, the cervelleite-like mineral grains range in color from greenish gray to brownish gray. Where associated with hessite, the mineral is greenish gray, whereas cervelleite associated with bornite is brownish gray. Electron-microprobe results, as discussed below, show that the color is dependent on Cu content. As for cervelleite-like minerals from the Ivigtut deposit (Karup-Møller 1976) and Mayflower mine (Spry & Thieben 1996), no color etching was observed in any of the studied grains; this is inconsistent with observations by Criddle *et al.* (1989). The cervelleite-like mineral has a lower reflectance than hessite and is isotropic. No internal reflections were observed.

Chemical composition

The chemical composition of the cervelleite-like mineral is given in Table 2 and compared with analyses of cervelleite from the Bambolla mine, Mexico (Criddle *et al.* 1989), together with other similar phases from other localities (Aksenov *et al.* 1969, Karup-Møller 1976, Gadzheva 1985, Spry & Thieben 1996). Eleven grains were analyzed for Ag, Te, S, Cu, Zn, As, Fe, Pb and Sb. The concentrations of Fe, Pb and Sb are generally below the detection limit (0.05 wt.%). The atomic proportions, as given in Table 2, were calculated based on 6 atoms (4 Ag + Te + S), assuming an ideal formula of Ag_4TeS .

On the basis of the Cu content of the cervelleite-like mineral, two distinct ranges of composition can be recognized: Cu-rich (4.01 to 6.18 wt.%, analyses 1–4, Table 2) and Cu-poor (0.04 to 0.26 wt.%, analyses 5–7,

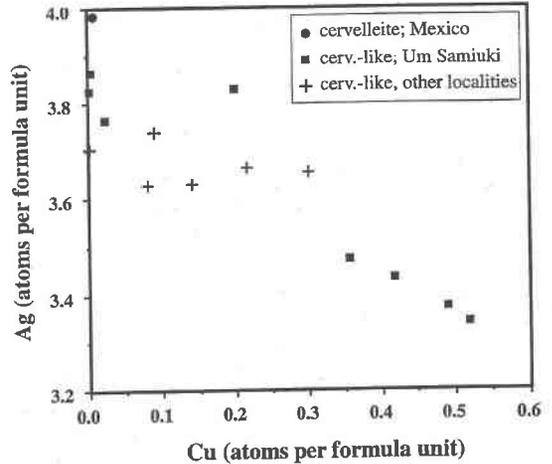


FIG. 7. The variation of Ag and Cu contents in cervelleite and cervelleite-like mineral from Um Samiuki prospect and other localities (data from Table 3).

Table 2). It is worth noting that the Cu-rich crystals occur in bornite-rich samples, whereas the Cu-poor ones are usually associated with galena in barite-bearing samples. The Ag content in the Cu-rich grains ranges from 63.5 to 66.56 wt.%. The variation in Ag content in the Cu-poor variety is generally small (69.64 to 70.56 wt.%). Figure 7 illustrates the variation of Ag versus Cu in the cervelleite-like mineral from Um Samiuki and from other localities. A relatively wide range of variation in Te content (22.01 to 24.54 wt.%) is characteristic of the cervelleite-like mineral from Um Samiuki as for that from the Ivigtut deposit, Greenland (Karup-Møller 1976), whereas in the Bambolla mine, cervelleite shows little variation in Te content (Criddle *et al.* 1989). Zn (up to 0.40 wt.%) and As (up to 0.14 wt.%) are minor constituents. From the calculated formula of the cervelleite-like mineral, there appears to be a slight deficiency of Ag+Cu coupled with an excess of S.

The Cu-poor cervelleite-like mineral from Um Samiuki is similar in composition to cervelleite from the Bambolla mine (Table 2). The Cu-rich variety bears a compositional resemblance to mineral x from Shadiitsa (Gadzheva 1985).

DISCUSSION

Table 3 contains the available mineralogical information about the occurrences of cervelleite and the cervelleite-like mineral. In addition to Um Samiuki, two deposits are hosted in volcanic rocks, *i.e.*, Ivigtut, Greenland and Moctezuma, Mexico. The Mayflower deposit from Montana involves epithermal-type mineralization. According to the geological setting and the metal association (Zn–Cu–Pb–Ag), Um Samiuki is

TABLE 2. ELECTRON-MICROPROBE DATA ON THE CERVELLEITE-LIKE MINERAL FROM UM SAMIUKI AND OTHER DEPOSITS, AND ON CERVELLEITE FROM THE BAMBOLLA MINE, MEXICO

Sample No.	UC6C1 1	UC6C2 2	UC29-1 3	UC29-2 4	UC20 5	UC3 6	UCY 7	UCX 8	9	10	11	12	13
S	6.48	6.26	6.64	6.08	5.71	6.01	5.98	5.82	5.30	7.00	5.80	5.62	3.54
Fe	0.06	0.12	0.06	0.07	0.13	0	0.08	0.11					
Cu	5.61	6.18	4.76	4.01	0.04	0.26	0.11	0.21	0.10		2.50	3.36	0.94
Zn	0	0	0.34	0.22	0.40	0	0.05	0.13					
As	0	0	0.04	0.14	0.12	0	0	0.08					1.25
Ag	65.84	63.5	66.56	66.47	70.56	69.84	69.12	68.83	73.00	68.00	68.60	68.12	67.35
Te	23.37	22.91	22.01	24.11	22.05	24.54	22.12	21.92	22.20	22.00	23.00	22.54	25.49
Bi	0	0	0	0	0	0	0	0			0.30		
Pb	0	0	0	0	0	0	0	0			0.80		
Se	0	0	0	0	0	0	0	0				0.10	2.79
Total	101.37	98.97	100.41	101.1	99.01	100.65	97.46	97.10	100.60	97.00	101.00	99.74	101.36
Atomic proportions based on 6 total atoms (4Ag+Te+S)													
S	1.118	1.109	1.152	1.069	1.052	1.091	1.114	1.089	0.972	1.282	1.043	1.013	0.659
Fe	0.006	0.012	0.006	0.007	0.014	0	0.008	0.012	0.012				
Cu	0.488	0.518	0.417	0.356	0.004	0.024	0.002	0.02			0.215	0.301	0.09
Zn	0	0	0.028	0.019	0.036	0	0.001	0.012					
As	0	0	0.006	0.011	0.010	0	0	0.007					0.102
Ag	3.375	3.342	3.434	3.473	3.864	3.767	3.827	3.829	3.990	3.705	3.666	3.657	3.740
Te	1.013	1.019	0.957	1.065	1.021	1.119	1.036	1.031	1.026	1.012	1.037	1.024	1.199
Bi	0	0	0	0	0	0	0	0			0.006		
Pb	0	0	0	0	0	0	0	0			0.023		
Se	0	0	0	0	0	0	0	0				0.006	0.21
Sum	6.000	6.000	6.000	6.000	6.001	6.001	5.988	6.000	6.000	5.999	5.990	6.001	6.000

Note that _ stands for no data. References: 9: cervelleite of Criddle *et al.* (1989); 10: mineral Z of Aksenov *et al.* (1969); 11: mineral B of Karup-Møller (1976); 12: mineral X of Gadzheva (1985); 13: cervelleite-like mineral from the Mayflower mine (Spry & Thieben 1996). The electron-microprobe data are expressed in weight %.

much closer to the Precambrian massive sulfide type of deposits (Franklin *et al.* 1981). It is generally accepted that such deposits formed at, or near, the discharge sites of submarine hydrothermal systems. Although no direct estimate of temperature of formation was made at Um Samiuki, fluid-inclusion studies in similar deposits (Tokunaga & Honma 1974) and modern analogs in present-day ocean-floor deposits (Scott *et al.* 1997) indicate temperatures of deposition in the range 300°C to 200°C. The precipitation of base and precious metals is due to cooling and changes in Eh, pH and oxygen and sulfur activity brought about by mixing of the ore-forming solutions with seawater (Franklin *et al.* 1981, Helmy & Shalaby 1996). The Um Samiuki mineralization and the host rocks underwent greenschist-facies metamorphism and postdepositional faulting and small-scale shearing (El Aref *et al.* 1985). Primary and metamorphic textures are present (Helmy & Shalaby 1996). In highly metamorphosed volcanogenic massive sulfide deposits (*e.g.*, Sabir 1981), the tellurides occur as replacements of sulfides. The microscopic observations at Um Samiuki suggest that silver tellurides were initially deposited during hydrothermal activity on the seafloor.

The small size of the grains of cervelleite-like mineral precluded reflectivity or X-ray-diffraction investigations. However, the identification of the mineral as

cervelleite is supported by the chemical data, and the optical properties are close to those of cervelleite from the Bambolla mine (Criddle *et al.* 1989). The mineral is also optically and chemically similar to cervelleite-like minerals from other localities (Karup-Møller 1976, Spry & Thieben 1996). In the following, the possible physicochemical conditions under which cervelleite formed will be discussed. In most of the occurrences of cervelleite and the cervelleite-like mineral, the mineral is associated with native silver, hessite, benleonardite, and acanthite, and a rather variable association of sulfides.

Since cervelleite is a newly identified mineral, its stability has yet not been investigated experimentally. The relative stability of Ag-telluride minerals with respect to oxides, sulfides and other tellurides is a function of $Te_{2(g)}$, $S_{2(g)}$, $O_{2(g)}$ fugacities and pH (*e.g.*, Afifi *et al.* 1988a, b, Zhang & Spry 1994b, McPhail 1995, Cooke *et al.* 1996). The mineral associations and the textural relationships between cervelleite and the other minerals may allow an estimation of the $Te_{2(g)}$, $S_{2(g)}$, and $O_{2(g)}$ fugacities and the prevailing pH and temperature during its formation.

The cervelleite-like mineral in the Um Samiuki prospect was observed in two textures, *i.e.*, as subhedral inclusions in hessite and galena, and as a thin rim surrounding hessite. In these textures, the mineral seems

TABLE 3. A COMPILATION OF THE MINERALOGICAL DATA CONCERNING OCCURRENCES OF CERVELLEITE AND THE CERVELLEITE-LIKE MINERAL

Locality	Sulfide paragenesis	Silver and telluride paragenesis	Gangue minerals	Type of mineralization	Ref.
Moctezuma, Mexico	Sp, Py	Ag, Hs, Ac, Ben	MgCO ₃	VHMS?	1 2
Zyranov, Russia	no data	Hs, Ben?	no data	no data	3
Ivigtut, Greenland	Ccp, Gn, Sp, Tt, Py, Po, Cc	Ag, Ac, Ben?	FeCO ₃	VHMS?	4
Shadiitsa, Bulgaria	no data	Hs	no data	no data	5
Mayflower, Montana	Py, Mr, Tt, Gn, Sp, Ccp, Cc	Fb, Sv, Pz, Hs, Sz, Cvt, Ben, Te	CaCO ₃ , MgCO ₃	epithermal	6
Um Samiuki, Egypt	Py, Sp, Ccp, Gn, Bn, Tt, Apy	Ag, Hs, El, Ac, Fb, Mk	CaCO ₃ , MnCO ₃ , BaSO ₄	VHMS	7

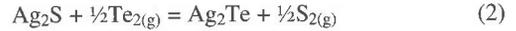
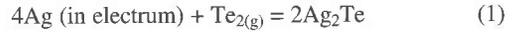
Symbols: Py: pyrite, Sp: sphalerite, Ccp: chalcopyrite, Gn: galena, Tt: tetrahedrite-tennantite, Po: pyrrotite, Cc: chalcocite, Mr: marcasite, Bn: bornite, Apy: arsenopyrite, Ag: native silver, Hs: hessite, Ac: acanthite, Ben: benleonardite, Fb: freibergite, Sv: sylvanite, Pz: petzite, Sz: stutzite, Cvt: calaverite, El: electrum, Mk: mckinstryite, and Te: native tellurium. References: 1: Criddle *et al.* (1989), 2: Stanley *et al.* (1986), 3: Aksenov *et al.* (1969), 4: Karup-Møller (1976), 5: Gadzheva (1985), 6: Spry & Thieben (1996), 7: this work.

to be in equilibrium with the associated sulfide parageneses. The observed sulfide assemblages (chalcopyrite – bornite – tetrahedrite-tennantite – sphalerite and pyrite – sphalerite – galena – chalcopyrite) in the Um Samiuki samples indicate $f(S_2)$ values near or below the chalcopyrite – bornite – pyrite buffer but above the pyrite – pyrrotite buffer. Oxidizing conditions are suggested by the occurrence of bornite, arsenopyrite, barite, rhodonite and tephroite. The occurrence of magnetite and the absence of hematite suggest $f(O_2)$ values below the magnetite – hematite buffer. The widespread occurrence of calcite and rhodochrosite (as in sample UC3) suggests formation under near-neutral conditions. Similar estimates (Zhang & Spry 1994a) of $f(O_2)$ and pH were suggested for mineralization at Mayflower, Montana. The similar paragenesis of sulfide minerals and the occurrence of Fe and Mg carbonates in other cervelleite-bearing deposits (Table 3) are consistent with the suggested ranges of $f(S_2)$ and pH.

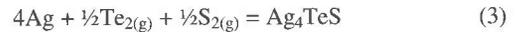
The mutual relationships among minerals at Um Samiuki suggest the following order of deposition of the silver minerals: 1) hessite, freibergite and acanthite, 2) cervelleite, 3) electrum and native silver, and 4) mckinstryite. The occurrence of native silver, Ag-rich electrum (Ag₇₀Au₃₀) and the absence of any other tellurides (*e.g.*, Au, Pb and Fe tellurides) at Um Samiuki (and other localities in Table 3) indicate a low $f(Te_2)$ value (Afifi *et al.* 1988b). On the basis of thermodynamic data and calculated equilibria, Afifi *et al.* (1988a)

suggested that deposition of hessite needs the minimum $f(Te_2)$ values required to stabilize silver tellurides.

The appearance of hessite at Um Samiuki reflects an increase in $f(Te_2)$ values above the hessite–Ag (1) or the hessite–acanthite (2) reaction



but probably much lower than the galena–altaite reaction. As the initial sequence of tellurium minerals generally is a succession of phases of progressively lower Te content (Kelly & Goddard 1969), and the compositions of individual ore minerals reflects the activities of components in their environments (Barton 1970), the stabilization of cervelleite needs lower $f(Te_2)$ values than hessite [assuming that they are formed under similar conditions of $f(S_2)$ and temperature]. The cervelleite-like mineral replacing hessite (as in Fig. 5) is consistent with a decrease in $f(Te_2)$ at the site of deposition. The deposition of cervelleite signals a decrease in $f(Te_2)$ values below the hessite–Ag reaction (equation 1), possibly according to the reaction:



This reaction proceeded as a result of a decrease in the ratio $f(Te_2)/f(S_2)$. The variation in the $f(Te_2)$ and $f(S_2)$ values may be due to changes in total concentrations of Te and S, a decrease in the oxidation state, or cooling. As the variation in $f(O_2)$ has a minor effect on the mineral stability (Afifi *et al.* 1988a) and as the solubility of native Te is temperature-dependent (McPhail 1995), cervelleite may well have precipitated in response to cooling or changes in total concentrations of Te and S (or both factors).

Karup-Møller (1976) and Spry & Thieben (1996) estimated a temperature range of 230°C to 195°C for the formation of the cervelleite-like mineral. The critical $f(Te_2)/f(S_2)$ value required to precipitate the cervelleite-like mineral and the suggested small range of temperatures may account for the small grain-sizes of cervelleite and similar phases from the various deposits. Figure 8 shows a schematic representation of the assumed field of stability of cervelleite at various temperatures. The precipitation of cervelleite requires a very high activity of Ag, which is apparent from the silver-rich paragenesis at Um Samiuki. The Cu-content of the cervelleite-like mineral most probably reflects the bulk composition of the host rock. This is evident from the mineralogical study; the Cu-rich cervelleite-like mineral is commonly associated with a sulfide paragenesis dominated by bornite, chalcopyrite, and tetrahedrite-tennantite, whereas the Cu-poor variety occurs in a paragenesis dominated by pyrite – sphalerite – galena. The compositional variations of tetrahedrite-tennantite and the strong correlation of Ag and Cu (Fig. 3) in the

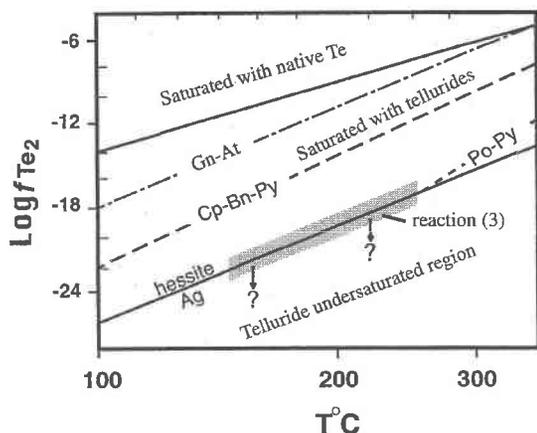


FIG. 8. A schematic representation of the assumed field of stability of cervelleite (modified from Afifi *et al.* 1988b).

massive sulfide ore support this suggestion. Mineralogical data (Table 3) and the composition of cervelleite and the cervelleite-like mineral from other deposits (Table 2) also support this inference.

A re-investigation of the system Ag–Te–S is needed to understand the stability of newly identified silver sulfotellurides like cervelleite and benleonardite.

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