EDGARBAILEYITE
THE FIRST KNOWN SILICATE OF
MERCURY, FROM CALIFORNIA AND TEXAS

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ABSTRACT

Edgarbaileyite, idealized as $Hg_6^{+1}Si_2O_7$, is monoclinic, space group $C2/m(12)$, with refined unit-cell parameters $a = 11.725(4)$, $b = 7.698(2)$, $c = 5.967(2)$ Å, $\beta = 112.07(3)°$, $V = 499.2(2)$ Å^3, $a:b:c = 1.5231:1:0.7751$, $Z = 2$. The strongest eight lines in the X-ray powder pattern are $[d\ (I)\ (hkl)]$:6.28 (20) (110); 3.160 (100) (021); 3.027 (27) ($\bar{2}$21); 2.952 (34) ($\bar{2}$02); 2.765 (20) (002); 2.715 (63) (400); 2.321 (24) ($\bar{4}$21); 1.872 (36) ($\bar{6}$02). The mineral is rare, but rather widespread. At the Socrates mine, Sonoma County, California, it has been identified as thin crusts on fracture surfaces, as disseminated rounded to mammillary masses in small cavities, and as hollow mammillary nodules; it is most closely associated with chalcedonic quartz, native mercury, cinnabar and montroydite in a host rock composed principally of magnesite and quartz. At the Clear Creek claim, San Benito County, California, the habit is identical to that at the Socrates mine; it is most closely associated with native mercury and montroydite

Figure 1. **Nodular masses of edgarbaileyite in a quartz-lined cavity. Field of view is 17 mm (Socrates mine).**
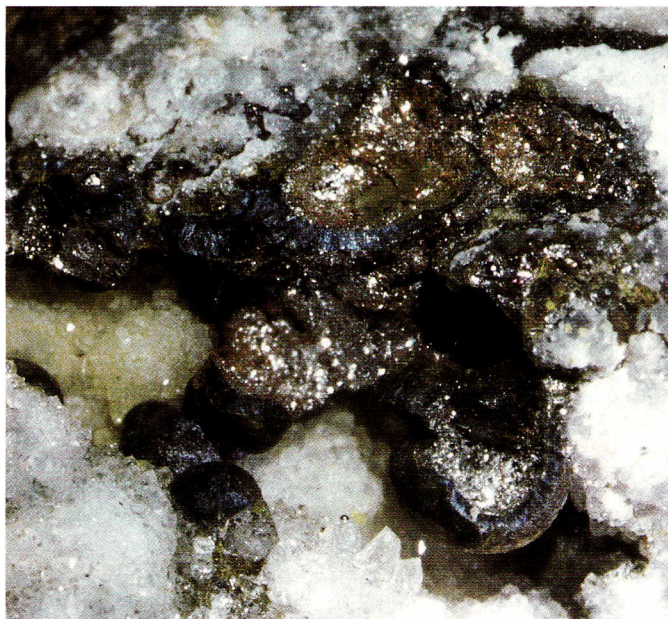
in a host rock composed principally of quartz, magnesite and chalcedony. Edgarbaileyite has also been identified on a museum specimen from Terlingua, Brewster County, Texas, as ill-formed tabular aggregates and sheaves of crystals in cavities and fractures; it is most closely associated with montroydite, terlinguaite, eglestonite and native mercury in a matrix of calcite, quartz and barite. Crystals range from cryptocrystalline and anhedral up to 0.2-mm platy crystal aggregates with dominant {100} form. Crystals are polysynthetically twinned on {100}. Edgarbaileyite is photosensitive and is varicolored; freshly exposed material is lemon-yellow to orangish yellow; exposed surfaces range from dark olive-green to a lighter yellowish green to dark green-brown. Physical properties include: pale green streak with a yellow tinge; vitreous (crystals) to resinous (masses) luster; translucent (crystals) to opaque (masses); non-fluorescent; VHN$_{100}$ 192 (range 153–217); calculated Mohs' hardness 4; brittle; irregular to subconchoidal fracture; density 9.4(3) g/cm^3 (9.11 calc. for empirical formula). The mineral is optically biaxial with all refractive indices greater than 2; it has weak pleochroism and strong absorption. In polished section, edgarbaileyite is weakly to strongly bireflectant and is not pleochroic. In plane-polarized light it is gray to slightly lighter gray with pale lemon-yellow internal reflections. Measured reflectance values for 2 grains in air and in oil are tabulated. Maximum and minimum calculated refractive indices (at 590 nm) are 2.58 and 2.10. Electron microprobe analyses (from the Socrates mine) yielded Hg$_2$O = 89.6, SiO$_2$ = 8.6, sum = 98.2 weight %, corresponding to Hg$^{+1}_{6.00}$Si$_{2.00}$O$_7$, based on O = 7. Virtually identical results were obtained from microprobe analyses of Terlingua material. The mineral is named for Dr. Edgar Herbert Bailey (1914–1983), distinguished geologist and mercury commodity specialist for the U.S. Geological Survey.

INTRODUCTION

The new mineral species described here, edgarbaileyite, was first brought to the attention of one of us (RCE) by Dr. Edgar Bailey. He had received a specimen containing an unidentified yellow mercury-bearing mineral from Leo Rosenhahn, who had originally collected the material at the Socrates mine, Sonoma County, California in 1963. The first X-ray powder pattern was run in March, 1968, and could not be identified with any known inorganic phase listed in the Powder Diffraction File. Somewhat later, in 1972, Edward H. Oyler collected some specimens at the Clear Creek claim, San Benito County, California, and submitted a massive yellow-orange phase to RCE for X-ray identification. Oyler's unknown was found to be identical to Rosenhahn's previously unidentified mineral. However, a lack of sufficient pure material prevented a more detailed mineralogical study at that time. In 1987, Mr. Oyler and John Parnau brought RCE some additional specimens from the Socrates mine, which Parnau had collected in 1963. Megascopic examination and X-ray powder diffraction study confirmed the presence of the same mineral previously identified in 1968 and in 1972. In addition, the same mineral from Terlingua, Brewster County, Texas, was found by AJC during the acquisition of optical reflectance and chemical data for a range of oxide minerals for eventual inclusion in the QDF (*The Quantitative Data File for Ore Minerals*, Criddle and Stanley, 1986). The identity of the Terlingua material with that from the Socrates mine was confirmed by comparison of its X-ray powder data with the unpublished X-ray powder data previously submitted to the Commission on New Minerals and Mineral Names, I.M.A. Subsequently, AJC wrote to the senior author, and it was agreed that the chemical, optical and crystallographic data for the Terlingua material should be included in the present paper. Sufficient material was then available from both California and Texas for a comprehensive mineralogical study and full characterization; the results are reported here.

We take great pleasure in naming this new mineral *edgarbaileyite* after Dr. Edgar Herbert Bailey (1914–1983), a distinguished geologist who worked for the United States Geological Survey as a mercury commodity specialist, and who studied and described mercury deposits both in the U.S. and in Turkey. Two of the occurrences within the continental U.S. on which he reported were the Socrates mine (Bailey 1946) and the deposits at Terlingua (Yates and Thompson, 1959). The mineral and name have been approved by the Commission on New Minerals and Mineral Names, I.M.A. The type locality is hereby designated the Socrates mine for two reasons: (1) chronologically, it was the first verified occurrence, and (2) most of the megascopically identifiable edgarbaileyite comes from this locality. The holotype specimen, which has been broken into two hand specimens, several mineral fragments, two polished grain mounts and two SEM stubs, is preserved within the Systematic Reference Series of the National Mineral Collection at the Geological Survey of Canada, Ottawa, under catalog number NMC 65531. The hand specimen containing edgarbaileyite from Terlingua, Texas, is housed within the mineral collections of the British Museum (Natural History), London, under catalog number BM 1906, 190.

OCCURRENCE

Edgarbaileyite has been identified at two widely separated localities in California and in a museum specimen labeled as originating from Texas. The localities are: the upper workings of the abandoned Socrates mercury mine, Sonoma County, California (latitude 38°45'47"N, longitude 122°45'30"W); a small prospect pit near the long-abandoned Clear Creek mercury mine, New Idria District, San Benito County, California (latitude 36°22'59"N, longitude 120°45'58"W); and the Terlingua deposit, Brewster County, Texas (latitude 29°20'N, longitude 103°39'W). The mineral is rare, but is rather widespread at both occurrences in California. Its spatial distribution at Terlingua is unknown, but we assume it to be very rare.

At the Socrates mine, edgarbaileyite is most closely associated with quartz, native mercury, cinnabar and montroydite in host rock principally composed of magnesite and quartz. Other minerals identified are chalcedonic quartz, opal and chromite. For more information regarding the mercury deposits found within Sonoma County and, specifically, the Socrates mine, the reader is referred to the report by Bailey (1946). Collectors should be advised that the Socrates mine has been bulldozed and that there are no remnants nor dump from which specimens may be obtained.

At the Clear Creek locality, edgarbaileyite is closely associated with native mercury, montroydite and minor cinnabar. The host rock is predominantly quartz, magnesite, chalcedony with minor pecoraite, opal, goethite, chromite, montmorillonite, huntite, dolomite, gypsum and chlorite. Mercury-bearing minerals identified by X-ray diffraction analysis include edoylerite (Erd *et al.*, in preparation, IMA approved), wattsite (Erd *et al.*, in preparation, IMA approved), metacinnabar, eglestonite, calomel, terlinguaite, mosesite, gianellaite and five unnamed mercury-bearing phases that are currently under investigation. A description of the geology of the Clear Creek mercury mine is given by Eckel and Myers (1946).

At both Californian localities, edgarbaileyite has been identified in several different varietal forms: as thin crusts on fracture surfaces, generally coating cinnabar or quartz; as disseminated rounded to mammillary masses in small cavities that are usually lined with quartz or chalcedony; and as hollow mammillary nodules as much as 3.4 mm in diameter with a wall thickness of 1.2 mm (Fig. 1).

The Terlingua specimen, which was purchased from Dr. F. Krantz, Bonn, Federal Republic of Germany, in 1906 by the British Museum (Natural History), consists of intergrown crystals of montroydite, terlinguaite, eglestonite and edgarbaileyite in cavities and fractures in a matrix of crystalline calcite, quartz and barite. Native mercury is also abundant within the cavities. For more information and references on the Terlingua deposit, the reader is referred to Hill (1903), Yates and Thompson (1959), Crook (1977), Roberts *et al.* (1981) and Origlieri (1990).

MORPHOLOGY

Most edgarbaileyite at the Californian localities occurs as crypto-crystalline anhedral masses without obvious crystal form. Rarely, crystalline masses composed of aggregates as much as 50 μm in size (Fig. 2) were observed in small vugs. Individual crystals have a platy micaceous habit with average dimensions of 0.1 x 5 x 5 μm. The dominant face, based on single-crystal examination, is {100} (Fig. 3).

At Terlingua, edgarbaileyite is characteristically intergrown with montroydite, where ill-formed tabular crystals of edgarbaileyite aggregate, and sometimes form sheaves of crystals as much as 2 x 2 mm. Only two discrete single-crystals, as much as 200 μm in size, were found. These have a pronounced platy habit with {100} face (Fig. 4)—identical to those from the Socrates mine. Crystal-structure studies indicate that these crystals are polysynthetically twinned on {100}.

Figure 2. Scanning electron photomicrograph of a vug containing edgarbaileyite crystal aggregates (Socrates mine).
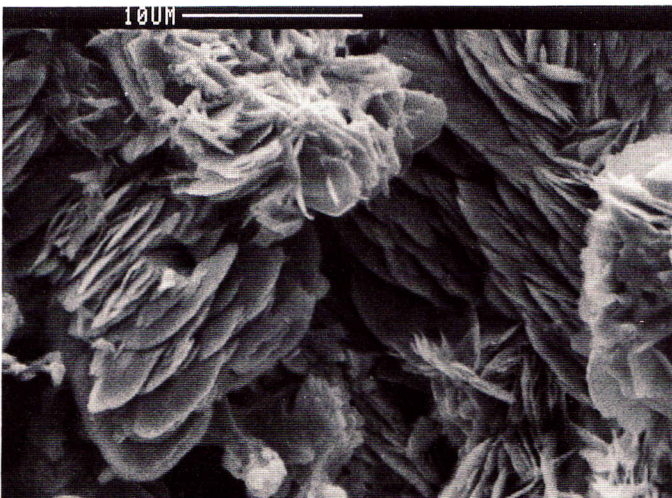

PHYSICAL AND OPTICAL PROPERTIES

Edgarbaileyite is variable in color; freshly exposed material is lemon-yellow to orangish yellow; exposed surfaces are varicolored from dark olive-green, to a lighter yellowish green, to a dark green-brown. The mineral is photosensitive and darkens with exposure to ultraviolet, infrared, X-radiation, and the visible light spectrum. The streak is pale green with a definite tinge of yellow. Crystal aggregates

are translucent with a vitreous luster; nodular masses are opaque with a resinous luster. The mineral is brittle, possesses an irregular to subconchoidal fracture, and is nonfluorescent under both longwave and shortwave ultraviolet light. The measured density of the Socrates mine material, determined by Berman balance on 11.65 mg of hand-picked sample containing approximately 1% native-mercury contamination, is 9.4(3) g/cm³; the calculated density, based on the empirical formula, is 9.11 g/cm³.

Microhardness measurements were made with a Leitz Miniload 2 tester. The range for VHN_{100} from three badly fractured but measurable indentations is 153 to 217, the average is 192. This corresponds very approximately to a Mohs' hardness of 4.

Optically, edgarbaileyite is biaxial with all refractive indices greater than 2. The lowest refractive index (X') is greater than 2, with low to medium relief; the highest refractive index (Z') is much greater
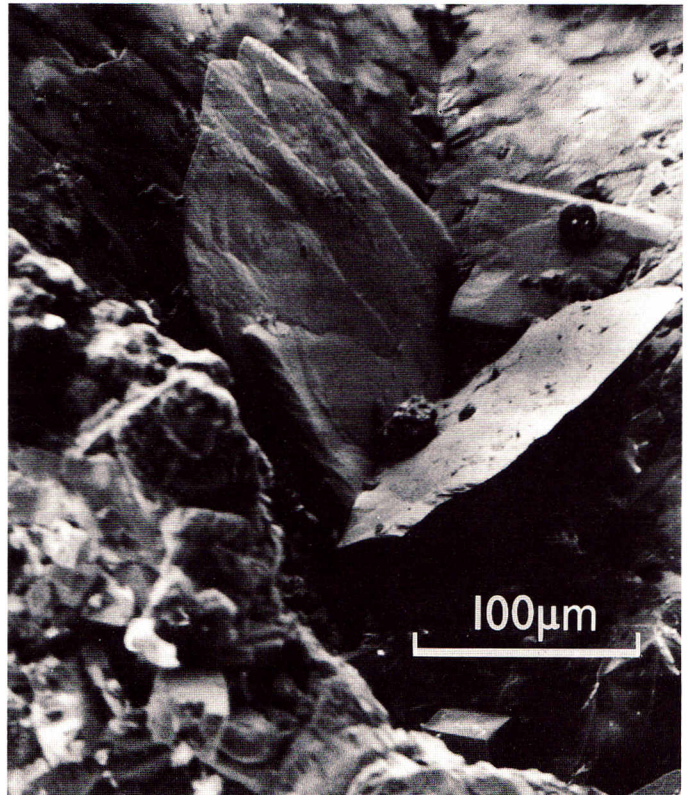
Figure 4. **Electron-photomicrograph of three crystals of edgarbaileyite on calcite/dolomite. Note the platy habit of the crystal in the foreground (Terlingua).**

Figure 3. **Scanning electron photomicrograph showing the typical morphology of edgarbaileyite crystals (Socrates mine).**

than 2 with high relief. The color of the mineral under oils is lemon-yellow. The pleochroism is weak, from lemon-yellow to a deeper shade of yellow; it is partially obscured by the strong change in relief. There is also strong absorption, especially for the higher index. Grain-size limitations made it impossible to determine the optical sign, orientation or extinction angles. Edgarbaileyite is slowly attacked by high-index immersion media.

In polished section, in reflected light, edgarbaileyite from Terlingua (depending on orientation) is weakly to strongly bireflectant and is not pleochroic. In plane-polarized light (at a color temperature of about 3300°K) it is gray to a slightly lighter gray. The surface properties are, however, generally masked by the pale lemon-yellow internal reflections. Reflectance measurements on four grains were made rel-

ative to a Zeiss SiC reflectance standard (no. 472) using the equipment and procedures described by Criddle *et al.* (1983). The areas measured are virtually free from internal reflections (*cf.* Dunn *et al.* (1988), on ingersonite). Representative reflectance spectra are shown in Figure 5, and minimum (R_1) and maximum (R_2) reflectance for the least and most bireflectant grains are given in Table 1. A characteristic feature, observed between crossed polars, of all of these grains is that they are finely twinned, or compound and finely fibrous. The five measurements on the four grains were taken on areas that are apparently untwinned and monocrystalline. The reflectance spectra in Figure 5 confirm that edgarbaileyite is strongly bireflectant (hence, strongly birefringent), they also demonstrate that its biaxial character is more pronounced below 500 *nm*. Refractive indices calculated from the R and ^{im}R data are all greater than 2, and their dispersion follows the same trend as the R spectra; with $r < v$. The same is true for the absorption, and, as was noted above, the absorption for R_2 (approximating to Z' for the most extreme values of R) is higher throughout the visible spectrum than for R_1 (X'). The maximum and minimum refractive indices (taken from all of those calculated from the five sets of R data) at 590 *nm* are 2.58 and 2.10. Gladstone-Dale calculations for the mean refractive index of 2.34 (mean of the ten R-derived values), using the constants reported by Mandarino (1981), the idealized formula, and the calculated density, gave the following values for the compatibility index: $+0.017$ for the Hg_2O constant $k = 0.144$, and -0.047 for the Hg_2O constant $k = 0.134$ ("superior" and "good," respectively, in the terminology of Mandarino, 1981).

CHEMISTRY

Edgarbaileyite from the Socrates mine was analyzed chemically by means of a CAMEBAX electron microprobe, utilizing a 20-kV operating voltage, a 30-nA beam current, a 10-second count rate, and a 6-micron beam diameter. The standards employed were natural quartz (Si) and natural cinnabar (Hg). A wavelength dispersive microprobe scan indicated the absence of any other elements with atomic number greater than 9 except those reported here. The average of five analyses, calculated after the crystal structure was determined, gave $Hg_2O = 89.6(1.0)$, $SiO_2 = 8.6(6)$, total = 98.2 weight %. With O = 7, the empirical formula is $Hg_{6.00}^{+1}Si_{2.00}O_7$, or ideally, $Hg_6^{+1}Si_2O_7$ with $Z = 2$. This idealized formula requires $Hg_2O = 91.24$, $SiO_2 = 8.77$, total = 100.01 weight %. An infrared absorption spectrum (Fig. 6) indicates the absence of both (OH) and H_2O vibration bands and confirms the anhydrous nature of the mineral.

Edgarbaileyite from Terlingua was chemically analyzed by means of a Cambridge Instruments Microscan IX electron microprobe utilizing a 20-kV operating voltage, a 25-nA beam current and a defocussed 20-micron beam diameter. The standards employed were wollastonite (Si) and cinnabar (Hg). The average of three analyses gave Hg = 87.5, Si = 3.7, O(calc.) = 7.8, total = 99.0 weight %. The empirical formula, assuming 15 atoms for the formula unit, is $Hg_{6.2}Si_{1.9}O_{6.9}$. These data are very similar to those reported above for the edgarbaileyite from the Socrates mine.

Edgarbaileyite is the first reported mercury-bearing silicate to occur naturally or to be synthetically prepared. Röpke and Eysel (1978) investigated the HgO-GeO_2-SiO_2 system in the presence of water up to 600°C and 4 kb. They found that no mercury silicate compound, and only one mercury germanate compound (Hg_2GeO_4) exists in that system under those conditions. To our knowledge, the system Hg_2O-SiO_2 has not yet been investigated.

The mineral is easily soluble in cold 1:10 HCl; it quickly turns white, appears to "bloom" somewhat, and then disintegrates to a powdery residue. In cold 1:1 HNO_3 the mineral dissolves rather rapidly and leaves a transparent shell that is both isotropic and gelatinous.

HEATING EXPERIMENTS

Gentle heating to low red heat in a closed tube destroys the structure.

Grain:	1		2		1		2	
λnm	R_1	R_2	R_1	R_2	$^{im}R_1$	$^{im}R_2$	$^{im}R_1$	$^{im}R_2$
400	16.7	20.2	20.0	24.9	5.32	7.42	7.42	11.25
10	16.9	19.85	20.25	24.6	5.43	7.20	7.64	10.9
20	17.1	19.5	20.45	24.4	5.53	7.02	7.48	10.5
30	17.2	19.3	20.1	24.2	5.53	6.93	7.14	10.2
40	17.0	19.2	19.4	23.9	5.38	6.83	6.63	9.91
450	16.75	19.0	18.75	23.5	5.18	6.83	6.16	9.63
60	16.4	18.8	18.1	23.2	4.91	6.48	5.73	9.33
70	16.1	18.5	17.5	22.8	4.69	6.24	5.38	9.12
80	15.8	18.2	17.0	22.5	4.50	6.03	5.08	8.88
90	15.5	18.0	16.6	22.2	4.34	5.85	4.82	8.67
500	15.3	17.7	16.2	21.9	4.21	5.70	4.63	8.49
10	15.1	17.5	15.9	21.7	4.13	5.57	4.49	8.37
20	14.9	17.3	15.7	21.5	4.07	5.47	4.38	8.25
30	14.7	17.0	15.4	21.25	4.00	5.37	4.26	8.12
40	14.6	16.8	15.2	21.1	3.93	5.26	4.16	8.00
550	14.5	16.65	15.0	20.9	3.87	5.15	4.07	7.88
60	14.3	16.5	14.9	20.7	3.81	5.05	3.98	7.77
70	14.2	16.4	14.7	20.6	3.75	4.97	3.90	7.67
80	14.2	16.2	14.6	20.5	3.71	4.90	3.84	7.59
90	14.1	16.1	14.5	20.3	3.65	4.83	3.78	7.50
600	14.0	16.0	14.4	20.2	3.61	4.77	3.73	7.43
10	14.0	15.95	14.3	20.1	3.58	4.72	3.70	7.37
20	13.95	15.9	14.2	20.0	3.54	4.68	3.66	7.30
30	13.9	15.8	14.2	19.9	3.52	4.65	3.62	7.25
40	13.85	15.8	14.1	19.8	3.50	4.60	3.59	7.21
650	13.8	15.7	14.0	19.75	3.48	4.57	3.57	7.16
60	13.75	15.6	14.0	19.65	3.46	4.53	3.54	7.12
70	13.7	15.55	13.9	19.6	3.41	4.48	3.51	7.06
80	13.7	15.5	13.9	19.5	3.39	4.44	3.49	7.03
90	13.6	15.5	13.8	19.4	3.38	4.41	3.45	6.99
700	13.6	15.4	13.7	19.4	3.34	4.39	3.43	6.95

Color values relative to CIE illuminant C:

x	0.297	0.296	0.290	0.298	0.283	0.284	0.272	0.289
y	0.300	0.302	0.291	0.303	0.283	0.287	0.265	0.293
$Y\%$	14.5	16.7	15.1	20.9	3.87	5.15	4.10	7.87
λd	474	477	473	476	473	473	471	475
$P_e\%$	6.8	6.7	10.5	6.1	13.8	13.0	20.1	10.4

Mercury is liberated almost immediately and is deposited on the sides of the tube. Edgarbaileyite turns white and remains that color. The reaction product was subjected to X-ray diffraction and yielded only the characteristic X-ray powder lines of a poorly crystallized opal-cT. Prolonged heating at 1000–1100°C for a period of 14 hours yielded a product that when X-rayed was found to be composed of major amounts of tridymite and minor amounts of cristobalite.

X-RAY DIFFRACTION

Despite repeated attempts to isolate suitable material from the Socrates mine for a single-crystal precession study, only two crystalline fragments, each less than 0.1 mm in longest dimension, were found that produced diffraction nodes on zero-level films. One fragment was mounted with b^* parallel to the dial axis, and the other fragment was mounted with c^* parallel to the dial axis. The levels collected using Zr-filtered Mo radiation were $h0l$, $0kl$ and $hk0$. All final photographs were of extremely poor quality; nodal streaking produced by crystal
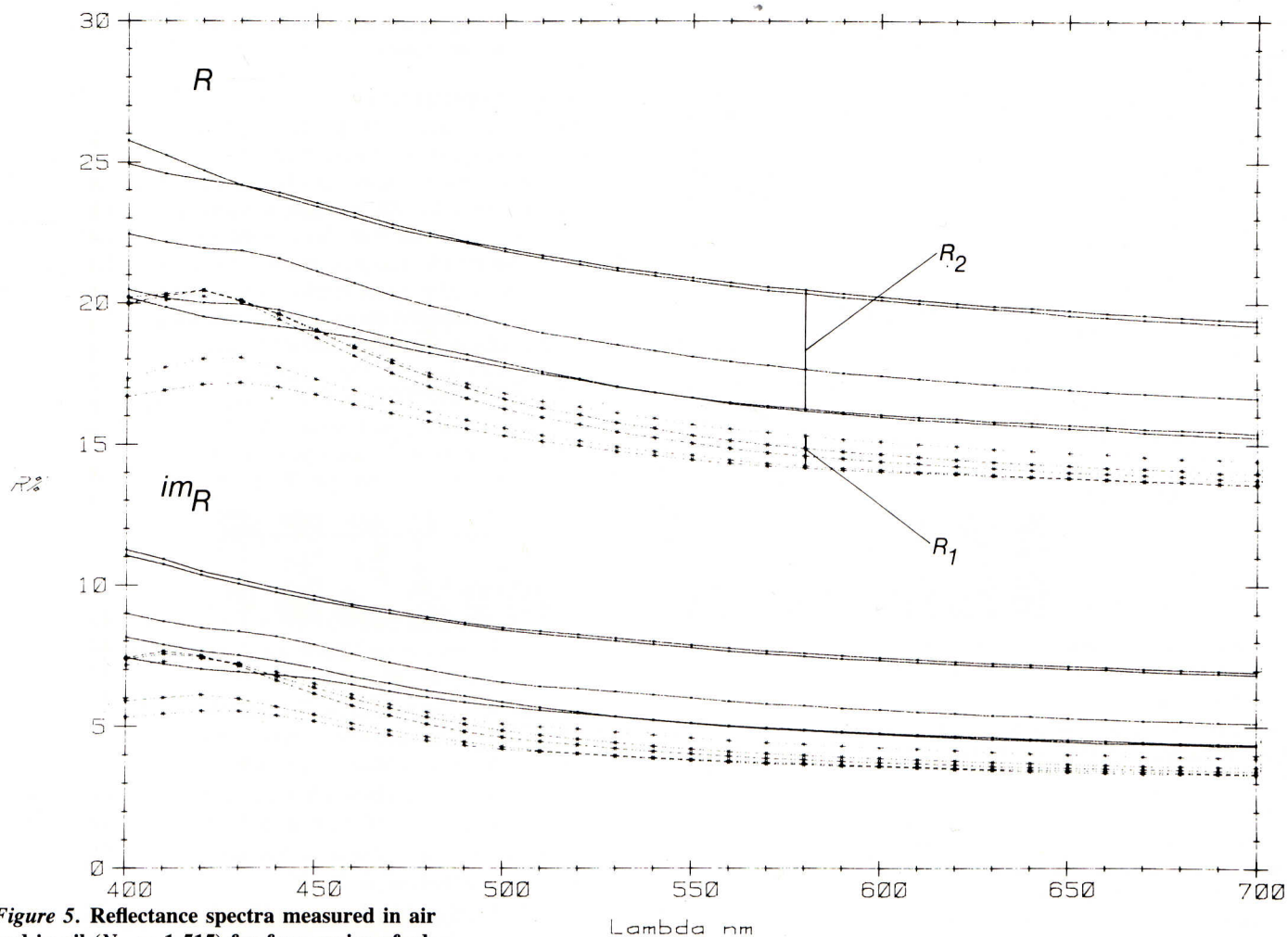
Figure 5. Reflectance spectra measured in air and in oil (N_D = 1.515) for four grains of edgarbaileyite.
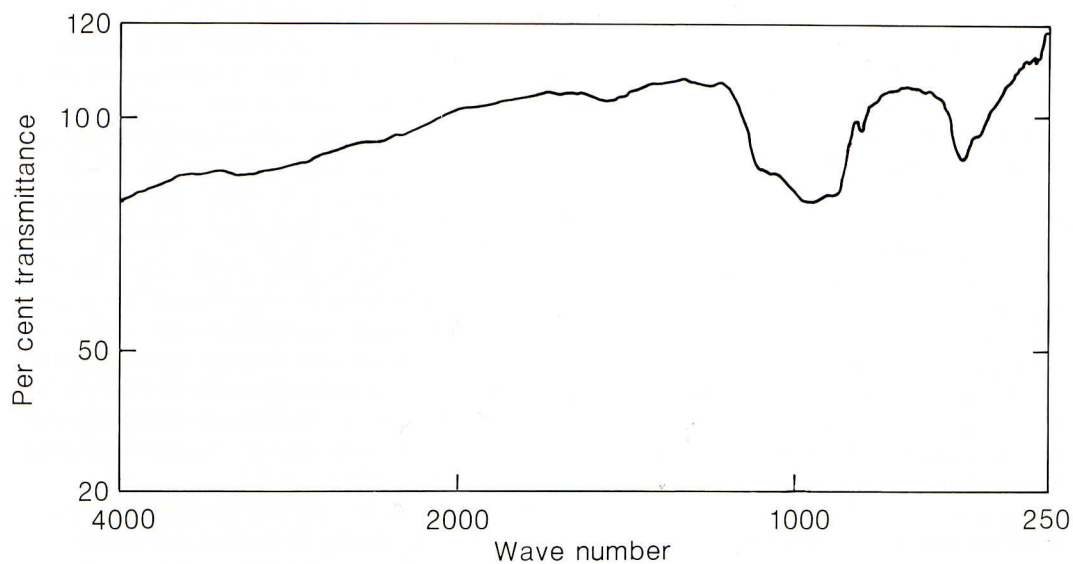

Figure 6. Infrared absorption spectrum for edgarbaileyite.

multiplicity was clearly evident on all films. Upper-level zones were also photographed, but the films were either blank or were uninterpretable. Inspection of the zero-level films showed that edgarbaileyite has monoclinic symmetry with measured and calculated unit-cell parameters: a = 10.98, b = 7.70, c = 5.94Å, β = 98.53°. The only observable systematic absence, $0k0$ with k = $2n$, dictated that the space-group choices were $P2_1/m$ (11) or $P2_1$ (4). However, crystal-

lographic studies of the coarser Terlingua material have shown that the true space-group choices are $C2/m$(12), Cm(8) or $C2$(5). Polysynthetic twinning on {100} causes the apparent C-lattice violations noted above on the precession films of Socrates mine crystallites. The structure of edgarbaileyite from Terlingua was refined in space group $C2/m$(12) and gave the following unit-cell parameters: a = 11.755(3), b = 7.678(2), c = 5.991(2)Å, β = 111.73(3)°. A full description

Table 2. X-ray powder data for edgarbaileyite.

$I_{(meas)}$	$d\text{Å}_{(meas)}$	$d\text{Å}_{(calc)}$	hkl	$I_{(meas)}$	$d\text{Å}_{(meas.)}$	$d\text{Å}_{(calc.)}$	hkl
20	6.28	6.28	110	7	2.222	2.219	420
10	5.53	5.53	001	5	2.161	2.158	202
2	5.43	5.43	200	3	2.144	2.141	401
7	4.90	4.91	$\overline{2}01$	10	2.094	2.094	330
14	4.68	4.69	$\overline{1}11$	3	2.068	2.068	$\overline{4}22$
8	3.85	3.85	020			2.066	$\overline{5}12$
5	3.76	3.76	111	3	1.954	1.952	$\overline{6}01$
3	3.28	3.28	310	12	1.927	1.925	040
100	3.160	3.159	021	36	1.872	1.871	$\overline{6}02$
27	3.027	3.028	$\overline{2}21$	3	1.834	1.831	331
34	2.952	2.953	$\overline{2}02$	3	1.813	1.811	600
20	2.765	2.765	002	17	1.766	1.766	$\overline{2}23$
63	2.715	2.717	400	14	1.743	1.741	$\overline{6}21$
7	2.509	2.507	221	3	1.685	1.683	$\overline{6}22$
2	2.480	2.474	311	8b	1.657	1.658	530
6	2.454	2.452	$\overline{4}02$	9	1.613	1.612	$\overline{2}42$
17	2.353	2.353	$\overline{1}31$	5	1.580	1.580	042
24	2.321	2.321	$\overline{4}21$	12	1.572	1.575	203
7	2.245	2.246	022			1.570	440

Gunier-DeWolff camera; Co radiation, Fe filter ($\lambda CoK\alpha_1$ = 1.78892Å)
b = broad line
Intensities measured from diffractometer trace.
Indexed on a = 11.725, b = 7.698, c = 5.967Å, β = 112.07°

of the structure will be published elsewhere, but it should be noted that the structure refinement clearly shows that all the Hg present must be in the 1+ oxidation state.

Fully indexed Guiner-De Wolff powder data are presented for Socrates mine material in Table 2. The data have been indexed on the C-lattice determined from the Terlingua study. Refined unit-cell parameters, based on 34 diffraction lines between 6.28 and 1.572Å, gave: a = 11.725(4), b = 7.698(2), c = 5.967(2)Å, β = 112.07(3)°, V = 499.2(2)Å³, $a{:}b{:}c$ = 1.5231:1:0.7751. It should be mentioned that the mineral is very stable. Except for the color change due to photosensitivity, the X-ray powder patterns remain unchanged for material that was originally collected over 25 years ago.

PARAGENESIS

The mineral is a secondary product formed, most probably, by the reaction of mercury and quartz. The conditions of formation are unknown. Edgarbaileyite from the Socrates mine has been found replacing quartz crystals *in situ*. The crystals morphologically and physically resemble quartz except that the color is opaque dark green. X-ray powder and single-crystal studies of one of these pseudomorphs showed no evidence of residual quartz lines in the powder pattern, and also showed that the pseudomorphs are composed of cryptocrystalline edgarbaileyite aggregates. At the Socrates mine and at the Clear Creek claim, edgarbaileyite is one of the latest minerals in the paragenetic sequence and is found near the center of the quartz veins that transect the host rock. At the Socrates mine some veinlets of edgar-

baileyite have been found that were altered to a homogeneous mixture of montroydite and quartz.

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