EDOYLERITE

$Hg_3^{2+}Cr^{6+}O_4S_2$
A NEW MINERAL FROM THE CLEAR CREEK CLAIM SAN BENITO COUNTY, CALIFORNIA

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ABSTRACT

Edoylerite, idealized as $Hg_3^{2+}Cr^{6+}O_4S_2$, is monoclinic, space group $P2_1/a$, with refined unit-cell parameters $a = 7.524(7)$, $b = 14.819(8)$, $c = 7.443(5)$ Å, $\beta = 118.72(5)°$, $V = 728(3)$Å^3, $a:b:c = 0.5077:1:0.5023$, Z = 4. The strongest six reflections in the X-ray powder pattern are [dÅ$(I)(hkl)$]: 5.94(40) (011, $\bar{1}11$); 4.88(50) (120, 021, $\bar{1}21$); 3.212(100) (210, $\bar{2}02$, $\bar{1}41$, 012); 3.012(60) (131); 2.307(40) ($\bar{1}61$); 2.185(40) ($\bar{1}33$, $\bar{2}52$). The mineral is a rare constituent of a small prospect near the long-abandoned Clear Creek mercury mine, New Idria district, San Benito County, California. It is most closely associated with cinnabar, from which it is a primary alteration product, in a host rock composed predominantly of quartz, chalcedony and ferroan magnesite. Edoylerite typically occurs as acicular to stellate crystal groupings on and around corroded masses of cinnabar. Individual crystals are acicular to prismatic, elongate [101], do not exceed 0.5 mm in length, and have a maximum length to width ratio of 60:1. The average crystal length is 0.2 mm. Forms observed are: {010}, {$\bar{1}11$}, {001} and {101}. The mineral is canary yellow to orangish yellow, and possesses a yellow streak and an adamantine luster. Physical properties include: opaque (masses) to transparent or translucent (individual crystals); nonfluorescent; brittle and inflexible; subconchoidal fracture; weakly photosensitive to X-radiation; good cleavage {010} and fair cleavage {101}; calculated density 7.64 g/cm^3 (for empirical formula), 7.13 g/cm^3 (for idealized formula). The mineral is optically biaxial with all refractive indices greater than 1.78; it has weak pleochroism and strong bireflectance and absorption. In polished section, edoylerite is weakly bireflectant and weakly pleochroic and is light gray in color. In plane-polarized light it is bluish gray to gray with brilliant pale yellow internal reflections. Measured

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Figure 1. **Stellate and acicular crystal groupings of edoylerite on holotype specimen NMC 65026.**

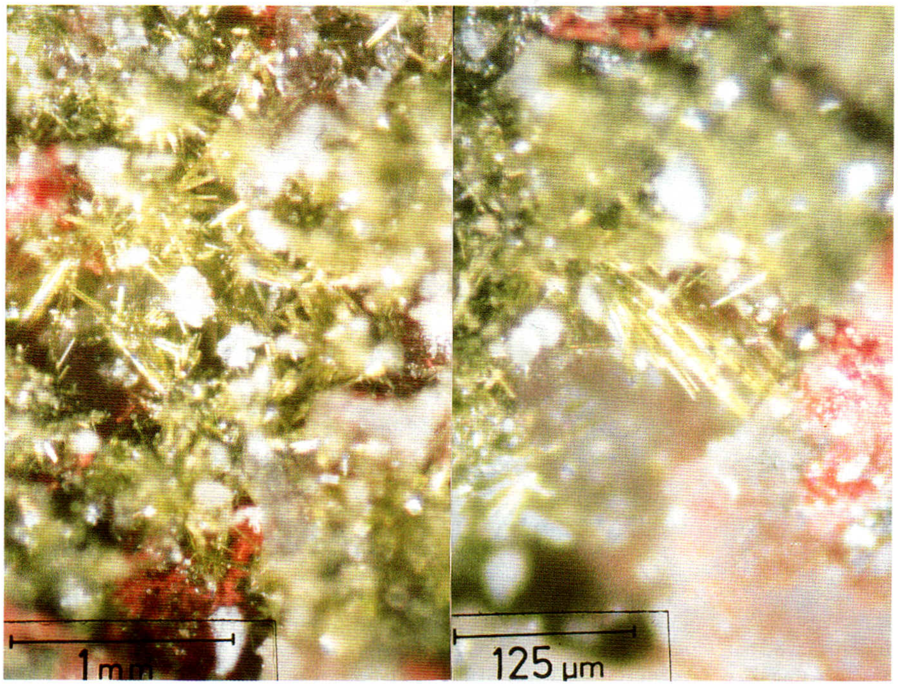
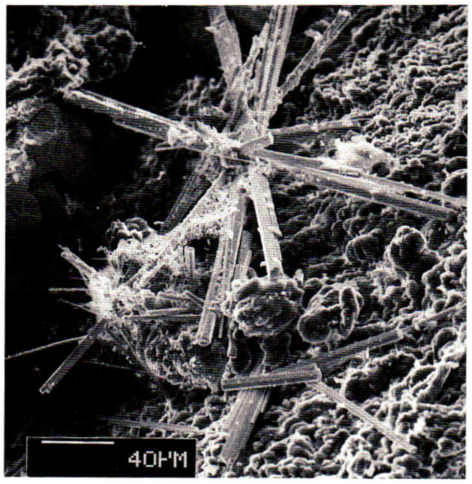


Figure 2. **Scanning electron photomicrograph of a stellate group of edoylerite crystals.**



reflectance values, in air and in oil, are tabulated. The crystal structure shows that mercury exists in two different coordination environments, therefore mercury was partitioned to Hg and to HgO. Averaged electron microprobe analyses yielded Hg = 51.6, HgO = 27.9, CrO_3 = 11.5, S = 8.2, total = 99.2 weight %, corresponding to $Hg^{2+}_{3.26}Cr^{6+}_{0.97}O_4S_{2.16}$, based on O = 4. The mineral is named for Mr. Edward H. Oyler (1915–), a well-known California mineral collector, who first discovered and collected the mineral.

INTRODUCTION

The new mineral edoylerite, described herein, was first discovered by Mr. Edward H. Oyler, a talented collector and specialist in the minerals of mercury, in late 1961. He brought the material to the late Edgar H. Bailey and one of us (RCE) who, after X-ray powder and single-crystal study and a preliminary electron microprobe analysis (by E. D. Ghent), recognized it to be a new mineral species. Unfortunately, the nature of the material then precluded further investigation. The study was renewed in 1986 with the finding of crystals sufficiently large for a crystal-structure determination and in sufficient quantity for a full mineralogical characterization.

The new mineral species is named in honor of Mr. Oyler, not only for its discovery, but, for his long service in providing many materials for mineralogical research. He was born February 4, 1915, in Fresno County, California, and has collected minerals since 1927. The mineral and mineral name have been approved by the Commission on New Minerals and Mineral Names, I.M.A. Holotype material has been deposited within the Systematic Reference Series of the National Mineral Collection at the Geological Survey of Canada under catalogue number NMC 65026. This is also one of the holotype specimens for deanesmithite (Roberts *et al.*, 1993).

OCCURRENCE

The new mineral was first discovered in a large meter-sized boulder (Fig. 4), near a small prospect area known informally as the Clear Creek claim. It was later found in an outcrop of the silica-carbonate rock on the west side of the claim. The Clear Creek claim is situated near the long-abandoned Clear Creek (also Boston; Morning Star) mercury mine, one of the Flint Group of mines in the New Idria district, San Benito County, California. Sparse details regarding the Clear Creek mine are given by Eckel and Myers (1946). The mine is correctly located in R. 11 E. on Plate 8, but is erroneously reported in R. 12 E. (p. 106) of their report. The exact location of the Clear Creek claim is at the coordinates 36°22′59″ N. and 120°43′58″ W., or in the NW1/4 NE1/4 sec. 11, T. 18 S., R. 11 E., Mount Diablo meridian, found on the Idria 7½-minute Quadrangle of the U.S. Geological Survey. Both the Clear Creek claim and the Clear Creek mine are in a large, elongate, tectonically emplaced serpentinite body which is completely surrounded by parts of the Panoche Formation (Upper Cretaceous) and the Franciscan Complex (late Mesozoic to early Tertiary) (Eckel and Myers, 1946; Millage, 1981; Fox, 1983; Boctor *et al.*, 1987). Portions of the serpentinite mass have been hydrothermally altered to a rock composed principally of quartz, chalcedony and ferroan magnesite which is the chief host rock for mercury deposits in the Coast Ranges of California. An extensive discussion of the silica-carbonate rock is provided by Bailey and Everhart (1964, pp. 58–64). The Clear Creek mine and the Clear Creek claim are situated in small bodies of the silica-carbonate rock that were mineralized by cinnabar following the hydrothermal alteration of the serpentinite.

At the edoylerite locality, the host rock is composed of quartz, chalcedony, opal, ferroan magnesite, dolomite, goethite, and minor chlorite. Severely altered to relatively fresh ferroan magnesiochromite occurs as a minor accessory mineral. Magnesiochromite is a ubiquitous mineral in the Coast Range serpentinites, often in deposits of commercial size (Walker and Griggs, 1953; Rice, 1957). Minerals formed during the mercury mineralization, in rough order of abundance, are cinnabar, elemental mercury, edgarbaileyite (Roberts *et al.*, 1990a), metacinnabar, montroydite, eglestonite, calomel, an unidentified yellow massive cryptocrystalline mercury mineral, edoylerite, wattersite (Roberts *et al.*, 1991), giannellaite, mosesite, deanesmithite (Roberts *et al.*, 1993), and a single occurrence of szymańskiite (Roberts *et al.*, 1990b). Despite extensive search, only microgram quantities of edoylerite have been found since 1961. Edoylerite is a primary alteration product of cinnabar.

X-RAY DIFFRACTION

Precession single-crystal studies, employing Zr-filtered Mo radiation, showed that edoylerite is monoclinic with space group $P2_1/a$. The following levels were photographed: *h0l* ➧ *h4l*, *0kl* ➧ *4kl*, and *hk0* ➧ *hk2*. The refined unit-cell parameters: a = 7.524(7), b = 14.819(8), c = 7.443(5) Å, β = 118.72(5)°, V = 728(3) Å^3, a:b:c = 0.5077:1:0.5023 are based on 18 powder reflections representing d-values between 3.012 and 1.755 Å for which unambiguous indexing was possible, based on visual inspection of precession single-crystal films. Details regarding the crystal structure will be published elsewhere, but it should be noted that the structure refinement clearly shows three Hg^{2+} atoms in octahedral coordination, two S^{2-} atoms in tetrahedral coordination, and one Cr^{6+} atom in tetrahedral coordination.

The powder data (Table 1) are unique and bear no resemblance to any other inorganic phase in the Powder Diffraction File up to and including Set 42. Edoylerite is the second reported mercury chromate sulfide (the first was deanesmithite).

***Table 1*. X-ray powder diffraction data for edoylerite.**

$I_{est.}$	$d_{Åmeas.}$	$d_{Åcalc.}$	*hkl*	$I_{est.}$	$d_{Åmeas.}$	$d_{Åcalc.}$	*hkl*
10	7.42	7.41	020	5	2.627	2.625	$\bar{1}42$
5	6.54	6.53	001	25	2.468	2.470	060
40	5.94	5.97	011	3	2.431	2.430	$\bar{2}42$
		5.91	$\bar{1}11$	25	2.351	2.348	$\bar{3}21$
50	4.88	4.93	120	40	2.307	2.306	$\bar{1}61$
		4.90	021	35	2.208	2.213	$\bar{3}31$
		4.86	$\bar{1}21$	40	2.185	2.191	$\bar{1}33$
20	3.94	3.95	130			2.180	$\bar{2}52$
		3.94	031	3	2.152	2.153	013
		3.92	$\bar{1}31$	20	2.121	2.124	$\bar{3}13$
25	3.71	3.71	040	10	2.066	2.064	$\bar{2}61$
5	3.66	3.65	$\bar{2}11$	5	2.038	2.041	$\bar{1}43$
10	3.339	3.353	$\bar{2}21$			2.032	$\bar{2}43$
		3.325	$\bar{1}22$	5	2.011	2.016	170
100	3.212	3.220	210			2.014	071
		3.219	$\bar{2}02$	10	1.967	1.968	$\bar{3}33$
		3.211	$\bar{1}41$	30	1.908	1.907	202
		3.187	012	5	1.882	1.880	$\bar{4}02$
60	3.012	3.019	131	30	1.852	1.851	171
3	2.964	2.972	$\bar{1}32$	10	1.822	1.822	$\bar{4}22$
		2.952	$\bar{2}22$	3	1.806	1.804	$\bar{2}24$
25	2.738	2.744	230	30	1.779	1.782	270
		2.723	032			1.776	072
20	2.704	2.704	150	15	1.755	1.757	261

—114.6 mm Debye-Scherrer powder camera
—Ni-filtered Cu radiation (λ Cu Kα = 1.54178 Å)
—intensities estimated visually
—indexed on $a = 7.524$, $b = 14.819$, $c = 7.443$ Å, $\beta = 118.72°$

PHYSICAL and MORPHOLOGICAL PROPERTIES

Edoylerite occurs as acicular to stellate crystal groupings (Fig. 1) on and around corroded masses of cinnabar. Most crystals do not exceed 0.5 mm in length with a maximum length to width ratio of 60:1 (Fig. 2). The average crystal length is 0.2 mm. Individual crystals are acicular to prismatic, are elongate [101], and are pseudo-orthorhombic to almost pseudo-hexagonal in morphology. Crystals suitable for goniometric measurement are rare and measurable faces give multiple signals. Forms, measured with a two-circle goniometer, and arranged in decreasing order of importance, are {010}, {$\bar{1}$11}, {001} and {101}. The mineral is canary yellow to orangish yellow, has a yellow streak and an adamantine luster. Crystals of edoylerite are transparent to translucent, but massive material appears opaque. There is a very good cleavage on {010} and a fair cleavage on {101}; fracture is subconchoidal and no parting has been detected. Neither hardness nor density could be measured due to size limitations and paucity of material. The mineral is brittle and inflexible. Edoylerite is photosensitive, but a few months time is required to turn the crystals olive-green; Zr-filtered Mo X-radiation produces a dark orange color. No differences are apparent in the X-ray powder diffraction patterns of fresh and exposed edoylerite. The mineral is both nonfluorescent and nonmagnetic.

OPTICAL PROPERTIES

Edoylerite is biaxial with positive elongation (Z = [101]) and is slightly pleochroic with X = Y lemon yellow, Z = slightly darker lemon yellow, and Z > X = Y. We are unable to determine other optical properties due to the high indices of refraction, strong birefringence (estimated at 0.2 ± 0.02), and strong absorption. The indices of refraction greatly exceed 1.78, but the mineral reacts rapidly with high-index immersion media above this value.

In reflected, plane-polarized light (in polished section), edoylerite is light gray, weakly bireflectant and weakly pleochroic. Individual grains, or crystals, have no discernible internal reflections, but, when clustered together in the polished section, a diffuse yellow color is apparent. Between crossed polars, brilliant pale yellow internal reflections are readily apparent and mask the anisotropy of the mineral. When immersed in oil ($N_D = 1.515$), the reflectance pleochroism—from bluish gray to gray—is seen in a few small grains, but is generally masked by the bright canary yellow internal reflections.

Reflectance measurements (using the equipment and procedures outlined by Criddle *et al.*, 1983) were made relative to a Zeiss SiC reflectance standard (no. 472) with X40 objectives, the effective numerical apertures of which had been adjusted to 0.26. Immersion measurements were made using Zeiss oil, $N_D = 1.515$, at an ambient temperature of 20° C. The samples, which had been polished with diamond abrasives, were lightly buffed with MgO immediately before measurement.

Edoylerite presented some difficulty for measurement: in plane section, its prismatic to acicular habit and small grain size meant that the largest areas of crystals exposed by polishing were 60 x 10 μm and 40 x 20 μm, and the abundance of internal reflections effectively reduced sample selection to one area of one crystal of less than 10 μm diameter, which further dictated that the measured area was less than 4 μm. Inevitably, given the much reduced light flux, the *R* data are less reliable than could have been hoped for. In addition, the orientation for measurement had to be made photometrically. For all of these misgivings, the reflectance spectra (Fig. 3) obtained were reproducible, and are consistent with the qualitative observations. This is more readily understood by reference to Table 2 where, in addition to the *R* data, the color values are tabulated. Here, it can be seen that R_1 is not only lower reflecting than R_2, but is more saturated and blue, thus accounting for the reflectance pleochroism.

Application of the Koenigsberger equations to the *R* and ^{im}R data

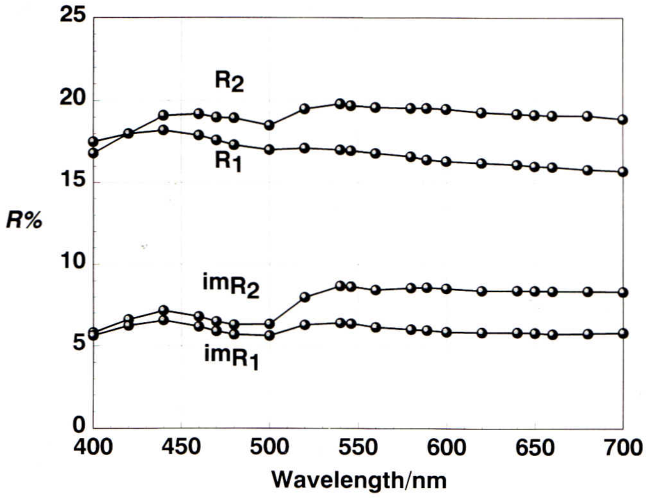


***Figure 3.* Reflectance spectra measured in air and in oil ($N_D = 1.515$) for edoylerite.**

Figure 4. **The area of the Clear Creek claim with Ed Oyler posed by the discovery boulder for edoylerite.**

gives results which are at variance with the observed transparency of the mineral, i.e., absorption coefficients (at 590 *nm*) of 0.9 and 0.7 respectively for R_1 and R_2, with the corresponding refractive indices of 2.08 and 2.06. These data are clearly erroneous, and the errors are almost certainly the product of unequal increments from internal reflections added during air and oil reflectance measurement, *cf.*, Dunn *et al.* (1988). Recalculation of the measured data at 590 *nm* using the Fresnel relation (for transparent media) immediately proves the incompatibility of the air and oil reflectances; for $R_1/^{im}R_1$, the corresponding n_1 values are 2.37 and 2.49; for $R_2/^{im}R_2$, they are 2.58 and 2.77. In this instance, the best *approximations* to the real values for n_1 and n_2 are the mean values, 2.43 and 2.67 (Embrey and Criddle, 1978).

CHEMISTRY

Edoylerite was analyzed chemically by means of a Cameca CAMEBAX electron microprobe, using a 20-kV operating voltage, a 30-nA beam current, a 5-second count rate, and a 6- to 8- micron beam diameter. The standards employed were natural cinnabar (for Hg, S) and synthetic Cr metal (for Cr). A wavelength-dispersive microprobe scan indicated the absence of any other elements with atomic number greater than 9 except those reported here. The structure was known prior to the interpretation of the analytical data. Because mercury exists in two different coordination environments, it was partitioned to Hg and to HgO based on the results of the crystal structure. The Hg and S values were processed using Love and Scott (1981) matrix correction procedures. The average of five analyses gave: Hg = 51.6, HgO = 27.9, CrO_3 = 11.5, S = 8.2, total = 99.2 weight %. The

Table 2. **Reflectance values for edoylerite: for ^{im}R, N_D = 1.515.**

λ*nm*	R_1	R_2	$^{im}R_1$	$^{im}R_2$
400	17.5	16.8	5.61	5.79
420	18.0	18.0	6.22	6.61
440	18.2	19.1	6.55	7.17
460	17.9	19.2	6.15	6.79
470	*17.6*	*19.0*	*5.88*	*6.48*
480	17.3	18.95	5.68	6.28
500	17.0	18.5	5.60	6.32
520	17.1	19.5	6.26	7.99
540	17.0	19.8	6.38	8.69
546	*16.95*	*19.7*	*6.34*	*8.64*
560	16.8	19.6	6.13	8.46
580	16.6	19.55	6.00	8.58
589	*16.4*	*19.55*	*5.94*	*8.61*
600	16.3	19.5	5.85	8.54
620	16.2	19.3	5.81	8.41
640	16.1	19.2	5.81	8.42
650	*16.0*	*19.15*	*5.78*	*8.40*
660	15.95	19.1	5.71	8.38
680	15.8	19.1	5.75	8.38
700	15.7	18.9	5.80	8.34
COLOR VALUES (Illuminant C):				
x	.303	.312	.306	.330
y	.309	.320	.315	.339
Y%	16.8	19.4	6.06	8.21
λ_d	478	570	487	576
P_e%	3.6	1.6	1.6	11.4

empirical formula, on the basis of O = 4, is $Hg^{2+}_{3.26}Cr^{6+}_{0.97}O_4S_{2.16}$ or, ideally, $Hg^{2+}_3Cr^{6+}O_4S_2$. The density, calculated for the empirical formula with Z = 4, is 7.64 g/cm³ and the calculated density for the idealized formula is 7.13 g/cm³. The ideal formula requires: Hg = 51.31, HgO = 27.70, CrO_3 = 12.79, S = 8.20, total = 100.00 weight %.

Edoylerite is insoluble or only slightly soluble in cold mineral acids, but dissolves slowly in aqua regia. The mineral turns greenish yellow after 24 hours at 115° C under infrared radiation but shows no change in its X-ray powder diffraction pattern after this treatment. At higher temperatures (red heat) in a closed tube, the mineral loses Hg and S, turns yellowish black, and then dark green upon cooling. The green residue gives the X-ray powder pattern of Cr_2O_3 (the synthetic equivalent of eskolaite).

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REFERENCES

BAILEY, E. H., and EVERHART, D. L. (1964) Geology and quicksilver deposits of the New Almaden district, Santa Clara County, California. *U.S. Geological Survey Professional Paper,* **360**, 1–206.

BOCTOR, N. Z., SHIEH, Y. N., and KULLERUD, G. (1987) Mercury ores from the New Idria mining district, California: Geochemical and stable isotope studies. *Geochimica et Cosmochimica Acta,* **51**, 1705–1715.

CRIDDLE, A. J., STANLEY, C. J., CHISHOLM, J. E., and FEJER, E. E. (1983) Henryite, a new copper-silver-telluride from Bisbee, Arizona. *Bulletin de Minéralogie,* **106**, 511–517.

DUNN, P. J., PEACOR, D. R., CRIDDLE, A. J., and STANLEY, C. J. (1988) Ingersonite, a new calcium-manganese antimonate related to pyrochlore, from Långban, Sweden. *American Mineralogist,* **73**, 405–412.

ECKEL, E. B., and MYERS, W. B. (1946) Quicksilver deposits of the New Idria district, San Benito and Fresno Counties, California. *California Journal of Mines and Geology,* **42**, 81–124.

EMBREY, P. G., and CRIDDLE, A. J. (1978) Error problems in the two-media method of deriving the optical constants *n* and *k* from measured reflectances. *American Mineralogist,* **63**, 854–862.

FOX, K. E. (1983) Melanges and their bearing on late Mesozoic and Tertiary subduction and interplate translation at the west edge of the North American plate. *U.S. Geological Survey Professional Paper,* **1198**, 1–40.

LOVE, G., and SCOTT, V. D. (1981) Updating correction procedures in quantitative electron-probe microanalysis. *Scanning,* **4**, 111–130.

MILLAGE, A. H. (1981) Mineralogy of the Victor Claim, New Idria district, San Benito County, California. *M.S. Thesis, Stanford University, Stanford, California,* 1–172.

RICE, S. J. (1957) Chromite *in* Mineral commodities of California. *California Division of Mines and Geology Bulletin,* **176**, 121–130.

ROBERTS, A. C., BONARDI, M., ERD, R. C., CRIDDLE, A. J., and LE PAGE, Y. (1991) Wattersite, $Hg^{1+}_4Hg^{2+}Cr^{6+}O_6$, a new mineral from the Clear Creek claim, San Benito County, California. *Mineralogical Record,* **22**, 269–272.

ROBERTS, A. C., BONARDI, M., ERD, R. C., CRIDDLE, A. J., STANLEY, C. J., CRESSEY, G., ANGEL, R. J., and LAFLAMME, J. H. G. (1990a) Edgarbaileyite—the first known silicate of mercury, from California and Texas. *Mineralogical Record,* **21**, 215–220.

ROBERTS, A. C., ERCIT, T. S., ERD, R. C., and OSCARSON, R. L. (1990b) Szymańskiite, $Hg^{1+}_{16}(Ni,Mg)_6(CO_3)_{12}(OH)_{12}(H_3O)^{1+}_8 \cdot 3H_2O$, a new mineral species from the Clear Creek claim, San Benito County, California. *Canadian Mineralogist,* **28**, 703–707.

ROBERTS, A. C., SZYMAŃSKI, J. T., ERD, R. C., CRIDDLE, A. J., and BONARDI, M. (1993) Deanesmithite, $Hg^{1+}_2Hg^{2+}_3Cr^{6+}O_5S_2$, a new mineral from the Clear Creek claim, San Benito County, California. *Canadian Mineralogist,* **31**.

WALKER, G. W., and GRIGGS, A. B. (1953) Chromite deposits of the southern Coast Ranges of California. Chapter 2 *in* Pt. 2 of Geological investigations of chromite in California. *California Division of Mines and Geology Bulletin,* **134**, 39–88.