

# INESITE

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## *from the Hale Creek mine, Trinity County, California*

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**T**he Hale Creek manganese deposit has afforded some of the largest and finest examples of crystallized inesite in the world. In addition, the discovery of several new inesite crystal forms makes this occurrence especially interesting.

### INTRODUCTION

Fine crystallized samples of inesite,  $\text{Ca}_2\text{Mn}_7\text{Si}_{10}\text{O}_{28}(\text{OH})_2 \cdot 5\text{H}_2\text{O}$ , were first recovered from the abandoned Hale Creek manganese mine in 1971. Although the mineral was recognized from the deposit as early as 1941 (Trask *et al.*, 1943), the well-formed pink crystals were not generally known to the mineral community until mineral collectors first etched them out of surrounding calcite with acid.

Since many mineral collectors now possess fine samples of Hale Creek inesite, we decided to describe this interesting locality in the light of new observations on the crystal morphology made by the authors during an optical study of a number of crystals. Our study resulted in the discovery of several new crystal forms not previously known to exist on inesite found at other world localities (Ryall and Threadgold, 1968).

While most inesite from various world locations is commonly described as forming aggregates of radiating acicular crystals, the Hale Creek inesite forms rare terminated crystals. Inesite with visible crystal faces has so far been reported from Långban, Sweden (Hamberg, 1884; Flink, 1900, 1916); Durango, Mexico (Farrington, 1900); Nazenbach, West Germany (Schneider, 1887); Rendaiji, Japan (Takasu, 1955); Broken Hill, Australia (Ryall and Threadgold, 1968); the Crescent mine, Washington (Cannon, 1975), and the Wessels mine, South Africa (Wilson and Dunn, 1978). Additional U.S. localities for inesite have been described by Glass and Schaller (1939); Van Loenen (1980), and Pemberton (1983).

### LOCATION

The Hale Creek mine is located within the rugged Six Rivers National Forest in NW¼ sec. 23, T15S, R6E, about 90 km northeast of Eureka, California. A poorly graded road fords the Mad River near Ruth Dam and ascends a ridge parallel to Hale Creek for about 3 km, terminating at the mine.

The topography of the area is typical of the northern California Coast Ranges which consist of rugged mountains, largely inaccessible, separated by narrow, long valleys. Dense brush and timber cover much of these northwest-southeast trending ranges. Heavy rainfall is common during the winter months which, over time, has resulted in chemical weathering and the formation of a heavy soil mantle that obscures the underlying rocks in many places. The summer months can be relatively hot. Hale Creek is one of the largest tributary streams in the area and flows into the Mad River.

### HISTORY

Most of the California manganese deposits occur in chert of the Franciscan Formation which is extensively exposed in the Coast Ranges of northwestern California. Trinity County contains the largest number of manganese deposits of any county in California, with over 100 localities having been recorded (Trask *et al.*, 1943).

The Hale Creek manganese deposit was discovered and located by S. Hutchins and H. T. Moore of Ruth, California, before 1941 and subsequently leased to W. Doty and S. Killingsworth of Mad River, California. It was not actively developed until manganese

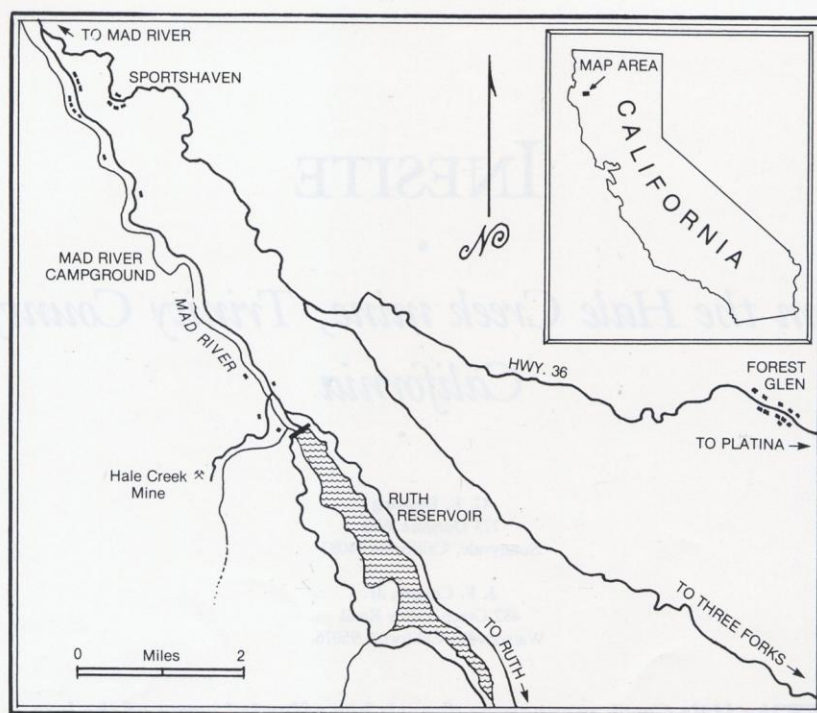


Figure 1. Location map.

prices increased during World War II, making mining profitable. Trask (1950) states that during the summer of 1941 about 600 tons of rhodochrosite ore had been mined and stockpiled beside the deposit. At that time the carbonate ore could not be marketed because of government ore restrictions.

When the site was revisited in August of 1944 by M. D. Crittenden of the California Division of Mines nearly 4,000 tons of ore had been mined since 1943 by W. H. Snyder and R. F. Helmke. The ore at that time averaged 42% manganese, 1% iron, and 21% silica (Trask, 1950; O'Brien, 1965). By the end of 1944, the tabular orebody had been depleted and mining ceased.

The massive manganese orebody occurred near the crest of a flat-topped spur which made stripping of the chert and sandstone overburden relatively simple. Mining was done by open-cut methods, using a bulldozer to remove the sandstone from above the orebody. After removal of the overburden, the exposed ore was blasted and then stockpiled for loading into trucks via a wooden hopper to be taken to the shipping point at either Carlotta or Alton on the Northwestern Pacific Railroad, a distance of 88 km (Trask, 1950).

The orebody measured 50 meters long and 1 to 4 meters thick in 1944 and was lying nearly horizontally in a sequence of thin-bedded white chert encased in sandstone.

Both Trask *et al.* (1943) and Trask (1950) recorded the presence of inesite in the deposit as occurring in veins of silky radiating crystals between 1 and 1.5 cm in size associated with small amounts of chrysocolla, native copper and cuprite. The inesite and calcite veins were nearly vertical and followed along fractures in the orebody above a greenstone intrusion.

The first specimens of crystallized inesite were collected in 1971 by A. L. McGuinness and J. Parnau, both affiliated with the Bay Area Mineralogists, Menlo Park, California. Their trip to the Hale

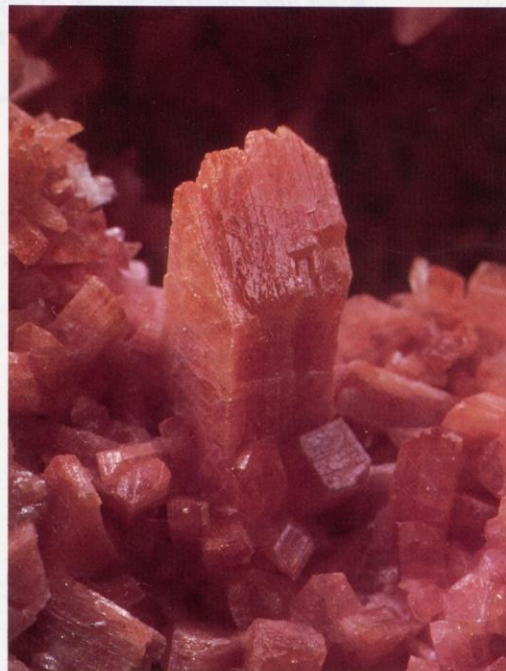


Figure 2. Inesite crystals to 7 mm lining a vug in manganese ore. G. Dunning specimen.

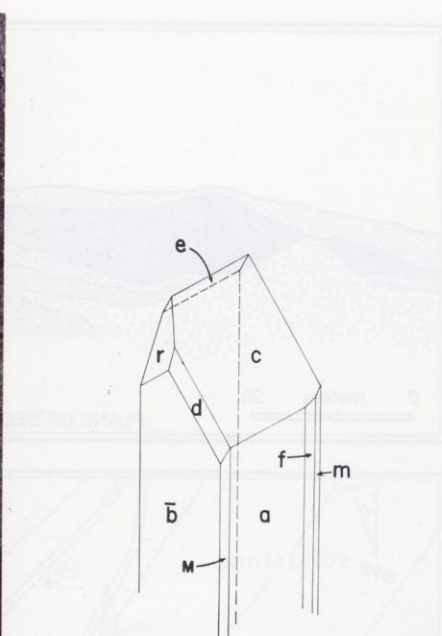


Figure 3. Crystal drawing of inesite showing several of the forms including the new form  $r\{111\}$ .

Figure 4. Inesite crystals to 2.2 cm lining a vug in manganese ore. G. Dunning specimen.

Figure 5. Inesite crystals to 1 cm lining a vug in manganese ore. G. Dunning specimen.



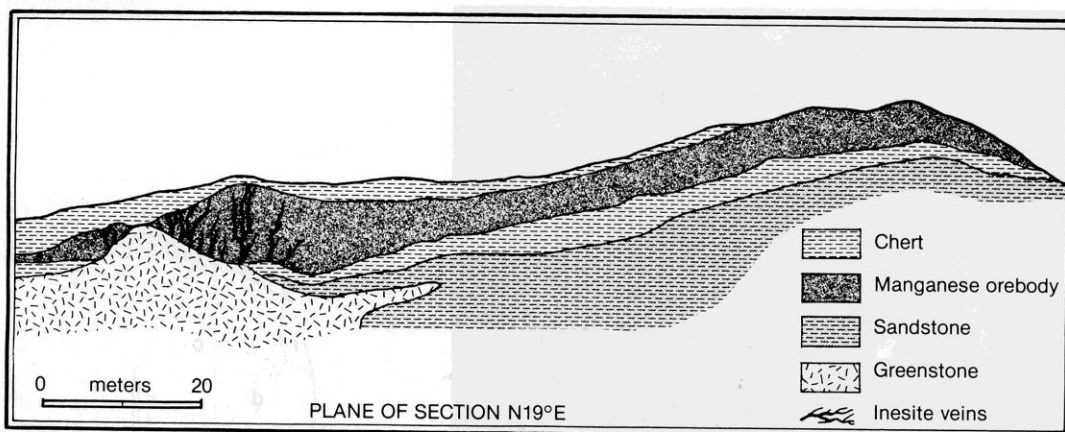
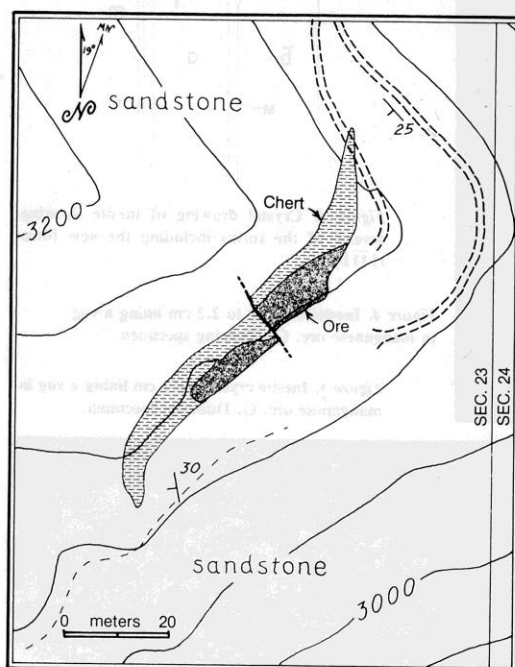


Figure 6. Geologic map (left) and section of the Hale Creek mine, Trinity County, California (after Trask, 1950). The section runs about 100 feet northwest of the outcrops as shown on the area map.



Creek mine was inspired by the occurrence and description of crystallized inesite made by Trask (1950). (It is not uncommon to find hidden references to many promising mineral occurrences in the pages of mining bulletins and journals.) Upon arriving at the abandoned mine site they soon discovered considerable vein material rich in massive to coarsely crystallized inesite covered with calcite. Also, a number of potentially good specimens were recovered from the hillside below the mine bench but above Hale Creek. After collecting, they returned and began to carefully dissolve away the surrounding calcite, revealing the bright pink euhedral inesite crystals, many up to 2 cm in size. Occasional subhedral barite crystals, secondary copper minerals, and several copper sulfides were also discovered. Many of the inesite crystal groups were then made available to the public.

Since the original discovery in 1971, the authors have made trips to the Hale Creek mine in 1972, 1973 and 1975. Samples which we collected formed the basis for the current morphological study.

The current ownership and collecting status of the Hale Creek mine is not known but from time to time since 1975 collectors have visited the abandoned site unhindered and have obtained a few specimens (quantity unknown).

Today many fine inesite crystal groups can be found in private and museum collections. Although a large number of inesite specimens have been recovered from this locality, one can only wonder how much material was lost to the ore crusher after mining.

#### GEOLOGY

The geological features of the Coast Ranges, and more specifically the genesis of manganese deposits contained therein, have been described by Taliaferro and Hudson (1943); Trask *et al.* (1943); Trask (1950); and Page (1966). These Coast Ranges are composed of late Jurassic, Cretaceous, Tertiary and Quaternary sediments, volcanics and shallow intrusive bodies.

The rocks exposed at the Hale Creek mine are typical of the Franciscan-Knoxville group of late Jurassic age and consist of sandstones, shales, cherts, greenstones, and graywackes. Page (1966) describes this formation as a vast, diverse assemblage of eugeo-synclinal rocks with unsystematic structure.

Trask (1950) described the Hale Creek manganese orebody as a nearly flat-lying massive tabular lens enclosed in chert and sandstone. Unlike most Franciscan manganese deposits, which occur within chert lenses 10 to 100 times the thickness of the ore, the chert here formed only a thin envelope separating the orebody from the sandstone. Near the western end of the orebody 2 meters of buff to greenish chert occurred interbedded with thinly laminated red shale; near the eastern end of the orebody, it was separated from the sandstone above by 15 cm of white chert. A greenstone intrusion occurs near the western end of the orebody and cuts across the chert and sandstone. Trask (1950) states that this intrusion caused marked hydrothermal alteration of the orebody near the contact.

The ore in the original exposure consisted largely of fine-grained manganiferous chert and some manganese carbonate. As mining progressed, dark reddish brown hausmannite began to appear, and

constituted about 30% of the exposed ore in 1944. Trask (1950) found that the earliest minerals to form were dark reddish brown hausmannite in irregular aggregates, surrounded by light-colored bementite and rhodochrosite. These minerals were then cut by veins of calcite, rhodochrosite, bementite and barite. For a distance of 1 cm from the boundary of these veins, the hausmannite was altered to a cloudy mass of bementite in which the form of the original hausmannite aggregates was preserved.

Post-ore fracturing related to the greenstone intrusion provided ideal channelways for ascending hydrothermal solutions which deposited inosite followed by calcite which filled the remaining voids of the fracture system. These veins extended nearly vertically for about 8 meters.

Oxidation of the manganese minerals did not extend more than 1 meter from the original surface, except along open fractures, and even then only thin films of oxides were observed (Trask, 1950).

Taliaferro and Hudson (1943) have concluded that the manganese deposits of the Coast Ranges are syngenetic chemical sediments formed at the same time and in the same marine environment as the cherts with which they are associated. They also concluded that the iron, manganese and silica had a common origin, because there is a close association both in time and space between the basic volcanics of the Franciscan group and the cherts.

## MINERALOGY

Inosite is by far the most interesting of the manganese minerals found at the Hale Creek mine. Although it occurs rather sparingly in most other manganese deposits, it is relatively abundant and unusually well crystallized at Hale Creek.

In addition to inosite, other manganese minerals at Hale Creek include rhodochrosite, bementite and hausmannite. Accessory minerals include barite, bornite, calcite, chalcocite, chrysocolla, cuprite, digenite, julgoldite, malachite and native copper.

**Inosite**  $\text{Ca}_2\text{Mn}_7\text{Si}_{10}\text{O}_{28}(\text{OH})_2 \cdot 5\text{H}_2\text{O}$

### Physical Description

Taliaferro and Hudson (1943) state that inosite is of common occurrence in veins cutting deposits that have been rather strongly recrystallized or subjected to weak hydrothermal action. At Hale Creek, inosite crystallized along fracture surfaces in the rhodochrosite-bementite-hausmannite orebody just above the greenstone intrusion. These fractures, which become veins for ascending solutions, ranged from 3 to 10 cm wide, with local enlargements to 15 cm. They were lined with dark pink crystalline inosite which graded into subhedral to euhedral prismatic crystals, often complexly intergrown. Local enlargements provided for the formation of larger crystals often exceeding 2 cm in length. On rare occasion, doubly terminated crystals formed in the masses of flattened subhedral crystals.

The prismatic habit closely resembles the habit of crystals from Nanzenbach, West Germany; Långban, Sweden; and Durango, Mexico (Ryall and Threadgold, 1968). In contrast, the crystals from Rendajji, Japan, and Broken Hill, Australia, exhibit a characteristic "chisel-shape" developed by the  $g\{201\}$ .

Hale Creek inosite crystals vary from a light to dark pink. Exposure to light and weathering have resulted in thin, dark, manganese oxide films on the faces. Occasionally small crystals, less than 3 mm, can be found which are transparent and gemmy and can be recognized by their high reflectivity. They are either colorless or very light pink or light ginger-brown in color, depending on the degree of oxidation.

### Crystal Morphology

Preparatory to studying the unknown crystal forms, we reviewed the inosite crystal morphology compiled by Ryall and Threadgold (1968). In their research, they reported 16 crystal forms for inosite

from various world localities, including a new form from Broken Hill, Australia. To further identify the Hale Creek forms, individual crystal drawings were constructed along each of the crystallographic axes using the crystallographic data of Wan and Ghose (1978).

Inosite is triclinic, space group  $P\bar{1}$ , and belongs to the pinacoidal class. Its symmetry consists of only a center and, therefore, all crystal forms are pinacoids consisting of only two similar and parallel faces. Aside from the common front, side and basal pinacoids, various first, second, third and fourth-order pinacoids with different axial intercepts are possible. The presence of a positive pinacoid in no way indicates that the corresponding negative form will be present.

In general, the Hale Creek inosite crystals are well-developed but only rarely doubly terminated. Intergrowth of two or more crystals is very common and may obscure many of the smaller forms. The larger crystals exhibit parting planes along the  $c$  axis which is the result of one of the two cleavages in inosite.

The axial pinacoids  $a\{100\}$ ,  $b\{010\}$  and  $c\{001\}$  are present on all crystals examined. Other forms common to Hale Creek inosite include  $d\{011\}$ ,  $e\{101\}$ ,  $M\{110\}$  and  $g\{201\}$ , although the latter form was observed on only one crystal. The rarer forms  $m\{110\}$  and  $f\{210\}$  were also observed on a few crystals. All of these forms were found to be quite narrow and not of high quality. None of the rare forms  $h\{311\}$ ,  $i\{747\}$ ,  $j\{301\}$ ,  $k\{101\}$ ,  $n\{301\}$ ,  $o\{532\}$  or  $s\{946\}$  were identified on the Hale Creek inosite.

Identification of the first, second, and third-order pinacoid forms was made by a comparison of SEM photographs oriented along each of the principal axes and compared to the corresponding drawings of the known forms tabulated by Ryall and Threadgold (1968). However, during the optical examination a majority of the crystals showed the development of a negative left fourth-order pinacoid face (see Hurlbut, 1956 for a description of triclinic crystal form nomenclature) at the approximate intersection of the zone  $[\bar{1}11]$ , which contains the faces  $\bar{m}(110)$  and  $\bar{e}(101)$ , with the zone  $[011]$ , which contains the faces  $d(011)$  and  $\bar{a}(100)$ . Preliminary estimation of the interfacial angles of this face with adjacent known faces suggested that its index might be  $\{111\}$ , a form not previously noted on inosite crystals from other localities (Ryall and Threadgold, 1968).

To confirm our tentative findings we submitted three small single crystals containing the forementioned forms to Dr. A. Pabst who graciously consented to examine them using an old but very reliable Stoe two-circle reflecting goniometer. Because of the triclinic symmetry of inosite the crystallographic settings of Ryall and Threadgold (1968) were used in orienting the crystals. Dr. Pabst was able to establish the presence of the three axial pinacoids,  $a\{100\}$ ,  $b\{010\}$ , and  $c\{001\}$ ; the first-order pinacoid  $d\{011\}$ ; the third-order pinacoids  $M\{110\}$  and  $f\{210\}$ , and the fourth-order pinacoid  $\{111\}$ . We have designated this latter new form as  $r$ , one found on many triclinic pinacoidal minerals, especially the sulfates.

Using the information kindly provided by Dr. Pabst on inosite form development, the authors examined nearly 100 additional crystals using a binocular microscope. During the course of this rather time-consuming examination, four additional forms which appeared to be new were observed on several small crystals. These are: a first-order positive similar to  $d\{011\}$  but intersecting the positive  $b$  axis; a second-order negative similar to  $g\{201\}$  but intersecting the negative  $a$  axis; a third-order negative similar to  $f\{210\}$  but intersecting the negative  $b$  axis, and a fourth-order negative right similar to the newly discovered  $r\{111\}$  but intersecting the positive  $b$  axis. Because of the small face size, poor reflective quality, and intergrowth with other crystals, the crystals containing these possible new forms were not suitable for goniometric measurements.

Identification of these forms was based solely on SEM photographs and comparison to individual drawings along each axis containing these possible new forms.

We have concluded that the four additional forms observed compare favorably with the forms {011}, {201}, {210} and {111}, and we have designated them as *D*, *G*, *F*, and *R* respectively, following convention. If single crystals become available which are suitable (small and not complexly intergrown) for goniometric measurements, these forms should be confirmed and their interfacial angles established.

The frequency of form development was found to vary with each sample containing a group of crystals. The first, second, and third-order forms generally were found only on crystals less than 3 mm in size and gemmy in appearance. One exception was the development of the two fourth-order forms  $r\{111\}$  and  $R\{111\}$  on nearly all crystals, even those 1 cm or larger. The three axial pinacoids occur on all terminated crystals and are usually well developed despite the presence of multiple cleavage partings along {010} which tend to easily spall off. The first and second-order pinacoids  $d\{011\}$ ,  $D\{011\}$ ,  $g\{210\}$ ,  $e\{101\}$  and  $G\{201\}$  are quite rare and were observed on fewer than five crystals. Forms  $g\{201\}$  and  $G\{201\}$  were the least developed of all, although the former, however, is quite common on the Broken Hill and Rendaiji crystals and forms a characteristic "chisel-shape" habit (Ryall and Threadgold, 1968). The third-order pinacoids  $m\{110\}$ ,  $M\{110\}$ ,  $f\{210\}$  and  $F\{210\}$  are present on less than 5% of the crystals examined and were found to be very narrow, pitted, and not well-formed. The two fourth-order pinacoids  $r\{111\}$  and  $R\{111\}$  are the most common except for the axial pinacoids and occur on at least 80% of the examined crystals. The  $r\{111\}$  was found to be more abundant than the  $R\{111\}$ , and no crystal was observed which was developed by both forms simultaneously.

It can be argued that the presence of the  $R\{111\}$  is equivalent in form to the  $r\{111\}$  and that it only represents a visible lower terminated development of a doubly-terminated crystal with the upper half being the base. In fact, this argument can be extended to include several of the new forms found, namely the  $D\{011\}$ ,  $G\{201\}$ , and  $F\{210\}$  which have not been observed with the corresponding  $d\{011\}$ ,  $g\{201\}$ , and  $f\{210\}$  forms.

Since visible doubly-terminated crystals are quite rare at Hale Creek (we observed only two), it would be difficult to state with any degree of certainty that this is not the case. However, until further observations are made of doubly terminated crystals to determine the form development, we propose that the new forms identified here be considered individual forms, and that the condition of single form development on a crystal is due to a crystal growth phenomenon.

Table 1 is an extension of Table 2 of Ryall and Threadgold (1968) and compares the Hale Creek crystal form development with those of other world localities. Table 2 lists those forms identified by goniometer with their associated angles. The angles A, B and C were calculated from the observed  $\phi$  and  $\rho$  values determined by Dr. Pabst using the triclinic crystallographic formulas listed by Palache *et al.* (1941).

#### Crystal Structure

Richmond (1942) determined the chemical composition of inesite as  $\text{Ca}_2\text{Mn}_2\text{Si}_6\text{O}_{20}(\text{OH})_2 \cdot 5\text{H}_2\text{O}$ , and placed it in the rhodonite group of pyroxenoids on the basis of its cleavage characteristics and unit-cell dimensions. Ryall and Threadgold (1968) concluded that inesite contains a single silicate chain with a five-tetrahedral repeat based on infrared absorption spectra of several pyroxenoids, including inesite.

Recently Wan and Ghose (1978) solved the crystal structure of inesite using samples from both the Crescent mine, Washington,

Table 1. Comparison of inesite crystal form development.<sup>a</sup>

Form	Långban Sweden	Durango Mexico	Nanzen- bach Germany	Rendaiji Japan	Broken Hill Austral.	Hale Creek USA
$a\{100\}$	X	X	X	X	X	X
$b\{010\}$	X	X	X	X	X	X
$c\{001\}$	X	X	X	X	X	X
$m\{110\}$	X					X <sup>c</sup>
$M\{110\}$			X	X	X	X <sup>c</sup>
$f\{210\}$				X	X <sup>b</sup>	X
$F\{210\}$						X
$g\{201\}$	X	X	X	X	X	X
$G\{201\}$						X
$e\{101\}$	X	X	X	X		X
$l\{101\}$	X		X			
$n\{301\}$	X					
$f\{301\}$	X					
$d\{011\}$	X	X	X	X	X	X
$D\{011\}$						X
$r\{111\}$						X
$R\{111\}$						X
$h\{311\}$					X	
$o\{532\}$			X			
$i\{747\}$			X			
$s\{946\}$		X				

<sup>a</sup> Non-USA localities compiled by Ryall and Threadgold (1968).

<sup>b</sup> Face (210) absent but face (210) present.

<sup>c</sup> Both  $\bar{m}\{110\}$  and  $M\{110\}$  also present.

X — Form present.

Table 2. Angle table for Hale Creek inesite crystal forms.

Forms <sup>a</sup>	$\phi$	$\rho$	A	B	C
$a\{100\}$	82°	90°	—	82°	46°
$b\{010\}$	0°	90°	82°	—	83°
$c\{001\}$	80°	43°	45°	83°	—
$M\{110\}$	121°	90°	39°	121°	59°
$f\{210\}$	65°	90°	17°	65°	49°
$d\{011\}$	143°	54°	67°	131°	48°
$r\{111\}$	—147°	59°	124°	136°	91°

<sup>a</sup> Forms observed but not measured by goniometry  $e\{101\}$ ,  $g\{210\}$ ,  $m\{110\}$ ,  $D\{011\}$ ,  $G\{201\}$ ,  $F\{210\}$ ,  $R\{111\}$ .

and Hale Creek, California. This crystal structure provides the first example of double silicate chains with a periodicity of five tetrahedra. The structure contains two components: (a) a polyhedral band, composed of a sequence of seven edge-sharing Mn octahedra and two Ca pentagonal bipyramids, connected to two similar sequences on either side by edge-sharing; and (b) double silicate chains with a five-tetrahedral-repeat period, which contains alternating six- and eight-membered rings. These silicate double chains knit the adjacent Ca and Mn polyhedral bands into a three-dimensional framework.

#### Bementite $\text{Mn}_6\text{Si}_6\text{O}_{15}(\text{OH})_{10}$

Massive bementite occurred as one of the ore minerals comprising the orebody. It is light brown with a distinct fibrous habit. Rounded masses still remaining at the site are commonly coated with black oxides of manganese.

#### Hausmannite $\text{Mn}^{2+}\text{Mn}_2^{3+}\text{O}_4$

Dark reddish brown hausmannite comprised about 30% of the

orebody and in many places was surrounded by bementite and rhodochrosite.

#### Neotocite $(\text{Mn,Fe}^{+2})\text{SiO}_3 \cdot \text{H}_2\text{O}$ (?)

The only reference to neotocite is found in the description of the manganese orebody by M. D. Crittenden in 1944 (Trask, 1950). He describes veinlets of pink rhodochrosite and resinous neotocite cutting the other ore minerals.

#### Rhodochrosite $\text{MnCO}_3$

Massive to crystalline rhodochrosite was quite common when mining first began. Trask (1950) records over 600 tons having been mined in 1941. Although no crystals were recorded by either Trask (1950) or O'Brien (1965), some probably existed. Remnant samples of rhodochrosite at the site show typical surface oxidation in the form of black manganese oxides.

#### Barite $\text{BaSO}_4$

Trask (1950) reports barite veins in the orebody cutting older hausmannite, bementite and rhodochrosite. Subhedral to euhedral, pale salmon-pink barite crystals, commonly reaching 4 cm in length, were found associated with inesite in the veins.

#### Julgoldite $\text{Ca}_2\text{Fe}^{+2}(\text{Fe}^{+3},\text{Al})_2(\text{SiO}_3)_2(\text{OH})_2 \cdot \text{H}_2\text{O}$

Julgoldite, the ferrous-feric analog of pumpellyite, occurs rarely as minute dark green to black masses of subhedral prismatic to acicular crystals on the wall rock along the inesite veins (Pemberton, 1983).

#### Copper Minerals

Small amounts of copper sulfides and native copper were found associated with inesite and were introduced into the orebody during the hydrothermal activity related to the greenstone intrusion. These minerals include native copper, bornite, chalcocite and digenite. Oxidation of these minerals has produced small films and veins of malachite and chrysocolla.

#### ACKNOWLEDGMENTS

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Table 3. Minerals identified from the Hale Creek mine.

<b>Ore Minerals</b>	
Bementite	$\text{Mn}_8\text{Si}_6\text{O}_{15}(\text{OH})_{10}$
Hausmannite	$\text{Mn}^{+2}\text{Mn}_2^{+3}\text{O}_4$
Inesite	$\text{Ca}_2\text{Mn}_2\text{Si}_6\text{O}_{28}(\text{OH})_2 \cdot 5\text{H}_2\text{O}$
Neotocite	$(\text{Mn,Fe}^{+2})\text{SiO}_3 \cdot \text{H}_2\text{O}$ (?)
Rhodochrosite	$\text{MnCO}_3$
<b>Accessory Copper Minerals</b>	
Bornite	Barite
Chalcocite	Calcite
Chrysocolla	Julgoldite
Copper	Quartz
Digenite	
Malachite	

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