

ART. XV.—*On the Crystallization of Gold*; by EDWARD S. DANA.

THE attention of the writer has been directed recently to some specimens of crystallized native gold offering several points of interest and novelty. The crystallization of the native metals, gold, silver and copper, is a subject of more than usual difficulty, and for our knowledge in this direction we are largely indebted to the excellent work of Rose.\* More recently vom Rath has made an important contribution in regard to the complex crystallized plates and thread-like forms of gold; Helmhacker† has described the interesting gold crystals from Sysertsck;‡ while v. Jeremejew,§ Lewis,|| Fletcher¶ and Werner\*\* have added to the list of observed forms.

\* Pogg. Ann., xxiii, 196, 1831; Reise nach dem Ural, i. 198, 1837, *et al.*

† Zeitsch. Kryst., i, 1, 1877. ‡ Tschermak's Mineral. Mittheilungen, 1877, 1.

§ Verh. Min. Ges. St. Petersburg, II, v, 402, 1870.

|| Phil. Mag., v, iii, 456, 1877. ¶ Ibid., ix, 1880. \*\* Jahrb. Min., i, 1, 1881

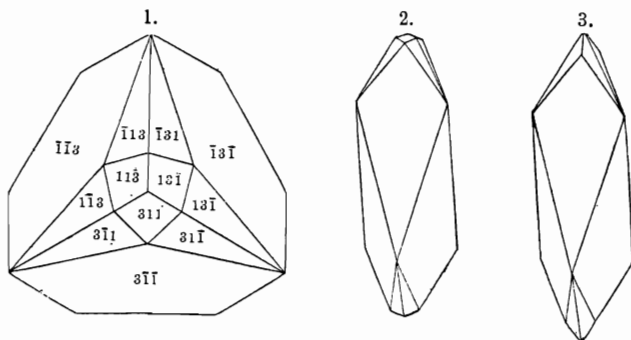
1. *Gold from Oregon.*

The delicate crystalline threads and arborescent forms of the gold from the White Bull mine in Oregon have long been a prominent ornament of collections, especially in America, but, so far as the writer is informed, no attempt has been made to describe them. A brief sentence is devoted to the subject in his *Text-Book of Mineralogy*, but the statement there is only partially correct.

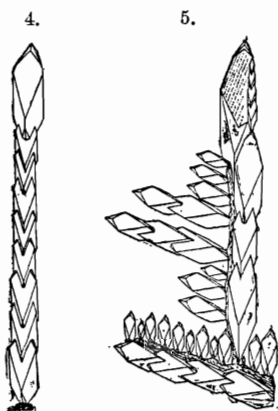
The beauty and delicacy of these forms are perhaps unrivaled in the species, but to decipher them crystallographically does not seem at first to be especially easy. If examined superficially the threads appear to be made up of acute rhombohedral forms, closely crowded upon each other. The terminal crystal, which is in many cases much the largest of the series, usually shows also the presence of a six-sided pyramid at the apex, a form often only faintly indicated in the other crystals. In rare cases, where this terminal crystal is unusually well developed, close examination reveals also the presence of three other minute planes forming an obtuse termination to the hexagonal pyramid. The position of these planes at once suggests an explanation of the form, and a few measurements show that this explanation is the correct one. The planes observed are all those of the tetragonal trisoctahedron 3-3 (311), common in the species, and the peculiar appearance and apparent rhombohedral symmetry are due to the fact that the crystals are uniformly elongated in the direction of the octahedral or trigonal axis.

This is then simply a case of pseudo-symmetry, analogous to that by which a regular octahedron may be transformed into a rhombohedron with prominent basal plane, or into a simple acute rhombohedron if these two planes are suppressed; or again, to that in which a rhombic dodecahedron becomes a hexagonal prism terminated by rhombohedral planes; or, still again, like that which turns the trisoctahedron 2-2 (211) into a combination of an obtuse rhombohedron, a scalenohedron and a hexagonal prism. These are cases that have been long recognized. The case now described is remarkable for the regularity of the resulting forms and the way in which they are combined. This tendency in nature to thus imitate the symmetry of one system by the development of crystals belonging to another system, is in part explained by the fact that the planes whether referred to the one system or the other, have in either case rational symbols. Thus if we place a cube with its trigonal axis vertical, and regard it as the fundamental rhombohedron with a rhombohedral angle of  $90^\circ$ , the planes of the trisoctahedron 3-3 group themselves as follows (figs. 1, 2 and 3).

The planes 113, 311, 131, with the three opposite, form an obtuse rhombohedron with the symbol  $\frac{2}{3}R$  (2025) and having a terminal angle (supplement) of  $50^\circ 29'$ . The six adjoining planes,  $\bar{1}\bar{1}\bar{3}$ ,  $3\bar{1}\bar{1}$ ,  $3\bar{1}\bar{1}$ ,  $1\bar{3}\bar{1}$ ,  $\bar{1}3\bar{1}$ ,  $\bar{1}\bar{1}3$ , with their opposites, form a hexagonal pyramid of the second series, with the symbol  $\frac{4}{3}2$  (2243); the terminal angle is here  $50^\circ 29'$  and the basal angle  $62^\circ 58'$ . The six remaining planes of the twenty-four, namely  $\bar{1}\bar{1}3$ ,  $3\bar{1}\bar{1}$ ,  $\bar{1}3\bar{1}$ , and those opposite, form an acute rhombohedron with a symbol  $4R$  ( $40\bar{4}1$ ), and a terminal angle of  $117^\circ 2'$ .



The predominating form is uniformly this last mentioned acute rhombohedron; though traces of the pyramid can usually be seen. The simple crystalline threads are built up of a series of these rhombohedrons in parallel position and crowded closely together. This is shown in fig 4. The terminal crystal is often larger than the



others, and frequently of the skeleton type with prominent salient edges and the larger part of the face depressed, and perhaps made up of a series of fine parallel wires of frosted gold, suggesting some of the most delicate ornaments made by a skillful worker in gold.

The threads, however, are not limited to a single line of parallel crystals; generally there are two lines close together with a depressed furrow between them, and a third in which the crystals are also in parallel position with each other, but elongated according to another octahedral axis. In these last cases each plane of a crystal in one line is parallel to one in the other, but these planes have a different value in the rhombohedral development. Figure 5 shows a string of these crystals

branching off from another line at the bottom; here the second line of crystals parallel to the first is concealed from view, but the third is shown consisting of those elongated in the direction of the other axis. These last are represented as having the same rhombohedral development as the others, which is often true, but it is also common to find them with this elongation scarcely shown so that they deviate much less from the ordinary trisoctahedral form. These threads are then made up of the line or lines of sharp rhombohedral forms and this other line of minute bead-like crystals. These compound threads often taper down to a fine wire with crystalline markings on the surface but showing no distinct forms.

No fullness of description could give a satisfactory idea of the variety of these forms, as no drawing could adequately represent their beauty and delicacy. The arborescent branching forms are the most beautiful. Here we pass from examples where from a single stem a series of little lines run off, to others where the branching is again repeated, and yet again with such perfection that each individual crystal can be clearly made out. Other forms take the shape of a feather with a strongly defined central axis and with the fine threads branching from it on both sides at a slightly oblique angle ( $\phi \wedge \phi = 70^\circ 32'$ ). The central line is here normal to a plane  $111$ , while the branches go off in directions normal to  $1\bar{1}1$  and  $11\bar{1}$  respectively; in all cases we have to do with parallel grouping only, and there is no necessity to appeal to twinning to explain the forms observed. The only distinct examples of this method of growth in gold, which the author has been able to observe, are these from the Oregon mine, with the exception of a single Hungarian specimen in the cabinet of Mr. Clarence S. Bement of Philadelphia, which appears to be developed in a similar manner.

## 2. Gold from California.

The gold mines of California have produced large numbers of specimens of finely crystallized gold, but unfortunately it is only rarely that they have been preserved. But little has been published upon the subject; a recent article somewhat popular in character, by W. P. Blake\* of New Haven, is deserving of mention. The specimen to which the writer's attention was first directed belongs to the Yale collection, and is labeled as having come from Tuolumne County. It consists of a series of octahedrons in parallel position, and passing from the small solid crystals to larger ones with cavernous faces and their edges in ridges, and then to others looking as if they had been made of bent wire. In addition to the large octahedral faces ( $o$ ), there

\* The various forms in which gold occurs in nature, 25 pp.; from the Report of the Director of the U. S. Mint for 1884.

are also prominent those of the trisoctahedron 3-3 (*m*), usually strongly striated; a hexoctahedron, one set of whose edges are apparently truncated by the trisoctahedron and traces of a second hexoctahedron. The determination of this first mentioned hexoctahedron, as will be seen, requires exact measurements, and on all the larger crystals the planes are not bright enough to be used on the goniometer. A single very small crystal ( $\frac{1}{8}$  mm across) was found, however, on which these faces were brilliant though excessively minute. On this the three angles of the hexoctahedron were measured (with the usual compound goniometer), as also the inclination of a face upon the adjacent octahedral and trisoctahedral faces. Two independent measurements for different faces were obtained in each case. These measurements are liable to an error of from 5' to 10' in consequence of the want of sharpness of the images obtained, but they are accurate enough to prove beyond all question that the true symbol is  $18\cdot\frac{1}{2}$  ( $18\cdot10\cdot1$ ). This will be seen from the following comparison of measured and calculated angles:

	Edge A. 18·10·1 $\wedge$ 18·1·10	Edge B. 18·1·10 $\wedge$ 18·1·10	Edge C. 18·10·1 $\wedge$ 10·18·1
Meas. ....	35° 50', 36° 9'	5° 43', 5° 41'	31° 53', 32° 1'
Calc. ....	35° 58'	5° 34'	31° 51'

	<i>x o</i> 18·10·1 $\wedge$ 111	<i>x m</i> 18·10·1 $\wedge$ 311
Meas. ....	35° 44', 35° 45'	18° 2', 18° 10'
Calc. ....	35° 41'	18° 4½'

It will be seen that the agreement between measured and calculated angles is remarkably close, considering the nature of the faces. The goniometer also showed, independently of the calculations, that the trisoctahedral planes do not actually truncate the edges of the hexoctahedron, although the planes 18·10·1, 311, 10·18·1 do fall very nearly in a zone.

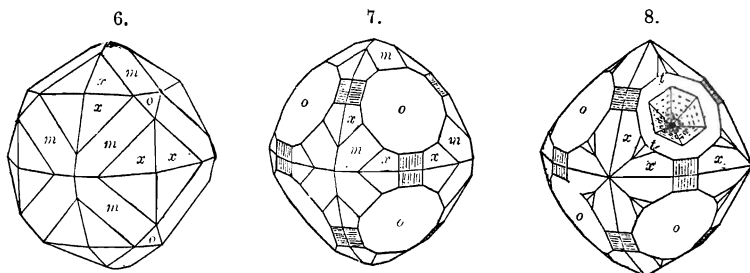
The positive determination of the form is of some interest, both because it is so common in the California crystals, as will be noted later, and because it was observed by Rose\* on specimens from the Ural many years ago. In his paper, already referred to, he remarks upon the occurrence of a hexoctahedron in conjunction with the dodecahedron, octahedron, trisoctahedron 3-3 and the hexoctahedron 4-2; he gives several figures, one of which has been copied in Dana's Mineralogy (f. 53, p. 3). The crystals examined by Rose\* afforded only rough measurements, and to the symbol obtained  $19\cdot\frac{1}{4}$  ( $19\cdot11\cdot1$ ) he consequently did not attach very great importance.

\*Rose uses the letters *t* for this hexoctahedron and *n* for 4-2; the writer, following Miller, restricts the letter *m* to 3-3, *t* to 4-2, and uses *x* for the hexoctahedron  $18\cdot\frac{1}{2}$ .

It was suggested by Naumann,\* that  $15\frac{5}{8}$  ( $15\cdot9\cdot1$ ) was a more probable symbol, since it satisfied the measured angles about as well as the other, and at the same time was a form whose edges (A) were truncated by the common trisoctahedron 3-8 (311). This suggestion Rose was inclined to accept, and later writers have followed him (e. g. Klein).† A comparison between Rose's angles and those required by the form  $18\frac{2}{3}$  ( $18\cdot10\cdot1$ ), positively determined on the California crystals, leaves no doubt that the latter symbol should also be given to Rose's plane since it satisfies the measured angles as well or better than either of the others suggested.

	Calculated.			Measured.
	Edge B.			Rose.
For $19\frac{11}{11}$	$15\frac{5}{8}$	$18\frac{2}{3}$		
$5^{\circ} 13'$	$6^{\circ} 33'$	$5^{\circ} 34'$		$5^{\circ} 10$ to $5^{\circ} 41'$
Inclination on $o$ (111)				
$35^{\circ} 28'$	$34^{\circ} 32'$	$35^{\circ} 41\frac{1}{2}$		$36^{\circ} 50'$ to $37^{\circ} 10'$
On $d$ (110)				
$15^{\circ} 9'$	$14^{\circ} 24'$	$16^{\circ} 11'$		$15^{\circ} 30'$ to $15^{\circ} 50'$

This is an interesting example of a case in which the so-called zonal law, so often employed to decide a doubtful symbol



does not hold good. Figure 6 shows one form of the crystals now being described; another is given in figure 7 which also exhibits an additional point of interest. The octahedral edge is here, in some cases, apparently truncated by the dodecahedral plane, in others beveled by a pair of planes; closer inspection, however, shows that this edge is formed simply by an oscillatory combination of the adjacent planes of the hexoctahedron. In other crystals of more octahedral habit the edges are all thus finely striated. The faces of the trisoctahedron  $m$  are also, though not always, striated in a similar manner, and sometimes the place of the plane seems to be taken by this oscillatory combination of the hexoctahedral planes.

This hexoctahedron  $x$ ,  $18\frac{2}{3}$ , appears to be a common form

\* Pogg. Ann., xxiv, 385.

† Jahrb. Min., 1872, 129.

in the California gold. A beautiful specimen in the cabinet of Professor Brush from the Spanish Dry Diggings in El Dorado county shows it very plainly. This specimen consists of large crystalline plates bound together by a little quartz; the plates are in part solid with triangular markings on the surface, or hexagonal depressions made by the planes of this hexoctahedron, and in part consist of open work formed of delicate crystalline ribs branching at angles of  $60^\circ$  and  $120^\circ$ . These plates are essentially flattened octahedrons, and their edges are all formed by an oscillatory combination of the hexoctahedral planes, producing a fine striation similar to that on the specimen before described. Occasionally the edge is beaded with distinct crystals, and in cavities other crystals are to be seen, the small ones entire, or at most, with hexagonal pittings (figure 8), the larger ones, skeleton forms, as if formed of gold wire. Measurement proved the hexoctahedron to be the same as that already determined, while a second hexoctahedron  $t$ , 4-2 (421) is sometimes sufficiently developed to admit of determination.

The writer has recently had an opportunity to examine the fine series of crystallized gold in the cabinet of Mr. C. S. Bement of Philadelphia, and has observed a number of specimens showing the hexoctahedron  $18\frac{2}{3}$  and very similar in habit to those described. Two of these specimens were from El Dorado county; another from Tuolumne county was octahedral in habit with the edges replaced in the manner described by the oscillations of  $x$ ; still another from Yreka county showed several thin triangular plates with the striations on the edges, and with also hexagonal pittings formed by the planes of the same hexoctahedron. In the article by Prof. Blake, already alluded to, a description is given with figures of octahedral gold crystals, similar in form to those here mentioned. These crystals were from the Princeton mine in Mariposa county, and they agree so closely in form and habit with those here figured as to leave no doubt that the planes, if determined by measurement, would be found to have the same symbols.