

*Mineralogical notes on Western Australian Tellurides:
the non-existence of 'Kalgoorlite' and 'Coolgardite'
as mineral species.*

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SINCE the occurrence of tellurides of gold in Western Australia was first recognized by Mr. Arthur G. Holroyd¹ in May, 1896, these minerals have proved to be of the greatest importance as a source of gold; and in fact the telluride mines at Kalgoorlie in the East Coolgardie gold-field now yield as much gold as all the remaining gold-fields of Western Australia taken together.

Although the occurrence of traces of telluride of gold has been reported from one or two other localities in the neighbouring portions of Western Australia, it is only in a quite small area around Kalgoorlie that the tellurides are mined. Here they occur as lodes, or rather as large lenticular masses and as impregnations, in schistose rocks. It is only, however, below a certain depth that the tellurides are found; nearer the surface, where the rocks have been weathered and altered, these minerals have been decomposed with the separation of native gold.

The tellurides occur in irregularly bounded crystalline masses, and unfortunately appear never to have been found as crystals with plane surfaces. The discovery of such crystals would be full of interest from a scientific point of view, and would afford a solution of many problems, which must, for the present, be left undecided. With the occurrence of such large crystalline masses of tellurides there can be little doubt but that one day crystals will be found; and these will probably surpass those hitherto obtained from other parts of the world. Cavities in the ore appear to be only rarely present, and when these are met with they should be searched for crystals.

¹ For references to original papers see p. 289 below.

In the present paper are given the results of a purely mineralogical examination of the specimens of Western Australian tellurides preserved in the mineral collection of the British Museum. In this collection there are 129 samples of gold-ores and auriferous specimens from Western Australia, of which sixty-five came from Kalgoorlie; tellurides¹ are present on forty-eight of the Kalgoorlie specimens, which have been acquired at various times since 1897. I have also had opportunities of inspecting many other specimens of Western Australian tellurides at the London offices of some of the gold-mining companies and at the Colonial Exhibition in London in 1902, but have seen nothing essentially different from the British Museum specimens to be described below.

The whole of this rich material, with the exception of only two specimens, has been presented to the Trustees by the several gold-mining companies, by the Government of Western Australia, through the Royal Commission appointed for the exhibition of the products of that State, and by various private individuals. Many of the specimens thus made available for examination by the generosity of the various donors are of considerable intrinsic value. A large proportion of this material had been specially collected by Mr. A. G. Holroyd, the Mineral Curator of the exhibits, for the Paris Exhibition of 1900; previous to this it had been shown at the Coolgardie Exhibition of 1899, and subsequently at the Glasgow Exhibition of 1901, and at a small Colonial Exhibition at the Royal Exchange in London in 1902. At the close of the last exhibition an immense amount of valuable material, including numerous large, showy masses of native gold and gold telluride, was sent by the owners to be converted into bullion. In 1900, Mr. L. Fletcher, F.R.S., Keeper of Minerals in the British Museum, after inspecting the mineral specimens at the Paris Exhibition, called the attention of Mr. Holroyd and of the exhibiting companies to the importance to science of the permanent preservation of specimens illustrative of the modes of occurrence of gold in Western Australia, and as a result was promised, for the British Museum, the gift of various specimens as soon as they should be no longer required by the companies for the purpose of exhibition. In 1902, during the last days of the Colonial Exhibition in London, Mr. Fletcher personally interviewed the

¹ Besides the Kalgoorlie tellurides, there are specimens of tetradymite (bismuth telluride) with native gold in white quartz from the Dunallan No. 1 gold-mine near Coolgardie in the Coolgardie gold-field, which were presented to the Museum by Mr. A. O. Watkins in 1895.

Hon. H. W. Venn, President of the above-mentioned Royal Commission, and the Hon. H. B. Lefroy, Agent-General for Western Australia and formerly Minister of Mines, and enlisted the active sympathy of both; a large series of specimens, enthusiastically selected by Mr. Holroyd, who was familiar with their peculiarities, was thus saved from destruction, and was presented by the owners to the Trustees of the British Museum.

Calaverite. This is the most abundant and the richest in gold of all the tellurides, and was also the first to be discovered at Kalgoorlie. It is easily recognizable by its pale bronze-yellow colour with bright metallic lustre, and its sub-conchoidal fracture with absence of cleavage. It somewhat resembles iron-pyrites in appearance, and in fact some of the material found by Mr. Holroyd in 1896 had actually been thrown away as such on the waste-heaps.

The mineral occurs sometimes in masses of considerable size, as is shown by a very large specimen (No. 86066) in the British Museum. This mass, from the Associated Gold Mines of Western Australia, is said to be the largest that has been raised. With the matrix of greenish schist it weighs 180 pounds, and over the whole of one surface, measuring about 63×18 cm. (25×7 inches), there is a thick deposit of various tellurides; the calaverite, however, predominates in amount, being in one place continuous over an area of 40×15 cm.

When calaverite is heated on charcoal in the oxidizing flame of the blowpipe, the tellurium it contains is readily oxidized, giving rise to dense white fumes and imparting a bright bluish-green colour to the flame, a bead of gold being left behind. When heated in a bulb-tube, calaverite gives a black sublimate of metallic tellurium, and a less volatile sublimate of drops of tellurous oxide (TeO_2), which is yellow when hot and white or colourless when cold; a yellow malleable bead of gold is not obtained in this way. During the cooling of the beads so obtained, either on charcoal or in the bulb-tube, the interesting phenomenon of *recalescence* was sometimes observed—after a red-hot bead had become dark it suddenly and momentarily again flashed out red and glowing. This behaviour, which was also exhibited by beads obtained from sylvanite, appeared to depend on the presence of a small amount of tellurium still remaining in the bead.

Several chemical analyses have been made of the calaverite from Kalgoorlie, and these, for convenience of reference and comparison, are collected together below. The calculated percentage composition corresponding to the formula AuTe_2 is given at the head of the list.

Analyses of Calaverite from Kalgoorlie.

Analyst.	Te.	Au.	Ag.		Total.	Sp. gr.
AuTe ₂	56.3	43.7	—		100.0	—
Holroyd (1897) . . .	55	44	trace		99	—
” . . .	54	39.2	3		96.2	—
Mingaye (Pittman, 1897)	56.65	41.76	0.80		99.21	9.377
Simpson (1898) . . .	57.27	41.37	0.58		99.22	9.311
Rogers (quoted by Simpson, 1898) . . .	59.69	38.70	1.66	{ Cu, 0.21; Fe, 0.18; } S, 0.09; Pb, Bi, Zn. traces.	100.53	—
Klüss (Krusch, 1901) . . .	58.63	37.54	2.06	{ Cu, 0.29; Fe, 0.09; } Ni, 0.07; Se, 1.13; S, 0.10; gangue, 0.23. }	100.14	—
Carnot (1901) . . .	60.30	33.90	4.82	Cu, 0.63; Fe, trace .	99.65	—
McGeorge (quoted by Simpson, 1902) . . .	54.1	42.6	0.7	Arsenopyrite, 2.4 .	99.8	—
MacIvor (1902) . . .	57.00	42.15	0.60		99.75	9.314

Sylvanite. This is of much less frequent occurrence at Kalgoorlie than the other tellurides containing gold. It is recognizable by its silver-white colour with brilliant metallic lustre and its perfect cleavage in one direction. It occurs in masses of some size, much larger than those from Transylvania and Colorado; thus one of the British Museum specimens shows the perfect cleavage uniform in direction through a mass 8 cm. in length, and another mass measures 4½ cm. in a direction perpendicular to the cleavage. These large crystalline individuals show no plane crystal-faces, but sometimes, on their rough, striated exterior, there are unmistakable indications of twinning about a plane perpendicular to the direction of cleavage.

It is, however, to be noted that the silver-white colour and the single perfect cleavage are characters possessed by krennerite as well as by sylvanite. Both minerals are further referable to the same type of chemical formula, namely (Au,Ag)Te₂; but while sylvanite appears to be fairly constant in composition, approximating to the formula AuAgTe₄, krennerite on the other hand varies considerably, the amount of silver, for example, having been given at 0.46, 5.87, and 19.44 per cent. in different analyses of material from Transylvania and Colorado. It would thus be only possible to distinguish with certainty between these two species when crystals are available for the determination of their symmetry, sylvanite being monoclinic and krennerite orthorhombic.

The silver-white, cleavable gold and silver telluride of Kalgoorlie may thus be either sylvanite or krennerite, or possibly both. Under the circumstances it appears best, for the present, to refer to it as sylvanite, since krennerite has as yet been found only in minute crystals which are not twinned. Again, the krennerite of Transylvania and Colorado is described as decrepitating violently when heated before the blowpipe: none of the Western Australian material in the British Museum behaves in this way, but fuses readily and quietly.

Attention may be called here to a statement by Mr. E. S. Simpson (1898, p. 48): he mentions 'small rhombic crystals with deep vertical striations of a telluride of gold, perhaps Krennerite,' as being associated with calaverite, coloradoite, and native gold on a specimen from the Kalgurli mine. This observation, if correct, is of some importance, but no mention of it is made by Mr. Simpson (1902) in his collected notes on Kalgoorlie tellurides: moreover, cleavable telluride is also referred by him to calaverite and goldschmidtite¹.

Of the analyses quoted below, three approach the formula AuAgTe_4 , while the first, in containing much less silver, is quite distinct: for this reason the material analysed by Dr. Frenzel has been referred by Professor Hintze² to krennerite.

Analyses of Sylvanite (and Krennerite?) from Kalgoorlie.

Analyst.	Te.	Au.	Ag.		Total.	Sp. gr.
AuAgTe_4	62.5	24.2	13.3		100.0	—
Frenzel (1897)	58.63	36.60	3.82		99.05	8.14
Wölbling (Krusch, 1901)	60.83	28.55	9.76	$\left\{ \begin{array}{l} \text{Cu, 0.32; Fe, 0.06;} \\ \text{Ni, 0.10; Se,} \\ \text{0.20; S, 0.09;} \\ \text{gangue, 0.05.} \end{array} \right\}$	99.96	—
Carnot (1901) Higgin (quoted by Simpson, 1902)	60.45 54.50	29.85 36.95	9.18 8.30		$\left\{ \begin{array}{l} \text{Cu, 0.15; Ni, 0.10} \end{array} \right\}$	99.73 99.75

Petzite. This is readily distinguished from the other gold and silver tellurides by its iron-black colour with metallic lustre and the marked conchoidal fracture with absence of cleavage. It is, however, absolutely indistinguishable in appearance from the mercury telluride, coloradoite;

¹ Goldschmidtite was described in 1899 as a gold and silver telluride from Colorado, but was proved the following year to be identical with sylvanite.

² Handbuch der Mineralogie, 1901, vol. i, p. 898.

and it also resembles more or less closely another Kalgoorlie mineral to be mentioned below, namely, fahlerz.

When heated on charcoal in the oxidizing flame of the blowpipe, petzite produces only slightly the bluish-green colouration of the flame and the dense white fumes characteristic of tellurium; only when fused with sodium carbonate does it give a white malleable bead, and this when placed in nitric acid becomes yellow. Calaverite and sylvanite, on the other hand, are much less stable, and are readily converted into a bead of gold by simply heating on charcoal in the oxidizing flame; this, however, takes place much more readily with calaverite than with sylvanite, since the latter contains more silver in combination with the tellurium.

The analyses quoted below agree closely, like the analyses of petzite from other localities, with the formula $(Ag,Au)_2Te$, in which $Ag : Au = 3 : 1$; the formula may therefore be written as $3Ag_2Te \cdot Au_2Te$ or Ag_3AuTe_2 .

Analyses of Petzite from Kalgoorlie.

Analyst.	Te.	Au.	Ag.		Total.
Ag_3AuTe_2	32.8	25.4	41.8		100.0
Wülbling (Krusch, 1901)	32.60	24.33	40.70	{ Cu, 0.10; Fe, 0.07; Ni, 0.08; Se, 1.45; S, 0.26; gangue, 0.12. }	99.71
Carnot (1901)	31.58	23.58	43.31	{ Hg, 0.88; Cu, 0.20; Fe, trace; Sb, 0.30. }	99.85
"	32.33	24.16	41.22	Hg, 2.00; Cu, 0.10	99.81
"	33.00	23.42	41.37	Hg, 2.26; Cu, 0.16	100.21
Grace (quoted by Rickard, 1901)	34.60	24.64	40.47	Hg, 0.29	100.00
"	34.83	24.62	40.55		100.00

The mercury shown in these analyses, especially in two by Professor Carnot, is no doubt due to the presence of coloradoite as an impurity (cf. p. 284).

Two other analyses, not quoted above, of gold and silver telluride from Kalgoorlie are given by Dr. Krusch¹ and by Professor Carnot². The formulae corresponding to these analyses may be split up as follows:—

$$(1) (Ag,Au)_5Te_3 = 2\frac{1}{3}(Ag,Au)_2Te + \frac{1}{3}(Au,Ag)Te_2,$$

$$(2) (Ag,Au)_4Te_3 = 1\frac{2}{3}(Ag,Au)_2Te + \frac{2}{3}(Au,Ag)Te_2,$$

	Te.	Au.	Ag.	Hg.	Cu.	Fe.	Ni.	Zn.	Sb.	S. Gangue.	Total.	
¹	36.90	15.06	45.95	—	1.16	0.08	0.06	0.04	0.12	0.45	0.22	100.04
²	41.11	26.10	30.43	0.70	0.60	0.40	—	—	0.80	—	—	100.14

suggesting that the substances analysed were probably mixtures of petzite and calaverite. It should be noted, however, that the percentage of silver given by Dr. Krusch is higher than in any of the petzite analyses quoted above, and this may indicate the presence of hessite (see p. 282). Professor Carnot himself suggests that the material he analysed was a mixture.

All these analyses of Western Australian tellurides have of necessity been made on massive material, and in no case does it appear that special precautions were taken to collect pure material all of one kind. Accurate analyses of carefully selected and measured crystals are desirable.

It seems probable that in these tellurides the gold and silver do not isomorphously replace each other, as is usually considered to be the case, but that they are present in atomic proportions, as indicated in the formulae adopted above. These formulae may represent double tellurides or possibly simple salts (perhaps tellur-aurates, analogous to sulph-antimonites).

Coloradoite. This telluride of mercury, with its iron-black colour and well-marked conchoidal fracture, is identical in appearance with petzite, from which it can only be distinguished by chemical tests. In fact, it has no doubt previously been mistaken for petzite, and, as will be shown below, a mixture of coloradoite and petzite has been described as a supposed new mineral species under the name 'kalgoorlite.'

Only two of the several authors (Rickard and Simpson) writing on Western Australian tellurides have mentioned coloradoite as being present on the specimens examined by them; and it has been considered to be of rare occurrence. In reality, however, it is comparatively abundant, for of the forty-eight Western Australian telluride specimens in the British Museum, coloradoite is present on twenty-eight.

In the examination of these specimens ninety-nine fragments of coloradoite were separately determined. This can be done very readily and quickly by heating on charcoal before the blowpipe or in a bulb-tube; in each case the reactions are quite distinct from those of petzite (and of fahlerz, which also somewhat resembles coloradoite in appearance). On charcoal the mineral readily fuses and colours the flame bright bluish-green, emits dense white fumes, and in a very short time completely disappears. In the closed tube it fuses with spluttering to a black globule, and gives a sublimate of globules of mercury and a much less volatile sublimate of

drops of tellurous oxide, the latter being yellow when hot and white or colourless when cold; with a larger fragment of material a black sublimate of metallic tellurium is also obtained.

The only quantitative analysis made on Western Australian coloradoite is by Mr. E. S. Simpson (1899), who obtained the results quoted below. The same author had previously (1898) given the specific gravity of another sample of material as 9.21.

Hg.	Ag.	Au.	Te (by difference).
50.40	0.12	trace	[49.48].

These numbers give the formula Hg_2Te_3 , and not $HgTe$, the accepted formula for coloradoite deduced by Professor F. A. Genth for the Colorado mineral discovered by him in 1877. The material analysed by Professor Genth was, however, very impure, containing admixed quartz, gold, sylvanite, and native tellurium up to nearly 50 per cent.; but the heavier portions obtained by levigation contained more mercury and less tellurium, and approximated more closely to the formula $HgTe$. The Colorado material was therefore scarcely suitable for establishing the formula of the mineral, while on the other hand the formula proposed by Mr. Simpson is based only on a single mercury determination. It therefore seemed desirable to make a new analysis, especially as a large amount of pure material was available for this purpose.

The specimen (Brit. Mus. No. 85221) chosen from which to collect material for the present analysis was one on which no petzite or fahlerz had been detected. The only other telluride¹ observed is sylvanite, which shows a brilliant cleavage surface several centimetres across, and could not possibly have been confused with the coloradoite. The bright coloradoite shows excellent conchoidal fractures over comparatively large areas, in one case 2×2 cm., and in every way seems to be quite pure. The matrix of the specimen, which is from the Great Boulder Main Reef gold-mine at Kalgoorlie, is a green schist interbanded with white granular dolomite; quartz and iron-pyrites are also present.

Three separate lots of material were collected from the same part of this specimen. In detaching material it usually broke up into quite

¹ To be quite accurate, there was afterwards detected a small compact mass, which, from its appearance under the microscope and its behaviour before the blowpipe, probably consists of an intimate intermixture of petzite and sylvanite. This was the single case in which there was any doubt in the determinations. It is here of no moment, since it is quite separate from the coloradoite and could not possibly have been confused with this.

small fragments. Each of these fragments was examined under a lens on a sheet of white paper and in a good light, being turned about with a needle mounted in a handle. Each fragment on which the bright conchoidal fracture was interrupted was then separately picked up and again examined under a microscope, the one-inch objective of which is fitted with a lieberkuhn. Further, of the material so collected, twenty-one fragments were examined by heating on charcoal or in a bulb-tube to make certain that no petzite was present and that all was coloradoite.

The coloradoite so collected for analysis was of an iron-black colour with bright metallic lustre, and was quite opaque. It had an excellent conchoidal fracture with no indication of cleavage. The streak was black and shining. The mineral was rather brittle, but extremely friable. Hardness, $2\frac{1}{2}$. The specific gravity was determined with a 3 c.c. pycnometer on the three lots of material with the following results (reduced to water at 4°C.):—

Sp. gr.	Weight of material used.
8.074	2.0505 gram.
8.077	1.7032 „
8.062	1.2911 „
Mean 8.07	

This result differs considerably from previous determinations. Mr. Simpson gives for the Kalgoorlie coloradoite the value 9.21; and Professor Genth gives 8.627 for the Colorado mineral after allowing for the large amount of impurities present.

The following are the results of one complete, and one incomplete, analysis, together with the calculated percentage composition corresponding to the formula HgTe:—

	I.	II.	HgTe.
Hg	60.95	59.4	61.2
Te	39.38	35.8	38.8
	<u>100.33</u>		<u>100.0</u>

In analysis I, 1.2833 gram of powdered material was decomposed with nitric acid; the decomposition took place readily and completely, and after expelling nitric acid, the residue was completely soluble in water and hydrochloric acid; gold and silver were therefore absent. The sulphides, precipitated by hydrogen sulphide, were separated by digestion with hot, yellow ammonium sulphide, and the insoluble mercury sulphide dried at 100°C. (H₂S, 0.9074 gram). The tellurium

was precipitated in the metallic state from a boiling hydrochloric acid solution by ammonium bisulphite and dried at 100°C. (Te, 0.5054 gram).

These results are confirmed by another analysis previously made, in which more direct determinations were attempted. The behaviour of the mineral when heated in a bulb-tube suggested that, if heated in a combustion-tube in a current of air, metallic mercury and tellurium dioxide could be weighed separately. Under these conditions, however, the tellurium was not completely oxidized, and part of it volatilized with the mercury. The same also happened when the mineral was heated with sodium carbonate. The powdered material (anal. II, 2.1091 grams) was therefore mixed with a little potassium nitrate and an excess of sodium carbonate and heated in a combustion-tube, at the closed end of which sodium bicarbonate had been placed to expel the last traces of mercury. A globule of mercury (Hg, 1.2536 gram) was collected under water; as, however, some nitrous fumes were evolved, the mercury was slightly attacked in the cool part of the tube. The residue in the tube was dissolved in hydrochloric acid and the tellurium precipitated by ammonium bisulphite (Te, 0.7546 gram), but it was afterwards found that the precipitation was not quite complete.

These analyses conclusively prove that the formula of coloradoite is HgTe , and not Hg_2Te_3 , as suggested by Mr. Simpson. The formula HgTe is the one to be expected from the relation of coloradoite to metacinnabarite (HgS) and tiemannite (HgSe). These minerals, which resemble coloradoite in their black colour and absence of cleavage, have been found as tetrahedral-cubic crystals, and it is probable that crystals of coloradoite when met with will be found to have the same symmetry. As shown in the following table there is an anomaly, for which no explanation can be given, presented by the specific gravity of this group of isomorphous minerals, the specific gravity of coloradoite being less than that of tiemannite, instead of greater, as is to be expected.

	Formula.	Crystal-class.	Sp. gr.
Metacinnabarite.	HgS	Tetrahedral-cubic	7.81 (Penfield)
Tiemannite . .	HgSe	Ditto	8.19 "
Coloradoite . .	HgTe	Ditto ?	8.07 "

The determinations of Mr. E. S. Simpson, namely, the formula Hg_2Te_3 , and sp. gr. = 9.21 (which it must be remembered were not both determined on the same sample of material), led him to consider whether the mercury telluride of Kalgoorlie he examined was identical or not with

that of Colorado. Though of course it is possible that other mercury tellurides besides coloradoite (HgTe) may occur in nature, it will be best, for the present, to consider all the Kalgoorlie material to be coloradoite, as does Mr. Simpson himself.

Altaite. This mineral, the cubic lead telluride (PbTe), which has not hitherto been recorded from Western Australia, was found in small amount on three of the British Museum specimens, all from the Great Boulder Proprietary gold-mine. It is of a lead-grey colour, sometimes with a yellowish tarnish, and has three perfect cleavages at right angles to each other; measurements of the cleavage angles on the goniometer gave approximately 90° . In appearance it resembles galena, but qualitative chemical tests, both before the blowpipe and in the wet way, proved the presence of lead and tellurium and the absence of sulphur.

It may be useful to place on record, in the following table, the various tellurides which were found more closely associated together, i. e. on the same specimen, and the several mines from which they come. This table is, however, only complete so far as concerns specimens now preserved in the British Museum collection.

Of these forty-eight specimens, calaverite is present on twenty-nine, sylvanite on ten, petzite on fourteen, coloradoite on twenty-eight, and altaite on only three. More than one kind of telluride is shown by twenty-five of the specimens, and on eleven there are three kinds.

The minerals found in association with the tellurides on the British Museum specimens now remain to be briefly described.

Gold. Native gold is more abundant in the upper, oxidized portions of the lodes, having here resulted by the decomposition of the tellurides. This secondary gold is present in a finely divided state: when in loose, finely crystallized aggregates it is known as 'sponge-gold'; when dull and lustreless, with quite the appearance of yellow ochre, it is known as 'mustard-gold'; and when in bright films as 'paint-gold.' A large quantity, about 70 pounds, of specially fine and pure 'sponge-gold' was found in a single pocket in the Great Boulder Proprietary gold-mine; this consists of a cellular aggregate of minute crystals of gold, which, when examined under the microscope, appear to be cubo-octahedra.

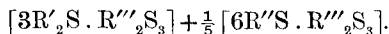
Films of secondary gold are also present on one or two of the telluride specimens; but most of the native gold which occurs actually intermixed with the tellurides appears to be of primary origin and to have been deposited at the same time as the tellurides themselves. This

Specimen No. (Brit. Mus.).	Gold-mine at Kalgoorlie, W. A.	Calaverite.	Sylvanite.	Petzite.	Coloradoite.	Other minerals present.	
83433	(Not stated) . . .	x			x	(Quartz, iron-pyrites, sericite, chlorite, and dolomite on most specimens.)	
83636 <i>a</i>	Lake View Consols . .	x					
83636 <i>b</i>	" " . . .	x					
83637	" " . . .		x				
83638	" " . . .	x					
83639	" " . . .	x					
83640	" " . . .	x	x		} Films of secondary gold.		
86002	" " . . .		x				
85932	Hannan's Block 45 . .	x					Calcite.
85217	Great Boulder Main Reef		x				
85218	" "		x			Fahlerz.	
85219	" "		x		x	Fahlerz.	
85220	" "		x	x			
85221	" "		x				
85980	" "	x			x		
85344	Great Boulder Proprietary	x			x		
85345	" "				x	Gold.	
85958	" "				x		
85959	" "	x			x		
85960	" "	x			x	Gold.	
85961	" "				x	Gold.	
85962	" "				x	Gold.	
85963	" "	x			x	Altaite.	
85964	" "	x					
85965	" "			x			
85967	" "			x	x		
85969	" "	x			x		
85970	" "	x			x		
85971	" "	x		x	x		
85972	" "	x		x		Altaite.	
85973	" "	x			x	Altaite.	
85974	Great Boulder Perseverance				x	{ Chalcopyrite. } Gold.	
85977	" "				x	Gold.	
85978	" "				x	Gold.	
85979	" "	x	x	x			
85981	Associated Gold Mines, W. A.	x			x	Gypsum.	
85983	" "		x		x		
86066	" "	x			x	Fahlerz.	
85984	Associated Northern Blocks				x	Gold.	
85985	" "	x				Gold.	
85991	Ivanhoe Gold Corporation	x				Chalcopyrite.	
85993	Golden Horse-Shoe Estates	x		x	x	Gold	
85994	Brown Hill Extended .	x			x		
85995	" "	x			x	Tourmaline.	
85996	Hannan's Brown Hill .			x		{ Tourmaline. } Brown-spar.	
86000	Hannan's Star . . .				x	Gold.	
86008	South Kalgurli . . .	x		x	x	Magnetite.	
86009	" " . . .	x		x	x	Fahlerz.	

primary gold is present in thicker and more lumpy masses than the finely divided secondary gold.

Fahlerz. This somewhat closely resembles the petzite and coloradoite in appearance; it has the same conchoidal fracture, but the iron-black colour is rather darker and often somewhat dull on the surface. The streak is black; H. = 4. Qualitative analysis showed the presence of copper, sulphur, and arsenic, with rather less antimony and a little iron and zinc. Small patches of the massive mineral were found on four of the telluride specimens.

This is without doubt the same mineral as the copper-ore noted by Dr. Krusch (1901, p. 202, footnote), for which he gives no name, but states that the composition is near that of enargite. From the analysis he gives, I have deduced the fahlerz formula¹—



This formula partly accounts for the excess of sulphur, which is, in any case, much less than that required by the enargite formula. The analysis shows the presence of 16.87 per cent. of arsenic and 4.30 per cent. of antimony, so that the mineral is nearer to tennantite than to tetrahedrite.

Magnetite. Three or four crystals, each measuring about a centimetre across, were found embedded in the tellurides on a single specimen from the Kalgurli mine. They are iron-black with a bright metallic lustre, and are strongly magnetic. The small faces present on one crystal were determined on the goniometer to be those of the octahedron and rhombic dodecahedron. The crystals are remarkable in possessing perfect parting-planes parallel to the faces of the octahedron. From the surfaces of parting are often to be seen deep-red flashes of reflected light; and when a piece of the mineral is crushed and examined under the microscope many fragments are seen to be blood-red by transmitted light and to be doubly refracting. The streak of the mineral is dark purplish-brown, but that of the portion of the powder attracted by a magnet is black. In these crystals there has therefore been a partial alteration along the parting-planes of the magnetite to hematite, and they really represent a stage in the formation of *martite*.

Calcite appears to be present on only one specimen, this being a portion of the original material from Hannan's Block 45, discovered by Mr. Holroyd in 1896. It has the character of a white crystalline limestone, in which the calaverite is embedded. *Dolomite*, on the other

¹ Compare this Magazine, 1899, vol. xii, p. 202.

hand, is present on most specimens; it usually forms grey, compact bands interfoliated in the greenish schist. On one specimen are cleavable masses of *brown-spar* (probably mesitite).

Tourmaline occurs as small black needles, 2 to 3 mm. in length, embedded in iron-pyrites and in the rock. It has a specific gravity of about 3.2, and the dichroic colours vary from quite black to nearly colourless. A very little *chalcopyrite* is enclosed in coloradoite on one specimen; on another it is represented by a mere speck in quartz. Veins of fibrous *gypsum* penetrate the altered rock of one specimen.

The matrix¹ of the telluride specimens is usually a pale greenish **sericite-schist** with a silvery reflection, and soft enough to be scratched by the finger-nail. Minute grains and crystals, usually cubes, of *iron-pyrites* are scattered throughout the whole rock. *Chlorite* is also often present, and the rock is then of a darker green colour, and may approach a chlorite-schist in character. Interfoliated with the schist are often bands of grey, granular dolomite, so that at times the rock has rather the character of a calc-schist. Patches of massive, colourless *quartz* and of finely granular iron-pyrites are sometimes present, especially in close association with the tellurides, though not in very large amounts. The tellurides are embedded in the schist as irregular masses of variable size, and often follow joint-planes oblique to the schistosity; the rock appears never to be finely impregnated with tellurides as it is with iron-pyrites.

A more detailed examination was made of the rock of the large specimen (No. 86066). A thin section, perpendicular to the schistosity, showed under the microscope much *sericite* and a considerable amount of quartz. The quartz is present as fairly large, irregular individuals, usually with a more or less marked undulose extinction, and also as patches of mosaic. Much iron-pyrites is present as small grains; only one speck of black telluride was to be seen. There are also many irregular patches of *ilmeneite*, which shows well-marked planes of parting and has been largely altered to 'leucoxene.' These small masses of ilmeneite give rise to a knotted appearance on the surfaces of foliation as seen in a hand-specimen of the schist. A chemical examination of the

¹ The matrix of the ore is often stated to be hornblende-schist. No hornblende was detected on any of the British Museum specimens; and in published analyses (Simpson, 1902) of these rocks the small amount of magnesia in the portion of the rock insoluble in hydrochloric acid indicates that not much, if any, hornblende can be present. Bands of hornblende-schist are no doubt sometimes present in the sericite-schist. Much confusion between observed fact and theory has been occasioned by the attempts of various authors to explain the origin of these schists.

rock showed the presence of silica, alumina, iron, alkalis (potash and soda), and a little lime; when heated in a bulb-tube it blackens and gives off scarcely any water. The ilmenite was proved to contain iron and titanium, and to be non-magnetic.

The altered rocks from the upper portions of the lodes are soft and clayey and yellow in colour, but they usually still retain their schistose character. Besides *limonite* and the finely divided secondary gold, few other minerals are found in these oxidized ores. On one specimen, from the Golden Horse-Shoe Estates, the 'sponge-gold' is accompanied by a few small colourless rhombohedra of dolomite, and a yellowish-green ochreous substance which is perhaps massicot (PbO)¹.

With the alteration of such large quantities of tellurides one would expect to find other secondary minerals together with the native gold, such, for example, as native silver (from the petzite) and oxygen compounds of tellurium (tellurite (TeO₂), emmonsite, durdenite, &c.), but none of these were detected² on the British Museum specimens. Mr. Simpson (1898, p. 46) suggests the occurrence of emmonsite (hydrated ferric tellurite), and Mr. Rickard (1901, p. 712) mentions the presence of tellurite of iron on a specimen from Kalgoorlie. Silver chloride is stated to have been found in considerable quantity near the surface in one of the mines (Pittman, 1898, p. 11).

Other minerals, which have been described as occurring with the Kalgoorlie tellurides, but which were not detected on the British Museum specimens, are native tellurium (Holroyd, 1897; MacIvor, 1900) and roscoelite (Pearce, 1897). Hessite (Schmeisser, 1897, p. 50; Krusch, 1901), amalgam (Pittman, 1898), and native mercury (Rickard, 1901, p. 715) have also been mentioned; and Simpson gives several other names in his lists of minerals, but without particulars.

'KALGOORLITE' AND 'COOLGARDITE.'

'Kalgoorlite' was described by Mr. E. F. Pittman in 1898 as a new mineral species with an iron-black colour and sub-conchoidal fracture, a specific gravity of 8.791, and a chemical composition expressed by the formula $\text{HgAu}_2\text{Ag}_6\text{Te}_6$. The analysis, by Mr. J. C. H. Mingaye, from which this formula was deduced, is quoted below. The material on

¹ A chemical examination showed the presence of much lead, with a little copper and water, and possibly some antimony.

² It is possible that some of the yellowish earthy material, taken to be limonite, may contain tellurium in the oxidized state, but none of this was examined chemically.

which the new name was based came from the Lake View and Boulder Junction gold-mine at Kalgoorlie. Recently Mr. E. S. Simpson (1902) states that in 'a sample from the Ivanhoe Mine' he found gold 19.4, silver 30.1 per cent.

'Coolgardite' was based by Professor Adolphe Carnot in 1901 on the results of three analyses, from which he deduced the formula $(\text{Au, Ag, Hg, Cu, Fe, Sb})_2\text{Te}_3$, or more simply $(\text{Au, Ag, Hg})_2\text{Te}_3$; the new mineral being defined as a sesquitelluride of gold, silver, and mercury. The material he examined was supplied for analysis by Mr. A. G. Holroyd from the Western Australian exhibits at the Paris Exhibition of 1900; it consisted of fragments, isolated from the matrix and contained in six tubes, all of which, with the exception of one tube of sylvanite, were labelled as being from the Great Boulder Proprietary gold-mine at Kalgoorlie. Professor Carnot remarks that the material contained in each tube was not always the same in appearance and colour, but adds that he took the precaution of separating the different kinds when the quantity of material available for analysis permitted. He further remarks that the material contained in each tube may have been taken from different specimens. In addition to 'coolgardite' he made analyses, quoted above, of sylvanite, calaverite, and petzite.

Two analyses (Nos. 1 and 2 in the following table) of 'coolgardite' were made on material belonging to the same lot. This is described as only exceptionally showing indications of cleavage, the fracture being almost always conchoidal: the colour of the different fragments was iron-grey, or yellowish-grey inclining to bronze; separate analyses were therefore made of two fragments. Another analysis (No. 3) was made on a sample of material described as yellowish-grey with a conchoidal fracture.

	Te.	Au.	Ag.	Hg.	Cu.			Total.
'Kalgoorlite'	[37.26]	20.72	30.98	10.86	0.05; S, 0.13.			100.00
'Coolgardite' (1)	56.55	23.15	16.65	3.10	0.10	trace	0.20	99.75
" (2)	53.70	27.75	13.60	3.70	0.25	trace	0.15	99.15
" (3)	51.13	37.06	4.71	3.70	0.88	0.90	1.20	99.53

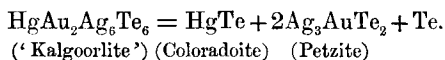
That 'kalgoorlite' is not a homogeneous mineral, but a mixture, has already been suggested by Mr. T. A. Rickard (1901, p. 715), who with reference to it remarks: 'As the crystallographic features [i. e. external characters] do not differ materially from coloradoite, it can hardly be considered as more than an impure variety of the latter, and may be looked

upon as a mixture of petzite and coloradoite.' Again, Professor Carnot applies the name 'kalgoorlite' to a 'mercurial petzite,' of which he gives three analyses (quoted above, under petzite); the 'kalgoorlite' of Carnot is, however, considerably different in composition from the 'kalgoorlite' of Pittman, and this adds support to Rickard's suggestion.

A fact that strikes one as being specially remarkable is that neither Mr. Pittman nor Professor Carnot, both of whom describe more than one kind of telluride, makes any mention of coloradoite. This telluride of mercury is, as noted above, of frequent occurrence at Kalgoorlie, and, furthermore, had been found there before the descriptions of 'kalgoorlite' and 'coolgardite' were published: it was recognized by Mr. T. A. Rickard in 1897, and in the same year a specimen showing calaverite and coloradoite was represented in the British Museum collection. This is a point of special importance, since it is impossible to distinguish between coloradoite and petzite by their appearance alone. It would be extremely difficult, if not impossible, to collect pure material for analysis from a mixture of these two minerals, even when it is known that both are present; and in case the presence of coloradoite was not suspected, and not tested for, it would of course be quite overlooked. It is therefore highly probable that the mercury shown in the analyses of 'kalgoorlite' and 'coolgardite' was due to the presence of coloradoite.

Even a study of the original papers themselves suggests that 'kalgoorlite' and 'coolgardite' cannot be distinct mineral species. A massive mineral, which in a single analysis gives, like 'kalgoorlite,' an unusual and complex formula, has, in most cases, little claim to rank as a distinct species, and absolutely none when its composition can be just as well, or even better, explained on the assumption that the material analysed was a mixture of known minerals. Mineralogical literature is unfortunately heavily burdened with numerous imperfectly and incompletely determined 'new species' of this kind.

The formula of 'kalgoorlite' may be split up as follows:—



The atomic ratio, 3:1, of silver to gold is exactly that given by all analyses of petzite. The excess of tellurium scarcely needs explanation, since this element was not determined directly in the analysis, but only by difference.

The wide variations in the three analyses of 'coolgardite' are in themselves enough to suggest that the material analysed was not homogeneous;

and this impression is amply supported by the brief description Professor Carnot gives of the external characters of his material. As pointed out above (p. 273), the material used in three other of Carnot's analyses was very probably not homogeneous, and in one case this is even admitted by Carnot himself. A point which is perhaps in favour of the existence of 'coolgardite' is the fact that the results obtained in three separate analyses can, on the assumption of isomorphous mixing, be all made to agree more or less closely with one general formula: the calculated¹ atomic ratios of (Au,Ag,Hg):Te are 1:1.551, 1:1.483, and 1:1.610 in the three analyses respectively.

The empirical formulae corresponding to Carnot's analyses are:—

- (1) $\text{HgAg}_{10}\text{Au}_{7.6}\text{Te}_{28.8}$.
- (2) $\text{HgAg}_{6.8}\text{Au}_{7.6}\text{Te}_{22.9}$.
- (3) $\text{HgAg}_{2.4}\text{Au}_{10.2}\text{Te}_{21.8}$.

These, by solving simultaneous equations, may be split up as follows:—

- (1) $\text{HgTe} + 1.23\text{Ag}_3\text{AuTe}_2 + 0.07\text{AuTe}_2 + 6.3\text{AuAgTe}_4$.
 - (2) $\text{HgTe} + 1.15\text{Ag}_3\text{AuTe}_2 + 3.1\text{AuTe}_2 + 3.35\text{AuAgTe}_4$.
 - (3) $\text{HgTe} + 0.73\text{Ag}_3\text{AuTe}_2 + 9.27\text{AuTe}_2 + 0.2\text{AuAgTe}_4$.
- (Coloradoite) (Petzite) (Calaverite) (Sylvanite)

The third analysis would thus appear to have been made on material consisting mainly of calaverite; and this is in agreement with Carnot's statement that the material was yellowish-grey with a conchoidal fracture. In the first two analyses more of the iron-black tellurides and more sylvanite would be present, and in No. 1 practically no calaverite; this, again, is in agreement with Carnot's statement of the external characters of the material, which he describes as varying in colour from iron-grey to yellowish-grey, and usually with a conchoidal fracture, but sometimes a cleavage. Although not stated by Carnot, it would appear that analysis No. 2 was made on a yellower fragment. The difference in colour is explained by Carnot as due to the difference in the relative proportions of gold and silver shown in the analyses, but this is scarcely likely to be the case. Of special importance is the fact that Carnot made no serious attempt to separate the black from the yellow, for, as he distinctly states in his paper, he simply took for each analysis

¹ The small amounts of antimony, copper, and iron, calculated by Carnot with the metals, are here neglected, as it seems doubtful whether the antimony should be taken with the tellurium or with the gold; it is not unlikely that they are impurities due to the presence of fahlerz. The atomic weights used here and elsewhere in the present paper are those recommended in 1901 by the Atomic-Weight Commission of the German Chemical Society.

(Nos. 1 and 2) only *one* piece of material. It would be extremely unlikely, under the circumstances, for such material to be pure and all of one kind.

I have been informed by Mr. F. T. Trouton, the assistant curator of the Western Australian exhibits at Paris, &c., that the material supplied to Professor Carnot for analysis consisted of fragments which had become detached from various specimens. It is thus not unlikely that some of Carnot's material was actually from specimens now in the British Museum. I have myself collected such a tube of fragments, which, owing to the extremely friable nature of the tellurides, have become detached during the transportation and handling of the specimens. From such a collection of fragments of all kinds and from several specimens it would not be at all easy to collect material suitable for analysis. The sylvanite, if coarsely crystallized, could no doubt be easily picked out, but not so easily calaverite from coloradoite and petzite; these are sometimes associated together in the same fragment, and it is only with difficulty that the actual junction of the calaverite with the iron-black mineral can be detected, while the coloradoite and petzite are absolutely indistinguishable.

Although I have had some experience in collecting pure material for analysis, I should be unwilling to deal with such a sample. On this occasion I have given (p. 276 above) more fully the method I adopt for collecting opaque minerals¹ for analysis. Whenever possible, however, only crystals are taken, and these are broken up and each fragment collected separately; and in cases where there can be any possible doubt as to the identity of the mineral, every crystal or crystal fragment is measured on the goniometer. All this of course takes time, and the collection of even less than a gram of material may mean several weeks' work, but it is the only way by which errors are to be avoided. Even with all care and precaution the material may be rendered impure by the presence of an unsuspected mineral, as was undoubtedly the case with coloradoite in 'kalgoorlite' and 'coolgardite.' An exactly similar case has occurred with the material collected by myself for analyses of stannite². On the results of these analyses, especially together with the remarkable development of the crystals, there could have been based a far more plausible 'new mineral' than either 'kalgoorlite' or 'coolgardite.' The analytical results could, however, be explained on

¹ e. g. andorite, argyrodite, fahlerz, pligionite, &c., described in the pages of this Magazine.

² This volume, p. 61.

the assumption that the material used was a mixture of stannite and andorite, and on again examining the part of the specimen from which the material had been collected, this was amply confirmed.

With the object of testing whether these doubts as to the existence of 'kalgoorlite' and 'coolgardite' have really any ground, I have made a detailed examination of all the British Museum specimens of Western Australian tellurides. Although I have not had an opportunity of examining the original material on which the names were based, yet, as noted above, a large amount of the available material came from the same source as did that examined by Professor Carnot, and, indeed, possibly from the same specimens.

Five specimens have at various times been received at the Museum labelled as 'kalgoorlite,' but on whose authority was not stated. On none of these was anything found which answered (except in external characters) to the description of 'kalgoorlite.' On two specimens the only telluride to be found was coloradoite; on another calaverite and coloradoite; on a fourth calaverite and petzite; while on one specimen calaverite, coloradoite, and petzite were all detected, but no other telluride.

The material was examined before the blowpipe in the manner described above. When any mercury was given off in the bulb-tube the mineral was in all cases completely decomposed with the formation of metallic mercury and tellurous oxide; while, when no mercury was given off in the tube, the same fragment afterwards gave a metallic bead on charcoal. Numerous fragments when first heated on the charcoal completely volatilized without leaving the slightest residue. All these fragments were therefore either mercury telluride or gold and silver telluride, and none could have contained all three metals as required by 'kalgoorlite' and 'coolgardite.' These tests, which are reliable and also quickly and readily performed, were made use of for the purpose of distinguishing between the iron-black minerals with conchoidal fracture, namely, coloradoite, petzite (and fahlerz), and also to detect if possible the presence of any 'kalgoorlite' and 'coolgardite.' The fragments tested were detached from the specimens by a needle, and each examined under a lens; only quite small fragments showing the conchoidal fracture uninterruptedly over the whole surface were selected.

In this way 133 fragments¹ of the iron-black tellurides taken from

¹ This includes twenty-one fragments examined to test the purity of the material collected for the qualitative analyses of coloradoite. Of the 112 fragments taken at haphazard, thirty-four were petzite and seventy-eight coloradoite; this gives an idea of the relative frequency of occurrence of these two tellurides.

different portions of thirty-five specimens were separately examined; of these, thirty-four were found to be petzite and the remainder coloradoite. In addition to these, about thirty fragments of calaverite and sylvanite were examined before the blowpipe. On the forty-eight specimens examined, more than one kind of telluride was found on twenty-five; calaverite and coloradoite were found together on seventeen, and petzite and coloradoite on seven (see table, p. 279).

Petzite and coloradoite being indistinguishable in external appearance, it is possible to take fragments in which both these tellurides are present, and which are to all appearance homogeneous; such fragments will of course be found to contain gold, silver, and mercury, and will thus answer perfectly to the description of 'kalgoorlite.' On these larger fragments, however, the conchoidal fracture was not continuous over the whole surface, indicating that the fragment consisted of more than one crystalline individual of the same kind of mineral, or even (as is actually the case) of different minerals. When, however, small fragments with a continuous conchoidal fracture were taken they were found in *every* case to be either coloradoite or petzite, containing either no gold or no mercury.

After this fairly exhaustive search for 'kalgoorlite,' one is perfectly justified in assuming that no such mineral exists, especially when the single analysis on which the name is based can be simply explained by the intermixture of the two minerals, petzite and coloradoite, which in external appearance are indistinguishable, and which have been shown to actually occur intimately associated together at Kalgoorlie.

While the cause of the error in the case of 'kalgoorlite' is readily explained, it is less easy to believe that such an error could have been committed in the case of 'coolgardite'; for there are marked differences in the external characters of the iron-black tellurides (petzite and coloradoite) and the light-coloured tellurides (calaverite and sylvanite), which must have been present in the mixtures analysed. Professor Carnot indeed notices these differences, but makes no mention of the possibility of the material being a mixture.

There appears to be little to support Professor Carnot's supposition that mercury is capable of isomorphously replacing gold and silver, beyond the fact that these metals, like so many others, crystallize in the cubic system. And it might be suggested that 'coolgardite' is a mixture of coloradoite and a hitherto unknown sesqu telluride of gold and silver, $(\text{Au,Ag})_2\text{Te}_3$, as given by Carnot's formula. The ratio $(\text{Au,Ag}) : \text{Te}$ is then 1 : 1.640, 1 : 1.586, and 1 : 1.739 in the three analyses respectively.

The excess over 1 : 1.5 could then be readily explained by the admixture of small amounts of the known tellurides, calaverite and sylvanite. This view receives some support from the fact that, on the assumption of a mixture of known tellurides as here adopted, there must have been four different tellurides present in the material used for analysis No. 2¹. On none of the British Museum specimens were more than three different kinds of tellurides found associated together, and it thus seems unlikely, but not impossible, that there should have been three or four kinds in a single fragment such as is stated by Carnot to have been used in two (Nos. 1 and 2) of his analyses. On the other hand, if several fragments from the miscellaneous sample had been used for analysis, as may have been the case in analysis No. 3, there is less objection to the assumption of a mixture of four different tellurides. Again, in the mixtures suggested above, the amount of sylvanite seems to be excessive; this, however, would be less if the calaverite were assumed to contain some silver, or if hessite be present (cf. pp. 274, 282). The probable existence of an intimate mixture of sylvanite and petzite has been noted above (foot of p. 275).

There thus appears, on the whole, to be no more evidence for the existence of a mineral having the composition $(\text{Au,Ag})_2\text{Te}_3$ than for minerals with the compositions $(\text{Au,Ag})_6\text{Te}_3$ and $(\text{Au,Ag})_4\text{Te}_3$ (see p. 273); and it seems best, for the present at least, to assume that in all these cases the material used for analysis consisted of mixtures of known tellurides.

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¹ The small amount of calaverite in No. 1 is negligible; and in No. 3 there would be no sylvanite if the calaverite contained even a little silver.

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