On the mode of occurrence of Gold.

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IN the present paper an attempt will be made to summarise known facts respecting the mode of occurrence of gold in its matrix, and to draw certain inferences from these facts as to the manner in which the gold has been deposited. The general opinion of miners that it has been introduced by igneous action, in a state of either fusion or volatilisation, does not agree with modern theories of the origin of metalliferous veins, which ascribe their existence to hydrothermal action, or at any rate suppose the metals to have been introduced in aqueous solution.

The deposition of the definite crystalline mineral gold alone will be dealt with, excluding the occurrence of gold more or less intimately combined with tellurides, sulphides, etc.: or, to use the gold miner's expression, " free reef-gold " will alone be considered.

A study of the paragenesis of gold seems to be the best method of approaching the subject. The following table accordingly gives as complete a list as possible of all minerals known to the author as ever occurring with gold in the same deposit, although it cannot be supposed that their deposition was in all cases contemporaneous with that of the gold. The author wishes to acknowledge with thanks the valuable assistance received from Mr. H. A. Miers in compiling this list. All those minerals which may be looked upon as common in auriferous deposits are distinguished by full type.

LIST OF MINERALS.

I.—Non-metallic Minerals.

Minerals.	Localities.
Quartz	
Clays	
Chlorite	

Mica	
Serpentine	Russia
Orthoclase	Colorado
Garnet (Grossularia, Siam)	
Calcite	
Dolomite	California, Transylvania
Magnesite	Australia
Aragonite	New Zealand
Apatite	Ottawa
Fluorite	
Selenite	
Tourmaline	
Hornblende	
Prehnite	Craddock, Cape Colony
Pyrophyllite	Beresovsk
Sulphur	,,
Barytes	
Lignite	Transylvania

II.—METALLIC MINERALS.

MINERALS.	LOCALITIES.
Iron Pyrites	
Mispickel	
Löllingite	Idaho
Copper Pyrites	
Erubescite	Beresovsk
Covelline	
Redruthite	
Stibnite	
Galena	
Zinc Blende	
Cinnabar	
Bournonite	
Tetrahedrite	California
Pyrargyrite	
Molybdenite	
Tetradymite	Hungary
Argentite	Siberia
Aikenite	
Stromeyerite	Siberia

Clausthalite	Harz
Hessite	Transylvania
Melonite	California
Ilmenite	
Magnetite	
Hæmatite	
Limonite	
Siderite	
Vivianite	Victoria
Manganese Blende	Transylvania
Rhodochrosite	,,
Bustamite	Mexico
Pyrolusite	
Wad (?)	
Chrysocolla	Namaqualand
Malachite	Beresovsk, etc.
Azurite	,,
Wolfram	Victoria
Scheelite	Italy, Bohemia
Pyromorphite	Wales
Mimetite	Nevada
Crocoisite	Beresovsk
Melanochroite	,,
Vauquelinite	,,
Vanadinite	,,
Cerussite	,,
Anglesite	,,
Cervantite	Victoria
Valentinite	,,
Kermesite	,,
Scorodite	Beresovsk
Jarosite	,,
Bismutite	Pilgrim's Rest, Transvaal
Lead	Victoria
Bismuth	
Arsenic	
Silver	Mexico

The above list comprises no less than 77 species, and even then it is possible that a few of the rarer occurrences have been overlooked. Only about 12 of these can be designated as plentiful in auriferous veins, the others being for the most part very rare. Many are secondary products arising from the decomposition of other, perhaps common, species; their presence is thus only due to the previous existence in the auriferous matrix of some of the common minerals which can alone, therefore, be looked upon as the original constituents of the vein matter.

Looked upon as a whole, this list strongly supports the hydrothermal, as opposed to the igneous, theory of the origin of gold, as it does not contain a single mineral the introduction of which could not fairly be ascribed to hydrothermal action, whilst all that series of minerals which are characteristic of volcanic rocks is conspicuously absent.

Turning first to the non-metallic minerals, of which there are 21 species, only four of them, namely, quartz, clay, chlorite and calcite, can be set down as occurring at all commonly as constituents of auriferous veins.

Quartz is of course the usual, it may almost be said the universal, gangue of auriferous veins; the author does not remember ever to have come across any reef gold that was not accompanied by more or less quartz, and in by far the larger number of instances quartz may be looked upon as the sole veinstuff. Auriferous quartz veins may be of any type of vein: fissure, segregated or intercalated; there is of course no difficulty in accounting for the fact that the filling of these veins should consist of quartz, but the association of gold with it is too invariable to be accidental; and it seems reasonable to suppose *a priori* that the solvent which carried the quartz into the vein carried also the gold in solution at the same time.

Of all the other non-metallic minerals it may be said that they occur rather as secondary minerals filling up crevices than as integral parts of the vein.

Orthoclase, however, does occur as a true ingredient of the veinstuff in some parts of Colorado; although it is an important ingredient of many rocks which have an igneous origin, yet there are many instances of the occurrence of this mineral in veins, into which it has obviously been introduced in aqueous solution.

Calcite is usually a secondary mineral constituent, being often deposited upon the primary vein ingredients, as is well exemplified, for instance, in some of the Nova Scotian gold reefs, where it is found in the cavities of the reefs beautifully crystallised upon quartz, gold, arsenical pyrites and other minerals that constitute the veinstuff proper. It forms, however, at times an integral portion of the matrix, as, for instance, in the curious occurrences at Kabin, Siam, where the gangue consists of an intimate mixture of calcite, quartz, common garnet and grossularia, forming apparently lenticular gash veins.

Clay, of course, is a universal concomitant of all veins, especially in schists, slates or shales, either as a " gouge " on the walls of the veins, or else filling up crevices in their body; its presence needs no explanation, and, as it has evidently been introduced subsequently to the formation of the vein, its occurrence is of no importance in the present connection.

Chlorite is plentiful in many gold-quartz veins; as a notable example may be cited the well known fissure veins at Moodies, near Barberton, Transvaal, where the veinstuff consists largely of quartz veins coloured bright green by disseminated chlorite, the country rock being a much metamorphosed, highly chloritic schist.

Prehnite occurs with gold at Craddock, Cape Colony, and nowhere else as far as known. The author has not visited the locality, so unfortunately can say nothing of the nature of the deposit; he has, however, in his possession specimens from it, showing prehnite in well developed crystals.

Tourmaline is a frequent constituent of auriferous veins, but it is often noticeable that such portions of the vein as are richest in this mineral are poorest in gold, and *vice versâ*. Mica is rare, and mostly occurs in gold veins traversing granite.

None of the remaining non-metallic minerals call for any especial notice; they are either salts of the alkaline earths, whose presence is easily intelligible as secondary products introduced into the vein in solution, either contemporaneously with, or subsequently to the deposition of the quartzose veinstuff, or else they are silicates, such as would naturally be expected to occur in veins traversing highly metamorphosed schistose strata, this being the usual condition under which gold-quartz occurs.

Sulphur is a very rare mineral in gold veins, being a secondary product, no doubt resulting from the decomposition of pyrites.

It may be said of all these non-metallic minerals, excepting quartz, that the most curious feature about their occurrence is not so much their presence in these veins, as rather their great rarity, especially when compared with their frequency in other metalliferous veins. Why, for instance, should fluorite be plentiful in lead and copper bearing veins, and scarcely ever occur in auriferous ones ?

As regards, in the next place, the metallic minerals, a few are plentiful in all gold districts; others, again, are secondary products derived from, or arising out of the decomposition of the former. Thus hæmatite, limonite, siderite and vivianite are oxidation products of iron pyrites, pseudomorphs after which latter mineral are by no means rare. Cervantite, valentinite and kermesite are oxidation products of stibnite, which occurs in some of the Victorian gold fields, whilst a whole series of lead minerals have been produced by the decomposition of galena. Other minerals, again, are practically confined to one special district, and no doubt owe their existence in the auriferous veins to purely local causes, the reasons for which can but rarely be traced. Such, for instance, are those comprised in the series of lead chromates and other lead compounds found in the gold veins of Beresovsk.

The following are really the only metallic minerals that can be looked upon as ordinary constituents of auriferous quartz veins:—

Iron Pyrites
Galena
Copper Pyrites
Titaniferous Iron Ore
Arsenical Pyrites
Zinc Blende
Stibnite
Magnetite.

The two oxides of iron may possibly be oxidation products of the pyrites; but from the fact that they are plentiful in veins that carry but little pyrites, that they occur as well in depth as near the surface, and that they are thoroughly disseminated through and intimately commingled with the quartz of the vein, they must rather be regarded as true original constituents of the reef matter, derived in all probability directly from the metamorphosed country rocks.

Iron pyrites is an almost universal constituent of gold quartz veins. It is worthy of note that whilst cubical iron pyrites is thus very abundant, marcasite never seems to occur in a gold reef. The author has never seen any indications of its existence, not even pseudomorphs after it, which latter might reasonably be expected to occur, even if the readily decomposable mineral itself had been destroyed, seeing how abundant pseudomorphs after cubical pyrites are. It is not known under what conditions bisulphide of iron crystallises as marcasite, rather than as cubical pyrites, but whatever these may be, it is pretty clear that they are either unfavourable to the deposition of gold, or else that the solutions from which marcasite crystallises are incapable of dissolving gold. There do not even seem to be any authentic records of the occurrence of auriferous marcasite.

Seeing, then, that quartz containing magnetite and ilmenite, together with the few sulphides named above, form the regular matrix accompanying native reef-gold, it remains to be seen whether any consistent theory can be framed to account for this paragenesis. Although there are serious difficulties in the way of accepting any theory hitherto formulated, yet the author would suggest, as the most rational view, that gold and quartz have been simultaneously introduced into veins in the form of alkaline solutions. That alkaline solutions are a ready solvent of quartz is of course well known, and so is the fact that many natural waters are alkaline. It is equally well known that alkaline solutions are capable of holding gold in solution in the form of aurates, and also that gold is attacked by fused alkalies in the presence of air or of an oxidising agent like fused nitre, alkaline aurates being produced. There is therefore no reason why alkaline solutions should not be able to carry gold in solution into the reefs in which it is now found; admitting this view, the deposition of the gold may be due to several causes. It may be the result of the same causes that led to the separation of the quartz from its solution, whatever these causes may have been: it may be a result of electrolysis; or it may be due to the action of the metallic sulphides, which are the all but universal concomitants of gold in reefs: or possibly again the same reducing agents that led to the deposition of these sulphides also caused the precipitation of the gold. It would thus be an open question whether the coexistence of gold and sulphides is an effect caused by the presence of the latter minerals, or whether both owe their existence to some other precipitant.

The author has found experimentally that sulphides, such as galena and iron pyrites, will precipitate gold from alkaline solutions—but it must be noted that in these experiments an alkaline chloride was always present in the solution, as would also probably be the case in natural waters.

The presence of silver in all native gold is very difficult to explain, as there seems no reason why the solutions that contained gold should also have carried silver.

The above brief notes have been put together more in the hope of inducing a fuller investigation of these problems than with the pretence of having helped much towards their settlement. The author ventures to think, however, that the hypothesis here suggested that gold has been carried in nature in alkaline, rather than as a chloride in acid solutions, as generally held, may be found worthy of consideration.