

Colloidal gold as a colouring principle in minerals.

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MANY attempts have been made to discover the causes of the various colours displayed by minerals. If we except fluorescence and allied phenomena, the different theories advanced may in general be grouped under one or other of the following classes:

(1) Colour may be due to an intrinsic property of atoms, ions, or molecules. Examples are copper atoms, chromate ions, and ferric oxide molecules.

(2) Colour is sometimes attributed to structural causes. The blue tints of certain halites have been explained in this way; but a fresh suggestion is made in this communication.

(3) A pigmentary impurity may cause the observed colour. The colour of the ruby is believed to be caused by the presence of a red chromic oxide.¹ The blue tint of a Yorkshire aragonite is shown later to be due to a copper salt.

(4) Some minerals show plays of colours due to interference and/or grating effects. Labradorite and opal are cases in point. Into this group also fall minerals like bornite which become iridescent from tarnish.

(5) Finally, some minerals owe their colour to the presence of foreign substances in colloid form. This differs from ordinary pigmentation in that the colour of the impurity itself bears no relation whatever to that of the mineral, because the colour is due to scattered light, not reflected light. The impurity may, when by itself, be actually colourless. Particles of colloid dimensions are too small to reflect incident light; they can only scatter it; hence for any one particular colloidal substance its own degree of dispersion will determine the wave-length or colour of the scattered light, whilst its concentration will fix the actual depth or intensity of that colour.

¹ C. W. Stillwell, Journ. Physical Chem., 1926, vol. 30, p. 1441; also *vide infra*.

Two very important features of this theory are:

(a) It is not necessary to assume the presence of a different chemical inclusion with each of the colours shown by a mineral in these circumstances, as must generally be the case when the colour is due to pigimentary particles. Theoretically almost any colour may result from a given colloidal inclusion by mere adjustment of the particle size.

(b) The quantity of material in colloid form required to produce a decided colour is invariably much less than in the case of a pigment. The substance may thus easily escape identification. Thus, for example, 0.5 mg. of gold present as chloride in 50 g. of water—equivalent to 10 parts per million—are imperceptible with the unaided eye. On reduction to colloidal gold, however, a clear rose colour develops, if tannic acid is employed. Under favourable conditions 1 to 4 p.p.m. of colloidal gold may produce a detectable tint in an otherwise colourless mineral.

The present research originated in an attempt to ascertain whether or not any members of the rare-earths, hitherto seldom found in the British Isles although relatively abundant in certain localities in Scandinavia, could be detected in British minerals containing the alkaline earths. In the first instance the minerals were spectrographed using a Hilger quartz spectrometer, and we happened to notice that lines due to gold were present in some coloured celestines, notably those from the Yate area, Gloucestershire. It occurred to us that their colours and perhaps those also of specimens from other localities might be due, in part at any rate, to this gold being present in the colloid state.¹ A search through the literature showed that, although this particular aspect of the subject had not received much attention, there were indications that it was worth careful study.

In their research on the Malvern crystalline rocks, Brammall and Dowie² invariably found silver and usually traces of gold. Although the authors did not discuss the possibility that these metals might influence the colour of the rocks, they did mention that the higher values of these elements were associated with the red granites and with various types of 'mixed' rock to which the red granites had been contributory. One strongly reddened granite contained 4.6 p.p.m. (72 grains per ton) of gold and 65 p.p.m. (42.4 dwt. per ton) of silver.

Bruce³ has mentioned the association of gold with coloured quartz in

¹ J. N. Friend and J. P. Allchin, *Nature*, London, 1939, vol. 144, p. 633. [M.A. 7-527.]

² A. Brammall and D. L. Dowie, *Min. Mag.*, 1936, vol. 24, p. 260.

³ E. L. Bruce, *Trans. Roy. Soc. Canada*, 1934, ser. 3, vol. 28, sect. 4, p. 7. [M.A. 6-264.] In the paper numerous references are quoted to coloured quartz.

Canada and suggests that the colour may not be due to any particular foreign substance but to the state in which the foreigner may occur. The spectrograph of the Dunkin blue quartz, reproduced in Bruce's paper, shows the gold line 2676. This, of course, does not prove that the colour was caused by colloidal gold. Professor Bruce has informed one of us that he could not guarantee that the quartz, when spectrographed, was entirely free from specks of mechanically included gold. Nevertheless, the coincidence is interesting.

Of all the elements gold is one of the most easy to convert from the dissolved into the colloid state. The action, even, of hot water alone may suffice to produce blue colloidal gold from aurous chloride.¹ Owing to its chemical inertness, once the metal has been reduced from its compounds it is very permanent. If, therefore, traces of gold derivatives become disseminated throughout a mineral, any agent that can effect their reduction to the metal, whether by chemical or purely physical means, may also effect a very permanent tinting of that mineral. Various tints of red, purple, and blue are the most frequent colours shown by colloidal gold, and Long² has given reasons for supposing that the blue form may be the most stable of all.

Gold is known to be widely diffused in nature in small quantities, but our experiments appear to indicate that it may be even more widely distributed than has hitherto been believed. It is not one of the sensitive elements, spectrographically, and may easily escape detection; the lower limit is given as some 10 p.p.m. by ordinary spectrographic methods. The 'Glimmschicht' procedure, developed by Goldschmidt and his co-workers, is claimed to be some fifty times more sensitive³ but does not appear to have come as yet into general use amongst mineralogists. We have frequently succeeded in detecting traces of gold in minerals by chemical tests although none of the characteristic lines appeared in the spectrograph.

It was decided, therefore, to examine as many specimens of celestine as possible from different localities in an endeavour to ascertain if any connexion existed between the colour and the gold content. Other minerals were then added to the list. They were first spectrographed and the presence of suspected inclusions checked by chemical methods; quantitative microchemical analyses were also made.

¹ L. Vanino and L. Rössler, *Zeits. Chem. Ind. Kolloide*, 1910, vol. 6, p. 289.

² S. H. Long, *Proc. Univ. Durham Phil. Soc.*, 1913, vol. 5, p. 113.

³ L. W. Strock, *Spectrum analysis*, 1936. [M.A. 6-291.]

METHODS OF ANALYSIS.

As some of our analytical methods, though based on recognized procedure, were somewhat different in detail and have been found to yield consistent results, it may be useful to place them on record.

Gold was estimated both gravimetrically and volumetrically. In the former method some 5 g. of the finely powdered mineral (other than silicates) were digested three times with aqua regia which extracted the gold, leaving a colourless residue. The gold was reduced with phenylhydrazine and citric acid, collected on a sintered glass filter, and weighed on a microbalance.¹

The volumetric method, proving more sensitive than the foregoing, was used in the later determinations. The solution containing the gold, obtained as above, was taken to dryness, re-dissolved in three drops of concentrated nitric and six of hydrochloric acids. Excess chlorine and nitrosyl chloride were removed in a current of air and the resulting solution diluted with water to 50 c.c. in a Nessler tube. 0.5 c.c. of a 5 % aqueous solution of ammonium hydrogen fluoride was added with 1 c.c. of a 0.1 % solution of *o*-dianisidine in 0.1 % aqueous hydrochloric acid. After shaking and standing, the solution was titrated with hydroquinone, slightly acidified with acid, until the red colour developed by the chlorauric acid with the *o*-dianisidine was discharged as the gold suffered reduction to metal.² With siliceous minerals it was necessary first to fuse with potassium hydrogen sulphate, leach with water, and take the residue to dryness with acid to render the silica insoluble. The gold was then extracted with aqua regia as before.

Manganese was estimated colorimetrically by the usual persulphate method, the manganese being oxidized to permanganate.

Nickel was estimated by the dimethylglyoxime method; a separate portion of the mineral was fused with potassium hydrogen sulphate and the nickel estimated colorimetrically in the usual way.

Titanium. After fusion of the mineral with potassium hydrogen sulphate and leaching, the insoluble portion was taken up in hydrochloric acid and estimated colorimetrically after addition of hydrogen peroxide.

Zinc, Copper, and Iron were estimated in the same portion of

¹ Using M. E. Pozzi Escot's method of reduction, Ann. Chim. Anal., 1907, vol. 12, p. 90.

² This method is based on that recommended for testing urine in the 'B.D.H. Book of reagents for delicate analysis', 7th edit., 1930, p. 64. The solution of hydroquinone we used contained 0.0335 g. per litre, 1 c.c. \equiv 0.04 mg. gold. (From W. B. Pollard, Analyst, 1937, vol. 62, p. 597.)

aragonite(no. 23).¹ After dissolving the mineral in dilute hydrochloric acid and oxidizing any iron with a drop of nitric acid, the solution was brought to about 4.9 pH with ammonium acetate and hydroxide, controlled with the British Drug Houses universal indicator.

The solution so obtained was shaken with successive small amounts of 0.1 % solution of 'dithizone' (diphenyl thiocarbazone) in chloroform, each extract being separately washed with ammonium acetate solution of 4.9 pH. The zinc and copper yield complex derivatives with the dithizone which are soluble in the chloroform, the iron remaining in the aqueous portion.

Shaking the chloroform solution with dilute hydrochloric acid extracts the zinc complex, and the acid solution is taken to dryness and organic matter is removed by oxidation with hydrogen peroxide and perchloric acid in the usual way. Glacial acetic acid is added, together with a little hydrochloric acid, KI, HNH_4F_2 , and excess potassium ferricyanide solution, using starch as indicator. The blue colour thus developed is discharged by titration with *N*/500 thiosulphate in a microburette.

The chloroform contains the copper complex and is taken to dryness, organic matter removed by warming with concentrated nitric and sulphuric acids, and the residue taken up in water. Aliquot portions are rendered alkaline with ammonia and a few c.c. of 0.1 % aqueous sodium diethyldithiocarbamate² added whereby a brown colour develops. This brown colouring matter is extracted in four successive extractions with carbon tetrachloride and its intensity measured with a Bolton and Williams colorimeter using light of λ 570 $\mu\mu$.

To the original aqueous solution containing the iron, 2 c.c. of 20 % citric acid solution are added, the whole made alkaline and 0.2 c.c. of 50 % thioglycollic acid introduced. The intensity of the colour developed is measured with the colorimeter using light of λ 530 $\mu\mu$.

Strontium was estimated in the aragonite (no. 23) by dissolution in nitric acid, extracting the residue with anhydrous acetone,³ in which calcium nitrate is soluble, filtering through a Gooch crucible, and drying the residue of strontium nitrate at 105° C.

CONSIDERATION OF THE RESULTS.

The results obtained are summarized in the accompanying table, and may now be discussed in the same order.

¹ The details of this method were worked out by Mr. E. A. Hardy, to whom we take this opportunity of expressing our indebtedness.

² See B.D.H. Book of reagents, p. 103.

³ P. E. Williams and H. T. Briscoe, Chem. News, 1932, vol. 145, p. 177.

Gold appears to be even more widely distributed in minute amounts in minerals and rocks than has hitherto been recognized.

We would emphasize that many factors may be involved in producing the colours of minerals. The mere fact that gold may be proved to be present does not of necessity also prove that this element is the cause of the colour or even contributory to it. On the other hand, its possible influence should not be ignored.

Celestine. The blue colour of certain celestines, to which, indeed, the mineral owes its name (Latin *caelum*, sky), is often attributed to traces of vivianite¹—a mineral possessing deep pigmentary power. When, however, our specimens (nos. 1 to 3) from Yate were gently heated, the blue crystals lost their colour and assumed a very pale pink tint. The colourless and reddish-brown crystals remained virtually unaffected. As vivianite turns neither pink nor colourless on gentle heating it seems improbable that the colours of our specimens could be due to this cause.

In 1915 Doelter² suggested that the colouring agent of celestine might be colloidal sulphur produced by reduction of some of the sulphate. This view has the advantage of offering an explanation for the observed variations in colour; but evidence that colloidal sulphur is actually present in the celestine is lacking. Whilst agreeing with Doelter that the colour may quite well be due to some impurity in colloid form, we venture to suggest that it may be due in part or in its entirety to colloidal gold. All our coloured celestines contained sufficient of this element to yield the observed colours. Ultramicroscopic examination of both blue and red specimens from Yate showed the presence of colloid particles. In specimens nos. 1 to 3 from Yate the depth of colour rose with the gold content. As the iron content was greatest in the colourless crystals (no. 1) and as no iron could be detected in the blue celestine from Girgenti (no. 9) it would seem that iron must be absolved from any complicity in the matter. Titanium likewise appears to be ruled out.

The three colourless specimens, nos. 1, 11, and 12, contained no gold although iron was present. The white Kingston mineral was the richest in iron. Opaque rust-brown patches occurred in the Renfrew specimen; these were entirely different in appearance from the translucent reddish-brown colour of the Yate celestine (no. 3) and were probably due to iron.

Gypsum. Through the kindness of Mr. Arthur Russell we have been able to examine a specimen of reddish-brown gypsum (no. 13) from the

¹ Dana, *System of mineralogy*, 6th edit., 1892, p. 906; H. A. Miers, *Mineralogy*, 1902, p. 524.

² C. Doelter, *Die Farben der Mineralien*. Braunschweig, 1915. [M.A. 1-227.]

same locality (Yate) as our analogously coloured celestine (no. 3). The intensity of the colour varied greatly in different parts of the gypsum which was, in general, less translucent than the celestine. A little gold was present, but the iron content was high, especially in the darker portions. It is not clear why the gold should have shown so marked a preference for the celestine.

The two specimens of gypsum from Blue Anchor (nos. 14 *a* and *b*) were similar in appearance to that from Yate; but only one of them contained gold in varying amounts. The specimen from Tyburn (no. 15) had a pale opaque reddish-brown tint, and contained only a trace of gold. It came from red Triassic clay from a well bore-hole at a depth of 200 feet from the surface. There were other layers of gypsum at various depths, some white, others green, the latter lying in greenish clay. The colour appeared to be governed by the state of oxidation of the iron.

The *calcareous stalactite* (nos. 16 *a* and *b*) was a portion of one of Mr. W. Pengelly's original specimens taken from Kent's Cavern, Torquay, about the middle of last century. It was given to one of us by Mr. W. J. Else, curator of the Hastings Museum, Worcester, many years ago, and is of special interest because sporadic gold has been found in the neighbourhood of the cavern, notably at Daddy Hole and Hope's Nose.¹ In cross-section the stalactite was oval and measured 7 and 5 cm. across. The outer portion was very pale yellowish pink and surrounded a pinkish disk, some 3.5 cm. in diameter. The specimen readily broke along the edges of this disk suggesting that an interval had elapsed after the stalactite had first attained the dimensions of the inner portion before it began to grow again. Only the merest trace of gold could be detected in either the outer or the inner portion—of the order of 1 p.p.m. Iron was present, but no manganese.

It is known that the clays, &c., from which alkali salts have crystallized in nature are usually richer in noble metals than the alkali salts themselves.² It was of interest to ascertain if this likewise applied to our calcite. Analysis of two portions of clayey earth (nos. 17 *a* and *b*) from the cavern showed them to contain much more gold than the calcite; their iron content was, as expected, enormously greater. A piece of stalagmite (no. 17 *c*) from the cave floor was relatively rich in gold but was contaminated with a considerable amount of clay.

¹ W. T. Gordon, *Nature*, London, 1922, vol. 109, p. 583; A. Russell, *Min. Mag.*, 1929, vol. 22, p. 159.

² See, for example, J. Goubeau and L. Birckenbach, *Zeits. Anorg. Chem.*, 1938, vol. 236, p. 37.

We were a little surprised at the absence of gold in the Madoc *baryte* (no. 21) and *wollastonite* (no. 22), both of which showed a pale translucent blue cast, not unlike the anhydrite (no. 26) mentioned below, and suggestive of colloidal matter.

The mauve and pale green tints of the Ontario *calcites* (nos. 18 and 19) and the more ruddy colours of the Frontenac *baryte* (no. 20) and *stilbite* (no. 24) were not due to gold.

Special interest is attached to the pale green *aragonite* from Lunehead mine, Yorkshire. It occurred in a lead-baryte vein in which Mr. Russell had noticed minute crystals of *chalcopyrite* associated with the *baryte*. Acting on a hint from Mr. Russell we made a more detailed analysis than usual. The results are given in the table. The colour is due to some copper salt, presumably the carbonate. The presence of 4.7 % strontium carbonate suggests identity with *mossottite*, recorded from the Lias at Gerfalco in Tuscany;¹ this latter mineral had nearly 7 % of strontium carbonate; its density was 2.884 as against 2.889 for our specimen.

Ruby. In 1798 Vauquelin, the discoverer of chromium, detected that element in the spinel-ruby; in 1837 Gaudin² observed that addition of a small amount of chromic oxide to alumina and fusion in an oxyhydrogen flame yielded the colour of the natural ruby; since then the colours of both the spinel and true ruby have been attributed to chromium. Numerous analyses have confirmed the presence of chromium, but it is not clear that gold has been definitely searched for. Vogel³ found natural and artificial rubies to exhibit the same absorption curves. O'Leary, Royer, and Papish⁴ observed that the depth of colour of natural rubies is apparently proportional to their iron and chromium contents; also that the amount of these oxides in the more deeply coloured specimens coincides with that which must be added to synthetic preparations to yield the same colour.

This would appear to be conclusive; nevertheless, in view of the classical use of gold in the production of 'ruby' glass, it seemed of interest to make a direct search for gold in the natural stone. Examination of a specimen (no. 25) of typical ruby colour failed to detect either spectroscopically or chemically any trace of gold. Chromium was present. The stone had been purchased in 1920 from a mineralogist and was undoubtedly a natural one.

¹ Dana, *System of mineralogy*, 6th edit., 1892, p. 283.

² M. A. Gaudin, *Compt. Rend. Acad. Sci. Paris*, 1837, vol. 4, p. 999.

³ P. Vogel, *Neues Jahrb. Min., Abt. A*, 1934, Beil.-Bd. 68, p. 401. [M.A. 7-129.]

⁴ W. J. O'Leary, G. L. Royer, and J. Papish, *Science*, New York, 1934, vol. 80, p. 412.

Anhydrite frequently possesses a blue cast and its translucent, colloid character has been recognized. The blue colour of a Japanese anhydrite was attributed by Kinoshita¹ to colloidal calcium sulphate. Specimen no. 26 from Cropwell Bishop, Nottinghamshire, was found to contain sufficient gold to impart the observed pale blue cast, although other equally blue specimens have been found to contain no gold.

Rock-salt is frequently found coloured in nature, the more usual colours being violet, blue, and pink, although a light yellow has also been observed.² The blue halite of Stassfurt has, in particular, received much attention since Sir Humphrey Davy observed it in 1818, and various suggestions have been offered to account for the colour. Siedentopf³ suggested that it was due to colloidal sodium, and prepared a synthetic blue halite by heating the colourless salt in sodium vapour. Cornu⁴ supported this theory and it was regarded as satisfactory until Spezia⁵ observed that the synthetic and natural blue halites did not possess identical properties; the former, for example, on dissolution in water gave a more alkaline solution than the colourless salt, whereas the natural blue and colourless halites were equally alkaline.

More recently, Phipps and Brode⁶ have prepared blue, pink, and green halites by Siedentopf's method; using a modified hydrogen electrode method of great delicacy, they found that all of these coloured specimens were distinctly alkaline. On the other hand, six colourless specimens of halite from Navarre (Michigan), two from Stassfurt, and five natural blue ones, also from Stassfurt, showed zero alkalinity. Further, spectrophotometric study of the natural and artificial blue halites showed marked differences in their absorption curves. The authors, therefore, conclude that colloidal sodium cannot be the cause of the colour in the natural halite. They regard the colour as due to abnormality in constraint upon electrons which belong properly to the halite lattice.

Doelter⁷ has for many years continued to regard the colour as due to foreign inclusions other than alkali metals, whether colloidal or other-

¹ K. Kinoshita, Journ. Geol. Soc. Tokyo, 1925, vol. 32, p. 9. [M.A. 3-118.]

² K. Prziham, Nature, London, 1936, vol. 137, p. 107.

³ H. Siedentopf, Physikal. Zeits., 1905, vol. 6, p. 855. Also R. Zsigmondy, Zur Erkenntnis der Kolloide, 1905, p. 58.

⁴ F. Cornu, Neues Jahrb. Min., 1908, vol. 2, p. 22. Also T. Svedberg, Colloid chemistry, 1924, p. 67.

⁵ G. Spezia, Centralbl. Min., 1909, p. 398.

⁶ T. E. Phipps and W. R. Brode, Journ. Physical Chem., 1926, vol. 30, p. 507.

⁷ C. Doelter, Monatsh. Chem., 1929, vol. 52, p. 241. [M.A. 4-252.] References are given to his earlier work.

wise. He favours the idea of mixtures of iron and manganese, although sulphur and organic substances are not ruled out. We have found traces of iron to be present (see table) in our specimens, but no manganese.

Kennard, Howell, and Yaeckel,¹ however, have recently decided against any pigmental theory. They examined spectroscopically a specimen of colourless Stassfurt halite containing a distinct blue zone. No difference could be detected in chemical composition between the coloured and colourless parts. In addition to small amounts of calcium, traces of lithium, potassium, aluminium, silicon, and titanium were present in both, together with still smaller amounts of magnesium, strontium, and barium. They mention that titanium, strontium, and barium had not been recorded before. They associate themselves with those who regard the colour as structural.²

Apparently the presence of traces of gold has not hitherto been specially looked for. Mention has already been made of the fact that it may easily escape detection. It occurred to us, therefore, that conceivably the coloured halites contain this element. It appeared possible because it is known that sea-water frequently contains gold. Caldwell,³ using an improved method, finds it may amount to 0.2 mg. per metric ton, equivalent to some 6.6 mg. per metric ton of halite, or roughly 1 part in 150 million of sea-water. If during evaporation this gold became concentrated locally it might easily, upon reduction to the colloid state, give rise to coloured streaks in the resulting rock-salt. Further, Przibram⁴ has already noted a similarity between the blue tints of anhydrite and rock-salt, and we have shown gold to be present in blue-tinted anhydrite from Cropwell Bishop (no. 26). We accordingly examined several coloured halites and, as shown in the table, gold was present in all of them. Of all those quantitatively examined the blue specimen from Stassfurt (no. 27) contained the maximum amount of gold and was also the most deeply tinted.⁵ A minute black inclusion (no. 29) in the pink translucent halite (no. 28) appeared to be the source

¹ T. G. Kennard, D. H. Howell, and M. P. Yaeckel, *Amer. Min.*, 1937, vol. 22, p. 65. [M.A. 6-503.]

² Particularly K. Przibram, *Sitzungsber. Akad. Wiss. Wien, Abt. II A*, 1934, vol. 143, p. 489; 1924, vol. 132, p. 262; &c. [M.A. 3-116, 6-263.] F. C. Guthrie, *Nature*, London, 1929, vol. 123, p. 130; Phipps and Brode, *loc. cit.*

³ W. E. Caldwell, *Ind. Eng. Chem. Anal.*, 1937, vol. 9, p. 530. [M.A. 7-435.]

⁴ K. Przibram, *British Chemical Abstracts*, 1938, p. 482; from Kali, 1936, vol. 30, p. 61. [M.A. 7-526.]

⁵ J. N. Friend and J. P. Allchin, *Nature*, London, 1940, vol. 145, p. 266. [M.A. 7-527.]

of waves of pink in its vicinity. It was extracted and analysed together with some of the more deeply tinted halite surrounding it. As is seen in the table, both the gold and the iron contents were higher than in the rest of the crystal.

The effect of gentle heat on the blue halite was very similar to that on the celestine. The blue colour disappeared, yielding successively violet, lilac, and very pale pink; ultimately the salt became colourless. This is in harmony with numerous other observations recorded by earlier workers.

Specimen no. 30 from Cheshire was less translucent than the two others and more earthy; its colour was no doubt influenced by its iron content. The colours of the two translucent salts (nos. 27 and 28), however, could quite well have been caused by colloidal gold. The pink and blue specimens from Hallstatt and Wieliczka respectively contained gold, but the amounts could not be ascertained as the specimens were too small.

GOLD CONTENTS OF VARIOUS MINERALS.

No.	Mineral.	Colour.	Locality.	Source.	Parts per million.
1	Celestine	White	Yate, Glos.	B. Topley, Oldbury	Au nil Fe 19
2	"	Pale blue, translucent	"	"	Au 49 Fe 4
3	"	Red-brown, translucent	"	"	Au 85 Fe 4 Ti nil
4	"	Blue, translucent	Coast of North Berwick	R. Scottish Museum, Edinburgh	Au 34 Fe 11 Ti nil
5	"	"	"	"	Rich in Ba Au 30 Fe 10 Ti nil
6	"	"	"	J. Whitecross N. Berwick	Au 55 Fe 5
7	"	Extremely pale pink	Seacliff quarry E. of North Berwick	"	Au 5 Fe 25 Mn trace Ti nil
8	"	Blue, translucent	Lanark Co., Ontario	Govt. of Ontario, 1922	Au 9 Fe 30 Ti nil
9	"	"	Girgenti, Sicily	British Museum	Au 5 Fe nil Ti nil
10	"	"	Sicily	National Mus. Wales	Au 5 Fe 52

No.	Mineral.	Colour.	Locality.	Source.	Parts per million.
11	Celestine	White	Kingston, Ontario	Govt. of Ontario, 1922	Au nil Fe 53
12	„	White, with rust-brown streaks	Renfrew Co., Ontario	„	Au nil Fe 13
13a	Gypsum	Red-brown	Yate, Glos.	A. Russell	Au 6 Fe 5
13b	„	Red-brown, deeper than 13a	„	„	Au 9 Fe 230
14a	„	Red-brown, similar to 13a	Blue Anchor, Somerset	British Museum	Au 0 Fe 130
14b	„	„	„	Museum, Birmingham	Au 45, 95 Fe 55, 49
15	„	Very pale red-brown	Tyburn, Birmingham	—	Au 1 Fe 99
16a	Calcitic stalactite	Very pale yellow-pink (outer shell)	Kent's Cavern, Torquay	Museum, Worcester	Au trace Fe 25 Mn nil
16b	„	Very pale yellow-pink (inner portion)	„	„	Au trace Fe 33 Mn nil
17a	Clay earth	Red	„	—	Au 19 Fe 3.19%
17b	„	„	„	—	Au 26 Fe 3.05%
17c	Floor stalagmite	„	„	—	Au 21 Fe 4.32%
18	Calcite	Very pale mauve	Lanark Co., Ontario	Govt. of Ontario, 1922	Au nil Fe 332
19	„	Pale green	Rideau Lake, Ontario	„	Au nil Fe 237
20	Baryte	Red-brown	Frontenac Co., Ontario	„	Au nil Fe 114
21	„	Pale blue, translucent cast locally, otherwise white	Madoc, Ontario	„	Au nil Fe 130
22	Wollastonite	Very faint blue cast	Lewis Co., New York	Foote Mineral Co.	Au nil Fe 40
23	Aragonite	Pale green	Luncheon mine, Yorks.	A. Russell	Au nil Ni nil Cu 237 Zn 1240 Sr 4.7%
24	Stilbite	Deep red- brown	Unknown	British Museum	Au nil Fe 2600

No.	Mineral.	Colour.	Locality.	Source.	Parts per million.
25	Ruby	Ruby-red	Unknown	Purchased in 1920	Au nil Cr present
26	Anhydrite	Very pale-blue cast	Cropwell Bishop, Notts.	A. Russell	Au 4 Fe 4
27	Rock-salt	Indigo-blue, translucent. Colour zones sporadic	Stassfurt, Prussia	Gregory, Bottley & Co.	Au 23 Fe 32 Mn nil
28	„	Pale pink translucent	Unknown	—	Au 7 Fe 6 Mn nil
29	„	Pale pink, translucent but with small black inclusion	„	—	Au 12 Fe 8 Mn nil
30	„	Pale pink to brown	Meadow mine, Cheshire	Gregory, Bottley & Co.	Au 9 Fe 41 Mn nil
31	„	Blue	Wieliczka, Poland	British Museum	Au present
32	„	Pink	Hallstatt, Austria	„	„

SUMMARY.

1. Gold appears to be even more widely distributed in minute amounts in minerals and rocks than has hitherto been generally recognized.

2. It is emphasized that many factors may be involved in producing the colours of minerals. The mere presence of gold is not in itself proof that it is responsible for the colour.

3. Nevertheless, reasons are given for the suggestion that the translucent blue tints of the specimens of celestine, anhydrite, and halite could be caused by colloidal gold.

4. The translucent pink and reddish-brown tints of the halite and celestine specimens examined may likewise be connected with their gold contents.

5. Gold has been found in several other minerals, but not in a natural ruby.

6. Aragonite from Lunehead mine, Yorkshire, was tinted with copper and bore a close resemblance to mossottite from Tuscany.

The authors desire to express their deep indebtedness to the various institutions and persons mentioned in the table who have so generously supplied them with the mineral specimens described.