AN UNUSUAL OCCURRENCE OF GYPSUM AT KALGOORLIE, WESTERN AUSTRALIA

REX T. PRIDER, *University of Western Australia, Perth, Western Australia.*

ABSTRACT

During flooding of several mines at Kalgoorlie, Western Australia, extending over a period of approximately 30 years, certain workings appear to have existed as airlocks, and selenite encrustations have been developed on the walls and roof above the apparent water level in such airlocks. The occurrences are described, also the crystallography and genesis of the gypsum encrustations. From the discussion it appears most probable that the deposits have been developed during a comparatively short period while the mines were being unwatered and pressures in the airlocks decreasing.

INTRODUCTION

In the course of a short visit to the underground workings in the Oroya South Blocks shaft of the Gold Mines of Kalgoorlie property at Kalgoorlie, in January 1939, the writer's attention was drawn to an unusual deposit of gypsum at the No. 11 level of this mine. During flooding, certain parts of this mine appear to have existed as airlocks and the walls and roof of such airlocked chambers (above a well defined water mark) are covered with a layer of coarsely crystalline gypsum.

An exactly similar occurrence was noted during the unwatering of the Paringa Mine at Kalgoorlie in 1934. As there appears to be no record of any similar occurrences, these unusual deposits warrant some record.

DESCRIPTION OF THE OCCURRENCES

(a) *At the No. 11 level (1,096 ft.), Oroya South Blocks shaft, Kalgoorlie.*

The roof and upper parts of the walls of both the east and west crosscuts leading from the shaft are encrusted with well crystallized gypsum, the crust ranging from half an inch to three or four inches in thickness. There is a well defined water mark (emphasized by a coating of ferric oxide) on the walls which apparently indicates the highest level to which standing water could rise as the mine gradually filled with water, after the abandonment of this property about 1910. The cross sections through the shaft and west crosscut (Fig. 2, A and B) show the positions of this water mark and also (Fig. 2, B) the occurrence of the gypsum above the water level. Proceeding westwards from the shaft, where the water level is at the roof of the crosscut, the water line gradually approaches the floor of the workings, because the floor of the tunnel rises gradually from the shaft in that direction (it is the usual practice in mining to drive slightly inclined tunnels to allow drainage to take place into the shaft

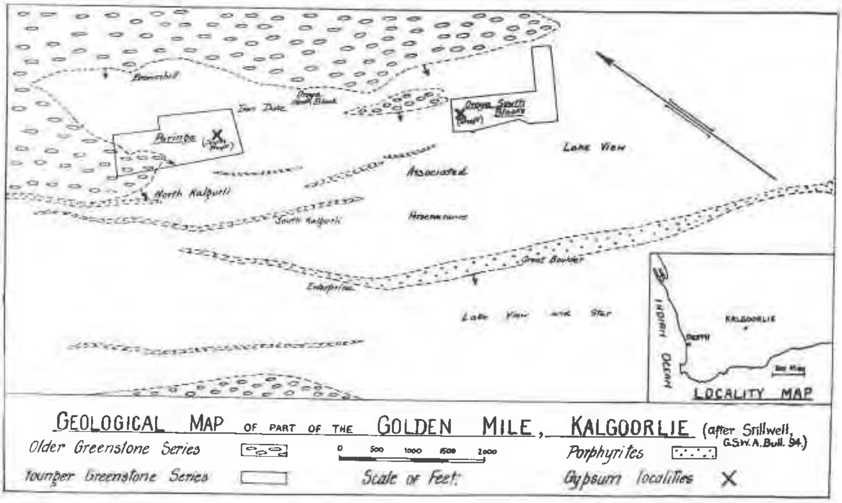


FIG. 1. Geological sketch plan of part of the Golden Mile, Kalgoorlie, Western Australia showing localities where the gypsum deposits occur.

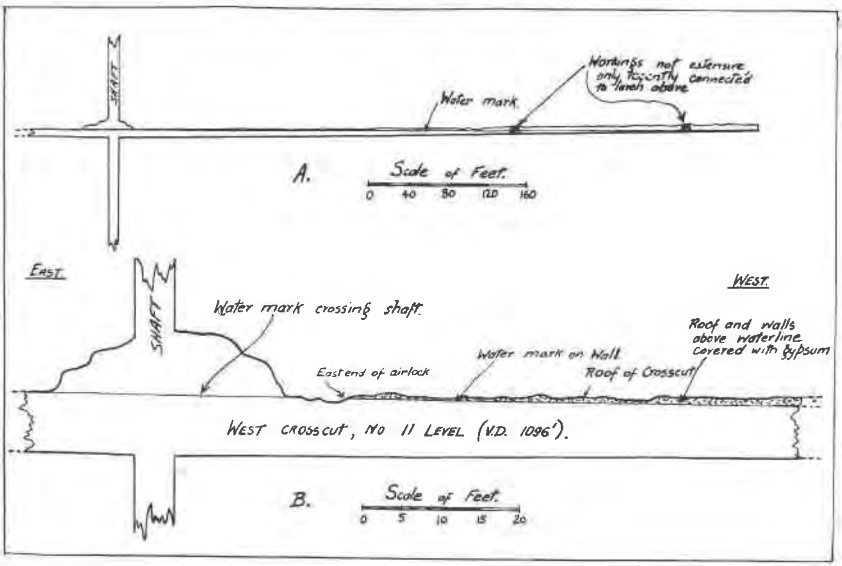


FIG. 2. Vertical sections along the west crosscut, No. 11 level, Oroya South Blocks Mine, Kalgoorlie, Western Australia, showing the development of gypsum above water level.

A. Total length to show rise of crosscut and "air-lock."

B. Detail near the shaft (from data supplied by Mr A. Blatchford) and to facilitate haulage—the average rising gradient away from the shaft is approximately 1 in 100). It will be apparent that with further rise of water above this level, the part of the tunnel above this water line would remain as an airlock, as the workings at the time of flooding were not connected with the levels above. The only effect of continued flooding of the mine would be to fill up the shaft and the workings at higher levels and to increase gradually the pressure in the airlock and to decrease gradually the volume of the airlock as the water rises. In this particular instance, when unwatering was commenced in 1935, the mine was flooded up to 450 feet from the surface, so that at this time the pressure in the airlock at the 1096 ft. level was the effect of a head of 646 feet of water (i.e., a pressure of approximately 20 atmospheres).

The water line is composite in character, being made up of several lines spread over a width of eleven inches, indicating that the pressure varied from time to time. A less definite iron stained line crosses the shaft at the level of the roof of the crosscut (Fig. 2, B) indicating that the water stood at this level for a considerable period. There is no gypsum on the walls of the shaft.

In the crosscuts (both east and west from the shaft) gypsum occurs in two forms:

(1) As encrustations up to four inches thick on the roof and walls *above the water line.* This is coarsely crystalline material, the crystals averaging $1\times\frac{1}{2}\times\frac{1}{4}$ inch in size. A noticeable feature is that the crystals are arranged at random, with their long axes pointing in all directions. The thickest deposit is immediately above the water line but the crystals are developed over all the walls and roof above this level.

(2) As a thin irregular coating up to $\frac{1}{8}$ inch thick of minute crystals *below the water line.* This appears to represent a normal evaporation deposit from the water left on the walls after the mine was unwatered. Such thin encrustations are not uncommon in Kalgoorlie mines.

Plate 1 (A) shows the well marked line between (1) above and (2) below the water line.

Details regarding the water levels (which give some indication of the pressures obtaining during the crystallization of (1)) and the period between flooding and unwatering of the mine (which gives some indication of the time during which the crystals may have developed) are:

No. 11 level where the gypsum occurs, 1096 feet vertically below the surface.

Level of water when unwatering was commenced, 450 feet vertically below the surface.

The crosscuts were driven in 1905, the lower levels were abandoned about 1910 and the upper levels shortly afterwards.

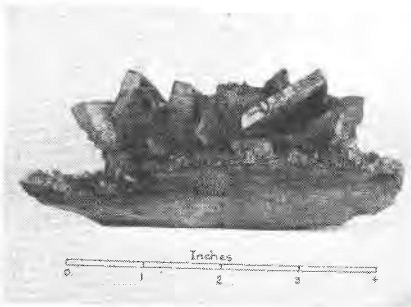
The mine was unwatered in 1935.

These figures indicate that the "airlock," if such could exist (see dis-

PLATE 1

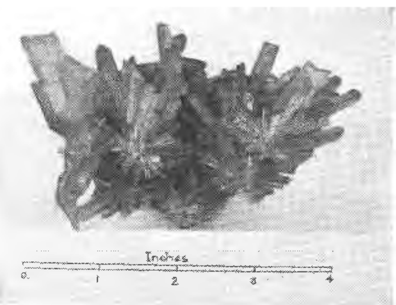
A

A. Photograph of wall of west crosscut, No. 11 level, Oroya South Blocks Mine, showing the profuse growth of gypsum crystals above the water line and their absence below.



B

B. Crystals growing on the wall rock, from the Oroya South Blocks Mine. Showing random orientation of the crystals, development of "swallow tail" twins, striation of the prism and clinopinacoid, central iron stained growth zones within the crystals and the notching of the edge between the prism faces. Several of the larger crystals also show the $\bar{3}02$ cleavage



C

C. Spherulitic growths of gypsum crystals which have developed on the earlier encrustation represented by B (above), from the Oroya South Blocks Mine. Shows "swallow tail" twinning and absence of growth zones and iron staining. The crystals were attached to the earlier growth at the central points of the spherules at the bottom facing the observer.

cussion in next section), has been subject to a pressure of 646 feet of water (approximately 20 atmospheres) for a period of approximately 25 years.

(b) *At the 800 ft. level, South Shaft of the Paringa Mining and Exploration Company's property, Kalgoorlie.*

The occurrence here is similar in all respects to that described above. The gypsum, which is in crystals up to $3\frac{1}{2} \times 1\frac{3}{4} \times \frac{1}{2}$ inches is a clear selenite and has grown with random orientation in an airlock in the top of the tunnel. The features of the occurrence are shown in Fig. 3—all the walls and roof of the drive and crosscuts above the water line are covered with gypsum. The most remarkable feature of this occurrence is that the crystals are developed over the walls and roof of the rises at both the north and south ends of the drive, i.e., in places 11 feet above the water line.

The details regarding the pressure and duration of flooding are:

Level of occurrence: 800 feet vertically below the surface.
Level of water prior to unwatering: 380 feet vertically below the surface.
Approximate date of closing down of the mine: 1901.
Date of unwatering: July, 1934.

The pressure on any airlocks at the 800 ft. level during the period of 33 years while the mine was flooded was therefore due to a head of 420 feet of water (approximately 13 atmospheres).

Possibility of Existence of Airlocks

Before proceeding to a description of the crystals it is desirable to examine the possibility of existence of airlocks under the high pressures to which the above examples have been subjected. The main factor is the porosity of the country rocks. In both the examples described above, the country rock is a dense fine grained, little sheared, carbonated greenstone which appears to be absolutely impermeable. In the Oroya South Blocks occurrence the existence of an airlock in which the volume has suffered some change (as reflected in the composite water mark) can be demonstrated, but it seems probable that under the 20 atmospheres to which it has been subjected it would be of much smaller volume than is at first apparent.

According to Boyle's law regarding the relation between pressure and the volume of a gas that "the volume occupied by the same sample of any gas at constant temperature is inversely proportional to the pressure," the volume of the airlock at the No. 11 level of the Oroya South Blocks mine would be reduced to approximately one-twentieth of its original volume (as indicated by the lowest water mark), and that at the 800 ft. level of the Paringa mine to one-thirteenth of its original volume. Unfortunately, owing to a lack of knowledge of the extent of the side workings and stoping in the Oroya South Blocks occurrence the volume of the airlock cannot be calculated. In the Paringa airlock, however, the full volume of the workings is known and it is possible to calculate the volume of the airlock at one atmosphere pressure and so determine the

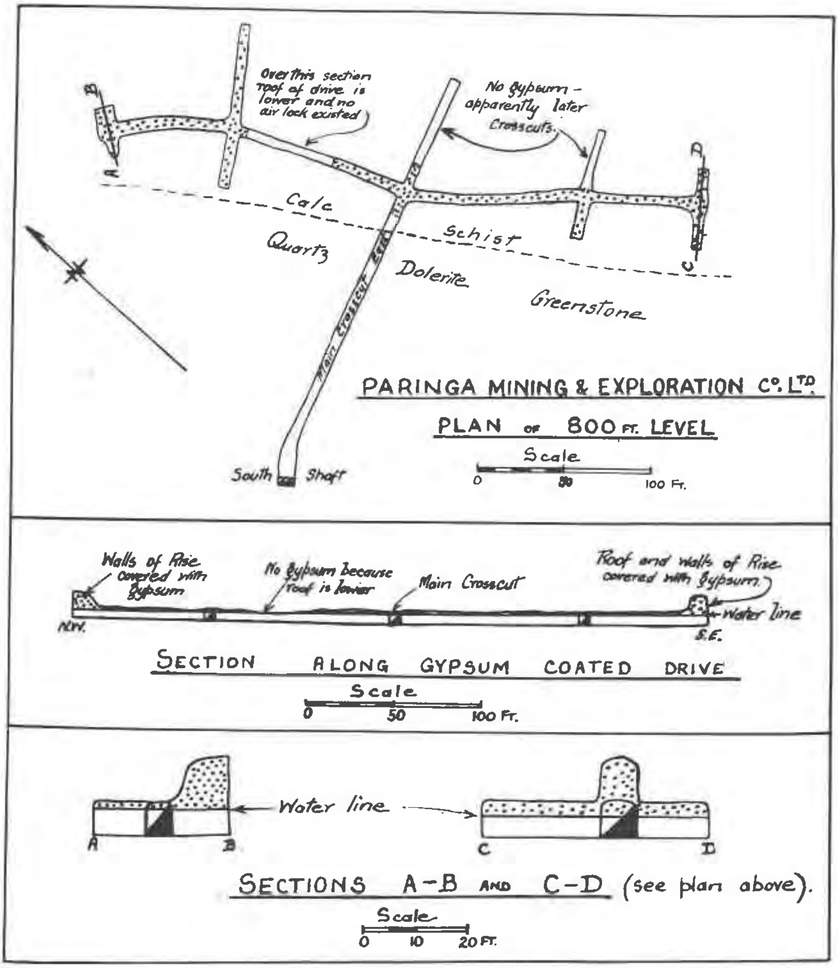


FIG. 3. Plan and sections of the 800 ft. level, South Shaft, Paringa Gold Mine, Kalgoorlie, Western Australia, showing the occurrence of gypsum encrusting walls (dotted) of airlocked workings.

(From data supplied by Dr. C. O. G. Larcombe.)

level at which the water stood when the pressure of 13 atmospheres was effective. Assuming that the average rise of the workings of one foot per hundred holds in this case, the volume of an airlock in these workings at one atmosphere would be approximately 4900 cubic feet. This, when subject to a pressure of 13 atmospheres, would be reduced to approximately 380 cubic feet—barely sufficient to fill the raises at each end of the drives (Fig. 3, sections AB and CD). Although much smaller than would appear from an examination of the water line, there is little doubt that such an airlock has existed.

Description of the Crystals

In the thick encrustations in the Oroya South Blocks occurrence there appears to be two distinct growths. The earlier forms crusts up to $2\frac{1}{2}$ inches thick covering the walls, made up of crystals which average 1 inch in length and which are very uniform in habit. They are flattened on (010) and generally elongated parallel to *c*, although some crystals

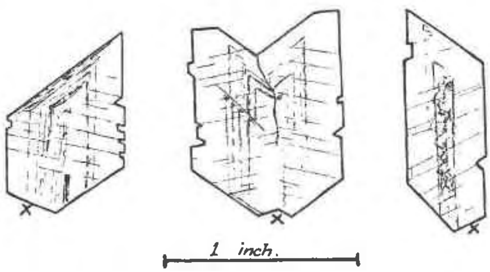


Fig. 4. Section parallel to (010) showing iron stained growth zones, ($\bar{3}02$) cleavages and notching of the acute angle between the prism faces. The crystals were attached at the points marked x. Crystals from the Oroya South Blocks mine.

are elongated parallel to *a*. The forms developed are (010), (110), (111) and ($\bar{3}02$). The (010) and (110) faces are vertically striated and are always the best developed forms. (111) is well developed except on crystals which have grown vertically down from the roof to the water line—here the (111) faces are rounded and etched. The form ($\bar{3}02$) is always poorly developed, having curved faces, and appears to be best developed on crystals from near the water line, which have suffered considerable etching.

Most of the crystals are twinned on (100) giving the characteristic "swallow tail" twins. Cruciform interpenetration twins are also present.

All of the large twinned crystals show the development of a cleavage parallel to the *b*-axis, making an angle of 77° with the edge between (110) and ($\bar{1}10$), and thus having the indices $\bar{3}02$ (Fig. 4). The edge between the two prism faces is always notched as shown in Fig. 4, these notches being bounded by the faces (111) and ($\bar{3}02$), or by ($\bar{3}02$) and (110).

This earlier growth of crystals is invariably iron stained to some extent, especially against the wall rock. The iron stains in the crystals are of interest; generally speaking the crystals show more staining in the parts nearest the wall to which they were attached. Sections cut parallel to the clinopinacoid (Fig. 4) show that the iron staining is arranged in zones, there being often as many as 6 iron stained "ghosts" within a crystal. The forms commonly assumed by these "internal ghosts" are (010), (110) and (111), and they are twinned in the same manner as the enclosing crystal. In most instances the first formed "ghost" crystals were almost as long as the enclosing crystals which have grown by addition of material in the prism zone rather than by growth along the *c*-axis. The cause of the rhythmic growth of the crystals is not apparent, but may be due to changes in pressure within the airlock as the number of periods of growth of the crystals (5 or 6) corresponds to the number of different lines which can be distinguished in the composite water mark (Fig. 5).

A later growth of crystals occurs in places on the surface of the earlier growth described above. In this second "crop" the crystals are arranged in spherulitic aggregates (Plate 1, C) of crystals up to 1½ inches in length. The forms developed on these crystals are (010), (110), (111) and twinning on (100) is common. There is no iron staining in these crystals, they have no ($\bar{3}02$) cleavage, no notching of the edges between the prism faces and no striations on the (010) and (110) faces.

The crystals from the Paringa mine are all water-clear selenite, though there are occasional crystals having a narrow lath-shaped central zone along *c* which is stained with ferric oxide. The forms developed were (110), (010) and (111). Owing to the absence of marked iron stains in these crystals no information regarding their growth is available.

Genesis of the Deposits

It will be seen then that these crystals have developed in a place that was apparently not accessible to standing water, and also in a closed chamber in which there could be no evaporation. They are, therefore, of interest as they appear to differ in origin from the normal sulphate deposits formed by precipitation from saturated solutions or by evaporation of sulphate-bearing solutions.

The following possible explanations of the origin of these deposits have occurred to the writer:

I. They are deposits formed by evaporation of waters seeping down through the overlying rock before the tunnel was flooded. Such material

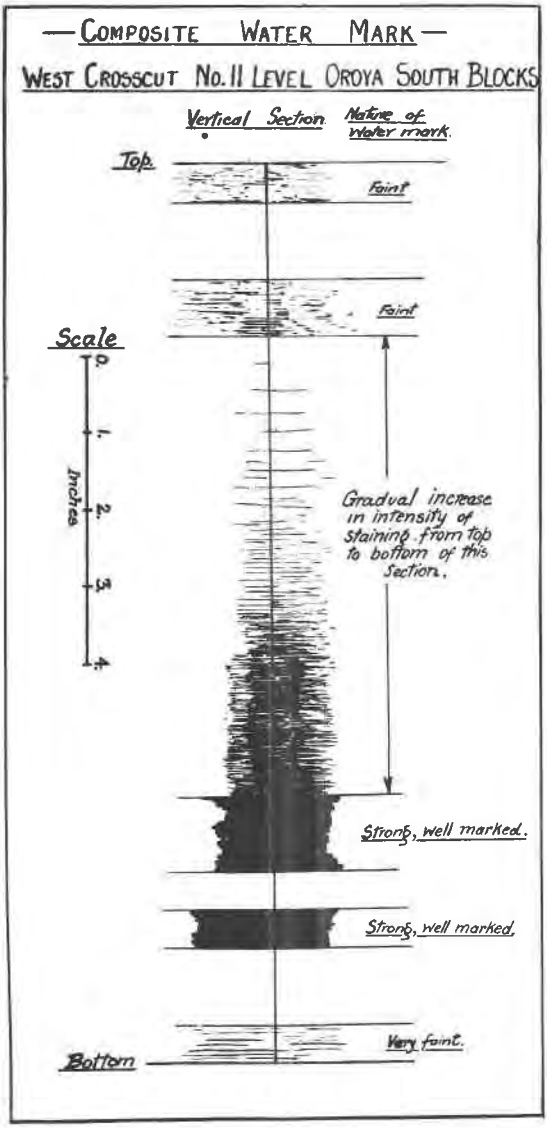


FIG. 5. Detailed section of the composite water line showing the distinguishable water marks due to changes in pressure in the airlock, No. 11 level, Oroya South Blocks mine. (From data supplied by Mr. A. Blatchford.)

would be deposited all over the roof and walls of the tunnel and subsequently be removed by solution up to the water mark as the water gradually rose during flooding of the mine.

The underground water in this area carries a considerable amount of $CaSO_4$ in solution, as will be seen from the following analysis, which appears to be the best available from this region:

	Parts per cent
$CaCO_3$	0.0395
$FeCO_3$	Tr.
$CaSO_4$	0.1878
$MgSO_4$	0.3908
$MgCl_2$	0.5229
NaCl	3.2142
KCl	0.0700
$Al_2O_3(Fe_2O_3)$	0.0047
SiO_2	0.0009
Total solids	4.4308

Analysis of water from Maine Shaft, Lake View and Boulder Junction Gold Mine, Kalgoorlie, Western Australia. (Analyst: E. S. Simpson)[1]

Any evaporation of such water would result in the precipitation of $CaSO_4$ in the form of gypsum. The high concentration of $CaSO_4$ in some of these underground waters was noted by the writer in 1931 when sections of the main pump column were removed from the shaft of the Croesus mine at Kalgoorlie. The pipe had a diameter of approximately 6 inches, but examination after removal showed that the effective diameter was only about 2 inches as there was a coating several inches thick of crystalline gypsum, consisting of "swallow tail" twinned prisms, growing out normally from the walls of the pipe.

The main arguments against the above theory are:

(1) The possibility of water seeping through these rocks, other than along joints or faults (where the gypsum would be deposited locally) seems remote, because if the rocks were at all permeable the airlock would not be able to exist under the high pressure to which it has been subjected.

(2) If the gypsum were formed in this manner it would be expected that the encrustation would be of uniform thickness all over the walls, but as noted above the growth is most profuse on the walls immediately above the water line.

(3) If such theory were tenable one should expect to find similar

[1] Simpson, E. S., *Geol. Surv. West. Aust., Bull.* **67**, 164, (1916).

occurrences in other workings which have not been flooded. No such occurrences are known in this area.

II. They are deposits formed by reaction of constituents of the atmosphere of the airlock with the wall rocks.

The author has noticed that, when certain mines in this area have been recently unwatered, the atmosphere in the unwatered workings contains considerable amounts of H_2S, probably derived from decomposing organic material left in the workings, or from the alteration of pyrite which is scattered sparsely throughout the country rocks. Here, then, is a constituent of the atmosphere which has possibly played a part in the formation of the gypsum. The source of the lime is not hard to find as in both of the occurrences described the workings are in calc schist (a highly carbonatized "greenstone") which contains a considerable amount of calcite. An analysis of the country rock in the Oroya South Blocks Mine is:

"Chlorite schist," Oroya South Blocks Mine, Kalgoorlie, Western Australia. Analyst: C. G. Gibson.[2]

SiO_2	40.61
Al_2O_3	8.85
Fe_2O_3	—
FeO	12.42
MnO	0.21
MgO	4.50
CaO	14.27
Na_2O	0.84
K_2O	3.17
H_2O-	0.10
H_2O+	2.30
TiO_2	0.15
CO_2	12.75
FeS_2	0.29
	100.91

The development of gypsum by reaction of sulphuric acid solutions with calcite-bearing rocks is well known.[3] Wilder considers that many gypsum deposits may have been formed by the action of sulphurous vapours on limestone.[4] It is conceivable, therefore, that in the present instance the gypsum may have developed through oxidation of H_2S in the damp atmosphere of the airlock to H_2SO_4 which would be deposited on the walls and then react with the calcite of the wall rocks to give gypsum, thus:

[2] Simpson, E. S., *Geol. Surv. West. Aust., Bull.* **67,** 74, (1916).
[3] Stone, R. W., *U. S. G. S., Bull.* **697,** 25, (1920).
[4] Wilder, F. A., *Bull. Geol. Soc. Am.,* **32,** 391, (1921).

$$\underset{\text{(of wall rock)}}{CaCO_3} + \underset{\text{(of atmosphere)}}{H_2S + 4O + H_2O} \rightarrow \underset{\text{(gypsum)}}{CaSO_4 \cdot 2H_2O} + CO_2 \cdot$$

If this process operated there would not be sufficient oxygen in such a closed space to produce the quantity of gypsum observed. If we consider the walls and roof of a chamber 400 ft.×5 ft.×4 ft. to be covered by an encrustation of gypsum half an inch thick, then the total weight of gypsum is approximately 21,000 pounds, whereas in this space there is only 75 pounds of oxygen available for oxidation processes, so it is clear that the above hypothesis is inadequate.

Pyrite is a constituent of the wall rocks and oxidation of this mineral above the water level would give rise to a sulphuric acid solution, covering the walls, which would react with the calcite to produce gypsum. In the Paringa occurrence there is an abundance of pyrite available as the workings are in lodestuff (highly pyritized calc schist), but it is doubtful whether in the Oroya South Blocks occurrence sufficient pyrite was available. In any case, the objections regarding an insufficiency of oxygen as noted above also holds in this instance.

III. They are deposits from solutions which have wetted the walls above the water level, crystallization being caused by a lowering of pressure.

The walls of the chamber would be kept wet by condensation from the saturated atmosphere, and over a long period of time it is likely that calcium sulphate from the standing water might diffuse through this thin layer. If this were the case, one should expect that the thicker deposits would be developed just above the water line where the supply of $CaSO_4$ would be more quickly renewed—this agrees with the observed distribution of the gypsum encrustation which is thicker just above the water line than in the higher parts of the tunnel. In addition the $CaSO_4$ content of the solution wetting the walls may be increased by the reaction of H_2S in the atmosphere with the wall rock as described under II above.

It would appear possible then to have a $CaSO_4$ solution developed on the walls but the question of the precipitation of the $CaSO_4$ is more difficult. We are dealing here with a closed system in which evaporation can not take place once the atmosphere becomes saturated. There are two possible factors which may have caused precipitation:

A. *Temperature changes.*

The solubility of $CaSO_4$ varies with the temperature. According to Hulett and Allen[5] the solubility of gypsum in water increases up to a

[5] Hulett, G. E., and Allen, L. E., *Jour. Am. Chem. Soc.*, **24**, 674, (1902).

maximum at 40°C. and with further rise of temperature the solubility decreases. The figures quoted for saturated solutions of gypsum in water at various temperatures are:

At 0°C. saturated solutions contain	0.17590 gm. $CaSO_4$ per 100 cc. soln.
30°C.	0 20905
35°C.	0.20960
40°C	0.20970 (max.)
45°C.	0.20835
55°C.	0.20090
75°C.	0.18475
100°C.	0.16190

Small temperature changes would, therefore, tend to bring about changes in the equilibrium of saturated solutions; below 40°C. any lowering of temperature would tend to produce precipitation, and above 40°C. any rise in temperature would produce a like result. Ground temperature changes need not be further considered here as a cause of the gypsum deposits since we have no reason to think that they have occurred in the last 40 years.

B. *Pressure changes.*

There are very few data available regarding the solubility of $CaSO_4$ in water at various pressures. Comey and Hahn[6] give the following:

100 gms. saturated $CaSO_4$ solution at 1 atmosphere and 15°C. contain 0.206 gm. $CaSO_4$.
100 gms. saturated $CaSO_4$ solution at 20 atmospheres and 15°C. contain 0.227 gm. $CaSO_4$.

Gibson[7] says that the increase in solubility of gypsum per 1000 bars increase in pressure is 57%.

From these figures it appears that the precipitation from saturated $CaSO_4$ solutions could only be effected by a decrease in pressure.

In the occurrence of gypsum from the Oroya South Blocks mine at Kalgoorlie there is a close relation between the number of growth zones in the crystals (Fig. 4) and the number of distinguishable marks in the composite water line (Fig. 5), which appears to indicate the close relation between precipitation and pressure changes. The figures quoted above indicate that precipitation is more likely to be brought about by lowering of the pressure, and it would appear most probable that the greater part of the gypsum in these airlocks was deposited during the period when the mine was being unwatered and the pressure in the airlock was being

[6] Comey, A. M., and Hahn, D. A., *A Dictionary of Chemical Solubilities* (2nd Edition), New York, **1921,** p. 946.

[7] Gibson, R. E., On the effect of pressure on the solubility of solids in liquids: *Am. Jour. Sci.*, **35*A*,** 65, (1938).

reduced. Some, however, may have been developed previously owing to changes in the water level by intermittent working in neighbouring mines, because changes in the water level of these mines would undoubtedly affect the water level in the Oroya South Blocks.

The selenite crystals of the Paringa mine, although they show no growth zones, may have developed in a similar fashion.

IV. They are deposits from solutions which have wetted the walls, crystallization taking place under conditions of falling pressure and by evaporation.

The possibility of the existence of airlocks in these flooded mines has been discussed above—it has been shown that under the high pressures to which such airlocks have been subjected, they would be reduced to very small dimensions. Consequent upon the reduction of pressure during unwatering operations the airlock would expand and evaporation would be possible into the larger space available. The sequence of events in the formation of the gypsum deposits in these airlocks seems to be:

(1) Flooding of the mine giving rise to an airlock which was gradually reduced to a very small volume. This airlock has persisted for a number of years and the ground water (under high pressure) has become heavily charged with $CaSO_4$. There is no reason for any crystallization of gypsum during this period because the pressure (and therefore the solubility of gypsum) was increasing and also because no evaporation could take place.

(2) Unwatering of the mine causing a decrease in the pressure and consequent increase in volume of the airlock, the walls of which would be wet with $CaSO_4$-saturated solution. With relief of pressure the $CaSO_4$ will begin to crystallize and this crystallization will be assisted by evaporation from the walls into the larger airspace now available.

In the Oroya South Blocks there were probably a number of causes in the sinking of the water level as unwatering proceeded due to extensive workings (including large stopes) at various levels which had to be emptied before the pressure at that stage was effectively reduced. This would give rise to the distinct water marks which have been correlated with the growth zones in the crystals. In the Paringa mine, unwatering took place uniformly and comparatively rapidly (because of the limited extent of the workings and the absence of large stopes) so that the crystals have grown uniformly and have not, at successive stages of their growth, been covered with iron oxide films.

Conclusion

It appears, from the above discussion, that the hypothesis described under IV is most probable and this indicates that the gypsum crystals were formed in a very short period (of several months) while the mine was being unwatered and not during the longer period when the mine was flooded.

Gypsum Occurrences in Natural Cavities

A natural cavity in quartz dolerite greenstone, filled with gypsum, occurred at the 700 ft. level in the Main shaft workings of the South Kalgurli Gold Mine at Kalgoorlie, and is of interest in connection with the above occurrences in artificial openings. The original cavity was somewhat irregular in shape measuring 15 ft.×8 ft.×3 ft. thick and was filled with clear selenite from which cleavage fragments up to several feet long could be obtained. It would appear to be very similar in origin to the occurrences described above and may have developed comparatively recently when mining operations brought about a lowering of the water table and led to a decrease in pressure on the solutions in this cavity.

An interesting occurrence of gypsum in a natural cavity has been described by Jutson[8] from the Sand Queen mine at Comet Vale, Western Australia. The cavity was a transverse, nearly vertical opening in the main reef and was traceable downwards for several hundred feet. This "vugh" was filled with calcite and selenite from which large cleavage fragments were obtainable. This again appears to be a deposit which could have been formed in the manner outlined above.

Acknowledgments

The writer wishes to acknowledge his indebtedness to Mr. A. Blatchford who drew his attention to the Oroya South Blocks gypsum encrustations and who supplied data regarding this deposit. Also to Dr. C. O. G. Larcombe and Mr. A. W. Winzar for information regarding the Paringa occurrence and to Professors E. de C. Clarke and N. S. Bayliss for discussion during the preparation of this paper.

[8] Jutson, J. T., *Geol. Surv. West. Aust., Bull.* **79**, 21, (1921).