deposits appears at present to be very scanty, and further investigation is greatly needed.

EXPLANATION OF PLATES XX AND XXI.

Plate XX.

FIG. 1. *Ortonella furcata*, gen. et sp. nov. Section through a typical nodule. Natural size. Base of the *Seminula gregaria* sub-zone, Ravenstonedale, Westmorland.

,, 2. *O. furcata*. Thin section through above. × 20.

,, 3, 4. *O. furcata*, showing dichotomous branching of tubes. × 55.

Plate XXI.

FIG. 1. *Spongiostroma* cf. *Malacostroma concentricum*, Gürich. × 2·5. Base of the *Seminula gregaria* sub-zone, Fawcett Mill, near Orton, Westmorland.

,, 2. *Mitcheldeania gregaria*, Nich. × 26. Showing coarse and fine tubes. Zone of C_1–C_2 of Dr. Vaughan's classification. Scully Grove, Mitcheldean.

,, 3. *Aphralysia carbonaria*, gen. et sp. nov. × 13. Intergrown with layers of a flocculent deposit—'*Spongiostroma.*'

,, 4. *A. carbonaria*, gen. et sp. nov. × 30. From the 'Algal Band' associated with *Ortonella*. Base of *Seminula gregaria* sub-zone, Wath, near Orton, Westmorland.

IV.—Gypsum and Anhydrite in Genetic Relationship.

By Robert C. Wallace, M.A., Ph.D., D.Sc., F.G.S.,
Professor of Geology and Mineralogy, University of Manitoba.

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IN certain geological horizons where there is evidence of continuous deposition of salts from the waters of inland basins, gypsum and anhydrite are found closely associated, while in other similar horizons gypsum may occur with apparently no trace of anhydrite. Some Upper Silurian occurrences in North America, the Lower Carboniferous of Eastern Canada, and the Zechstein of Northern Germany are illustrative of the association of both minerals, while in more recent gypsum horizons anhydrite seems to appear less frequently. Even in the one horizon anhydrite is found to be of only local occurrence. In New York and in Michigan the Salina formation contains both gypsum and salt deposits, but practically no anhydrite. In Manitoba, on the other hand, in an Upper Silurian formation which cannot be definitely correlated with the Salina of New York, but which is at any rate of approximately the same age, gypsum and anhydrite occur in the most intimate relationship.

The conditions of stability of gypsum and of anhydrite, whether in presence of water or of salt solutions, were investigated by van't Hoff and his co-workers by vapour-tension methods. The relationship of both forms to the half-hydrate ($CaSO . \frac{1}{2}H_2O$), which is obtained by ordinary calcination processes, and to 'soluble anhydrite', which is formed when precipitated gypsum is maintained at temperatures

60°–90° C. *in vacuo* in contact with phosphorus pentoxide, was also studied. The results may be briefly tabulated as follows[1]:—

Natural anhydrite transforms into gypsum—
(*a*) At 30° C. in presence of a saturated solution of sodium chloride.
(*b*) At 66° C. in presence of water.

Soluble anhydrite transforms into gypsum—
(*a*) At 65° C. in presence of a saturated solution of sodium chloride.
(*b*) At 89° C. in presence of water.

Half-hydrate transforms into gypsum—
(*a*) At 11° C. in presence of a saturated solution of magnesium chloride.
(*b*) At 76° C. in presence of a saturated solution of sodium chloride.
(*c*) At 101·5° C. under atmospheric pressure.
(*d*) At 107° C. in presence of water.

If, then, at a certain stage of evaporation an inland sea is saturated as regards calcium sulphate and sodium chloride, and if the temperature is not below 30° C., anhydrite will form. The frequent association of anhydrite and salt beds in nature would consequently seem to indicate, at the time of deposition, rather high temperatures in the bodies of water from which these minerals were precipitated. This view has usually been taken in connexion with the Stassfurt Beds, and was suggested by van't Hoff as a geological deduction from his experimental work. If, however, gypsum beds, intercalated with beds of salt, be in course of time buried to depths of 1,500 feet or more, and if the average surface temperature be taken as 15° C., the gypsum is, under such conditions, above transformation temperature, and will presumably go gradually over into anhydrite. Arrhenius and Lachmann[2] believe that in the case of the Stassfurt sulphates the faunal evidence is against the probability of temperatures so high as 30° C. in the inland seas of Northern Germany in late Permian times, and that the anhydrite of Stassfurt is a transformation product from originally deposited gypsum. The reverse reaction would necessarily take place, and gypsum would again be formed, in the case of the anhydrite horizon reaching a higher relative level owing to the denudation of the overlying beds, or in the case of the abstraction of the associated salt beds by solution.

In the course of an investigation, for the Geological Survey of Canada, of the gypsum and the salt horizons in the limestones of Palæozoic age in Manitoba, the writer has had occasion to examine a surface exposure of gypsum, with associated anhydrite, at Gypsumville, the present terminus of the Canadian Northern Railway branch line which skirts the east side of Lake Manitoba. The following section was obtained from the face of the quarry that is now being operated:—

(*e*) Surface capping (gypsite and soil) .	1–3 feet.
(*d*) Red argillaceous gypsum	29 ,,
(*c*) White foliated gypsum	75 ,,
(*b*) Bluish-grey anhydrite	25 ,,
(*a*) Hard reddish gypseous rock . .	5 ,,

[1] *Untersuchungen über die Bildungsverhältnisse der ozeanischen Salzablagerungen*, 1912, p. 189.
[2] *Geologische Rundschau*, Bd. iii, Hft. iii, p. 141.

The immediately underlying beds are not exposed in this locality, but from the evidence of a core section they appear to be a reddish calcareous clay. The anhydrite forms heavy beds 2–4 feet thick, which show no evidence of disturbance. The overlying white gypsum beds are 2–4 inches thick, and are sharply folded. At the quarry there is a dip, which is only of local significance, towards the north; consequently the anhydrite appears only at the south end of the quarry. The line of contact between the gypsum and anhydrite follows fairly closely the bedding-plane, wherever the top of the anhydrite beds is exposed. A similar close association of the two minerals may be observed in several of the gypsum exposures which occur in the Gypsumville district, and which cover in the aggregate an area of nearly 5½ square miles. In one locality, 6 miles north-east of the quarry, anhydrite occurs at the surface, and is found by boring to extend at least 90 feet vertically downwards, entirely free from gypsum; while half a mile further east an exposure of gypsum of considerable extent appears, with only occasional outcrops of anhydrite.

The horizon in which these surface exposures lie is near the top of the Upper Silurian. The highest beds of the Silurian in Manitoba, as determined by Kindle,[1] skirt the western side of the gypsum outcrop, and consist of thin-bedded magnesian limestones, rather poor in fossils, but characterized by the presence of *Leperditia hisingeri*. These beds overlie the gypsum. Underlying the gypsum horizon are dolomites and dolomitic limestones, in which but few fossils have been found. They belong to the Stonewall Series, which is probably the western equivalent of the Niagara and Guelph horizons in the east. The Palæozoic beds, which form in this locality a western fringe to the Canadian Shield, dip almost imperceptibly towards the south-west. The topography is relatively flat, the elevations of the surfaces of Silurian and Devonian formations ranging from 750 to 900 feet above sea-level. An escarpment of soft Cretaceous shales rises rather sharply from the Upper Devonian Limestones on the west side of Lake Winnipegosis and Lake Manitoba to a height of 2,500 feet above sea-level. The distance from the Gypsumville quarry (elevation 850 feet) to the top of the escarpment, measured in an east and west line, is approximately 80 miles. Almost certainly these Cretaceous shales formerly extended eastwards over the gypsum exposures, which were consequently buried to a depth of 1,700 feet at least. While salt has not been found in association with the gypsum horizon, the presence of glauberite ($CaSO_4 . Na_2SO_4$) from a core obtained by drilling at the quarry shows that the concentration of sodium ions was high in the solution from which the calcium sulphate was precipitated; and on the west side of Lake Winnipegosis numerous salt springs occur in the Upper Devonian, so that the gypsum horizon, when deeply buried, was probably saturated with a brine solution. Conditions may then have been favourable for the transformation of gypsum into anhydrite when the Upper Silurian was buried beneath the Cretaceous shales. The problem in this case

[1] Geological Survey of Canada, Summary Report, 1912.

and in similar cases is whether the anhydrite was originally deposited, or was formed by transformation at a later stage, when, owing to increasing depth of sedimentation, a temperature of 30° C. was undoubtedly reached.

In seeking to explain the origin of deposits such as these, one may consider the two alternatives that are generally offered: First, the theory of Ochsenius,[1] that the salts have been deposited from an arm of the sea, which is in only partial communication with the outer ocean; second, the theory that limestones have been converted into the sulphates by the action of water containing SO_4 ions. In the case under consideration the gypsum does not grade laterally into limestone: basal red beds occur, and one complex sulphate at least has been found. Such facts are not in accord with the theory that the beds were originally limestones. On the other hand, the sequence gypsum, anhydrite, and gypsum (with glauberite) is explicable on the assumption of an evaporating basin, separated from the outer ocean by a bar over which calcium salts might reach the inner evaporating pan. The more soluble chlorides of sodium and potassium, sulphates of magnesium and complex salts, have not been found in this locality; but brines which reach the surface in Upper Devonian limestones contain a high percentage of potash, and may be genetically connected with this horizon.

The applicability of Ochsenius' hypothesis to the Stassfurt salts has recently been questioned by Walther,[2] who believes that the salts were precipitated from an inland basin entirely cut off from the sea, that, as the shallower parts of the lake dried up, the salts were redissolved and carried down to the deep basins, and that only such deep basins are represented by the present distribution of the deposits. Grabau[3] has made a still wider application of the desert hypothesis in his explanation of the Salina deposits of New York and Michigan. He considers that the land surface of the Niagara Limestones, reworked by weathering agents under desert conditions, supplied—mainly through the connate waters with which the limestones were impregnated—the salts which were finally carried down, by streams due to intermittent rains, into circumscribed desert basins. The annual rings at Stassfurt might be accounted for, according to Walther, as due to salts carried down after successive rainfalls; and the same authority considers that the absence of fossils cannot be explained if communication with the open sea remained established during the whole period of precipitation. In the Gypsumville deposits there are no annual rings; no indication of subaerial weathering has been found in the underlying rock; the homogeneous character of the heavy anhydrite beds is difficult of explanation on a desert erosion hypothesis; and the absence of fossils in the anhydrite-gypsum section might be accounted for, as at Stassfurt,[4] by postulating a rather extended bar where communication was made with the outer ocean,

[1] *Die Bildung der Steinsalzlager und ihrer Mutterlangensalze*, 1877.

[2] *Lehrbuch der Geologie von Deutschland*, 1910.

[3] Mining and Metallurgical Society of America, Bulletin 57, p. 39; also *Principles of Stratigraphy*, 1913, ch. ix.

[4] Arrhenius & Lachmann, l.c., p. 142.

so that the organisms which entered these inimical waters might be able to effect their escape. In the district in question such a barrier would, in all probability, lie far towards the north. In the limestones of Devonian age the fauna is distinctly European in type, and seems not to have commingled with that of the New York and Michigan Devonian seas till late Devonian times. These Devonian limestones in the Mackenzie River basin overlap the Silurian beds on the edge of the Archæan shield, and the character of the underlying Silurian in that district has not been ascertained. At a single exposure, however, on the Bear River, gypsum is found interstratified with dolomites.[1]

To return to the main problem before us, the primary or the secondary character of anhydrite. It is very evident that transformations take place with extreme slowness. In the district to which particular attention has been devoted in this paper, the Cretaceous shales were elevated, and in all probability eroded, in early Tertiary times. Since that time anhydrite has been the unstable modification. Notwithstanding this, solid anhydrite may be found, as already indicated, to a depth of over 90 feet, with no gypsum on top. It is true that glacial erosion has taken place since that time, but boulders of compact anhydrite which lie on the surface fully exposed to atmospheric influence are surrounded by only a thin film of gypsum. Geological evidence points unmistakably to a very prolonged lag in the transformation anhydrite → gypsum, and it is not at all likely that at temperatures not much above 30° C. the change gypsum → anhydrite goes on more rapidly. Indeed, the burying of gypsum under considerable thicknesses of subsequently formed sediment tends to maintain the gypsum as such, for there is an increase of volume in the transformation gypsum → anhydrite + water, and although the liquid phase will at once seek regions of lower pressure, it is the volume relationships at the moment of transformation that regulates transformation conditions.

In the opinion of the writer, the anhydrite in the Upper Silurian of Manitoba is primary, and the order gypsum–anhydrite–gypsum represents the mineralogical sequence of deposition in Upper Silurian times. The presence of gypsum underneath the anhydrite is rather conclusive evidence against the secondary character of the anhydrite zone. With regard to the upper gypsum, there has unquestionably been a certain amount of transformation into gypsum of the top beds of the anhydrite since Tertiary times. Analyses of the upper anhydrite beds show a continuously increasing water value from the middle of each bed to the margin, an evidence that a gradual change is taking place. Besides, the folded structure of the gypsum beds is most naturally explained as a 'Gekröse'[2] phenomenon, due to an internal increase of volume in the solid phase, consequent on transformation. It is believed, however, that only the lowest beds of the upper gypsum have so originated, and that the internal pressure has been transmitted to the overlying gypsum, which had been precipitated as such at a late stage of the evaporation.

[1] J. M. Bell, Geological Survey of Canada, 1899, xii, 25 C.
[2] Koken, *Zentralb. f. Min.*, u.s.w., 1902, 3.

The physical conditions would seem to have been somewhat as follows:—Owing to elevation in late Niagara times, the sea withdrew towards the north, and an inland arm of the northern sea was placed in imperfect communication with the outer ocean. Chemical precipitation of the carbonates took place, followed by deposition of the sulphates as gypsum. Later, communication with the ocean closed, the temperature of the waters of the basin rose, and anhydrite began to form. At a still later stage lower temperatures prevailed, probably because of the entrance of ocean waters, and continuous deposition of gypsum ensued. The concentration of sodium salts became so great that part of the sodium ions was precipitated in the form of double sulphate. It is still an open question whether evaporation reached the stage of the deposition of the chlorides. When, finally, deeper-water conditions again prevailed, carbonates and traces of sulphates were thrown down, and formed the limestone which now represents the highest beds of the Silurian in Manitoba.

To summarize, the following conclusion of general applicability may perhaps be legitimately derived from the study of a particular gypsum–anhydrite association. While secondary transformations are possible at considerable depths, and also at the surface, the general character of gypsum–anhydrite deposits may be accounted for most directly, and with least difficulty, as due to original deposition. This applies most obviously in cases where the bedding-plane defines with fair accuracy the contact between anhydrite and gypsum. Where anhydrite occurs in masses irregularly distributed through gypsum rock, transformation processes at or near the surface have played a relatively greater part; but direct geological evidence has yet to be adduced before the theory can be accepted that transformation of gypsum to anhydrite, at great depths below the surface, takes place to such an extent as to be of geological importance.

REVIEWS.

I.—Memoirs of the Geological Survey of Scotland. Geology of Central Ross-shire (Explanation of Sheet 82). By B. N. Peach, LL.D., F.R.S., John Horne, LL.D., F.R.S., and others; with Petrological Notes by J. S. Flett, D.Sc., LL.D., F.R.S. 8vo; pp. vi, 114. Edinburgh, (1913) 1914. London: T. Fisher Unwin, 1 Adelphi Terrace, W.C. Memoir, 2*s*. 3*d*.; map, 2*s*. 6*d*.

THE area included in Sheet 82 is approximately 429½ square miles in extent; about 2½ square miles of salt water at the head of Loch Carron enter into the limits of the map. With the exception of a small part of Inverness-shire in the south-east corner, on either side of Glen Strath Farrar, the whole map falls within the County of Ross.

This is a typical Highland area, in which cultivation and population are reduced to a minimum and confined to the seaboard and a few spots along the larger river-valleys. The ground is mountainous, wild, and inaccessible, and is given up to deer forest and grouse moor, with small and decreasing areas of sheep-grazing at Kinlochewe, Loch Carron, and Scardroy.