The petrology of the evaporites of the Eskdale no. 2 boring, east Yorkshire.

PART III. *The upper evaporite bed.*

By F. H. STEWART, B.Sc., Ph.D., F.G.S.

With a chemical analysis by E. A. VINCENT, B.Sc., A.R.I.C., F.G.S.

Department of Geology, Science Laboratories, University of Durham.

[Read January 11, 1951.]

I. INTRODUCTION AND ACKNOWLEDGEMENTS.

THE rocks of the lower and middle evaporite beds of the Permian, passed through by the D'Arcy Exploration Company's boring in 1938–39 (Lees and Taitt, 1946), have been described in earlier communications (Stewart, 1949, 1951). The present paper deals with the petrography of the upper evaporite bed (3655–3860 feet below surface). The material examined comprises:

Core samples of known depth collected by I.C.I. while drilling was in progress, and consisting of pieces of core, up to 6 inches in length and 4½ inches in diameter, taken at intervals of 2 feet in the following depth ranges: 3738–70, 3772–74, 3778–94, 3798–3816, 3818–30, 3838–42 feet below surface.

The uppermost 83 feet of the bed was not cored, so that there are no available samples from this depth range (3655–3738 feet). The range 3738–3820 feet is fairly well represented, but the lower 30 feet of the bed is represented by only two core samples.

Well cuttings taken at intervals of 5 to 10 feet, covering the whole depth range of the bed, and consisting of insoluble residues.

My sincere thanks are due to Imperial Chemical Industries and to the D'Arcy Exploration Company for supplying material for examination and for allowing me to use data obtained by them. The analytical details of KCl percentages were provided by I.C.I., and are quoted with their kind permission. I am indebted to the Durham Colleges for a research grant, and to Mr. G. O'Neill for taking the photographs which illustrate this paper.

II. The general succession.

		Thickness in feet.
	Saliferous marls.	
3655 feet		
	Not cored	83
3738 feet		
Zone of silty halite	Brown to colourless halite, with a considerable quantity of brown anhydritic silty material. A few flakes of talc, and traces of sylvine and carnallite.	18
	Reddish-brown to pink halite, with scarce silty material and anhydrite. A few flakes of talc and traces of sylvine and carnallite.	12
	Reddish-brown to pink halite, with a considerable quantity of brown anhydritic silty material. Talc abundant. Traces of carnallite.	14
	Pink, brown, and colourless halite, with small amount of brown anhydrite and silty material. A few flakes of talc, and traces of carnallite.	8
3790 feet		
Zone of granular halite (with scarce rinneite)	Pink granular halite with occasional layers and patches of coarse pink and colourless halite. Contorted layers of anhydrite and anhydrite-halite-rock, with subordinate magnesite. No appreciable quantity of detrital material. Significant amounts of sylvine and rinneite in specimens from 3802–3806 feet and 3824–3826 feet, and small quantities of these minerals in other samples.	44
3834 feet		
Anhydrite zone	Largely anhydrite, with subordinate magnesite and dolomite, and halite-anhydrite pseudomorphs after gypsum in samples from 3838 and 3840 feet. Solution cavities in anhydrite cuttings suggest that pseudomorphs are present below these depths.	26
3860 feet		

As in the middle evaporite bed, polyhalite and kieserite are conspicuous by their absence. The range of halite in the lowest group is not known, since only two specimens were preserved. Neither do we know whether there is a potassium-bearing zone above the halite zone, since the upper part of the bed was not cored. The well cuttings in this upper range consist of brown silt with some anhydrite, quartz, and a little magnesite and dolomite.

The distribution of potassium.

The details in the following table were provided by Imperial Chemical Industries. These figures are higher than those of the lower part of the middle evaporite bed. Each six-inch specimen was cut in half longitudinally, and the material for analysis scraped evenly from the flat surfaces so obtained.

Depth below surface in feet.	Total KCl %.	KCl % on water soluble material.
3738	0·48	0·52
3740	0·41	0·53
3742	0·51	0·62
3744	0·41	0·43
3746	0·54	0·59
3748	0·42	0·48
3750	0·32	0·45
3752	0·60	0·66
3754	0·59	0·77
3756	0·30	0·33
3758	0·48	0·48
3760	0·35	0·35
3762	0·36	0·36
3764	0·40	0·40
3766	0·30	0·30
3768	0·30	0·37
3770	0·36	0·48
3778	0·40	0·41
3780	0·48	0·51
3782	0·36	0·39
3784	0·30	0·33
3786	0·35	0·36
3788	0·33	0·34
3790	0·36	0·37
3792	0·51	0·51
3794	0·25	0·44
3798	0·48	0·48
3800	3·22	3·23
3802	0·82	0·82
3804	0·51	0·51
3806	0·54	0·54
3808	0·48	0·48
3810	0·22	0·40
3818	0·62	0·62
3820	0·40	0·40
3822	0·48	0·48
3824	6·66	6·71
3826	0·32	0·43
3828	0·43	0·43
3838	0·08	0·42

III. ROCKS OF THE ANHYDRITE ZONE.

The two available specimens are from near the top of this range (3838 and 3840 feet). They consist of alternate layers of light grey anhydrite-magnesite-rock and anhydrite-magnesite-halite-rock with pseudomorphs after gypsum, the layers being up to one inch thick, roughly horizontal, but wavy and contorted. Brown layers, a few millimetres in thickness, consisting largely of magnesite, are frequent. Quartz is present in small quantity. Detrital and carbonaceous material are almost absent.

The magnesite, which is the main carbonate of this evaporite bed, forms tiny rounded granules (up to 0·01 mm. in diameter), aggregated together or disseminated through the anhydrite. Very little magnesite is enclosed in halite. There is nothing to suggest that it is not a primary mineral. Its mode of occurrence is similar to that of the fine-grained dolomite of the other evaporite beds of this boring and to the magnesite of the Texas–New Mexico potash-field (Schaller and Henderson, 1932, p. 48). The relatively large hexagonal plates found in the other evaporites of this boring have not been detected in this bed. Eight refractive index measurements of magnesite from this bed give the value ω 1·700–1·702.

FIG. 1

FIG. 2

FIG. 1. Anhydrite-magnesite-rock with halite-anhydrite pseudomorphs after gypsum. 3838–40 feet. Natural size.

FIG. 2. Anhydrite-magnesite-rock, with halite-anhydrite pseudomorphs after gypsum. The dark matrix is rich in magnesite. 3840–42 feet. × 4.

Anhydrite generally forms fine-grained aggregates of irregular grains, but some larger plates, often showing strain shadows, are seen to be in various stages of breakdown to form finer material. Some recrystallization of anhydrite has taken place, leading to the development of euhedral rectangular crystals. Halite areas are nearly always fringed by euhedral elongated anhydrite crystals, and isolated crystals of anhydrite are often enclosed in halite. There has been some replacement of these crystals by halite, the anhydrite being broken up into residual pieces with common optical orientation.

Halite, pink in colour and rarely containing numerous tiny plates and rods of haematite, is present mainly as a constituent of the pseudomorphs. These pseudomorphs (figs. 1, 2) are considerably smaller than most of those of the middle evaporite bed (Stewart, 1951) and are comparable with many of those found in the polyhalite zone of the lower bed (Stewart, 1950, p. 652). They reach one inch in length, are six-sided in cross-section, and often show swallow-tail twin terminations. Some consist entirely of anhydrite, but most consist of halite, with or without zones of anhydrite arranged parallel to the edges of the pseudomorphs. They are all embedded in a matrix of anhydrite and magnesite, and commonly magnesite is especially abundant at the edges of the pseudomorphs, having apparently been pushed aside as the original gypsum grew at the expense of anhydrite. More rarely, magnesitic layers pass from the matrix through the pseudomorphs, giving further evidence of the secondary nature of the gypsum.

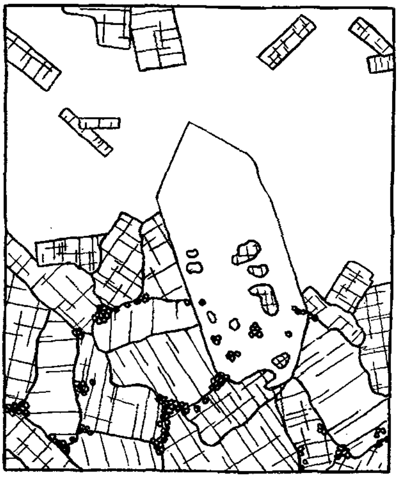

FIG. 3. Halite-anhydrite-magnesite-rock, showing replacement of anhydrite by a large crystal of quartz. 3838–40 feet. × 32.

Quartz is present in both these rocks as a subordinate constituent. It sometimes forms irregular grains surrounded by fine-grained anhydrite, but frequently occurs as euhedral doubly-terminated prismatic crystals, which may reach 1 mm. in length. It is always euhedral towards halite, and sometimes towards anhydrite. The mineral occurs in both pseudomorphs and matrix. It frequently encloses small magnesite granules and rounded grains of anhydrite, and evidence of replacement of anhydrite by quartz is shown by the common optical orientation of corroded anhydrite relics (fig. 3).

The replacements in this zone are, then, anhydrite→gypsum→ anhydrite and/or halite; anhydrite→halite; and anhydrite→quartz. Magnesite has not taken part in these replacements.

The well cuttings suggest that most of this zone consists of rocks similar to those described, but dolomite (ω 1·682) has been found in cuttings from near the base.

IV. Rocks of the zone of granular halite (with scarce rinneite).

At its base this zone gives place abruptly to the anhydritic basal zone. At its upper limit there is a fairly abrupt change in the nature of the halite, which becomes less pure and loses most of its granular texture, and this change is associated with the appearance of brown silty material. The zone can be subdivided as follows:

3790–3800 feet	Pale pink granular halite, with scarce thin layers of anhydrite. Most of the halite grains are under 1 cm. in width, but there are patches of coarse colourless or pink halite (grains up to 3 inches in width). Red sylvine has been observed in very small quantity.
3800–04	Coarse colourless halite with rinneite and sylvine.
3804–05	Granular pink halite, with coarse colourless halite, and little anhydrite.
3805–06	Coarse colourless halite with rinneite and sylvine.
3806–10	Granular pink halite, with a few thin anhydrite layers and trace of rinneite.
3810–14	Interbedded anhydrite-rich layers (up to 5 inches thick) and halite-rich layers with scarce rinneite.
3814–16	Interbedded anhydrite-rich layers, and layers of pink granular halite.
3816–24	Pink granular halite, with patches of coarse pink halite, and scarce thin layers of anhydrite. Traces of rinneite and sylvine.
3824–26	Coarse colourless halite with rinneite and sylvine.
3826–30	Pink granular halite and coarse pink to colourless halite, with scarce thin anhydritic layers and traces of rinneite.
3830–34	No samples available. The drilling log indicates that this range is largely halite.

It can be seen that most of this zone consists of halite, usually pink and granular, but occasionally colourless and very coarse. The mineral has irregular boundaries, and small liquid-filled cavities (sometimes cubic in shape) are commonly seen in thin sections. Most of the halite-rich rocks contain some anhydrite, and evidence that most of the halite has recrystallized since its formation is shown by the ejection of impurities, especially anhydrite, to form a lacy network at the edges of the halite grains. In one specimen anhydrite grains are also arranged along the halite cleavages. A few small flakes of talc have been observed, lying along the cleavages of the halite.

Contorted anhydritic layers, usually very thin, but occasionally several inches in thickness, nearly always contain tiny granules of magnesite. Much halite may be present in these layers. The anhydrite forms aggregates of small irregular grains with some larger irregular platy grains, and recrystallized elongated euhedral crystals especially where in contact with halite. There has been some replacement of anhydrite by halite. Quartz is present in small quantity in these layers, as crystals up to 1 mm. in length, and there is evidence of replacement of anhydrite by quartz. A small amount of carbonaceous material is present, but there is very little detrital material.

Sylvine occurs as small irregular bright red grains (full of haematite inclusions) associated with halite, in very small quantity. In a specimen from 3790 feet, the mineral occurs with halite in a thin layer between layers of halite and anhydrite. In some specimens rinneite occurs in this way, and it is possible that this sylvine has been derived from rinneite.

Characters and occurrence of rinneite.

Due to the exposure of the samples to the air, for several years after the boring was completed, much of the rinneite has altered to a brown mixture of halite, sylvine, and iron hydroxide. This alteration has proceeded in some cases to about one inch inwards from the surface of the core. The crust of alteration products, however, has prevented rapid decomposition of the salt, and fresh rinneite has been found in the interior of the samples. The mineral is highly deliquescent, and on exposure to air forms a brown liquid, from which sylvine and halite crystallize as small cubes. When moist material is dried in a desiccator, small deep red-brown crystals of erythrosiderite (biaxial positive, high 2V, α 1·715, β 1·751, γ approx. 1·8, strong dispersion $r>v$) form on the surface. Erythrosiderite has also been found as a constituent of the altered crust of rinneite in thin sections, and small irregular yellow grains have been found enclosed in halite. It is unlikely that erythrosiderite was an original constituent of these rocks. Slavík (1912) has recorded the mineral as an alteration product of rinneite exposed to air.

The rinneite has the following characters: transparent and almost colourless when fresh, sometimes showing a delicate violet tint which may be due to the presence of manganese; much more brilliant lustre than halite and sylvine; very brittle; conchoidal fracture; poor prismatic cleavage; no crystal boundaries developed; H. 3; sp. gr. 2·35; does not fluoresce in ultra-violet light; readily soluble in water; taste highly astringent. The mineral is uniaxial and positive, but some sections give a biaxial interference figure with very low optic axial angle. The refractive indices for sodium-light are ω 1·588, ϵ 1·589. The dispersion is strong, and this and the low birefringence give the mineral anomalous ultra-blue interference colour in thin section and crushed fragments.

Two chemical analyses[1] of hand-picked material are given below, with analyses of material from Germany for comparison. The Eskdale analyses agree with the formula $K_3Na(Fe,Mn)Cl_6$. The analysed material from Hildesia contained 0·2 % kieserite as impurity.

Analyses of rinneite from Eskdale and Germany.

	I.	II.	Mean.	No. of cations to 6Cl.	III.	IV.
Fe	13·52	13·55	13·53	0·992 } 1·005	13·94	13·57
Mn	0·18	0·18	0·18	0·013	—	—
K	28·76	28·60	28·68	3·005	28·90	28·99
Na	5·71	5·62	5·66	1·008	5·61	5·69
Cl	51·94	51·94	51·94	6·000	51·87	52·02
Ca	nil	—	nil		—	—
Mg	nil	—	nil		—	0·03
SO_4	nil	—	nil		—	0·12
	100·11	99·89	99·99		100·36	100·44

I and II. Eskdale no. 2 boring, 3802·04 feet. (Analyst, E. A. Vincent.)
III. Wolkramshausen, province of Saxony. Also Br 0·04. (Boeke, 1909a.)
IV. Hildesia, Hildesheim, Hanover. Also H_2O 0·02. (Rinne and Kolb, 1911.)

---

[1] *Method of analysis:*

Chlorine.—Solution of salt titrated with standard silver nitrate solution, using dichlorofluorescein as adsorption indicator.

Iron.—Solution oxidized by saturating with chlorine gas, the excess of which was boiled off, and the ferric hydroxide precipitated with ammonia.

Alkalis.—Filtrate from ferric hydroxide evaporated to dryness, ammonium salts driven off, and alkalis estimated in the residue: potassium as potassium chloroplatinate, and sodium as sodium zinc uranyl acetate.

Manganese.—Estimated colorimetrically in a separate portion of the salt decomposed with strong sulphuric acid.—E. A. V.

Rinneite has been found rarely in the German salt deposits. It was first described by Boeke (1909a) from Wolkramshausen, as coarse-grained lenticular masses up to five centimetres in thickness and a few metres in length, lying parallel to the bedding of the associated halite-sylvine-anhydrite-rock. It was later described from Hildesheim (Boeke, 1909b; Schneider, 1909; Rinne and Kolb, 1911) and Salzdetfurth (Boeke 1911) associated with kieserite, halite, and sylvine; from Riedel (Rinne and Kolb, 1911) in small quantities in halite-sylvine-rock; and from Hope (Harbort, 1928) associated with halite, anhydrite, zirklerite, quartz, dolomite, and clay. The mineral has also been recorded as a sublimation product at Vesuvius (Zambonini and Restaino, 1925; Zambonini, 1931) and the crystal structure of artificial material and of material from this locality has been worked out by Bellanca (1948).

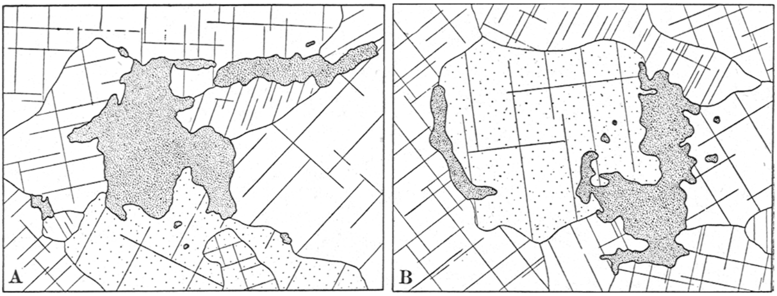

Fig. 4. Halite-sylvine-rinneite-rock. Rinneite (heavily stippled) has irregular boundaries against halite (clear) and sylvine (lightly stippled). The rinneite has been partly replaced by halite and sylvine, and small rinneite relics are enclosed in both these minerals. 3802–04 feet. Natural size.

A. Vertical section of core. B. Cross section of core.

In the Yorkshire potash-field the mineral occurs in these upper evaporites in the Eskdale no. 2 boring (Stewart, 1949), and has been found by the Geological Survey in the marls between the upper and middle evaporites in the recent I.C.I. borings (Fleck, 1950). Rinneite from these marls in Fisons's boring at Robin Hood's Bay has been exhibited to the Geological Society by Hollingworth and Stewart (1950). There it is undoubtedly of secondary formation, being associated with halite, sylvine, and carnallite, filling cracks in the marls.

In the zone of granular halite of the Eskdale no. 2 evaporites, the mineral occurs in some abundance in samples from 3800–04, 3805, and 3824–26 feet. These are coarse halite-sylvine-rinneite-rocks, with very scarce anhydrite (figs. 4, 5B). Analyses show 3·22 % KCl at 3800–02 feet; 6·66 % KCl at 3824–26 feet. The halite forms colourless irregular grains up to three inches in width. In slice, it contains abundant elongated liquid-filled cavities, arranged in many cases along dodecahedral planes. The lines of inclusions are sometimes curved, and the individual inclusions streaked out and curved in common directions, giving evidence of movement of halite under strain. The halite cleavages are, however, regular and straight, showing that the halite has recrystallized after it was distorted. Sylvine occurs in these rocks as irregular milky-white grains, free from haematite inclusions, and reaching one inch in width. The sylvine grains contain many tiny rounded inclusions of halite. Rinneite forms patches rarely reaching 2 inches in width, with very irregular boundaries against halite and sylvine. In many cases these patches consist of a single large grain of rinneite; in other cases they

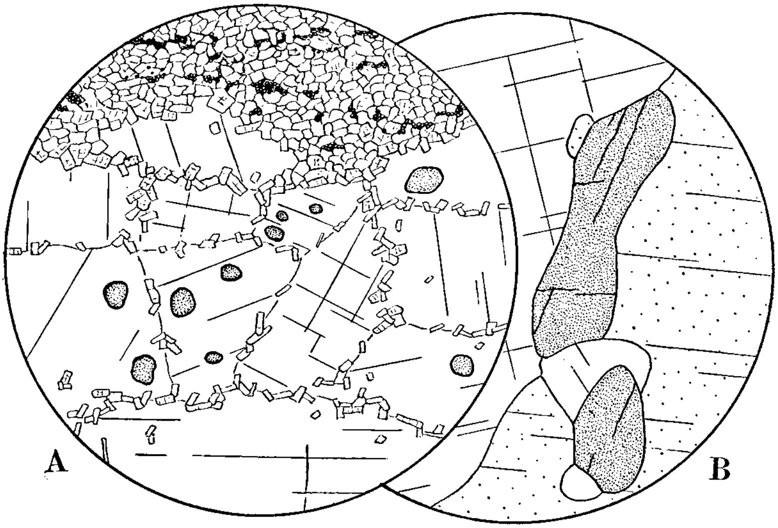

FIG. 5A. Halite-anhydrite-rinneite-rock, with (at the top) part of a layer of anhydrite-magnesite-rock. Rinneite (stippled) forms rounded relics, all having the same optical orientation. The distribution of anhydrite grains between halite grains suggests that this anhydrite has formed during or after replacement of a large rinneite grain by halite. 3810–12 feet. × 12.

FIG. 5B. Halite-sylvine-rinneite-rock. Two rounded relics of rinneite (heavily stippled) have common optical orientation, and the same orientation as larger grains outside the field of view. Rinneite has been replaced by sylvine (lightly stippled) and halite. 3802–04 feet. × 8.

consist of coarse-grained aggregates. The intricate nature of the margins suggests replacement of rinneite by both halite and sylvine, and this is borne out by the occurrence of small rounded relics of rinneite, in the same optical orientation as adjacent larger patches, enclosed in both halite and sylvine. In such a replacement $FeCl_2$ must have been removed in solution. The lack of displacement of the rinneite relics would indicate that the replacement took place at a late stage, after movement of the halite under the load of the overlying rocks.

Many other specimens from this zone show small quantities of rinneite, as rounded grains associated with halite. In two specimens (3810–12, 3812–14 feet) the mineral occurs with halite in layers up to a centimetre in thickness, between anhydritic and halite-rich layers. Although we do not know which was the upper side of the specimens, it seems likely that the succession from base to top is anhydrite-magnesite-halite-rock, halite-anhydrite-rock, halite-anhydrite-rinneite-rock. The specimens consist of a repeated series of these units. In these rocks, again, there is definite evidence of replacement of rinneite by halite. Small relics of rinneite, enclosed in halite, have common optical orientation over wide areas in thin section, so that the original rinneite must have occurred as large grains (fig. 5A).

The occurrence of rinneite in the layered series described above suggests that it may have been a primary mineral. There is no evidence that it has replaced any other mineral. However, the late recrystallization in these rocks would tend to destroy evidence of early replacements.

V. Rocks of the zone of silty halite.

The main divisions of this zone have been shown above in the table of the general succession, and it has been mentioned that the upper part of the zone was not cored. The minerals found are halite, sylvine, carnallite, anhydrite, magnesite, haematite, quartz, and talc. All these minerals may occur in the same rock. In addition, very small quantities of an unidentified green, highly deliquescent mineral, containing ferrous and potassium chloride, have been found as inclusions in halite.

There is a considerable quantity of brown silty material in many specimens, sometimes forming irregular layers, but normally occurring as patches between halite grains. This material consists largely of angular grains of quartz, with chloritic and clay material, a few flakes of muscovite, and haematite. Crystals of anhydrite and euhedral quartz are found in the silt patches, and these patches are impregnated with halite, and often veined by halite, anhydrite, and quartz. Silt is particularly abundant in the depth ranges 3738–56 and 3768–82 feet.

Halite varies from colourless to pink and reddish-brown, and is very variable in grain-size, the grains sometimes being as much as two inches across. Haematite inclusions in halite are relatively rare. The concentration of impurities in interstitial patches and the distortion of anhydritic and silty patches indicate that the halite has suffered widespread recrystallization. Sylvine is very scarce and occurs as small pink or red grains, full of haematite inclusions, associated with halite. Carnallite (α 1·467, β 1·475, γ 1·498, sodium-light) occurs in most specimens in very small amount, as irregular pink grains up to a few millimetres in diameter, associated with halite. These grains are free from haematite inclusions, and sometimes contain many small elongated euhedral crystals of anhydrite. No replacement involving carnallite or sylvine has been noted.

In the lower rocks of this range anhydrite occurs as thin contorted layers and patches, pink or brown in colour due to admixture with silty material. In the upper rocks anhydrite is not so abundant, and forms small patches, and isolated crystals enclosed in halite or associated with silt. The veining of silt patches by anhydrite shows that there has been some redistribution of this mineral. Beautiful examples of large recrystallized euhedral anhydrite plates enclosed in a very fine-grained anhydrite matrix are seen in several slices (fig. 6B). There has been some replacement of anhydrite by halite and by quartz.

Magnesite is very scarce, and only a few small grains have been observed. Haematite occurs as tiny hexagonal plates and rods enclosed in sylvine and rarely in halite, and is an abundant constituent of the silt patches.

Quartz is extraordinarily abundant, even more abundant than in the halite zone of the middle evaporite bed. Non-detrital quartz forms over 5 % of some slices. Euhedral crystals are found in large quantity projecting into halite from the edges of silt patches, and occur in smaller quantity as isolated crystals enclosed in halite, and in layers and patches of anhydrite. They frequently enclose detrital quartz grains, but have not normally grown in optical continuity with these. Quartz crystals enclosed in halite have been seen to contain a rectangular network of talc plates, lying parallel to the talc which lies along the cleavages of the enclosing halite. This indicates replacement of halite by quartz, after the formation of secondary talc (fig. 6A).

A few flakes of talc can be detected in most specimens, and this mineral becomes very conspicuous in the range 3768–82 feet. It occurs as very thin silvery plates, with irregular outline, up to a few millimetres across. Its characters are similar to those of the talc of the lower evaporite bed, and refractive index measurements give α 1·540, $\beta = \gamma$ 1·587. As in the lower evaporite bed, it is invariably associated with halite, and forms rectangular networks of plates lying along the halite cleavages. Intergranular boundaries between halite grains are sometimes lined with talc, and plates pass from these boundaries along the cleavages of the adjacent halite. It would appear that it is a secondary mineral (Stewart, 1949, pp. 665–669). Talc has recently been recorded from the potash-field of New Mexico, where it is considered to be secondary (Bailey, 1949).

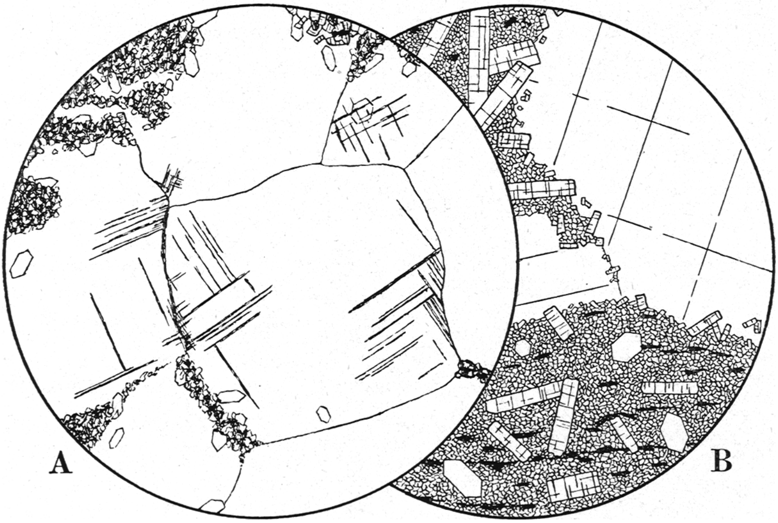

FIG. 6A. Halite-talc-quartz-rock, with some anhydrite, and patches of clastic material full of angular quartz grains. Talc plates lie along cleavages and intergranular boundaries of halite. Halite cleavages are not shown in this diagram except where talc is present. Euhedral quartz is abundant, and in the upper right quadrant talc plates pass through a quartz crystal, indicating replacement of halite by quartz after the formation of talc. 3780–82 feet. × 12.

FIG. 6B. Halite-anhydrite-quartz-rock, with elongated patches of clastic material. Patches of fine-grained anhydrite contain euhedral quartz and anhydrite porphyroblasts. 3782–84 feet. × 12.

VI. SUMMARY AND CONCLUSIONS.

The evaporite bed is 205 feet thick, and has been divided into three main zones; a basal anhydrite-rich zone; followed upwards by a zone of granular halite, with subordinate anhydrite and rinneite; and then a zone of silty halite, with subordinate anhydrite and a considerable quantity of clastic material.

Recent I.C.I. borings (Fleck, 1950) have proved a sylvine-halite zone in the upper evaporites of this potash-field. No such zone has been found in the rocks described here, but since the upper 80 feet of these evaporites was not cored it is possible that such a zone exists in that range. However, consideration of the sections published by Fleck suggests that this zone should lie above the granular halite zone with its rinneite-bearing rocks, but not far above this zone, and it seems quite possible that the sylvine-halite zone does not exist at this locality.

The following minerals have been found: anhydrite, carnallite, dolomite, haematite, halite, magnesite, quartz, rinneite, sylvine, and talc. The major constituents are halite, anhydrite, and magnesite. Quartz is even more abundant than in the middle evaporite bed. Talc is widespread in the zone of silty halite and is believed to be a secondary mineral. Rinneite is found over a range of 30 feet, and there is no evidence that it has replaced any other mineral. Early gypsum is represented by anhydrite-halite pseudomorphs in the basal zone. Quartz, magnesite, and potassium salts make an appearance, and dolomite disappears, much earlier in the succession than in the middle evaporite bed.

There has been widespread recrystallization of halite and anhydrite. There is evidence of the following replacements: anhydrite → gypsum → anhydrite and/or halite; anhydrite → halite; anhydrite → quartz; halite → quartz; rinneite → halite; rinneite → sylvine. The replacements involving gypsum are thought to have taken place at an early stage, during the deposition of the evaporites. If, as is thought probable, most of the halite has recrystallized under load, the other replacements may be late ones, since recrystallization of halite would tend to obscure the microscopic evidence of early replacements.

This paper concludes the petrological study of the evaporites of the Eskdale no. 2 boring. It may be said in general conclusion that the study has shown that each of the evaporite beds has its own distinctive characters. The evaporites from this locality show many features not as yet recorded from the outlying parts of the salt-field; in addition to the potassium salts and their associates, the occurrence of magnesite and quartz as important constituents is striking. Talc has not been recorded from the outlying districts, but I have seen this mineral in cores from the I.C.I. borings in the Guisborough-Redcar district. I have also seen abundant pseudomorphs of anhydrite after gypsum in a specimen from the D'Arcy Exploration Company's boring at Hayton, and these pseudomorphous rocks should be looked for in other parts of the salt-field. Although the British and German deposits show many features in common, there are also striking differences; the abundance of quartz, the presence of talc, and the relative scarcity of magnesium-bearing minerals in the chloride zones, are obvious examples. The recent borings should provide interesting data on the lateral and vertical distribution of the accessory minerals of these deposits and on the nature and extent of the replacements recorded, and will give much scope for research on the problems of salt petrology.

List of References.

BAILEY (R. K.), 1949. Talc in the salines of the potash field near Carlsbad, Eddy County, New Mexico. Amer. Min., vol. 34, pp. 757–759. [M.A. **11**–59.]

BELLANCA (A), 1948. La rinneite: strutture e relazioni cristallochimiche con la cloromanganocalite. Periodico Min. Roma, vol. 16, pp. 199–213. [M.A. **10**–533.]

BOEKE (H. E.), 1909a. Rinneit, ein neugefundenes eisenchlorürhaltiges Salzmineral. Centr. Min., pp. 72–75.

—— 1909b. Das Rinneitvorkommen von Wolkramshausen am Südharz. Neues Jahrb. Min., vol. ii, pp. 19–56.

—— 1909c. Die künstliche Darstellung des Rinneit auf Grund seines Löslichkeitsdiagramms. Sitz.-ber. Akad. Berlin, vol. 24, pp. 632–638.

—— 1911. Ueber die Eisensalze in den Kalisalzlagerstätten. Neues Jahrb. Min., vol. i, pp. 48–76.

CHENG (Chen-Wen), 1929. Beitrag zur Kenntnis des Rinneit. Diss. Leipzig, 62 pp. (Neues Jahrb. Min. Ref., 1931, vol. i, p. 53.)

FLECK (A.), 1950. Deposits of potassium salts in north-east Yorkshire. Chemistry and Industry, Supplement, October 17, 15 pp. [M.A. **11**–215.]

HARBORT (E.), 1928. Über Zirklerit. Ein neues durch Thermo-Dynamometamorphose gebildetes Mineral aus einigen Salzstöcken der norddeutschen Tiefebene. Kali und verwandte Salze, Halle, vol. 22, pp. 157–161. [M.A. **4**–14.]

HOLLINGWORTH (S. E.), and STEWART (F. H.), 1950. Exhibit of specimens from a deep boring for potash at Robin Hood's Bay, Yorkshire. Abstr. Proc. Geol. Soc. London, no. 1467, pp. 4–5.

LEES (G. M.) and TAITT (A. H.), 1946. The geological results of the search for oilfields in Great Britain. Quart. Journ. Geol. Soc. London, vol. 101 (for 1945), pp. 255–317.

RINNE (F.) and KOLB (R.), 1911. Chemische Natur, Bautypus und Vorkommen des Rinneit. Centr. Min., pp. 337–342.

Schaller (W. T.) and Henderson (E. P.), 1932. Mineralogy of drill cores from the potash field of New Mexico and Texas. Bull. U.S. Geol. Surv., no. 833, 124 pp., 39 pls. [M.A. 5-168.]

Schneider (O.), 1909. Zur Kristallform des Rinneits. Centr. Min., pp. 503-506.

Slavík (F.), 1912. Mineralogische Notizen. Bull. Internat. Acad. Sci. Bohème. (Neues Jahrb. Min., Ref., 1913, vol. ii, p. 9).

Stewart (F. H.), 1949. The petrology of the evaporites of the Eskdale no. 2 boring, east Yorkshire. Part I. The lower evaporite bed. Min. Mag., vol. 28, pp. 621-675.

—— 1951. The petrology of the evaporites of the Eskdale no. 2 boring, east Yorkshire. Part II. The middle evaporite bed. Min. Mag., 1951, vol. 29, pp. 445-475.

Zambonini (F.), 1931. Le ricerche chimiche eseguite sui materiali della zona vulcanica della Campania . . . Boll. Soc. Geol. Italiana, vol. 49, pp. 179-264. [M.A. 5-2691.]

—— and Restaino (S.), 1925. Sulla presenza del cloruro ferroso fra i prodotti dell'attuale attività del Vesuvio. Annali R. Osservatorio Vesuviano, ser. 3, vol. 1 (for 1924), pp. 121-126. [M.A. 3-104.]