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Albite and other authigenic minerals in limestone from Bengal.

(With Plate V.)

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[Read June 16, 1925; communicated by Professor P. G. H. Boswell.]

IN that part of the Gangpur State immediately to the north of the Bengal-Nagpur Railway between Biara and Garpos, lies a tract of dolomite- and limestone-bearing country which has been referred, on lithological grounds, to the Cuddapah (? Algonkian or Palaeozoic) formation.[1] From this area, all the dolomite and most of the limestone requirements of the Bengal iron and steel industry are at present derived, and the close proximity of the enormous haematite ore reserves of Singhbhum indicates a still greater economic importance for these materials in the future.

The most northerly and extensive of these deposits is situated about twelve miles north of the railway, near the village of Raipura. This area was mapped and examined in detail by the writer in 1920, on behalf of Messrs. Bird and Company, Calcutta, with a view to its systematic development on a large scale.

[1] J. M. Maclaren, Rec. Geol. Survey India, 1904, vol. 31, p. 73.

Field Characters, Stratigraphical Relationships.

The beds have a high angle of dip (usually of the order of 70° to 80°) in a northerly direction. The strike is mainly east and west with local variations due to folding. The succession from south to north is approximately as follows:

	Approximate thickness.
White or grey crystalline dolomite	300–450 feet.
Calcareous sandy beds	400–600 ,,
White or flaggy grey crystalline dolomite	200–800 ,,
Fine sandy grey flaggy dolomites (transitional)	50–100 ,,
Banded white and grey granular limestone passing into Massive or flaggy grey limestone (with albite zones)	1000–2000 ,,
Ferruginous black shales or mudstones. Sandstones ...	Indefinite.

From some hundreds of chemical analyses of these calcareous beds, the following facts are selected as having a possible bearing on the conditions of sedimentation.

(*a*) The dolomite, on the whole, contains less insoluble matter than the limestone, but this condition does not necessarily hold locally. The non-soluble portion of the dolomite is mainly fine-grained argillaceous or micaceous matter. In the limestone it may be argillaceous or sandy. The albitic limestone has usually a lower total alumina-content than the argillaceous non-albitic limestone.

(*b*) Traces of pyritic material occur disseminated through the dolomite and limestone, with a tendency to segregation in the argillaceous bands of the limestone.

(*c*) Carbonaceous matter occurs throughout the grey limestone. It is found inside the albite, quartz, and tourmaline crystals, and is more abundant in the argillaceous bands than in the purer limestone. The dolomite is mostly free from carbonaceous matter.

(*d*) In the field, the change from dolomite ($MgCO_3.CaCO_3$) with 21 per cent. MgO to limestone with less than 6 per cent. MgO takes place rapidly, and has evidently resulted from a change in the conditions of sedimentation.

The transition-beds are mostly dolomitic and sandy. They vary from white at the base to dark-grey at the top. The thickness of these beds is usually less than 50 feet.

These facts suggest that the dolomite was formed under clear-water conditions. Changes then set in which brought fine sandy sediment. Next followed conditions favourable to the deposition of calcium carbonate together with some organic matter and occasionally argillaceous and sandy material. It was during the last-mentioned stage that the conditions appear to have been favourable to the formation of authigenic albite, quartz, etc.

Albite zones.

The albite zones occur from about the middle to near the top of the grey limestone. The boundaries of the zones are not very definite, but their general arrangement is parallel to the bedding. The largest 'zone' has a maximum width of about 150 feet and can be traced for about 3/4 mile along the strike.

The albite crystals usually occur sparsely scattered through these zones, but in some places they are so crowded as to leave an adherent skeleton of crystals after solution of the limestone in acid. The crystals usually weather out on the bedding-planes of the limestone slabs as tabular lozenge-shaped individuals ranging from one or two millimetres to a little over a centimetre in length.

The limestone associated with the albite is usually fairly free from argillaceous material, but some of the banded limestone contains albite crystals in the calcite material between the argillaceous layers. A few smaller ill-defined crystals sometimes occur in the argillaceous substance itself.

Description of the Minerals in the Albitic Limestone.

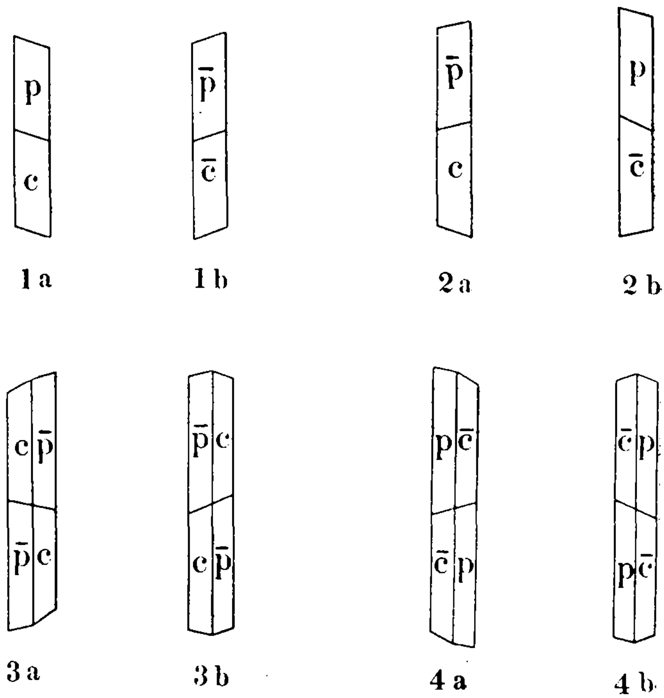
On solution of the albitic limestone in hydrochloric acid, a dark-grey residue containing the following minerals remains:—

(1) Albite, as crystals and crystal-fragments.
(2) Quartz, as grains and terminated prisms.
(3) Mica, as flakes, some with hexagonal outlines.
(4) Pyrite, as crystals and spherical aggregates.
(5) Tourmaline, as stout prisms or slender rods and fragments.
(6) Rutile, as crystals and fragments.
(7) Sphene, as partly-rounded fragments.
(8) Zircon, as crystals and grains.
(9) Garnet, as rounded grains.

The relative amounts of albite, quartz, and mica vary with the proportion of argillaceous matter present in the limestone; together they constitute the main bulk of the residue. Zircon, sphene, and garnet are scarce. The characters of each mineral will now be described.

(1) *Albite.*

Crystal-Habit.—The albite crystals have the form of lozenge-shaped tablets flattened on *b* (010), and bounded on the edges by the faces *c* (001) and *p* ($\bar{1}$11). Small rudimentary prisms of the form *f* (130) sometimes truncate the acute angle of the lozenge. The length of the crystals,



Twinning of Albite crystals.

(Diagrammatic sketches. c = (001), $\bar{c}$ = (00$\bar{1}$), p = ($\bar{1}$11), $\bar{p}$ = (1$\bar{1}\bar{1}$).)

Fig. 1. (*a*) Fundamental lozenge; (*b*) same rotated through 180° about the normal to (010), i. e. Albite twinning. Top or bottom views.

Fig. 2. (*a*) and (*b*). Forms obtained by conjunction of 1 (*a*) and 1 (*b*) on composition-plane (100). Top or bottom views.

Fig. 3. Right-handed twin, obtained by twinning 2 (*a*) on the Carlsbad-law: (*a*) front or back view, (*b*) top or bottom view.

Fig. 4. Left-handed twin, obtained by twinning 2 (*b*) on the Carlsbad-law. (*a*) front or back view, (*b*) top or bottom view.

measured on the long diagonal, reaches a maximum of a little over a centimetre. The cleanest and best-developed crystals are usually one to two millimetres long. The thickness varies from about one-tenth to one-fifth of the length. Pl. V, fig. 1, shows a group of small crystals mounted on the brachy-pinakoid and viewed by transmitted light. The acute angle of the lozenge formed by the intersection of (001) and $(1\bar{1}\bar{1})$ with (010) is seen to be about 52°.

Twinning and Parallel Growth.—The albite crystals all show twinning on the Carlsbad-law, with composition-plane (010). This would bring a pyramid-face $(\bar{1}11)$ against the basal plane (001) along each edge of the lozenge. Simple Carlsbad-twinning, however, would not suffice to explain the following peculiarities exhibited by these crystals:

(*a*) The angle between the brachy-pinakoid (010) and the adjacent basal plane (001) is acute (86°30′) along each of the four edges of the lozenge.

(*b*) There are no re-entrant angles between the (001) and $(\bar{1}11)$ faces.

(*c*) The oblique and very obtuse 'roof' formed by $(001:\bar{1}11)$ slopes alternately in opposite directions from (010) along adjacent edges of the lozenge.

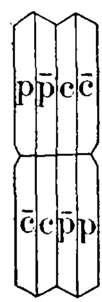


FIG. 5. *Albite*-Carlsbad (Roc Tourné) twin of Albite. (After G. Rose.)

These characters give rise to right-handed and left-handed twin-forms, both types being developed in the Raipura crystals. In the one, the front upper basal plane is on the left with the slope of the 'roof' to the right (fig. 3 *b*); in the other, the front upper basal plane is on the right and the slope is to the left (fig. 4 *b*).

A simple manner in which this twin form can be obtained from the fundamental lozenge (fig. 1 *a* and *b*) showing the forms (010), (001), and $(\bar{1}11)$, is to assume first an albite-twin, with twin-axis normal to (010) and composition-plane (100) (fig. 2 *a* and *b*). If two of these twins fig. 2*a* are now twinned on the Carlsbad-law, the right-handed twin fig. 3*b* results. The same process of Carlsbad-twinning with two of the twins fig. 2*b* results in a left-handed twin fig. 4*b*.

Somewhat similar crystals have been described by G. Rose (29)[1] and by A. Lacroix (17) from the Modane limestone. In these, other combinations also occur, and the Roc Tourné and Carlsbad-twinning is usually accompanied by simple albite-twinning, the forms shown in plan in fig. 5 being commonly developed. By the suppression of the two inner albite lamellae, twins of the type described above are yielded.

[1] *Numbers in parentheses refer to the list of papers on p. 379.*

In the Roc Tourné crystals, there is generally a vertical 'gutter' along each of the (010) faces, owing to the development of prism-faces, the Roc Tourné contact-plane being (100). In the Raipura albite-twins these gutters were not observed. Sometimes an irregular line along the (010) faces marks the position of the surface of composition. A. Lacroix has pointed out that in addition to the right- and left-handedness, some of the Roc Tourné twins show different terminations on the front and back of the crystal. Parallel growth extending along the vertical axis is also noted (17, pp. 166–7). Both these features are common also in the Raipura albites, as is indicated by pl. V, figs. 1 and 2, showing such crystals viewed on (010).

Inclusions.—The crystal-faces are rarely as sharp and clear as those of the Roc Tourné albites. The surface is usually rough or pitted, often coated with dark-coloured carbonaceous or ferruginous matter and sometimes spangled with flakes of mica. Some of the larger crystals show small quartz prisms growing out from the rudimentary prism-faces of the albite, or from the acute end or edges (001 : $\bar{1}$11) in a direction normal to the pinakoid (100). The smaller crystals, especially from the purer granular limestone, are sometimes fairly clean and free from included matter. These are of a light-grey colour. The albite from the less pure limestone, especially near the argillaceous bands, is usually dark-grey to black in colour, and often crowded with inclusions of carbonaceous matter or small mica-flakes. A rude attempt at arrangement of the carbonaceous material along crystallographic directions in zones, especially parallel to (001), is sometimes seen. The centre of the crystal is often opaque with inclusions, the outer portion being relatively clear (see pl. V, fig. 2).

The included mica is mainly oriented with the basal plane parallel to the brachy-pinakoid of the albite crystal. The flakes are frequently idiomorphic, with hexagonal outlines and bevelled edges (see pl. V, fig. 5).

Extinction-angles.—In sections giving a uniform extinction on (010), the extinction relative to the basal cleavage varies from about 18·5° to 22°. The extinction seen on cleavage-fragments parallel to (001), measured on the trace of (010), varies from 1° or 2° up to about 6°.

Chemical Composition.—The following analyses, the first by Mr. K. B. Sen, B.Sc., of Messrs. Bird and Company, Calcutta, and the second by the writer, were carried out on selected large crystals, clean but dark-grey to black in colour :—

	No. 1.	No. 2.
Silica (SiO_2)	66·95 ...	67·10 per cent.
Alumina (Al_2O_3)	19·72 ...	19·95 ,,
Ferric oxide (Fe_2O_3) ...	0·50 ...	0·55 ,,
Calcium oxide (CaO) ...	0·66 ...	0·50 ,,
Magnesium oxide (MgO) ...	0·88 ...	0·70 ,,
Potassium oxide (K_2O) ...	0·52 ...	0·60 ,,
Sodium oxide (Na_2O) ...	9·95 ...	10·30 ,,
Ignition loss	0·63 ..	0·85 ,,
	99·81	100·55

The mineral is practically pure albite. Small quantities of included mica would account for the magnesia and some of the potash. The lime is remarkably low for a felspar associated with calcium carbonate, a feature which has been noted in other occurrences of albite in limestone and dolomite.

(2) *Quartz.*—This mineral occurs in the form of irregular grains and as doubly-terminated prisms up to 2 mm. in length. Crystal-faces are rarely well developed. Abundant carbonaceous or graphitic inclusions occur within many of the crystals, with some attempt at zonal distribution. Some individuals have rejected the impurity towards the ends of the prism, then included it as a dense zone beyond which a further growth of relatively clear quartz may be seen (pl. V, fig. 4). Many of the irregular grains of quartz appear to consist of aggregates of rudimentary crystals grown together on the rhombohedral faces.

(3) *Mica* occurs mainly as irregular plates up to 1 mm. diameter. Some of the flakes show hexagonal outlines and bevelled edges, especially when included in the albite crystals (pl. V, fig. 5). The colour varies from pale yellow to brownish-yellow, and the flakes are sometimes dark with carbonaceous inclusions. The optic axial angle varies from a few degrees up to about 20°. The mica is probably phlogopite.

(4) *Pyrite.*—This mineral occurs mainly as spherical grains, about 0·05 mm. in diameter, but a number of small faceted crystal-aggregates showing cubic symmetry occur.

(5) *Tourmaline* occurs as prisms, 0·1 to 0·04 mm. long, colourless to pale yellowish-brown. The crystals show hemimorphic terminations, but the end-faces are usually not well developed. Abundant carbonaceous or graphitic inclusions occur within the crystals. Sometimes two or more prisms are seen growing together. The mineral appears to be authigenic.

(6) *Rutile* and (7) *Sphene.*—Small idiomorphic foxy-red crystals of rutile 0·1 to 0·02 mm. in length occur, often associated with irregular fragments of sphene in such a manner as to suggest a genetic relationship

between the two minerals. The rutile frequently shows geniculate twinning. Some of the mineral grains are partly rounded and may be detrital.

(8) *Zircon.*—A few partly-worn crystals of zircon occur, clear and free from inclusions. The mineral is clearly detrital.

(9) *Garnet.*—Occasional rounded grains of pink garnet, 0·15 mm. in diameter, were observed. These grains are obviously detrital. No inclusions were seen.

Numerous irregular fragments, up to 0·15 mm. diameter, of a positive uniaxial mineral with high refractive index (about 1·72) and strong pleochroism from light greenish-yellow to pinkish-brown were also observed. Most of these fragments appear to be aggregates of smaller individuals. This mineral has not been identified with certainty.

The mineral residues from the adjacent banded limestone and dolomite were also examined for comparison with the mineral assemblage of the albitic limestone. The banded limestone contained much the same mineral assemblage as the albitic limestone, except for the absence of albite crystals and the smaller proportion of quartz. The mica and tourmaline were of lighter colour and contained fewer carbonaceous inclusions than those of the albite-zones. In the dolomite, the residue consisted almost entirely of light yellow to practically colourless mica and colourless tourmaline crystals. The latter show little, if any, pleochroism and no carbonaceous inclusions. These colourless tourmalines are of perfect form, but somewhat smaller than those of the albite zones.

Authigenic Nature of the Albite.

The idiomorphic form and other characters of these albite crystals preclude a clastic origin. A metamorphic explanation would also involve many difficulties, amongst which are (*a*) the arrangement of crystals in zones parallel to the bedding, (*b*) the absence of other minerals of purely metamorphic origin, (*c*) the source of the sodium, and (*d*) the relative purity of the albite, especially freedom from lime.

The limestone has certainly suffered metamorphism, and in places the folding has been intense. This metamorphism, however, does not appear to have resulted in any mineralogical rearrangement, and the albite present in the folded areas has shared in the metamorphism, having become strained and sometimes shattered, without evidence of reconstitution. The fractures are often clean and sharp, the crystals having obviously been formed prior to this movement. Pl. V, fig. 3 shows a section of albitic limestone from a folded area. The large splintered albite crystal has developed albite-twinning and undulatory extinction as a result of pressure. The fractures are seen to be clean.

The adjacent dolomite and banded limestone have been folded in the same manner and yet contain little or no felspar. There are no signs of igneous activity in the neighbourhood. It appears highly probable, therefore, that this albite is authigenic, in which case a similar origin for the idiomorphic quartz crystals, the pyrites, the rutile, most of the mica, and probably most of the tourmaline, might also be possible. The individual crystals of this mineral assemblage often exhibit good crystal-outlines and contain abundant carbonaceous inclusions, either scattered or arranged in zones. In the case of the mica included within the felspar, the two minerals have obviously grown simultaneously in parallel arrangement.

This view of an authigenic origin for these minerals is strengthened by a comparison with other recorded occurrences of felspar in sedimentary limestones and dolomites, many of which have been definitely shown to be authigenic.

Comparison with other occurrences.

One of the earliest recorded occurrences of albite in sedimentary dolomite appears to be that by G. Rose (29), who described and figured the peculiar 'fourlings' found in the dolomite of the Alpine Trias, near Modane, Savoy. These twin-crystals are illustrated in Dana's 'System of Mineralogy' and are generally termed 'Roc Tourné' twins. The crystals are twinned once on the albite-law and once on the Carlsbad-law, with the plane of composition (100). A development of prism-faces at the contact-plane due to the grouping of two individuals on (100) gives rise to the characteristic vertical trough on each side-pinakoid.[1]

A few years before G. Rose described these crystals in detail, A. Drian (7), in a note on the same occurrence, pointed out that the crystals contained a small quantity of opaque mineral, but no dolomite, adding that from the manner in which they were disseminated, it could be inferred that they had developed while the rock was in process of formation and not as a result of subsequent metamorphism. He also pointed out that a neighbouring black dolomitic limestone contained albite crystals of a similar type, although smaller and dark in colour. This rock left a black mud on solution in acid, which consisted of ferruginous clay, albite, and carbonaceous matter. The albite crystals were black with inclusions, but became white on ignition. The crystal-faces were rough and the crystals a little deformed, but the habit and twinning established an identity of crystallization with that of the Roc Tourné albite.

At about the same time C. Lory (21) examined these occurrences and arrived

[1] The writer has been able to examine samples of the dolomite and albite crystals from Modane forwarded by Professor L. Cayeux to Professor P. G. H. Boswell, at the University of Liverpool.

at very similar conclusions regarding the origin of the albite, namely, from aqueous solution at a temperature certainly not high. He noted that the limestone which contained these crystals was no more crystalline or more altered in appearance than very many of the fossiliferous Alpine limestones; and its structure was exactly that of the limestone which at the Fort of Eseillon contained imprints of shells. The crystals were sharp and all traces of fusion were absent. He concluded that they were formed while the rock was still in the state of mud.

Later, the same writer (22) showed that albite of microscopic dimensions occurs throughout the greater part of the Triassic dolomite of the western Alps, and further (25) showed that microscopic crystals of felspar (which he referred to orthoclase) were of persistent occurrence in many of the Jurassic limestones of the French Alps. He found such microscopic orthoclase crystals actually within an ammonite shell. Lory pointed out the common occurrence of doubly-terminated quartz, pyrite, and bituminous matter in association with the orthoclase, and of idiomorphic quartz and mica with the albite. In one instance he found small tourmaline prisms associated with the microscopic albite in a belemnite-bearing limestone belonging to the Lias, near Vilette. He concluded that the formation of these disseminated felspars was independent of the local mechanical metamorphism involved in the Alpine movement and suggested that their origin was related to the special characters of the deposits and to conditions which favoured their crystallization.

In 1879 C. de Stefani (32) described small albite crystals in dolomitized limestone belonging to the Trias of the Apuan Alps. The crystals showed double twinning.

G. Spezia (31) in 1880 described an occurrence of albite in a foraminiferal magnesian limestone from Argentera (Cuneo). The crystals were tabular on (010), with a maximum length of 3 mm. and were twinned on the Roc Tourné plan. The albite occurred in association with doubly-terminated quartz prisms, bituminous matter, and some graphitic carbon. Carbonaceous matter was also scattered through the albite crystals. A section of the limestone, containing skeletons of *Turbinolia* and an albite crystal, is illustrated in Spezia's paper. He indicated the close resemblance of this occurrence to that described by C. Lory from Villarodin.

A. Lacroix in 1888 (16) described an occurrence of macroscopic albite crystals in the yellow Chalk of the Upper Pyrenees, and later noted a somewhat similar occurrence in the Lower Pyrenees. In the former, the felspar occurred in association with quartz and leuchtenbergite. The albite was twinned on the Carlsbad-law and was of Roc Tourné type. The crystals attained a length of 4 mm. In the Lower Pyrenees (near Escambele), the albite was associated with phlogopite, pyrite, and leuchtènbergite in the limestone at or near a contact with diabase (lherzolite).

Later, in his 'Minéralogie de la France', Lacroix (17) reviewed the accounts of albites in sedimentary limestones and dolomites, and attributed the above, together with somewhat similar occurrences in limestones of the Upper Garonne and Algiers, to contact metamorphism by diabase and lherzolite. The Roc Tourné albites of Modane and the valley of the Arc were regarded as formed beyond the action of eruptive rocks, but he suggested that the apparent absence of such rocks required confirmation, and remained of the opinion that the felspar was of hydrothermal origin. He recorded the occurrence of small tourmaline prisms and sphene in association with the albite of the Modane limestone and dolomite.

In 1886 F. J. Kaufmann (15) recorded microscopic albite crystals, less than 0·1 mm. in length, together with quartz prisms, from the Jurassic, Cretaceous, and Eocene limestones of the Swiss Alps.

A. Issel (13, 14) in 1890 recorded the occurrence of macroscopic albite crystals enclosing radiolarian remains in a calciphyre of Eocene age, near Rovegno, Pavia. The calciphyre is associated with hardened black siliceous schists, serpentine, and diabase, and contains numerous species of radiolaria, a few of which were also observed within or partially enclosed by the albite crystals, together with numerous opaque inclusions. The albite crystals formed tablets reaching 10 to 20 mm. in length, flattened and twinned on (010). Issel remarked that in this case a fossiliferous sediment of Tertiary age, rich in plagioclase felspar, had been recrystallized without derangement of stratification. He concluded that the phenomenon was brought about by hydrothermal action.

An important contribution to these occurrences of authigenic felspars was made by H. B. Foullon in 1891 (8). Working on the Eocene limestone of the Island of Rhodes, in the Aegean, he found macroscopic crystals of albite up to 2 or 3 mm. in length. The crystals were tabular on (010) and showed albite-twinning; more rarely Carlsbad-twinning was present. The Roc Tourné type was rare or absent. The crystals contained numerous inclusions, some of which occurred as six-sided plates arranged parallel to the brachy-pinakoid of the felspar. These were possibly mica. Analysis showed the felspar to be practically pure albite, and Foullon concluded that the albite had grown *in situ* during the slow deposition of the calcareous sediment. The importance of this contribution lies in the fact that it is the first instance of macroscopic felspar being definitely and unquestionably regarded as of authigenic origin.

In 1895 L. Cayeux (2) recorded microscopic felspars in the mineral residues of the Chalk from the Paris Basin. The crystals were clear and untwinned, the length being about 0·1 mm. or less. On microchemical and optical evidence he referred the felspar to orthoclase and concluded that the mineral was authigenic.

Cayeux also described (3) an occurrence of macroscopic albite crystals in the dolomite of the Cretan Trias.[1] A fault of large throw brings the dolomite against a bed of gypsum. The albite crystals abound in the dolomite near the fault, but are absent in the adjoining gypsum. He concluded from this that the albite has not been produced by the general metamorphism which had been held to account for the production of macroscopic crystals of albite in the Alpine Trias, but that their formation is connected with the local dislocation of the beds. The crystals were tabular on (010), with a length and breadth of about 7·5 mm. or less. They were dark-grey in colour, and full of minute, rounded, inclusions of carbonaceous matter and of a mineral of high refractive index. These inclusions became crowded together along certain zones, mainly parallel to crystal-faces in the zone of (100) and (001). The crystal-faces were clear and sharp and the individuals were all twinned on the albite-law.

[1] A specimen of this dolomite was kindly sent by Prof. Cayeux to Prof. Boswell of the University of Liverpool. Plate V, fig. 6, shows a number of the crystals mounted on (010) and photographed by transmitted light. The crystal-form and the zoned arrangement of the inclusions is clearly seen.

In 1909 and 1910 F. Grandjean (9, 10, 11) published the results of a detailed examination of the authigenic felspars, at first thought to be orthoclase, of the Chalk of the Paris Basin. He recorded the occurrence of similar felspars at various other horizons in Cretaceous and Jurassic limestones at other French localities. Analysis proved the felspars to be the potash variety, and on microscopic evidence he referred them to microcline. The crystals were found to contain numerous inclusions of calcite and of an opaque substance, often arranged along surfaces following the crystal outline. Many of the individuals consisted of aggregates of smaller crystals in parallel-growth. The dimensions ranged from 0·05 mm. downwards. He noted that the optical features were in many respects peculiar to these authigenic felspars and were such as are not found in felspars of igneous origin. Some of the crystals appeared to have formed about a kaolinized grain of detrital felspar. He pointed out that limestone of lacustrine origin does not appear to yield authigenic felspar. He also recorded the occurrence of microscopic authigenic felspar in the *Fusulina cylindrica* zone of the Carboniferous Limestone of Miatschkows, near Moscow, which is worthy of note as being the first recorded occurrence of authigenic felspar in Palaeozoic rocks. The felspar crystals were small and occurred in the familiar form of simple Carlsbad-twins composed on (010), elongated parallel to the vertical axis, and sometimes displaying a little interpenetration. Grandjean concluded that in all the occurrences of authigenic felspars recorded by him, the felspars had grown relatively rapidly during slow sedimentation and that the crystals probably ceased to grow after being once buried. He considered it highly probable that felspar is at present crystallizing out on the sea-bottom.

More recently, D. Trümpy (33) and A. Heim (12) have described authigenic albite in association with other authigenic minerals in the Jurassic limestones of Switzerland. D. Trümpy, working on the strata of western Switzerland, found microscopic albite and orthoclase in the Tertiary Flysch, the albite being characterized by lamellar-twinning and the orthoclase by simple Carlsbad-twinning. At various horizons in the Jurassic limestones of the same region he found authigenic albite associated with authigenic mica and sometimes with authigenic idiomorphic quartz crystals. The albite was usually less than 0·08 mm. across. The mica was of about the same dimensions, and varied from brownish to colourless.

A. Heim (12) found albite in association with ankerite and pyrite, all authigenic, in the Jurassic limestone (Argovian and Bajocian) of the Churfirsten-Mattstock group of the Swiss Alps. The albite occurs up to 0·2 mm. in length and contains calcite inclusions.

R. A. Daly (5) in 1917 epitomized some of these accounts of authigenic felspars in European limestones and dolomites and pointed out the features which they possess in common. He described an occurrence of orthoclase in the dolomite of the Waterton formation (Alberta) which he believed to be authigenic. The felspar occurred as glass-clear grains, 0·01 to 0·05 mm. in diameter, or as cementing material to the dolomite grains. Sometimes the felspar was in such quantity as to constitute about 40 % by volume of the rock. The beds are of Cambrian or pre-Cambrian age, but are devoid of any signs of metamorphism, by igneous action or otherwise.

J. de Lapparent (18) has recorded the occurrence of authigenic albite and quartz crystals in the Flysch (Upper Cretaceous) limestone of the Pyrenees.

The albite existed as microscopic crystals flattened on (010) and twinned on the albite- and Carlsbad-laws. Some crystals consisted of two *generations*, both flattened on (010), the first elongated parallel to the edge (110 : 1$\bar{1}$0), and the second forming lozenge-shaped hexagons limited by the forms (001), (110), (1$\bar{1}$0), ($\bar{1}$01). The Carlsbad-twinning of the first generation was masked by the grouping of the second. The albite only occurred in the lower littoral zone of the Flysch and in that part of the limestone which consisted of small granules. This granular limestone had been produced in part by the action of algae of the *Girvanella* group, and de Lapparent suggested that these algae had been the possible 'first cause' in the production of the felspar. The felspar was not found in the associated marine beds nor in the two upper divisions of the Flysch. He concluded that the microscopic study of these crystals and associated limestone necessitated the view that the felspars were produced at the time the rocks acquired their crystallinity. The same author has recently described (20) the occurrence of authigenic felspar and quartz crystals in the Muschelkalk of Alsace and Lorraine. The quartz forms small terminated prisms containing numerous minute inclusions of calcite. The felspar crystals are microscopic and are referred to orthoclase and microcline. He suggested that algae were here also instrumental in causing the formation of the felspar crystals.

Additional references to the occurrence of felspars and other authigenic minerals in limestones and iron-formations will be found in the bibliography on pp. 379–380.

Summarizing the various European occurrences and comparing them with the albitic limestone of India, we observe:

(1) In all cases the felspar occurs disseminated through the limestone or dolomite in beds or zones, under such circumstances as to render a clastic origin, and in most cases a metamorphic origin, impossible.

(2) The felspar is often macroscopic. One instance of macroscopic albite described by H. B. Foullon resembles the Raipura (Indian) occurrence in many of its features. Foullon, apparently without hesitation, described this albite as authigenic.

(3) The Indian and many of the European occurrences contain idiomorphic quartz, mica, pyrite, and bituminous matter in association with the felspar. The bituminous matter and mica sometimes occur within the felspar.

(4) The Indian limestone also contains small disseminated tourmaline rods and prisms. Two European occurrences have been noted in which small tourmaline crystals also occur in association with albite.[1]

(5) The macroscopic albite in the dolomite of the Alpine Trias has generally been ascribed to hydrothermal metamorphism developed under

[1] H. Wichmann (Neues Jahrb. Min., 1880, vol. ii, p. 294) has described authigenic tourmaline in sandstones, but did not observe felspar of similar origin.

the influence of eruptive basic igneous rocks with which the rocks are sometimes associated. One of the early observers, A. Drian, suggested, however, that the Modane albite was of authigenic origin, on the grounds of its disseminated occurrence through the dolomite and limestone. C. Lory arrived at very similar conclusions with regard to the origin of these occurrences, and later showed that albite of microscopic dimensions occurred throughout the Trias of the French Alps, often in regions removed from possible metamorphic action. L. Cayeux showed that hydrothermal or regional metamorphism could not account for the occurrence of albite in the Trias of Crete, and drew attention to the wide distribution of albite in the limestone and dolomite of the Trias from the French Alps to the Eastern Mediterranean.

It seems highly probable, therefore, that in these cases the felspar in sedimentary limestones and dolomites is of authigenic origin.

Summary and Conclusions.

Idiomorphic albite crystals occur disseminated through certain zones in limestone of Cuddapah age at Raipura, India. The felspar occurs in association with idiomorphic quartz, mica, rutile, pyrite, carbonaceous matter, and some small prisms of tourmaline. The albite crystals often contain included crystal-plates of mica and dispersed carbonaceous matter. The quartz, mica, and tourmaline also contain included carbonaceous material. The limestone has been metamorphosed by later movements and the albite crystals have been fractured and strained. There is no evidence of reconstitution along the fractures. Associated banded limestones contain little or no albite, but idiomorphic quartz, mica, pyrite, and carbonaceous matter are present, together with some tourmaline rods. The dolomite below the limestone contains mica and small, almost colourless, prismatic tourmaline crystals free from carbonaceous matter. A little pyrite and very little quartz are present, but no albite.

From the available evidence, it appears highly probable that the albite in the Cuddapah limestone is authigenic, and this view is strengthened by a comparison with other occurrences of felspar in limestones and dolomites. The evidence for an authigenic origin for the idiomorphic quartz crystals, the mica, the pyrites and rutile, and possibly for the tourmaline crystals, is also strong.

In conclusion the writer wishes to express his great indebtedness to Professor P. G. H. Boswell for continuous help, especially with regard to foreign references, and for his kind advice and criticism while the work was in progress at the University of Liverpool; also for seeing this paper through the press. In addition, he desires to thank Messrs. Bird and Company, Calcutta, for permission to publish analyses and other information relating to the Raipura limestones.

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Explanation of Plate V.

Figs. 1–5 from the limestone of Raipura, Bengal.

FIG. 1. Small albite crystals from Raipura limestone, seen on the face (010) by transmitted light. Note lozenge-shaped tabular habit, pitted surfaces, and included carbonaceous matter. × 6.

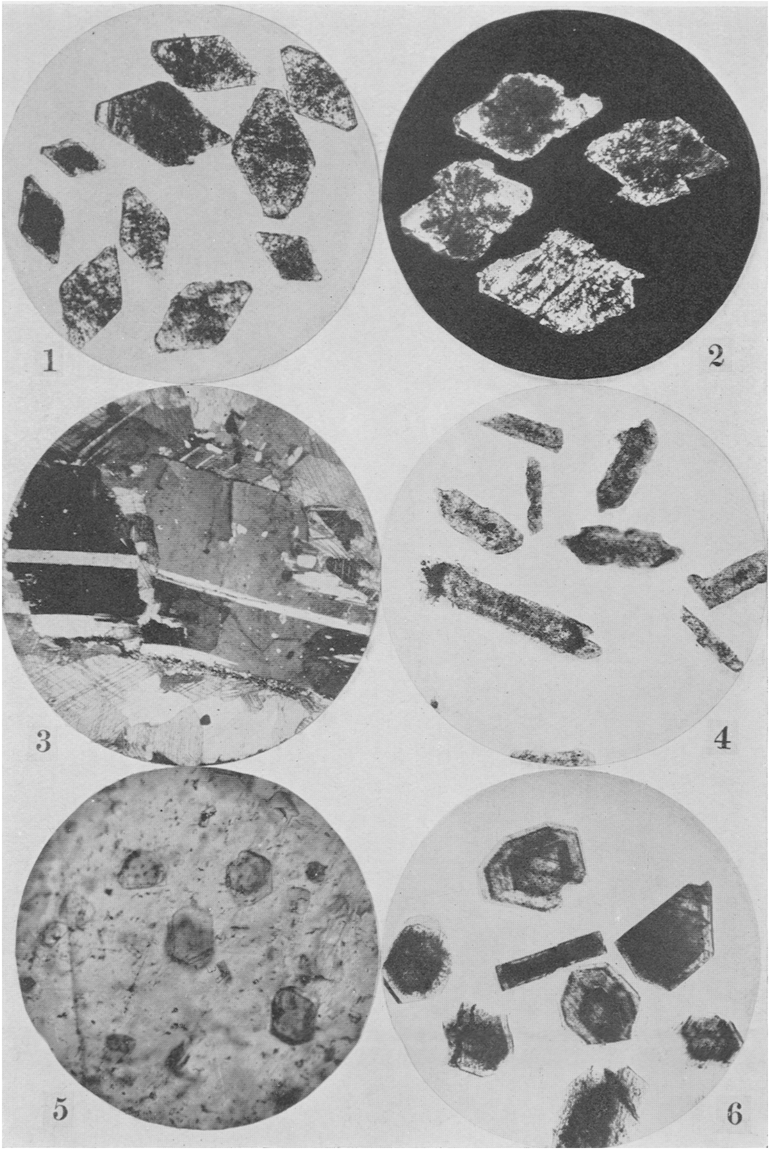
FIG. 2. Selected small albite crystals showing tendency to form 'fourlings' with (010) common. Crossed nicols. × 7.

FIG. 3. Section of albitic limestone showing broken and partly-bent albite crystal. Note clean fracture and slight pressure-twinning. Crossed nicols. × 12.

FIG. 4. Authigenic quartz crystals from albitic limestone. Note carbonaceous zones enveloped by clear quartz. × 15.

FIG. 5. Section of an albite crystal cut parallel to (010), showing small idiomorphic mica crystals (phlogopite ?) arranged with basal plane parallel to the (010) face of the albite crystal. × 80.

FIG. 6. Albite crystals from dolomitic limestone, Crete. × 6.



E. SPENCER: ALBITE, ETC., IN LIMESTONE.