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NOTES ON THE OCCURRENCE OF ZEOLITES, ARDGLEN, NEW SOUTH WALES.

By

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(Plates xxvii-xxix; Figs. 1-3.)

Some years ago the New South Wales Railway Commissioners opened up a quarry of basalt, situated on the western side of the Great Northern Railway Line, about a quarter of a mile north of Ardglen railway station. The "blue metal" is used by the Commissioners for road-making, ballast, etc. At the present time the quarry face is about a hundred feet high and seventy-five yards wide; from here the Museum obtained over two hundred and fifty specimens, more than half of which were collected by the Director, Dr. C. Anderson, M.A., the remainder being either presented by Messrs. A. Mitchell and H. Gosden or collected by the writer.

At least three distinct basalt flows have been recognised. The uppermost flow is columnar and is separated from the middle flow by an irregular band of very coarse volcanic breccia (Fig. 1). It has yielded only a comparatively few zeolites, the majority having been obtained from the tuff and the middle flow. It is remarkable that, while there is an abundant supply of zeolites, the range of varieties is small.

The Upper Flow (Pl. xxvii, fig. 1): It is impossible to estimate the thickness of this, owing to the eroded state of the surface, but its greatest would be at least a hundred feet. Columnar structure is very well developed; the columns are hexagonal in form and vary from one foot to as much as seven feet in diameter, the former measurement being by far the most common. Almost invariably they are separated from each other by a "selvage," which is in the main only a few millimeters thick, but is as much as ten centimeters in some cases. On the surface of the flow where the rock has been laid bare this "selvage" produces quite a curious effect; the appearance is that of a tessellated pavement, the light-coloured selvage emphasising the effect.

The thin selvage consists of a crystalline complex of calcite and natrolite with a very little admixture of clayey material. The character of the thick selvage is somewhat different, as it consists of a soft yellow clay which becomes more compact as the central portion of the selvage is reached. This central portion is often hollow and lined with acicular crystals of natrolite and, in a few cases only, small crystals of calcite.

Scattered irregularly throughout the flow are vesicles which are lined with crystals of natrolite and apophyllite, though the latter is very scarce.

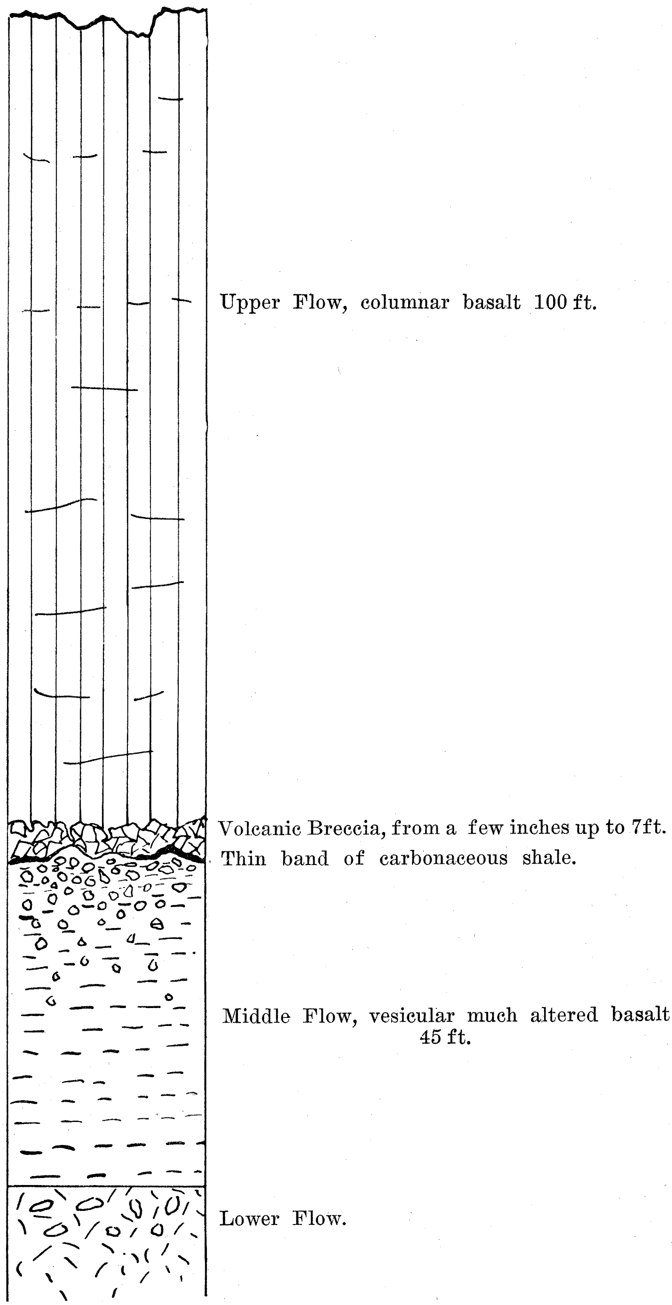


Fig. 1.
Vertical section through the basalt flows, Railway Quarry, Ardglen, New South Wales.

In the hand specimen the rock is very compact, with a dark bluish-grey colour, and here and there a phenocryst of glassy felspar. The fracture is sub-conchoidal. Under the microscope the rock is holocrystalline with fluidal fabric. The predominating mineral is andesine, which is lath-shaped and very fresh. Phenocrysts of labradorite are also present and are sometimes zoned. The augite consists of little grains filling the interstices between the felspar laths. A little perfectly fresh olivine and natrolite are present. Magnetite and apatite occur as accessory minerals.

The rock was analysed, giving the following result:—

		Norm.	
SiO_2	52.16		
Al_2O_3	17.58	Or	11.12
Fe_2O_3	3.37	Ab	35.63
FeO	5.23	An	23.35
MgO	4.97	Di	6.58
CaO	6.68	Hy	11.75
Na_2O	4.24	Ol	0.76
K_2O	1.95	Mt	4.87
H_2O —	0.43	Il	3.95
H_2O +	1.05	Ap	0.62
CO_2	nil	H_2O, etc.	1.49
TiO_2	2.14		
P_2O_5	0.36		
SO_3	abs	Magmatic name.—Andose.	
S	abs		
NiO & CoO	trace		
MnO	0.01		
CuO	abs		
	100.17		
Specific Gravity	2.719	Analyst, T.H.S.	

The Volcanic Breccia (Pl. xxvii, fig. 2): This lies immediately below the upper flow, the line of contact being very irregular but quite distinct. It consists of very coarse fragmentary material; individual fragments measure up to fifteen centimeters in diameter and consist of basalt and shale. The upper flow has intruded it in a number of places. The junction with the middle flow is irregular and in places marked by a thin band of carbonaceous shale, indicating that the middle flow had undergone considerable erosion and probably supported a luxuriant vegetation before the deposition of the breccia. The coarseness of the breccia and the fact that it contains fragments of basalt would seem to suggest that the volcanic centre from which it was ejected was at no great distance from the quarry.

In the breccia occur very irregularly shaped vughs conforming more or less to the shape of the fragmentary material. One of these vughs on being opened up was found to continue in a zig-zag course for about a metre, having a cross-sectional area of about three centimeters by eight centimeters. These vughs are occasionally filled or partly filled with a banded amorphous material resembling chert in appearance. The dark bands in the illustration (Pl. xxviii) are a very dark drab colour and the lighter bands a light drab-grey. Occasionally there is present a thin white band composed of analcite. The cherty material has a smooth to subconchoidal fracture, is brittle, with a hardness of nearly 5, and effervesces with cold, dilute, hydrochloric acid. Under the microscope no crystalline structure is discernible except in the occasional bands of analcite. The material is by no means homogeneous in chemical composition and consequently an analysis of it is of no special value; for example, in three analyses the lime content varied as much as twelve per cent. A similar deposit has been recorded by Cross and Hillebrand[1] in the amygdules of the basalt of the Table Mountains, Golden, Colorado, U.S.A. The authors refer to the deposit as a stratified zeolitic material. It is interesting to note the presence of calcite, which is apparently in a very finely divided state. The sides of the vughs are always coated with a thin black lining. Under the microscope this lining is seen to be composed of a fibrous radiating mineral with straight extinction and a refractive index of about 1.60. It is colourless to dark brown. In addition there is a brown scaly mineral probably chalybite, which partially dissolves with effervescence in cold, dilute, hydrochloric acid, leaving a small residue of dark-coloured material insoluble in hot acid, as well as a little gelatinous silica. When the vugh is not completely filled with the banded amorphous material it is still coated with the black lining, on which analcite, calcite and natrolite have been deposited.

One very interesting specimen (Pl. xxix) obtained from the breccia consists of stalactites of black material, completely coated with analcite on which some crystals of calcite and tufts of acicular natrolite have been formed. The diameter of the stalactite including the analcite is about five millimeters, and the black core is about two millimeters in diameter. One of these stalactites was broken off, sectioned, and examined under the microscope. The black material was found to be identical with the lining of the vughs. The stalactites are composite, being made up of a number of columns of the fibrous radiating mineral with the brown scaly mineral occupying the interstices between the columns. A few small acicular crystals of natrolite have been deposited on these composite stalactites and are completely surrounded by analcite.

The Middle Flow (Pl. xxvii, fig. 2): This may be divided into two parts; whether they are really separate flows or two phases of the one flow it is difficult to say, for the central portion is covered by debris from the quarry. I am inclined to consider them as two phases of the one flow, the upper portion representing the more vesicular part and the lower portion the more solid part. The upper surface is quite irregular as mentioned above. The present thickness at the quarry averages about forty feet.

[1] Cross W. & Hillebrand W. F.—Bull U.S. Geol. Surv., 20, 1885, p. 14.

The upper portion is very vesicular and much decomposed; the vesicles are sometimes lined with diabantite, analcite, natrolite, calcite and chabazite, the last-named mineral being of very rare occurrence. There are two generations of calcite, the earlier colourless and the later stained reddish. In a number of cases the vesicles are completely filled with zeolitic and calcareous material, giving to the rock a general spotted appearance. On this account the quarrymen and local residents have applied the name "native cat" to the rock. Under the microscope the rock is seen to be much altered. The plagioclase, which is lath-shaped, has been completely zeolitised. The pyroxene, which is titaniferous augite, does not seem to have undergone such a complete change, though in places it has been altered to a green chloritic material. The olivine has been completely altered to scaly serpentine bordered by brown opaque hematite. In some cases, where the felspar has been entirely zeolitised, it is embedded in a fibrous, pale green, chloritic material, the fibres of which are at right angles to the surface of contact with the felspar. The rock is amygdaloidal, the amygdules, lined with chlorite, consist of either analcite or natrolite.

The lower portion of the flow is very much decomposed, often crumbling in the hand. It appears to be vesicular in places, but it is possible that these vesicles may represent spaces left by minerals that have been completely dissolved away. Occasionally a nodule of fairly fresh rock remains, and sections from these nodules show that the rock was an olivine basalt. The olivine is fairly fresh, but a little serpentine is developing along the cracks. The felspar is labradorite and lath-shaped; occasionally the centres of the laths have undergone some decomposition with the formation of a saussuritic mass. The augite is slightly pleochroic and when it occurs as phenocysts is idiomorphic. Both olivine and the plagioclase occur as phenocrysts and the ground-mass consists of little plagioclase laths and granular augite with much iron oxide. A little apatite, biotite and devitrified glass are also present. The specific gravity of the rock is 2.937. Other material obtained from this portion of the flow had undergone considerable alteration. The felspar is completely zeolitised and the olivine altered to serpentine and hematite. The rock is porphyritic in felspar, augite and olivine. When the augite occurs as phenocrysts it has suffered very little alteration. The ground-mass consists of small laths of zeolitised felspar set in a brown glass containing a considerable amount of finely divided iron ores. A little analcite, natrolite and a pale green isotropic mineral are also present.

No specimens of zeolites were obtained from this portion of the flow.

The Lower Flow outcrops on the bed of the creek running below the quarry. The junction with the middle flow is fairly regular and horizontal over the short distance that it can be seen. The rock is similar to the "native cat" in appearance. Under the microscope the rock is seen to have undergone considerable alteration. In some cases the felspars have been zeolitised, though a number have escaped any serious alteration. The pyroxene consists of little prisms and grains of titaniferous augite. The olivine has been completely altered to serpentine. Fluidal fabric is well developed and the rock is somewhat vesicular, the vesicles being lined with a pale green, fibrous, chloritic material and filled or partly filled with either analcite or natrolite.

The only zeolites obtained were natrolite, in stout white crystals, and colourless, well crystallised analcite.

Unfortunately the writer was unable to trace these flows to their source or obtain sufficient data to determine their geological age. On the geological map of New South Wales (1914) issued by the Geological Survey, they are marked as Tertiary. While this may be true of the upper flow I suggest that it is at least doubtful whether the lower flows belong to the same period; on the other hand, the deeply eroded surface and advanced state of decomposition of the middle flow, compared to the freshness of the upper flow, cannot be accepted as evidence of any great time gap between them. It was thought that a comparison of the chemical composition of the upper flow with that of other basalts in New South Wales might throw light on the age of the flow, but basalts of both Palaeozoic and Tertiary age were equally comparable in composition to this flow. In regard to the lower one, as stated above, only a very small outcrop was examined but on the evidence available it seems fairly certain that both lower and middle belong to the same period. The following crystallographic notes have been supplied by the Director, Dr. C. Anderson:—

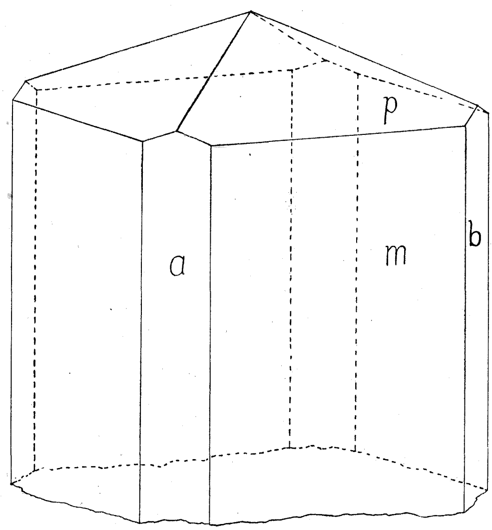


Fig. 2.

Natrolite, Ardglen, New South Wales. Forms a(100), b(010), m(110), p(111).

"*Natrolite* (Fig. 2) : The crystals are long prisms with the forms *a* (100), *b* (010) and *m* (110), *m* predominating, terminated by the form *p* (111). Other single planes giving very large indices are probably accidental impressions or contact planes resulting from the pressure of neighbouring natrolite crystals or crystals of analcite. As these planes generally give good signals it is probable that they are due to analcite. A further proof that these are not true faces is evidenced by the occurrence of frequent 'nicks' with perfectly smooth boundaries, in an otherwise good crystal.

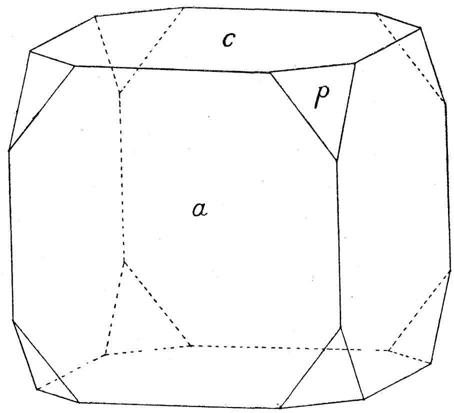


Fig. 3.

Apophyllite, Ardglen, New South Wales. Forms c(001), a(100), p(111).

"*Apophyllite* (Fig. 3) : The faces are wavy though brilliant and give distorted and multiple signals. The crystals are suspended among natrolite needles and are also penetrated by them. They are doubly terminated and the prisms are striated slightly parallel to the edge *a*:*c*. The forms *c*(001), *a*(010) and *p*(111) are present.

"*Analcite*: The only form present is the trapezohedron *n*(211), and in this it is similar to the analcite of Ben Lomond, New South Wales.

"*Chabazite*: Of the few crystals obtained none is suitable for measurement. However they were recognised as the variety phacolite, twinned on the vertical axis."

Calcite (T.H.S.) : The crystals deposited on the stalactites referred to above are doubly terminated and the only form present is the positive rhombohedron *M*($40\bar{4}1$). Both generations of the calcite in the middle flow are more or less etched and are not measurable. They are not doubly terminated and are of scalenohedral (?) habit.

The distribution of the zeolites and calcite is shown in the table below:—

Mineral	Upper Flow	Breccia	Middle Flow	Lower Flow	Selvage
Natrolite	1. acicular	3. rad. tufts	4. rad. tufts	stout white	1. acicular & rad. tuft colourless
Apophyllite	2. colourless rare	......	......	......	......
Analcite	......	1. colourless	1. colourless	colourless	......
Chabazite	......	......	2. rare	......	......
Calcite	......	2. reddish	3. whitish 5. reddish large	......	2. massive

The numbers refer to the order of crystallisation in any one flow and are to be considered as only approximate; it is certain that in some cases there is an overlapping in the periods of growth. In the case of the lower flow no numbers are given because the order of crystallisation is not at all evident.

Paragenesis: The most significant fact about the upper flow is its freshness. The few vesicles that do occur are lined with comparatively large crystals of natrolite and apophyllite, while the crystals of natrolite and calcite occurring in the selvage material between the columns are quite small. If it be assumed that the natrolite and calcite of the selvage are derived from magmatic waters, then it is reasonable to expect that the vesicles in the basalt itself would contain calcite, or at least a calcium-bearing mineral in some quantity. But this is not the case, for, although apophyllite is present, it is the rare exception. The pale yellow clayey material in the selvage is undoubtedly decomposed basalt, and must be regarded as the result of the action of surface waters. The natrolite and calcite were deposited along with this clayey material, and, where the latter has not completely filled the crevices, crystals of natrolite have been deposited on it, and in some cases the clay has been indurated by the action of the solutions containing the zeolitic material. The upper surface of the flow has been much eroded, and its decomposition would be capable of supplying the selvage material. If this be the case, the action would be carried down to the breccia. This has occurred, for both natrolite and analcite are found there, but, in addition, there is present analcite which has crystallised before either the natrolite or calcite. To return to the upper flow, unfortunately only one vesicle was examined *in situ* and there is no trace of the passage of ground waters either along crevices or through the rock; this applies to a number of specimens collected by workmen and others. The rock when examined under the microscope is particularly fresh. This raises the question of the origin of the analcite found in the breccia. Doelter[2] has pointed out that analcite crystallises between 180°C. and 440°C. and natrolite between 0°C. and 180°C. It is hard to conceive that the plane of critical temperature of ascending waters would exactly coincide with the uneven upper surface of the breccia. The analcite is never found in the selvage material, even where this extends right down to the breccia, but it is found in the underlying basalt. Tschermak[3] has shown that natrolite consists of $SiO_4H_4(Kn)$ and analcite of $Si_2O_6H_4(Kn)$, where $Kn{=}Si_2Al_2Na_2O_8$; that is to say that in the former case Kn is united with one molecule of orthosilicic acid and in the latter with one molecule of disilicic acid. From the nature of the case it is highly improbable that any interaction of the solution with the material of the breccia and the lower flow would be responsible for this change in composition. If we accept the theory of the cooling of a lava as indicated by the columnar structure advanced by A. V. G. James[4], the temperature of the upper flow would gradually decrease at a more or less uniform rate from its upper surface downwards, and at the time of crystallisation of the zeolites the temperature gradient could be such that natrolite would form in the vesicles of the flow and analcite in the tuff. It is to be regretted that the position of only one vesicle in the upper flow is known for certain. This was found in the higher level of the flow, but it seems doubtful whether any were found near the base. Obviously the problem of the paragenesis of the zeolites occurring in the middle flow is much more complex. From the data available it is impossible to say how much the middle flow has been affected by magmatic solutions accompanying the upper flow or by surface waters containing material in solution derived from it. The flow has certainly been affected by surface waters, but here and there nodules of rock have withstood this weathering. A study of these nodules reveals a widespread zeolitisation of the felspars although portions of the flow have not been subjected to such treatment. There appears to be no definite arrangement of such affected and unaffected portions.

2 Doelter—Tscher. min. und petr. Mitt. xxv, 1906, pp. 79-112.
3 Tschermak—Sitz. Akad. Wiss, Wien, math.-nat. Kl. cxxvvii, 2 & 3, 1918, p. 285.
4 James—Jour. Geol. xxviii, 5, July-August, 1920, pp. 458-469.

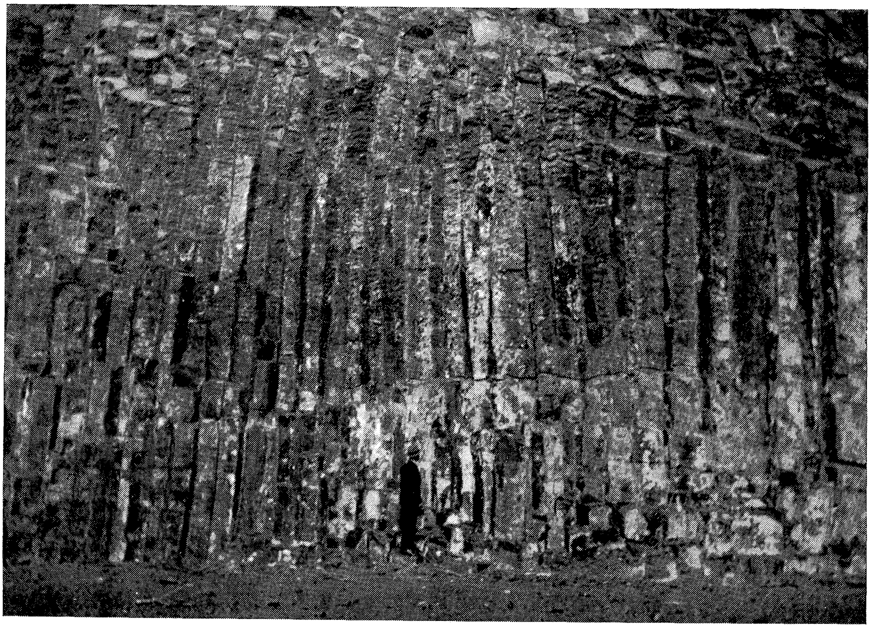
It is concluded therefore that the natrolite and apophyllite in the vesicles of the upper flow and the analcite of the breccia are primary and contemporaneous, that is they have crystallised from the same magmatic solutions, while the natrolite and calcite of the selvage and tuff are secondary, that is derived from the action of surface waters. The feldspar of the middle flow has been zeolitised by magmatic solution accompanying the extrusion, and zeolites have been deposited from this solution, but the action of surface waters with the deposition of zeolites has been so active and widespread that it is difficult to separate secondary and primary zeolites in the hand specimen. In the case of the lower flow not enough evidence has been collected to throw any light on the paragenesis of the zeolites.

My thanks are due to the Director, Dr. C. Anderson, M.A., Prof. W. R. Browne, D.Sc., and Mr. G. J. Burrows, B.Sc. for much valuable help.

EXPLANATION OF PLATE XXVII.

Fig. 1. The upper flow, Railway Quarry, Ardglen, New South Wales, showing the columnar nature of the basalt.

Fig. 2. The volcanic tuff, Railway Quarry, Ardglen, New South Wales, showing the junction with the upper and middle flows.



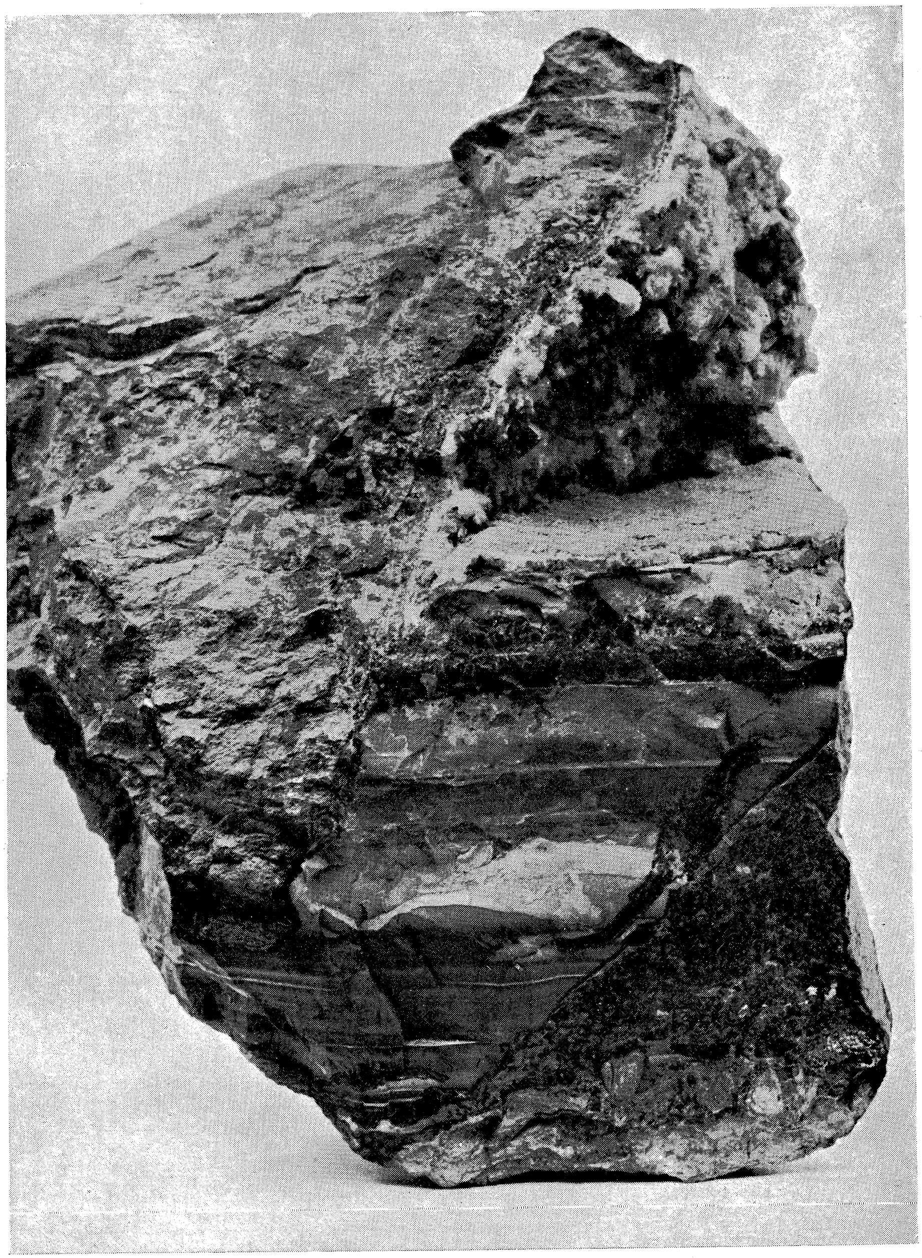
1

2

C. ANDERSON, photo.

EXPLANATION OF PLATE XXVIII.

A vugh occurring in the volcanic tuff, Ardglen, New South Wales, partly filled with a banded amorphous material. The remaining portion of the vugh is coated with analcite, calcite and natrolite.



ANTHONY MUSGRAVE, photo.

EXPLANATION OF PLATE XXIX.

Stalactites occurring in a vugh in the volcanic tuff, Ardglen, New South Wales. These are coated with analcite on which some crystals of calcite and natrolite have been formed.

G. C. CLUTTON, photo.