'Bauxite' from Kashmir.

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[Communicated by Prof. W. W. Watts, F.R.S.; read March 20, 1928.]

ALTHOUGH frequent references have been made during recent years to the 'bauxite' deposit of Jammu in Kashmir, no complete account giving its geological relations is yet available.[1] The only published account is that of Middlemiss,[2] and Fox[3] has also made brief references to it in his recent book on bauxite. Previous work on bauxite by the present writer[4] induced him to examine these rocks, and through the kind intervention of Prof. W. W. Watts a complete set of them was obtained from the authorities in Kashmir. Only the petrological and chemical aspects of these specimens have been dealt with here, and consideration of any possibility of their economic use has been avoided.

Field relations.—The deposit is said to form a bed from 7 to 10 feet thick overlying the 'Great Limestone' of 'unknown age but probably older than Trias', and it is separated from this by a thin zone of siliceous breccia. Laterally it passes into a bed of clay, and it is generally overlain by the Sabathu coal beds, with which it is also laterally continuous in one locality. The coal beds are Eocene in age. From certain points of similarity to the French bauxite and with the evidence obtained in the field during the recent work of the Geological Survey of India, Middlemiss has been able to deduce an age between Gault and Eocene for this deposit. It is stated that the area, where this deposit occurs, has been elevated into a set of elliptical domes breaking through the Siwaliks of the sub-Himalayan zone with

[1] Since writing this paper a report by C. S. Middlemiss on this deposit has been published by the Mineral Survey Department of the Jammu and Kashmir Government. [Min. Abstr., vol. 4, p. 78.]

[2] C. S. Middlemiss, Presidential Address, 9th Indian Sci. Congress, Proc. Asiatic Soc. Bengal, 1922, n. ser., vol. 18.

[3] C. S. Fox, Bauxite, London, 1927, pp. 33–4, 89, 127–8, and 141–2.

[4] T. V. M. Rao, A study of bauxite. Min. Mag., 1928, vol. 21, pp. 407–30.

the 'Great Limestone' forming their core. Further, according to Fox, the area has suffered great tectonic disturbance.

Megascopic characters.—In hand-specimens these rocks are mostly massive, though spherulitic types are not uncommon. The spherules are closely cemented by the matrix and present a crushed appearance. The rocks are hard and scratch glass easily. Many of them show a bedded structure, probably reminiscent of the rocks from which they are derived, and a few have developed a distinct cleavage in one direction due to metamorphism. The colour varies from cream-white to grey, the latter owing to the presence of organic impurities. The average specific gravity is 3·2.

Microscopic characters.—Thin sections of these specimens are opaque and have to be examined by reflected light. The texture is compact except for the presence of a few empty holes. But many sections show distinct traces, such as of bedding planes, suggesting their probable origin from beds of clay. The spherules, the structure of which is seen to greater advantage in thin sections, have lost their rounded shape and have become elongated. Embedded in the opaque material can often be seen clusters of minute crystals of diaspore showing the characteristic high birefringence and bright polarization-colours.

But an examination of the grains obtained by crushing the rock reveals several important features. There are numerous grains of opaque aluminous material, and along the edges of some of them are found attached minute crystals of diaspore. In a few cases these opaque grains are slightly stained with iron, which, besides being present in this form, occurs also as grains of haematite and limonite. Ilmenite and anatase, the latter as deep-blue and brown grains, are the forms in which titanium occurs in these rocks. An appreciable amount of gibbsite and an occasional waterworn grain of brown tourmaline are not of uncommon occurrence.

Chemical characters.—From a chemical standpoint also these rocks are not without interest. All the specimens examined are found to be highly refractory, and special treatment[1] is invariably necessary to reduce them to a state fit for carrying out chemical analysis, a complete report of which is given below. Microscopic examination of the unattacked part of the residue obtained after the first fusion with sodium carbonate proved that diaspore was the refractory

[1] Prolonged heating with potassium bisulphate or repeated fusion with sodium carbonate is necessary to get all the diaspore present into solution for carrying out the analyses.

material present in the rock, and this was further confirmed by a similar treatment of a fresh specimen of that mineral obtained from the Imperial College collection. Owing to the indefinite amount of diaspore present, the refractory nature varied in its extent in the different specimens.

Chemical analyses of typical specimens from the Jammu deposit.

	Pisolite West of Jangal.	Chakar, C.d. 3rd foot.	Chakar, C.s. 1st foot.	Chakar, C.v. 1st foot.	Chakar, D.c. 2nd foot.	Chakar, D.e.[1] 3rd foot.
SiO_2 ...	0·84	6·78	6·53	14·07	0·79	1·31
Fe_2O_3 ...	1·09	3·56	1·68	3·88	0·75	1·86
Al_2O_3 ...	78·34	70·71	73·43	61·70	80·74	78·24
MgO ...	0·13	0·05	0·02	0·03	0·77	0·04
CaO ...	0·20	0·02	0·10	0·22	0·10	0·21
K_2O ...	nil	nil	0·24	nil	n.d.	0·15
Na_2O ...	nil	nil	0·42	0·56	n.d.	nil
H_2O+...	14·99	14·37	13·87	14·48	12·15	14·59
H_2O-...	0·03	0·71	0·21	0·39	0·11	0·13
TiO_2 ...	4·35	4·36	3·08	3·90	3·38	2·48
C ...	0·22	0·12	0·11	0·82	1·46	1·35
	100·19	100·68	99·69	100·05	100·25	100·36

It will be noticed that the alumina content is very high in these specimens and in a few cases the silica is also considerable. The rather low water content needs special mention. Alkalis, magnesia, and calcium oxide, whenever present, are only in very small amounts. Carbon is an invariable constituent and in some cases its amount is appreciable. Although special search was made, the carbon was found to occur in no form other than as an organic impurity imparting a dark grey colour to the specimens. The associated coal-bearing beds may possibly account for the presence of this element in the rock.

Mineral composition.—Excluding the minor constituents, the percentage of alumina and water present in these specimens is approximately 85 and 15 respectively, thus corresponding to a monohydrate in composition. The amount of diaspore present in them is too insignificant to give this composition to all the alumina, and consequently the opaque material forming the bulk of the rock should also bear a composition corresponding to a monohydrate, resembling the earthy mineral occurring in France and described by Böhm.[2]

[1] These letters below the localities of the specimens refer to the trial pits, the positions of which are marked on the maps in the Mineral Survey Report.

[2] J. Böhm, Zeits. Anorg. Chem., 1925, vol. 149, p. 203. [Min. Abstr., vol. 3, p. 430.]

There seems to be a strong tendency in commercial circles to designate all rocks and minerals used in the extraction of aluminium and the preparation of its salts as 'bauxite'. For reasons given elsewhere [1] a restricted use of the term has been attempted, and in accordance with that the Kashmir material will have to be included among the monohydrates. The monohydrate occurring in France, since called boehmite by J. de Lapparent,[2] has been found on examination to give a characteristic X-ray spectrum [3] suggesting that it is a definite mineral distinct from diaspore. Although it has not been possible to carry out a similar X-ray examination with the Kashmir specimens, so far as can be made out from their chemical and physical properties the opaque monohydrate present in them corresponds to the boehmite occurring in France.

The process of formation of the aluminium-bearing rocks occurring in Jammu, Kashmir, may be described summarily as follows. The bed of clay overlying the limestone was lateritized, giving rise to bauxite. Through some process not yet clear, the bauxite, as has happened in France, was partly dehydrated, giving rise to boehmite. The alteration of part of this mineral into diaspore was probably brought about through thermodynamic metamorphism during the tectonic disturbances of the Himalayan uplift. So it is evident that this deposit in Kashmir is really composed of a mixture of a small amount of diaspore and abundant boehmite with a few accessory minerals.

Professor C. G. Cullis has informed the writer of what may be a similar case in Naxos, Greece. A blanket of laterite appears to have been dehydrated and converted by metamorphism into emery, the latter carrying a certain proportion of diaspore which is presumed to represent the bauxitic material of the laterite only partly dehydrated. That the area has suffered infra-plutonic metamorphism is suggested by the occurrence at no great distance from the emery deposits of a granite batholith and by the alteration of sedimentary limestones and shales associated with the emery deposits into marble and mica-schists respectively. The Jammu deposits have probably undergone alteration on parallel lines, though not so intensively as at Naxos.

[1] T. V. M. Rao, loc. cit., p. 425.

[2] J. de Lapparent, Comp. Rend. Acad. Sci. Paris, 1927, vol. 184, p. 1661. [Min. Abstr., vol. 3, p. 369.]

[3] W. F. de Jong, Zeits. Krist., 1927, vol. 66, p. 303. [Min. Abstr., vol. 3, p. 430.]

Highly siliceous beds, formed by the accumulation of the silica leached out during lateritization, are of common occurrence below deposits of laterites (vide Fox, loc. cit., p. 30). On the other hand, Middlemiss definitely considers from field evidence that the siliceous breccia beds underlying the boehmite deposits of Jammu are not genetically related to them, but form part of the 'Great Limestone'.

In conclusion, the writer wishes to record his indebtedness to Prof. W. W. Watts for facilities afforded for carrying out this work and also for kindly reading the manuscript of this paper. He is grateful to Dr. H. F. Harwood for helpful suggestions and supervision of the chemical analyses. Thankful acknowledgement is to be made to Mr. C. S. Middlemiss and to the Foreign and Commerce Minister of Kashmir for providing the material and also for granting the necessary permission to make use of it.