

MINERAL SURVEY REPORTS

JAMMU & KASHMIR GOVERNMENT.

BAUXITE DEPOSITS

OF

JAMMU PROVINCE,

BY

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(with Plates 1 to 17).



JAMMU :

Printed at "The Ranbir Press,"—30-8-85—300.

P R E F A C E.

During the first few years of its tentative existence the Mineral Survey of Kashmir printed none of its reports but was indebted to my old department of the Geological Survey of India for publishing in their *Records* accounts of certain mineral occurrences. Since then four subsequent reports have been printed by order of the Kashmir Government. The present report on the Bauxite deposits of Jammu Province is therefore the fifth of this latter series (See list at end of Preface). Like its predecessors it appears under my name, and the responsibility for its contents and form, and for a great part of the field and other work on which it is based rests with me.

Nevertheless much intrinsic help in map work, pit sinking and drilling, and in determinative (and a certain amount of analytical) work was supplied by my colleagues, Mr. Joti Parshad, B. A., F. G. S., late Senior Assistant Superintendent, and Messrs. Labhu Ram Badyal, M. Sc., and Sohani Ram, B. Sc., Junior Assistant Superintendents. The field work on the Panhasa and Sukhwalgali-Jangalgali areas was entirely carried out by Mr. Sohani Ram.

Mr. D. N. Wadia, M.A., F.G.S., of the Geological Survey of India, then Professor of Geology at the Prince of Wales College, Jammu, contributed most of the earlier chemical work on the bauxite. Subsequently the British Aluminium Company, London, did a set of analyses and a working test free of cost, and, on the advice of and with the co-operation of the then Director of the Geological Survey of India and the Imperial Mineral Resources Bureau (now a branch of the Imperial Institute), analyses were made by Messrs. J. & H. S. Pattinson of Newcastle-on-Tyne and further analyses and research work were done at the University of Birmingham under the supervision of Professor T. Turner. A few analyses were done by the Aluminium Company of America.

Mr. R. Carter Speers of the Forman Christian College, Lahore, and the Industrial Chemist, Srinagar, also contributed some analytical work on our bauxites and a few experiments were made by commercial firms in India in connection with oil decolourants and paper making which were without any satisfactory results. They are not again referred to in the body of the report because of their incompleteness or inconclusiveness.

The present published account will be followed by others on fuels, on the metallic and non-metallic minerals, and on the precious and semi-precious gemstones, ornamental stones, etc. These, it is hoped, will appear as soon as the material can be put up and passed through the press; so that, before long, the economic minerals of Jammu and Kashmir will be permanently recorded, so far as at present known, for general information.

Subjoined is a list of all the printed reports on Kashmir minerals that have so far appeared since the Mineral Survey started work in 1917 :—

- (1) Note on the Aquamarine mines of Daso on the Braldu R., Shigar Valley, Baltistan, by C. S. Middlemiss and Joti Parshad (published in *Records Geological Survey of India*, Vol. XLIX, pt. 3, 1918 with plates 6 to 10).
- (2) Possible occurrence of Petroleum in Jammu Province : Preliminary note on the Nar-Budhan dome of Kotli tehsil in the Punch Valley, by C. S. Middlemiss (published in *Records Geological Survey of India*, Vol. XLIX, pt. 4, 1919, with plates 13 to 16).
- (3) Lignitic Coalfields in the Karewa formation of the Kashmir Valley, by C. S. Middlemiss (published in *Records Geological Survey of India*, Vol. LV, pt. 3, 1923, with plates 28—30).
- (4) Abrasives: Note on the Polishing material of Risin Spur Khunamuh near Srinagar, by C. S. Middlemiss (printed by order of the Kashmir Government, with plates 1 & 2).
- (5) The Graphite deposit of Braripura, Uri tehsil, Kashmir, by C. S. Middlemiss (printed by the order of the Kashmir Government, with plates 1 to 5).
- (6) Ochre deposits of Nur Khwah, Rata Sar and Jhuggi in the Jhelum Valley, Uri tehsil, Kashmir, by C. S. Middlemiss, (printed by order of the Kashmir Government, with plates 1 to 6).
- (7) The Gypsum deposit of the Lachhipura, Bagna, Islamabad, Limbar and Katha nalas, Uri tehsil, Kashmir, by C. S. Middlemiss (printed by order of the Kashmir Government).

C. S. MIDDLEMISS.

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The BAUXITE deposits of JAMMU PROVINCE,
by C. S. MIDDLEMISS, C. I. E., F. R. S.,
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INTRODUCTION.

THE bauxite deposits of Jammu Province consist of extensive surface spreads of generally hard, dense varieties which, chemically considered, are in the monohydrate, amorphous form of diaspore, and somewhat akin to what is known as the Mediterranean or terra rosa type, but containing much less iron and more alumina as a rule.

General statement. In March 1919 I first detected this bauxite in its pisolitic form near the village of Chakar in Riasi district, because of the resemblance it bore to the lateritic bauxite of Central and Southern India, with which I had long been familiar. It had escaped the special notice of the earlier geologists working in Jammu before the year 1907 (Medlicott, LaTouche and Simpson of the Geological Survey of India) for the simple reason that bauxite was not then known as an ore of aluminium. Subsequently, however, I learnt that Mr. Godwin, whilst prospecting for coal for the Kashmir Government in 1907-1908, had briefly mentioned in his diaries the occurrence of highly aluminous rocks near Salal, without realizing their full import; and later still that certain geologists exploring on behalf of a mineral syndicate had recognised the bauxite and referred to it in their reports.

After the first discovery (as I imagined) I immediately began a full examination of the deposit, and thus my Departmental Reports. department of the Mineral Survey of Kashmir at all events were the first systematically to define, describe and analyse it, and eventually during the year 1920 to 1922 to issue nine consecutive departmental reports on it with detailed maps showing its position, extent, thickness and quality in each of the various fields where it gradually became known. Extra-departmental chemical and research work done on large samples in England on behalf of the Mineral Survey, and which occupied some time, will be referred to later in this paper.

In January 1922 I included a very brief account of it in my Presidential address to the Indian Science Congress held at Madras.¹ A few references to it have appeared in Dr. C. S. Fox's two works on bauxite,² and Dr. T. V. M. Rao has read a short paper³ on his examination of samples which I supplied him with recently at his request.

The publication of the present condensed, but I hope comprehensive, report on it has long been overdue. It was delayed by certain chemical difficulties which it was desirable to clear up first. My object herein is to define and describe the bauxite occurrences, with the practical object of interesting those who may develop and work them, rather than with any more scientific aim.

The known localities that are of importance lie in the Riasi Tahsil of Jammu Province, between lat. 33° 0' and 33° 12' and between long. 74° 35' and 75° 2'. They are as follows (given in order from W. N. W. to E. S. E.) :— Chakar and Chhapparbari (16 miles W. N. W. of Riasi town), (2) Sangar Marg, (3) Panhasa, (4) Salal and (5) Jangalgali—Sukhwalgali (12 miles E. S. E. of Riasi). See Outline Map, Pl. 6).

The following table of geological formations that are present in this region, arranged in their natural order of superposition, and the few appended remarks on them are necessary in order to define the age, geological position and association of the bauxite deposits :—

Table of formations.

Formation and Age.	Description.	Thickness.
(6) MURREE SERIES (U. Tertiary).	Sandstone and shales of purple and chocolate colours.	Very great thickness but unmeasured. Top not seen.
(5) NUMMULITIC SERIES (Eocene).	Concretionary limestones and shales.	About 400 ft.

1. See *Proceedings As. Soc. of Bengal*, New Series, Vol. XVIII, 1922.
2. See *Mem. Geol. Surv. of India*, Vol. XLIX, pt. 1., 1922, and *Bauxite* London Crosby Lockwood and Son, 1927.
3. See *Mineralogical Magazine*, 1928.

Table of formations.—concluded.

Formation and Age.	Description.	Thickness.
(4) COAL MEASURES (Eocene?).	Carbonaceous shales with coal beds and ironstone bands and lenticles.	About 120 ft.
(3) BAUXITE SERIES.	Bauxite, bauxitic clays and kaolin, with local ironstone and a little coal.	4 to 24 ft. and over.
(2) BRECCIA (age unknown).	Chert fragments mainly in calcareous and siliceous cement.	20 to 30 ft.
(1) GREAT LIMESTONE (age unknown but probably older than Trias).	Massive grey limestone with bands of chert. No organic remains.	Of great but unknown thickness. Base not seen.

The Great Limestone has been usually considered and shown as of Jurassic age (with a query mark added), in the maps and reports of the Geological Survey of India. As, however, this thick formation has proved entirely unfossiliferous, except for a few doubtful markings, after very thorough search through great thicknesses and extent, this suggested age can no longer be upheld. It is a massive blue-grey limestone with numerous bands of chert. These characteristics, together with its peculiar mode of weathering, lead one to correlate it much more reasonably with the limestone coming below the Trias of Hazara.¹ Thus there is no definite evidence for the age of it, except that it is probably older than Trias—and it may be very much older. The point cannot be further discussed here.

The Breccia (or Brecciated Quartzitic Grit as it is also designated) is manifestly in the main a residual rock, derived from the exposed surfaces and edges of the Great Limestone, since all stages in the process of disintegration of the chert and limestone layers are found. The cementing material is calcareous

and sandy. Although only of small thickness, the breccia constitutes rough country and weathers into great blocks, littering the slopes and river gorges with its debris. In its upper part this predominantly chert breccia generally passes up into more quartzose rocks and into beds of comminuted angular chert set in a base of greenish iron silicate, which latter constitutes the protore from which, by alteration everywhere actively going on, has been generated the limonite and hematite lumps, pockets and veins that are to be found in the Breccia, wherever that formation has been deeply dissected by denudation. At all such places (especially remarkable near Chakar) this extremely hard breccia has been pierced by innumerable vertical pits, 15 to 30 feet deep, now mostly fallen in and overgrown, which rumour and the evidence of the oldest inhabitants credit to the local iron-workers of a bygone but still remembered age. This point cannot be further discussed here, except to remark that the ant-like industry of those old workers in riddling the country-side with these vertical chimney-like shafts in such refractory rock is difficult to understand if iron ore were their only aim, since plenty of ore (limonite, earthy hematite and siderite) lies exposed at the surface close by among the easily excavated Coal Measures formation.

Whatever be the age of the Breccia and its associated finer textured beds, it clearly marks a great stratigraphical break. On this irregularly surfaced layer of breccia the Bauxite Series, immediately followed by the Coal Measures, repose as a rule.

The Bauxite Series, among which the bauxite proper is found, in one or two instances passes laterally into hard coal which is possibly older than the friable coal beds usually classified as Eocene in this part of India and which latter directly underlie and pass up into the Nummulitic Series. From evidence found in the neighbouring area of Hazara district, similar coal beds and an underlying pisolite (the probable equivalent of the Jammu bauxite) are certainly younger than Cenomanian (or Gault, according to more recent investigations²) as shown by good fossil evidence.

From this the age of the Bauxite Series must be something between Gault and Eocene, and this is as near as we can get from the evidence before us. The question is not of vital importance to us at present, since the bauxite itself will presently be shown to be largely due to subsequent superficial modification of the exposed surfaces of the series with which it is now associated.

1. See Middlemiss: *Mem. Geol. Surv. of India*, Vol. XXVI, 1896.
 2. See Cotter: *Rec. Geol. Surv. of India*, Vol. LIX, pt. 4, 1926.

This Bauxite Series is a definite physical unit, having a thickness of **Variations in the Bauxite Series.** from 4 to 24 feet, or even more in rare cases. This relatively thin layer adheres to the underlying breccia like a layer of butter or bread, and, when the breccia passes underground, accompanies it, sandwiched as it were between it and the overlying Coal Measures. But it varies in composition from point to point. Besides bauxite proper, after which the series is named, it comprises kaolin, ferruginous layers and rarely coal. The uppermost layer, which invariably has a pisolitic structure, is regular and constant, and its junction surface, where it passes below the shales and other members of the Coal Measures, is also regular and sharp. The variations in petrological facies and composition which appear among the rest of the Bauxite Series are partly connected with the uneven and sometimes pot-hole like hollows into which the underlying Breccia has been worn—which latter condition also accounts for occasional rapid increase in the thickness of the Bauxite Series. But all these sudden lateral changes cannot be accounted for in this way by the uneven surface on which they were accumulated. There must have been other potent activities at work. Some of these doubtless operated whilst the Bauxite Series was first forming as a mixed colloid. Others, which have chiefly affected the upper exposed layers, have certainly been of the nature of weathering by meteoric agencies which has been something like, but not identical with, lateritization.

Tectonics. A few structural facts are now necessary to explain how the outcrops run with regard to the physical features of the country, and more particularly to indicate the process by which extensive areas of this relatively thin layer of bauxite have come to lie where they are now. Under the next sectional heading these areas will be defined more particularly from a geographical and physiographical standpoint.

All the considerably elevated, hilly and much broken country between Chakar and Jangalgali primarily consists of an elongated upheaved, anticlinal dome in the Great Limestone, round which on the north-west, north-east, and south-east sides the younger formations appear concentrically dipping away from the central dome of limestone.

Faulting on the south-west of the dome has dropped the upper formations from the Breccia up to and including the Murrees Series and brought the still younger Siwalik Series in juxtaposition with the Great Limestone. This dome of old rocks, bursting through the younger Sub-Himalayan zone in this unusual way is one of a row of similar features peculiar to this part of Jammu. Its formation must date

from late Siwalik times, because the outcropping edges of the folded Siwaliks on the south run diagonally up against the line of fracture where they are abruptly truncated.

The hill-sides constituting the dome surfaces of the Great Limestone, not taking into consideration for the moment the deep rift-like gorges threading through it, are frequently dip-slopes. But in many places these are covered by expanses of the Breccia, and these again by fairly extensive sheets of the Bauxite Series. The Breccia sheets are often isolated as outliers on the Great Limestone and the Bauxite sheets are similarly left as outlying, isolated, or wanderingly connected, patches on the Breccia uncovered by anything else.

DISTRIBUTION OF THE BAUXITE SERIES.

It is owing to this local persistence of the Bauxite Series as
 As outliers easy to quarry. outliers on dip-slopes that the series, with its attendant pure bauxite, has come to lie stranded, with no overburden at all, in positions favourable for it to be won by simple quarrying. All these dip-slopes of bauxite and also those of breccia present bare surfaces, generally without a trace of vegetation of any sort upon them, especially noticeable where the pisolitic top layer is preserved. The localities where the Bauxite Series has been thus preserved will now be defined.

The map of Chakar area (Pl. 7) will make the detailed distribution of the Bauxite Series at that locality
 Chakar area map. clear. It depicts spreads of it in the vicinity of the villages of Chakar (lat. $33^{\circ} 11'$ long. $74^{\circ} 36'$) and Chhapparbari and in the Kainthu forest, their positions all being on gentle to moderately steep sloping hill spurs of the Great Limestone covered by breccia, which branch downwards in a westerly and southerly direction from the western prolongation of the ridge marked Sangar Marg (5,824 ft.) shown on the 1 inch to 1 mile Survey of India Sheet 43 K/12. The lowest point, where the Bauxite Series of this area appears, is at an altitude of 3,750 feet at Chakar, and the highest is at 4,652 feet in Kainthu forest.

The map is a combination of areas lettered A, B, C, and D,
 Combined from large-scale plans. reduced from the four original plane-table sheets specially constructed by the Mineral Survey on a scale of 1 inch to 100 feet. This has permitted considerable accuracy in delineation.

The patch of the Bauxite Series marked B. b, together with those in the northern part of C area, and the whole of the D area patches contain the best bauxite, D area being particularly rich. The spreads of poorer quality in A and most of B areas are continued still further out of the map to the south in narrow outcrops extending many miles, with complicated folding, down to the boundary fault near Krul. The western prolongation of the C area exposures similarly diminish in outcrop and quality and eventually become lost or only found in traces where the Great Limestone bends over sharply to the north. These are not of any commercial value and will not be further defined.

The Sangar Marg area is simply a continuation of that of D area Chakar and would have been described along with it but for the fact that the general map of it (Pl. 10.) is on a different scale, being as regards its topography a reduction from a 4-times enlarged outline of part of the Survey of India 1 inch to one mile map sheet, 42 K/12, and not a plan specially surveyed by the Mineral Survey. Its scale is therefore only one-third of that of the Chakar area map and the geological details on it cannot be so accurate. The general maps of all the areas to follow are also depicted on topographical outlines enlarged in the same way.

The Sangar Marg area embraces a set of sloping side-spurs given off from Sangar Marg hill in S. W. and W. directions in the neighbourhood of Chenar Sangar, Saro-da-Bas, Bansioth, Malhad and Marioth. The Bauxite Series is represented by a number of small isolated patches overlying the Breccia and dotted about on these spurs or capping them in disconnected outliers. This productive area lies between Ikhani village on the north and Gai spur on the south and between the elevations of 5,000 and 5,750 feet. The underlying Breccia steepens downwards and then becomes dissected by steep-sided gorges at its junction with the Great Limestone. It is only towards the central part of the area near Saro-da-Bas and Malhad that the Bauxite Series is overlaid by the Coal Measures and Nummulitics to a very limited extent.

Some of the best quality bauxite layers are found N. of Chenar Sangar in map squares IV-V 5, VI 5, VI-VII 6, also along the main Sangar Marg ridge in scattered outcrops on map squares IX 6, X 6 and XI and XII 7 and finally to the south of Marioth on map squares IX-X 13 among the slopes covered with oak forest under Dargari hill (5,828 ft.). (See Pl. 10.)

For convenience sake, although slightly out of order, I take the large area of Salal fort-hill next for definition.
Salal fort hill slope. A break of 8 miles of broken limestone country

intervenes between Sangar Marg and Salal, where denudation has carved ravines and lofty craggy peaks out of the core of the anticlinal dome. No traces of the younger overlying formations is left anywhere throughout this intervening tract, except, of course, along the continuous slender thread of them marking the outcrop of the steeply inclined northern limb of the anticline and the small spreads at Panhasa, the description of which I shall return to later (see Outline map Pl. 6.).

The Salal dip-slope is in lat. $33^{\circ}10'$, long. $74^{\circ}49'$, and faces north instead of south or west, being a portion of the northern limb of the anticline. The continuous and regular inclined plane, which the Bauxite Series lying on the Breccia makes at an angle of between 15° and 20° , is a very noticeable and arresting feature, as seen even from a good distance. It is the largest area known and slopes down to the Chenab river where the latter takes a sharp bend round to the south. The lowest point of the slope covered by the Bauxite Series is the 1,500 ft. contour and the highest the 3,250 ft. contour (see Pl. 12.).

Except for the lower splayed-out eastern part of this slope, which is steeper than usual, and the patches of bauxite small and scattered lying thereon, the rest of the slope shows a remarkably coherent layer of the Bauxite Series, more coherent in fact than is known anywhere else in these parts. This is partly covered over by Coal Measures and Nummulitic rocks at two places, the first being the Fort part of the hill down to near the 3,000 ft. contour and the second, a smaller patch, near the lower north-west end of the slope near Gura.

The best bauxite found in the area occurs in map squares VIII 3, 4 and 5, IX 3, 4 and 5, X 3, 4 and 5, XI 3 and 4, XII 4 and XIII 4.

The relatively small patches of the Bauxite Series at Panhasa lie a few miles west of Salal in lat. $33^{\circ}11'$, long. $74^{\circ}45'$, and just north of the rugged barren area we have skipped. They are few in number and irregular in shape, occurring on varying slopes of the Breccia covering the Great Limestone in the normal way and are inclined in varying directions which will be best understood from the map and sections. Their altitudes vary between 3,000 and 3,800 feet, the occurrences being perched somewhat obscurely on spurs of the Great Limestone cut off from the main mass to the south by the gorge of the Rad nala.

In spite of their relatively small size, they contain much useful material of good quality. (see Pl. 14.).

The last area to be noticed lies almost at the extreme south-east end of the anticline, some 2 to 4 miles E. and S. E. of Trikta hill (8,876 ft.) in the neighbourhood of lat. $33^{\circ} 1'$ long. $75^{\circ} 1'$. It is a long straggling outcrop showing all the usual features and geological sequence, widening out a little here and there and extending from the ridge near Sukhwalgali at 7,200 feet, down to Jangalgali at 4,250 feet or even to Lain, a thousand feet lower still (see Pl. 16.).

The Sukhwalgali spread is the largest of these. Although the range of altitude through which the series goes is very great, some good bauxite occurs along its much scattered line of outcrop.

The above are all the areas that contain good material of appreciable dimensions. There can be no others of any great consequence throughout the Jammu Province east of long. $74^{\circ} 5'$; though a few small occurrences may possibly have escaped the vigilance of the Mineral Survey.

Before proceeding to a detailed summary of the petrography of the Bauxite Series, it will be well to enunciate a few distributional laws of general application to the main varieties, namely the simple kaolin, the intermediate variety, the bauxite proper, the ferruginous variety and those having a pisolitic structure. The recognition of the above varieties and the working out of the laws regarding their distribution took time and experience to effect; but in all essentials the laws will be seen to be in harmony with a single hypothesis as to the origin of the bauxite.

- (1) The lower part of the Bauxite Series is usually kaolin, the upper part in certain places is bauxite, and there are intermediate varieties between the two. The top capping layer has invariably a pisolitic structure.
- (2) Wherever the Bauxite Series passes under, or lies near, the overlying formations, the whole thickness of it, including even the pisolite, is found to be in the condition of kaolin, and there is an absence of bauxite.
- (3) Wherever the Bauxite Series lies flatly in the form of a low-angled dip-slope of 10° or less, and under or near the alluvium along stream beds, the series is mainly kaolinic below with intermediate bauxitic clays above, but there is no high grade bauxite.

- (4) Wherever the Bauxite Series lies on slopes of about 20° and at a distance of 300 feet or more (the further the better) from the scarped edge of the overlying higher formations, the upper layers constitute the true bauxite of the area. Inferior qualities with increasing silica impurity appear in the underlying layers and kaolin or ferruginous varieties at the base. On slopes over 20° good bauxite may extend nearer to the overlying formations and there are a few other exceptions to this rule.
- (5) On slopes with an inclination very much over 20° the Bauxite Series has been unable to retain its position. Denudation on such steep slopes has completely swept it away.
- (6) In exceptional cases the Bauxite Series passes laterally into coal within the distance of a few yards, and, in some places especially those where the series is of very abnormal thickness, owing to deposition in hollows or synclinal folds of the Breccia, there is a marked increase in the iron and titanium content of some of the lower layers.

PETROGRAPHY OF THE BAUXITE SERIES.

The kaolinic varieties of the Bauxite Series are best seen at the foot of and round the winding scarped edge of that series. They are sometimes of a pure white or pale grey colour and powdery and soft. These varieties frequently become secondarily washed out and redeposited as a "slaked" plastic clay locally termed "makol". Generally, however, the kaolinic varieties are of a slightly darker grey or drab tint and consolidated into a hardened clay or shale. All are fairly pure kaolin, with hardly a trace of grit and having a specific gravity of 2.46 to 2.64 and they are splintery, scaly or flaky, breaking up easily into small cakes or splinters and along joint fissures. Nearly all the kaolinic varieties have a slight excess of alumina.

The kaolin and derived "makol" clay have been successfully experimented with in the manufacture of ornamental tiles, insulators and other pottery and even procelain articles. The subject is given a separate treatment elsewhere and will not be further touched on in this paper.

In most cases the intervening layers between the kaolin and the overlying bauxite are of intermediate type and so become bauxitic or highly aluminous hardened clays or shales with specific gravities of from 2.7 to about 2.9. These varieties have a compact, finely streaky texture in layers of varying composition and in neutral-tinted drab or grey colours. The substance presents smooth, often shiny, unweathered surfaces and takes a remarkably fine polish. According to their varying percentage of silica, these may be classified among those for use in the manufacture of abrasives, refractories and cements.

All the facts of its mode of occurrence mentioned at page 9 point to the conclusion that the Bauxite itself, which is our principal concern in this paper, has been formed as a secondary product by the desilicification of the upper layers of the original kaolin, a process which may best be regarded as brought about by exposure of the kaolin to subaerial meteoric agencies during the period that it has remained a surface layer after removal of the superincumbent strata. This theory of the formation of the bauxite from kaolin agrees with that advocated by O. Veatch for the deposits of Wilkinson County, Georgia¹ wherein the change is attributed to the action of alkaline meteoric waters.

In the process of desilicification the material has become harder and denser; so that this capping rock of bauxite presents a resistant crust which has tended to preserve the series in the form of sheets of irregularly scalloped outline and with characteristic perfectly vertical edges. In many places, especially well seen at Salal on the slopes below the fort hill, this crust remains intact over considerable areas and has given rise to the inclined uniform slopes that are so unusual in Himalayan scenery of the older geological formations. Elsewhere the pisolite crust is only continuously preserved close to the Coal Measures borders, from which both it, and further away the true bauxite, extend outwards on the ridge spurs which thereby assume a flatly sloping appearance. The resemblance to the flat-topped lateritic plateaux of Central and Southern India is noticeable, with this important difference that the Jammu sheets are always inclined and not horizontal. The more they are inclined, up to the limit of stability that the formation will bear, the more complete is the transformation into bauxite.

When once the hard crust has been broken through, the straight little cliff that then appears is due to the softer nature of the underlying kaolin. This readily disintegrates and becomes washed away, as is

1. See Geol. Surv. Bulletin No. 18, p. 430 of 1909.

evidenced by the fact that in heavy rain the runnels and streamlets discharging down the slopes become milky white from what is presumably the kaolin carried in suspension.

Undoubtedly the pisolitic variety of the capping rock which is a **Pisolitic variety of bauxite.** foot or a little over in thickness is the first to arrest the eye. It is the hall-mark of bauxites all over the world. Nevertheless in the Jammu occurrences the pisolitic structure is not confined to the bauxite proper, being equally characteristic of the top layer of the less pure bauxite and even of the simple kaolin rock where the series disappears under the Coal Measures. Also some of the richest bauxites of these parts are not pisolitic in any marked degree (see Pl. 1 and 2.).

The pisolite grains are frequently crowded together and make a peculiar knobby rock in the more typical examples that led me in the first place to the discovery of them as being bauxite. The pisolites in size are a little larger than buck-shot and not so large as a small bullet. They are apt to weather out and litter the surface of the ground like peas. Although incomplete and rather flatly spherical, they are commonly used as bullets by the local shikaries.

The pisolitic bauxite is mostly grey or of a mottled grey and white colour and iron-stained, but in some important spreads it is of a nearly white (putty) or delicate cream colour. These latter, should their specific gravity exceed 3 and approach 3.2 invariably indicate a very pure bauxite with an alumina content in the neighbourhood of 80 per cent. and a correspondingly low silica and iron content. The best examples of this pale rich variety are found high up on the Chakar slopes of D area and on Sangarmarg hill. Throughout all the Jammu bauxite occurrences no bright red or pink and white tints are ever found, such as are so remarkable in the Gold Coast and many other bauxites.

Similarly the pale, non-pisolitic or only slightly pisolitic or pellety **Non-pisolitic variety of bauxite** varieties, especially those of a cream colour which follow below the pale pisolite, if their specific gravities are from 3 to 3.2, always constitute excellent bauxite, with very low silica, round about 1 per cent.

Where they are not of this pale cream tint they may be of a putty colour. Others again are a dull grey or faintly lavender or lilac tint splashed with white, having a dusty appearance on fractured surfaces. Others of this variety are finely granular or dusty looking and mottled dark and light grey and sometimes spangled with minute glistening particles. All are hard, with a hardness of 6.5 of Mohs' scale, and

rough-looking, and they weather massively into thick-bedded scarps or into tumbled blocks. Good examples of these are seen in many areas well away from the overlying Coal Measure rocks and especially where the capping pisolite has also been removed by denudation. Some of these rather dark finely granular rocks, in the absence of the capping of pisolite, were not at first recognised as being bauxite of high alumina content. Indeed, the neutral colours and common appearance of these varieties would never have roused interest, had they not, by their association with more typical bauxites, got swept in with them for examination.

Varieties of intermediate type between bauxite and kaolin have already been referred to; but there is another kind, with silica predominant, occasionally found, as in C. a. pit Chakar and D. area Chakar, where the iron-titanium content rises rapidly. These are fortunately rare; and so the confusion between them and the equally heavy highly aluminous varieties does not often present itself. A characteristic of these ferriferous varieties that may generally lead to their distinction from the aluminous varieties is their colour, texture and fracture. The colour always takes on a jaundiced yellow, greenish, or dark brown tint, the texture becomes compact and the fracture conchoidal or flinty. Some of these types become very dark and have a high iron and titanium content, such as those occurring between the 9th and 15th foot of C. a. pit. They also attain considerable thickness, especially noticeable in the northern part of C and D areas Chakar.

CHEMICAL ANALYSIS.

The chemical composition of a commercial bauxite, and particularly the amount of its combined silica, which should be as small as possible, are of great importance in estimating any new bauxite deposit. As soon as the bauxitic qualities of the Chakar material became evident in the field, the necessity for quantitative chemical work was felt to be urgent. But, since it was impossible to do analyses in the field, Mr. D. N. Wadia, now of the Geological Survey of India but at that time Professor of Geology at the Prince of Wales College, Jammu, was deputed to attend to the analytical side of the work. Specimens and samples, as collected in the field, were sent to him early in 1920 by post and he replied sending his results as they became available. The majority of the samples were collected from pits or open cuts made in the bauxite cliff. A whole foot cube of the rock was extracted, broken up to the size of road metal and coned and quartered.

After making a poor start in A and B areas, Chakar, where as already explained good bauxite is rare, the analyses very soon showed good and even excellent results.

Subsequently it was considered advisable to have some analyses done by chemists who were experts in that line in England. The British Aluminium Company kindly analysed a set free of charge at their Burntisland Laboratory in 1920. Another set were simultaneously analysed by Messrs. J. & H. S. Pattinson & Co. of Newcastle-on-Tyne. Three analyses were done by the Aluminium Co. of America. Later still in 1924-1925 six more were done under the supervision of Prof. Thomas Turner, Professor of Metallurgy in the University of Birmingham.

As this analytical work progressed it became evident that these Jammu bauxites presented certain difficulties to analysis on account of their intractable nature. Prof. Wadia remarked :—

“Our rocks, especially the white stuff, are quite different from the ordinary bauxites of India and are very difficult to dissolve and decompose by the ordinary methods. They all have an insoluble, very refractory residue, after the H_2SO_4 treatment as well as the $KHSO_4$ fusion method, which is likely to be taken for SiO_2 , although it is only insoluble Al_2O_3 which readily passes into solution on a second fusion with $KHSO_4$, leaving only an insignificant SiO_2 residuum.”

Mr. E. J. Bloore, one of the research workers at Birmingham who was afterwards engaged on solubility tests, gave the following details of the procedure which he found best adapted for chemically analysing them :—

“As some difficulty was experienced in analysing these bauxites, the final successful method is given in order to help future investigators.

The ores are very refractory and difficult to get into solution. It was therefore found necessary to fuse with fusion mixture, dissolve the mass, as far as possible, in hydrochloric acid, and fuse the residue with sodium bisulphate. The latter operation is required to transform the titania into soluble form.

DETAILS OF METHOD

The bauxites were analysed for SiO_2 , Al_2O_3 , Fe_2O_3 , TiO_2 , and loss on ignition.

Loss on Ignition.

1 gm. of bauxite is weighed into a porcelain crucible and heated to 900°C ., for half-an-hour, in a muffle. Loss in weight $\times 100$ gives loss on ignition per cent.

Solution.

The calcined bauxite, originally 1 gm. in weight is mixed with 10 gms. of fusion mixture and brushed into a platinum crucible. The mass is carefully sintered over a bunsen and then maintained at full red heat over a blow-pipe for half-an-hour.

The crucible is then cooled on an iron slab, and if a crater is formed on top of the melt, it is fused for another ten minutes, or until no crater is formed on cooling.

The cake is then loosened from the sides of the crucible, by filling with distilled water, and gently heating. The cake and liquid is now transferred to an evaporating dish, and the crucible washings added to it; any firmly adhering particles are dissolved off the crucible and lid by heating them in the liquid in the basin. When the melt has dissolved, the crucible and lid are washed with distilled water, the washings being added to the liquid in the basin. The basin is covered with a clock glass, and the liquid in it carefully made acid with concentrated hydrochloric acid from a pipette. The solution is evaporated to dryness on the hot plate and the residue baked for half-an-hour. The dish is cooled, its contents dissolved in hydrochloric acid, and the solution filtered. The residue which is washed with distilled water is dried and ignited, and contains the silica with a certain amount of titania. It is fused with potassium bisulphate in a silica dish, heated over a large meker burner. Heating is gentle at first, but afterwards the mass is heated to a good red heat. When all effervescence has ceased, the dish is allowed to cool, and the contents dissolved in 5% sulphuric acid. The residue, which is pure silica, is filtered, washed with warm water, ignited and weighed.

Weight of precipitate $\times 100$ gives SiO_2 per cent.

The combined filtrates, from the two fusions, are made up to 250 cc. and samples taken for the estimation of Fe_2O_3 , TiO_2 , and Al_2O_3 .

These three estimations present no difficulty, and are carried out in the usual manner."

I have given the above details because one or two other chemists in India who did a few analyses on these **Other unreliable analyses.** bauxites, but who were without any special experience of them, obtained results widely different from those obtained by all the other five experienced chemists. Hence their analyses must be deemed unreliable and they are not quoted here. Those which are reproduced below are convincing, if only from the fact that they were carried out independently and in many cases on identical samples and that in these latter instances the analyses are nearly always in the closest agreement. It should also be remembered that the analyses by the chemists of the British and American Companies and Messrs. J. & H. S. Pattinson, were carried out by men who are constantly occupied in the course of their professional work in valuing consignments of bauxite.

In the lists appended the following contractions are used:—

Prof. D. N. Wadia	Wadia
British Aluminium Co.	B. A. C.
Messrs. J. & H. S. Pattinson	J. & H. S. P
Mr. E. J. Bloore	Bloore
Aluminium Co. of America	A. C. A.

For the convenience of the reader the results are sorted out and **Arrangement and scope of the analyses.** rearranged in the order of the bauxite areas already adopted in this paper. Generally the samples analysed have been taken from the upper few feet of the different pits and vertical cliff cuts, because it was soon recognised that they alone were likely to yield the best results. Here and there, however, samples of the lower softer and more obviously kaolinic varieties were also taken for analysis in order to make sure about their composition; but, as a rule, sampling was stopped when the obviously clayey, siliceous or highly ferruginous lower layers were reached.

All the analyses were done on samples dried at 100°C.

CHAKAR.

Localities.	A. pit 1st ft. pisolite Wadia.	A. pit 3rd ft. non-pisolite Wadia.	A. pit 7 ft. Wadia.	B. pit 1st ft. Wadia.	B. pit 4th ft. Wadia.	B. pit 6th ft. Wadia.	B. pit 12th ft. Wadia.	B. a. pit 1st ft. J. & H. S. P.	B. a. pit 2nd ft. Wadia.	B. a. pit 2nd ft. B. A. C.	B. a. pit 2nd ft. J. & H. S. P.	B. a. pit 2nd ft. A. C. A.
S. G.	2·81	2·60	2·56	2·76	2·60	2·63	2·54	2·90	2·91	2·91	2·91	2·91
SiO ₂	18·50	40·25	41·85	23·58	42·30	39·00	44·15	28·05	8·45	13·11	13·15	14·15
Al ₂ O ₃	66·50	48·80	45·70	64·60	46·60	50·30	....	49·11	77·25	67·43	67·27	67·03
Fe ₂ O ₃	....	....	....	....	....	....	....	5·00	....	1·98	0·78	0·63
TiO ₂	....	....	....	....	....	....	....	3·06	....	3·64	4·12	3·54
H ₂ O	....	....	....	....	....	....	....	14·15	....	13·77	14·55	14·24

CHAKAR—(continued).

Localities.	B. a. pit 3rd ft. J. & H. S. P.	B. a. pit 8 ft. Wadia.	B. a. pit 14 ft. Wadia.	C. pit 6 ft. Wadia.	C. a. pit 2nd ft. Wadia.	C. a. pit 2nd ft. B. A. C.	C. a. pit 2nd ft. J. & H. S. P.	C. a. pit 3rd ft. J. & H. S. P.	C. a. pit 4th ft. Wadia.	C. a. pit 7th ft. Wadia.	C. a. pit 7th ft. J. & H. S. P.	C. a. pit 9—15 ft. Wadia.
S. G.	2·87	2·58	2·54	2·61	3·07	3·07	3·07	2·98	2·95	3·00	3·00	average 3·03
SiO ₂	14·58	44·00	45·00	41·60	5·40	8·53	9·40	6·70	13·35	19·80	18·08	(most of the Al ₂ O ₃ replaced by Fe ₂ O ₃ C. a. 12 ft. contains 55 per cent. Fe ₂ O ₃ the iron in the ferrous state.
Al ₂ O ₃	66·12	46·50	....	45·70	83·10	71·70	67·71	58·03	40·20	44·85	38·61
Fe ₂ O ₃	0·91	....	....	....	....	2·26	1·29	5·14	22·50	24·25	16·54
TiO ₂	3·86	....	....	....	....	4·84	7·31	16·51	....	....	14·23
H ₂ O	14·40	....	....	....	....	13·22	14·00	13·10	....	....	12·00

CHAKAR—(continued).

S. G.	Localities.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	H ₂ O
2-81	C. b. pit 1st ft. Wadia.	27-10	43-40	16-80	....	....
2-89	C. b. pit 2nd ft. Wadia.	10-70	74-90	3-00	Estimated from colour of ppt.	15-00
2-95	C. b. pit 3rd ft. J. & H. S. P.	7-15	72-39	0-96	3-33	15-00
2-90	C. b. pit 4th ft. Wadia.	12-40	69-90	3-00	Estimated from colour of ppt.	15-00
2-50	C. b. pit 9th ft. Wadia.	41-10	Other constituents not determined because of high Fe ₂ O ₃ about 15%.			
2-87	C. c. pit 3rd ft. Wadia.	10-85	73-80	3-00	Estimated.	....
2-99	C. d. pit 2nd ft. Wadia.	3-00	82-00			14-20
2-99	C. d. pit 2nd ft. B. A. C.	4-36	73-60	2-55	5-55	13-51
2-99	C. d. pit 2nd ft. J. & H. S. P.	4-53	71-40	0-81	8-81	14-25
2-97	C. d. pit 3rd ft. J. & H. S. P.	4-93	71-74	1-10	7-58	14-60
3-01	C. d. pit 5th ft. Wadia.	15-30	63-00	7-00	....	....
2-78	C. e. pit 1st ft. Wadia.	28-50	45-80	10-80	....	....

CHAKAR—(concluded).										SANGAR MARG.		
Localities.	D. area Bloore.	D. area 1st ft. Wadia.	D. area 1st ft. B. A. C.	D. area 1st ft. B. A. C.	D. area 1st ft. J. & H. S. P.	D. area 3rd ft. J. & H. S. P.	D. area 6th ft. Wadia.	D. area 6th ft. B. A. C.	D. area 6th ft. J. & H. S. P.	Map Square IV—V. 5 Wadia.	Map Square IV—V. 5 B. A. C.	Map Square IV—V. 5 A. C. A.
S. G.	3·08	3·08	3·08	3·08	3·08	3·00	3·05	3·05	3·05	3·13	3·13	3·13
SiO ₂	0·75	0·41	1·06	1·25	1·25	4·65	3·00	1·11	2·28	2·00	1·06	1·32
Al ₂ O ₃	78·82	84·50	78·12	77·88	79·87	76·58	} 81·95	79·57	78·11	84·00	79·90	79·43
Fe ₂ O ₃	3·45	3·00	3·42	3·31	0·91	1·00		1·85	1·96	} 2·00	2·09	0·47
TiO ₂	3·80	3·00	3·20	3·88	3·39	3·19		3·88	3·19		3·28	4·88
H ₂ O	14·15	...	14·06	13·85	14·50	14·45	....	14·05	14·30	12·00	14·05	14·45

SANGAR MARG—(concluded).								SALAL.					
Localities.	Map Square IV—V. 5 B. A. C.	Map Square IV—V. 5 Bloore.	Map Square IX. 7. S. E. B. A. C.	Map Square IX. 7. S. E. J. & H. S. P.	Map Square IX. 13 B. A. C.	Map Square IX. 13 J. & H. S. P.	Map Square XII. 7. N. J. & H. S. P.	Map Square VIII. 4 Wadia.	Map Square VIII. 4 B. A. C.	Map Square VIII. 4 J. & H. S. P.	Map Square VIII. 4—5 Wadia.	Map Square VIII. 4—5 B. A. C.	
S. G.	3·14	3·14	2·93	2·93	3·28	3·28	3·01	3·04	3·04	3·04	3·11	3·11	
SiO ₂	0·92	1·07	7·42	12·28	2·34	10·78	12·43	} 80·00	5·50	10·94	12·88	10·80	11·33
Al ₂ O ₃	78·34	78·92	72·40	67·54	77·31	68·34	67·32		71·34	69·15	75·01	67·52	
Fe ₂ O ₃	2·28	0·80	4·87	2·86	3·26	0·81	1·15		1·42	0·36	} 4·50	4·12	
TiO ₂	4·40	4·18	2·76	2·93	4·04	5·54	5·09		2·96	3·04		2·68	
H ₂ O	13·88	14·41	13·80	14·15	13·35	14·50	13·95	.. .	14·09	14·40	....	13·77

SALAL—(continued).

Localities.	S. G.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	H ₂ O
Map Square VIII. 4—5 B. A. C.	3-11	9-76	70-89	2-70	3-44	13-73
Map Square VIII. 4—5 J. & H. S. P.	3-11	10-85	69-66	1-24	3-33	14-60
Map Square VIII. 6. N. E. 2nd ft. Wadia.	3-12	3-50	77-00	....	....	....
Map Square VIII. 6. N. E. 2nd ft. B. A. C.	3-12	11-67	66-55	4-40	3-52	13-45
Map Square VIII. 6. N. E. 2nd ft. J. & H. S. P.	3-12	15-85	63-62	1-29	3-59	14-50
Map Square VIII. 6. N. E. 3rd ft. Wadia.	3-15	2-00	80-00	4-00		13-80
Map Square VIII. 6. N. E. 3rd ft. B. A. C.	3-15	7-51	72-37	3-26	3-72	13-45
Map Square VIII. 6. N. E. 3rd ft. J. & H. S. P.	3-15	9-17	70-93	1-14	4-19	14-35
Map Square VIII. 6. N. E. 4th ft. J. & H. S. P.	3-09	9-10	72-58	0-53	3-19	14-40
Map Square VIII—IX. 4 1st ft. J. & H. S. P.	3-11	8-15	72-77	0-81	3-33	14-70
Map Square VIII—IX. 4 2nd ft. J. & H. S. P.	3-13	12-40	68-73	0-96	3-06	14-50
Map Square IX. 5. N. E. Blore.	3-16	3-90	77-34	1-68	3-68	14-51

SALAL—(continued).

Localities.												
S. G.	3·16	3·16	3·16	3·16	3·03	3·03	2·77	2·77	3·11	3·11	3·11	3·11
SiO ₂	4·70	3·05	3·64	2·85	10·64	6·20	31·35	26·70	5·80	5·83	8·35	7·25
Al ₂ O ₃	} 82·10	77·64	75·63	77·83	70·82	75·74	52·57	56·14	76·20	74·63	71·44	72·38
Fe ₂ O ₃		2·64	3·46	1·32	1·95	0·71	1·05	0·36	....	3·31	3·31	1·80
TiO ₂		3·28	3·45	3·19	3·45	3·02	1·85	2·66	....	3·45	3·45	3·46
H ₂ O		13·64	12·81	14·60	13·67	14·24	13·57	14·05	13·06	13·56	14·85
	Map Square IX. 5. N. E. 2nd ft. Wadia.	Map Square IX. 5. N. E. 2nd ft. B. A. C.	Map Square IX. 5. N. E. 2nd ft. B. A. C.	Map Square IX. 5. N. E. 2nd ft. J. & H. S. P.	Map Square IX. 5. N. E. 3rd ft. B. A. C.	Map Square IX. 5. N. E. 3rd ft. J. & H. S. P.	Map Square IX. 5. N. E. 4th ft. B. A. C.	Map Square IX. 5. N. E. 4th ft. J. & H. S. P.	Map Square X. 3 Wadia.	Map Square X. 3 B. A. C.	Map Square X. 3 B. A. C.	Map Square X. 3 J. & H. S. P.

MIDDLEMISS : Bauxite deposits of Jammu Province, Kashmir.

SALAL—(concluded).									PANHASA.	JANGALGALL.
Localities.	Map Square XI. 3 Wadia.	Map Square XI. 3 B. A. C.	Map Square XI. 3 J. & H. S. P.	Map Square XIII. 4 Wadia.	Map Square XIII. 4 B. A. C.	Map Square XIII. 4 B. A. C.	Map Square XIII. 4 J. & H. S. P.	Map Square XIII. 4 Bloore.	Map Square III. 4 Bloore.	Bloore.
S. G.	3·07	3·07	3·07	3·20	3·20	3·20	3·20	3·20	....	....
SiO ₂	6·50	5·64	4·25	1·50	0·62	1·15	0·70	0·63	2·02	1·13
Al ₂ O ₃	75·00	73·85	76·40	80·00	80·00	79·51	81·12	82·25	77·61	78·62
Fe ₂ O ₃	....	2·55	0·81	....	2·22	2·07	0·28	0·55	1·17	1·17
TiO ₂	....	4·32	4·22	....	3·52	3·28	3·36	3·40	4·02	3·56
H ₂ O	....	13·64	14·20	....	13·38	14·05	14·45	15·00	14·71	14·37

In the lists given above I have omitted very small quantities of MnO, CaO, MgO, and P₂O₅, which are shown in **Other accessory components.** many of the analyses as accessories. For instance the British Aluminium Company's chemists have shown percentages of MnO and CaO, Messrs. J & H. S. Pattinson have shown those of CaO, MgO, and P₂O₅. These percentages are all very minute, seldom straying individually out of the second places of decimals.

It is clear from the percentage of combined water in the above **Chemically resembles the Mediterranean type.** analyses that, chemically considered, the purer Jammu bauxite must contain the alumina in the monohydrate form; having the composition of diaspore, and that therefore, from that point of view, it belongs to what is comprehensively known as the Mediterranean type of bauxite which includes those of Spain, France, Italy, Yugo-Slavia and Roumania except that the best Jammu ore contains more alumina and less iron as a rule, the former percentage more frequently than not being between 70 and 80, and only being equalled elsewhere by the lilac and white varieties of France (Herault and Baux). This is also borne out by the opinion of the Aluminium Company of America and that of others who have examined this better quality ore. It probably contains minute crystals of diaspore here and there among the non-crystalline paste.

Equally it is clear that it differs chemically from the Tertiary or **Chemically unlike the Tertiary type of America.** geologically younger type, including those of America in great part, those of West and East Africa, of Peninsular India and of Australia, which seldom contain less than 25 per cent. combined water.

The chemical resemblance to the Mediterranean type is not however **But differs in its physical characters from both.** ever supported by some of its physical characters, it being much denser and harder than that type and probably than any other known type.

A glance at the tables will show the great uniformity in the **Uniform percentage of water, iron and titanium.** amount of combined water and a nearly similar uniformity in the iron and titanium present. Only very seldom do the latter two oxides become noticeable among the analyses for their high percentages. This last characteristic is of course chiefly explained by the fact that all such varieties among the rocks we are considering are easily recognised in the hand specimens as containing much iron; and so, except very occasionally, were not sent for analysis, our object being to identify bauxite, not iron ore. Of course many bauxites in commercial use are not disqualified by a large iron content, but in the Jammu rocks unfortunately much iron generally

implies more silica than is allowable, as well as reduces the amount of alumina present. These ferruginous varieties are only found here and there in the Jammu areas, at or near the bottom of the thicker deposits, and are not characteristic of the deposits as a whole.

A result of great practical importance follows from the above. Specific gravity and uniformity as regards the amounts of combined silica percentage. water and iron and titanium, namely, that the percentage of silica present and the specific gravity of the material are found to vary inversely. This has proved very convenient for rough field testing.

Dr. C. Fox in his book on bauxite has remarked on the difficulty generally found in the field in distinguishing many of the red French bauxites from chocolate clays and shales, and that even the most experienced geologist may not be able to say whether a given substance is bauxite or not.¹

No such difficulty is commonly found with these pale Jammu bauxites. In consequence of the alumina being always in the monohydrate form and the iron and titanium practically constant, the specific gravity is a very sure guide in distinguishing bauxite from kaolin or kaolinic bauxite, and even in estimating the silica percentage within rather close limits.

The following list and the diagram (Plate 5) showing the specific gravities and silica percentages of the samples analysed in vertical and horizontal graduations respectively will make this clear.

N. B.—All the exceptional samples in which the iron, or iron and titanium, are unusually high have been omitted here for obvious reasons:—

Specific gravity.	Silica percentage.
2.50	41.10
.51	....
.52	....
.53	....

Specific gravity.	Silica percentage.
2·54	45·00, 44·15
·55	....
·56	41·85
·57	....
·58	44·00
·59	....
·60	42·30, 40·25
·61	48·70, 41·60
·62	....
·63	39·00
·64	....
·65	....
·66	....
·67	....
·68	26·70
·69	....
·70	....
·71	....
·72	....
·73	....
·74	35·80

All the above are classed as kaolin :—

Highest SiO₂ % =48·70

Lowest do. =26·70

Average do. =40·87

Specific gravity.	Silica percentage.
2·75	....
'76	....
'77	31·35, 26·70
'78	28·50
'79	21·40
'80	12·00
'81	18·50
'82	19·25
'83	....
'84	....
'85	....
'86	....
'87	14·58, 10·85
'88	....
'89	14·40, 10·70
'90	28·05, 12·40
'91	{ 8·45, 14·15 13·11, 13·15
'92	

Specific gravity.	Silica percentage.
2.93	7.42, 12.28
.94	....
.95	8.15

All the above are classed as highly aluminous kaolin :—

Highest SiO ₂ percentage	= 31.35
Lowest do.	= 7.42
Average do.	= 16.26

Specific gravity.	Silica percentage.
2.96	....
.97	4.93
.98	....
.99	3.00, 4.36, 4.53
3.00	4.65
.01	12.43, 14.00
.02	14.10
.03	10.64, 6.20, 11.40
.04	5.50, 10.94, 12.88
.05	3.00, 1.11, 2.88, 3.60
.06	....
.07	{ 9.40, 6.50, 5.40, 5.64, 4.25, 8.53.

Specific gravity.	Silica percentage.
3·08	0·41, 1·25, 1·25
·09	9·10
·10	10·80
·11	{ 10·85, 5·20, 10·54, 10·80, 7·09, 7·25, 8·15
·12	3·50, 11·67, 15·85
·13	2·00, 1·32, 1·06, 12·40
·14	5·50
·15	2·00, 7·51, 9·17, 1·90

All the above are classed as 1st and 2nd grade bauxite :—

Highest SiO ₂ %	= 15·85
Lowest do.	= 1·06
Average do.	= 6·80

Specific gravity.	Silica percentage.
3·16	4·70, 3·64, 2·85
·17	....
·18	....
·19	....
·20	1·50, 0·62, 0·70, 0·80
·21	....
·22	....

Specific gravity.	Silica percentage.
3.23	....
.24	....
.25	2.34

All the above are classed as 1st grade bauxite :—

Highest SiO ₂ percentage	—4.70
Lowest do.	—0.62
Average do.	—2.14

It will be seen at once that as the specific gravity rises from 2.50 to 3.25 the percentage of silica drops from well over 40 to about 1. The progression is irregular as regards individual analyses, but fairly regular when groups are considered. This is well shown in the diagram, where the clusters of points representing the intersections of the specific gravity and silica percentage coordinates tend to a diagonal position though individual points stray away from it. This, of course, indicates either that there were actual variations in the portions of the samples taken or, in some instances perhaps, that a margin of error must be allowed for in the analytical work.

We see also from the list, and even more distinctly from the diagram, that the following generalisations hold :—

Varieties indicated.

- (1) Varieties having S. G. 2.50 to 2.74 may be classed as kaolin with a silica percentage averaging 40.
- (2) Varieties having a S. G. 2.75 to 2.95 may be classed as highly aluminous clays with much less silica.
- (3) Varieties having S. G. 2.97 to 3.15 may be classed as one half 1st grade bauxite with 5 per cent. or less silica, and one half 2nd grade bauxite with between 6 and 15 per cent. silica.

- (4) Varieties having S. G. 3.16 to 3.25 are all 1st grade bauxite with 5 per cent. or less silica.

This ability of computing the silica percentage from the specific gravity alone was gradually appreciated and became a very powerful weapon in attacking the question of the richness and quantity of good bauxite in different parts of the various fields where analyses had not so far been done. Combined with the data given by superficial characteristics such as colour, hardness and texture of the sample it has enabled us in our later examinations to come to fairly rapid reliable conclusions about the quality and grade of any particular bauxite layer or patch without an analysis being necessary.

It is not contended of course that this rough and ready method is infallible for any one particular sample that has been, or may be, taken; but it gives results that are trustworthy in the aggregate.

Limitation of it.

Nor is it contended that as a consequence chemical analyses are no longer necessary. On the contrary, opportunities must be taken to thoroughly sample and analyse all the bauxite fields in still more detail as soon as opportunity offers, or as soon as some policy of exploiting the bauxite deposits is determined on.

AMOUNT OF BAUXITE AVAILABLE IN THE DIFFERENT AREAS.

A rapid synopsis will now be given of the potentialities of the Chakar, Sangarmarg, Salal, Panhasa, and Sukhwal Gali-Jangal Gali fields, taken each separately, based on :—

Principle of calculation.

- (a) *Superficial extent* :—as shown on the more or less detailed maps.
- (b) *Thickness* :—as proved by pits, trenches and natural exposures, and
- (c) *Quality* :—as shown by actual analyses in some places, and by the specific gravity in combination with lithological characters in other places.

All the areas and patches of commercial bauxite lie on the surface of the ground, uncovered by any overburden. This is a necessary condition dependent on their accepted mode of origin.

CHAKAR FIELD.

A. area.

No first-grade bauxite is known certainly from this area. The rather small and separated patches are from **No 1st grade bauxite.** 6 to 7 feet thick, sometimes well exposed and lying rather flatly often among alluvium. (See Pl. 7).

In the original patch explored in 1919, at the extreme west edge of A area as shown on the large-scale plan, the upper 4 ft. are highly aluminous clay with from 13 to 21 per cent. silica and from 60 to 70 per cent. alumina, the specific gravity ranging between 2.79 to 3.00.

At the pit marked A the first foot is coarse dark pisolite with 18.50 per cent. silica, and 66.50 alumina; kaolin setting in from the 3rd foot downwards.

B. area.

This area also contains no first-grade bauxite except in B. b. patch (judging by specific gravity and appearance of the latter). In the cliff-cut at B. pit the thickness of the series is 16 feet. All this, except the top foot, is in kaolin with some excess of alumina. The top foot of pisolite, with 23 per cent. silica and 65 per cent. alumina, ranks as highly aluminous kaolin.

B. pit is less than 50 feet distant from the overlying formations and we must assume that desilicification has hardly operated at all. The 15 ft. of kaolin is a fine deposit.

B. a. pit further to the north is over 100 feet distant from the succeeding formations above. The series there is **B. a. pit.** 15 feet thick. With the greater distance from its overburden and a slope of 18°, a small improvement has set in.

The upper 3 or 4 feet (the top foot being pisolitic) have formed into a grey, hard, compact, massive stratum, analysing from 8 to 28 per cent. silica, 77 to 49 per cent. alumina and with a specific gravity 2.87 to 2.91. It may be classed as highly aluminous kaolin.

The lower 12 feet is of pale soft splintery kaolin with a little excess of alumina.

B. b. patch lying to the east and two smaller ones north of it are entirely isolated and some 400-500 feet away **B. b. patch.** from the overburden. The absence of a pisolitic

cap and their rugged appearance caused them to be overlooked at first. No analyses have been made; but the colour, texture, hardness, and specific gravity indicate that this variety may rank as 1st and 2nd grade. Its colour is dull grey mottled light and dark, with white spots and small patches and it is granular and rough with a few small pisolites. It breaks up into very massive irregular pieces. Its specific gravity being 3.00, the probability is that the silica percentage ranges from about 3 to 15.

The total area covered by it is 60,000 square feet. From the size of the blocks one must judge it to be at least 4 ft. thick. Reckoning only half of this as first grade, we may calculate the quantity in the patch as 10,000 tons of first-grade ore. There are a few more isolated patches S. E. and E. S. E. of B. pit on the slope up towards D area. I have no details, but from their position there should be some fairly good material here. (See Pl. 7).

C. area.

This area is fairly large and comprises a number of connected and isolated patches on a dip-slope of about 18°, which rounds off flatly at the crest of the spur preparatory to a very steep turn over to the north of the dip of all the formations, where of course no further dip-slopes are to be found.

Many varieties of different quality are here to be found. Being the first large area to be examined by the Mineral Survey, it has been explored more in detail than other areas in order to get an accurate preliminary knowledge as early as possible from which to work further afield with confidence.

Pits or cliff-cuts in the bauxite were made at 20 places as follows
20 pits made. (See Pl. 7) :—

C., C. a., C. b., C. c., C. d., C. e., (made in 1919, the samples analysed in detail).

C. l., C. m., C. n., C. o., C. p., C. q., C. r., C. s., C. t., C. u., C. v., C. w., C. x., and C. y., (made in 1923, the samples not yet analysed.)

The pit marked C, lying to the south of the area, is about 400 feet from the overlying formations. Here the Bauxite Series is 7 feet thick, lying on the Breccia—which is the rule everywhere. The specific gravities, which range from 2.74 in the top pisolitic layer to 2.59 at the bottom, indicate that all are

C. pit.

kaolinic. One analysis only, made at the 6th foot, gave 41.60 silica and 45.70 alumina.

C. a. pit lies N. E. of C at the edge of the large-scale plan and 1,500 feet away from the overburden of higher formations. The Bauxite Series here reaches the large thickness of 22 feet, but most of the lower part is highly ferri-ferous instead of being kaolinic.

After the first foot of dark grey ferruginous pisolite, the 2nd and 3rd foot by analysis gave silica 5.40 to 9.40 and specific gravity 2.98 to 3.07. At the 3rd foot, although the silica is only 6.70, the iron and titanium are all increasing, and the alumina is consequently down to 58.03. These two feet can be classed as 1st and 2nd grade bauxite.

C. a. 4th foot, with a specific gravity of 2.95 and silica 13.35 and with a further increase of iron to 22.50 and decrease of alumina to 40.20, can doubtfully be admitted to 1st and 2nd grade.

Of C. a. 5th, 6th, 7th, and 8th ft. there are no analyses, but they have the same S. G. (just under 3.00) the iron apparently increasing.

C. a. 9th foot is a dark greenish-black flinty looking rock with 55 per cent. Fe_2O_3 . It and all the rest down to the 15th foot must be regarded as iron ore.

C. a. 18 to C. a. 22 are kaolin.

C. b. pit lies W. N. W. of C and 200 feet from the overburden. The series here is 12 feet thick. The first foot is pisolitic with SiO_2 27.10 and Fe_2O_3 16.80. C. b. 2nd, 3rd and 4th foot have S. G. ranging from 2.89 to 2.95 and SiO_2 , 7.15 to 12.40. The alumina however is high, about 70 per cent. All are grey, compact, faintly pisolitic, with streaky and wavy lamination and smooth surfaces which take a good polish. They are classed with the highly aluminous kaolin, but coming near 2nd grade bauxite.

The lower 8 feet are soft pale kaolin with low S. G. and presumed high silica judging by one analysis of C. b. 9th foot with 41.10 SiO_2 . This locality is too near the overlying Coal Measures and Nummulitics to expect any 1st and 2nd grade bauxite.

C. c. pit E. N. E. of C. b. and 1,000 feet from the overburden has only the third foot analysed yielding 10.85 silica, over 70.00 alumina and with a S. G. of 2.87. It is dark grey, compact, pisolitic, streaky or brecciated. The 2nd, 3rd

and 4th foot may be classed as highly aluminous kaolin coming near to 2nd grade bauxite.

C. c. 6th to 8th foot are pale grey, compact, streaky and take a high polish; but their very low S. G. 2.58 to 2.63 only, indicate that they and the rest of the softer class to the bottom at the 12th foot can only be ranked as kaolin.

C. d. pit a little S. W. of C. a. pit is 1,100 feet from the overburden and 16 ft. thick. C. d. 1st foot is missing in the section. C. d. 2nd and 3rd foot are very hard and compact, grey, streaky and faintly and minutely pisolitic with smooth surfaces and taking an extremely high polish. Their high S. G. of 2.97 to 2.99, very low silica 3.00 to 4.93 and over 70 per cent. alumina put them with the 1st grade bauxite. It is rare to find samples of the appearance of the above analysing so well, but there can be no doubt about the latter being correct. The agreement of all the chemists on this point is convincing.

With C. d. 5th foot we get rather high iron and titanium and below that C. d. 6th to 9th foot, from their S. G. and appearance, rank with the highly aluminous kaolin. They are followed by 7 feet of kaolin.

C. e. pit, lying close to the scarp of the overlying Coal Measures, is only 7 feet deep down to the Breccia below. The 1st foot has been analysed. Its silica 28.50, alumina only 45.80 and rather high iron percentages put it only doubtfully with the highly aluminous kaolin. The rest are all kaolin.

The remaining pits put down in 1923 in C. area number fourteen.

Remaining pits put down in 1923, C. d. patch.

No analyses have been made of any of the samples taken but the appearance and specific gravity of many of them are promising. For instance, several pits in the C. d. patch have yielded good looking material of high specific gravity, such as C. m. pit at the north edge west of C. d. with its 6 feet of dull grey and dark grey, fine grained to compact material with S. G. from 2.86 to 3.15. Also C. o. pit east of C. d. with its dull, putty coloured material 2 feet thick and an average S. G. of 2.96. Also the similar material of C. p. pit 6 feet thick with an average S. G. of 2.98. On the other hand C. q. pit of the same patch and C. r. of the attenuated patch to the south only gave low specific gravity stuff. Among the alluvial patch north of C. d. patch there is also some good-looking material of the hard, dense rough character similar to that of B. b. patch. On the eastern margin of C. r. patch there is a little of the white or cream coloured pisolite, like

that presently to be described in D. area, which is most probably very good.

C. s., C. t., C. u., C. v., C. w., C. x., and C. y. pits are scattered over the more western parts of C. area and have yielded respectively 3 feet of S. G. 2·95, 6 feet of S. G. 3·06, 5 feet of S. G. 2·91, 4 feet of S. G. 2·98, 2 feet of S. G. 2·88, 6 feet of S. G. 3·01, 3 feet of S. G. 2·97. The material is as above in most of the other new pits, namely dull, hard, fine-grained to compact and of grey or putty coloured tints. From further experience elsewhere of varieties having this appearance and of which analyses have been made I judge most of these to be high-grade bauxite.

It will have been seen from the large number of pits and cuts made in C. area that the evidence for thickness of good bauxite is a little variable. This is only what may be expected from a rock formation of this kind, according to the theory of its origin which we have been led to adopt. Dr. Fox in his treatise on Bauxite¹ has drawn attention to similar irregularities in bauxitic laterite mantles where the enriched aluminous zone rises and falls in thickness according to the facilities that have prevailed for percolation of ground water. Along with all these irregularities in detail there is a general average regularity in C. area, except for the strip of the Bauxite Series lying near the overlying scarp of the Coal Measures. Omitting that strip we may rely on a three foot thickness at least for 1st and 2nd grade qualities. Allowing that of this at least 1 foot of first grade bauxite with 5 per cent. silica and less covers the whole area and taking that area to be 620,000 square feet (as obtained by weighing areas cut out of paper from the original map of 1 inch to 100 feet) we get 66,000 tons for the amount of first-grade bauxite available from C. area as a minimum. But there may be much more.

D. area.

D. area is an isolated spread of the Bauxite Series situated just above the Kainthu forest as marked on the 1 inch Survey of India map and the large-scale plan (plate 7). It may be connected with the north-east edge of C. area by intermediate patches, but, if so, the connection is hidden by cultivation and alluvium. Towards the south-west it overhangs steep slopes of Breccia and Great Limestone, with only a few remnants of pisolite occurring lower down

Position of the Bauxite Series.

in the direction of A. and B. areas. These latter have been alluded to before (p. 34), but have not been examined or collected from in detail.

Though not a very large spread, it is a particularly interesting and valuable one. It consists of 4 or 5 patches of different size strung out more or less in a N. W.-S. E. direction and clinging precariously to a rather steep slope of 20° . The uniformity is however broken along the N. E. edge of the set of patches by a sharp little steepening of the dip, giving the effect of a half synclinal fold or pucker of the bauxite mantle. This fold has its axis parallel to the line of patches and it brings the upturned edge of the beds on its N. E. border plainly into view dipping 50° to 60° S. W.

By measuring across these upturned edges the thickness of the Bauxite Series in this D. area comes out much greater than anywhere else. Most of this however is due to the large development just here of the lower ferruginous layers which exceeds that at C. a. pit described in the last section. It amounts to as much as 40 feet in the vicinity of D pit, some of it being a good iron-ore and the rest a dark greenish ferruginous bauxitic shale weathering reddish.

In the very large-scale plan of a portion of D. area (plate 8) and the sections through it (plate 9) the Bauxite Series is shown differentiated into three layers, the upper one being white pisolitic and non-pisolitic bauxite, the middle one being kaolin and rather thin, and the lower one ferruginous shale and iron-ore.

The preservation of the bauxite of this area from the destructive action of denuding agents tending to split it up and carry it away down hill, appears to have been largely due to the little synclinal fold alluded to in a preceding paragraph, which has sunk the Bauxite Series below the general slope of the hill-side and so preserved it. The fold may have been assisted by an original hollow in the Breccia, the deepest parts of which were filled up by the heavier iron silicate being precipitated first.

The upper bauxite layers are remarkable for their white to cream colour, which is more noticeable here than in any other part of the Chakar field. From the analyses made on the material collected from the original cut at pit D and other places in the vicinity (See Table of Analyses) we see that these upper layers of pale pisolitic and non-

Analyses: quality excellent.

pisolitic bauxite have an average silica percentage of 1.75 and an average specific gravity of 3.06, which places them up among the first-grade bauxite.

Since the first collected specimens were analysed with the above results a more detailed examination of the area was made in 1923 when pits D. a., D. b., D. c., D. d., D. e. and D. f. were dug and sampled and again in 1925 when the above were checked and fresh pits D. m., D. n. and D. o. put down centrally in some of the more important patches. These samples have not been analysed yet ; but by means of the specific gravity tests, combined with the colour, appearance and the texture of the samples, we can arrive at the following approximations.

The most easterly patch at D. a. pit exposes in the upturned edges of the layers, a good thickness of bauxite of dull white, dirty white, or cream coloured tints. There are four feet of pisolite underlaid by four feet of non-pisolitic material, all of excellent appearance. The average specific gravity is 2.99. There is a similar section exposed at D. c. pit. But in the centre at D. m. pit and at the southern edge as shown by old iron pits the thickness of the upper pisolite is not so clear. It apparently becomes broken up into very large blocks which are displaced and many of which must have rolled down the slope and disappeared. The lower non-pisolitic kind also thins out or passes into kaolin towards the south edge.

In calculating the amount of 1st grade bauxite in this patch, I reckon therefore only 2 feet of good pisolitic bauxite of 1st grade and 1 foot of the non-pisolitic kind. This, together with the specific gravity of about 3.00 and with the superficial area of the patch as 20,000 square feet, promises an amount equal to 5,050 tons 1st grade bauxite. Below in every case comes ordinary soft kaolin, breaking up into the usual thin cakes and splinters, 10-12 feet thick at the northern outcrop. It is underlaid by about 8 feet of the ferruginous variety and then comes the Breccia.

The next important patch is that marked by pits D., D. o. and D. n. It is semi-detached from the remaining area to the west. D pit or trench at the northern outcrop showed 2 to 4 feet of good-looking white or whitey grey pisolite followed by 4 feet of equally good non-pisolitic bauxite, of an average specific gravity of 3.17 Under this is a thin layer of kaolin followed by 40 feet of iron silicate weathering

into a reddish ferruginous shale. D. o. and D. n. pits put down centrally did not show any falling off in the thickness as was the case in D. a.—D. n. patch. So that this patch of 30,000 square feet reckoned as 6 ft. thick and with a specific gravity of 3.17 is calculated to hold 15,000 tons of first-grade bauxite.

The remainder of the big D patch, has to be estimated from the partially explored area of D. d., D. e., and D. f. pits. D. d. shows 5 ft. of excellent white or putty coloured pisolite and non-*pisolite* whose specific gravity averages 3.12, below which comes 2 feet of kaolin. D. e. pit shows 6 feet of similar excellent stuff with average specific gravity 3.12, underlaid by 2 feet of kaolin. D. f. shows 8 feet of similar, but sometimes slightly darker stuff with average specific gravity 3.11.

We may estimate the total amount in this part of D. area as about three times that of D., D. o., and D. n. part, namely 45,000 tons of excellent bauxite.

The other isolated and as yet undifferentiated small patches which have not been collected from may be roughly estimated to contain altogether as much as D. a.—D. m. patch, namely 5,050 tons.

The total then for D. area is about 70,000 tons of first-grade bauxite.

There may be more bauxite of quality and quantity unknown underlying the alluvium further west and so connecting up with C. area. As this is problematical I have not included anything from here in the calculations.

THE REMAINING BAUXITE LOCALITIES.

As mentioned in the section devoted to the Distribution of the Bauxite Series, the Sangarmarg field and all the others to follow have not been examined (except very locally) in as detailed a way as the Chakar field. The maps illustrating these areas as a whole are 4-times enlargements of the Survey of India 1 inch to 1 mile sheets, and only a small amount of pit-sinking in the Salal area has been done.

The reason for this is that, in the progressive methods adopted by my survey, we start in all cases of importance with the 4-times enlarged 1 inch sheets and only proceed to the more detailed delineation

Reason for this.

later as circumstances and opportunities offer. When the Chakar area was finished on the large scale-plans, certain difficulties arose in connection with the alleged insolubility of the bauxite in the caustic soda treatment for purifying the alumina. At one time it seemed that these difficulties might be insuperable. Hence the further detailed surveying of the other fields was held in abeyance; and, since then, although the solubility difficulty has been removed, no further large-scale plans with one or two exceptions have been constructed.

Notwithstanding this paucity of detailed delineation, a good deal of information about these extensive spreads of bauxite has been obtained which I will now proceed to summarise.

SANGARMARG FIELD.

Two patches only in this large field at the extreme west end of the hill mass have been planned out on a scale of 1 inch to 50 ft. They occur N. W. of Chenar Sangar in map squares IV-V-4 and IV-V-5 of the enlarged Survey of India Sheet as shown (Pl. 10) and the latter is separately reproduced (Pl. 11). The bauxite here is white or pale cream coloured resembling that of D. area, Chakar. From the analyses given in the tables it will be seen that these samples have a S. G. 3·13 to 3·14, silica percentage of between 0·92 and 2·00 and alumina percentage 78·34 to 84·00. So that they all fall into the class of first-grade bauxite. They are composed of pisolitic and non-pisolitic varieties which are together about 4 feet thick and are underlaid by a small amount of kaolin and then by 6 feet or more of greenish yellow compact ferruginous and siliceous bauxite and ferruginous shale with some good hematite layers. This rich hematite, having perhaps 60 per cent. iron, lies on the surface here as also in parts of the Chakar area and has not been touched by the ancient iron workers. Possibly they could not manage such a rich and intractable ore and so took immense pains to obtain the poorer, but possibly self-fluxing, ore from pits made in the hard breccia.

I estimate the amounts in these two patches, IV-V-4, and IV-V-5, to be 11,750 and 2,500 tons respectively of first-grade ore. first-grade bauxite.

The rest of the high-grade bauxite found at intervals over this large but very much split up tract must be summarised more generally. Its occurrence as little cappings lying on the sloping crests of the side-spurs and main Sangarmarg ridge, obeys the same law as already been found operative in the Chakar area, namely that it is only found as outliers uncovered by any higher beds on slopes of about 20°

and at some distance away from the out-crops of those higher formations. Hence the Bauxite Series round about the villages of Saro-dabas and Malhad and one other spot south-east of Chenar Sangar contains no highly aluminous bauxite because of their proximity to the overlying strata. All the other spurs north-east and south of these, on the other hand, do provide numerous examples of first-grade bauxite.

Since we have only a few more chemical analyses to go on, we must in most cases roughly estimate the qualities of the remaining spreads from their specific gravities and physical characters, according to the principle which we already found to hold in the Chakar areas and in the two patches north-west of Chenar Sangar, namely, that high specific gravity (over 3.00) together with colour of a dull white or putty tint and a texture that is rough and granular to pisolitic, indicate 1st and 2nd grade bauxite. This principle, as already explained, cannot be said to be infallible in any individual instance, but is true in the aggregate, being based on a large number of already proved cases.

These remaining spreads in the Sangarmarg field will simply be enumerated, taking them in order and progressing from the last-described locality of Chenar Sangar in an easterly direction through the horseshoe-shaped upland valley of the Sangarmarg area. All the specimens have the requisite pale, dull colour, or putty colour with a pisolitic or granular texture and are rough and hard, besides being generally found weathered out into massive irregular blocks. They, or the patches they represent, are referred to by the letter and number of the map squares to which they belong, followed by the specific gravity. Any special remarks called for are given in brackets :—

- V. 4, S. G. 3.15 (other specimens in the same map-square are of the basal ferruginous bauxite). VI. 5, North, S. G. 2.99 (other specimens from here too are ferruginous, and indicate, as does the one above, that most of the upper rich bauxite has been denuded away). VI. 6, S. G. 2.87 (large patches near Chenar Sangar, though these have the physical qualities as above, their rather low S. G. indicates that these patches are of the quality of highly aluminous kaolin rather than 1st or 2nd grade bauxite). VI-VII. 5, S. G. 3.14 (also another of S. G. 2.92 less good). VII. 6, S. G. 3.02. VII. 8, S. G. 2.97 (there is a black variety with S. G. 2.60 in VII. 7, which is a highly carbonaceous kaolin. It is associated with the overlying formations). VIII. 5, S. G. 3.12, near the summit of

Sangarmarg. VIII. 7, S. G. 3·00 (VIII. 7, S. E. with S. G. 2·94, though classed with the highly aluminous kaolin group, is very near the next higher group). IX. 7, south, S. G. 3·12, IX. 7, S. E., S. G. 3·12 (this pisolite of the required colour and texture, etc., has been analysed—see tables—the silica percentage being 7·42 and 12·28 and the alumina percentage 72·40 and 67·54 according to the different analysts' results. Another patch from IX. 7, S. E. with S. G. 3·02 is yellowish brown and compact to finely granular. It probably owes its high S. G. to undue iron. IX. 9, S. G. 2·79 is a soft dark grey pisolite belonging to the class of highly aluminous kaolin. IX. 9, S. E., S. G. 2·63 is a pale greenish yellow splintery and soft kaolin). IX. 13, S. G. 3·05 (one specimen) 3·28 (another specimen) (specimens from this map square have been analysed with varying results one giving SiO_2 , 2·34 and Al_2O_3 , 77·31 and another SiO_2 , 10·78 and Al_2O_3 , 68·34. Massive blocks of it cover a large area in oak forest near Dargari peak and look very promising). X. 6; S. G. 2·97 (pisolite rather dark flinty looking matrix. Below it comes white compact rather soft kaolin S. G. 2·84). X. 13, S. G. 3·00 (a continuation of the good material at IX. 13). XI. 7, S. G. 3·00 (little patches on the ridge, XI. 12, S. G. 3·00). XI. 10, S. G. 2·91 is only highly aluminous kaolin. XI. 13, S. G. 2·76 is kaolin. XII. 7, North, S. G. 3·01 (this pisolite has been analysed—see tables— SiO_2 , 12·43, Al_2O_3 , 67·32). XIV. 10, S. G. 2·55 and XV. 11, S. G. 2·67, both soft splintery kaolin.

It is not easy to compute the amount of first grade bauxite in these patches which are scattered so at random over a large area. That the small patches cannot be accurately represented on the scale of the 4 inch map may be easily seen by comparing those in map squares IV-V. 5 and XIII-4 with the large-scale plane-table reproductions afterwards made of the same. Furthermore it is not pretended that bauxite of first-grade quality is present everywhere even in the map squares where the Bauxite Series is shown and has been enumerated above. In order to avoid exaggeration and so to keep on the safe side in this computation, I shall first calculate the total of those patches and then allow only one foot thickness throughout. By cutting out and weighing the areas taken from the map in paper we get 3,011,000 square feet as the combined area and the

same number of cubic feet at one foot thickness. This with a specific gravity of 3.00, gives roughly 250,000 tons as the available first-grade bauxite in Sangar Marg field in addition to the amounts already calculated for map-squares IV-V. 4 and 5. There is almost certainly more than this as shown on the map, and very probably there are patches here and there on the numerous slopes which for one reason or another have escaped observation and registration on the map.

It is obvious that much detailed work still remains to be done in the Sangar Marg field in the direction of large-scale delineation of the various grades of bauxite as found therein.

Much detailed work yet to do.

One or two exceptional features of the Bauxite Series and Breccia, as developed in this area, are briefly mentioned below :—

In map-square IX-9. S. E. near Bamliia Sangar there is found under the poor bauxite or highly aluminous kaolin of the ridge-spur a bed 6 feet thick in which the iron, instead of being evenly disseminated, has been collected into lumps of pure hematite. Some of these reach a size of 6 inches by 4 or 5 inches. The S. G. of these lumps is 4.5.

Hematite lumps.

In map-square XIV. 9-10 near Malhad, the breccia formation loses its breccia character and becomes a well bedded saccharoid quartzite with carbonaceous layers throughout a thickness of from 80 to 100 feet.

Carbonaceous layers in quartz, etc.

SALAI. FIELD.

Only one or two patches in this, the largest and most coherent of all the bauxite fields, have been surveyed in detail, that is to say on large-scale specially constructed plans. For all the rest we have to rely on the geological mapping done on the 4-times enlarged 1 inch to the mile sheet of the Survey of India. About half-a-dozen pits and cliff cuttings were made to obtain reliable samples. The position of these can be seen from the map (Pl. 12). The analyses of the samples as shown in the tables are more numerous than those done for the Sangar Marg field and nearly equal in this respect to those done in the Chakar field. Still, the number of pits being much smaller than those put down in the Chakar area, it is obvious that many of the analyses have been made on material gathered at the surface outcrop, just as was the case with the Sangar Marg analyses.

Very little detailed work.

I must call attention again to the larger and more continuous area of the Salal deposit as compared with that of all the other localities. It controls the value of the deposit in two opposite ways. Firstly it points to a greater quantity of easily available material conveniently situated, secondly it enjoins caution, because we have already found out that the conversion of the Bauxite Series of originally kaolinic material into industrially useful bauxite is not so complete in large continuous spreads as in the smaller isolated portions on the denuded fringe of these spreads.

A great many more pits must be sunk to prove how far the continuity of richly alumina concentration has proceeded laterally from the scarp edges. The importance of this was early appreciated by us and has been equally insisted on by Dr. Fox in his published volumes¹.

It was with this in view that in 1921, when a ton of the better quality bauxite was collected for trial purposes from the Salal and other fields, that a few of the patches were traced outwards in this way. The method was actually to follow at the surface or just under the surface any particular, good-quality bauxite (already known by its analysis) by means of its colour, texture, specific gravity and general appearance. The result showed that a fair continuity was often maintained; but the scope of the work was not sufficient to prove anything but a most irregular law of distribution, excepting of course as regards those general principles already established and categorically enumerated (see pp. 9-10). The conclusion of the whole matter is that similar detailed step-by-step work must be carried out over the whole area before we can really be said to have proved the deposit properly. The Salal localities actually treated as above were those of map-squares XIII. 4 and IX. 5, N. E. 2nd foot, and the results are shown in Plate 11. Those of the other fields of Chakar and Sangar Marg have already been alluded to.

It is noteworthy that Salal has not yet furnished any examples of the white or very pale cream-coloured bauxite, such as that found in D area Chakar and IV-V. 4-5 Sangar Marg, although some specimens come rather near this. The actually best-quality ore according to the analyses is a pale lilac or lavender coloured variety found in map-square XIII. 4. The bauxite of other patches almost equally good belongs to the dull

1. See *Bauxite* p. 31.

granular, faintly pisolitic rough and dusty looking varieties which exhibit various shades of mottled grey.

The chemical analyses made of Salal bauxites are 37 in number, but they refer to only 13 different samples or specimens (see table pp. 21-24). Of these, IX. 5, N. E., 1st and 2nd foot, XI. 3. and XIII. 4 by reason of their specific gravity and chemical composition, fall definitely within the first grade, containing not more than 5 per cent. silica.

VIII. 4, VIII. 4-5, VIII. 6, N. E. 2nd, 3rd, 4th and 6th foot, VIII-IX. 4, 1st and 2nd foot, IX. 5 N. E., 3rd foot and X. 3 similarly, according to the same rule, fall within 1st and 2nd grade, whilst IX. 5, N. E. 4th foot belongs to the highly aluminous kaolin group.

For all other specimens gathered at the surface in the various map-squares, we have only the specific gravity and appearance to judge by. There are not very many of these and, where favourable in their indications, they generally lie intermediately among the map-squares quoted in the preceding two paragraphs, and need not be further specified.

One or two special features in this field require mention. No very ferruginous varieties. Throughout the area the lower members of the series are never ferruginous, except slightly so at the northern and lowermost edge of the area in map-squares VII, VIII and IX. 3. This is presumed from the greenish or yellowish colour of the flinty looking material. All over the rest of the area the lower beds become soft and kaolinic.

As a rule the thickness of the Bauxite Series is not great in this field, it being somewhere in the neighbourhood of 8 feet on an average. This estimate has been based on one or two pits and on cliff sections. Most of the pits were stopped when the definitely kaolinic material was struck. But the record shown in the rock-cut IX. 5, centre, is somewhat abnormal. The section there exposed is in a scarp of 20 ft. thickness, the beds dipping rather more steeply than usual towards the north (see Pl. 4). The peculiarity here is that material of moderately high density (2.95-2.74) is found from the 7th foot to the 12th foot in addition to the 2nd and 3rd foot. From partial analyses of some of these by D. N. Wadia the silica percentages are as follows:—

2nd ft.	S. G.	2.94	SiO ₂ %	12.20.
5th ft.	"	2.68	"	26.70.
8th ft.	"	2.81	"	18.50.
11th ft.	"	2.95	"	12.40.

Below the 12th foot the specific gravity rapidly sinks from 2.72 to 2.57 at the 17th foot where the breccia begins.

It is clear from the above that a large thickness, of about 8 feet, Unusual thickness of at this place must be classed as rather high up highly aluminous kaolin. among the highly aluminous kaolin.

One more unusual feature in this map-square (IX. 5.) is that a Coal in the Bauxite little further to the south there is an exposure Series. 100 yards long, the upper 1½ ft. being of grey massive bauxite covered by a trace of pisolite. This is directly underlaid by 1½ ft. of coal and that in turn underlaid by dark grey splintery bauxite. The whole exposure makes a scarped cliff edge such as is normally found limiting a bauxite spread. The coal dies out laterally in each direction among the bauxite. It has not been analysed, but we burnt some of it in camp one evening. This occurrence will be referred to again and discussed in the report on the Jammu Coalfields.

In all other respects the laws governing the distribution of the Other peculiarities. richer forms of bauxite agree with those already formulated. For instance, all the area to the south, immediately surrounding the Nummulitics and Coal Measures of the Fort part of the hill yields only soft kaolinic material right through the Bauxite Series and including even the pisolite. The same rule holds near the village of Gura, except that immediately to the south of, and therefore above, the Gura Nummulitic patch, the Bauxite Series lies temporarily with a steeper dip than usual, of 20°-30°. This seems to be part of a small warp or pucker, which extends further east as far as map-square X. 4. and is analogous to that which we found so well marked in D area Chakar. At these places, where the bauxite mantle has been bent into a steeper fold than usual (the normal inclination of the slope with its bauxite layer being only 15°) it is richly aluminous right down to where it passes beneath the Gura overburden.

A feature of the Salal slope of some interest is connected with Sagging of bauxite those parts where the streamlets flowing straight crest along drainage down the slope have cut back deeply into, and lines. apparently through, the bauxite capping. This

is not always as decisive as it appears at first sight. Much of the erosion has acted on the soft kaolin below the bauxite surface and the latter, instead of being removed altogether has sagged down accompanying the erosion.

In order to be well within the mark, I estimate the amount of 1st grade bauxite in the Salal field to be the equivalent of 1 foot thickness over the whole area where the Bauxite Series is exposed, namely about 1,000,000 tons.

As in the Sangar Marg field, much detailed work yet remains to be done on the Salal slope before the deposit can be considered as in any way definitely proved and divided up into its different qualities of bauxite, bauxitic and kaolinic material.

PANHASA FIELD.

The remaining two bauxite fields of Panhasa and Sukhwalgali-
 Much 1st and 2nd grade bauxite. Jangalgali were the last to be surveyed on the 4-times enlarged Survey of India sheets. As shown by the table of analyses, only one sample from each of these areas has so far been analysed but with very good results, the silica percentage of the Panhasa sample being as low as 2.02 and the alumina reaching 77.61. There can be no doubt however that, commensurate with the smaller surfaces concerned, much first and second grade bauxite in addition to much of the lower grades, occurs in these fields. The ground for this assertion is the now well-established principle that the specific gravities, combined with certain familiar colours and textural characteristics, are an index to the quality of the samples as a whole.

The Panhasa area, like that of Salal on a larger scale, may be considered as forming part of the northern limb of the dome anticline, but complicated by being thrown into some minor folds, which fortunately have preserved the bauxite deposit whilst the overburden has been removed. Thus the area lying to the south of Panhasa hill and Doga village constitutes a synclinal trough and it is followed on either side by minor anticlinal folds. As in all the other occurrences described in this paper, it is only where the deposit forms a mantle or skin at the surface of a dip-slope that the bauxite becomes of economic importance. In every respect the underlying and immediately overlying formations agree with those found in force in all the other areas and they need no further comment.

The Panhasa field is composed of three separate spreads, namely the Panhasa spread to the north, the Doga spread on the hill-spurs in the western part of the map (Plate 14) and the Baldhanun spread on a spur to the east. The map and the sections (Plate 15) will make their shape and position sufficiently clear.

No regular pits were sunk, but advantage was taken of natural cliff and stream-bed exposures to collect samples from different levels at selected places. These places are indicated on the map by the pit symbol.

The thickness of the Bauxite Series varies within certain well-marked limits as in other fields, namely from 4 ft. to about 18 ft. Other variations vertical and lateral are similar to those in the areas already described, the richest bauxite being near the surface, but generally lying below the uppermost pisolite layer, and the kaolinic varieties being found below that. The lateral variations also are similar, the portions of the spreads, near the Nummulitic cover being relatively of poor quality, and those further away richer. Map squares III. 4., II. 3. S. E., II. 1. east and VI. 3. S. E. are examples of the latter.

The samples collected have been taken from pits or cliff-cuts :—
 Map-square II. 3. shows the upper 6 feet to be probably ranked with 1st and 2nd grade bauxite. The specific gravities, from above downwards foot by foot, are 2·99 (pisolite), 3·20, 3·12, 3·04, 3·11 and 3·11 ; all but the pisolite, which is yellowish, being hard and pale grey coloured and fine-grained.

Map-square II. 1. east shows 4 feet of similar material but darker and more compact, the S. G.'s from above downwards being 2·92 (pisolite) 3·00, 3·10 and 3·19. All the above are underlaid by some feet of kaolinic material and then there follows a rather fine-grained, sandy representative of the breccia.

Map-square III. 4. west shows from the 1st to the 6th feet a set of samples which range in S. G. from 2·91 to 3·10. They are generally dark in colour, the upper 5 feet being coarsely pisolitic and the 6th and 7th compact and grey with white specks. They possibly owe their rather high density to iron and titanium in some excess. Below the 8th foot the S. G. sinks to 2·82 and we are among the aluminous kaolin varieties.

Map-square VI. 3. S. E. has the top 3 feet of hard dense granular grey-coloured good-looking material, with S. G.'s 3.04, 3.11 and 3.10 ; but below that the S. G. falls rapidly from 2.88 to 2.47 down to the breccia at about 12 feet depth.

Collections at the surface where no cliffs presented themselves were made at map-square III. 4. It is a hard dense putty coloured pisolite resembling that of D. area, Chakar, its S. G. being 2.90. Also at II. 3 south, where a similar variety is found. Both are very good-looking.

The total approximate area as calculated by weighing paper areas traced from the map against equivalent paper squares amounts to 4,791,600 square feet, which I estimate as likely to yield 200,000 tons of 1st grade bauxite as a minimum.

Total area and cubic contents.

SUKHWALGALI-JANGALGALI FIELD.

This area, as will be seen from the Outline map, lies at the extreme S. E. end of the elongated dome of older rocks. The intervening area between Salal and Sukhwalgali, a distance of about 20 miles, except for a patch or two at Kothri (5 miles N. by W. of Sukhwalgali) and a few traces at other places, is devoid of any spreads of the Bauxite Series.

Description.

The deposit of the area is split up into a number of individual patches stretching over a length of 5 miles, all as a rule of rather small width (see Pl. 16).

The Sukhwalgali area embraces the Sukhwalgali spread and others as far as Jangalgali. The former is the largest of all, being about a mile long and 1/6 mile wide at its widest part. Its rather steep uniform slope, jutting out from the Coal Measures and Nummulitic scarp, makes a conspicuous object as seen from below.

Sukhwalgali spread.

Its free southern edge is composed of rich material whilst towards the bottom of the slope the deposit gets ferruginous and much poorer.

Beyond this largest spread there is a fairly large one west of Jangal village and another between the two points marked "Jangalgali" on the map with only narrow strips elsewhere.

Spread west of Jangal.

No pits were made throughout the area from Sukhwalgali to Lain (Laran), but collections were made from surface outcrops and cliff sections. The spots collected from are indicated on the map by a double circle.

With the exception of the patch $\frac{1}{2}$ mile S. S. E. of Jangalgali gap, where the top layer and the one below have low S. G.'s of 2.71 and 2.57 and which are therefore poor, the rest of the localities met with before Lain (Laran) is reached have yielded results as follows:—
Qualities of bauxite. Sukhwalgali spread, east locality, S. G. 2.94 a hard dense putty coloured pisolite. Central locality, S. G. 3.04 a grey hard dense granular variety. Western locality, S. G. 3.06 a hard dense greyish white variety. Patch west of Jangal village, S. G. 2.99 a hard putty coloured pisolite. Patch west of Jangalgali gap, 2nd layer, 1 foot below the surface and $1\frac{1}{2}$ feet thick, S. G. 3.05, grey hard and partly pisolitic. A three-foot layer follows below this, S. G. 3.00, a pale grey hard variety, and then comes soft white kaolin $6\frac{1}{2}$ feet thick, $\frac{1}{4}$ mile S. S. E. of Jangalgali gap S. G. 3.03 grey and hard.

At Lain (Laran), where the outcrops of the Bauxite Series in a southerly direction ends by disappearance beneath the Recent gravel banks, there is a clean section in the stream-bed of the series dipping steeply E. S. E. at 70° and succeeded regularly above by the Coal Measures and Nummulitics. The Bauxite Series here is a little over 20 feet thick with a pisolite (S. G. 2.54) and pale grey compact non-pisolitic rock in the upper few feet like that at B. a. pit Chakar 2nd and 3rd ft. (S. G. 2.72), followed downwards by yellow soft coarse-grained rock (S. G. 2.61) and then by red ferruginous varieties like those in C. a. pit Chakar (S. G. 2.94). There is then only about 5 feet of Breccia and then the Great Limestone.

The point to be noticed in this well exposed steeply dipping section is that there is no concentration of alumina into bauxite proper at all, although a short distance away to the north-east where the series is found at the foot of the Great Limestone slope pieces of much better bauxite can be met with having S. G. 2.90 to 3.10.

There is thus throughout this Sukhwalgali-Jangalgali field a fair
Estimated amounts of amount of pale grey hard bauxite of about S. G. 3.00, that is to say of bauxite coming in the 1st and 2nd grade class. The material at my disposal and the one analysis made which gave silica 1.13 and alumina 78.62 per cent. only enable me

to make a rough estimate of the 1st grade bauxite here. We shall be well within the limits of safety in estimating this to be the same as in the Panhasa field, namely 200,000 tons.

TOTALS OF FIRST GRADE BAUXITE.

If we tabulate the amounts calculated above of first grade ore, having from 1 to 5 per cent. silica and 80 to 75 per cent. alumina, we obtain for all the five main areas :—

	Tons.
Chakar, B. b. area	... 10,000
" C "	... 66,000
" D "	... 70,000
Sangar Marg IV-V. 4	... 11,750
" " " 5	... 2,500
" " remaining areas	... 250,000
Salal	... 1,000,000
Panhasa	... 200,000
Sukhwalgali-Jangalgali	... 200,000
	<hr/>
Total	... 1,810,250

The above is a cautious estimate based on known conditions.

How long supplies will last.

There may very likely be much more that will come to light in covered ground or in new and as yet undiscovered spots. Assuming that the bauxite is collected and quarried solely for the manufacture of the metal aluminium and its numerous alloys, and that 4,000 tons of this first grade ore (in the present condition of the trade) could be treated every year for this purpose, we shall see that the stocks available ought to last for 450 years.

OTHER GRADES OF BAUXITE.

No attempts have been made to estimate accurately the quantities available of 2nd grade bauxite having from 6 to 15 per cent. silica and 75 to 65 per cent. alumina nor of the highly aluminous kaolin of still lower grade. At the lowest estimate these together amount to 10,000,000 tons and there is an equal or greater amount of pure kaolin coming below these.

Some of the 2nd grade bauxite will certainly be useful in other industries such as for refractories, high alumina cements, oil purification and for chemical purposes. **Uses of lower grades.** Dr. Fox has suggested in his published work on bauxite¹ that in conjunction with the establishment of a ceramic industry in Jammu (for the large amount of pure kaolin) there might be attempted the manufacture of "mullite" or artificial sillimanite, for use in the preparation of Indian-made sparking plugs.

But as time goes on and industrial processes mature, whilst the purer bauxite reserves of the world become diminished in quantity, it is a moral certainty that much of our 2nd grade bauxite will then become elevated to 1st grade rank. **Lower grades will appreciate with time.**

I do not propose to burden these pages with considerations of processes that are certain to change with time. **Industrial process not discussed here.** We are here strictly concerned with recording our bauxite assets in such terms as will not change, but on the other hand will, I trust, remain permanent whatever vicissitudes the concerned metal and other industries may experience in the future. When the time comes to develop these resources of ours, the industrialists undertaking it will need no suggestions printed herein as regards the treatment of the ore—suggestions which may well become antiquated almost as soon as they are published.

There is, however, one feature of the Jammu bauxites to which a short reference must be made in the Section to follow. I refer to the question of the solubility of the ore in the caustic soda treatment—the first stage in the, at present universally-used, Bayer process. Some difference of opinion has been expressed and some misconceptions apparently have been entertained by certain authorities on this important point, which it is desirable to clear up or at least ventilate.

THE SOLUBILITY QUESTION.

In connection with the refractoriness of the ore, which all the chemists experienced who analysed it, the **Adverse views.** British Aluminium Company undertook a free practical test of a $\frac{1}{2}$ ton sample, and they found that the same intractability was responsible for the bauxite being difficultly soluble in caustic soda. Their final decision on this most important feature is summed up in their letter No. JSB/GW dated 31st May 1922. In that letter they say :—

1. p. 90.

“In the case of your (Jammu) material the alumina averages about 78 per cent. of the weight of the bauxite. Of this it would apparently be possible to extract on an average about 58 per cent. which would represent 45 per cent. only of the total weight of the bauxite, whereas with French bauxite containing 58 per cent. alumina and an extraction of say 95 per cent. we get alumina equal to 55 per cent. of the weight of the bauxite used.”

The Aluminium Company of America on the sample sent to them wrote in much the same strain saying :—

“The ore appears to be in a monohydrate form which is very insoluble in the aluminium making process. The trihydrate form which is found in North and South America, although sometimes containing a smaller percentage of alumina yields a better return on account of its higher solubility.”

It was in consequence of these adverse views that I advocated research work being done in England regarding this solubility question. The Imperial Birmingham University. Mineral Resources Bureau (since amalgamated with the Imperial Institute), at the Darbar's request, enlisted the services of Professor Thomas Turner of the Department of Metallurgy, Birmingham University, for this enquiry, and the latter put several chemists on to the work under his supervision. The results are embodied in a long and exhaustive preliminary report by L. F. Wharton, B. Sc., who was however unable to finish the work on account of his proceeding abroad, and in the final and quite satisfactory report by Mr. E. J. Bloore.

Satisfactory results.

Mr. Bloore's experiments as described by himself are as follows :—

“They were made with a small autoclave having a capacity of about 500 ccs. fitted with a pressure gauge and capable of withstanding a pressure of at least 150 lbs. per square inch. An electric heater was constructed for the autoclave and stirring mechanism provided.

The mixture in the autoclave consisted of 200 ccs. of 45° Be sodium hydroxide solution, with 125 grams of bauxite, ground to pass a 100 mesh sieve. In this mixture the ratio of Al_2O_3 to Na_2O is approximately 100 to 110. Commercially this ratio is 100 : 108·4 to 114, according to the quality of the ore used. A pressure of 100 lbs. per square inch was maintained for 8 hours, the liquid being continuously stirred.

The liquid obtained was analysed for alumina, and percentage extraction calculated.

Bauxite Sangar Marg IV.-V. 5	.. 125 grams taken.
Al ₂ O ₃ extracted	.. 71.8 per cent.
Al ₂ O ₃ present in the ore	.. 78.92 „ „
Yield of Al ₂ O ₃	.. 91.00 „ „

It was found that if the amount of ore used in the experiment was reduced to 10 grams, the volume of the solution being kept constant, the same yield was obtained by heating for only 4 hours, no stirring being necessary. A 10 gram sample of ore was therefore used for the rest of the tests.

Solubility tests were carried out on seven ores, the poorest having a silica percentage of 4.93 per cent.

RESULTS OF SOLUBILITY TESTS.

Sample.	Al ₂ O ₃ extracted.	Al ₂ O ₃ present.	Yield of Al ₂ O ₃ .
1. Salal XIII. 4. ..	75.65	82.25	93.2
2. D. area Chakar ..	76.5	78.82	97.2
3. Sangar Marg IV-V. 5 (a) ..	71.80	78.92	91.0
4. Sangar Marg IV-V. 5 (b) ..	70.85	78.92	89.9
4. $\frac{1}{2}$ mile S. of Jangalgali gap	73.10	78.62	93.0
5. Panhassa III. 4. ..	69.70	77.61	89.8
6. Salal IX. 5. N. E. ..	70.65	77.34	91.4
7. Chakar C. D 3rd ft. ..	63.90	71.74	89.0

3 (a) 125 grams of ore heated 8 hours continuous stirring.

3 (b) 10 grams of ore heated 4 hours no stirring.

The above results show the amount of alumina dissolved in the liquor from the autoclave; practically all this could be precipitated, the loss in that operation being small.

It will be seen that with the usual working conditions (a pressure of 100 lbs. per square inch and a 45° Be caustic soda solution), 90 per cent. of the alumina contained in the ores can be dissolved.

I have proved, as far as is possible in a laboratory, that the type of ore occurring in Kashmir is capable of being purified by the Bayer process, and have indicated the best conditions for obtaining a good yield. It will be seen that it is not necessary to calcine the ore, but the extra cost involved in the calcining process might be compensated for in other directions: grinding could be more easily and rapidly performed and either the pressure or the time of heating in the autoclave might be reduced with a consequent reduction in cost.

In order, however, to decide finally whether these ores could be economically worked on a commercial scale, it would be necessary to consult a firm who have experience in the process.

The filtration of the aluminate liquors, for instance, is an operation, the ease of which varies very greatly with the kind of ore used and can only be properly tested in a full-size plant. The degree of fineness to which the ore should be ground and the advisability of calcination are also questions for a chemical engineer to answer."

Professor Thomas Turner remarks on this work carried out under his supervision as follows:—

Professor Turner's conclusion.

"The bauxites examined are shown to be of excellent chemical quality and to be amenable to extraction by the ordinary process of digestion with caustic soda. They should therefore be suitable for using in the aluminium industry.

They are harder in texture than the bauxite available here and therefore will involve more cost in crushing. It might possibly be worth while to roast in order to diminish the work of crushing.

I do not think that the Indian (Jammu) bauxites can compete in price in England on account of the cost of carriage; but, with water power available, I see no reason why there should not be a very important Indian Aluminium Industry."

The Industrial Chemist, Srinagar, Kashmir, also made some experiments which confirm the favourable results arrived at by Mr. Bloore in Birmingham. After a high pressure autoclave was acquired by the laboratory, the ordinary method of Bayer was tried and it was found

that the Jammu bauxites submitted well to the process. Alumina to the extent of about 70 per cent. was found to exist in the solution, the percentage quantity of alumina in the bauxite being 84.

I cannot of course presume to decide a matter in which recognised authorities differ, except to suggest that the usual Bayer process as worked by the British

Summary. Aluminium Company may have been to blame in not being properly modified to meet the requirements of the Jammu bauxites. For instance on account, of its hardness our bauxites may not have been ground sufficiently fine, a contingency quite likely since the British Aluminium Company do not roast their French ore. It is clear that the Jammu ore contains 70-80 per cent. alumina and that this can be extracted up to 90 per cent. as shown by experiments on a good scale made in Birmingham University, and this gives a yield of 67 per cent. as regards the bauxite itself. The difference between this 67 per cent. and the 45 per cent. extracted by the British Aluminium Company seems far too great to be accounted for by the difference between a laboratory and a works test. It would probably have been less had the latter been adapted to the particular ore.

EXTRACTION OF THE ORE.

Extraction of the ore will present no more difficulties than ordinary quarrying. Sometimes a foot or so of the overlying poorer-quality pisolite will have to be removed first.

Care must be taken to test the ore from place to place. The better qualities take on different superficial aspects, but all of them can be recognised and followed if ordinary precautions are observed. The specific gravity balance should be constantly at work, and everything round about 3.00 and over should be scrutinised to see whether the high density is not due to excessive iron or titanium. All pale yellow, orange, olive green or dark brown flinty-looking material should be rejected; it is sure to be high in silica and iron.

The reason for this constant attention to the physical characteristics of the ore is connected with the assumed origin of it by desilicification due to exposure to the agents of weathering and meteoric water. These agents have not acted uniformly, but have attacked different parts of the bauxite material with different facilities and in different degrees. Scarps and all free edges and surfaces have been the most vulnerable places of

attack. A little care at the start and at intervals during the collection of the ore will enable the richer layers to be followed and traced along in all their various phases and will prevent much disappointment by unskilled labourers amassing by mistake quantities of relatively poor ore. Specific gravity tests should every now and then be checked by chemical analyses, specially as regards the percentage of silica, for on this will depend the final grading of the ore. The supervision of a petrologist in the earlier periods of working the ore will be necessary to guide the workmen in recognising at sight and by feel in the hand the numerous local varieties.

With regard to these varieties I quote the following from Commercial varieties. Dr. Fox's article on bauxite in the *Quinquennial Review of Mineral Production of India for the years 1919-1923*, p. 322, based on an article in the *Mining Journal* of December 30th, 1922 :—

“Aluminium reduction companies will seldom accept bauxite with more than 5 per cent. silica although they have been known to take delivery of ore with as much as 20 per cent. ferric oxide. Chemical works do not refuse bauxite containing 10 per cent. silica if the alumina content is high and the ferric oxide percentage is below 3 per cent. They seldom accept ore with more than 5 per cent. ferric oxide. Manufacturers of abrasives, while demanding the best grades of normal bauxite, often utilize ore with less than 50 per cent. alumina and more than 10 per cent. silica or 15 per cent. ferric oxide. Makers of furnace refractories stipulate that the ferric oxide content must be low but may accept bauxite with as much as 25 per cent. silica. In some cases they prefer to use a material so rich in silica that it can scarcely be called bauxite.”

COAL AND WATER POWER.

A favourable feature of the bauxite area of Jammu, described in the preceding pages, is that excellent-quality anthracitic coal occurs in association with those areas. This coal, which is well-known, lies everywhere in the overlying strata within 100 feet or so of the bauxite spreads. Besides being required in the preliminary roasting of the ore, coal on the spot is a general asset for any works and for transport purposes. There is no need to say more here on this point, since a full report on the Jammu Coal Measures is under preparation and will be printed and issued shortly uniform with the present report on bauxite.

Water power is available very centrally at Dhian Garh on the Chenab river, a short distance above Riasi, and quite close to the Salal bauxite field. A scheme
Site for Hydro-Electric Power Station.

for the utilization of this for hydro-electric purposes has been reported on fully by Mr. A. T. Arnall, B. Sc., M. Inst. C. E. and has been printed for the information of the Kashmir Government. There is no doubt, therefore, that in the immediate neighbourhood of the bauxite fields, these two main factors exist for reducing the ore to the metallic state, namely a reliable and abundant source of electricity and suitable coal.

WORKING THE BAUXITE.

Notwithstanding all the above favourable conditions for the utilization of our bauxite resources, I feel it **A difficult proposition.** advisable to end this report with a word of caution. The working of our ore in the only ways that can be made profitable will be no child's play. It will involve commercial strategy and generalship of a high order, which only men of experience can tackle.

The following remarks taken from Dr. Fox's article in the *Quinquennial Review* pp. 312-313 (*Records Geological Survey of India*, Vol. LVII, 1925) are to the point :—

“Efforts have been made to float companies for the reduction of aluminium in India without due appreciation of the situation. It is insufficiently realised that in most cases in India electric power can only be obtained by construction of elaborate and very expensive storage dams, that all the cryolite must be imported, and that the purification of the bauxite to alumina and the preparation of high-grade carbon electrodes involves the working of specialised processes on a big scale. The aluminium production of the world is in the hands of only four great groups of producers, the output capacity of whose works is larger than the present demands which they supply. These monopolistic firms have assured sources of supply as regards their raw materials, bauxite and cryolite. There are probably no cheaper sites for hydro-electric power than those they use. In addition to purifying their bauxite in alumina works owned by themselves, they possess factories for the manufacture of carbon electrodes, foundries for making alloys and castings, rolling-mills for the output of sheets, circles, wire, etc. Finally they have excellent shipping facilities and their markets are not only established but cultivated. In the present state of the aluminium market such powerful organisations could not allow a new company of any pretensions to come into being. Such a venture might be successful if backed by overwhelming advantages, *e. g.* cheap electric power, good quality bauxite in favourably located occurrences, assured supplies of cryolite, and a highly skilled staff for operating the alumina plant and in making carbon

Reports of the Mineral Survey of Jammu and Kashmir.

electrodes. But if the Indian demand for aluminium be considered insufficient to justify this outlay and the Indian producer be unable to face competition, the general question of developing the bauxite resources of India, apart from the establishment of an aluminium industry, is one well worthy of attention. However it is necessary that the requirements of the markets be studied and understood by the vendors of bauxite.

At the present time the world's production of bauxite is used in the following approximate proportions in several industries :—

	per cent.
For aluminium after conversion to alumina	60
For the manufacture of chemicals	.. 20
In the production of abrasives	.. 10
For the preparation of refractories	.. 8
Used in the manufacture of bauxite cement, for the purification of kerosene and for other purposes excluding building stone..	3

If the world's output of bauxite be taken roughly as 500,000 tons annually, it is evident that the quantities absorbed in the minor manufacturing industries are attractively large."

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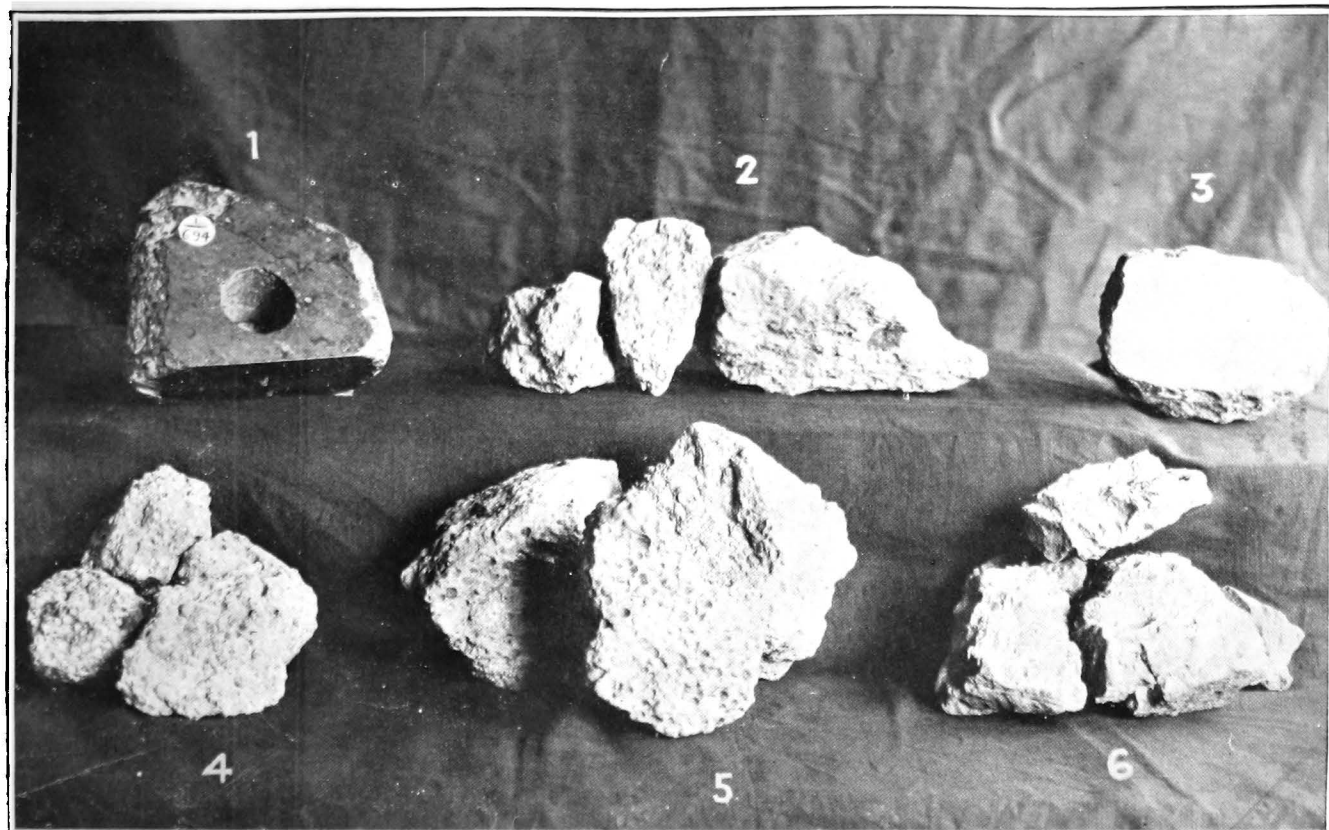
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MINERAL SURVEY OF KASHMIR.

Plate 1



MINERAL SURVEY OF KASHMIR.

Plate 2



MINERAL SURVEY OF KASHMIR

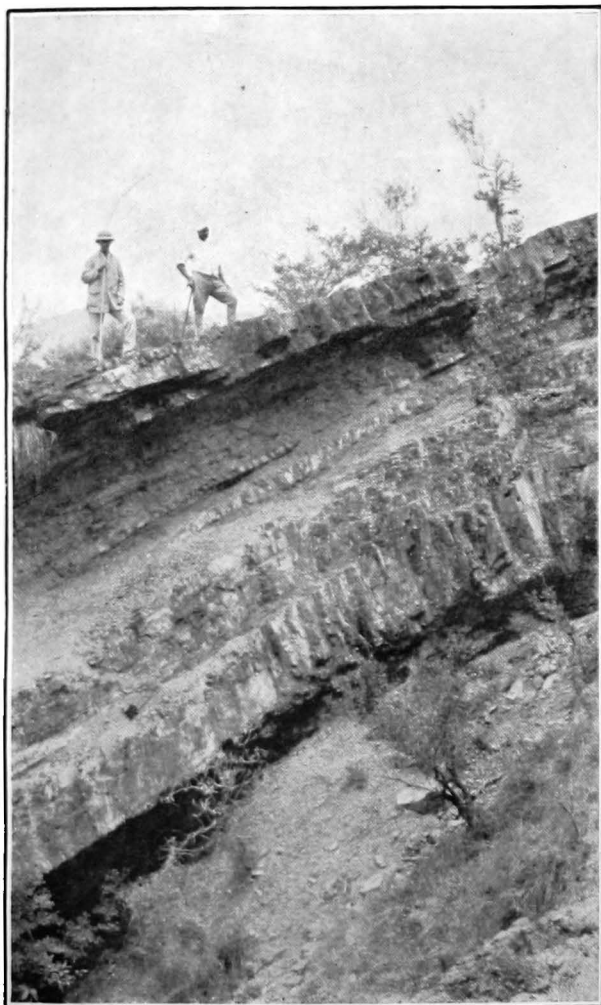
Plate 3



BAUXITE CHAKAR G AREA

MINERAL SURVEY OF KASHMIR.

Plate 4



BAUXITE SCARP SALAL.

MINERAL SURVEY OF KASHMIR

Specific Gravities

Plate 5

