Some Recent Advances in Indian Geology.*

By W. D. West,

Geological Survey of India.

2. Deccan Trap Volcanic Activity.

IN India we have one of the best developments extant of the 'plateau basalt' type of igneous activity, known as the Deccan Trap. The importance of a thorough study of these rocks will readily be appreciated when it is understood that in the opinion of many geologists the basalt, which is the predominant type in this series of rocks, is probably the primitive rock from which most other rock types have been evolved by some process of differentiation. The remarkable similarity in chemical composition which all plateau basalts throughout the world exhibit suggests that they have been derived directly from some primitive source without the intervention of any process of differentiation, and their study is, therefore, of great importance in relation to several branches of geology. So far, considering the very great area which these lavas cover in India, the extent to which they have been studied in detail is lamentably small. Their study is conveniently divided into two sections. On the one hand we have the immense thickness of horizontally bedded basalts and dolerites which make up the greater part of the Deccan Trap, and which are typical 'plateau basalts'. These show, even in detail, great uniformity of character, though certain slight differences in chemical composition can be discerned between the earlier and later outpourings. On the other hand, there occur certain areas along the north-west corner of the Deccan Trap outcrop, notably in Gujerat, Kathiawar and Cutch, in which differentiation has proceeded along special lines to an advanced stage giving rise to a great variety of rock types. It is essential for a complete understanding of either of these groups that both should be studied.

The most important contribution to our understanding of the petrography of the rocks of the former category has been provided by Dr. L. L. Fermor, whose study of the lavas penetrated by a deep boring at Bhusawal, some 250 miles north-east of Bombay, has provided us with an accurate statement of the petrography of these rocks.[1] In a study of the 29 flows penetrated, it is shown that the predominant type of rock is a basalt or dolerite of specific gravity 2·91, consisting essentially of labradorite felspar ($Ab_1 An_2$), enstatite-augite (pigeonite), iron ore and glass, while olivine, always completely altered, occurs in 18 out of 29 flows. This description may be regarded as typical of the greater portion of the flows of the Deccan Trap of India. In this paper particular attention is paid to the minerals of late crystallisation, occurring either as linings and infillings to the amygdales of the flows, or as alteration products of the glassy base and of some of the minerals. To the former group belong the minerals chlorophæite, delessite, chalcedony, opal, quartz and lussatite, and the zeolites heulandite, apophylite and ptilolite, with calcite; while to the other group belong palagonite, chlorophæite, celadonite, chabazite, together with iddingsite, delessite and serpentine which are pseudomorphous after the olivine. The conclusion is reached that, with the possible exception of the calcite, these minerals have been formed during a late stage in the final consolidation of the lavas, and have not been deposited by meteoric waters. This is the first time these minerals of late crystallisation have been adequately described. Both in this and in subsequent papers the process known as 'palagonitisation' is discussed in detail,[2] a subject which also receives attention in a paper by D. N. Wadia.[3] Finally, a further point brought out by Dr. Fermor is that in a number of the flows the olivine, and sometimes the labradorite, phenocrysts have sunk to the base of flows which were apparently more fluid than the rest at the time of eruption. This observation of the sinking of the crystals leads the author to suggest that the ultrabasic rocks found occasionally in the Deccan Trap, such as in Baluchistan, may have originated by some such mode of gravity differentiation, a point which is referred to again below.

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[1] *Rec. Geol. Surv. Ind.*, 1925, **58**, 93.

[2] *Op. cit.*, 1928, **60**, 411; and *Geol. Mag.*, 1931, **68**, 266.

[3] *Rec. Geol. Surv. Ind.*, 1925, **58**, 338.

In 1916 Drs. L. L. Fermor and C. S. Fox published an account of the Deccan Trap lava flows near Linga in the Chhindwara district, Central Provinces, with a map showing the distribution of five separate flows. Specimens representing four of these flows have now been analysed and the results discussed by Dr. Fermor.[4] Although of the four specimens analysed two are basalts and two are dolerites, the analyses are all very similar. It is only when the norms are calculated that slight differences are brought out. These show that from the lowest to the highest flow the direction of change is increasing alkaline felspars, increasing total felspars, and increasing total pyroxenes, with decreasing total iron ores. When compared with the norm of the eleven analyses of Deccan Trap made by Washington, after arranging these latter into their probable order of extrusion, it is found that the differences in composition as one ascends in the Traps is similar in direction but much larger in degree than that shown by the four specimens. From this it is deduced that the tendency to differentiation illustrated by the lavas of Linga on a small scale is an epitome of that generally applicable to the lavas of the Deccan Trap series as a whole.

As regards the field relations of these plateau basalts and their associated dykes and sills, a good deal of work has recently been done by H. Crookshank along the northern slopes of the Satpura hills, in the north Chhindwara and south Narsinghpur districts, where both the field relations and the petrology of these rocks present many features of interest. A memoir on this area is shortly to be expected. The chief interest of the area concerns the abundant intrusive sills and dykes. Generally speaking, the high ground to the south and east of the area is occupied by Deccan Trap, and the low ground to the north and west by Upper Gondwana rocks. And although the sills are found to some extent in the southern area intruded between the basalt flows, they attain their grandest development in the Upper Gondwanas. The dykes are frequently composite and vary from fine-grained basalts to coarse-grained porphyritic dolerites. The sills are only very rarely composite, and are nearly all coarse-grained somewhat porphyritic dolerites. Normally the minerals of these rocks are the same as those described by Dr. Fermor from Bhusawal, but there are also interesting variations. The sills, which are frequently several hundred feet thick, show well the phenomenon of the sinking of the olivine crystals, though not of the labradorite. In some cases not only has olivine sunk but a cryptocrystalline residue, representing the last part of the magma to consolidate, is concentrated in the upper parts of the sills. This latter contains primary quartz and micropegmatite. Quartz cannot of course crystallise in the presence of olivine; but the removal of olivine by sinking has evidently allowed crystallisation to proceed along lines favouring the formation of quartz, and the observation is of more than local interest. In one or two cases biotite was found partially altered to chlorophæite, and Mr. Crookshank suggests that this mineral may once have been more abundant, but has in most cases been destroyed by the palagonitisation. One dyke, which has been traced intermittently for eight miles, deserves special mention. It is a porphyrite consisting of oligoclase, quartz, enstatite, augite, hornblende and micropegmatite, with an SiO_2 percentage of 63. Nothing like it has hitherto been noted in the Central Provinces.

Coming now to the second portion of our subject, we have to deal with a large variety of rock types, some very basic, some very acid, and others markedly alkaline, which are found mainly in the peninsula of Kathiawar and the adjacent country. These rocks are definitely part of the Deccan Trap volcanic episode, but represent the results of advanced differentiation localised about certain areas or along certain lines. Ever since the days of F. Fedden[5] it has been realised that the peninsula of Kathiawar was exceptional in containing several foci of eruption in which differentiation had proceeded to yield a large variety of rocks. So long ago as 1893 Dr. J. W. Evans made a collection of rocks from Junagarh State, and subsequently published a paper describing one of them, a monchiquite containing primary analcite, which he found on the margin of a nepheline-syenite.[6] Recently one or two of his students have re-examined this collection and shown it to be very varied. M. S. Krishnan has made a detailed petrographical study of those collected from the Girnar and Osham hills.[7] Of these the

[4] *Rec. Geol. Surv. Ind.*, 1934, **68**, Pt. 3. (in the Press).

[5] *Mem. Geol. Surv. Ind.*, 1885, **21**, 73.

[6] *Quart. Journ. Geol. Soc.*, 1901, **57**, 38.

[7] *Rec. Geol. Surv. Ind.*, 1926, **58**, 380.

majority are nepheline-syenites and dolerites, but other less common types include quartz-porphyry, syenite porphyry, syeno-diorite, diorite-gabbro, porphyrite, andesite, olivine-gabbro, lamprophyre, limburgite, obsidian, rhyolite and pitchstone. In this paper six new analyses are given, which the author considers indicate a petrographical province of the 'Atlantic' type. At about the same time K. K. Mathur, V. S. Dubey and N. L. Sharma published a small-scale map of the rocks of Mount Girnar, representing the first attempt to map this focus of eruption. In the accompanying paper intrusions of olivine-gabbro, diorite and monzonite, granophyre, and nepheline-syenite are described.[8] These are intruded into typical Deccan Trap lavas which they have domed up forming Mount Girnar. Although there is apparently no direct evidence of the mode of origin of these rocks, reasons are given for supposing them to have been derived by differentiation *in situ* through progressive crystallisation, estimates being given to show that the parental magma was of intermediate or dioritic composition. It is thought that crystal settling through gravity has not been operative. More recently, other rocks of Dr. Evans's collection, from the West Gir forest, have been described by S. K. Chatterjee.[9] These are mostly basic dykes, chiefly olivine-dolerites, but mention is also made of irregular intrusions of acid rocks consisting of spherulitic granophyre, pitchstone, rhyolite and other types. Seven new analyses by the author are given. Other more general papers which include references to the Deccan Trap of Kathiawar, and which are not generally known, are E. Howard Adye's two memoirs on the "Economic Geology of Navanagar State"[10] and on the "Economic Geology of the Porbandar State",[11] which are illustrated by a large number of photomicrographs; and a paper by K. P. Sinor on the "Igneous and Sedimentary Rocks of Bhavnagar Territory,"[12] also illustrated.

As regards the more acid types of rock, which have been known to occur in the Deccan Trap ever since W. T. Blanford published his observations on the geology of the Tapti and Lower Narbada valleys,[13] K. K. Mathur and P. R. J. Naidu have recently described some acid intrusions and lavas on the coast north of Bombay comprising trachytes, granophyres and rhyolites.[14] These include the "granophyric trachyte" of Kharodivadi described by M. S. Krishnan.[15] Associated with these rocks are glassy gabbros and dolerites. As a result of calculating the silica percentage of the glassy base of these rocks, shown to be about 68%, the authors are led to believe that the acid intrusions represent the same glassy base after it has separated from the partly crystallised magma and solidified away from it. They further conclude that these acid intrusions are a very recent phenomenon. Subsequently, in his presidential address to the geology section of the Indian Science Congress, 1934, Mathur brought together all known occurrences of both acid and very basic rocks of Deccan Trap age, and discussed briefly their origin and age.[16] He suggests that the acid types occur mainly along two lines, one running north and south, from Pavagad hill in the Panch Mahals in the north, to Bombay Island in the south, and one running east and west, along the Narbada valley to as far as Barda hill in Porbandar State in Kathiawar. He further suggests that their origin may be due to the assimilation of acid rocks by the molten basalt, basing his conclusions on certain observations made by W. T. Blanford and P. N. Bose. His view, however, that the rhyolite on Pavagad hill is an intrusion has now been shown to be incorrect, A. M. Heron having confirmed the original view of Dr. Fermor that it is a flow capping the hill and part of the general succession of lavas.[17] As regards the age of these rocks, while recognising the possibility that in certain cases both the acid and the very basic types were extruded at the beginning of the Deccan Trap period, he inclines to the view that for the most part they are very recent in age, attributing their age in some cases to a period subsequent to the establishment of the present

[8] *Journ. Geol.*, 1926, **34**, 289.

[9] *Op. cit.*, 1932, **40**, 154.

[10] E. H. Adye, *Memoir on the Economic Geology of Navanagar State*, Bombay. 1914, 262.

[11] E. H. Adye, *Reports on the Economic Geology of Navanagar State*, Bombay. 1917, 198.

[12] K. P. Sinor, *Petrographic Descriptions of the Igneous and Sedimentary Rocks of the Bhavnagar Territory*, Bombay, 1927, 72.

[13] *Mem. Geol. Surv. Ind.*, 1869, **6**, 163.

[14] *Malaviya Commemoration Volume*, 1932, 787.

[15] *Rec. Geol Surv. Ind.*, 1929, **62**, 371.

[16] *Proc. 21st Ind. Sci. Congr.*, Bombay, in the press.

[17] *Rec. Geol. Surv. Ind.*, 1934, **68**, 17-18.

topography, a conclusion which perhaps some geologists will find it difficult to accept.

It was mentioned above that Dr. Fermor had suggested means whereby the ultra-basic rocks of Deccan Trap age, such as those in Baluchistan, might have been derived from the normal basaltic magma by the sinking of some of the phenocrysts. Further light has been thrown on this problem by W. D. West, who has examined the cores of rock brought up by deep borings put down through Deccan Trap lava flows in different parts of Kathiawar.[18] These rocks include very basic types such as limburgite and ankaramite, interbedded with the more normal Deccan Trap type of basalt. A study of the phenocrysts of olivine, augite and felspar found in these very basic lavas shows that in each type of rock the composition of the phenocrysts is closely related to the composition of the rock in which they occur. Thus the felspar phenocrysts in the more basic types are bytownite-anorthite as compared with the medium labradorite which occurs in the normal Deccan Trap basalt, while the olivines are more magnesian and the pyroxenes more calcic than those found in the normal basalt. These facts are thought by West to show that the different rock types did not originate during the Deccan Trap volcanic period by the sinking of phenocrysts as they crystallised from the basalt, since the phenocrysts differ markedly in composition from those found in the basalt; but that differentiation of the basalt took place long before Cretaceous times, and that the various rock types so formed were already available for extrusion when re-melting took place during Upper Cretaceous times.

There is clearly still a large field for research into problems of Deccan Trap volcanic activity, and it is a field which is admirably suited to research by those unattached to official surveys. It must, however, be controlled by detailed and accurate field work, aided by chemical analyses, if it is to be of any real value.

[18] *Rec. Geol. Surv. Ind.*, 1934, **68**, 17.

[19] *Op. cit.*, 1932, **66**, 18.

Chalcolithic Civilisation.

THE explorations carried out between the years 1928-1931 by Mr. N. G. Majumdar of the Archæological Survey of India have resulted in the discovery of sites on the western banks of the Indus which are reported to be older than Mohenjo-daro in the Indus valley. The people who lived in these areas had not attained any considerable prosperity, for apparently the hilly tracts which they occupied were neither fertile, nor rich in mineral resources. Their dwellings appear to have been constructed out of crude materials such as reeds and wood on a stony basement, and burnt bricks were practically unknown to them. At two places, Ali Murad and Khotras, the remains of the fortified places which have been unearthed, reveal walls built of stones which are in contrast with similar structures composed of bricks in Mohenjo-daro. The hillmen, the lake dwellers and the river inhabitants appear to have known the art of making pottery on the wheels for domestic purposes. Mr. Majumdar in his report draws attention to the fact that these utensils are capable of being divided broadly into four classes, a classification which he bases on the scheme of colouration, their geometrical shapes, the paintings on their surface and on the degree of polish. Compared with such finds in Mohenjo-daro and Harappa, the Chalcolithic vessels point to an earlier civilisation of great historical importance, of a race of people contemporaneous with the races who dwelt in Baluchistan, Persia and Mesopotamia in the third and fourth millennium B.C. Near the lake Mancher and at the upper levels of Jhukar and Lohumgo-dara, the excavations have brought to light a class of pottery which illustrates the later phases of Mohenjo-daro culture. We await the publication of fuller details of these extremely interesting pre-historic sites.