THE DECCAN TRAPS.

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Introduction.

A perusal of the several papers published from time to time dealing with the Deccan traps of India shows that this extensive rock-formation offers many problems of great interest and importance in the geological history of India. The object of this paper is to review briefly our present knowledge of these rocks and offer a new interpretation of their mode of accumulation and geological history—an interpretation which if it does nothing more, may at least serve to stimulate and provoke further thought and discussion on lines leading to a satisfactory solution of the many knotty problems connected with this great volcanic rock-formation.

Some facts about the Deccan Traps.

Let us recapitulate at the outset some of the main facts about the Deccan traps which have been definitely established. These may be briefly summarised as follows :—

(1) They are the result of the accumulation of subaerial lava flows of the nature of fissure eruptions.

(2) They extend through about 10° of latitude and 15° of longitude, thus covering an enormous area of not less than 200,000 sq. miles at the present day.

(3) The maximum thickness of the formation near Bombay is about 7,000 feet or more ; the average thickness, considering the entire area being about 2,000 feet. The actual thickness, however, varies from place to place, being in some cases as low as about 100 ft.

(4) The individual flows making up the total thickness in any given locality, are comparatively thin—their average thickness being only about 40–80 feet.

(5) These lava flows show an almost persistent horizontality practically throughout their area, the minor exceptions to this rule being easily proved as due to local and minor post-trappean disturbances.

(6) Associated with these lava flows in some areas are noticed several volcanic ash beds, which appear and gradually become more frequent in the upper half of the entire formation.

(7) Intercalated between some of these lava flows are a few distinctly sedimentary fossiliferous beds—the inter-trappeans—usually of freshwater origin. These inter-trappean beds are confined either to the lowermost or to the uppermost portions of the formation, the middle portion which forms more than two-thirds of the total thickness being entirely devoid of them.

(8) What we now see of the Deccan traps is only a remnant of the original formation, after the removal of a large part by subaerial denudation acting during the long period of time during which these lava flows have been in existence.

While these facts of observation have been generally accepted, there are certain other aspects of the formation about which there has been some difference of opinion ; and it is proposed to discuss a few of these in the course of this paper. In such a discussion, it is useful to remember that the Deccan traps of India are only one of several other similar fissure eruptions occurring in various other parts of the earth at about the same period of time. This will enable us to take a wider outlook and realise our kinship with similar geological problems elsewhere.

It has been generally accepted that these lava flows are of the nature of fissure eruptions where the emission of lava is a comparatively quiet process. Though it is true that the occurrence of ash beds locally interrupting these lava flows indicate a certain amount of explosive violence now and then, yet it must be admitted that such explosive phenomena are only local and temporary, and do not vitiate the truth of the general proposition that these lavas have issued quietly from fissures. Considering the volume of lava that has been thrown out and the wide area which it covers, one would expect the existence of a large number of these feeding fissures scattered all over, which we would now expect to see as long and narrow dykes, especially in the peripheral tracts of the present trap area ; and such indications of former vents have been noticed in some areas.

There is no doubt that the opening of these fissures must be connected with the intense diastrophism associated with the disruption of the Gondwana continent. As Joly[1] says : "It was at or near the close of the cretaceous and dawn of the eocene that this great continent (named by Suess Gondwanaland) broke up and as a continent disappeared. This event was, so far as we know, synchronous with the overwhelming of peninsular India by a mile deep covering of the basaltic substratum. And further, it is believed that the diastrophism in Gondwanaland was connected with the movements which led to the outflow of the Deccan ; for the fissures which emitted the lava had the same

[1] Joly, *The Surface History of the Earth*, 1925, p. 135.

east to west trend as ancient faults which traversed the northern part of Gondwanaland and along which the later movements were directed." It is now generally recognised that the disruption of the Gondwana continent took place in stages, somewhat as follows: The connection between Australia and India (united with Madagascar and South Africa) disappeared soon after the jurassic period; the connection between South America and Africa disappeared in the lower to middle cretaceous; and the connection between India and Madagascar (the Lemurian bridge) broke down at the beginning of the tertiary. It is this last stage in the disruption that we have to remember in connection with the Deccan lava flows. It has been customary to think that this land connection extended right across the present Arabian Sea connecting Western India with Abyssinia and Somaliland. But the recent observations of Dr. Fox[2] on the Abyssinian lavas of Magdalla and Ashiangi show that they never extended as far east as Aden and certainly did not cover the Somali peninsula; and so these lavas can have nothing to do with the Deccan traps of India. Thus, it is altogether unlikely that the Deccan traps cover much of the floor of the present Arabian Sea. According to Dr. Fox, "the region of Somaliland and Southern Arabia was open sea in upper cretaceous and early tertiary times, while the region to the west was land in that geological period. I think a great bay connecting with an open sea to the north lay over the northern part of the present Arabian Sea in late cretaceous and early eocene time." At the time of the first eruption of the Deccan lavas, therefore, the land probably extended only southwest of Bombay as a land bridge connecting India with Madagascar, to the north and west of which lay an arm of the Northern Sea. The first effect of the disturbances which led to the foundering of this land connection, must have been the formation of numerous fissures all over the area. These fissures were doubtless due to tensile forces which must naturally originate, according to Joly[3] as a result of the fusion of the basaltic substratum below. The actual mechanics of the rise of basic magmas along such through-striking fissures has been discussed by Bucher,[4] and he comes to the conclusion that "the same stresses which create the relief of pressure along fracture lines (by a pulling apart of the resisting crust) also furnish the driving power that carries the heavy liquid up into the light crust." When once these fractures and fissures have been established through which the lavas begin to flow out, the question to consider is, did they simply flow out all over the area

[2] Kindly conveyed to me in the course of a recent letter, for which I am greatly indebted to him.

[3] Joly, *The Surface History of the Earth*, 1925, p. 94.

[4] Bucher, *The Deformation of the Earth's Crust*, 1933, p. 272.

simultaneously and continuously for some time and then stop ; or did they come out in stages, periods of eruptive activity alternating with periods of quiescence ? In other words, we have now to consider the history and duration of this eruptive activity.

Duration of Eruption.

This question regarding the duration in time represented by these Deccan eruptions is a very important one, not only in itself but also because of its bearing on another very interesting question—the age of the Deccan traps. On this point regarding the duration of the Deccan trap period, W. T. Blanford wrote as follows[5] so far back as 1867 : "Those who have fully appreciated the gradual conviction which has of late years been forced upon the minds of most field geologists of the enormous periods of time which have been necessary for the accumulation of the various rock masses forming the earth's crust will have no difficulty in understanding that a large division, even of geological time, may very probably have elapsed during the accumulation of the Deccan traps. The thickness of these beds cannot be much less than 5,000 feet ; perhaps it is considerably more. * * * That long intervals of time, in some cases at least, elapsed between the different lava flows of which this enormous thickness is composed, is shown by the local accumulation of freshwater deposits abounding in remains of animals and plants. In each of these cases a lake must have been formed, and have become tenanted by a large number of different species of mollusca, etc.—a very slow process. In some places, near Baroda, I met with large accumulations of rounded pebbles not only of metamorphic and sedimentary rocks but of the trap itself, intercalated between beds of basalt and amygdaloid, so that denudation must have taken place to a considerable extent in the intervals between successive flows." Thus Blanford has mentioned three important considerations, the full implications of which we must recognise, indicating that a very long period of time must have elapsed between the beginning and close of the volcanic period. Add to these the fact that we frequently come across, between some of these trap flows, layers of red clay or bole which are due to the atmospheric disintegration of the surface of the basalt on which it rests before the eruption of the overlying flow. As Geikie has pointed out[6] these layers must be looked upon as "furnishing evidence of the lapse of an interval sufficiently extended to permit a considerable subaerial decay of the surface of a lava sheet before the flow of the next lava". And then also there is

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[5] W. T. Blanford, "Traps of Western and Central India," *Mem. Geo. Sur. Ind.*, 1867, 6, Pt. 2, p. 147.

[6] A. Geikie, *Ancient Volcanoes of Great Britain*, 1897, Vol. II, p. 204.

the pronounced difference in the nature of the fossil fauna and flora found in the inter-trappean beds at the base of the formation near Nagpur and those at the top near Bombay. The latter are decidedly much more highly evolved than the former and such evolutionary changes necessarily require quite a long period of time. In view of these considerations we have to conclude that "these outflows did not always rapidly follow each other but were separated by intervals of varying, sometimes even of longer duration"; or to quote Iddings[7] we must realise that "not one burst but repeated flows through long ages have built the plateau of the Deccan".

Geological history of the Deccan Trap period.

We know that from very early times the Deccan traps have been classified as follows[8]:

		Min. thickness.
Upper traps	(with numerous beds of volcanic ash and the inter-trappean sedimentary beds of Bombay)	1,500 ft.
Middle traps	(ash beds numerous above but less frequent towards the base; no sedimentary beds known)	4,000 ft.
Lower traps	(with inter-trappeans of Nagpur, Narbada valley, etc. Ash beds of rare occurrence or wanting)	500 ft.

The general geological conditions during the period of the Deccan trap eruptions have been nicely pictured to us by W. T. Blanford[9] when he says: "When first lava flows are poured over the irregular surface of a country shaped by subaerial denudation, as the surface of India appears to have been shaped before the first volcanic outbursts, hollows must be filled up and rivers dammed, so that shallow lakes will be formed. These will not, in all probability, be of any large size. Fresh flows of lava will fill up the first lakes, but by damming up other hollows, will produce new ones, and so on until by the constant accumulation of volcanic material the land has either been reduced to a plane or the intervals between different lava flows are too short to allow of the accumulation of sedimentary deposits. It is even possible that the region may have become barren and desolate, unfitted for organic existence. * * * It is in any case easy to understand that when rest from volcanic disturbances, showers of ash and lava flows permitted sedimentary

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[7] J. P. Iddings, *The Problem of Volcanism*, 1914, p. 22.

[8] Medlicott and Blanford, *A Manual of the Geology of India*, 1879, Pt. 1, p. 308.

[9] W. T. Blanford, "Traps of Western and Central India," *Mem. Geo Sur Ind.*, 1867, 6, Pt. 2, pp. 155–156.

deposits again to accumulate in the intervals between eruptions, the old lacustrine fauna of the district had died out, and the change had taken place, which is indicated by the fossils of the Bombay inter-trappeans. It is also in accordance with probability, I think, to suppose that the volcanic energy was less, the flows more partial, and the periods of intermission longer, at the commencement and towards the close of the trap epoch than in the middle of the period." While this description is no doubt generally true, recent and more detailed studies of the Deccan traps seem to show that the geological history of the area during this period was not so simple as all this. Before proceeding to consider what it must have been, let us remember some more facts which have got to be explained.

There is first of all the general horizontality of the traps, over large areas. While there is no doubt that this is partly due to the highly fluid nature of the basaltic lavas which issued from the fissures, yet this cannot offer the full explanation. The lava flows cover thousands of square miles at the present day ; immediately after extrusion, they must have occupied a much larger area. Practically throughout this area the lavas show a strikingly horizontal disposition. While it is true that basaltic lavas are highly fluid, it is also true that the distance through which a given flow will travel from the fissure can hardly exceed more than about 50–60 miles on horizontal or even gently sloping ground. So to explain the horizontal disposition of the traps over such a large area, we have to grant the existence of an exceedingly large number of feeding fissures in close proximity to one another, even at the commencement of the trappean period. If so all these fissures would naturally have been filled up by the consolidated lava later on and be left behind as dykes ; and at the present day, after denudation, we should have seen these dykes in large numbers, especially in the country just outside the present margin of the trap area, as in the case of the tertiary fissure eruptions near Mount Stuart, Washington.[10] And then again a satisfactory solution of this problem of the horizontality of the traps must naturally involve a consideration of the exact nature of the floor on which the first lava flows accumulated. Some opinions have been already expressed[11] about the character of the pre-trappean surface in certain areas ; but these have only a local significance and do not deal with the entire formation as a whole. To the present writer, it appears that a satisfactory explanation of this horizontality and all the other known

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[10] R. A. Daly, *Igneous Rocks and the Depths of the Earth,* 1933, p. 140.

[11] Medlicott and Blanford, *A Manual of the Geology of India,* 1879, Pt 1, p. 323; L. L. Fermor and C. S. Fox, "The Deccan Trap Flows of Linga, Chhindwara Dt., C.P.," *Rec. Geo. Sur. Ind.,* 1916, **47**, Pt. 2, pp. 88–89.

facts regarding the entire Deccan trap formation will be facilitated on the basis of an altogether different conception of the geological history of the trappean area.

It is generally accepted that at the beginning of the trappean period, a part of Gondwanaland still existed on the southwestern side connecting India with Madagascar. Thus the Deccan eruptions of lava covered not only a large part of peninsular India but must have also extended over quite a large area of this land to the southwest of the present coast line. This extensive area of eruptive activity appears to have been generally in the form of a broad, shallow, (probably saucer like) depression, more or less oval in outline with its longer axis roughly NE–SW. Of course the sides and bottom of this depressed area were not so smooth and regular as in the case of the analogy suggested, but were highly irregular, being composed of a number of more or less gently undulating ups and downs, with several lines of drainage determined by the irregularities of denudation necessarily present on such an ancient land area ; and it is presumed that the first fissures were split open on the floor of such a basin. We must however remember that, as Dr. Fox[12] has pointed out, the outpourings of lava for the various flows did not come from one particular locality but that fresh centres were chosen in most cases ; and that these centres "probably began in the east and gradually shifted to the west with, of course, some irregularities. In consequence of such local variations, there is found to be a certain amount of overlapping of the flows." Under these circumstances, with the continual emission of highly fluid lava—almost as thin as water, according to Iddings—from these fissures, the lavas will flow out, fill up all the minor depressions and thus ultimately tend to fill the entire basin from below upwards covering all the irregularities in this process ; and with the lavas highly fluid and mobile, they would naturally at all stages of this filling up show a more or less level surface. Further, when the basin is thus filled up by the consolidated lava, the main vents themselves through which the lavas came out would be covered up by the entire thickness of the lava flows above, thus concealing them from view altogether. Thus though fed only by a few vents on the floor of the basin, the highly liquid lavas would gradually extend out and cover more and more of the outer regions of the basin till at last the entire basin is filled up and the area becomes more or less a flat plain of lava. It would thus be possible to see along the peripheral regions, for instance, of such an area quite a thick series of lava flows, without any actual vent being noticeable below. These eruptions were frequently interrupted locally by long periods of quiescence

12 C. S. Fox, "Possibilities of finding coal-field at a workable depth in Bombay Presidency," *Rec. Geo. Sur. Ind.*, 1926, **58**, Pt. 2, p. 90.

affording opportunities, as Blanford has pointed out, for the deposition of freshwater sediments, now seen as inter-trappean beds These first lava flows are what we now recognise as the lower traps.

Then there appears to have been a pause in the eruptive activity. During this period, certain minor disturbances seem to have occurred in parts of this area producing a certain amount of gentle folding and faulting among these lava sheets, as is evidenced by the observations of Fermor and Fox[13] in the Linga area, Chhindwara District.

Some time later, there was a violent recrudescence of eruptive activity, and new fissures were opened out from time to time through which enormous volumes of lava were extravasated. But now there appears to have been a gradual diminution in the eruptive area, the general tendency being for the concentration of the eruptive fissures in the central part of the original basin, in the country within a radius of about 100–150 miles from Bombay. Side by side with this, as a consequence of the diastrophism which ultimately brought about the foundering of this part of the Gondwanaland southwest of Bombay, there appears to have arisen a gradual and gentle 'sagging' or 'warping' of the ground which became more and more pronounced as we approached the centre of the new area of eruptive activity. Thus there would come about in this region a fairly pronounced depression, gradually shallowing away as we went outwards and finally merging into the flat country of the lower traps all round. The lava flows succeeding the lower traps were more or less confined to this depressed area, the floor of which appears to have further subsided gradually in course of time under the weight of the increasing lava flows above. The diastrophism in this area accompanied by the voluminous extrusion of the underlying basaltic magma must have disturbed the isostatic equilibrium, so that locally the crust began to yield and sag under the increasing load above—a load composed of basaltic lava which is much heavier than normal sediments. Thus arose conditions favourable for the accumulation of enormous thicknesses of lava, reaching a maximum of about 5,000 feet or more in the central part of the area,—the different flows making up this thickness being under these conditions always more or less horizontal. These constitute what we now call the middle traps. This second eruptive activity was much more powerful than the first and very much larger volumes of lava were extravasated. These eruptions were obviously so continuous both in time and space, that no inter-trappean sedimentary beds could be formed. At the close

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[13] L. L. Fermor and C. S. Fox, "The Deccan Trap Flows of Linga, Chhindwara Dt., C.P.," *Rec. Geo. Sur. Ind.*, 1916, **47**, Pt. 2, pp. 103–120.

of this second and most important stage in the formation of the Deccan traps, the lava flows (of the first and second periods together) would have covered a very extensive area including part of the Gondwanaland to the southwest attaining their maximum thickness in the central part of the area near Bombay.

Some time after the formation of the middle traps, there was again a recurrence of eruptive activity, but now confined to an area even smaller than that of the second series of eruptions—just within a radius of a few miles round about Bombay. These lava flows, the upper traps of the present day, represent the last stages in the decline of volcanic activity, and were feeble and intermittent. These lavas, like the later flows of the middle trap period, had to come out through fissures cutting through a great thickness of the traps below, and were therefore naturally accompanied by the formation of ash beds. During the long interval of time that had elapsed subsequent to the formation of the middle traps, subaerial denudation had carved out irregularities on their surface giving rise to favourable conditions for the deposition of freshwater sediments here and there. These were covered by the subsequent upper lava flows and became inter-trappean beds. Similar patches of inter-trappean sediments were also formed locally in the interval between successive flows of the uppermost traps. Thus so far as the present Deccan trap area is concerned, it would appear there was a gradual shifting from east to west of the chief centres of eruption during the trap period ; or in the words of Dr. Fox[14] : "I have felt that in a general way the earliest outburst of activity was in northeastern India, and that, broadly speaking, the successive series of eruptions occurred in newer areas each further west than the previous."

Not long after the close of the upper trappean period, there came about the foundering of the land bridge between India and Madagascar and with it went down a part of this great trap formation below the sea. The western coast line of India was now established practically in its present configuration. From that day right up to the present moment, the Deccan trap formation in India has been subjected to a continuous process of subaerial denudation. All the irregularities of ground now seen throughout this area are the effects of this denudation, except in a few cases where they may be due to some comparatively more recent and local earth movements.

In connection with these ideas here suggested regarding the conditions of eruption of these lavas, we might recall some of the conclusions arrived at by Geikie[15] from his study of the ancient volcanoes of Great Britain.

[14] C. S. Fox, "The age of the Deccan Traps," *Curr. Sci.*, 1935, 3, No. 9, p. 430.

[15] A. Geikie, *Ancient Volcanoes of Great Britain*, 1897, Vol. II, pp. 468 and 470.

"There is one striking connection between the sites of the vents and ancient topographical features to which frequent reference has been made in the foregoing chapters. All through the long volcanic history, as far back as such features can be traced, we see that orifices of discharge for the erupted materials have been opened along low grounds and valleys rather than on ridges and hills. * * * A study of the records of volcanic action in Britain proves beyond dispute that the volcanoes of past time have been active on areas of the earth's surface that were sinking and not rising. * * * Subsidence and not upheaval is ultimately the rule over volcanic areas."

Before proceeding further, we may here consider the relationship between the main mass of the Deccan trap and its outliers, as seen at the present day. These outliers are commonly believed to have once formed part of the main area and thus considered as indicating the original extent of the trap formation. Let us consider the tenability of this idea with reference to the two important outliers, one near Rajahmundry and the other in Western Sind.

Rajahmundry Area.

The occurrence of this outlier has been known for quite a long time and was described by King[16] so far back as 1880. This outlier is now about 210 miles away from the main mass of the Deccan traps ; and the question has been raised whether this small outlier originally formed part of the main body, and has now become separated due to the denudation and removal of the traps in the intervening country, or whether this area of eruption was distinct and separate from the very beginning. W. T. Blanford while accepting that the traps at Rajahmundry belong to the Deccan series, does not think that it is yet satisfactorily shown that these rocks ever extended across the intervening area, although in his opinion, such a former extension is not improbable. A little consideration will show that such a former continuous extension of the traps, say from Nagpur to Rajahmundry, is altogether unlikely. Nowhere in the intervening area have been seen trap dykes which might be considered as representing the original vents through which the lavas flowed out. In the absence of any such indications of former vents the only other way of explaining a continuity is to imagine that the lavas which were extruded through vents located somewhere in the present peripheral regions of the main Deccan trap country, flowed southeast as far as Rajahmundry, a distance of more than 200 miles. This seems hardly possible. Moreover if all this country were once covered by lava, how is it that a small patch is left only near Rajahmundry while all through the intervening area where the lavas would probably be thicker they have been

16 W. King, "Coastal region of Godavari Dt.," *Mem. Geo. Sur. Ind.*, 1880, **16**, Art. 3.

completely denuded off? In view of these considerations it seems only reasonable to believe that the Rajahmundry area was the site of an independent eruptive activity during the Deccan trap period, having nothing to do with the main body of the lava flows in Central Provinces. During the first stage of the eruptions when the lower traps were laid down in the main area, there must have opened out an independent fissure probably in some small basin near Rajahmundry through which also some lavas were extruded. These eruptions, like those in other places along the margin of the main mass, ceased once for all at the close of the lower trappean period ; and what we now see are just the denuded remnants of these lava flows, which more or less correspond in age with the lowest traps of Central Provinces.

Western Sind.

In his account of the geology of Western Sind, W. T. Blanford[17] has referred to the occurrence of two thin bands of traps in this area—one interstratified with the sandstones just below the Cardita-beaumonti beds, and the other just above the Cardita-beaumonti beds and below the Ranikot series ; and reasons have been given to show that these bands must be considered as thin representatives of the great Deccan trap formation. Now the question is, which part of the latter do these two thin bands in Sind represent ?—a question the answer to which is intimately connected with another very important problem, the age of the Deccan traps, which we may now proceed to consider.

The age of the Deccan Traps.

This question has been recently receiving a lot of attention, and the present position in this matter has been briefly reviewed in a paper recently published by the present writer[18] on "The age of the Deccan Traps near Rajahmundry". We have now to discuss the question of the age of the Deccan traps as a whole First, let us consider when the eruptions started ; in other words, try to determine the lower age limit of these lava flows. In this connection we must, however, remember that as W. T. Blanford has said[19] "we have no proof that the basement beds of the trap are everywhere of the same age or what is the same, that volcanic outbursts commenced at the same time over all the area covered by them." But still let

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[17] W. T. Blanford, "Geology of Western Sind," *Mem Geo. Sur. Ind.*, 1880, **17**, Art. 1.

[18] L. Rama Rao, S R. Narayana Rau, and K. Sripada Rau, "The age of the Deccan Traps near Rajahmundry," *Proc. Ind. Acad. Sci.*, 1936, **3**, No. 2.

[19] W. T. Blanford, "Traps of Western and Central India," *Mem. Geo. Sur. Ind.*, 1867, **6**, Pt. 2, p. 151.

us get together all the available evidence. To begin with, take the Rajahmundry area. Here the lava flows (which are equivalent to the lowest flows in the main trap area) rest on a marine limestone which is uppermost cretaceous in age, and their inter-trappean beds have plant fossils with decided tertiary affinities. Then consider the Nagpur-Chhindwara area. Here the lowest trap flows overlie *unconformably* the Bagh and Lameta beds of middle cretaceous age, and here again the earliest inter-trappean beds have numerous plant fossils indicating a tertiary age.[20] The fossil fishes discovered near Dhamni and Dongargaon in Central Provinces have now been shown to belong to the lower inter-trappean beds of this area[21] and we know on the authority of Sir Arthur Smith Woodward that the age of this fish fauna is about lower eocene.[22] Thus from all these evidences in these two areas, it seems reasonable to conclude that the tertiary era had already dawned when the first lavas of the Deccan were poured out.

It appears to the present writer that the position in Western Sind further supports such a conclusion. It has been customary to think that the two thin bands of trap found here associated with the Cardita-beaumonti beds represent the topmost flows of the main area and hence fix the upper age limit of the entire formation. But it seems equally possible that the two bands in Sind are equivalent to the lower flows of the main area, just as in the case of the traps in the other outlying area near Rajahmundry; and this appears to be the more probable view. The Sind outlier to the northwest is perhaps similar to and bears the same relation to the main Deccan trap formation, as the Rajahmundry outlier to the southeast. As in Rajahmundry, so in Sind, there must have been a small independent centre of eruptive activity during the lower trappean period giving rise to a few lava flows. But unlike in Rajahmundry, what has happened in Sind is that these lavas partly flowed across the arm of the northern sea then existing in this area, where the Cardita-beaumonti and the Ranikot beds were being deposited, and thus came to be interstratified with them. These eruptions, however, ceased very soon, and the marine sedimentation simply continued to give rise to the Ranikot, Khirthar, and other tertiary fossiliferous beds of the area. It is significant to note that the two bands of trap in Sind are intimately associated with the Cardita-beaumonti beds, one occurring just below and the other just

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[20] B. Sahni, "The Deccan Traps. Are they Cretaceous or Tertiary?", *Curr. Sci.*, 1934, **3**, No. 4, pp. 134–136.

[21] C. A. Matley, "Stratigraphy, Fossils and Geological relationships of Lameta beds of Jubbulpore," *Rec. Geo. Sur. Ind.*, 1929, **53**, Pt. 2, p. 159.

[22] A. Smith Woodward, "On some fish remains from the beds of Dongargaon, C.P.," *Pal. Ind. N.S.*, 1908, **3**, No. 3, pp. 1–6.

above, a position almost identical with that in Rajahmundry where also the trap overlies a limestone equivalent to the Cardita-beaumonti beds ; and we know that these beds everywhere represent the topmost subdivision of the cretaceous, almost forming the passage into the lower tertiary. Thus on the assumption that the two thin bands of trap in Western Sind represent only the lower flows of the formation, we again come to the same conclusion, that the eruption of the Deccan traps in India started just after the close of the cretaceous, or what is the same, the beginning of the tertiary era—a period of time when extensive fissure eruptions of basaltic lavas appear to have started in many parts of the world.

Another important area where again we have some marine fossiliferous sediments associated with the traps is in the strip of country between Surat and Broach. In this area we see eocene beds overlying the traps along their western margin. From this it has been concluded that here again we have an indication of the upper age limit of the Deccan traps showing that the eruptions had ceased by the time the eocene nummulitics were laid down. To discuss how far this conclusion is acceptable, let us consider the geology of this area in greater detail. It is true that here we have the eocene beds overlying the traps ; but let us also remember that very frequently in this trap area, we see patches of the underlying cretaceous rocks exposed due to the denudation of the traps above ; and that northeast of Broach, for a distance of about 100 miles, the traps overlie directly the archæan rocks. Thus in this area, we have the archæans, a few patches of the cretaceous infra-trappeans (correlated with the Bagh beds), the traps, and the eocene nummulitics above the traps, all in close proximity. Now the question is to which part of the entire Deccan trap formation could these traps belong ? Before attempting to answer this question let us follow these traps eastwards and examine their position. Especially useful in this study are the detailed observations recorded by W. T. Blanford[23] in his paper "On the geology of the Tapti and Lower Narbada Valleys and some adjoining districts." From this paper we gather the following facts :

(1) On the western side of this area, near Rajpipla, Surat and Broach, the eocene nummulitics overlie the traps, and there is a pronounced unconformability between the two.

(2) All along the northern and eastern borders of this trap area we see patches of the underlying cretaceous beds which are stratigraphically equivalent to the Bagh beds.

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23 W. T. Blanford, "On the geology of the Tapti and Lower Narbada Valleys and some adjoining districts," *Mem. Geo. Sur. Ind.*, 1869, **6**, Pt. 3, Art. 6.

(3) Wherever the traps are seen to overlie the infra-trappean cretaceous beds, an unconformability is noticed.

(4) In some places as in the neighbourhood of Betul at the eastern end of the area, the traps (immediately above the cretaceous beds) have inter-trappean sediments with fossils like *Physa, Lymnea, Paludina* and *Valvata* similar to those of the inter-traps in the Nagpur-Chhindwara area.

(5) In some places, as for example in the country between the Machuk and the Tawa, large outliers of traps are seen to overlie the metamorphic rocks. "Where denudation has so far removed the traps that the old surface is once more visible, the hard ridges again protrude while some trap yet remains in the hollows between them. Trap dykes occur occasionally in the metamorphics."

All these considerations must naturally make us pause and think whether these traps including those of Surat and Broach could really represent the latest and therefore the youngest lava flows. If they do, the entire Deccan trap formation, on these evidences, would be confined to a very small period of time somewhere between the Cenomanian and the Danian—particularly so because of the pronounced unconformability noticed everywhere between the traps and the underlying Bagh beds on the one hand, and between the traps and the overlying nummulitics on the other. This proposition seems hardly tenable. What is more likely the case is that the trap rocks referred to above including those of Surat and Broach, really belong to the base of the formation, like those of the Nagpur-Chhindwara region. In both areas, they overlie the Bagh beds unconformably; but whereas in the Nagpur-Chhindwara area, these lower traps have not been covered by any later sedimentaries, those in the neighbourhood of Surat and Broach are locally overlaid by the eocene beds, just as in Western Sind where also we have the trap flows (overlying the Cardita-beaumonti beds) covered by the tertiaries. Of course, the tertiary sequence in Sind happens to be much more complete than near Surat and Broach; but this makes no difference. So far as the traps are concerned, the position in both the areas appears to be essentially the same. The eocene nummulitics in either case appear to mark only the close of the lower trappean period. Elsewhere the eruptive activity continued even with increasing vigour and finally died out only very much later. If so, what exactly is this upper age limit of the Deccan trap formation?

Here the inter-trappean beds associated with the highest traps near Bombay should help us if they contained any fossils of stratigraphical value. But so far no such fossils have been recognised. It may however be pointed

out that from a study of the volcanic rocks themselves of the coastal tracts near Bombay, Salsette and Bassein, Prof. K. K. Mathur[24] comes to the conclusion that there must have been an appreciable gap in time between the middle and the upper divisions of the Deccan trap formation, and says: "It is by no means certain that the Cardita-beaumonti beds of Sind fix the upper time limit for the igneous activity of the Bombay coast. There is at least a possibility that it may be of a much later date." Thus from all these considerations it would appear that the eruptions which began at the close of the cretaceous period not only continued throughout the eocene but extended even into later periods. This would imply that the Gondwanaland southwest of Bombay continued to exist throughout this period; for its final submergence happened only after the trappean period. Such a late survival of this part of the Gondwanaland is not at all unlikely; As F. R. Cowper Reed[25] says: "The truncated edge of the table land in South Africa (where the marginal faults involve the tertiary beds) and the similarly abruptly broken edge of the volcanic plateau of the Indian peninsula, prove that some of the downward movements took place much later and in post-cretaceous times" And then again, zoologists demand the existence of a land mass (Lemuria) in the western Indian Ocean as late as the development of the land forms of the present Oriental and African life-provinces in order to explain their distribution.

In any case there seems to be no doubt that the entire Deccan trap formation must have covered a fairly long period of geological time. In addition to some of the internal evidences in support of such a conclusion already enumerated in an earlier part of this paper, we have the evidence afforded by similar fissure eruptions elsewhere. Take for instance the Oregonian region in the United States. Here we have basaltic lava flows covering an area approximately equal to that of the Deccan trap formation but with only about half its maximum thickness; and yet the Oregonian eruptions are known to have begun in the eocene and reached their maximum in the miocene period. Consider again the case of the tertiary volcanic eruptions of Britain, after a full study of which Geikie[26] writes as follows: "The region within which volcanic activity displayed itself during older tertiary time in the British Isles embraces a total area of more than 40,000 sq. miles. Over that extensive region volcanic phenomena were displayed during an enormously protracted interval of geological time. The earliest beginnings of disturbance may possibly have

[24] K. K. Mathur and P. R. Jagapathi Naidu, "Volcanic activity of the coastal tracts of Bombay, Salsette and Bassein," *Malaviya Commemoration Volume*, 1932, p. 800.

[25] F. R. C. Reed, *The Geology of the British Empire*, 1921, p. 288.

[26] A. Geikie, *Ancient Volcanoes of Great Britain*, 1897, **2**, p. 462.

started in the eocene, and the final manifestations may not have ceased until the miocene period. So prolonged was the duration of the eruptions that enormous topographical changes from denudation, and probably also considerable variation in the fauna and flora, alike of land and sea, may have been effected."

When we thus see that in other parts of the world, fissure eruptions hardly equal to, and frequently much less than, half the magnitude of the Deccan traps require for their formation a period of time covered by the eocene, oligocene and miocene systems together, how can we believe that in India, the entire duration of the Deccan trap formation is confined to a small period of time just straddling the close of the cretaceous and the beginning of the tertiary era ?

Summary.

After recapitulating some of the main facts about the Deccan traps which have been definitely established, and drawing attention to the connection between this igneous activity and the disruption of the Gondwana continent, a new interpretation of the geological history of the Deccan trap period has been put forward on lines which it is expected may ultimately lead to a satisfactory solution of the many knotty problems connected with this great volcanic rock-formation. The relationship between the main mass of the Deccan trap and its two important outliers one near Rajahmundry and the other in Western Sind is next considered. The problem of the age of the Deccan traps is discussed on the basis of all the evidence available in the different areas, from which it would appear that the eruptions began at the close of the cretaceous, and continued not only throughout the eocene but extended even into later periods.