DARASHAW NOSHERWANJI WADIA MEDAL LECTURE–1977

HIMALAYA, ITS RISE AND PLATE TECTONICS

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INTRODUCTION

THE LOFTY HIMALAYA, covered with perennial snows, flanks the northern boundary of the Indian sub-continent. Presenting an arcuate outline in general, they stretch over a length of more than 2400 km from west to east and occupy a large area that is more than 80 km in width. From very ancient times, they have provided much inspiration to human mind in various walks of life, particularly metaphysics and divinity. In modern era also, the scientists have found within the rocky bosom of the terrain, immense material that has provided large amount of data for detailed study and analysis of nature and its forces. The geographer, the geologist and the geophysicist, as also the physicist and biologist from all over the world have endeavoured to understand the nature of the mountain system. Special efforts have been directed towards understanding the processes that have led the mountain to acquire its present form. Though much of the present day knowledge is based on preseverent and accurate observations in field, followed by detailed studies in laboratories, when we come to causes and processes, one often gets indulged in speculation and the same set of facts and data get interpreted differently by men, depending upon their own mode of thinking and possibly, predisposed bias. I venture to take this opportunity to present, here, some of the facts as they are, the solutions that have been offered for the rise and upheaval of the Himalaya, along with my own reactions, as also an alternative solution.

GEOMORPHOLOGICAL CONSIDERATIONS

Let us first have a look at the orographic characters of this great mountain system. Geomorphic studies indicate that the Himalaya is composed of a number of parallel ranges aligned in series, one behind the other, running from end to end of the chain. Each has its own average height that is fairly consistent throughout the length. Three of these ranges are particularly prominent as shown in a generalised transverse section (Fig. 1). The southernmost of these ranges, which is also the lowest one, is known as the Siwalik Hills, having an average height of 5–7 thousand feet. The middle ranges form the Lesser Himalaya and attain intermediate height of an order of 10 to 12 thousand feet. Finally, there are the Central Ranges which are more than 16 thousand feet high and embrace all the snow-covered peaks. It is to be noted that there is a difference of approximately 5 to 6 thousand feet in the average height of the

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*Since deceased. Prof. A. G. Jhingran, F.N.A., was to deliver the Lecture on October 16, 1977 which he could not due to illness. Subsequently, the Fellow passed away. The MS. was received from Dr. V. G. Jhingran on the 20th of September, 1978.

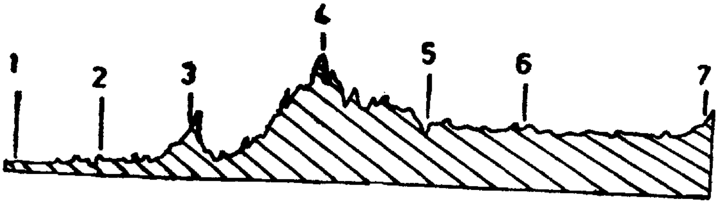

FIG. 1. Generalised section through the Himalaya (Vertical scale greatly exaggerated): (1) Indo-Ganga Plains; (2) Siwalik or Outer Himalaya; (3) Middle or Lesser Himalaya; (4) Great or Inner Himalaya; (5) Brahmaputra Valley; (6) Tibet Plateau; and (7) Kun Lun slopes.

three successive ranges, which is suggestive of a concept that the upheaval of the Himalayan system may have occurred in three principal phases, each elevating the relevant part of the crust at a time by approximately 5000 feet, resulting in the development of three-fold ranges in three phases of upheaval. I plan to leave the matter for the present and shall refer to it again at a later stage.

Another important point to be noted regarding the orography of the mountain system is the fact that the slopes of all the three groups of ranges are more or less similarly aligned, being very steep towards the southern side i.e., the Indian side and considerably gentle towards the north or the Tibetan side. One might be inclined to conclude from this feature that the nature and direction of forces responsible for the upheaval, in its three-fold or perhaps multi-fold phases were of alike nature.

The drainage system of the Himalaya presents quite a unique feature. It is noted that the principal watershed of the mountain system is located to the north of the highest ranges (Fig. 1). Even though the chain of mountains consists of several east-west running parallel ranges, no major river has carved any valley along the inter-space between them. Instead, the valleys of all the principal rivers like the Sutlej, the Yamuna, the Ganga, the Kosi, and the Gandak run in a general southerly direction cutting across several successive E-W aligned ranges. The Indus and the Brahmaputra, also observed the same trend at the western and eastern ends of the Himalaya respectively, though the first part of the channels in both the cases have an east-west alignment. Rising near the Mansarovar, both flow along the border of the Tibetan Himalaya for several hundred kilometres, before they set themselves on a transverse southerly course, cutting across the Himalaya. The location of the water divide to the north of the Central Axis of the Himalaya has been interpreted as a feature of antecedent drainage, indicating that the valleys had been in existence before the mountain system came into being, and that the rivers were able to maintain their valleys, while the mountains got upheaved through several sweeps of orogenic activity. This feature still remains to be examined in more detail and the study of the multifarious terraces occurring at various levels is awaited so as to recall the full history of drainage development.

While examining the drainage pattern in the Himalaya, as also the Indo-Ganga plains, it is worth noting that the rivers in the western region, except for the Indus, have a south-westerly flow, whereas those in the eastern part of the country have a south-easterly or southerly flow. Furthermore, this change in the direction apparently seems to have been controlled by the Aravalli-Delhi ridge that strikes in a NNE direction and provides the water divide in the Indo-Ganga plains. If we stretch the ridge further northwards transversely across the Himalaya it would emerge at a point close to the Mansarovar, that provides the water divide between the Indus system and the Tsangpo (Brahmaputra) valley (Fig. 2). Apparently, the Peninsula has not been an idle spectator to the orogenic activity in the northern part of the country, instead it has been a participant. To what extent, remains to be seen, and will be referred to later.

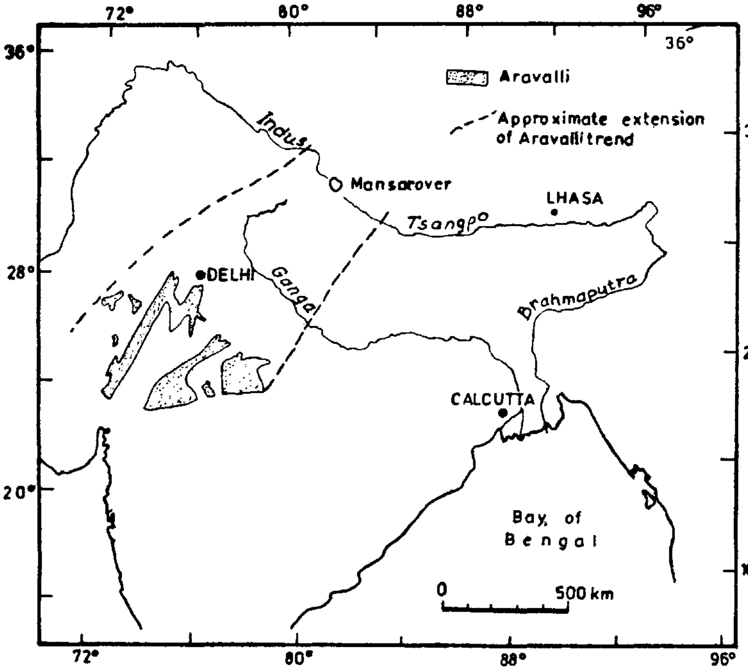

FIG. 2. Extension of the Aravalli trend.

SYNTAXIAL BENDS

The transverse valley through which the Indus cuts across the Himalayan ranges at their western end is a very significant feature, for herein one finds the mighty mountain to have got bent at a re-entrant angle. It has been designated by Wadia as the Syntaxial Bend (Fig. 3). It is, indeed, a unique feature in the world, for here one finds the various strata ranging in age from the Cambrian and the Pre-Cambrian to Pliocene repeated on either side of the bend without any serious dislocation, though the rocks have got folded to a considerable extent. A logical question arises as to why and how did the Himalaya bend at that point? An obvious answer to this query is that a tongue of the Indian continental mass protruding at this place pointing towards the northwest may have acted as the horst, an obstacle to the tectonic forces that were responsible for the upheaval of the Himalaya. I will not dialate on this point at this place as I feel I must pose all aspects of the problem before beginning an analysis of the possible solutions.

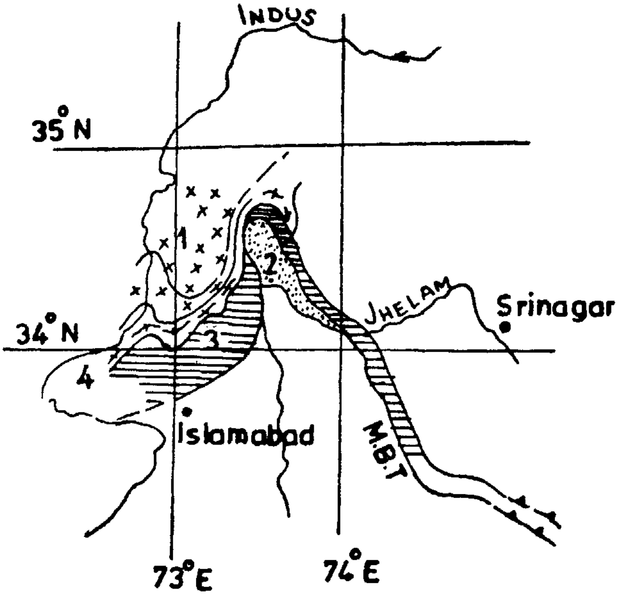

FIG. 3. North-western Syntaxis. (1) Mainly granite; (2) Mainly Murrees; (3) Mainly Palaeozoic; (4) Mainly Pre-Cambrian. M.B.T. — Main Boundary Thrust.

A similar re-entrant bend had been postulated, again by Wadia at the eastern end of the Himalaya, and is referred to in the literature as the Eastern Himalayan Syntaxis. The field work done by the scientists of the Wadia Institute of Himalayan Geology has however shown that no syntaxial bend exists in the east. In particular, the beds are found to terminate against a fault at the eastern extremity (Fig. 4).

ISOSTATIC COMPENSATION

A very interesting feature about the nature of the density of the rocky matter that composes the Himalaya came to light early in the last century, as a result of routine gravity surveys. It was revealed that a freely hanging plumb bob in the Indo-Ganges plain in the neighbourhood of the Himalaya would not deflect towards it in accordance with the theoretically computed value for the large mass of the mountain, rather it would deflect towards the plains, as if the latter were composed of heavier material. This exceptional behaviour led to the postulation of the principle of Isostacy, under which it was stipulated that the large mass of the material that is piled within any mountain is compensated by material of equally low density that must occupy proportionate space immediately underneath the same mountain. In other words, the mountain massif must have roots composed of material of equal density to that of its own, that would extend to depths, deep enough to maintain buoyancy and stability.

This concept is linked with the results obtained from seismic studies which led to the establishment of a discontinuity in the interior of the earth separating the crust, made up of light material rich in silica, alumina and alkalies, forming the well-known

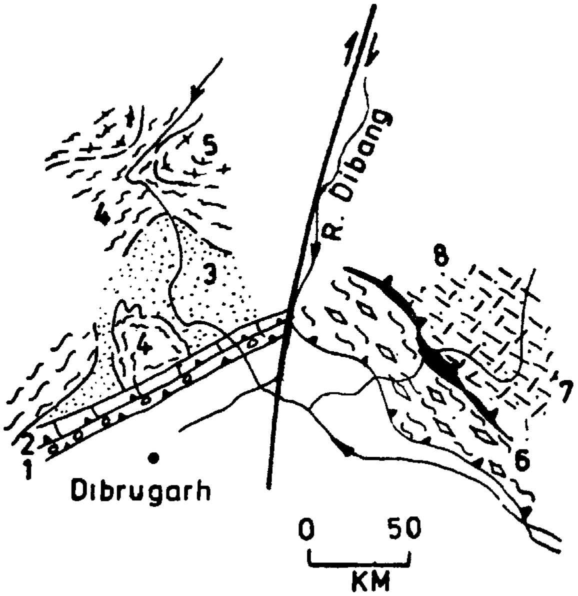

FIG. 4. North-Eastern syntaxis. (1) Siwalik; (2) Gondwana (Upper Palaeozoic); (3) Miri Group; (4) Siang Group; (5) Tuting Granite Gneiss (6) Mishmi Formation; (7) Tiding Formation; (8) Lohit Meta-Hornblende Granodiorite and Metadiorite.

SIAL, from the mantle, that is composed of denser material rich in iron and magnesium, that is known as the SIMA. This discontinuity is called the Mohorovicic discontinuity, after the Yugoslovak scientist of the same name. Under the continents it occurs at an average depth of 30–40 km from the earth's surface. Under the sea, it may be at a very shallow depth of 5 km, whereas under the high mountains it may be at as great a depth as 50–60 km (Fig. 5). The implication of this feature during an

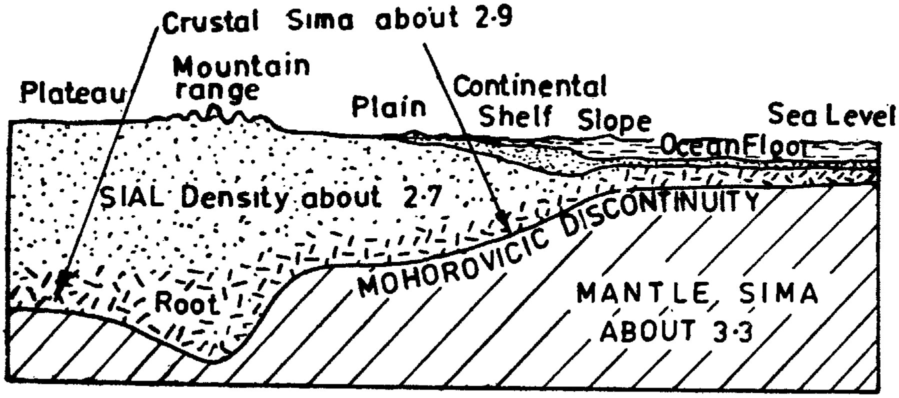

FIG. 5. Diagrammatic section through the earth's crust and the upper part of the mantle to illustrate the relationship between surface features and crustal structure. Based on gravity determinations and exploration of the distribution of Sial, Crustal Sima and Mantle Sima by earthquake waves.

orogeny are obvious. While considering the rise of a mountain by orogeny from the bottom of a sea to heights several thousand feet above sea level, one must also envisage for the development of its roots made up of sialic matter penetrating to appropriate depths. The orogeny thus causes a two way growth, both above the sea level as also to great depths within the crust, lowering the depth of the Mohorovicic discontinuity. It is an important problem and any theory suggested for the rise of mountains must account for this also.

ESSENTIAL GEOLOGICAL FEATURES

Let us turn our attention to the geological features. Broadly speaking, much like the orographical belts which I mentioned at the commencement of the talk, the Himalaya may be divided into four longitudinal structural zones, each extending from end to end, aligned more or less parallel to the length of the mountain chain (Fig. 6). These are :

(i) Siwalik zone;
(ii) Lesser Himalaya;
(iii) Central Crystallines; and
(iv) Tethyan Himalaya.

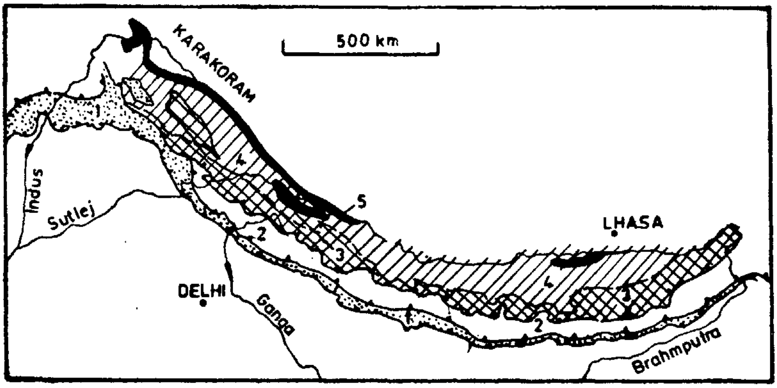

FIG. 6. Structural Zones (Litho-tectonic zones) of the Himalaya (modified after Gansser 1974): (1) Sub Himalaya; (2) Lesser Himalaya; (3) Higher Himalaya; (4) Tibetan/Tethys Himalaya; (5) Indus Suture Zone.

I propose to mention only the more important salient features of these zones, which have ultimately a bearing on the rise of the Himalaya.

Siwalik Zone : The first of these zones is made up of a thick sedimentary pile of sandstones, shales and conglomerates, which attained maximum development in Kashmir, becoming progressively thinner towards the eastern end of the Himalaya. These sediments range in age from the Middle Miocene to the Upper Pleistocene. These are all of fluviatile origin, the maximum aggregate thickness being about 4800 m in Kashmir. Recent work on palaeocurrent studies by the teachers and students of Delhi University (Tandon 1971) has shown that these sediments have been derived from a northerly to northeasterly provenance, and not the Indian Peninsula in the south, as had been believed earlier (Gansser 1964). This is a very interesting feature, for it would show that the nucleus of a southerly flowing drainage system had been developed in the Lesser Himalaya zone while the Siwaliks, the outermost zone, were in the making, laying the foundation for an ultimate antecedent drainage. Another important point is that there was no marine basin in the Himalaya from the Upper Miocene onwards, though small arms of sea continued to prevail in the neighbouring areas of Sind and Baluchistan.

Lesser Himalaya : The second geological zone forming the Lesser Himalaya actually consists of two sub-zones. The first of these consists of sediments, unmetamorphosed in nature, rich in fossils and of marine origin. They are of the Eocene to the Lower Miocene in age and have an aggregate maximum thickness of 2000 m. Like the Siwaliks, this sub-group is also developed in great force in Kashmir. Traced eastwards, it progressively becomes lesser in development, disappearing completely about the eastern end of the U.P. Himalaya. This would mean that during the Eocene-lower Miocene period, there was a small arm of sea in the Kashmir, Punjab and U.P. Himalayas, which was linked with the wider sea in Sind and Baluchistan, the waters of which got pushed out by the end of the lower Miocene.

The other sub-zone in the Lesser Himalaya consists of sediments and metasediments which have so far yielded fossils in very few localities. The rock units developed in various parts of the Himalaya in this zone vary a great deal in their lithology. In the U.P. Himalaya, for example, a calc-zone rich in dolomites and limestones has been developed in great force, such as is not found in the Eastern Himalaya. Structurally, this zone is very complicated, there being a large number of thrust sheets or nappes, several rock units having been moved over great distances, resulting in older rock units over-riding the younger ones.

Associated with these sediments are also masses of crystalline rocks, some of which seem to have been brought by thrusts from the next northerly zone, the Central Crystallines, while some may have developed through anatexis, local intrusive origin for others is also possible.

In addition to the above mentioned meta-sediments, some sediments located in the Kashmir Himalaya as also in the Eastern Himalaya have likeness to the Gondwana sediments in their lithology as also fossil contents. Some of them bear thin coal seams also. This opens up the possibility of this part of the Himalaya having been linked with the main Gondwana basin in the Peninsular India. Palaeogeographic reconstruction is somewhat difficult. However, the occurrence has to be accounted for.

The junction between these two zones of the Himalaya, the Siwalik and the Lesser Himalaya, is also very interesting. It has been designated as the Main Boundary Fault, the name indicating that it marked the northerly limit of the deposition of sediments of the Siwalik Group. Recently, however, some Siwalik sediments have been described from localities lying north of the fault also. Even then, the character of the fault is typical and indicates a lineament of fundamental importance.

Central Crystalline : The third zone, named the Central Crystalline, consists essentially of thick and very extensive mass of crystalline gneisses, showing considerable variation in metamorphism and textures from place to place, but in general presenting an overall likeness to each other. They are separated from the Lesser Himalaya by a great thrust zone, designated as the Main Central Thrust. Detailed studies have revealed that many of these gneisses have recorded as many as four successive minor fold events. This is very significant, and would corroborate that repeated impulses must have been involved in the rise of the Himalaya to its present form.

Tethyan Zone : Lastly there is the Tethyan zone, which bears a more or less unbroken record of fossiliferous sediments, measuring about 5000 meters, and ranging in age from the Cambrian to the Cretaceous except for some small breaks. In fact, vestiges of the Eocene are also known in several parts of the zone, particularly the Kailas mountain. It is rather significant that its contact with the Central Crystalline Zone is, at least in some sections, gradational and not sharp. To quote one instance the Pre-Cambrian metamorphics that compose the *Vaikrita System* and occur at the base of the stratigraphic column, pass laterally into the unmetamorphosed fossiliferous sediments of the Cambrian system (*Mem. GSI,* **XXIII**, 1891). It is also noted that no major volcanic suite of rocks are associated with these Cambro-Palaeocene suite of sediments. This is an unusual feature for such a long span of time. However, the close of the epoch is marked by an important development of ultrabasic intrusions along the lineament which marks the northern boundary of the zone and has been designated as the Indus Suture line by Gansser. The ultrabasics have been designated as ophiolite, as indicated by a mélange environment and association with intrusive plutonic granites and gabbros also. It is to be noted that the ophiolite has been so far recorded only near the western end of the Tethyan zone, i.e., close to the Indus valley. In the Tsangpo valley, its presence is only conjectural (Crawford 1974) and rocks with similar affinity that are met within the far-eastern Lohit valley have been proved to be much older in age, definitely pre-Cretaceous, possibly Pre-Cambrian.

EVOLUTION OF THE HIMALAYA

So far, I have briefly recounted the orographical, geophysical and geological features that characterise the Himalayan mountain system. Any hypothesis proposed to explain as to how this lofty and extensive system came into being, must account for the development of all these features. The widely believed present concept regarding the orogeny of the Himalaya is the one of continent-to-continent collision in the list of the Plate Tectonics.

Continental drift had of course been proposed by Wegener long while ago (1929). Scientific data like the occurrence of glacial deposits of Permo-Carboniferous age in various continents including South America, South Africa, India, Australia and Antarctica, followed by a thick pile of fluviatile sediments bearing thick coal seams and fossils of fauna and flora that would require intercontinental land bridges to enable their migration, led to the concept that all these continents must have been huddled together in the past forming a supercontinent, which has been given the name "Gondwanaland". According to this, during the Gondwana time, which meant the Permo-Carboniferous to the Jurassic period, India was geographically located in the southern hemisphere and lay side by side with Africa on its west, Antarctica in the south and Australia to the east (Fig. 7). Europe and Asia formed another superconti-

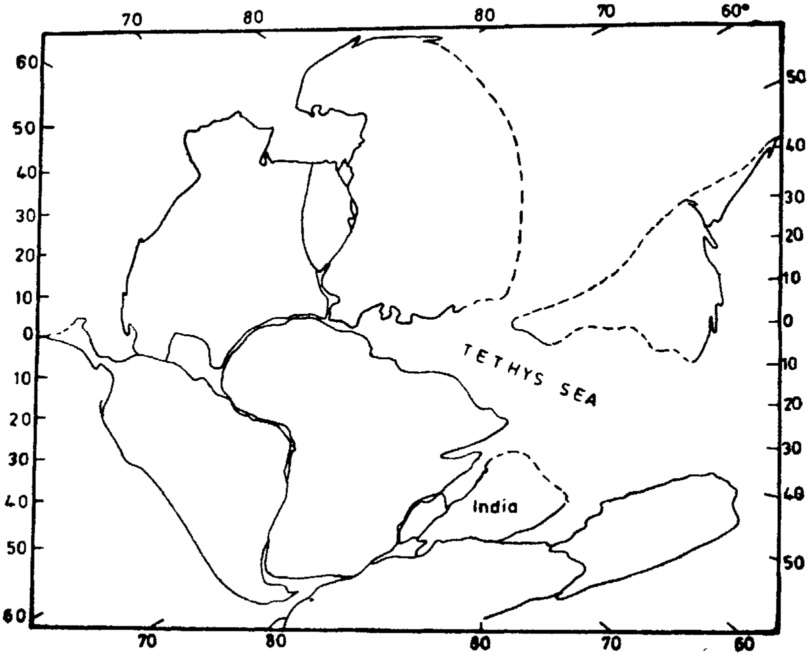

FIG. 7. Location of India during Gondwana time.

nent which was given the name Angaraland, the ocean in between being called the Tethys Sea. In accordance with the stratigraphic record, the Gondwanaland got disrupted towards the end of the Jurassic time. The constituent units gradually moved away in different directions to occupy their present positions. As a part of this movement, India travelled a distance of about 5000 km, in a northerly direction to begin with, swinging over to a northeasterly one, till it contacted the Sino-Eurasean block. In this act, the Tethys Sea got gradually squeezed out. This picture is actually quite an old one. The theory of Plate Tectonics has added a new feature to it in the form of a continent-to-continent collision with resultant subduction of a large part of the crust along the line of collision leading to a crustal shortening of several hundred kilometers, with concommitant obduction, that led to the rise of the Himalaya.

THE OPHIOLITE PROBLEM

As a strong evidence in support of this collision concept, it is claimed by several scientists (Dewey & Bird 1970; Santo 1972; and Molnar & Tapponier 1975) that the Indus Suture Zone, which marks a major lineament at the northern boundary of the Tethys Zone of the Himalaya represents the line of continental collision, and that the ophiolitic bodies that are present in considerable force along this lineament are the obducted part of the sea crust that came up as a sequel to the collision. We, in the Delhi University (Jhingran & Varadarajan 1978), have made a detailed study of the ophiolites from Dras which is a part of this area to determine the exact nature of the ultrabasic rocks that are present (Fig. 8). Our results go to show that the rocks present

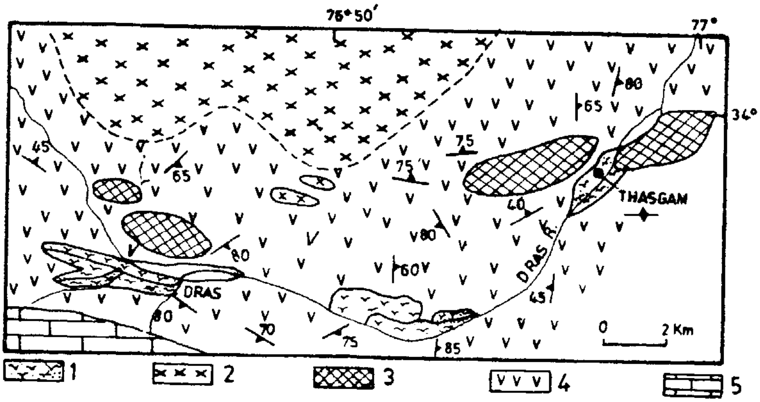

FIG. 8. Geological map of the area around Dras, Kashmir Himalaya : (1) Loose boulders, scree and alluvium; (2) Granite; (3) Ultramafics; (4) Dras Volcanics; (5) Triassic Limestone.

here are more akin to the alpine type and must represent only a source from a deep layer in the mantle rather than the oceanic crust. In particular it may be stated that whereas MgO/FeO ratio in the oceanic ultrabasic rocks vary from 2.75 to 8.2, with a maximum at 4/1 in the FeO/MgO frequency diagram, in the Alpine type it varies from 2 to 13 with a maximum at 5/1 (Sheynmann & Lutts 1974). The range of this ratio in the rocks from Dras falls between 5.61 and 6.81, indicating its affinity to the alpine type. Other characters, both chemical and mineralogical also support that these ophiolites have been derived from a deeper layer of the mantle, such as any ultrabasic intrusive rock would indicate. Thus in our opinion, the concept of the ophiolites of the Indus Suture Zone forming a part of oceanic crust is not substantiated.

In this connection, one may naturally make an enquiry as to which part of the crust, if any, got subducted. If it is maintained that the subduction was sequel to a continent-to-continent collision, one may logically expect and anticipate the front-most part of the Indian plate to get subducted. It leads to the next query as to what marked the northern limit of the Indian plate. If the Indus Suture Zone was the line of the collision-contact, obviously the Tethyan Zone of sedimentary formations, ranging from the Cambrian to the Palaeocene, and present in substantial force in the Tethyan Zone including the Spiti Valley, Byans and other areas, should have suffered a subduction. They are, however, very much there and the concept of subduction along the line gets completely negated.

In the above context it has been surmised that the vast pile of sediments that occurred in this area and which got subducted are now represented by the so-called exotic blocks that are present in substantial measure along the Indus Suture Line. These blocks have been, indeed, an enigma. They are fossiliferous and on the basis of their faunal affinity they are referable to an age spanning from the Permian to the Cretaceous. However, the fossils present therein have a Tibetan affinity, and not the Himalayan. That is why they have been termed exotic. Diener (1895, 1909) had suggested that their *in situ* home is somewhere in Tibet, and that a violent volcanic out-burst might have brought them to their present site. However, subsequent studies indicated that a southward thrust or nappe is responsible for their present position. Gansser (1974) regards them as having been formed by submarine gliding. However, biostratigraphic studies by Kumar and Prakash (1970) tend to indicate that the exotic nature of the blocks is doubtful. They are of the opinion that the blocks have resulted from slumping and penecontemporaneous deposition. Subduction is thus seriously questioned.

REGIONAL SETTING

Recently, based on seismic data, Kaila and Harinarain (1976) have proposed that the Indian plate extends in the north up to the Tien Shan Mountain. If this be accepted, the site of the continent-to-continent collision would *ipso facto* be shifted to the base of the Tien Shan and as a corollary, the subduction zone may also be in that very region, if at all. Several other workers, particularly Crawford (1974) also hold that India and Tibet have been linked to each other for most of the Phanerozoic time. From the point of orography, I think it is quite appropriate to assign Tibet and India to a closely connected region, for one should not consider the Himalaya mountain system in isolation of the Kun Lun mountain, the two originating from a common point in the Pamir Plateau. Furthermore, the Kun Lun more or less can make a sort of mirror image of the Himalaya in its arcuate line, and borders Tibet at its northern limit (Fig. 9). An analysis is called for to see if there is any link in the origin of these two mountain systems.

THE UPHEAVAL PHASES

Most workers on the Himalayan geology have regarded the rise of this mountain as a multiphased event. Krishnan (1968) in his text book, *Geology of India and Burma*

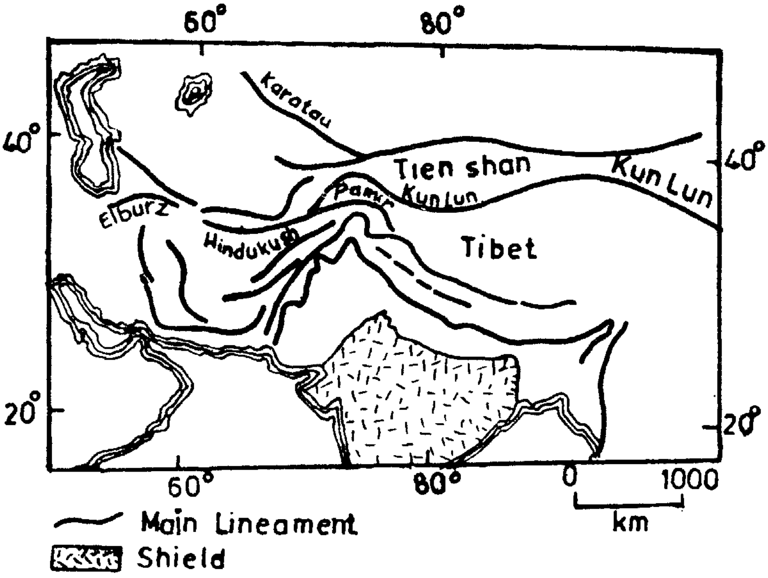

FIG. 9. Main lineaments of the Central Asia.

has outlined five phases of orogenic activity of which the earliest came off in the Upper Cretaceous, which actually caused only deepening of the Tethys in some parts and shallowing in others. Subsequently, throughout the Tertiary Era, repeated impulses caused the Himalaya to rise to its present form. In my interpretation, three of these upheavals were the more important ones, and may be reasonably linked with each other causing the rise one after the other of the three parallel ranges of the mountains, about which I talked in the opening part of my lecture. It may be recalled that these three ranges of mountains are located fairly parallel yet wide apart, to each other and have obvious difference in ages. The one composing the Central Axis with the Tethyan Zone adjacent to it, must have been the first to form towards the end of the Palaeocene. The Lesser Himalaya may have risen next, for within this area there occur the sediments of the Eocene to the Lower Miocene age. Finally, towards the end of the Upper Pliocene came up the third impulse which upheaved the Siwaliks. We have, therefore, to think of at least three major impulses of upheaval spread over the period between the early Eocene and the early Pleistocene, which means almost the whole of the Tertiary era.

Based on the correlation of various stratigraphic formations, some difference of opinion may arise on the exact dating of these upheavals, but the overall picture is not very affected. The question, however, arises as to which upheaval movement the collision of continents coincide? Alternatively, are we to believe in as many collisions as the number of orogenic upheavals, or that one of these was the major one, and the others were after-effects. Looking at the magnitude of the overall effect involved, it appears that the second upheaval, which is dated as the Mid-Miocene was of maximum magnitude, so that, possibly the continental collision may be treated to have occurred at that stage. Does it mean that the earlier orogenic upheavals had occurred in advance of the collision? In other words, it would appear that collision was not essential for the orogenic activity. Furthermore, the concept of orogenic activity as an after-effect of collision does not appear to have validity for, indeed, an upheaval which raises a vast stretch of land by as much as 5000 ft. must be treated as a major event and not an after-effect. In my opinion, collision cannot account for upheaval of the Himalaya.

ORIGIN OF THE HIMALAYAN ROOT

I would not like to dispute the wandering of the continent, but we have got to find an alternative to the collision hypothesis for the upheaval of the Himalaya, for which there is yet another major hurdle in the form of lack of a process for the extension of the sialic layer to substantial depths immediately below the mountain chain. Gliding of crustal matter to a major extent may be possible only when the rocks would attain high plasticity, such as may develop when the matter is under high temperature and pressure, which may prevail at a depth of more than 30–40 kilometres. At the surface, occurrence of such a phenomenon seems to me just impossible. Thus subduction is not the answer to the problem of the formation of the roots of the mountain. One must find an answer elsewhere.

A critical study of elements of the crust, mantle and the layers below the Mohorovicic discontinuity leads to rewarding results. We have often tended to lay too much emphasis on the apparent differences in the nature and the composition of the sialic granite, the simatic basalt or gabbro and the ultrabasics. Examining the great variety of igneous rocks, Bowen as early as 1928, in his classic book "*The Evolution of Igneous Rocks*" had suggested that all the multifarious varieties of igneous rocks can be derived from a single parent magma, and he thought it was of basaltic nature. This was corroborated by Daly (1953) five years later. Even then, many petrologists thought that one must conceive of a granitic magma also, for otherwise one would not be able to account for the enormously large masses of granitic rocks that abound in the continental masses and the crust. However, detailed laboratory studies have shown that a granitic mass on being subjected to a high pressure (15 to 20 kb) and high temperature (550° to 700° C) need not necessarily produce a complete granitic melt. The result will depend upon whether water is present in adequate quantities. In the event of there being deficiency of water, the rock may pass into a melt in the basaltic zone. It has been inferred that the probability of forming the granitic melt passes through a maximum of 20 to 30 km depth, beyond which the environment becomes unfavourable (Bayly 1968).

Studies of behaviour of matter at high pressure and temperature that have been carried out in recent years has established that there are so many cases of polymorphic conversion amongst common substances. It is well known that at sufficiently high temperature and pressure one can produce diamond from graphite. Taking examples from rocks, basalt and eclogite form a similar polymorphic pair. Though the two rocks are fairly similar in chemical composition except for MgO (Table I), they are radically different in mineral composition whereas basalt contains lime felspars in abundance along with pyroxenes in fair quantity, the eclogite has no felspars at all, instead it is rich in jadeite pyroxene along with garnet. It is to be noted that the specific gravity of the former (basalt) is 2.95, that of the latter is 3.3. Experimental studies have demonstrated that at a temperature of 500°C and pressure around 10,000 bars, basalt glass crystallises as gabbro, rich in felspar, and at pressures above 10 kilobar,

TABLE I

Composition of Basalt and Eclogite (Kennedy 1968)

	Olivine basalt	Eclogite
SiO_2	48.35	48.12
TiO_2	0.34	0.85
Al_2O_3	13.18	10.42
CaO	10.34	9.99
MgO	9.72	14.22
FeO*	13.31	13.92
Na_2O	2.42	1.45
K_2	0.58	0.58

*Total iron as FeO

the quantities of felspar steadily decreased, the melt finally crystallising to a rock predominantly made up of jadeite pyroxene (Robertson *et al.* 1957). The temperature and pressures chosen for this experiment are approximately the same as would prevail at the Mohorovicic discontinuity under the continents. It is thus noted that under high temperature and pressure as may prevail at the Mohorovicic discontinuity, the rock with lower density, basalt, can change into one, with high density eclogite. This leads to the inference that the Mohorovicic discontinuity principally indicates a level at which phase change takes place rather than the chemical change.

Kennedy (1968) has further shown that a relative study of the rate of increase of temperature with depth under the high mountains, continents and oceans show that its gradient is minimum under the high mountains. As a sequel to this, the necessary temperature and pressure requisite for the phase change would be at the shallowest level under the ocean, medium level under the continent and deepest level under the high mountains, which in other words mean that the Mohorovicic discontinuity would be at shallow depths under the sea, medium depth under the continent and great depth under the high mountains.

The theoretical and logistic considerations of these experimental results lead one to conclude that the rise of sediments originally at or below sea level to heights of a mountain can be achieved as a result of warming of rocks at the level of the Mohorovicic discontinuity, causing the level at which phase change may occur to migrate down. The dense rock would become lighter, leading to increase in volume and cause it to float up to higher levels.

In brief, the mountain building would be mainly a function of vertical movements and that the major faults and folds are largely of gravitational nature. However, one must bear in mind that the results of buoyancy developed as a sequel to phase change will be transmitted upwards only as and when the solid medium would allow movement of rock masses. So that the tension that gets generated would accumulate until it exceeds the cohesive forces of the crustal rocks, resulting in waves of upheaval as an intermittent activity. In this process some lateral forces are also apt to get developed which will lead to the formation of nappes or thrusts.

Thus, I visualise that the repeated impulses, 3, may be 5, which caused the upheaval of the Himalaya were generated by successive lowering of the Mohorovicic discontinuity. The nature of the forces that got developed each time were more or less identical in nature, resulting in development of roughly parallel range of mountains, with an overall similar pattern of slopes.

Kaila and Harinarain (1976) based on seismotectonics and deep seismic soundings have also concluded that the rise of the Himalaya was caused by block uplift against steep angle faults and not by a continent-to-continent collision involving subduction or underthrusting. Petrushevsky (1971), Qureshy (1969) and others have also supported the concept of origin by vertical uplift. F. Ahmad (personal communication) also recently changed his view and is convinced that rise of the Himalaya must have been only on essential vertical movement.

CONCLUSION

In my opinion, the drift of the Indian sub-continent may be accepted in so far as it would make this part of the crust to travel northwards and as Crawford (1974) has already observed lays it adjacent to the Sino-Eurasian block, until space would not permit to make it move any more northwards. The contact may have been somewhat violent, and as a sequel to that the numerous lineaments that were already present in this part of the crust got activated, which in due course allowed for vertical movement of crustal material. In a paper written jointly with Sinha (1975), I have focussed attention to the fact that there are several deep lineaments in the Himalaya, which run parallel to the general trend of this mountain system, and which have been intermittently active over a very long time in the history of the earth, almost from the Pre-Cambrian time. Four of these major lineaments include (i) Gilgit-Dras-Darchan deep seated fault, i.e., the Indus Suture line, (ii) Keylong-Badrinath-Malari Main Central Axial structural line of the Himalaya, (iii) Pir-Panjal-Darla lineament, and (iv) the Main Boundary Fault. It was the reactivation of these faults in the Tertiary period, combined with the lowering of the Mohorovicic discontinuity that caused the rise of the Himalaya.

It occurs to me that at least some of these lineaments may be treated as very ancient, possibly the Pre-Cambrian feature and have remained intermittently active for all the time. I venture to suggest that the Pamir Plateau provided a centre from where a series of radiating lineaments got developed early in the history of the earth. One of these led to the formation of the Himalayan system, the second to the Kun Lun system, the third to Hindukush and the fourth to the salt Range and Kirthar group of mountains, all diverging out from a common knot.

The high Himalayan terrain, much of which is now snow covered and is thus not freely available for observation, needs more intensive studies, so as to unfold and unravel their mysterious past. In the wake of the new knowledge we hope to find channels along which the metallogenetic solutions might have led to the formation of ore deposits. The research in this field is apt to be doubly rewarding. I look forward to a more revealing future.

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