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Sedimentology and Genesis of the Cenozoic Sediments of Northwestern Himalayas (India)

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With 4 figures

Zusammenfassung

Herkunft und Sedimentationsraum der im Nordwestabschnitt des Himalaya anstehenden känozoischen Sedimente werden ausführlich dargestellt. Die Ergebnisse beruhen auf detaillierten sedimentologischen, einschließlich mineralogischen, petrographischen und petrochemischen Untersuchungen von mehr als 3000 repräsentativen Proben.

Es wird gefolgert, daß der Detritus der känozoischen Schichtglieder hauptsächlich von metamorphen, in den angrenzenden Himalaya-Gebieten anstehenden Gesteinen stammt.

Der Detritus der ältesten Einheit der känozoischen Folge wurde in marinen Flachwassern abgelagert. Die übrigen Schichten stellen Anhäufungen räumlich und zeitlich schwankender, nicht-mariner Ablagerungsräume dar.

Abstract

The paper discusses at length the provenance and the environments of sedimentation of the Cenozoic sediments exposed in the northwestern sector of the Himalayas. The results are based on detailed sedimentological (including mineralogical, petrographical and petrochemical) investigations of more than 3,000 representative samples.

It is concluded that the detritus of the Cenozoic formations was derived mainly from metamorphosed rocks exposed in the adjacent Himalayan regions. A comparatively smaller proportion of the sediments was contributed by acid plutonic, volcanic and sedimentary rocks.

The detritus of the oldest unit of the Cenozoic sequence was deposited in shallow marine waters. The remaining formations represent the accumulations of nonmarine environments fluctuating in space and time.

Résumé

La provenance des sédiments cénozoïques et le domaine de sédimentation du secteur nord-ouest de l'Himalaya sont décrits en détail. Les résultats reposent sur des recherches sédimentologiques, à la fois minéralogiques, pétrographiques et pétrochimiques, de plus de 3000 échantillons représentatifs. Les résultats montrent que les détritiques pro-

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viennent principalement de roches métamorphiques affleurant dans les régions de l'Himalaya situées en bordure. Les détritiques de l'unité la plusancienne de la série cénozoïque se sont déposés dans des eaux marines peu profondes. Les autres couches sont des dépôts dans des bassins non marins, variant dans le temps et l'espace.

Краткое содержание

Подробно описаны происхождение и область седиментации кайнозойских осадочных пород северо-западного района Гималаев. Результаты основаны на детальных седиментологических, минералогических, петрографических и петрохимических исследования более чем 3000 проб.

Сделан вывод, что детритный материал кайнозойских слоев происходит гл. обр. из матеморфных пород областей, примыкающих к Гималаям.

Детритовый материал древнейших кайнозойских пород отлагался в районе прибрежных зон. Остальные отложения представлены породами не-морского происхождения.

Introduction

The present paper deals with sedimentological and genetic aspects of the Cenozoic sediments (older than recent and subrecent) exposed in the Panjab and Kumaon Himalayas which together, within the international territorial limits of India, comprise the northwestern sector of this great mountain chain of the world (Fig. 1).

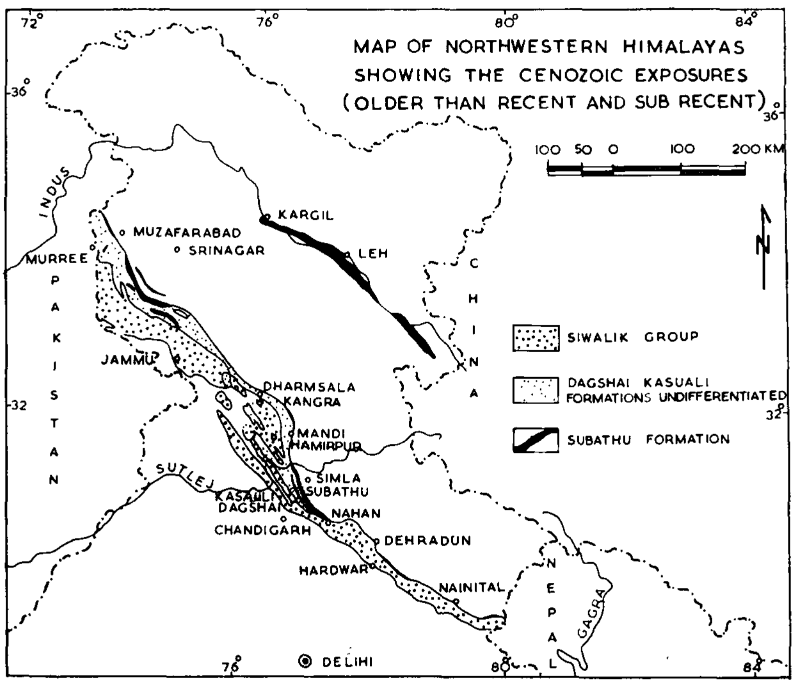

Fig. 1. Map of Northwestern Himalayas showing the Cenozoic exposures (older than Recent and sub-Recent). Modified after Geology and Mineral Map of India, 1968.

The Cenozoic sediments of this region are broadly classified into two groups which correspond in close approximation to the Paleogene and Neogene Periods of the Cenozoic Era. The Lower Tertiary (Paleogene) sediments include the Subathu, Dagshai and Kasauli formations (Sirmur Group) which represent the accumulations of Paleocene-Late Eocene, Late Eocene-Early Oligocene, Middle Oligocene-Early Miocene epochs respectively. The Upper Tertiary (Neogene) sediments are represented by the rocks of the Siwalik Group which comprise the Lower, Middle and Upper Siwalik formations and represent the deposits of Middle Miocene, Late Miocene-Early Pliocene, Late Pliocene-Early Pleistocene epochs respectively (CHAUDHRI, 1966 a, 1968, 1972 d, 1974). Various lithological units encountered in the Cenozoic rocks are shown in Fig. 4.

Not much work has been done in the past on the sedimentological aspect of the Cenozoic sediments exposed in this part of the Indian sub-continent. The notes and references made by previous workers are scattered in published geological literature.

The object of this paper is to discuss the sedimentological and genetic aspects of the Cenozoic sediments exposed in the northwestern sector of the Himalayas in the light of investigations carried out by the author during the past one and a half decade.

Sedimentological investigations

The sedimentological (including petrographical and petrochemical) studies of the Cenozoic sediments of northwestern Himalayas have been carried out by a number of workers including MCMAHON (1883), GANJU & SRIVASTAVA (1961, 1962), KHARKWAL (1964, 1966, 1969), RAIVERMAN (1964, 1968), RAIVERMAN & SESHAVATARAM (1965), CHAUDHRI (1966 a, b; 1969 b, c, d, e; 1970 b, c; 1971 b, c; 1972 a, b, c), RAJU (1967), BHATTACHARYA (1970), BHATTACHARYA & RAIVERMAN (1973), BHUSHAN (1973) and others.

While DATTA (1970) and MAHANDROO (1972) confined their studies to the Paleogene sediments, KRYNINE (1937), BABU & DEHADRAI (1958), MISRA & VALDIYA (1961), SIKKA, SAXENA, BHATIA & JAIN (1961), CUMMINS (1962), RAJU & DEHADRAI (1962 b, c), SAXENA, BHATIA & PANDE (1968), SINHA (1970), DASS & VANSHNARAYAN (1971), TONDON (1971, 1972 a, b) laid more emphasis on the study of Neogene sediments.

In order to maintain brevity of the publication, only the more important observations bearing on the petrogenesis of the Cenozoic sediments of the northwestern Himalayas are summarised herein.

Subathu Formation

Different petrological rock types met with in the Subathu Formation include intraformational conglomerates, quartz arenites, arenites (calcareous cement), arenites (ferruginous cement), clays/shales/siltstones and limestones (Fig. 4). Total absence of lithicwackes in the Subathu rocks is one of the most conspicuous feature. Fragments of metamorphic rocks are invariably absent in the arenaceous rocks while those of basalt, shales, limestones and sandstones are rarely present in small proportion not exceeding 2—3% of the rock composition. Most of the quartz grains show normal extinction (CHAUDHRI, 1971 c). The detrital fraction, in general, is of subangular to subrounded nature. Presence of glauconite, pyrite,

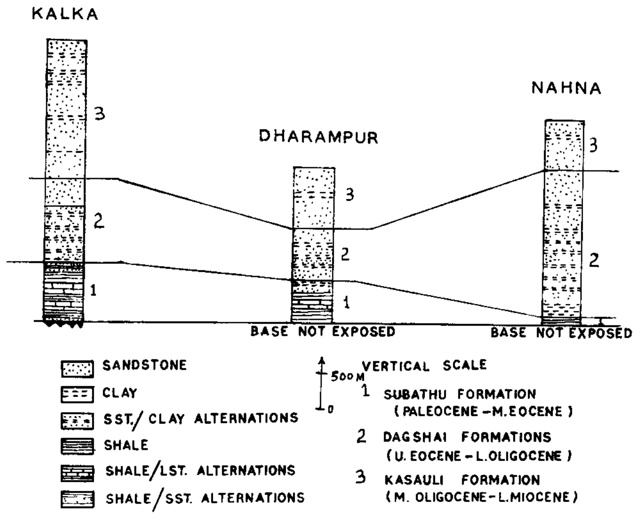

Fig. 2. Stratigraphic columns of the Subathu Dagshai and Kasauli formations.

gypsum and anhydrite in the Subathu rocks and an overall green colour of the sediments have an important bearing on the petrogenetic aspect. Occurrence of marine micro and magafossils is yet another character to note.

Dagshai Formation

The Dagshai rocks are characterised by their overall purple shade and total absence of limestones (Fig. 2). The lithicwackes make their appearance for the first time in the Dagshai Formation in the Cenozoic column of the northwestern Himalayas. The more common rock fragments constituting up to 30% of the modal composition of sandstones represent such rocks as quartzites, sandstones, clays/shales/siltstones, chlorite schists, muscovite-biotite schists, quartz sericite schist, carbonaceous schist and gneissose rocks. The next more important feature of the Dagshai rocks is the presence of perfect euhedral to subhedral grains of quartz showing very little impact of erosion/transportation. Polycrystalline quartz with sutured outlines and absence of fresh felspars are the other significant points to record. A good proportion of quartz shows undulose extinction and development of strain lamellae. A number of quartz grains bear inclusions of dark opaque and transparent minerals. The detritus, in general, is of angular to subangular nature. Amongst the minor mineralogical components, epidote constitutes a significant proportion. Total iron (both ferrous and ferric) in the Dagshaï rocks rarely exceeds 3% (CHAUDHRI, 1966 b) and the alumina content seldom crosses 15% of the chemical composition of the rocks under discussion.

Kasauli Formation

The various petrological units met with in the Kasauli Formation are essentially the same as those in the Dagshai Formation except the occurrence of quartz arenite which is extremely rare to almost absent (Fig. 4). Moreover, arenaceous rocks dominate over the argillaceous ones. The arenites and the wackes are more micaceous and bear an impact of metamorphism (CHAUDHRI, 1969 d). Limestones, micro- and megafossils, glauconite, gypsum, and anhydrite are conspicuously absent. Presence of fossil vegetable matter (logs of fossil wood, twigs and leaf impressions) in the arenaceous and argillaceous sediments is exclusive to the rocks of the Kasauli Formation and is not recorded in the older sediments (FEISTMANTEL, 1882; SAHNI, 1953; CHAUDHRI, 1969 a). Amongst the more important observations having a bearing on the petrogenetic aspect are the presence of micas and garnet in significant proportion and an appreciable decrease in epidote content; occurrence of certain minerals as "pay streaks" in the arenaceous rocks; replacement of silica by carbonate (etched margins of quartz) and higher percentage of mechanical clay matrix in the lithicwackes. Other features observed in the rocks of the Dagshai Formation except for the addition of fragments of carbonaceous schists and absence of purple colour and euhedral quartz are common to the Kasauli rocks also.

Lower Siwalik Formation

Different petrological units met with in the Lower Siwalik Formation include intraformational conglomerates, quartz arenites, lithic arenites (calcareous and ferruginous cement), lithicwackes and clays/shales/siltstones (Fig. 4) which eventually are just the same as observed in the Dagshai-Kasauli sequence and have a close resemblance in their main features with those of the latter (CHAUDHRI, 1971 a). The detritus falls in the angular to subangular grade and is poorly sorted. The rock fragments constitute a high proportion (30—35%) of the modal composition and represent such rocks as sandstones, clays/siltstones, limestones, chlorite schists, muscovite schists, biotite schists, carbonaceous schists and gneissose rocks. Along the contact of quartz and carbonate cement, development of reaction rims is frequently noticed. A major part of the quartz content shows undulatory extinction. Mineral grains showing non-undulatory extinction, however, are also present. Some of the quartz grains bear minute inclusions of various dark coloured minerals. The rocks, in general, are felspar poor. More important amongst minor mineralogical components, having a bearing on the petrogenesis of the sediments, are garnet, staurolite, epidote and flaky minerals (chlorite/chloritoid, biotite, muscovite). The rocks occasionally bear fossil vegetable matter, mainly, leaves and stems (DAYAL & CHAUDHRI, 1967).

Middle Siwalik Formation

Intraformational conglomerates, lithic arenites, lithicwackes and clays/shales/siltstones constitute the various petrological units of the Middle Siwalik Formation. Quartz arenites are conspicuous by their absence. The rocks are moderately to poorly indurated. While the angularity of the detrital grains, poor sorting and association of heterogeneous sizes and shapes continue to be more or less the same as for the Lower Siwalik sediments, the slightly coarser sized rock fragments constitute a little higher proportion (30—40%) and represent more varied types of schists including garnetiferous mica schists. Mechanical clay matrix of the lithicwackes shows a significant increase. Presence of prismatic euhedral grains of quartz with terminated pyramidal faces is a conspicuous feature to note. Percentage of polycrystalline quartz and quartz showing undulatory extinction also registers an appreciable increase. Frequency of occurrence of re-

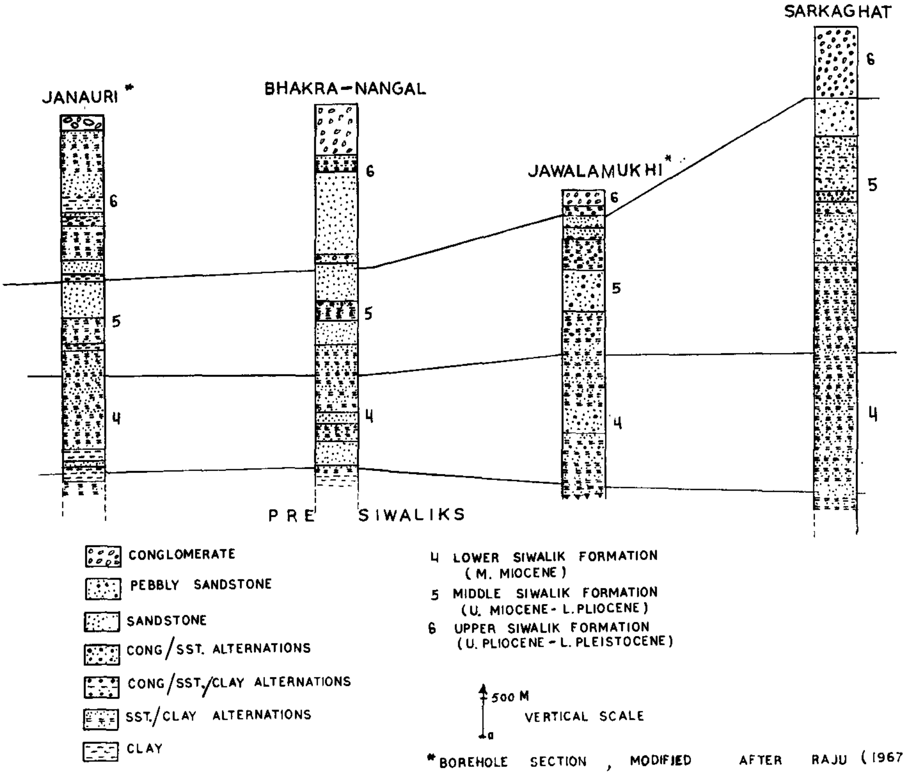

Fig. 3. Stratigraphic columns of the Siwalik formations.

action rims at the junction of quartz and carbonate cement is more or less the same. The rocks are felspar poor (up to 5% of modal composition) and show an increase in the mica content. The high felspar percentage (15%) reported by KRYNINE (1937) seems to be an exception rather than a generalization mainly because his studies are based on the microscopical examination of only 35 thin sections in contrast to the 3,000 thin sections studied by the author. Various minerals encountered in the Lower Siwalik sediments are met with in the Middle Siwalik rocks also. Addition of kyanite is rather significant. The sediments frequently bear a rich fossil flora, occasionally even complete tree trunks.

Upper Siwalik Formation

Amongst the various petrological types met with in the Upper Siwalik Formation (Fig. 3), three features are of greater significance. Firstly, the coarse clastic rocks represent the "true conglomerates" and not the intraformational types; secondly, the rocks are poorly indurated and are generally loose and friable, and, thirdly, the argillaceous units constitute a minor proportion of the rock types and wherever occur, the clay components are invariably found contaminated with the arenaceous fraction. The conglomerates represent boulder to granule sized subangular to well rounded fragments of various shades of quartzites, sandstones, siltstones/clays, limestones and various types of schists and gneisses. In the arenaceous rock, fragments of undecomposed parent rocks at places exceed 50% of the rock composition. While, in general, such fragments represent the rock types mentioned above, addition of fragments of basalt in the suite is a significant point to note. Clay matrix constitutes 20—30% of the composition of lithicwackes. Polycrystalline quartz and quartz showing undulatory extinction continue to dominate. There is an appreciable increase in the number and variety of minor mineralogical components, the most important being sillimanite.

Heavy mineral investigations and their bearing on the petrogenesis of sediments

An account of the heavy mineral distribution in the Paleogene sediments of the northwestern Himalayas was almost lacking till recent years when CHAUDHRI (1966 a, 1970 b) placed on record a comprehensive account of the heavy mineral frequency distribution in the Himalayan Lower Tertiary sediments. Heavy mineral investigations of the Neogene (Siwalik) sediments, however, were carried out by RAJU & DEHADRAI (1962 a), SINHA & KHAN (1965), RAJU (1967), CHAUDHRI (1970 c, 1972 a), SINHA (1970) and others.

More than twenty two heavy mineral species are recorded to occur in the Cenozoic sediments. Amongst the minerals of more frequent occurrence are included zircon, tourmaline, rutile, epidote (including zoisite and clinozoisite), garnet, chlorite/chloritoid, biotite, staurolite, kyanite and sillimanite. Andalusite, hornblende, sphene (very rare), apatite and enstatite are placed in rare to sporadic category. The opaque fraction includes magnetite and ilmenite (with frequent development of leucoxene). The authigenic suite comprises pyrite, anhydrite, hematite, limonite and barite. The statistical mineralogical data are tabulated in Fig. 4.

Although distribution of heavy minerals is controlled by a variety of factors such as weathering in the source area and at the site of deposition, post depositional changes, destruction by wear and tear, specific gravity and grain size of the minerals, yet the significance of heavy mineral assemblage in unfossiliferous sedimentary rocks remains undisputed, more so, for the sediments originated and accumulated under the conditions of active erosion, short transportation and rapid deposition. For such sediments, the heavy mineral assemblage directly reflects the petrography of the source areas.

An analysis of the heavy mineral distribution in the Cenozoic sediments (Fig. 4) reveals that each of the six formations is characterised by minerals which are either altogether absent in the preceding or succeeding units or present in different proportions.

The heavy mineral assemblage of the Paleogene sediments is suggestive of derivation of a major proportion of the sediments from metamorphic source rocks. Epidote and tourmaline (occurring in the Subathu and Dagshai formations) must have been derived from low and medium grade metamorphic rocks (HEINRICH, 1956). Presence of garnet and chlorite in the Kasauli Formation is suggestive of removal of overlying sedimentary and low and medium grade metamorphic veneer and denudation of slightly higher grade metamorphites. The presence of terminated euhedral grains of zircon with a high length-breadth ratio is also

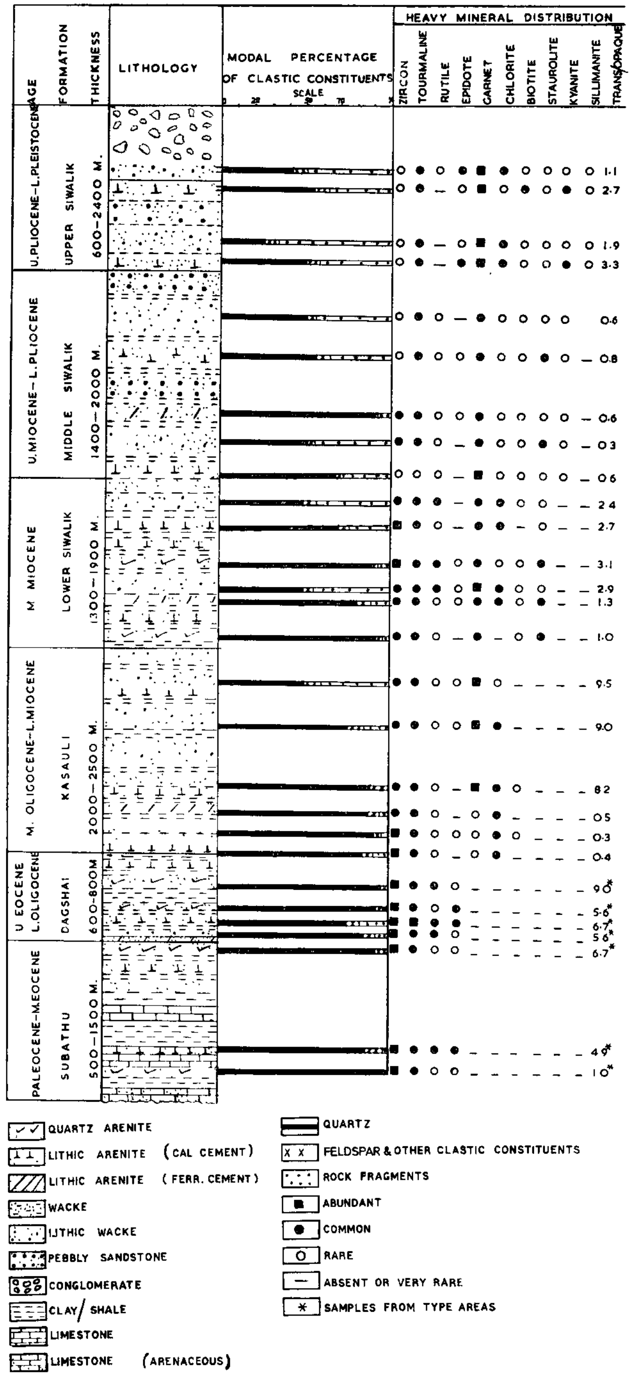

Fig. 4. Generalized section of the Cenozoic formations of Northwestern Himalayas showing the variations in lithology, modal composition and heavy mineral distribution.

indicative of non-sedimentary source rocks (POLDERVAART, 1955). The presence of authigenic pyrite and anhydrite in the Subathu sediments is suggestive of reducing and dehydrating land locked marine depositional environments.

A sizable number of mineral species (staurolite, kyanite, sillimanite, garnet, epidote, chlorite/chloritoid, biotite) of the heavy mineral assemblage of the Siwalik sediments is suggestive of the derivation of a large proportion of sediments from metamorphic provenance. The grade of metamorphism of the source rocks shows an increase with corresponding decrease in age of the sediments suggesting thereby exposure of deeper seated (more metamorphosed rocks) to denudation with progressive erosion and sedimentation (CHAUDHRI, 1966 a, 1969 c, 1971 b; RAJU, 1967; SINHA, 1970).

A critical review of the heavy mineral statistics reveals that the change in heavy mineral assemblage from Paleogene to Neogene sediments is rather gradational and is not abrupt and marked as pointed out by SAHNI & MATHUR (1964). Also, the statistical data reveal that the Paleogene sediments (Subathu and Dagshai) exhibit transparent/opaque ratio more than one. The observation made by RAJU (1967) that the pre-Siwalik sediments contain 70 to 80% of the opaques is not correct, in general, at least for the Paleogene sediments of the northwestern Himalayas. The analysis of the statistical data does not support both WADIA (1928) and KRYNINE (1937) in so far as their generalised observation about the distribution of heavy minerals in the Siwalik sediments is concerned. Instead, the statistical data suggest that the increase and/or decrease is related to certain mineral species and generalised statement seems to be unwarranted. The variation in the heavy mineral frequency distribution in the Cenozoic sediments of the northwestern Himalayas is suggestive of increasing intensity of diastrophism with decreasing age.

Discussion on genesis of the Cenozoic sediments

Sediments are a product of inheritance and environments. Mineralogical and chemical composition of the clastic rocks reflects the petrographical composition of the source rocks and is dependent upon climate, mode of transportation, distance of transport, environments of sedimentation, depth of burial and a number of related factors. Climatic factor determines the intensity of the source rocks decay in positive regions and the type of sediments likely to be deposited in negative areas. The tectonic conditions have an important bearing and control to a great extent the transgressive and regressive phases and affect the climatic conditions, provenance and environments of sedimentation (CHAUDHRI, 1972 b).

Source of the Cenozoic sediments

The detailed investigation of the Cenozoic sediments carried out by the author has revealed that the basal unit of the Cenozoic sequence has unconformable junction with the pre-Cenozoic sediments (CHAUDHRI, 1966 a, 1968) and overlies such formations as Simla Formation (Cambrian), Blaini Formation (Carboniferous), Infra-Krol Formation (Permian), Krol and Shali Formations (Triassic?) and Tal Formation (Jurassic and Cretaceous). This eventually suggests rather conclusively that the Himalayas (at least in certain parts) had experienced upheaval in the pre-Cenozoic time. The various lithostratigraphic units mentioned herein above suffered varying degree of denudation and were reduced to a mature topography. This is evidenced by the general absence of conglomerates at the Subathu pre-Tertiary contact. On the eroded surface of the pre-Cenozoic rocks were laid down the Paleocene-Eocene and younger sediments. The hypothesis of the rise of the Himalayas (in part at least) in the pre-Cenozoic time (CHAUDHRI, 1966 a) enjoys support from MEDLICOTT (1864), MCMAHON (1883), AUDEN (1934), NORIN (1946), KRISHNAN (1953), KRISHNASWAMI & SWAMINATH (1965), PANDE (1966, 1975), FUCHS (1968), SAXENA (1971) and others.

It is also a fact known to the students of Indian Geology that the Peninsular Shield composed of pre-Cambrian crystalline rocks, metamorphites and a thick pile of Vindhyan and Gondwana sediments was reduced to a very low elevation at the close of Mesozoic Era. The basic and fundamental principles of erosion and sedimentation are suggestive, at the very outset, that the source of the Cenozoic sediments must be sought in the rising Himalayas rather than in the Peninsular Shield.

An analysis of the maturity of sediments and the nature of fragments of undecomposed parent rocks is perhaps the single most significant factor that offers undisputed evidences regarding not only the provenance of the sediments but also of the prevalent paleotectonic conditions, distance of transport, mode of weathering and time gap between erosion and sedimentation. This is all the more important since in mineralogically immature sandstones the ratio of undulatory quartz to total quartz is almost the same as in source rocks (BLATT & CHRISTIE, 1963). Detailed petrographic study of about 3,000 representative thin sections has established rather conclusively that the proportion of quartz showing undulatory extinction and the presence of polycrystalline quartz show a secular rise from the rocks of Subathu Formation to the Upper Siwalik Formation. Local variations, however, do exist as can be expected in such a thick pile of sediments. The increasing proportion of quartz showing undulatory extinction and polycrystalinity is therefore suggestive of exposure of progressively metamorphosed and/or regionally deformed source rocks to denudation processes with the decreasing age of the sediments.

A critical review of the petrographical characteristics of the Cenozoic sediments has revealed that in the oldest lithostratigraphic unit (Subathu Formation), the fragments of undecomposed parent rocks are almost absent; wherever present, they do not make up more than 2—3% of the modal composition and represent such parent rocks as basalt (very rare), sandstones, shales and limestones. The petrography of Subathu rocks is, therefore, suggestive of stable tectonic conditions, chemical mode of weathering in the source areas and derivation of a major part of the sediments from sedimentary rocks (CHAUDHRI, 1966 a). The presence of a high proportion of quartz showing normal extinction reinforces the author's observation about the sedimentary nature of the source rocks.

In the Dagshai sediments, the fragments of such rocks as quartzites, sandstones, clays/shales/siltstones occur along with the fragments of chlorite schists, muscovite biotite schists, quartz sericite schists, carbonaceous schists and gneissose rocks. Such fragments constitute up to 30% of the modal composition of lithicwackes. Appearance of a high proportion of undecomposed rock fragments is suggestive of a disturbed tectonic environment in contrast to the one which prevailed during the sedimentation of the detritus of the Subathu Formation. The changed tectonic conditions (gentle upheaval in the Late Eocene time) introduced a change in the source rocks whereby deeper seated metamorphosed rocks were upheaved above the base level of erosion and were exposed to the erosion processes. Moreover, the weathering in the source areas was more of the mechanical disintegration type. The distance of transport must have been quite short, otherwise the fragments of schistose rocks would not have survived. The author's observations (CHAUDHRI, 1966 a) are supported by those of CAMERON & BLATT (1971). Moreover, the presence of the high proportion of undecomposed rock fragments is suggestive of first cycle of erosion and rapid accumulation of the detritus (CHAUDHRI, 1966 a). The observations are reinforced by the finds of BOGGS (1968). Presence of perfect euhedral to subhedral grains with little or no rounding is also suggestive of a short transportation. Presence of a high proportion of quartz showing undulatory extinction reinforces the author's contention about the metamorphic provenance for the detritus of the Dagshai Formation.

In the Kasauli sediments, the undecomposed rock fragments represent the identical source rock. An increase in the proportion of the fragments of carbonaceous schists is rather significant. All this eventually is suggestive of the continuation of the supply of the sediments from the source rocks which supplied detritus for the Dagshai Formation. The presence of carbonaceous schists (along with garnet) is indicative of a slightly higher grade of metamorphism of the source rocks. Large proportion of clay matrix in the sediments also indicates a metamorphic provenance (DAPPLES et al., 1953). Other conditions, such as the mode of erosion and distance of transport remained much the same as during the Dagshai period except that the tectonic conditions were little more unstable as is evidenced by the higher sand/shale ratio.

Petrographical characteristics of the Lower Siwalik Formation are suggestive of a steady supply of the detritus from the source rocks which contributed the sediments for the rocks of the Dagshai and Kasauli formations. More or less similar tectonic conditions and a short distance of transport are indicated by the petrographical studies. The mode of weathering was of a mixed type. By the time, the Lower Siwalik sediments were accumulating, the relief of the source areas was somewhat reduced and it is for this reason that the Lower Siwalik detritus represents the mixed environments and is matching with the Dagshai-Kasauli sequence together (CHAUDHRI, 1971 a, 1972 c).

In the rocks of the Middle Siwalik Formation, the rock fragments form a little higher proportion of the modal composition and represent more varied types of schistose rocks. The size of the fragments is also coarser. The presence of such minerals as staurolite and kyanite, a high proportion of quartz showing undulatory extinction and polycrystalinity are suggestive of contribution of the detritus by metamorphic rocks exhibiting still higher grade of metamorphism. BOKMAN (1952) and BLATT (1967) have attributed the source of polycrystalline quartz to metamorphic rocks. The petrographical evidences are suggestive of a fresh wave of gentle upheaval which rejuvinated the relief of the source rocks resulting in the resumption of mechanical mode of weathering. The short transport and rapid burial are indicated by the presence of a high proportion of undecomposed rock fragments and presence of logs of fossil wood.

The Upper Siwalik sediments represent the product of the most unstable paleotectonic environment. The rock fragments in the arenaceous rocks occasionally exceed 50% of the modal composition and represent still more varied types of schists and gneisses. Fragments of basalt is an important addition and indicates the contribution of the detritus, in part, by volcanic rocks. Arenaceous nature of clays and extreme coarseness of the detritus are suggestive of a high relief and disturbed physicotectonic environments. Presence of sillimanite in the Upper Siwalik sediments indicates still higher grade of metamorphism of the source rocks. The weathering was mainly of the mechanical disintegration type and the distance of transport was rather short.

The number and variety of minor mineralogical components show a rational increase with the decreasing age of the sediments (Chaudhri, 1970 b, 1972 a). The mineralogical characteristics of the various lithostratigraphic units of the Cenozoic sediments support the observation regarding the supply of the detritus from progressively metamorphosed rocks.

The sedimentological parameters, such as, subangular to subrounded nature of the detritus of the Subathu rocks (Chaudhri, 1969 e), an overall angular to subangular nature of the detrital fraction of the post-Eocene Cenozoic sediments and occasional occurrence of rounded to well rounded detrital grains support the conclusions drawn from petrographical and mineralogical investigations. The Subathu sediments have been mainly derived from the sedimentary veneer which must have covered the underlying metamorphic and plutonic rocks (Chaudhri, 1966 a, 1969 c, 1971 b). The reworked nature of the Subathu sediments has also been suggested by Raju (1967). The angular to subangular nature of the detritus of the post-Eocene sediments is suggestive of contribution by non-sedimentary source rocks. Closeness of the source rocks and basin of deposition is also suggested by the occurrence of large fragments of source rocks with the sand sized detritus. The subordinate rounded to well rounded fraction, however, represents the reworked sediments. Presence of inclusion bearing quartz also suggests a metamorphic provenance (Mackie, 1896; Krynine, 1940; Keller & Littlefield, 1950).

To sum up, a major part of the Cenozoic sediments has been derived from metamorphic rocks. The sedimentary, acid plutonic and trap rocks contributed only a minor fraction of the sediments. The petrographical general uniformity, almost identical nature of the heavy mineral suites of the various lithostratigraphic units of the Cenozoic sediments and the sedimentological parameters are indicative of identical type of source rocks for the Cenozoic sediments deposited in the region which is now known as Panjab and Kumaon Himalayas. This eventually suggests the derivation of a major proportion of the sediments from the newly upheaved mountain chain — the Himalayas. A subordinate proportion of the detritus, however, might have been derived from the Peninsular Shield.

The Himalayan source is also indicated by the paleocurrent studies carried out by Wakhaloo & Bhatia (1966), Raiverman (1968), Chaudhri (1970 a), Tondon (1971) and others.

The detailed studies carried out by the author do not support the observation that the Paleogene sediments were derived from the iron-bearing rocks of Peninsular India (Pilgrim, 1919; Wadia, 1932; Gansser, 1964; Pascoe, 1964;

KRISHNAN, 1968, and others). The general absence of high grade metamorphic minerals and a low percentage of iron and alumina content of the sediments also do not support the hypothesis of the derivation of a major part of the Paleogene sediments from Peninsular Shield which comprised high grade metamorphic and trap rocks at the close of the Mesozoic Era.

The observations based on detailed laboratory investigations seem to be related directly or indirectly to the evolutionary changes, the earth has witnessed (CHAUDHRI, 1972 b). The deposition of the carbonate precipitates in the Subathu time reflects relatively stable tectonic conditions, humid climate in the positive areas and biogenic sedimentation (in part) in the negative regions. The thick accumulation of the clastic detritus in the post-Eocene time is indicative of disturbed tectonic conditions (CHAUDHRI, 1966 a). The author's observations are confirmed by the finds of RONOV, MIGDISOV & BARSKAYA (1969). The general increase in the size of the detritus including sandy nature of the clays and an influx of large proportion of undecomposed rock fragments in the arenaceous rocks of younger geological horizons is attributed to unstable tectonic conditions resulting in the increased weathering intensity in the source areas, incomplete disintegration, short transportation and rapid accumulation of the detritus (CHAUDHRI, 1971 b). The fact has been recorded in other parts of the globe also by RONOV, MIKHAYLOVSKAYA & SOLODKOVA (1963). Higher percentage of polycrystalline quartz and an increase in number and variety of minor mineralogical components are subject to the same observations. The mineral suites become highly complex (including various unstable mineral species) in the younger horizons. The observations made by the author are in harmony on the global scale with those of PETTIJOHN (1957), KOPELIOVICH, KOSSOVSAYA & SHUTOV (1961) and RONOV, MIHAYLOVSKAYA & SOLODKOVA (1963).

Environments of sedimentation of the Cenozoic sediments

The most persistent feature of the Cenozoic sediments of the northwestern Himalayas is the dual nature of the sedimentation environments. The Paleocene-Eocene sediments in all parts of the Himalayas are invariably marine and the last deposit of the Cenozoic sequence — the Upper Siwalik Formation — is representative of the freshwater fluviatile environment. The boundary between the two environments has ever been enigmatic and remained an unsolved problem. The enigmatic nature can be attributed partly to the absence of detailed paleogeographical maps of the Himalayas and partly to the general absence of fossil fauna and flora in the beds that immediately succeed the Paleocene-Eocene marine sequence.

The basin of sedimentation of the Cenozoic sediments has been variously named as Eocene Sea, Eocene Basin, Lower Tertiary Basin, Indobrahm, Faulted Geosyncline, Siwalik River, Middle Tertiary River, Foreland, Local Intermittent Basin, Foredeep, Extensive Basin and even Geosyncline (including Tertiary Geosyncline and Exogeosyncline). The space does not permit to discuss the terminology used to name the basin of sedimentation nor does the author want to add to the confusion by suggesting yet another term. The nature of the basin is far more important for the establishment of environments of sedimentation of the Cenozoic sediments. It might suffice to mention that there existed a basin transverse to the main Himalayan drainage occupying roughly the seat of the Cenozoic belt.

The Paleocene-Eocene sediments of the northwestern Himalayas are characterised by the presence of marine micro and mega fossil fauna and such authigenic minerals as gypsum, anhydrite, pyrite and glauconite which conclusively establish the marine environment for the sedimentation of the detritus of the Subathu Formation. The marine conditions, however, were fluctuating in space and time. Three cycles of sedimentation have been distinguished in the Subathu sequence in the type area (CHAUDRI, 1966 a; 1975). SWAMINATH (1961) placed the detritus of the Subathu Formation in the "Black Shale Facies" and proposed low oxidation-reduction potential and euxinic environmental conditions. The detailed studies have revealed that the euxinic conditions prevailed but not with equal intensity in all parts of the basin. Highly reducing conditions developed in certain isolated parts of the basin and in estuaries where authigenic development of pyrite took place. The final evaporation in such isolated parts of the basin could result in the formation of gypsum and anhydrite. The overall paleoenvironmental conditions were more of epineritic type in the present Panjab and Kumaon Himalayan regions where the marine Paleocene-Eocene sediments represent the accumulations of coastal marine environments. The deep sea facies has been reported to occur further west in the territory which is now Pakistan (KRISHNAN, 1968). The distribution of fossil fauna also supports a shallow water nature of the basin. The author's observation regarding the shallow water nature of the sedimentation environment (CHAUDHRI, 1966 a) is supported by the trace element studies (V/Ni ratio) carried out by RAIVERMAN (1964), paleontological studies (BHANDARI & AGARWAL, 1966) and clay mineral studies (BATTACHARYA, 1970). The gentle upheaval in the Late Eocene time drove back the epineritic marine waters to further west and the freshwater conditions were established in the present Panjab and Kumaon Himalayan regions.

For the accumulation of the detritus of the Dagshai Formation, brackish water conditions and salt water lagoons were suggested by OLDHAM (1893), WADIA (1932), HAYDEN (1933), FUCHS (1968) and others. The detailed investigations carried out by the author revealed the existence of shallow freshwater sedimentation environment during the Dagshai period (CHAUDHRI, 1966 a, 1969 b). The marine fossil fauna is conspicuously missing from the Dagshai Formation. Nowhere in the Dagshai rocks, occurrence of salt cubes, gypsum, anhydrite, pyrite, glauconite are found. There is absolutely no evidence, whatsoever, which could possibly suggest the prevalence of salt water lagoons during the sedimentation of the Dagshai. The bathymetric considerations eliminate the necessity of bringing in the brackish water condition for long, such conditions did prevail for a short duration in the Subathu period itself and at the close of Subathu sedimentation, the advent of freshwater conditions is established not only by the mineralogical characteristics but also by paleontological considerations. The occurrence of *Bullinus*? and *Planorbis* (BHATIA & MATHUR, 1965) in the passage beds between the Subathu and the Dagshai Formations is a clear cut evidence of the advent of freshwater conditions towards the close of Subathu sedimentation in the region which is now known as Panjab and Kumaon Himalayas.

The Dagshai sediments owe their purple colour to the intense chemical weathering the sediments suffered in the source area in the Subathu period. The sediments which were entrapped in the depressions and could not find their way to the basin of accumulation suffered chemical weathering and almost complete oxidation of their iron content. At the close of the Subathu sedimentation, in the Late Eocene time, when the relief of the source area was rejuvinated, such highly weathered products were carried away to the basin of sedimentation and got accumulated to represent the present purple clays of the Dagshai.

The association of purple clays and drab sandstones and occasional presence of worm tracts and tubes strongly indicate that the distribution and/or nature of the pigment also depended on sedimentary environments. The diagenetic redistribution of the pigment during the redoxomorphic stage of DAPPLES (1962) seems to be mainly responsible for the uniform colouration of clays and siltstones and for the varying intensity of the pigment in different beds. The author's observations are in harmony with those of KRYNINE (1949) and CLARK (1962).

By the close of the Dagshai period, practically all the chemically weathered products (red sediments) were removed. The rejuvinated relief exposed deeper seated rocks to the weathering agencies. There seems to be a corresponding increase in the precipitation also in the source areas. The warm and humid climate supported luxurious growth of vegetation, the remains of which are found in the rocks forming upper part of the Kasauli Formation (CHAUDHRI, 1969 a). The heavily laden streams after a short distance discharged their contents into the freshwater basin which occupied the depression transverse to the drainage system. In the shallow freshwater subsiding basin were laid down the detritus which constitute the Kasauli Formation. The shallow water features such as frequent occurrence of ripple marks, presence of current bedding, logs of fossil wood and association of cobble and pebble sized fragments with sand grade detritus reinforce the author's contention about the shallow depth of the basin (CHAUDHRI, 1970 a). Freshwater conditions are also indicated by the total absence of marine organism in such a thick (2,000—2,500 m) pile of sediments.

Towards the end of the Kasauli period (Early Miocene), the relief of the positive areas was considerably reduced and the rigour of erosion and sedimentation also appreciably subsided as a result of which the chemical and mechanical weathering operated simultaneously in the source areas and the sedimentation was comparatively less rapid. On account of the combined factors, the Lower Siwalik sediments acquired the dual characteristics and are matching with the accumulations of the Dagshai-Kasauli sequence together both in petrological, mineralogical, sedimentological characteristics and in the environments of sedimentation.

After the comparatively less intense period of erosion and sedimentation, the relief in positive areas was rejuvinated and the still deeper seated kyanite schists, garnetiferous mica schists and associated schistose rocks were exposed to the rigour of erosion. The increased precipitation in warm and humid climate helped growth of prolific flora on which flourished the herbivorous (and carnivorous) animals, the fossil remains of which are found in abundance in the Middle Siwalik rocks (especially in the equivalents of Dhok Pathan Stage). The rivers discharged their rock waste after a short transport into the basin of sedimentation running transverse to the main Himalayan drainage. Since the topography was in its youthful stage, the disintegration was more of the mechanical wear and tear type. The time gap between erosion and sedimentation was quite less and the sediments did not have enough opportunity to sort them out. All these features are well documented and evinced in the Middle Siwalik sediments. It is because of these conditions that the facies change in the Middle Siwalik sediments is so very rapid and marked. The shallow water depositional environments were instrumental in the large scale development of ripple marks, current bedding, occurrence of pebbly beds in sandstones, profusely rich fossil floral assemblage including the presence of large logs of fossil wood and twigs. Presence of slumps in current bedded rocks and dominance of one lithology also suggest shallow water conditions (Packham, 1954). The basin was subsiding as is evinced by the rapid burial of sediments evidenced by the frequent occurrence of reaction rims at the contact of quartz and carbonate cement.

The sedimentation continued up to the Late Pliocene with more or less identical paleogeographical and paleoclimatological conditions. In these very conditions were laid down the lower part (Tatrot and Pinjore Members) of the Upper Siwalik Formation. After the accumulation of the lower part of the Upper Siwalik sequence, there was the more prominent upheaval in the Late Pliocene time which triggered the cold climate conditions in the Himalayas. At places, the Pleistocene glaciation had left its imprints in the Upper Siwalik Boulder Conglomerate which represents the accumulation of Early Pleistocene time (Mehdiratta, 1959; Sahni & Mathur, 1964). The youthful topography and rigour of running water could supply large boulders which accumulated as fan deposits at the mouths of rivers and rivulets that debouched their rock waste into the basins of sedimentation.

The Cenozoic sediments were upheaved by the most powerful Middle Pleistocene orogenic movements which eventually carved out the present sculpture of the Himalayas.

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Tectonics and Earthquake Mechanism of the Shallow Earthquake Seismic Belt, the Himalaya

By SURENDAR KUMAR, Chandigarh *)

With 8 figures and 2 tables

Zusammenfassung

Die Verteilung von Erdbebenherden im oberen Mantel, die zwischen 1961 und 1972 im Gebiet von Himalaya, Tibet und Hindukusch auftraten, wurde untersucht und verglichen. Die V-förmigen Taschen über einer senkrechten Ebene zeigten Ähnlichkeit mit normalen Verwerfungen bzw. Abschiebungen an den Rändern der Kontinentalplatten. Die linkslateralen und rechtslateralen Verschiebungen der Kirthar-Sulaiman-Scherzone bzw. Brailly-Verwerfung, die durch den Herdmechanismus gefunden wurden, deuten auf eine relative Differenz in der Bewegung zwischen dem Kaschmir- und dem Nepalgbiet, und die gleichmäßige, rechtwinklige Verschiebung des Tibet-Plateaus hat die Saradah-Depression hervorgerufen. Aufgrund seismischer und geologischer Beobachtungen wird ein einfaches tektonisches Modell vorgeschlagen.

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