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PALEOENVIRONMENTAL INTERPRETATION OF PALEOGENE STRATA NEAR KOTLI, AZAD KASHMIR, NORTHEASTERN PAKISTAN

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ABSTRACT:– In the Kotli area of east-central Pakistan, the Subathu Formation was deposited by a single cycle of transgression and regression during the early Eocene. The marine Subathu section, which is developed on a pre-Eocene bauxite, records the successive passage of a coastal coal swamp; a very muddy shoreline; shallow and highly turbid but quiet offshore waters depositing unfossiliferous green mud and organic debris; clearer and probably deeper but still occasionally turbid water over fetid muds and marls beyond the coastal turbid zone; progressively shallower water depositing shales and higher energy limestones; an oyster bank; a delta-related submergent sand-bar complex; and a back-bar bay or lagoon that trapped river muds. Finally, progradation of a brackish coastal marsh across the bay is inferred from the succeeding slowly accumulated and completely pedogenized onshore clays. The topmost marine shale is inferred to correlate with a regional regression at the end of the early Eocene.

INTRODUCTION

Outcrops near the town of Kotli are important because they intervene between the very different Paleogene facies exposed in the Hazara region (around Murree in the Margalla Hills and near Muzaffarabad) and those near Kalakot and Riasi villages in India (figure 1). They have been examined previously by Lydekker (1883) and Wadia (1928), and they have recently been remapped by Mr. Raffi Ullah of the Geological Survey of Pakistan and restudied by Ashraf and others (1983).

As shown on Figure 2, the Kotli outcrop is essentially an elliptical dome, elongated parallel to the regional NW-SE strike. The south side of the dome is breached by a major thrust fault and its crest is highly undulatory. The core of the dome incorporates the pre-Cenozoic Jammu Limestone, the Paleogene Subathu Formation, and the Oligocene or Miocene Murree Formation. The Kamroti area, which was examined in greatest detail, is at the southwestern corner of one of the undulations. In that area, the section is repeated by a high-angle reverse fault that breaks the northeastern side of the dome between Kamroti and Nikial 6 km to the east. The base of the upthrown block is a slice of Jammu Limestone, but the lowest stratum exposed on the footwall becomes progressively younger to the south: two miles north of Kamroti, Jammu Limestone is faulted against itself but south of the Kamroti-Nikial road it is juxtaposed against Murree beds. Intense drag folding of the Subathu beds near the fault can be seen along Batala Nala, a stream valley NE of Kamroti.

RESULTS: DESCRIPTIONS OF STRATA

Figure 3 summarizes the Kamroti section and shows both the nomenclature favoured by Ashraf and others (1983) and correlations with Singh's (1973) divisions of the Subathu in the Kalakot and Riasi areas. The lettering of the Kamroti sub-units in this paper is for ease of refrence only and is not proposed as a formal subdivision. The name Subathu is used here because the Kotli section has more in common with Subathu strata immediately

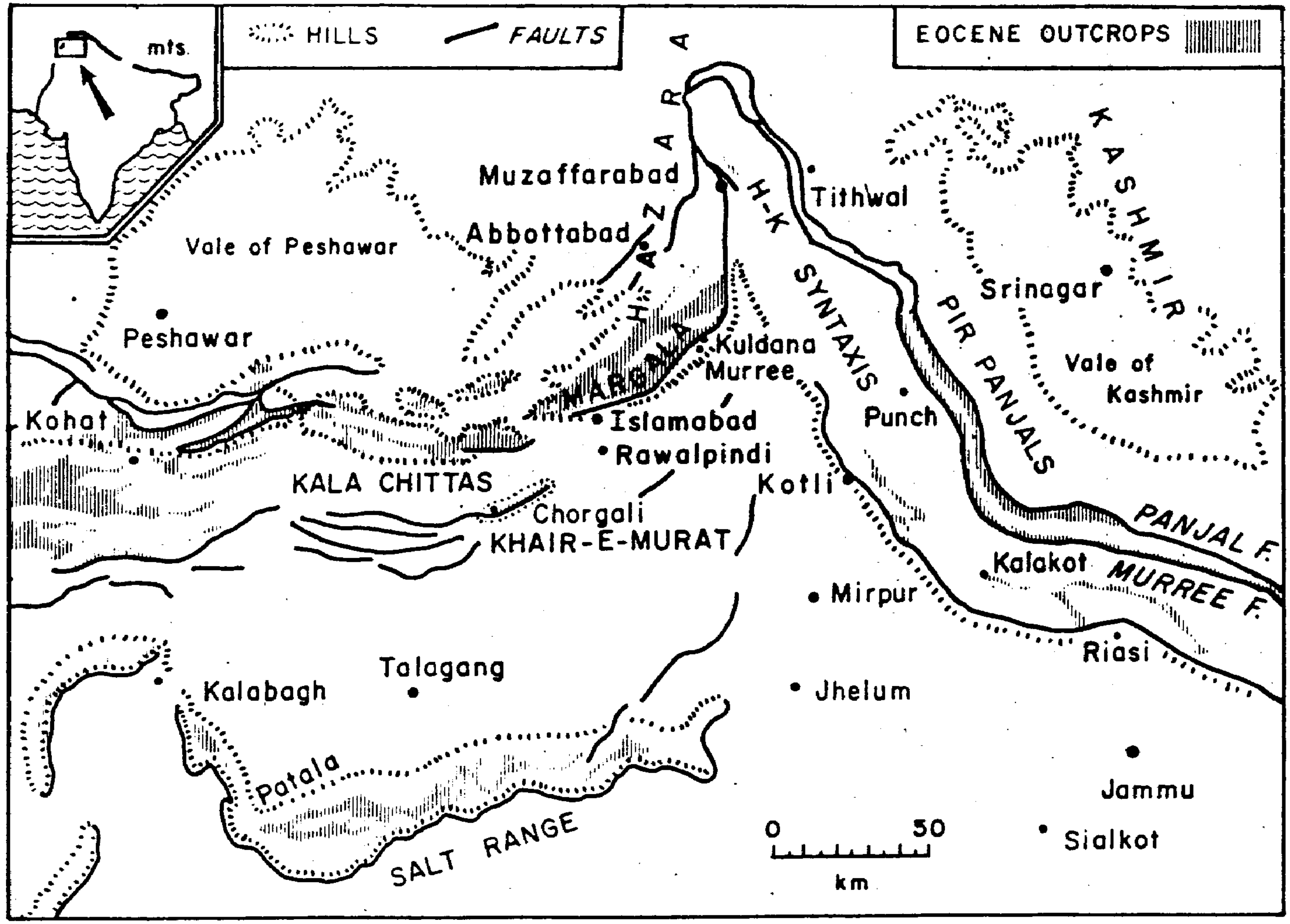

Figure 1: Faults, hill ranges, and Eocene outcrops around the Hazara-Kashmir syntaxis (arrow in inset map of Indo-Pakistan subcontinent shows location of figure).

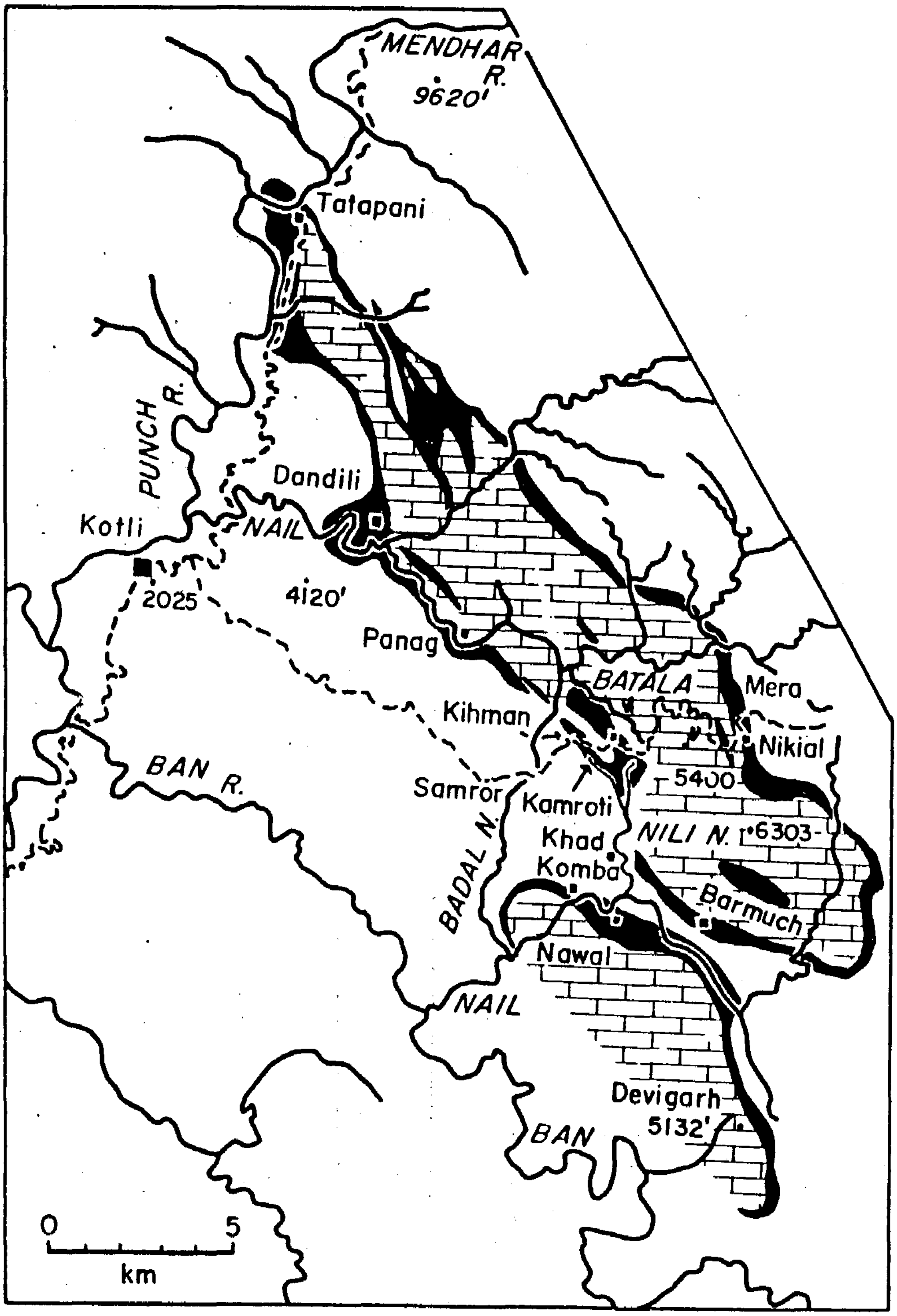

Figure 2: Map of Kotli area. Solid black shows outcrops of Eocene, limestone pattern shows Jammu "Limestone" (redrawn from Ashraf and others, 1983).

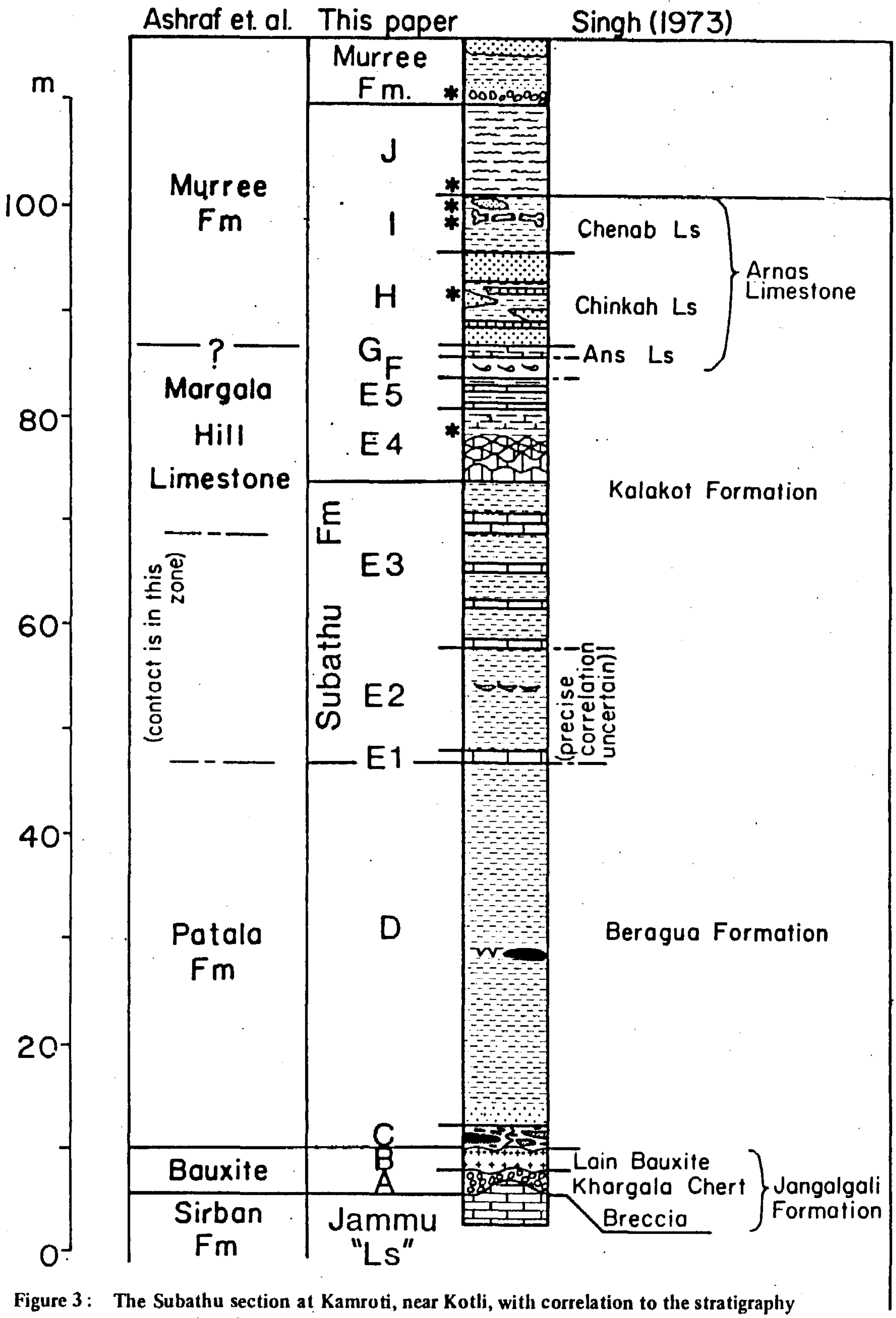

Figure 3 : The Subathu section at Kamroti, near Kotli, with correlation to the stratigraphy of Singh (1973) and Ashraf and others (1983). From Unit C up into unit E, the section is basically transgressive, whereas starting with Unit E-4 (if not lower), the section is regressive. Key: asterisks mark vertebrate fossil horizons; the broken bone in unit I marks the Batala Nala bone bed; concave upward marks in F and E-2 represent oysters, black in D & C is coal; and dots and crosses in B are boehmite pisolites and kaolinite clay respectively.

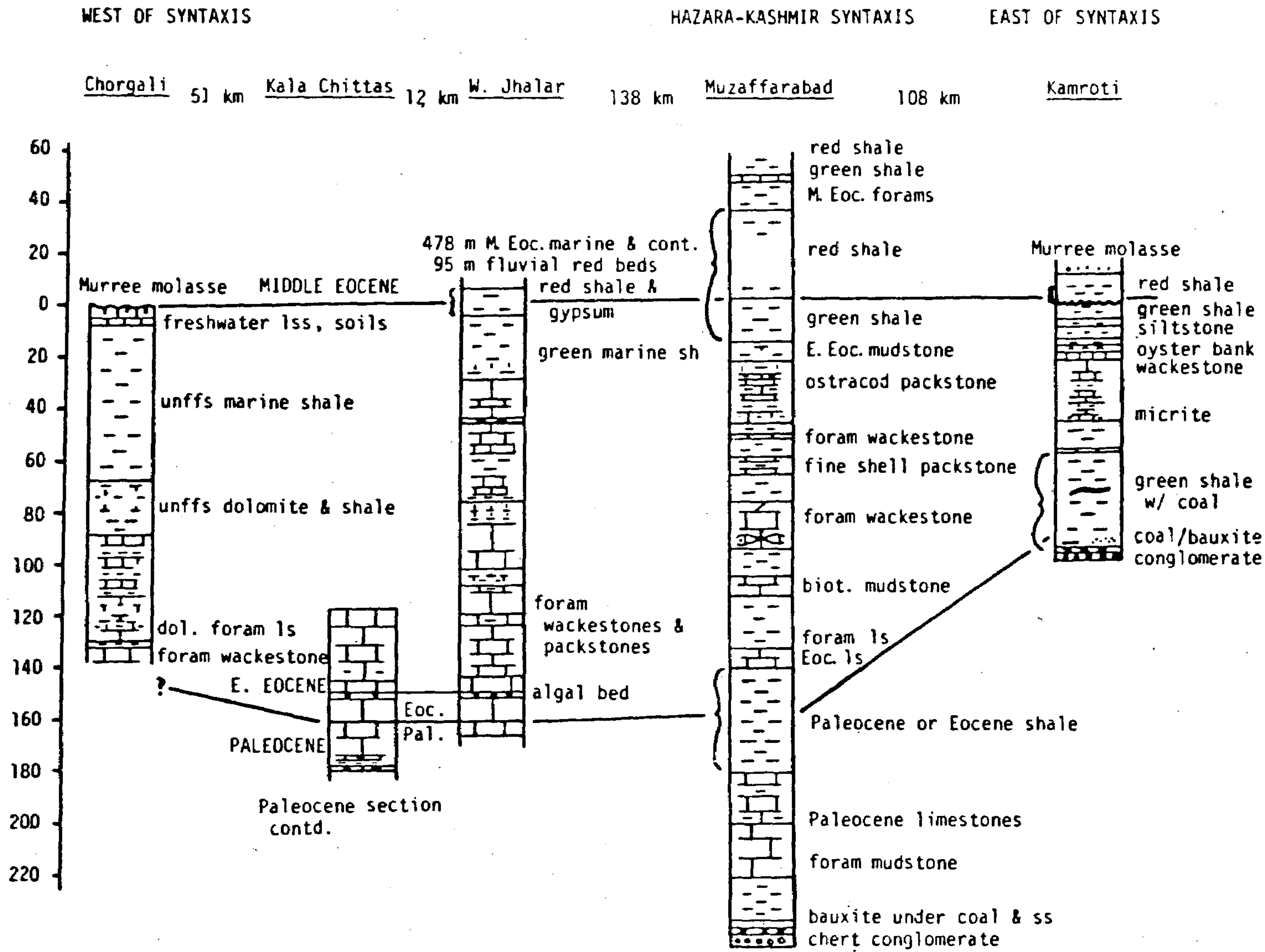

Figure 4: Correlation of early Eocene sediments around the Hazara-Kashmir syntaxis. Parentheses indicate uncertainty of correlations due to unfossiliferous sequences, but lines show best-guess correlations based on the paleogeographical hypotheses of Wells (1984). The structure around Muzaffarabad is very complex, and the section may well have been thickened by cryptic faulting or folding, so Wells has arbitrarily shrunken his measured section by 33%.

across the Indian border and with Subathu facies (predominantly olive shales) at the type section than with any Pakistan facies known to the authors. The name is not free of problems, as it has been used as a group (La Touche, 1888; Singh, 1973), a series (Wadia, 1975 and previous editions; Chaudhri, 1972), and a formation (e.g., nearly all papers by Sahni). It is retained as a formation in the study area: we are not dividing it formally because neither Singh's subdivisions nor ours are readily mappable and because area: we are not dividing it formally because neither Singh's subdivisions nor ours are readily mappable and because units H, I, and J would require redefinition or new names.

Jammu "Limestone"

In many parts of Kashmir, Paleogene beds are underlain by a widespread, very thick, well bedded, commonly dolomitized or silicified, and, excepting stromatolites, apparently unfossiliferous limestone. The Kotli exposures of this unit have been given many names: Great Limestone (Medlicott, 1876); Waishno Devi Limestone (Khan, 1973); Shali Group (in Himachal Pradesh); Sirban Limestone (extended from Sirban Mountain NW of Islamabad: Waagen and Wynne, 1874); Supra-Kuling (Lydekker, 1883); and others. Its assigned ages range from Precambrian to Jurassic. It is most commonly referred to as the "Sirban Limestone" (Singh, 1973; Sahni and Khare, 1973; Wadia, 1975; Karunakaran and Ranga Rao, 1976) or "Sirban Formation" (Ashraf and others, 1983). Gansser (1964), Le Fort (1975) and Valdiya (1980) refer to it simply as the Jammu Limestone. The latter two authors identify it as part of a probably Precambrian flysch and carbonate assemblage that extends along the front of the Himalayas from Jammu to Arunachal. From the perspective of Indian stratigraphy, this is not an unreasonable hypothesis. Latif (1970) dated the type section of the Sirban Formation as approximately Devonian and later redated it as Cambrian (Latif, 1974).

The Kotli exposures are as yet unfossiliferous, and until they are securely dated and correlated we recommend the least connotative local name, "Jammu Limestone", and we leave arguments over its age to those who know more about it. We do this because simplification of names is important for communication, but use of a name that implies an uncertain correlation has serious consequences. "Limestone" is put in quotation marks because Ashraf (personal communication) reports that all his samples from the Kotli area were dolomitized. Ashraf (personal communication) urges us to refer to the unit as the Jammu Dolomite. This would be in accordance with the North American Code of Stratigraphic Nomenclature (1983, article 18a), and should eventually be done, barring better correlation with the Sirban Formation. However, we did not study the unit, so we do not wish here to make changes to prior usage.

Surface topography on the top of the Jammu Limestone is not easily assessed. Its surface is irregular, as reported by Ashraf and Chaudhry (1980), but it is intensely folded, and around Kamroti and Nikial the Jammu "Limestone" and the Paleogene strata seem everywhere folded together, as seen in complex folding near the Batala Nala fault. North of Kamroti and in other places mild local pre-Paleogene topographic relief of a meter or two can be discerned over less than a hectare. More relief undoubtedly occurs over wider areas, and could account for such local differences in thickness as the 50 to 73 m change in lower units between Kamroti and Komba (as could cryptic faulting or structural thinning). Although no angular unconformity is evident in the immediate area of Kamroti and Nikial, a large discordance has been reported in the Punch valley (Wadia, 1975, fig. 34). However, in the areas we studied, we saw no clear indication of a karst surface, as inferred by Ashraf and Chaudhry (1980).

Subathu Formation: Units A & B
Siliceous Breccia and Bauxite

The general sequence at the base of the Subathu Formation is well displayed on a small hillside northwest of Kamroti that has been stripped for coal and bauxite. The Jammu Limestone is covered by a thin but irregular sheet of siliceous breccia (siliceous clasts cemented with silica), which is succeeded by 1 to 2 m of smooth, massive, brittle, and wispy to finely mottled light to medium grey kaolinite, which in turn passes up into hematite-stained bauxite of well-formed, 5 to 20 mm, concentrically laminated boehmite pisolites in a kaolinite matrix. The whole sequence is continuous: the massive kaolinite grades up into kaolinite with red-stained and close-packed pisolites through a 40 cm zone with a few, small, irregularly spaced and shaped grey boehmite nodules. Furthermore, it grades down into the siliceous beds through a thin zone with small, less than 10 cm masses of grus-like rotten quartz and, locally, almost schist-like rock with contorted quartz and clay laminae. Rich goethite deposits are locally developed, as at Naval, where goethite coats the breccia, and at Nikial.

The pebbles in the basal breccia are mostly clearly defined and angular pebbles of silicified carbonate. Judging by field comparisons, they came from the abundant chert beds in the Jammu Limestone. There are also some indistinct polycrystalline quartz clasts and some clasts of silicified carbonate whose edges grade into acicular or equant quartz cement. The breccia has been cemented with silica, in the form of rim cements of fine and acicular quartz crystals, quartz overgrowths, and polygonal pore-filling cement. (The clasts with the poorly defined edges may have been limestone pebbles that were silicified after redeposition, during cementation). Lastly, the breccia seems to have suffered dissolution of silica, particularly toward the top of the breccia where the fabric has been obscured by corrosion and stylolitization of the quartz along crystal boundaries and between clasts or cements. The masses of rotten quartz and the schist-like rock seem to have undergone the same history of extensive silicification and subsequent desilicification, but with removal of much more silica. This is indicated because the quartz laminae interlayered with kaolinite are actually strips of cement-like acicular quartz, polygonal quartz, and silicified carbonate like the chert pebbles that have become isolated between stylolites.

According to X-ray diffraction studies, units A and B are made up of silica, kaolinite $[Al_4(Si_4O_{10})(OH)_8]$, boehmite pisolites $[AlO(OH)]$ in kaolinite, and goethite $(FeO(OH))$. Wells (1984) identified dickite from X-ray diffraction, but Ashraf and Chaudhry (1980) identify kaolinite instead of dickite by differential thermal analysis. Further analysis by Wells suggests that kaolinite is indeed more likely. Ashraf and Chaudhry additionally identify some diaspore and gibbsite. Chemically, this is typical of a bauxite, which is to say that the components are relatively simple chemical segregates.

The question of the origins of bauxite is controversial (e.g., see discussions of the Jamaica bauxite by Comer, 1975, 1976; Comer and others, 1980; Sinclair, 1976, 1980), and, at the present stage of study, the standard arguments apply equally well to the Kamroti deposit. The possibilities are that the parent material was a) clays and other insolubles weathered from the Jammu Limestone, b) sediment washed into karstic depressions from elsewhere, or c) volcanic ash. Although far from proven, the first seems the most reasonable, given that the breccia seems to have been derived from the Jammu Limestone (Wells, 1984; Wadia, 1928, p. 262-264), that progressive dissolution in the upper quartz shows evidence of descent of the leaching zone, and that the area was in tropical and subtropical latitudes in the Mesozoic and early Cenozoic (Klootwijk, 1979); Klootwijk & Bingham, 1980). Wadia believed that the bauxite was formed recently in primary clay on modern moderately sloping limestone outcrops, because at one outcrop bauxite changed to clay as it disappeared into a hillside. However, he may have observed a fortuitously located lateral change of the sort seen by Rao (1931) to the southeast in India, where the same bauxites commonly change laterally into clay seams.

Unit C: Coaly Shale

This unit comprises a relatively constant 2 or 3 m of dark organic-rich shale and either coal or carbonaceous sandstone. At Tattapani, Nikial, Komba, and Kamroti, coal is absent where sandstone is present and vice versa. The coal is thin, low grade, friable, and pyritic (as are the shales) (see Simpson, 1904, for coal analyses). The shales contain many poorly preserved and fragmentary plant fossils. The sandstones are thin and probably broadly lenticular, and are interbedded with shales. No crossbedding was evident. One fine, pyritic, argillaceous calcarenite low in a dark shale sequence directly above the pisolitic bauxite contains ostracodes, relatively long fragments of molluscs, some echinoid debris, *Cibicides*-like foramanifera, a few miliolids, and some small coral intraclasts, all cemented with long and perpendicularly oriented calcite needles. A slightly higher and coarser, 20-cm-thick, argillaceous and organic-rich sandstone, located 2.4 m above the bauxite in a sequence of black, brown, and dark green shales, contains small, rare, and poorly preserved clams, echinoid plates, and many small Jammu Limestone lithoclasts.

Unit D: Green Shales

Above the basal coaly shales are about 35 m of dark to olive unfossiliferous shale. The unit is as thin as 21 m at Komba. North of Kamroti very shaly coal is quarried in the middle of the shale. Some associated limonitic siltstone shows two horizons of small mudcracks, and a little higher, in a coaly fine shale, is the lowest identified fossil, the pelecypod *Ostrea (Liostrea)* cf. *flemingi*. Ashraf and others (1986) have noted the shaly coal at several other localities near Kotli.

Unit E: Limestones and Shales

This part of the section shows an upward increase in fossiliferous limestone. The subdivisions described below are based on exposures around Kamroti: their facies are typical for this part of the section, but the units are not regionally correlable.

The basal limestone, unit E-1, is a 40 cm thick, hard, fetid, clayey, and echinoidal micrite with fragmentary echinoids (mostly spines), pelecypods, and gastropods. It also contains a considerable amount of silt-sized euhedral untwinned and unordered albite (95-100% Na, as determined by X-ray diffraction analysis according to the methods of Wright and Stewart, 1968a & b). Untwinned and unordered albite would seem to be volcanic in origin, and while no glass or other volcanic debris is evident, this unit apparently represents the only evidence, albeit indirect and reworked, of volcanism seen in this part of the Subathu (note that Wadia, 1928, reports peridotite dikes in the bauxite and Pascoe, 1964 p. 1561 ff., discusses volcanics interbedded with probable Laki-age Subathu-like beds in the Indus Valley volcanic belt far to the northeast).

Unit E-2, 10 m of shale, is a short-lived repeat of unit D shale, with the exception of a thin layer of quartz-silt-rich and moderately organic micrite with mollusc fragments and some poorly preserved foraminifera identified as *Nummulites* cf. *N. atacicus/mamilla*[1] and *Assilina granulosa* var. *spinosa/subspinosa.*

Because *Nummulites mamilla* is though to have been the alternate (haploid) generation of *N. atacicus*, the term *N. atacicus* could refer to both forms. However, the occurrence of one and not the other may be ecologically or environmentally significant. Therefore, in this paper, references to both the diploid and haploid forms of a foraminifer will follow the format "Genus microspheric form/ presumed megalospheric form". Otherwise, only the form mentioned is intended.

Unit E-3, 16 m of shale with argillaceous limestone and calcareous siltstone, represents a slight increase in both limestone and fossils. Most of the limesones are dark and pyritic. The beds vary from laminated to bioturbated. Fossils, mostly foraminifera and small pelecypods, are a lesser component of the rock. Foraminifera include small megalospheric *Assilina leymeriei* and *A. subdaviesi* and a disproportionately small number of the corresponding, large, microspheric forms *A. granulosa* and *A. daviesi. Nummulites atacicus/mamilla* is present. Fishbones and a fish tooth were also found. Fossils are both fragmentary and whole, but none have been bored and the fragments seem to represent the same population as the whole ones.

Unit E-4 includes a very distinctive lenticular to wavy-bedded limestone that was identifiable in all outcrops in the Kamroti and Nikkial area. Small-scale crossbedding is evident in the lenses and beds. The limestones are silty and organic micrites with mollusc fragments, complete, single-valve, and fragmentary ostracodes, echinoid spines, and a small *Cushmanella* – or *Lamarckina*-like rotalid foraminifer.

Unit E-5 is a 3.25 m limestone and shale sequence that grades from unit E-4 into the overlying oyster beds. The topmost meter has thin oyster-shell-rich layers, one of which contains an abundance of thick and 5 cm long echinoid spines. Some beds seem traceable for at least 1.5 km. The formainifera are primarily *Assilina: Assilina granulosa* var. *spinosa/A. leymeriei* var. *subspinosa, A. laminosa/sublaminosa*, and possible *A. dandotica*. Also observed were rare *Operculina sp., Lockhartia hunti* var. *pustulosa*, and *Nummulites mamilla*. All the *Assilina* species are heavily granulated as illustrated by Singh (1970): Gill (1953, p. 84) suggests that the more spiny or granulated varieties of *A. granulosa* (varieties spinosa and *subspinosa)* are found in limestones, whereas smoothness typifies shales.

Unit F: Oyster Bank

Unit F is a 2 m bed of oyster limestone that is recognizable in all Kotli outcrops. The oyster shells are very small fragments at base and increase in size to the top, where the oysters are whole and unbroken. The shell fragments are heavily bored (as much as 70% of a shell may have been removed). Most boring seems to have been done by sponges to produce tiny bulbous living chambers, and both sides of the shells are bored equally. The limestone is essentially a coquina with a matrix of clayey micrite.

Unit G: Nummulitic Limestone

Unit G is a 0.4 m shaly nummulitic limestone. This facies is not prominently exposed, but it is present stratigraphically above (i.e. shoreward of) the oyster limestone in most sections. It is packed with small megalospheric *Nummulites mamilla.* The corresponding microspheric from, *N.* of. *atacicus* is almost entirely absent, and those few that are present are very young. The rest of the unit is light to medium grey shale.

Unit H: Sandstones and Claystones

Unit H is a 10 m layer of clastics, comprising 30 to 50 cm thick and laterally variable shales, siltstones, and clean fine sandstones, all between two regionally extensive, prominent, ledge-forming 1 m thick, massive, and very well sorted fine sandstones. The massive beds are light brown in color and contain a very little calcite and clay and rare pelecypod fragments. They are completely bioturbated. More shaly beds are less bioturbated and individual burrows can be seen. Two impersistent 35 cm beds of greenish sandstone with small coal clasts contain bone concentrations, mostly of fish, and some large marcasite nodules. The top of the upper ledge-forming sandstone passes up into green shale through some 70 cm of light tan soft sandy shale.

Unit I: Green Shale

The marine section is capped by 0.5 to 6.8 m of plain olive-green shales. Near Kamroti the unit is 5.75 m thick and contains several fossil beds. On the east wall of the ravine heading south of Kamroti a narrow 10-cm-thick lens of silt, clay, small intraclasts, and small bones and teeth of fish and mammals occurs less than 1 m below the top of the green shales. Mammals include rodents, small artiodactyls, and a perissodacty. Turtles, crocodiles, and one or two species of small and high-spired snails are also represented. An almost idential deposit has been found on the mountain spur descending northeast of Nikial, and similar but smaller lenses without mammalian fossils are found near the top of the green shales in other areas.

Fragmentary turtle remains, small-to medium-sized mammalian bones such as phalanges, metapodials, and vertebrae, and a few teeth of *Pilgrimella* and at least one other large mammal were found scattered over two otherwise unremarkable horizons in the green shales 1.2 and 1.4 m below the transitional purple shales in Batala Nala, 1 km north of Kamroti. (See Wells and Gingerich, 1983, West, 1983, and Sahni and Khare, 1973 for more information about *Pilgrimella.*) The bones seem to have been oriented, for the ten bones that are more than 2.5 times longer than wide showed an average N75°W-S75°E orientation (standard deviation = 27°). The fossils do not touch each other and are in no way part of a lens of coarse material.

Unit J: Transitional Purple Clay

Unit J comprises a transitional, mostly purple, variegated clay zone between the top of the green clays and the base of the Murree Formation, which is in many places marked by a fluvial pebbly sandstone with clay intraclasts, soil nodules, bone fragments, and some reworked foraminifera. The transition is of variable thickness: 2.4, 3.0, 3.05, and 9 m in four localities. The base of the transition is in most areas a clay-clay boundary marked by an abrupt but irregular colour change from olive green to some shade of purple or blue-purple. The clay then changes gradually upward through red-purple to red-brown. Where the section is not interrupted by a sandstone, the clay shows a gradual colour shift into colours typical of the Murree Formation.

The basal purple clays seem mineralogically and texturally like those below, but in addition to their color differences they also differ in being thoroughly bioturbated in showing green root traces and reduction spheres, and in having soil nodules, highly irregular colouring, other pedogenic features, and some furrows and fissures that are filled with red clay from above. Locally, burrowing has introduced purple clay into the underlying olive-green shale.

The fauna of unit J includes some rare and isolated rodent and perissodactyl teeth, turtle fragments, and the freshwater snail *Planorbis.* On Kihman Hill, west of Kamroti on the Kotli road, 27 medium-sized (5-10 cm long) bones were found in a layer just above the base of the purple shales. According to field identifications by Dr. D. Russell, the bones included vertebrae, bits of a femur, a large astragalus, various other foot and hand bones, and a rib. Smaller wrist and ankle bones, a probable *Pilgrimella* premolar, and a lower right P4 of Kalakotia simplicidentata were found at approximately the same level about a hundred meters away. Isolated bones and teeth have also been found in unit J at Kamroti and Batala Nala. Wadia (1928) reports a seemingly nearly identical "ossiferous pseudoconglomerate" with chelonian and mammalian bones from the basal purple shales at Nikial. (Paleontologists of the University of Michigan and the Museum National d'Histoire Naturelle of France received permission to visit Wadia's sections in 1981, but they were unable to rediscover his fossil bed.)

Murree Formation

The Murree Formation comprises about 1500 to 2500 m of thickly interbedded reddened fluvial sandstones and floodplain muds. Wherever evident, crossbedding indicates flow essentially from the north, which is to say from the Himalayas, not from the Indian craton as incomprehensibly reported in many early geological accounts. The Murree beds in Azad Kashmir appear to be completely conformable with the underlying Subathu beds. The base of the Murree Formation must actually occur somewhere in Unit J, but because there is no clear break between red Murree shales and reddened Subathu shales, the base of the Murree can for convenience be drawn at the first sandstone above the highest non-red marine Subathu shale. The basal Murree sandstones contain reworked Eocene foraminifera and abundant pebbles of low-grade muscovite-chlorite-quartz-feldspar schists, which are not found in underlying Subathu sandstones.

INTERPRETATIONS OF DEPOSITIONAL ENVIRONMENTS

Shorelines must clearly once have been present at the top and bottom of the Subathu, because the bauxite and the Murree Formation and terrestrial, so it appears that the marine Subathu section is a single complete transgressive-regressive cycle.

Insofar as the bauxites are terrestrial and even the lowest arenites are marine, unit C should contain a shoreline, but none is apparent. The sandstones, being thin and interbedded with shales, are not particularly beach-like. Presumably, the shoreline deposits were either cannibalized during the transgression or they were very muddy, mucky and indistinct. The coal could either represent high spots, such as coastal, on-shore, swamp deposits between sandy inlets, or low spots between sand bars that collect drifting and waterlogged vegetation, depending on whether the coal turns out to be marine drift coal or *in situ* freshwater coal. The combination at Tattapani of relatively rich coal and what is either a topographically caused absence of bauxite or the local downcutting of a narrow coarse sandstone through the bauxite and kaolinite suggests local fluvial and coal swamp conditions. Unit C shales are therefore probably mostly sub-beach shoreline accumulations of organic rich muds along a low-energy, muddy, flat and well-vegetated coast, possibly with broad low hillocks of Jammu

Limestone inland.

In Unit D, the very muddy coast becomes a very muddy offshore zone. The abundance of shale and organic debris and the general absence of fossils and limestone suggest rapid sedimentation in relatively near-shore, turbid, and low-energy, but not necessarily deep, water. The mud appears to have limited the fauna despite local abundance of organic debris. The coal and mudcracked shale probably indicate the local formation of an emergent and vegetated muddy shoal or island. The occurrence of the mudcracked shale in the middle of unit C without other signs of shoaling, enclosing concentrations of beach sand, or the like further indicates low-energy conditions. The coal was seen in other sections by Ashraf and others (1986): if the coal outcrops form a continuous layer they would indicate either progradation of the coastline during a temporary stillstand or a temporary reversal of the general transgression.

The overall increase in limestone and fossils seen beginning with unit E is probably due to an overall (but fluctuating) decrease in turbidity of the water and consequently lower rates of clastic sedimentation. The similarity of the faunas of whole and fragmented fossils in Unit E-3 argues for an *in situ* population, but the lack of borings in those fossils, which argues for rapid silting, and the general sparsity and low diversity of the fossils all together suggest a rather inhospitable sea floor. The increased benthic fauna in E-4 and E-5 indicates increasing habitability. E-4's distinctive lenticular bedding results when ripple-forming currents can not scavenge enough sand-size material in a muddy environment to form a rippled sand sheet (Reineck & Singh, 1980, p. 113 ff.).

For unit F, one can deduce that sedimentation was slow, to allow time for the very extensive boring of the oyster shells. One can also conclude that wave energy was low, because very fragile bored shells and shell fragments have been preserved, and the little allochthonous sediment present is clay-sized. However, some shells are broken, shell fragments must have been turned occasionally to allow boring on both sides, and the upward coarsening implies at least a minimal energy gradient, so wave energy was not non-existent. The bed presumably represents the slow progradation of an oyster bank over its debris that had been winnowed seaward.

The abrupt change into the foraminiferal fauna in the unit G limestone above may indicate a less stable and/or less hospitable environment, for all *Assilina*, all *Operculina* and nearly all microspheric *Nummulites*, except for a few young ones, are excluded. The nummulitic beds can not be explained by selective concentration or winnowing of units E or F. Of the material in E and F, oyster shells and fragments span the size range of *N. mamilla*, the microspheric *Assillina* are larger and the megalospheric ones are the same size, and one or another of these would have been left behind or moved in with the *Nummulites*, depending on the manner of concentration. Therefore, G is interpreted as an unusual *in situ* community. The oyster bank could have been a positive feature and in quiet water it may have been a partial barrier to water movement, but unrelated salinity gradients (increasing or decreasing toward shore), increased environmental instability, or vegetational change could also adequately explain faunal restriction. The youthfulness of the few microspheric *Nummulites* present suggests that it was difficult to become a large old nummulite in this environment. On its own, the rarity of large tests might indicate that conditions were very good and favored early reproduction and/or asexual reproduction (see Wells, 1986; Hallock, 1985; Leutenegger, 1977), but the absence of other rotalines belies this.

The clean fine quartz sandstones and siltstones of unit H do, however, seem to indicate some sort of effective physical barrier or bar. They have been largely winnowed of clay and they separate organic-rich foraminiferal grey beds from unfossiliferous and organic-free but still reduced olive-green shales. The complete bioturbation of at least two beds thicker than a meter suggests slow net sedimentation, even on the bar. The absence of pedogenic features or red staining suggests that the bar may never have been significantly emergent. It might be possible to equate this with a distributary mouth bar off a delta or deltaic sands reworked into a post-abandonment delta-margin island sand, considering its moderate to high sorting, extensive bioturbation, and enclosure in clays.

The green clays of unit I are quiet-water deposits, logically lagoonal or bay muds that accumulated behind the sand bars of unit H. The fossil beds in the green clay apparently indicate upward shoaling of the green clay floor into the surf zone, which was evidently quite gentle. The mud pellet and fish bone lenses could have accumulated, been spread out in a lens, and been winnowed by the continual passage of waves over a depositional high spot. Appropriate sites of preferred deposition may have occurred at the confluence of two opposing currents or wave patterns or where a rip current died. The fossil bed at Batala Nala, in contrast, is more probably a lag, scavenged by the removal of a thickness of clay. The way the bones are scattered along specific horizons does not point to a bringing together of material so much as an exhumation and reorientation of unassociated rare coarse debris without otherwise moving or collecting it, in the manner of the formation of a desert pavement or hamada by deflation by wind.

Bioturbation of the shales and abundant rootlet mottling at the base of unit J probably represent a marshy shore at the back of a lagoon. The mammalian fossils, all terrestrial, in unit I demonstrate nearness to the shore. They might represent bodies flushed from the marsh into the sea. The actual shoreline must have been an almost insignficant emergence of wet mud under, for example, a salt marsh or mangrove swamp, for there is no obvious change in grain size to indicate a shoreline. Neither is there any indication of change in the manner of supply of sediment to correlate with the major change from green to red shale that undoubtedly reflects Eh change related to emergence from the sea and the onset of drainage. (Wells, 1984, found such color changes to be typical of many marine to continental transitions in Eocene strata throughout north-central Pakistan: see also Wells and Gingerich, 1983). The energy of incoming waves, such as they were, must have been almost entirely expended on the offshore sand bars and then finally dissipated in crossing the back-bar lagoon or bay and entering the vegetation. The similarity of later oxidation and pedogenization of mud that was at first deposited in salt water) implies a continual filtering of mud across the shoreline (through the marsh or swamp) and into the back of the bay without changes in its texture. The net movement of sediment from the land to the sea is shown by the presence of terrestrial mammals in the green shales, and the presence of turtles and freshwater snails in the transitional zone below fluvial sandstones supports the idea that at least some of the transitional section was originally deposited in fresh water.

Apparently similar fossil beds in an equivalent stratigraphic position have been reported 15 km along strike in India, in the Kalakot area (Ranga Rao, 1971, 1973; Sahni and Khare, 1971, 1973; Karunakaran and Ranga Rao, 1976; Sahni and Srivastava, 1976; Russell and Zhai, 1987). Note that Sahni and his colleagues place the J facies in the Subathu Formation, but that Ranga Rao refers the unit to the "Kalakot Zone" of the Murree Formation. Some comments on their taphonomy have been made by Ranga Rao (1972), Khan (1973), and Sahni and others (1981, 1983), but relatively little is known as yet. Ranga Rao (1972) notes that the fossils are very well preserved; were buried at different rates but with little transportation; include many more jaws than postcranial bones; represent a disproportionate number of juveniles; and indicate that tapiroids and artiodactyls lived in different areas. The action of soil acids can account for the selective preservation of relatively dense and massive jaw bones and enamelled teeth. The lack of transportation of fossils, their variable burial rates, the apparent extensiveness of the bone layers, and extensive soil formation together suggest that these bone layers may represent concentration in soil horizons by virtue of episodic but overall extremely slow sedimentation.

Overall, the deepest water, the switch-point from transgression to regression, may have occurred between the top of unit D or E-2 and the base of E-4, for D (or E-2) represents the limits of influence of shoreline muds, whereas the lenticular limestones at the base of unit E-4 represent occasionally or lightly felt wave action and precede more coastal deposits. Note, however, that cessation of mud deposition might be a factor of geography or supply processes rather than distance. The sporadic occurrence of foraminifera and limestones through unit E suggests that occasional excessive turbidity may have been a greater problem for colonization by benthic foraminifera than excessive depths, for depth should be a more stable and therefore inappropriately constant and consistent control. Compared to the transgressive sequence, the regressive sequence appears to have been a little less muddy and of slightly higher energy, given the crossbedding is E-4 and the sorted, though fine, sands in H.

DISCUSSION

Correlation from Kotli to Kalakot

The Kotli Subathu exposures, not surprisingly, correlate very closely with exposures at nearby Kalakot and Riasi to the southeast, in India, (Figure 3). Many of the units of Singh (1973) are readily identifiable: A is theKhargala Chert-Breccia Member and B is the Lain Bauxite Member of the Jangalgali Formation; C and D are the Beragua Formation; and E and perhaps the oyster bed F compose the Kalakot Formation. The rest is presumably equivalent to the Arnas Limestone, for its basal 5-20 m thick Ans Limestone Member is identifiable in the 0.4 m nummulitic bed in G. However, the 4-6 m Chinkah Limestone Member and the 2-5 m Chenab Limestone Member are not comparable with H and I, although they would seem to be equivalent.

These discrepancies show that Kotli and Kalakot-Riasi environments were not always precisely similar. Although the basal bauxite is widespread around Kalakot and Riasi (Wadia, 1928; Sign, 1973), both Sahni and Khare (1973) and Karunakaran and Ranga Rao (1976) depict sections that lack it. Both the amount and grade of coal (up to 7.5 m, but averaging less than a meter) and the amount and type of iron are very variable (Simpson, 1904). Sahni and Khare (1973) state, without presenting evidence, that in their section the coal, lower sandstones, and carbonaceous shales, apparently equal to C and D, are nonmarine, but Sahni and others (1983) indicate the presence of oysters and *Assilina* (*Nummulites*) *dandotica* low in the dark shales near Subathu village. The literature suggests a moderately varied landscape of poorly drained freshwater swamps, better drained higher areas, and brackish to saline muddy lagoons and bays with varying degrees of protection from waves and currents. Such environments were probably largely a result of pre-Subathu topography developed on the Jammu Limestone.

There appear to have been no major lateral changes in the main part of the formation, the marine limestones and shales of D and E. The whole formation generally thickens northwestward (Bhandari and Agarwal, 1966), but this trend is slightly reversed between Kalakot and Kotli. Khare (1976) identified a fossil shark, *Notidanus primigenius*, from the equivalent of E.

In contrast, the upper marine beds show a considerable change from the muddy lagoon or bay deposits of Kotli (units G, H, and I) to the foraminiferal Arnas Limestone across the Indian border. According to Singh (1973), the base is a depauperate nummulitic limestone, like G, with *Cibicides, Quinqueloculina,* and *Triloculina.* The succeeding shelly grey Chinkah Limestone Member contains only the latter two foraminifera, and the overlying greenish-grey Chenab Limestone Member is unfossiliferous. The passage shoreward from a normal assemblage upward through a nummulite and miliolid assemblage to a miliolids-only zone, and lastly into a foraminifer-free zone strongly suggests development of abnormal and restricted conditions toward shore.

An upward faunal restriction was also noted in Pakistan, but the fauna involved, its pattern of disappearance, and the associated lithologies are different. Kotli and Kalakot presumably shared the same climates and had much the same E-to-onshore depth ranges. Therefore, temperature and temperature variability should have been similar, except as associated with water movement. The most likely environmental problems are therefore salinity, turbidity, vegetation, and perhaps predation (Hottinger, 1982, 1983; Hallock and Glenn, 1986). Miliolid-only faunas have frequently been observed near Eocene evaporitic beds in the Kohat District in north-central Pakistan, suggesting their association with moderate hypersalinity (Wells, 1984, 1986). From the excess of clays and the paucity of miliolids at Kotli, it seems likely that G, H, and I were too brackish and perhaps too turbid for miliolids and other forams, perhaps because the area was on or too close to a delta, with the water becoming fresher and muddier toward shore. The Indian area was more likely a slightly hypersaline, protected or very gradually sloping, lower-energy coast, with limited influx of freshwater and clay from onshore and of normal sea water and clay from offshore.

By all accounts, the transitional shale of J changes little from India to Pakistan, so presumably soil-forming factors such as climate, vegetation, parent material, and drainage were similar in both areas. Mammals, freshwater snails, crodiles, and turtles have been recorded at many localities and a freshwater to possibly brackish fish fauna has been indentified in India (Wadia, 1928; Sahni and Khare, 1973; Karunakaran and Ranga Rao, 1976; Khan 1976; Khare, 1976; Sahni and others, 1981, 1983).

Age of Subathu Formation in Kashmir and Azad Kashmir

The age of the Kotli-Kalakot Subathu Formation is somewhat uncertain. Despite occasional reports of middle Eocene foraminifera (Ranga Rao, 1971), the most detailed work on the foraminifera produced none that were not predominantly early Eocene (Singh, 1970, 1973). Work on the Kotli foraminifera supports this conclusion, as does analysis of the ostracodes by Tewari and Singh (1966). However, this conclusion is only binding on unit E (the Kalakot Formation) because of the distribution of fossils.

Only one foraminifer, the early and middle Eocene *Nummulites atacicus/mamilla,* is present in unit G, the Ans Member. Singh (1973) considers this proof of a middle Eocene age for the whole Arnas Formation (units G, H, and I), because none of the other foraminifera in unit E below has an age range that extends into the middle Eocene. However, no other middle Eocene foraminifera are present either, and the presence of only one kind of large benthic foraminifera is easily interpreted as a result of local environmental conditions.

Units A and B have produced no definitive fossils. Singh (1973, fig. 4) includes them in the early Eocene, whereas Sahni and Khare (1973) claim that the breccia is Precambrian. Ashraf and others (1983) wisely exclude the breccia and bauxite from the Paleogene section because their development concluded with burial by Subathu sediments, thus implying no inherent relationship with Cenozoic sediments and an earlier age, possibly much earlier. There is no stratigraphical, paleontological or lithological basis for identifying them as Datta Formation (Jurassic, Salt Range), as has been informally suggested.

We found no definitive fossils in units C and D. Singh (1973) placed the Beragua Formation (C and much of D) in the early Eocene, whereas Sahni and Khare (1973) suggested a Thanetian (late Paleocene) age. Ashraf and others (1983) report "*Assilina, Lockhartia, Discocylina,* etc." and infer a Paleocene age. However, without specific identifications such a fauna could be early Eocene (Nagappa, 1959). Sahni and others (1983) report *Assilina dandotica,* which is according to Nagappa (1959) and others the only Paleocene *Assilina,* apparently from unit C. However, Sahni and others (1983) also note an unconfirmed report of the existence of an early Eocene *dandotica*. At present, the bauxite is probably best dated as pre-Eocene and the coaly shales as coincident with any major eustatic rise or tectonic change locally identifiable near the start of the Eocene.

. The transition zone J should eventually be exactly datable by vertebrate fossils (see Russell and Zhai, 1987). Some workers place it at the top of the Subathu Formation (Sahni and Khare, 1971, 1973) whereas others have included it in the Murree Formation (Bhandari and Agarwal, 1966, p. 62; Singh, 1970, 1973; Ranga Rao, 1971a, 1972; Khan 1973), but all identify it as essentially transitional or terrestrial yet coastal (following Bhatia and Mathur, 1965). Sahni and Srivastava (1977) now consider it to be middle Eocene (Lutetian) on the basis of its rodents. Ranga Rao, on the other hand, dates the same beds as early late Eocene because he identified middle or even upper Eocene foraminifera in the marine beds below and because he considers that the mammalian fauna is 1) younger than the middle Eocene Ganda Kas (Chharat) fauna of Pakistan, 2) older than the latest Eocene Pondaung fauna of Burma, and 3) probably older than the late middle to early late Eocene Irdin Manha fauna of Mongolia. Neither set of arguments is clearly superior: our mammalian fossils from units I and J all seem identical to species known from Indian Subathu sites and suggest to us a possibly latest early Eocene and/or middle Eocene age. Unit J seems to be a perfectly transitional link between the underlying unoxidized green shales and the overlying red shales and sandstones of the Murree Formation. The lowest Murree sandstones contain evidence of recent uplift (their reworked Eocene foraminifera and pebbles of low grade schist), and they also represent a reversal of the paleoslope from a northward slope to a southward one. However in the Kotli area, these changes are not represented by an angular unconformity or even an obvious erosional break. Proposed ages for the Murree Formation, which is very poorly dated here, range from Eocene to Miocene, so J may be a considerably condensed section or it may even contain a cryptic shale-on-shale paraconformity. Retreat of the sea from this area seems likely to be part of complete and more or less synchronous withdrawal of the seas from northern Pakistan: in the Kohat district to the west, at least, maximum regression is marked by deposition of the terrestrial lower part of the Kuldana Formation, which is dated as latest early Eocene and/or earliest middle Eocene (Gingerich and others, 1983; Wells, 1983, 1984). It seems best to conclude that the marine part of the section is entirely or almost entirely early Eocene in age and that unit J is possibly not.

Correlation across the Hazara-Kashmir Syntaxis into Pakistan

The exposures in the Hazara Hills between Islamabad and Murree, those at Muzaffarabad, and the parautochthonous ones between the Murree and Panjal thrusts from north of Punch to southeast of Dalhousie have long been referred to as the "Hazara facies" of the Subathu Formation and have been broadly split into the "Hill Limestone" and the overlying "Variegated Beds" (Pinfold, 1918; Pascoe, 1964). All have been brought closer to the Kotli area by thrusting.

Hazara Hills: The Hazara section north of Murree is the most studied of the "Hazara facies" outcrops (Lydekker, 1883, p. 93 ff.; Middlemiss, 1896; Latif, 1970 a & b, 1976). However, sections near Murree are much faulted and they are difficult to study.

Latif named the Hazaran Subathu facies as the Galis Group, which he subdivided into 1) variegated sandstone, lateritic limonite, pisolitic hematite, coaly shales, and coal, under fetid and well-bedded to massive limestones with mid-Paleocene foraminifera (the Mari Limestone); 2) late Paleocene open-marine shales (Kuzagali Shale); 3) dark grey, nodular to massive limestones with early Eocene foraminifera including *Assilina laminosa, Nummulites atacicus*, and *Alveolina elliptica* (the Margala Hill Limestone); 4) thinly bedded light grey marls and limestones with early Eocene foraminifera *Assilina daviesi, Globigerina prolata* and *G. yeguanesis* (Lora Formation); and 5) the Kuldana Formation. Near Murree town, the Kuldana Formation comprises 300 m of interbedded continental red beds, fluvial granulestones, "transitional" coastal-plain and marsh variegated purple shales, off-red pedogenized freshwater and saline-lacustrine marls and limestones, formerly evaporitic beds and lenses, and olive marine shales with lenticular foraminiferal limestones (Wells, 1984). Latif identified late early Eocene foraminifera and earliest middle Eocene foraminifera from the Kuldana Formation.

Latif's basal four units are the old "Hill Limestone". In keeping with recent trends to consolidate stratigraphic names in Pakistan, Latif (1976) and Shah (1977) have subsumed the Mari Limestone into both the Hangu Sandstone and the Lockhart Limestone (from the Samana Range, SW of Peshawar), the Kuzagali Shale into the Patala Shale (from the Salt Range), and the Lora Formation into the Chorgali Formation (from the Khair-e-Murat Range), and kept the Margala Hill Limestone and the Kuldana Formation.

Muzaffarabad: The outcrops at Muzaffarabad, referred to by Calkins and others (1975) as the Kala Chitta Group, comprise a basal unit of quartzose sandstone, coal-bearing cabonaceous shale, and/or pisolitic bauxite in kaolinite shale, followed by 50 to 600 m of grey to green shales and grey and locally foraminiferal nodular limestones, and an overlying 20 to 600 m "transitional zone" of marls alternating with red and green shales (Calkins and others, 1975). The basal unit is essentially identical to units A, B, and C at Kotli, and it is developed on locally stromatolitic but otherwise unfossiliferous Jammu-Limestone-like carbonates that Calkins and others identify as probably late Paleozoic Kingriali Formation.

The lower limestone and shale section (the "Hill Limestone") was measured by Wells in 1981 in a section along the Muzaffarabad-Neelum Valley road. This section is shown in Figure 4, although its scale has been arbitrarily reduced by one-third relative to the other sections to indicate uncertainty over true thickness and possible cryptic structural duplication. Despite the complex folding and faulting in the Muzaffarabad area, this section apparently shows extensive depositional interbedding of Margala Hill Limestone facies, Lora-Formation-like facies and shales like the Kuzagali Shale. Latif (1970a) mapped all such repetitions of units in the Murree area as the result of faulting and folding, but at least some, if not most, of the repetition in the Neelum Valley section seems due to primary interbedding. By analogy, this suggests that the succession of formations seen by Latif may have been an underestimate of more complex interbedding of facies types.

The proof of the interbedding of "formations" despite the probability of some structural repetition is that some of the possible repeats contain foraminifera of different ages. According to our foraminiferal studies, the lower 150 m or so of the section is Paleocene, as it contains *Operculina salsa/subsalsa* up to that level, in addition to *Lepidocyclina punjabica, Lockhartia haimei, Discocyclina*, and *Miscellanea miscella.* There is then an unfossiliferous 50-m shale, followed by an apparently Eocene limestone, with *Lockhartia haimei* and fragments of probable *Nummulites* and *Assilina.* At 259 m above the base, there are undoubtable, complete, lower Eocene *Nummulites atacicus, Assilina granulosa*, and *Alveolina.* The upper part shows interbedding of red beds (including thick green sandstones and minor freshwater micrites) with marine limestones, shales, and oyster beds, which are of middle Eocene age. The first red bed occurs at 341.5 m, and the succeeding green shale and limestone contain middle Eocene *Nummulites* cf. *uronensis, N.* cf. *pinfoldi, Assilina granulosa, A. umbilicata*, and *A.* cf. *papillata.* In short, then, given the nature of the section and the degree of local deformation, the thicknesses have a low probability of being correct, but the samples clearly indicate Paleocene through middle Eocene marine deposition.

Parautochthonous zone: The beds in the parautochthonous zone between the Murree and Panjal Faults, locally known as the Rajpur Formation, comprise just less than 300 m of brilliantly colored, unfossiliferous, variegated red, purple, and green shales with minor sandstones and limestones above 100 to 150 m of thick, dark grey, fetid, and foraminiferal limestones and shales with *Nummulites, Assilina, Alveolina, Operculina*, and *Ostrea* (Lydekker, 1883; Wadia, 1928, p. 258 ff.; Karunakaran and Ranga Rao, 1976, p. 6 & 17). The upper beds, as Wadia noted, are clearly like the type Lower Chharat (= Kuldana) in the southwest of the Hazara Range and the Kuldana beds near Murree in the southeast.

Beds almost identical to the Rajpur Formation crop out just in front of the Murree Fault, SE of Punch, as described by Wadia (1928). This constitutes the first Subathu-equivalent exposure northwest of Kotli. Wadia (1928, p. 265-268) named the beds the Jokan Limestone, but in describing them he apparently misinterpreted their age and structure (Karunakaran and Ranga Rao, 1976). The incompletely exposed sequence consists of a lower 100 m of olive-green shales and mostly lenticular foraminiferal limestones, and an upper 150 m of unfossiliferous thick red marly shales with intercalated thin green shales with oysters. The lower unit also contains minor red clays and greenish-grey fine sandstones and one 5-m thick non-lenticular limestone. The foraminifera in the highest limestones include *Assilina granulosa* var. *spinosa, A. daviesi*, and *Orbitolites complanatus*, and thus correlate with both the Kotli and type sections of the Subathu Formation (Karunakaran and Ranga Rao, 1976). Cotter (in Wadia, 1928) identified upper Eocene fossils from the same beds, but they may have been early to middle Eocene *Nummulites atacicus/mamilla.* In many respects, the upper part seems to be a multiple repetition of the Kotli facies F through J, whereas the lower unit is closer to facies D and E.

In short, the Hazara facies are divisible into a lower, more offshore, dark shale and fetid limestone section, and an upper section of intercalated shallow-water nearshore and on-shore green shales and variegated red beds. The Jokan Limestone/Rajpur Formation exposures link the bipartite Hazara facies to the essentially unipartite and essentially lower Eocene marine Subathu at Kotli with its single, essentially non-fluctuating, and conclusive regression. In turn, the Hazara facies are nicely linked to the Kohat Basin strata by way of facies exposed in the Kala Chitta hills (Wells, 1984; Figure 4). The Kotli section can be thought of as composed primarily of Hazaran "Hill Limestone" facies. Note, however, that the sections in the Kohat basin, and, to a lesser extent, those in the Kala Chitta hills and at Muzaffarabad, show a return of marine deposition after complete regression at the end of the early Eocene (Wells, 1984), whereas the Kotli section, like those in the Salt Range, shows only the single, unrepeated, transgression and regression.

Lastly, there are significant affinities between the Subathu Formation at Kotli and the Chorgali Formation in its type section in the Khair-e-Murat Range in the centre of the Potwar Plateau. The Chorgali Formation is also recognizable at the top of the lower Eocene in the Kala Chitta hills to the north and above the Sakesar Limestone in the Salt Range. Briefly, the type section of the Chorgali Formation comprises five main facies:

Although the apparent energy level of deposition decreases from the base of the section up to the 60 m thick shales, upward shallowing and an increase in salinity toward shore are indicated by the changing lithologies and faunas. From the base, these changes are: *Nummulites* in pelspari-

. . . . Top of section at Chorgali Pass . . . .

3 m	Pedogenized, variegated yellow, purple, red and white marls with rootlet traces and "craze-plane" microcracks (Brewer, 1964), which used to be ostracodal micrites and shales;
2.2 m	Locally silicified, marine, miliolid and ostracodal pelsparites grading up into partly silicified, formerly pelletal, pedogenized (dewatered, nodularized, and microcracked), possibly saline-lacustrine, ostracodal and gastropodal micrites;
60 m	Olive shales with rare layers of small nodules of silty ostracodal biomicrites and pelmicrites with mostly dissolved mollusc and echinoid fragments, locally capped by 2 m of purple-stained shale;
58 m	Essentially unfossiliferous but in places bioturbated marly to dolomitic light brown siltstones, with possible algal beds with very tiny miliolids at base and a thin rootlet-ridden limestone of oolitically coated intraclasts in the middle, that overall grade upward from 10% to 80% light olive grey shale; and
13 m	Shallow-water and upward-shoaling nummulitic limestones, *Assilina* dolomitized limestones, and silty ostracodal and/or *Lockhartia* dolomicrites, with *N. atacicus/ mamilla, A. laminosa/sublaminosa, Lockhartia conditi*, an intermediate between *L. tipperti* and *L. haimei (=L. hunti* var. *pustulosa), Orbitolites complanatus, Discocyclina* cf. *douvillei*, a small *Alveolina*, and small benthic forams such as bulimulids and *Nonion*. [NB: the basal 5 m may be definable as Margala Hill Limestone.]

. . . . Base of section at Chorgali Pass . . . .

tes; *Assilina* in partly dolomitized wackestones and packstones; *Lockhartia* and ostracodes in silty dolomicrite; and milioid-only shales. Dolomitization seems to have been relatively early in the *Lockhartia* beds, for it followed most bioturbation, but it is cut by and thus apparently preceded a late phase of mostly vertical burrows.

Insofar as the Chorgali Formation both comprises nearshore deposits of early Eocene age with a Kotli-like fauna of benthic foraminifera and shows a single regression late in the early Eocene that left the the land dry during middle Eocene fluctuations of the shoreline to the north and to the west, the Khair-e-Murat Chorgali exposures have an equivalent paleogeographic history to the Kotli exposures. The Khair-e-Murat section could be thought of as primarily H and I facies, expanded 5 to 10 times, over a slightly shallower-water, less reducing, and slightly dolomitized G – or E5-like limestone, and under a complex but partly J-like pedogenized zone. This suggests a lack of major changes in the coastline around or across the Hazara-Kashmir syntaxis.

Because there is a thin string of Subathu-age outcrops all the way across northern India (see Wells, 1984, fig. 6.5) and because they are composed mostly of nearshore deposits (Wells, p. 320-328), there is a tendency to think of the string as more or less parallel to the Subathu shoreline. However, the outcrops are produced by the frontmost two or three Himalayan thrust faults. There are a few outcrops in Nepal that are not dissimilar to the Muzaffarabad exposures (e.g. Tewari and Gupta, 1976), except that the would-be belt of exposures in that sector of the Himalayas tends to be hidden by overthrusts. One can make the hypothesis that exposures can be ranked in order of nearness to the shoreline by the thickness of Paleocene strata overlying the basal weathered zone: ca. 150 m at Muzaffarabad; 2-25 m or so at Kotli, 0 or 8 m at Subathu village (Mathur, 1969; Wells, 1984, p. 324). At first glance, this agrees broadly with the overall thickness of the marine section, and future data on the exactness of the agreement across northern India may tell us whether inundation and/or tilting were uniform along the subcontinent's leading edge. Note that the basal Subathu beds mark the southern shore of the Subathu sea (as shown by the absence of Subathu facies in deep boreholes just south of the outcrop belt in northern India (Bhandari and Agarwal, 1966), but, as mentioned, the base of the Murree Formation and its equivalents marks the arrival of Himalayan molasse from the north: this is the evidence for the aforementioned reversal of the Subathu paleoslope. A gentle slope reversal could account for the total or near total lack of sedimentation occuring in unit J, between Subathu and Murree beds.

OTHER CONSIDERATIONS

Ashraf and others (1983) have named units C and D, and possibly part of E, as Patala Formation and higher units as Margala Hill Limestone. In one sense, this may seem to fit with equating the Chorgali Formation with units H, I and J. However, the authors are not in agreement with such a nomenclature. First, we do not know enough to imply so close a correlation. Second, the creeping extension of certain formational names in Pakistan has the bad side effect of obscuring exact age relationship. Third, this practice also obscures lithological diversity and complicates paleogeographic analysis and facies correlations.

The basis for the first complaint is that if there are several limestones and shales at Muzaffarabad, we need to know which and how many are represented in Hazara and in Kotli. With respect to the complaint about obscuring age relationships, there is an all too common tendency to extend a formational name by lithological correlation and simultaneously and groundlessly to assume equivalent chronostratigraphic correlations between the same strata. Early Cenozoic stage boundaries are far from precisely located in most sections in Pakistan and within-stage correlations are necessarily based on concepts of paleogeographic development (e.g., Wells, 1984). This problem can be seen in recent treatment of the Patala Formation. Shah (1977) incorporated the Tarkhobi Shales into the Patala and refers them to the Paleocene, whereas Wells (1984) showed that some upper strata contained early Eocene foraminifera. Similarly, the dating by Ashraf and others (1983) of their Kotli Patala as Paleocene may have been unduly influenced by Patala ages elsewhere.

The third problem is indirect but serious. Formation names are extended to demonstrate and simplify regional correlation, which is quite properly the first order or business in regional stratigraphy. It should also lay the ground work for the next step, which is understanding the details and nuances of the region's geological history, which is to say understanding regional paleogeographic development. If all the strata have been incorporated into giant and far-reaching formations, the first step in paleogeography is dismantling the formations into smaller formations or members and rechecking ages and correlations. By this time, the literature will probably by quite confusing. As preparation for paleogeographic analysis, it would be far better stay as much as is possible and reasonable with initially defined local formations and to aggregate them into groups rather than into each other. Making correlations with other units is very important but it can be done without unification and subsumption of names.

CONCLUSIONS

The Subathu Formation at Kotli consists of:

A) a residual conglomerate of chert clasts and other insoluble material, all almost certainly weathered from the underlying Jammu Limestone;

B) a pre-Eocene bauxitic weathering profile;

C) carbonaceous shales, with thin coal in some places and sandstone in others, covered by

D) thick green unfossiliferous shales, which with C represent mostly sub-beach to turbid and shallow-water accumulations of mud and muck moved offshore by waves and currents from a very low energy, muddy well-vegetated, and swampy coast;

E) dark shales and fetid but mostly fossiliferous limestones that accumulated in slightly higher-energy waters, either when the transgression had moved the turbid coastal zone to the south or when the local supply of clastics ceased;

F) an oyster bank, characterized by slow sedimentation under conditions of just high enough energy to winnow clay;

G) an unusual single-species nummulitic limestone that apparently represents a chemically or thermally inhospitable and/or less stable environment;

H) a submergent, fine-clastic, offshore-bar complex that was highly burrowed and was frequently reworked by waves of low to moderate energy;

I) a brackish back-bar bay or lagoon that trapped mud and animal remains carried out to sea from the marshes along the shore; and

J) on-shore clays, completely pedogenized and apparently representing very slow sedimentation until the earlist Himalayan molasse was swept into the region.

This section correlates very closely with the Indian sections along strike that were described by Singh (1973), except that in India units H and I are replaced by well developed limestones. Units E through G are early Eocene, and C, D, H, I, and lower J may be too, although I an J may very well be middle Eocene.

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