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Upper Paleocene foraminiferal biostratigraphy and paleoenvironments of the Salt Range, Punjab, Pakistan

by

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CONTENTS

ILLUSTRATIONS

TABLES

UPPER PALEOCENE FORAMINIFERAL BIOSTRATIGRAPHY AND PALEOENVIRONMENTS OF THE SALT RANGE, PUNJAB, PAKISTAN

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Thomas G. Gibson

U.S. Geological Survey

ABSTRACT

Planktonic foraminiferal species, which were recovered from the uppermost part of the Patala Shale at Nammal Gorge in the Salt Range, Punjab, Pakistan, indicate that these strata are in planktonic foraminiferal <u>Morozovella</u> <u>velascoensis</u>/<u>M</u>. <u>subbotinae</u> Zone (Zone P6a) of latest Paleocene age. Based on previously reported planktonic species, the lowermost strata of the overlying Nammal Formation also belong in this latest Paleocene zone. Diagnostic planktonic species are not present in samples from the lower and middle parts of the Patala Shale, and specimens are too poorly preserved to identify in our samples in the Nammal Formation at Nammal Gorge. No age diagnostic planktonic species are present in any samples that were examined from the Lockhart, Patala, and Nammal Formations in the Khairpur #9 corehole farther east in the Salt Range; thus, no age assignments can be made for these units in those areas.

Benthonic foraminiferal assemblages that were examined from the Lockhart, Patala, and Nammal Formations in the Khairpur #9 corehole suggest deposition in shallow, open-marine, inner

neritic environments in waters less than 100-150 ft deep. The lower and middle parts of the Patala Formation at Nammal Gorge also were deposited in inner neritic environments in similar to slightly deeper waters; however, significant deepening to outer neritic environments (300-600 ft water depth) is indicated for strata in the uppermost part of the Patala Formation at Nammal Gorge. Severe diagenetic alteration of smaller foraminifers in samples from the Lockhart and Nammal Formations in Nammal Gorge precluded their use in this study.

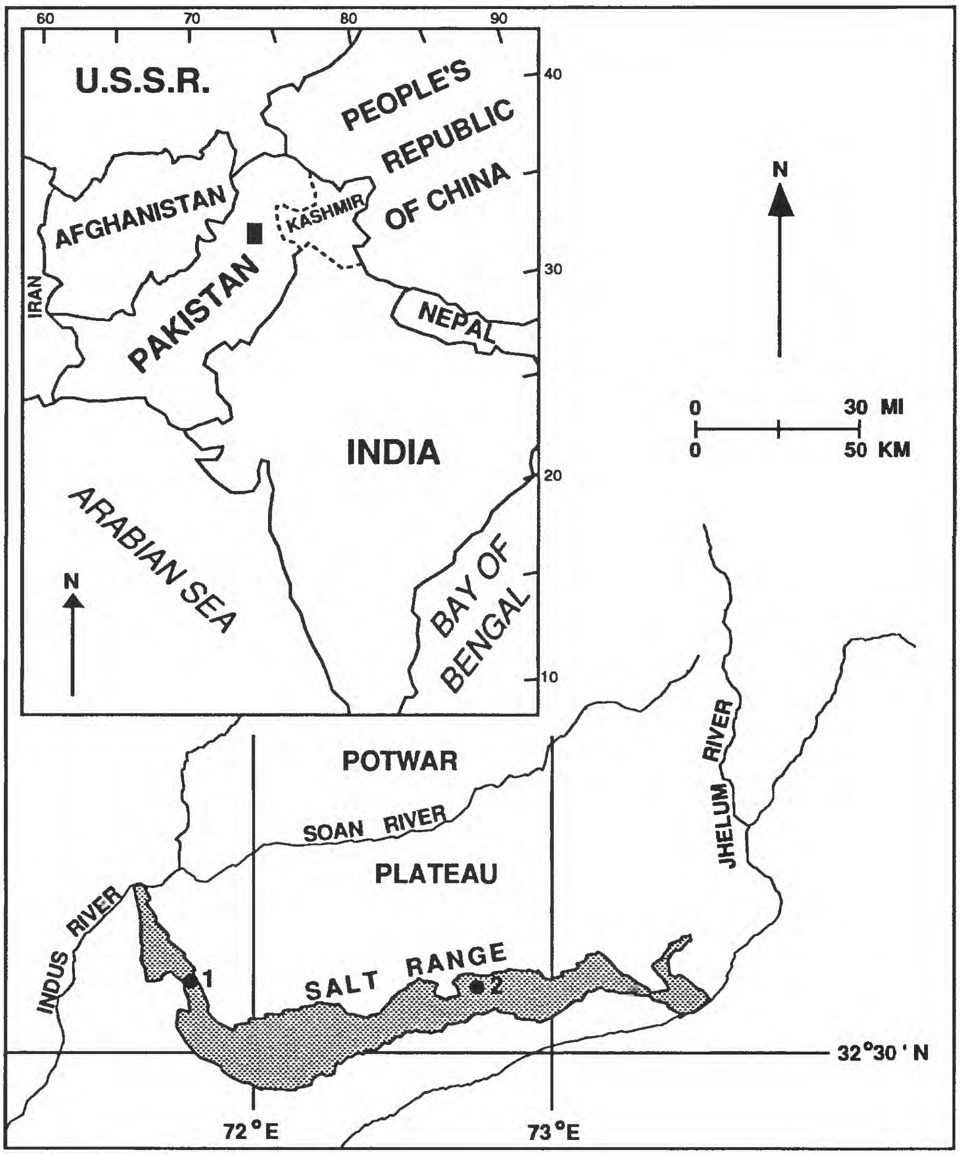
INTRODUCTION

Paleocene and Eocene strata in north-central Pakistan are well exposed in the Salt Range in the Punjab Province. One of the best known exposures of these strata is in Nammal Gorge in the western Salt Range (Fig. 1). Lower Paleogene units that are well exposed in Nammal Gorge include, from oldest to youngest, the Hangu Formation, Lockhart Limestone, Patala Formation, Nammal Formation, and Sakesar Limestone. Nammal Gorge is the type locality of the Nammal Formation.

The Paleocene and Eocene strata exposed in Nammal Gorge form one of the most important sections in Pakistan. The Nammal Gorge section is the only Paleocene and Eocene section in Pakistan in which biostratigraphic successions of both the larger and smaller foraminifers have been studied. In addition, the distribution of other biostratigraphically important microfossil groups, the calcareous nannofossils and dinoflagellates, also have been examined here.

The larger foraminifers of the Hangu through the Nammal Formations in Nammal Gorge were described by Davies and Pinfold (1937). Haque (1956) made a comprehensive study of the Paleocene and Eocene smaller foraminifers from Nammal Gorge. Haque described new genera and species for both benthonic and planktonic foraminifers and made a generalized biostratigraphic and paleoenvironmental analysis of the strata. Recently, Kothe (1988) studied Paleogene calcareous nannofossils and

Figure 1. Map of Pakistan showing location of the Salt Range and the sections studied at Nammal Gorge (1) and Khairpur #9 corehole (2).



60
70
80
90
U.S.S.R.
PEOPLE'S
REPUBLIC
OF CHINA
AFGHANISTAN
KASHMIR
IRAN
PAKISTAN
NEPAL
INDIA
ARABIAN SEA
BAY OF
BENGAL
N
40
30
20
10
N
0
30 MI
0
50 KM
POTWAR
SOAN RIVER
PLATEAU
JHELUM RIVER
INDUS RIVER
SALT RANGE
1
2
32°30' N
72°E
73°E

FIGURE 1

dinoflagellates from the Nammal Gorge Paleogene strata. This pevious work establishes Nammal Gorge as a reference section for local and regional biostratigraphy, paleogeography, paleoenvironmental analysis, and facies patterns in the Punjab Province, and this section can be used for comparative studies with sections in the other Pakistan provinces.

The Nammal Gorge Paleogene section is considered to be a critical Pakistan locality both for regional stratigraphic studies (Hunting Survey, 1961) and also for inter-regional studies (Nagappa, 1959; McGowran, 1968; and Adams, 1970). Adams (1970), noting the regional importance of this locality, suggested that there should be additional investigation here.

Since 1985, the United States Geological Survey (USGS) and the Geological Survey of Pakistan (GSP) have been conducting a coal resource exploration and assessment program (COALREAP) in Pakistan, under the auspices of the United States Agency for International Development (USAID) and the Government of Pakistan (GOP). In November, 1989, Jean Self-Trail of the USGS and Tariq Masood of the GSP collected samples of the Patala and Nammal Formations in Nammal Gorge as part of a stratigraphic study of the Paleogene strata of the Salt Range; the purpose was to determine the age and paleoenvironments of the coal beds occurring there in the Patala Formation. I conducted additional examination and sampling of the Nammal Gorge Paleogene section during February, 1990.

Preliminary examination of the foraminiferal assemblages in the USGS samples at Nammal Gorge suggested that a more detailed biostratigraphic and paleoenvironmental analysis of the Patala Formation could be made now because of the considerable advances since Haque's study in planktonic foraminiferal biostratigraphy and in benthonic foraminiferal paleoenvironmenal analysis. This new biostratigraphic information may resolve age uncertainty in Pakistan for some of Haque's genera and species that have been incorporated into regional and global interpretations (Banner, 1989).

The availability of a GSP corehole in a more easterly area of the Salt Range made possible the foraminiferal study of the age and paleoenvironments of the Lockhart, Patala, and Nammal Formations there. Outcrop samples in the eastern portion of the Salt Range contain few smaller foraminifers because of diagenesis. Depositional environments of the Paleogene formations in the central Salt Range were examined in Khairpur #9 corehole (Fig. 1); Paleocene units in this area, particularly the Patala, are considered to have been deposited in shallower marine environments than those determined for the same units in the Nammal Gorge area in the western Salt Range (Warwick and Shakoor, 1988; Gee, 1989). This proposed paleobathymetric model is based upon the presence of high-sulfur coal beds in the Patala Formation in the central and eastern Salt Range. The coal beds suggest that the associated marine sediments were deposited in shallow water because they contain the intercalated terrestrial facies. The coal facies is missing in the Patala in the western Salt Range, and it appears that the westerly sections had more continuous marine sedimentation and thus somewhat deeper marine waters.

METHODS and MATERIALS

Foraminiferal samples were taken from the less indurated, shaly horizons whenever possible, and these samples were disaggregated by gently heating and shaking them in a water solution of calcium carbonate. This process and lithology frequently yielded large numbers of smaller foraminifers with fair to good preservation. The larger-sized planktonic and benthonic foraminifers in these samples usually could be identified at the species level, while immature specimens and smaller-sized species were more difficult to identify because they exhibit greater diagenetic alteration. Detailed biostratigraphic and paleoenvironmental interpretations can be made only on the better-preserved Punjab samples.

It was necessary to disaggregate samples from moderately to strongly indurated intervals, usually represented by limestones and marls, by means of a process using repeated cycles of heating and cooling of the samples, which are submerged in varsol. Samples with this degree of induration usually yielded few smaller foraminifers, and commonly these specimens are so recrystallized that they cannot be identified even at the generic level. These indurated samples could not be used in this study, and the following discussion pertains entirely to the less indurated, shaly horizons. After disaggregation, the foraminiferal-bearing samples were washed through a 63 micron sieve. If most of the foraminiferal specimens in a sample were preserved well enough to be identified at the species level, a microsplitter was used to divide the assemblage into a subsplit of 300 to 1,000 specimens. The size of the subsplit was determined by the proportion of planktonic to benthonic specimens; the objective was to obtain a sample split that contained about 300 smaller benthonic specimens. The foraminifers were then mounted on microfossil slides and sorted into recognizable species. Number counts were made for smaller benthonic, larger benthonic, and planktonic specimens in the subsplit in order to calculate proportions among the three groups (table 1). Preservation varies among the genera and species. The more evident recrystallization of smaller specimens probably results in the recognition of fewer species in a sample than actually exist as the different species of the smaller genera, such as Bolivina, Buliminella, and Cassidulina are not separable in many samples.

The specimens that are illustrated in the plates were mounted on circular cover glasses, coated with carbon, and photographed using a Cambridge 100 Scanning Electron Microscope. The study specimens are deposited in the Cushman foraminiferal collection at the U.S. National Museum of Natural History (USNM) in Washington, D.C., U.S.A.

Five USGS samples from the Patala Formation at Nammal Gorge yield usable foraminiferal assemblages: NP (for Nammal Pass) 3-1, 3-3, 2-1, 2-2, and 2-3 (Fig. 2). These samples are all from the Patala Formation. Samples from the overlying Nammal Formation were also examined, but specimens were so diagenetically altered that few were identifiable at the species level.

Five samples were examined from less indurated intervals in the Lockhart, Patala, and Nammal Formations in the GSP Khairpur #9 corehole (Fig. 1), which is located in the central Salt Range. The GSP geologist for this corehole was Muhammad Anwar, and samples from the corehole were selected by Norman Frederiksen and Jean Self-Trail of the USGS.

NAMMAL GORGE PALEOGENE STRATIGRAPHY

Paleocene and Eocene formations in the Nammal Gorge include, from oldest to youngest, the Hangu Formation (mostly sandstone and shale), the Lockhart Limestone, the Patala Formation (mostly shale with subordinate limestone and sandstone beds), the Nammal Formation (dominantly marly shale and marl with some limestone beds in the lower part and mostly limestone with some shale and marl interbeds in the upper part), and the Sakesar Limestone.

Sample locations are shown on the Nammal Gorge stratigraphic section that was measured by Bruce Wardlaw and Wayne Martin (USGS) and Iqbal Hussain Haydri (GSP) (Fig. 2). Although my foraminiferally productive samples can be placed approximately within the earlier published Nammal Gorge section of Haque (1956), there are several differences in the formational thicknesses and boundries between the USGS section of Wardlaw and others and that of Haque.

The USGS section was measured in a side canyon leading eastward off the main Nammal Gorge toward Nammal Dam at the place where the lower part of the Lockhart Limestone is exposed in the floor of the gorge. The USGS measured section is on the south wall of this canyon just west of the dam. The middle part of the Patala Formation in the USGS section in this side canyon is poorly exposed and is traversed by a small stream, which results in a low, fairly flat surface for this part of the formation and this is represented by the covered interval shown

Figure 2. Measured section in Nammal Gorge by Wardlaw and others and location of samples studied. Inferred relationship of this section with section given by Haque (1956) is shown at left.

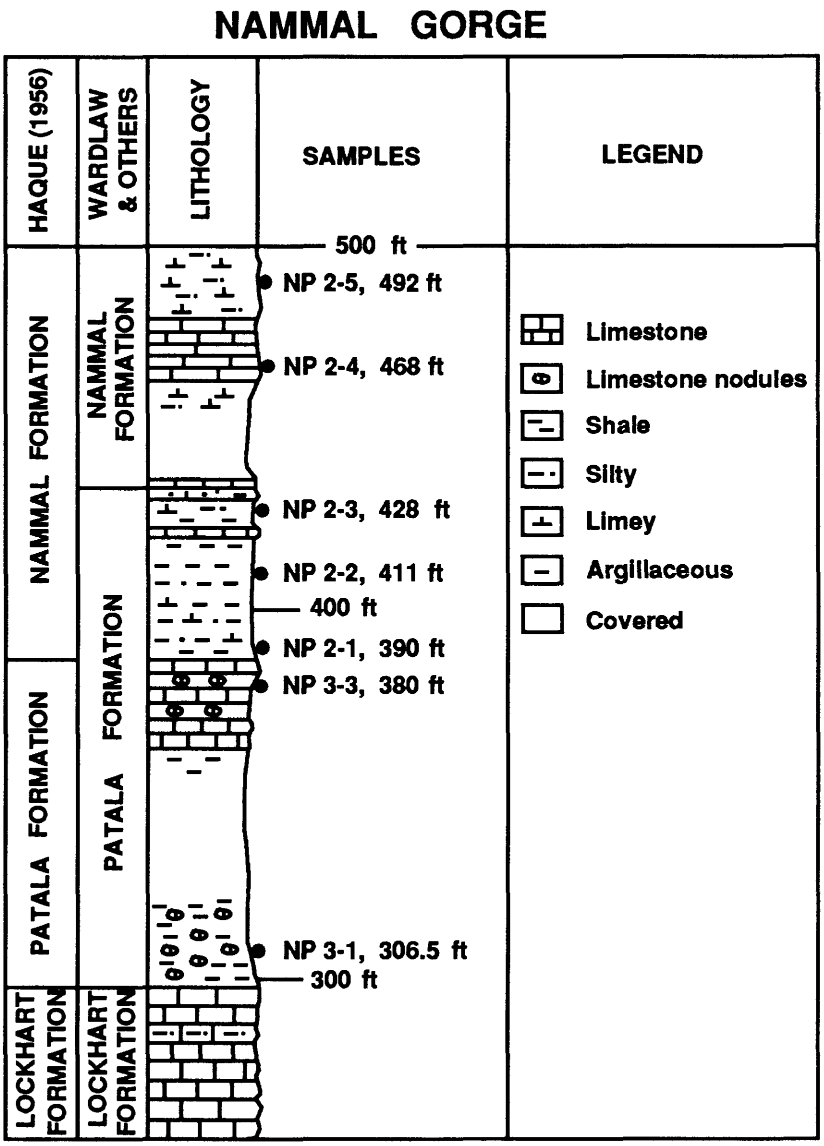

NAMMAL GORGE
HAQUE (1956)
WARDLAW & OTHERS
LITHOLOGY
SAMPLES
LEGEND
500 ft
NP 2-5, 492 ft
NP 2-4, 468 ft
NP 2-3, 428 ft
NP 2-2, 411 ft
400 ft
NP 2-1, 390 ft
NP 3-3, 380 ft
NP 3-1, 306.5 ft
300 ft
NAMMAL FORMATION
NAMMAL FORMATION
PATALA FORMATION
PATALA FORMATION
LOCKHART FORMATION
LOCKHART FORMATION
Limestone
Limestone nodules
Shale
Silty
Limey
Argillaceous
Covered

FIGURE 2

in Figure 2. Although Haque (1956) did not give a more precise location other than Nammal Gorge for his section, his detailed description does not show a covered interval in the middle of the Patala; this suggests that Haque's section was taken in a different location from the USGS section. A steeply dipping wall on the northward extension of the main gorge beyond the branching of the side canyon to Nammal Dam is the likely place for Haque's section. Examination of photographs of this northern wall suggests that an apparently complete exposure of the Patala Formation is present. A picture of the place of divergence of the side canyon to Nammal Dam and also of the possible northern wall of the gorge sampled by Haque is shown in Davies and Pinfold (1937, pl. 2).

The Patala Formation in Haque's section is thicker than in the USGS section. Haque indicated a thickness of about 340 ft from the top of the Lockhart Limestone to the top of the dark gray shales herein placed in the uppermost part of the Patala; this contrasts to a thickness between these horizons of approximately 130 feet in the USGS section. The two measured sections are probably from two adjacent canyons, and the reason for the thickness difference is unknown; possibilities include fault removal or addition of strata in one of the sections and inaccurate measurement through the covered interval of the USGS section.

The contact between the Lockhart and Patala Formations occurs in approximately the same stratigraphic position in both the USGS and the Haque measured section.

However, the contact between the Patala Formation and the overlying Nammal Formation has been placed differently by various workers because of the gradual lithologic change from the shaly Patala to the shaly/limy lower Nammal. Wardlaw and others, in the USGS measured section shown in Figure 2, placed the boundary at the top of the dark gray shale where a significant limestone ledge-forming bed appears; above this point the shales become more calcareous or marly, they are more bluish-gray in color, and limestones interbeds gradually become more common and thicker. Haque (1956) placed the top of his Patala Formation at the base of the dark gray shales (Fig. 2). Thus, these dark gray shale beds, which are the main focus of the present study, are considered uppermost Patala by Wardlaw and others and lowermost Nammal by Haque. Jurgan and others (1988) place the top of the Patala at a point where the limestone interbeds become considerably thicker, more prominant, and dominate the section; this contact is higher than that of either Haque or Wardlaw. The contact probably occurs at the base of the limestone where USGS sample NP2-4 was taken (Fig. 2), or possibly even higher.

Several interpretations have been made on the nature of the contact between the Patala and Nammal Formations in Nammal Gorge. Davies and Pinfold (1937) proposed an unconformity between the top of the Patala Formation and the overlying Nammal

Formation, but Haque (1956) showed the succession as continuous and conformable. Adams (1970) placed an unconformity between the Patala and Nammal Formations based upon his interpretation of the larger foraminiferal change reported in Davies and Pinfold (1937). Wardlaw (oral commun., 1990) proposed a disconformable contact based upon the lithologic change and the presence of clasts in the base of his Nammal Formation. However, analysis of the nature of the contact must take into account that a wide range of boundaries can be and have been placed in this gradational section.

Distinctive lithologic markers in the Lockhart Limestone and the Patala Formation make it possible to precisely locate the stratigraphic position of the material examined in this study in the previously published sections. Sample NP 3-1 (Fig. 2) is located near the base of the Patala Formation, which is marked by the upward change from massive limestone in the Lockhart to shale with nodular limestone beds in the Patala. The comparable position of our sample NP 2-3 in Haque's section can be determined with certainty as numerous foraminiferal species, including Marginulina glabra nammalensis Haque, Vaginulinopsis saundersi (Hanna and Hanna), Uvigerina subproboscidea Haque, and Coleites ornatus Haque, which are found in NP 2-3, are reported by Haque (1956) to occur only in his sample number 77 or immediately adjacent samples. Haque's sample 77 is located at the top of a relatively thick dark gray shale and immediately below a limestone ledge. USGS sample NP 2-3 also is located at the top of a dark gray shale sequence and just below a limestone ledge.

AGE AND PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY

The Patala Formation in the Salt Range was considered to be of early Eocene age in early studies (Davies and Pinfold, 1937). Smoot and Haque (1956) subsequently placed both the underlying Lockhart Limestone (=Khairabad Limestone) and the Patala Formation in the late Paleocene on the basis of the larger foraminiferal assemblages. Haque (1956) tentatively considered the Patala to be late Paleocene age on the basis of the overall age relationship of the few smaller benthonic foraminifers that he found in the formation. The Patala Formation was retained in the late Paleocene by Shah (1977). Haque (1956) considered the lowermost shaly strata of the Nammal Formation to be of late Paleocene age, based on the smaller benthonic and planktonic foraminifers. Haque correlated the Nammal with the Midway Formation of the U.S. Gulf Coast; this placement is too old as indicated by data from my study. Haque considered the remainder of the Nammal to be early Eocene in age, and Shah (1977) maintained this age placement. Haque's paper was published at a time when the biostratigraphic importance of planktonic foraminiferal species was just beginning to be recognized. However, his accurate identification and illustration of several planktonic species from the Nammal Gorge section (<u>Morozovella</u> <u>acuta</u> and <u>M</u>.

velascoensis) allowed subsequent workers to recognize these species and revise the age of the lower Nammal to the late Paleocene (McGowran, 1968; Banner, 1989).

A more precise placement within the late Paleocene is not possible based on the species that Haque recorded. There are additional biostratigraphically useful species in the current USGS samples, however, that make possible a more refined age assignment as discussed below. These biostratigraphically useful specimens come from what Haque considered the basal part of the Nammal Formation, but what Wardlaw and others now consider the uppermost part of the Patala Formation.

Age determination of beds higher in the Nammal Formation depend upon Haque's accurate illustrations of M. velascoensis. Specimens from the USGS samples from approximately equivalent intervals are too recrystallized to use for dating.

The age ranges of the planktonic species are taken from Stainforth and others (1975), Blow (1969; 1979), and Toumarkine and Luterbacher (1985). Figure 3 shows the planktonic foraminiferal and calcareous nannofossil zonations across the Paleocene-Eocene boundary and the eustatic sea-level curves proposed for this part of the Paleogene by Haq and others (1987).

Figure 3. Chart showing age relationships of planktonic foraminiferal zones, calcareous nannofossil zones, and eustatic sea level changes (from Haq and others, 1987).

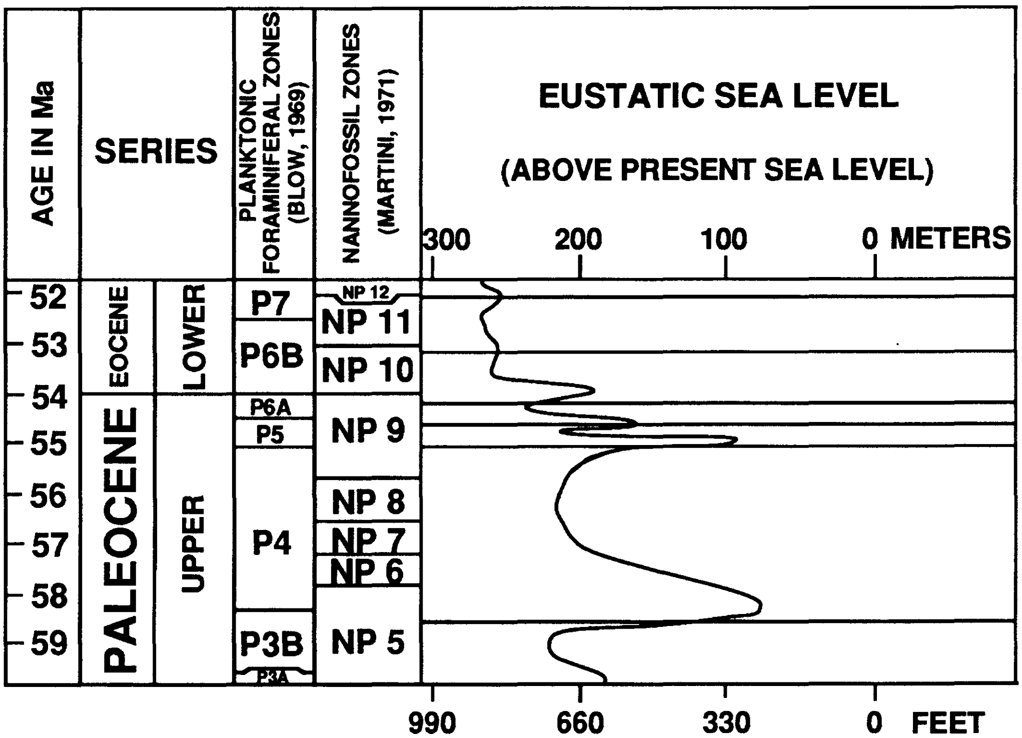

AGE IN Ma
SERIES
PLANKTONIC FORAMINIFERAL ZONES (BLOW, 1969)
NANNOFOSSIL ZONES (MARTINI, 1971)
EUSTATIC SEA LEVEL
(ABOVE PRESENT SEA LEVEL)
300
200
100
0 METERS
52
53
54
55
56
57
58
59
EOCENE
LOWER
PALEOCENE
UPPER
P7
P6B
P6A
P5
P4
P3B
P3A
NP 12
NP 11
NP 10
NP 9
NP 8
NP 7
NP 6
NP 5
990
660
330
0 FEET

FIGURE 3

Nammal Gorge

Patala Formation. Samples NP 3-1 (Fig. 2) from the lower part of the Patala Formation and NP 3-3 from the lower part of the upper Patala contain only a few, immature, planktonic foraminiferal specimens (Fig. 3 and Table 1); these few specimens represent a low diversity, non age-diagnostic assemblage, composed mainly of species of Subbotina. Haque (1956) reported no planktonic specimens from the lower Patala; he recorded only three long-ranging planktonic species from his upper Patala.

The three samples in the dark gray shale at the top of the Patala, NP 2-1, NP 2-2, and NP 2-3 (Fig. 2) contain abundant planktonic specimens (Table 1). The proportion of planktonic specimens in relation to benthonic specimens, as well as the planktonic species diversity, increases upward from the lowest of these Patala samples to the uppermost one (Fig. 4 and Table 1).

Sample NP 2-1, which has the lowest planktonic percentage of the upper three samples, 24.6% (Fig. 4 and Table 1), contains a moderately diverse planktonic assemblage that includes the following species:

Cheiloguembelina midwayensis nammalensis (Haque)
Globanomalina ovalis Haque
Morozovella acuta (Toulmin)

Table 1. Counts of the various foraminiferal components in assemblages from the Patala Formation in Nammal Gorge.

NAMMAL DAM FORAMINIFERAL ASSEMBLAGES

Sample Number	Foraminiferal Specimens	Smaller Benthonics	Larger Benthonics	Planktonics	Benthonic Species	*tau* Values
NP 2 - 3	1,238	540	0	698	31	1,748
NP 2 - 2	1,024	459	62	503	23	1,129
NP 2 - 1	1,045	732	56	257	25	615
NP 3 - 3	879	776	79	24	22	59
NP 3 - 1	595	591	0	4	18	13

TABLE 1

Figure 4. Graph showing upward increase in the proportion of the planktonic foraminifers and the changes in abundance in the larger foraminifers in samples from the Patala Formation at Nammal Gorge.

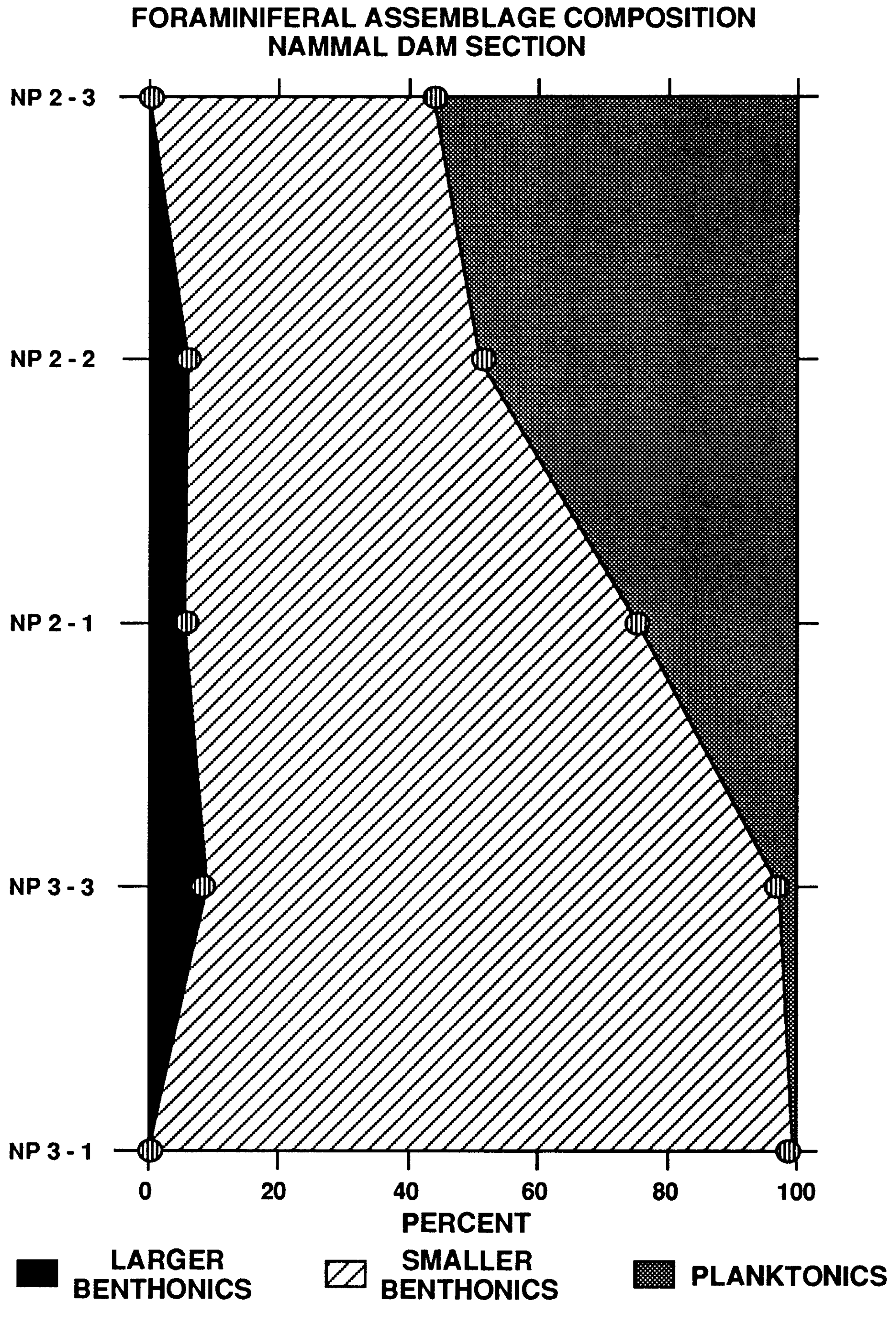

FORAMINIFERAL ASSEMBLAGE COMPOSITION
NAMMAL DAM SECTION
NP 2 - 3
NP 2 - 2
NP 2 - 1
NP 3 - 3
NP 3 - 1
0
20
40
60
80
100
PERCENT
LARGER BENTHONICS
SMALLER BENTHONICS
PLANKTONICS

FIGURE 4

M. aequa (Cushman & Renz)

M. subbotinae Morozova

The presence of *M. subbotinae* in this sample, which is no younger than late Paleocene based on the presence of the late Paleocene marker species *M. velascoensis* in the two overlying samples, indicates placement in the latest Paleocene *M. velascoensis*/*M. subbotinae* Zone or Zone P6a of Blow (1969) (Fig. 3). This zone is equivalent to the upper part of the *M. velascoensis* Zone of Toumarkine and Luterbacher (1985). The calcareous nannofossil assemblage from the same sample also indicates a latest Paleocene age; this sample can be placed in the upper part of calcareous nannofossil Zone NP 9 (Laurel M. Bybell, oral commun., 1990) (Fig. 3).

The overlying sample NP 2-2 contains a more abundant (49.1% planktonics, Fig. 4 and Table 1) and a more diverse planktonic foraminiferal assemblage than does sample NP 2-1. The following list includes the biostratigraphically most important species from this sample:

Acarinina soldadoensis soldadoensis (Bronnimann)

A. wilcoxensis (Cushman & Ponton)

Cheiloguembelina midwayensis nammalensis (Haque)

Globanomalina ovalis Haque

G. simplex Haque

Morozovella acuta (Toulmin)

M. aequa (Cushman & Renz)

M. occlusa (Loeblich & Tappan)

M. quetra (Bolli)

M. subbotinae (Morozova)

M. velascoensis (Cushman)

Subbotina velascoensis (Cushman)

The co-occurrence of M. velascoensis, M. subbotinae, and M. quetra places this sample in the latest Paleocene M. velascoensis/M. subbotinae Zone or Zone P6a of Blow (1969) (Fig. 3), which is equivalent to the upper part of the M. velascoensis Zone of Toumarkine and Luterbacher (1985).

The top Patala sample NP 2-3 contains the highest percentage of planktonic foraminiferal specimens (56.4%, Fig. 4 and Table 1) of any of the Patala samples at this locality. The planktonic assemblage in sample NP 2-3 is similar to that found in NP 2-2; however, M. velascoensis specimens are much more abundant in sample NP 2-3 than in NP 2-2; this may reflect the deeper water depositional environment postulated for sample NP 2-3. The following list includes the biostratigraphically important planktonic foraminiferal species found in sample 2-3:

Acarinina soldadoensis soldadoensis (Bronnimann)

Cheiloguembelina midwayensis nammalensis (Haque)

Globanomalina ovalis Haque

G. simplex Haque

Morozovella acuta (Toulmin)

M. aequa (Cushman & Renz)

M. subbotinae (Morozova)

M. marginodentata (Subbotina)

M. velascoensis (Cushman)

The co-occurrence of M. velascoensis, M. subbotinae, and M. marginodentata in this sample indicates placement in the M. velascoensis/M. subbotinae Zone or Zone P6a of Blow (1969) (Fig. 3), which is equivalent to the upper part of the M. velascoensis Zone of Toumarkine and Luterbacher (1985) (latest Paleocene).

The USGS samples from the Lockhart and Nammal Formation at Nammal Gorge contain only highly recrystallized foraminifers; many specimens in the Nammal appear to be of planktonic species, particularly species of Acarinina and Subbotina, but accurate identification is impossible.

Haque (1956) reported the presence of M. velascoensis (this can be readily confirmed from his illustrations) in his samples 68 through 83, which span the lower 85 feet of his Nammal Formation from its base to the top of the marly shale just below the limestone in which sample NP 2-4 was taken (Fig. 2). The last appearance of M. velascoensis marks the top of the M. velascoensis zone (the top of the Paleocene in most intercontinental zonations, i.e. Stainforth and others, 1975, Berggren and others, 1985, Toumarkine and Luterbacher, 1985, and Haq and others, 1987), and this occurrence places the lower part of the Nammal Formation of Haque, as well as Wardlaw and others in the latest Paleocene. The placement by Wardlaw and others of the lowermost shale unit of Haque's (1956) Nammal Formation into the uppermost part of their Patala Formation (this includes Haque's samples 68-77) still leaves approximately the lower 40 feet of their Nammal Formation (Haque's samples 78-83) containing M. velascoensis and thus still with a latest Paleocene age. The preservation of foraminifers generally deteriorates upward in the Nammal Formation, and it is possible that even more of the Nammal could contain M. velascoensis and also be of latest Paleocene age. Foraminifers in samples NP 2-4 and NP 2-5 in the lower Nammal and in the seven samples in the Nammal Formation above NP 2-5 are too highly recrystallized for accurate identification. McGowran (1968) examined the faunal list and illustrations in Haque (1956), and he considered that some of the beds in the lower Nammal Formation, which Haque considered to be early Eocene, were late Paleocene in age. I concur with this later placement. However, McGowran considered Haque's illustration of Pseudogloborotalia membranacea (Haque, 1956, pl. 22, fig. 3a-b) to be of Globorotalia (=Planorotalites) pseudomenardii (Bolli), which is characteristic of Zone P 4. In my opinion, this illustration is inconclusive as to which species of the Planorotaloides complex this figure belongs. My examination of the planktonic assemblages from the Nammal Gorge samples shows that although several species in the Planorotalites complex are present, including P. planoconica Subbotina, P. pseudomenardii is not present, and McGowran's re-identification of Haque's figure is considered to be incorrect. However, McGowran's reinterpretation of Haque's figure of M. aragonensis (Nuttall) as being of M. occlusa (Loeblich and

Tappan) is considered to be correct because abundant M. occlusa are present in the current samples, whereas M. aragonensis is absent.

Haq (1972), in the initial study of calcareous nannofossils from the Patala Formation in Nammal Gorge, placed this formation in the Discoaster multiradiatus Zone (= Zone NP 9 of Martini, 1971) (Fig. 3). Kothe (1988), from her study of dinoflagellates that she collected in the Patala Formation at Nammal Gorge, correlated this formation with calcareous nannoplankton Zones NP 8 and NP 9. However, Kothe did not give detailed stratigraphic sections and locations of sample intervals, and it is not possible to correlate her samples with those collected in the current study at Nammal Gorge. The strata placed in Zone NP 8 by Kothe are presumably from the lower part of the Patala. This placement in Zone NP 8 is based upon Kothe's indirect correlation of the contained dinoflagellates from the Patala in Nammal Gorge with the calcareous nannoplankton zonation she developed in other parts of Pakistan. Unfortunately, Kothe did not obtain both calcareous nanofossils and dinoflagellates from the same set of samples in any of her studied sections in Pakistan; thus the equivalence of her dinoflagellate zonation and the standard calcareous nannofossil zonation remains somewhat uncertain. The placement of the upper beds of the Patala into Zone NP 9 agrees with the placement based on planktonic foraminifers in the present work. The more refined placement of the uppermost part of the Patala into the upper part of Zone NP 9, done herein on the basis of the planktonic foraminifers, is corroborated by the most recent examination of the calcareous nannofossils from the same samples. Laurel Bybell (oral commun., 1990) found calcareous nannofossils characteristic of Zone NP 9 in sample NP 3-3 and an assemblage characteristic of the upper part of Zone NP 9 in samples NP 2-2 and 2-3; no diagnostic forms were found in the USGS samples from the lower beds of the Patala, and they could not be dated.

Khairpur #9 corehole

Abundant smaller benthonic foraminifers are present in the five samples prepared from the less indurated intervals in the Khaipur #9 corehole (Fig. 5). Few planktonic specimens were recovered from the five samples, and they do not yield any detailed biostratigraphic information.

Two samples were examined from the Lockhart Formation. The sample at 487.8 ft contains only two specimens of the planktonic foraminifer Globanomalina ovalis Haque, which has an undetermined range in the late Paleocene and earliest Eocene. The other sample at 509.9 ft contains no planktonic specimens. The sample from the Patala Formation at 420.4 ft does not contain any planktonic specimens, and the sample at 438.6 ft has only a single Globanomalina ovalis. The one sample examined from the Nammal Formation contains only two planktonic specimens; one is a broken juvenile specimen of Acarinina sp. and the other belongs in Globanomalina ovalis, which only indicates late Paleocene to earliest Eocene age.

Figure 5. Lithologic log of examined part of Khairpur #9 corehole and location of samples.

KHAIRPUR # 9 COREHOLE

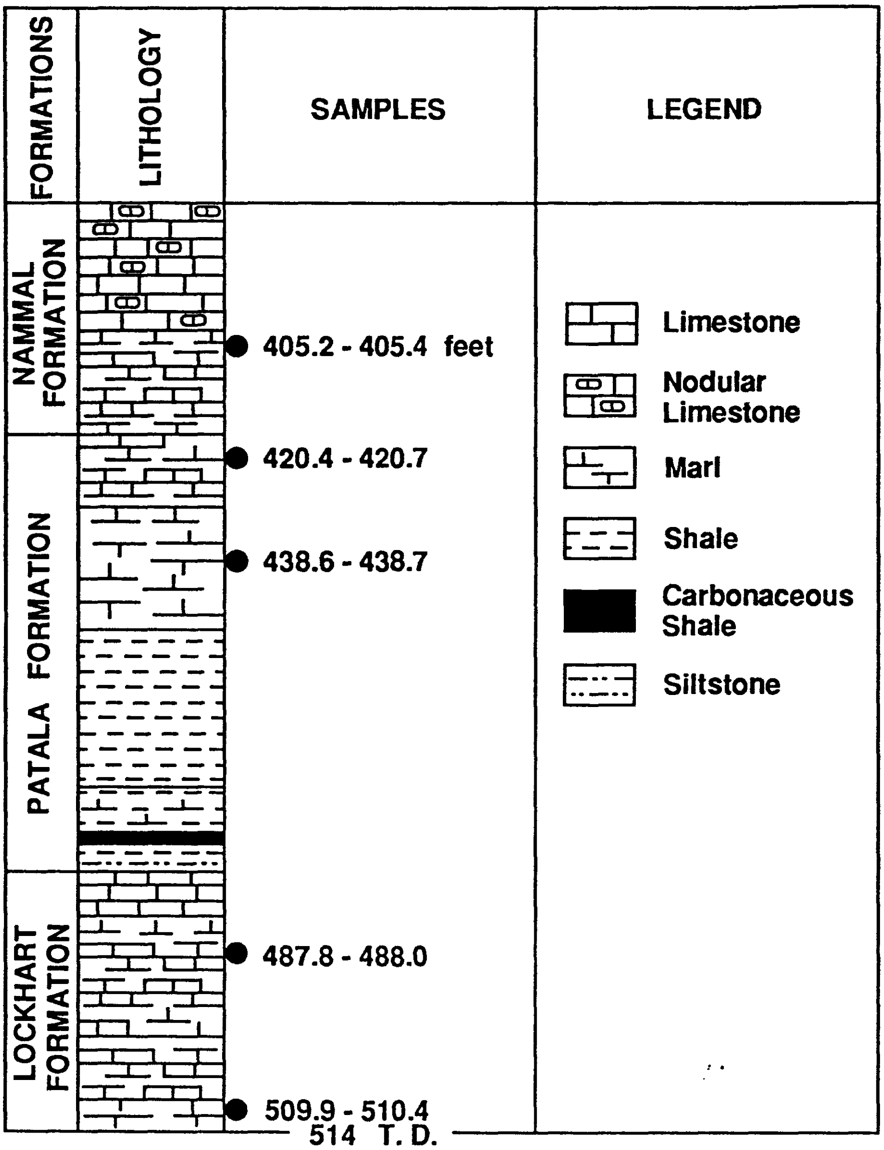


FIGURE 5

BENTHONIC FORAMINIFERAL BIOSTRATIGRAPHY

Not enough is presently known about the biostratigraphic distribution of smaller benthonic species in the upper Paleocene and Eocene strata of the Punjab to allow this group to be used for correlation. The only studied and published section of the biostratigraphic distribution of smaller benthonic species in the Salt Range is that of Haque (1956). Haque found a significant number of benthonic species restricted to only a part of the Nammal Gorge section. However, the distribution of smaller benthonic species, as well as larger ones, is, to a greater or lesser degree, controlled by paleoenvironmental factors. Thus, the biostratigraphic applicability of the species ranges from the Nammal Gorge section to other localities in the Punjab and other parts of Pakistan is to a large extent controlled by the similarity in paleoenvironments among the different areas.

<u>Anomalinoides</u> <u>bandyi</u> (Haque) is one example in the present study where the environment probably controls the stratigraphic range of a benthonic species. Haque reports this species only from the Lockhart and Patala Formation (of Haque) in the Nammal Gorge section; these formations were considered by Haque (and also by myself) to be of shallow marine origin. This species is absent in the shale at the base of the Nammal Formation of Haque (the uppermost bed of the Patala of Wardlaw and others) and throughout the remainder of the Nammal. I consider these beds to have been deposited in considerably deeper water marine

environments as discussed below. Thus A. bandyi appears to be found only in shallow marine environments as is true of many other species of this genus. In the Khairpur #9 corehole, however, where the Lockhart, Patala, and Nammal Formations were all deposited in shallow marine environments, this species occurs in all three formations. Other environmentally sensitive species show a similar increase of the species range toward the east (Khairpur # 9) where waters are shallower than in Nammal Gorge where deeper water paleoenvironments are more common in the upper Patala and Nammal. Sakhiella nammalensis Haque is found only in the upper middle Patala (of Wardlaw and others) in Nammal Gorge, but occurs in the Lockhart, Patala, and Nammal Formations in Khairpur #9 corehole. Woodella nammalensis Haque, known only from the upper middle Patala (of Wardlaw and others) in Nammal Gorge is found in the Lockhart and Patala in Khairpur #9 corehole. Pseudowoodella mamilligera Haque is restricted to the upper Patala and lower Nammal in Nammal Gorge, but is found in the Lockhart, Patala, and Nammal Formations in Khairpur #9 corehole.

Thus, the biostratigraphic use of smaller benthonic species will have to examined carefully in a number of geologic sections to ascertain the true first and last occurrences of the species. With more study, these benthonic species ranges will be correlated to the biostratigraphic ranges of planktonic foraminifers and calcareous nannofossils in order to determine the actual overall ranges of the benthonic species, not just their paleoenvironmentally controlled local ranges.

Many of the exposures of the Paleocene and Eocene strata in the Pubjab are dominated by shallow water deposition, and thus have sparse planktonic foraminifers; it will be quite useful to develop a series of benthonic foraminiferal zones. Even in the present limited study, some species appear to be restricted to a single horizon or formation both in Nammal Gorge and in Khairpur #9. For example, Ornatanomalina geei Haque, a robust form which seem to be moderately resistant to diagenetic effects, is found only in the Lockhart Formation in both areas studied and may prove to be biostratigraphically useful.

PALEOENVIRONMENTS

The Patala Formation becomes thinner to the east of Nammal Gorge and contains thin coal beds along with elongate quartzose sand bodies in the central and eastern part of the Salt Range (Warwick and Shakoor, 1988; Gee, 1989). These authors propose that the Patala strata in the central and eastern Salt Range were deposited in back-barrier and other fresh to near-marine environments based upon the presence of the coal beds. No Paleocene coal beds are present in the western Salt Range; thus, they considered that the Patala strata in the Nammal Gorge area were deposited in somewhat deeper water, open-marine environments.

Foraminiferal assemblages from the Patala Formation in Nammal Gorge in the western Salt Range and from corehole Khairpur #9 in the central Salt Range (Fig. 1), where the Patala contains coal, were examined to determine the depositional setting for these units. Foraminiferal assemblages were also examined from the overlying Nammal Formation and the underlying Lockhart Formation in Khairpur #9 corehole for comparison with the Patala assemblages. Fairly well preserved foraminiferal assemblages occur in a few intervals in all three formations in Khairpur #9; this contrasts with Nammal Gorge where adequately preserved assemblages were found only in the Patala Formation.

The paleoenvironmental interpretations, mainly paleobathymetric, determined in this study are based upon both the total foraminiferal assemblage characteristics and the presence of particular foraminiferal genera and species in the samples.

There are discussions of the bathymetric distribution of the various foraminiferal assemblage characteristics utilized in the specific papers mentioned below. These papers also contain extensive bibliographies of earlier studies. The foraminiferal compilations of Murray (1973), Boltovskoy and Wright (1976), and Haynes (1981) contain additional information concerning assemblage characteristics.

The following assemblage characteristics and their general bathymetric patterns are utilized in this study for paleoenvironmental analysis: 1) a general increase in the number of species (species diversity) composing the benthonic assemblage as the water depth increases (Gibson and Buzas, 1973), 2) an increase in the proportion or percentage of the total foraminiferal assemblage composed of planktonic specimens in the bottom sediments as water depth increases (Gibson, 1989), 3) an increase in the mathematical product of the above two measures, called tau by Gibson (1988) with an increase in water depth, 4) the fact that some genera and species are characteristic of certain bathymetric depth intervals, both in the living and in earlier Cenozoic assemblages (Phleger, 1960; Murray, 1973; Berggren and Aubert, 1975; Van Morkhoven and others, 1986; and Olsson and Wise, 1987), 5) the presence or abundance of larger foraminiferal specimens in the shallow waters of the photic zone because of the symbiotic relationship with algae and availability of vegetative food supply (a maximum depth limit of 35 m for most genera is given in Murray, 1973), and 6) the fact that the presence of diverse planktonic assemblages, including species of Morozovella and Acarinina, suggest deeper waters than those with low diversity assemblages mainly composed of Subbotina species.

The provincialism of some benthonic genera and species that are common in the Salt Range Paleogene assemblages makes paleoenvironmental determination more difficult because these taxa are absent from other areas where foraminiferal paleoenvironmental relationships have been studied. This limitation is particularly marked at the species level, but it extends also to the generic level; species belonging to the genera Ornatanomalina, Sakhiella, Woodella, and Pseudowoodella are common to abundant components of the benthonic assemblage in many samples examined in this study, but these genera presently appear to be endemic to Pakistan. It will be necessary to establish the paleoenvironmental limits for these taxa by relating their occurrences to regional lithofacies associations and to distribution with other better understood foraminiferal paleoenvironmental indicators.

Nammal Gorge

Patala Formation. Detailed foraminiferal data for the five samples studied from the Patala Formation are given in Figure 4 and Table 1. The samples are discussed from oldest to youngest (Fig. 2).

Sample NP 3-1. The smaller benthonic species diversity, 18, is the lowest of the examined samples. The dominant benthonic species are *Asterigerina cuniformis* Haque, *Cibicides* sp., and *Nonion* sp. cf. *N. graniferum* (Terquem). The very small planktonic foraminiferal component (0.7% of the total foraminiferal specimens) is composed of immature specimens of *Subbotina*.

The very low *tau* value of 13 (incorporating the species diversity and the few planktonic specimens), along with the composition of the dominant benthonic species (*Asterigerina* is considered characteristic of normal marine, inner shelf environments, Murray, 1973; Boltovskoy and Wright, 1976; Haynes, 1981). These results sugggest deposition in inner neritic water depths of less than 100 ft. The absence of larger foraminifers in this sample may indicate waters of slightly lower than normal open-ocean salinity because most living larger foraminiferal species occur in fully marine to slightly hypersaline environments (Murray, 1973).

Sample NP 3-3. This sample has 22 smaller benthonic species. The assemblage is dominated by both Asterigerina texana nammalensis Haque and larger foraminiferal specimens. Other relatively abundant or characteristic benthonic species in this sample include Nonionella spp. (including N. lakiensis Haque), a large Rotalia sp., Woodella nammalensis Haque, W. granosa Haque, Cibicides alleni (Plummer), and Sakhiella nammalensis Haque. The relatively small planktonic component (2.7%) consists of immature planktonic specimens.

The moderately low tau value of 59, together with the dominance of the shallow water benthonic species A. texana nammalensis and C. alleni (the latter considered characteristic of nearshore to shallow shelf environments by Olsson and Wise, 1987), suggests deposition in shallow, inner neritic, open marine water, which was no deeper than 100-150 ft. The precise depth distribution of the other characteristic benthonic species in this sample, Woodella spp. and S. nammalensis, is not known directly, but evidence from facies associations from Khairpur #9 corehole suggests that they live in very shallow marine environments (Warwick and Shakoor, 1988; Gee, 1989).

Sample NP 2-1. This sample contains 25 smaller benthonic species. The dominant foraminifers in this sample are Cibicides alleni (Plummer) and larger foraminiferal specimens. Other important constituents include Nonionella spp., Elphidium sp., Anomalinoides acutus (Plummer). Small numbers of specimens of

Uvigerina sp. and Bolivina spp. are recorded for the first time. The considerably higher planktonic component (24.6%) contains some mature specimens of Morozovella acuta, M. aequa, and M. subbotinae.

The considerable increase in tau value to 615, along with the initial appearance of Anomalinoides acutus (considered by Olsson and Wise, 1987, to be characteristic of middle to outer shelf depths), suggests deposition in middle neritic depths of 150-300 ft.

Sample NP 2-2. In this sample planktonic specimens compose 49.1% of the assemblage. Important benthonic species include: Nonionella sp., Alabamina wilcoxensis Toulmin, C. alleni (Plummer), A. acutus (Plummer), Elphidium sp., Coleites ornatus Haque, and Quinqueloculina gapperi Haque (the species used by Haque as the marker species for his Zone III or the upper dark gray shale bed of the Patala. Specimens of Bulimina, Bolivina, and Uvigerina are more abundant in this sample than in underlying strata.

An increase in the tau value to 1,129, the presence of A. acutus, and the increasing abundance of Bulimina, Bolivina, and Uvigerina suggest that these sediments were deposited in middle neritic depths of around 300 ft. The presence of C. alleni, a species considered characteristic of inner to middle neritic depths, as well as the presence of Elphidium sp., a genus mostly characteristic of inner neritic depths, would appear to limit the sample to middle neritic depths.

Sample NP 2-3. This sample has the highest number of benthonic species, 31, and the highest proportion of planktonic specimens, 56.4%, and thus has the highest *tau* value of 1,748. No single benthonic species dominates the assemblage, but species of *Bolivina*, *Bulimina*, and *Uvigerina* are the most abundant. Numerous species appear for the first time in this sample, including *Uvigerina subproboscidea* Haque, *Tappanina selmensis* (Cushman), *Cibicidoides* sp., *Tritaxia midwayensis* (Plummer), *Vaginulinopsis saundersoni* (Hanna and Hanna), *Marginulina glabra nammalensis* Haque, *Nodosaria nammalensis* Haque, and *Frondicularia* sp. cf. *F. tenuissima* Hantken.

The high *tau* value, the diverse planktonic assemblage, which includes abundant adult specimens of *Morozovella*, especially *M. velascoensis*, the complete absence of the larger foraminifers, *Elphidium* sp., and *C. alleni*, the dominance of the benthonic assemblage by species of *Uvigerina*, *Bolivina*, *Bulimina*, and lagenids, and the presence of *Tappanina selmensis* (considered a predominantly outer neritic species by van Morkhoven and others, 1986) suggest deposition in outer neritic water depths of about 300 to 600 ft.

Khairpur #9 corehole

This corehole is located in the Salt Range to the east of Nammal Gorge (Fig. 1). The five samples examined from Khairpur #9 corehole come from three formations (Fig. 5) and are discussed from oldest to youngest.

Lockhart Formation. Most of this formation is composed of limestone and indurated marl, but some softer, shaly intervals in the lower part of the formation contained the following two, relatively well-preserved foraminiferal assemblages.

509.9-510.4 ft. The dominant benthonic species is Anomalinoides bandyi (Haque); other common species include Asterigerina texana nammalensis Haque, Sakhiella nammalensis Haque, Cibicides alleni (Plummer), Cibicides sp., and Elphidium sp. Larger foraminiferal specimens are abundant; planktonic specimens are absent.

Cibicides alleni is considered to be characteristic of nearshore and shallow shelf environments (Olsson and Wise, 1987). Asterigerina is considered to be characteristic of normal marine, inner shelf environments (Murray, 1973; Boltovskoy and Wright, 1976; Haynes, 1981)). The other common benthonic species are all characteristic of the strata interpreted on foraminiferal information as having been deposited in shallow inner neritic environments in the Patala Formation in the Nammal Gorge section. The abundance of larger foraminifers and the total absence of planktonic specimens also suggest very shallow, open-marine waters probably less than 100 ft deep.

487.8-488.0 ft. The common benthonic species include Ornatanomalina geei Haque, Cibicides sp., Pseudowoodella mamilligera Haque, Sakhiella nammalensis Haque, and Woodella nammalensis Haque. Larger foraminifers are abundant; only two planktonic specimens are present.

Most of the benthonic species and genera occurring in this sample are endemic to Pakistan. These same taxa are found in Patala strata that are interpretated on other faunal evidence as having been deposited in shallow water in the Nammal Gorge section. The presence of these genera and species, combined with the presence of abundant larger foraminifers and very few planktonic specimens, suggests deposition in shallow, inner neritic, open-marine environments with water depths probably less than 100 ft.

Patala Formation. The lower part of the formation is dominated by shale, but it also contains a highly carbonaceous shale interval. Two, relatively well-preserved foraminiferal assemblages occur in the marl and limestone beds that comprise the upper part of the formation.

438.6-438.7 ft. The smaller benthonic assemblage in the sample is dominated by *Asterigerina texana nammalensis* Haque. Other important species include *Woodella nammalensis* Haque, *Sakhiella nammalensis* Haque, *Cibicides* sp., and *Pseudowoodella mamilligera* Haque. Larger foraminifers are abundant, but no planktonic specimens are present.

The benthonic assemblage is dominated by *Asterigerina* and larger foraminifers, which are both considered indicative of open marine, inner neritic environments. This conclusion is supported by the species composition of the other important smaller benthonic species (i.e. the endemic species that were determined to occur in shallow inner neritic environments of the Patala in Nammal Gorge as interpreted from the lithofacies patterns and other foraminiferal evidence) and by the absence of planktonic specimens. All of these characteristics suggest a shallow inner neritic, open-marine depositional environment probably less than 100 ft deep.

420.4-420.7 ft. *Asterigerina texana nammalensis* Haque is the most abundant smaller benthonic species in the sample. *Sakhiella nammalensis* Haque and *Cibicides* sp. also are common. Larger foraminifers are abundant; planktonic specimens are absent.

These characteristics suggest deposition in a shallow inner neritic, open-marine environment less than 100 ft deep.

Nammal Formation. The upper part of the Nammal Formation is a nodular limestone; the lower part consists of interbedded limestone and marl that yielded one useful foraminiferal sample.

405.2-405.4 ft. The sample is dominated by *Cibicides* sp. and larger foraminifers. Other important benthonic species include *Pseudowoodella mamilligera* Haque, *Anomalinoides bandyi* Haque, *Sakhiella nammalensis* Haque, *Elphidium* sp., and *Asterigerina texana nammalensis* Haque. Only two planktonic specimens are present.

The benthonic species present, the abundance of larger foraminifers, and the sparsity of planktonic specimens is similar to the other samples in Khairpur #9 corehole and suggests deposition in shallow, inner neritic paleoenvironments less than 100 ft deep.

The three formations studied from Khairpur #9 corehole all appear to have been deposited largely in very shallow, marine environments less than 100 ft deep. The changes in lithology from carbonate to shale thus must be largely related to the supply of fine clastic material to this area rather than water depth. The presence of back-barrier coal beds in the central and eastern Salt Range indicates periodically lowered sea levels in this area. Nevertheless, the major part of all three formations in the central Salt Range, as interpreted from the foraminiferal assemblages examined herein, was deposited in very shallow, open-marine environments rather than in restricted, brackish environments.

At Nammal Gorge the foraminiferal assemblages from the lower and middle parts of the Patala Formation also were deposited in very shallow marine, or possibly even marginal marine environments in the case of the lowest sample. There is little difference in water depth between the two areas except for the upper dark gray shale of the Patala Formation in Nammal Gorge. The middle to outer neritic environments represented in this upper shale indicate deposition in much deeper water than any found up to now in the central and eastern Salt Range.

REGIONAL RELATIONSHIPS

The deepening paleobathymetric trend in the uppermost Paleocene in the western Salt Range may be a result of eustatic sea-level change in the latest Paleocene, the result of localized tectonic downwarp, or the result of a more regional downwarp. Detailed biostratigraphic and paleoenvironmental examination of sections in surrounding areas of the southern Punjab, Sindh, and Balochistan can help determine the dominant cause of this paleobathymetric increase.

In the Nammal Gorge section, the water depth increases from approximately 100-150 ft in the middle Patala to about 300-600 ft in the uppermost part of the Patala. This represents a minimum increase of about 150 ft or a maximum increase of about 500 ft. Haq and others (1987) indicated a sea level rise of about 150 ft within Zone P6a (the upper part of Zone NP 9) (Fig. 3). Thus, the minimum water depth increase in Nammal Gorge concurs with the postulated global sea level rise. If the water depth increase at Nammal Gorge is considerably greater than 150 feet, it appears that, in addition to global sea level rise, other forces are involved.

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