Geol. Bull. Univ. Peshawar, 1989, Vol. 22, pp. 11-24

SYNCHRONOUS SEDIMENT ACCUMULATION, DECOMPACTION AND SUBSIDENCE IN THE MIOCENE FORELAND BASIN OF NORTHERN PAKISTAN

DOUGLAS W. BURBANK and RICHARD A. BECK

Department of Geological Sciences, University of Southern California
Los Angeles, CA 90089-0740, USA

ABSTRACT

Previous magnetostratigraphic studies in northern Pakistan provide a tightly constrained temporal framework within which to analyze the sediment accumulation history of the northwestern Himalayan foreland basin. Paleocurrent and provenance data indicate that a longitudinal drainage system flowing to the ESE persisted through much of the middle and late Miocene deposition. The subhorizontal cross-sectional surfaces defined by the paleodrainage configurations provide a reference frame for analyzing subsidence histories. Six magnetic sections in the Potwar Plateau have been decompacted as a function of burial depth and lithology to provide both accumulation and subsidence records. These records demonstrate consistently higher amounts of accumulation and subsidence in the northern portions of the basin, but also indicate that events of tectonic loading were experienced synchronously across the basin. Inflections in the curves of tectonically induced subsidence suggest that an important interval of thrust loading began ~11.5 Ma and terminated ~8 Ma.

INTRODUCTION

For more than one hundred years, geologists have recognized that histories of sediment accumulation and basin subsidence can provide useful insights into the tectonic controls on basin development and into the geometrical evolution of the basin through time. Until recently, however, detailed analysis of subsidence histories has been inhibited by three problems. First, precise chronological data and reliable time control of the stratigraphic record have been limited. Traditional reliance on paleontological data for time control has typically limited the resolution of subsidence histories to several millions of years due to uncertainties in biostratigraphic ages (Harland et. al., 1982). Second, post-depositional compaction of the sedimentary pile has not usually been accounted for adequately. Since marine shales compact so much more extensively than do typical sandstones (e.g., Van Hinte, 1978), failure to account for such lithologically dependent variability leads to inaccurate reconstructions of subsidence histories. Third, it has often been difficult to define the geometry of the former depositional surface through time. Water depth, erosion, and depositional slope all need to be considered.

Solutions to parts or all of these problems are now available. First, markedly improved

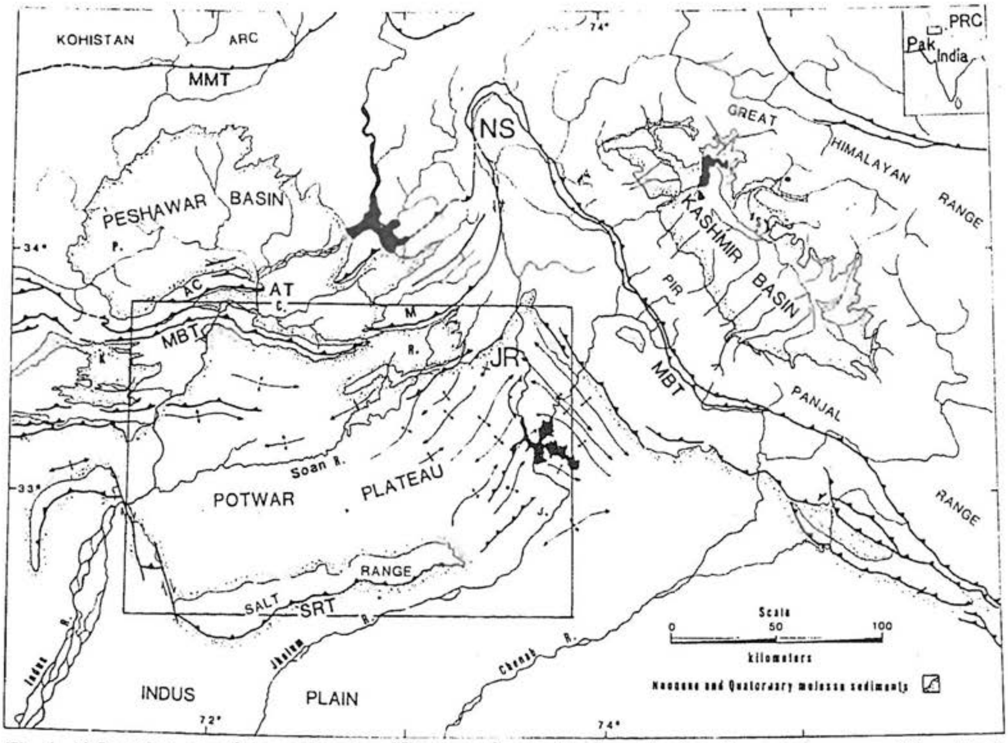
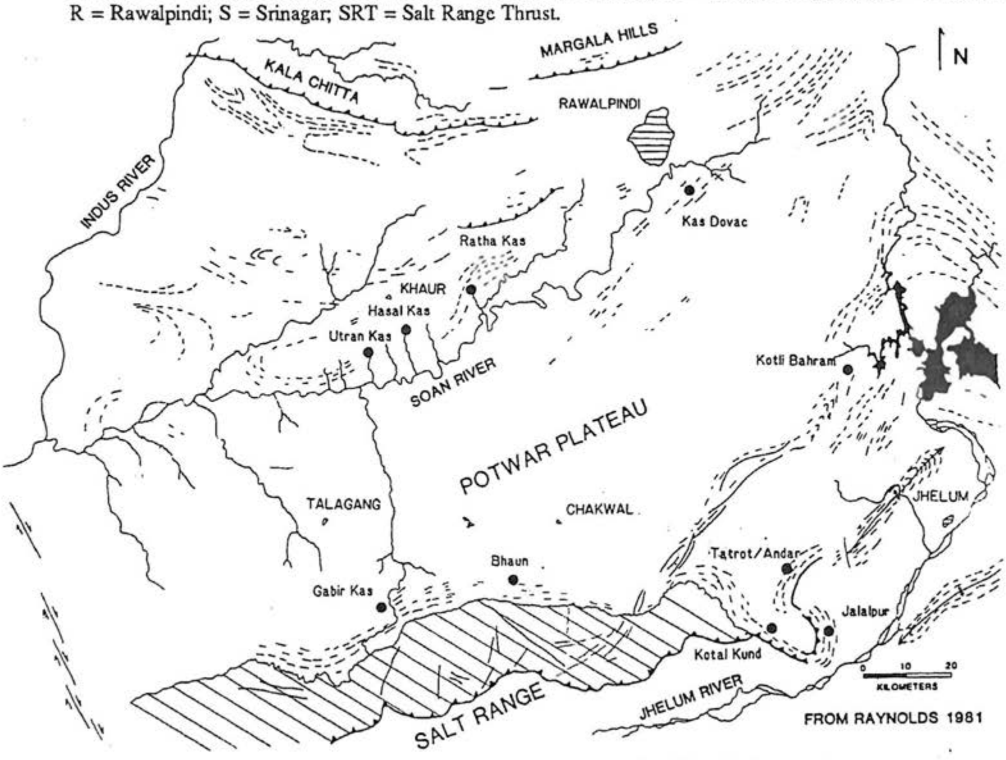


Fig. 1. A) Location map of the northwestern Himalayan foreland basins and adjacent mountain ranges. AC = Attock-Cherat Range; AT = Attock Thrust; C = Campbellpore; J = Jhelum; JR = Jhelum Re-entrant; M = Margala Hills; MBT = Main Boundary Thurst; MMT = Main Mantle Thrust; NS = Northwest Syntaxis; P = Peshawar; R = Rawalpindi; S = Srinagar; SRT = Salt Range Thrust.



B) Location map for sections studied in the Potwar Plateau region. See Fig. 1A for location.

radiometric dating and magnetic polarity stratigraphy have increased the temporal resolution that can be achieved in sedimentary sequences (Mankinen and Dalrymple, 1979; LaBreque et al., 1977; Berggren et al., 1985). Second, techniques for realistic decompaction of the sedimentary pile (Sclater and Christie, 1980; van Hinte, 1978; Steckler and Watts, 1978) allow us to address problems caused by post-depositional thickness changes. Third, new stratigraphic insights permit improved constraints to be placed on the geometrical shape of the depositional surface for each setting and time that is studied.

In this paper, we present results from subsidence analysis of the terrestrial molasse strata of the northwestern Himalayan foreland basin (Fig. 1). These strata provide an excellent setting in which to examine both changing patterns of subsidence through time and the interrelationships between tectonics, rates of sediment accumulation, and subsidence. More than a decade of paleomagnetic research (Barndt et al., 1978; Opdyke et al., 1979; Johnson et al., 1979, 1982, 1985; Raynolds, 1980; Tauxe and Opdyke , 1982) has generated a wealth of chronologic data on the sedimentary record of the Siwalik strata. Ranging in age from 18-0 Ma, the 40 magnetic sections presently available serve to define this succession of molasse sediments as one of the best dated foreland sequences in the world. This abundance of chronologic and stratigraphic data provide an extensive data base that can be utilized to develop histories of sediment accumulation and subsidence. Ultimately, full utilization of this data base should permit the creation of a highly detailed 3-dimensional analysis of the evolution of the foreland basin geometry through time.

METHODOLOGY

Decompaction

The primary input to the decompaction and backstripping analyses consists of lithologic and chronologic data derived from earlier studies, e.g., Tauxe and Opdyke, 1982; Johnson et al., 1982, 1985. Measured stratigraphic thicknesses, ages of magnetic boundaries, depth of burial, and sand/silt ratios are used to calculate both changes of porosity with depth and original sedimentary thicknesses (Sclater and Christie, 1980) prior to compaction during burial, i.e., "precompacted instantaneous accumulation" (Fig. 2). The slope of each segment of the resulting curve (Fig. 2) is proportional to the rate of sediment accumulation during deposition. Because all the underlying sediments below the surface are compacting while deposition is occurring, stacking of the individual decompacted packages does not provide an accurate picture of total sediment accumulation. However, by normalizing the instantaneous curve to the observed, compacted thickness, it is possible to locate more accurately the position of the inflection points in the sediment-accumulation history and to examine relative rates of sediment accumulation. Moreover, the instantaneous rates calculated by this method provide useful insights into significant changes in the accumulation history.

Establishing a reference frame

Before sediment accumulation can be converted into a subsidence history, it is necessary to determine the geometry of the depositional surface. Two contrasting configurations that could result from addition of a new packet of sediment to a previously formed foreland basin can function as end members of a continuum of possible geometries. Initially, we assume a sediment-filled foreland basin created by crustal flexure due to a thrust load (Fig. 3A). A new

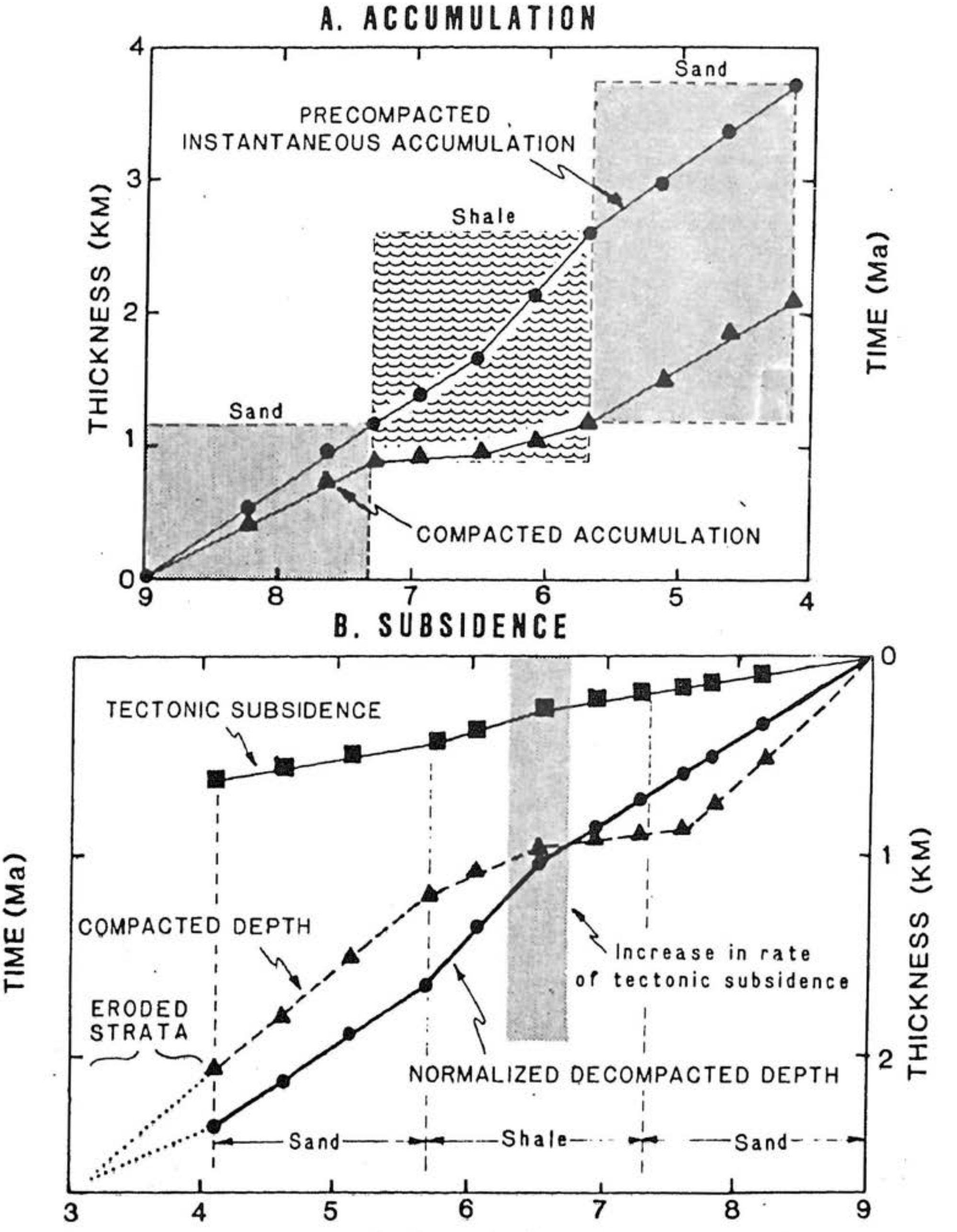


Fig. 2. A) Sediment accumulation curves showing the potential effects of lithology on decompaction. Because shales compact more than sandstone, inflections in the compacted sediment accumulation curve do not necessarily reflect actual changes in rate. Increases in compacted accumulation rates, such as at 5.7 Ma, may actually represent decreases in the rate when decompacted.

B) Subsidence curves for the hypothetical curve in Fig. 2A. 500 meters of strata younger than 4.1 Ma are assumed to have been erosionally removed. The inverted, precompacted instantaneous accumulation curve is normalized to the total actual thickness (2.1 km plus 0.5 km of eroded strata) in order to generate a realistic depiction of basin subsidence. A tectonic component of subsidence is required if the isostatic subsidence caused by the added sediment load is insufficient to accommodate the observed sediment thickness. If the depositional surface remains at the same altitude through time, then tectonic subsidence will amount to about 27% of the total subsidence.

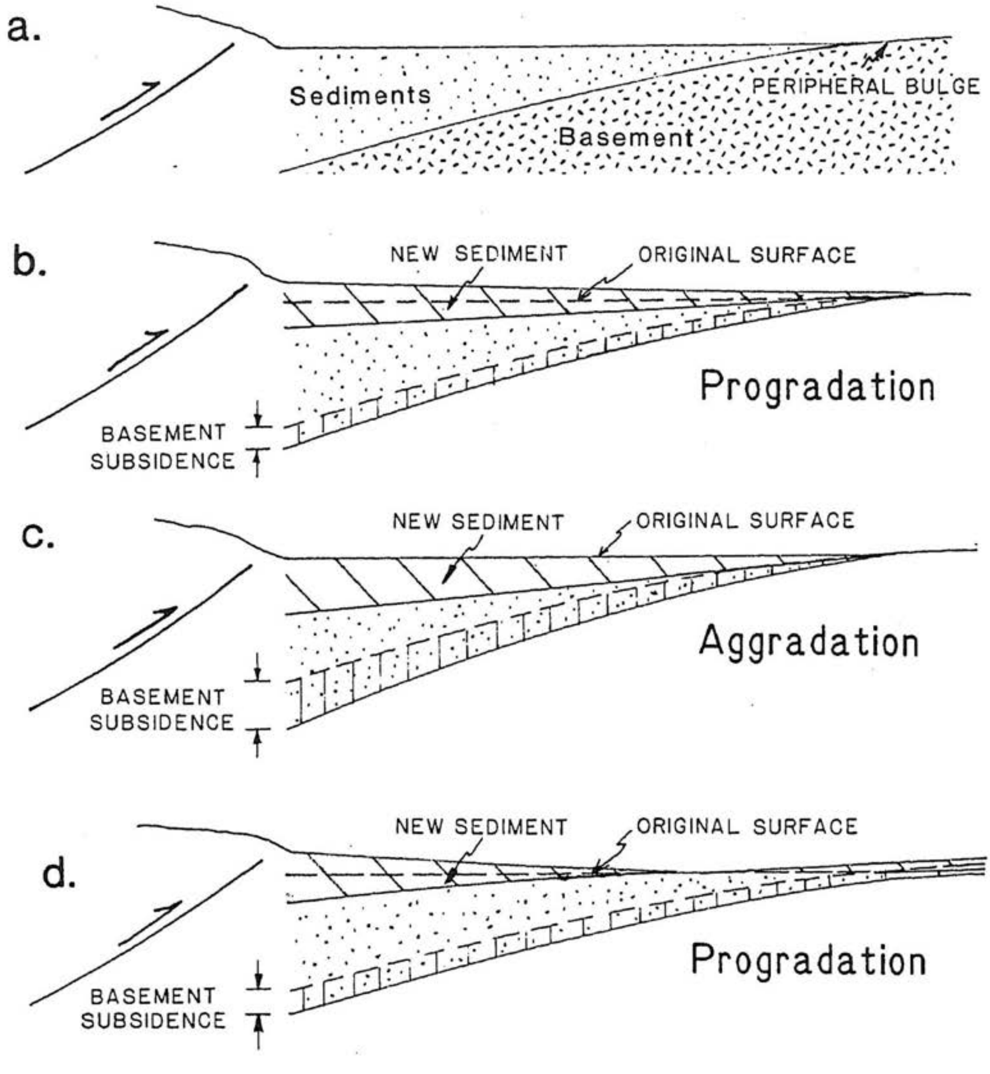


Fig. 3. A) Starting point for different depositional geometries. A foreland basin has resulted from thrust loading and is filled with sediments to a horizontal datum.

B) Progradational wedge model. Sediment accumulation occurs upon a depositional slope which tilts toward distal basin margin and fluvial system flows at high angles to the basin's structural axis. Vertically hachured area represents basement subsidence caused by this depositional geometry.

C) Aggradational wedge model. Sediment accumulation takes place on surfaces of very low slope with fluvial systems flowing at low angles to the basin's structural axis.

D) A progradational model with sediment also prograding from the peripheral bulge. This will also generate an axial drainage if the isostatic subsidence caused by the added sediment load is inadequate to accommodate the observed sediment thickness.

impulse of sediments could be distributed in two different ways. First, if a wedge of sediments progrades across the foreland, the upper surface of the wedge, i.e., the depositional surface, has a topographic slope from the proximal toward the distal side of the basin (Fig. 3B). In the second case, an equal thickness of sediment is added to the foreland, but it accumulates as an aggradational wedge and never develops a significant topographic slope across the basin (Fig. 3C). There is a distinctive contrast in the subsidence of the basin that would be expected in each of these two scenarios. Due to the growth of a topographic wedge in the former case, a volumetrically identical sediment input will reduce the magnitude of basin subsidence in comparison to a basin with a horizontal depositional surface.

How can we distinguish between these two possibilities in the geologic record? Clearly, where progradation has occurred, a transverse drainage system across the basin from the mountain front should be present, and a longitudinal river, if any, should be located against the peripheral bulge. In the case of aggradation, a longitudinal drainage system that "wanders" freely on the subhorizontal depositional surface should be present, such that a diverse array of paleocurrent directions should be observed from studies of isochronous strata. Paleocurrent directions collected in the Siwaliks from stratal packets that are 10.5 and 9.0 Ma old (Fig. 4) clearly indicate the presence of a longitudinal drainage system flowing from west to east across the Potwar Plateau (Beck et al., 1987). There is, however, condsiderable scatter in the data as predicted for a loosely constrained, longitudinal river flowing across a subhorizontal surface.

The presence of a longitudinal drainage system, however, does not by itself preclude the possibility that progradation has occurred on a large scale across the foreland basin. If extensive progradation also occurs off the peripheral bulge (Beaumont, 1981), a longitudinal drainage system could develop in the low trough between the two topographically inclined depositional surfaces (Fig. 3D). Can these two possibilities for creating longitudinal drainages be differentiated? One test would be to examine provenance of the sediments that are being accumulated within the foreland basin. In an aggradational model with a subhorizontal surface, sediments with a provenance derived from the orogenic belt should be distributed across the entire foreland, whereas in the topographically constrained model (Fig. 3D), sediments from the orogen should be distributed only as far as the longitudinal river system, whereupon sediments derived from the peripheral bulge or the craton should accumulate along the distal portions of the basin. Recent research on the detrital zircons in the Siwaliks (Cerveny et al., 1988) has provided unequivocal evidence that sediments at the feather edge of the foreland basin, where onlap of the pre-molasse cover was occurring 18 Ma, were derived from the Himalayan orogen. This Himalayan provenance persists throughout the filling of the foreland basin from 18 Ma until at least 7 Ma. Therefore, we conclude that the depositional surface was subhorizontal, that the longitudinal drainage system was loosely constrained, and that, because this system wandered freely across the foreland, sediments derived from the Himalayan Range were deposited throughout the foreland basin during nearly the entire depositonal history.

Subsidence Histories

If we accept that there was a subhorizontal topographic surface, and ignore the effects of compaction of the sediment lying beneath the molasse sediments, then it is possible to construct a subsidence history for each of the magnetic polarity sections. Once a reference surface is established, e.g., a persistent sub-horizontal depositional surface, normalized sediment-accumulation histories can be directly converted to subsidence histories by equating accu-

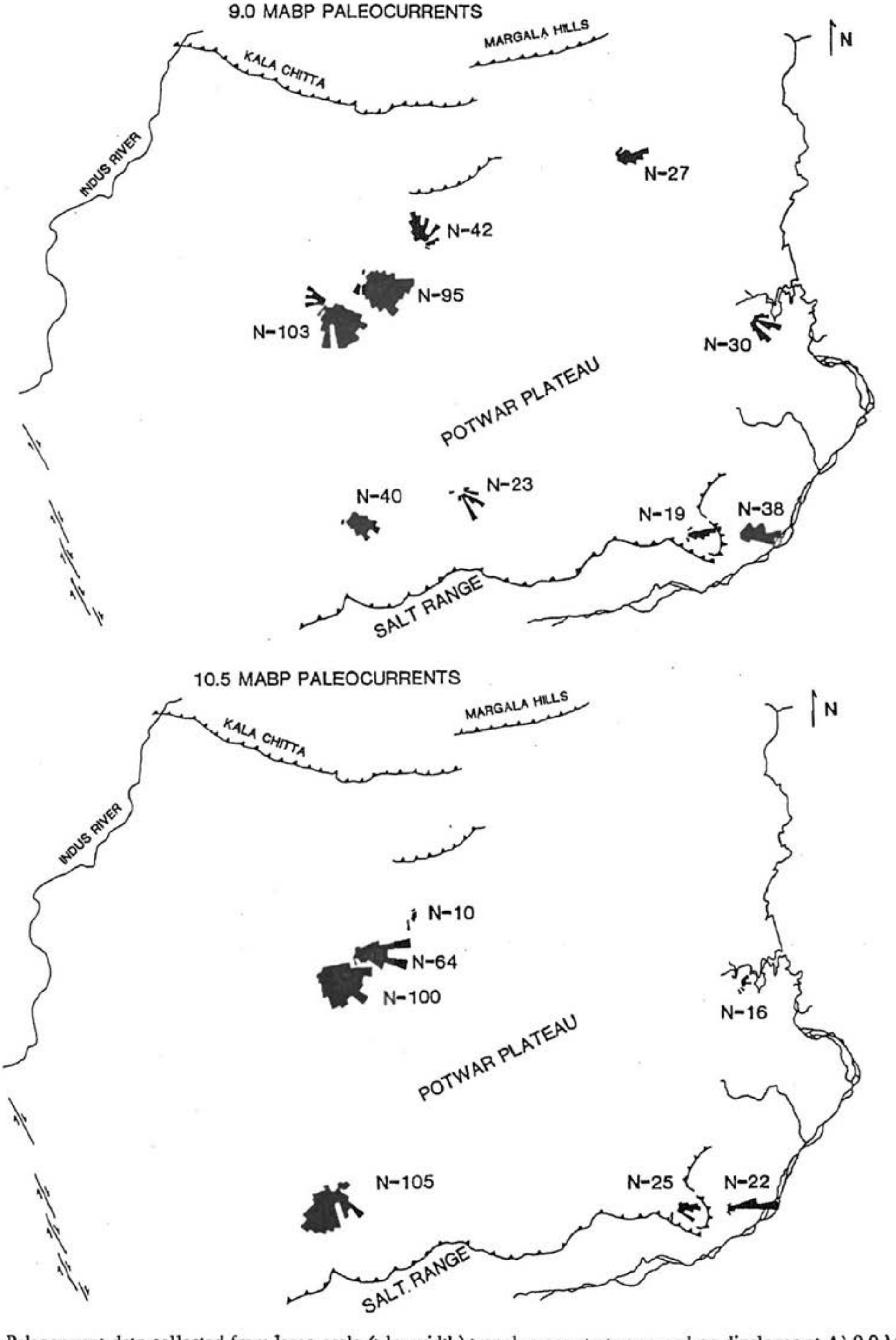


Fig. 4. Paleocurrent data collected from large-scale (>lm width) trough cross-strata exposed on dipslopes at A) 9.0 Ma and B) 10.5 Ma.

mulated thicknesses with the amount of basin subsidence that is required to accommodate these sediments relative to the reference surface. If it is also assumed that the depositional surface did not vary significantly in its altitude during sedimentation, then it is possible also to calcute the contribution to subsidence of sediment loading versus tectonic loading. Standard equations for Airy isostatic compensation (Sclater and Christie, 1980; Turcotte and Schubert, 1982) are inappropriate to use in a terrestrial foreland basin, because seawater is not being displaced. Therefore, the subsidence due to sediment loading is simply defined as

$$S_{sed.\ load} = S_{total} (\rho s/\rho m),$$

where S = subsidence, ρm = mantle density, and ρs = sediment density. The difference between total subsidence (Stotal) and subsidence due to sediment loading (Ssed. load) is attributed to tectonic loading of the foreland. If $\rho s = 2.4\ gr/cm^3$ and $\rho m = 3.3\ gr/cm^3$, then the tectonic component amounts to 27% of the total subsidence (Johnson et al., 1984). When the tectonically driven component of subsidence is separated from total subsidence, it permits an evaluation of the timing of important tectonic loading events that modified the pattern of subsidence.

RESULTS

In the following analysis, three assumptions are made. First, the correlation of the local magnetostratigraphies with the magnetic time scale is assumed to be reliable. Second, based on observations concerning both provenance and the geometry of the fluvial system, a subhorizontal cross-sectional surface is assumed to have been maintained during deposition. Third, further compaction of the rocks underlying the Siwaliks is assumed to be negligible. Given these assumptions, it is then possible to construct a subsidence history for each of the magnetic polarity sections. Initially, sediment-accumulation plots were developed for each dated sequence (Figs. 5 and 6). Based on the assumptions previously described, these accumulation histories were converted to records of subsidence showing three components: a curve of depth-versus-time based on the compacted, presently observable sedimentary thicknesses; a curve of depth-vs-time based on normalized decompacted thicknesses; and a curve of tectonic subsidence-versus-time (Figs. 7 and 8).

When we compare the subsidence curves from Gabir on the south with Khaur on the north (Figs. 7 and 8), there is a large difference in both the total observed thicknesses and depths, as well as in the amount of tectonically induced subsidence. One might ask whether the strong contrast between the Gabir and Khaur represents part of coherent pattern in which there is fairly simple north-to-south flexure of the foreland basin, or whether these are parts of a much more complicated geometrical pattern. We can begin to address this question by comparing the accumulation and subsidence histories from numerous localities along the northern and southern margins of the Potwar Plateau. Comparable histories of sediment accumulation are seen in the northern sections of Khaur and Kas Dovac (Fig. 9). Data from four additional sections in the south at Bhaun, Tatrot-Andar, Kotal Kund, and Jalalpur (Fig. 1) also show a rather similar pattern of subsidence between 11.5 and 6 Ma (Fig. 9). Sediment-accumulation rates are comparable between sections and inflections in the subsidence curves appear to be generally synchronous. The magnitude of both the subsidence and sediment accumulation in the southern areas is, however, considerably less than that observed in the northern sections. These contrasts suggest that there is indeed a coherent pattern of flexure from north to south across the foreland and that the southern localities have experienced considerably less subsidence than the northern localities.

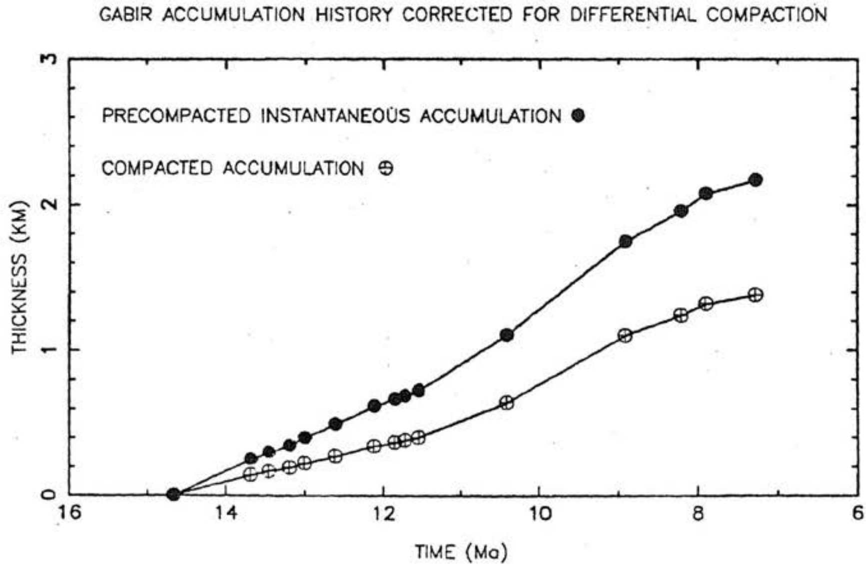


Fig. 5. Sediment accumulation versus time curves for Chittaparwala-Gabir. The compacted accumulation curve represents the apparent distribution plotted from magnetic stratigraphies after correlation with the magnetic polarity time scale (MPTS) (Johnson et al., 1982, 1985; Tauxe and Opdyke, 1982). The precompacted instantaneous accumulation versus time curve results from the decompaction of each polarity interval to zero overburden. The decompacted sediment thicknesses are then stacked to reconstruct the history of average rates of net sediment accumulation at or near the sediment surface before compaction. The instantaneous accumulation curves do not represent incremental reconstructions of basin geohistory or basin depth or thickness. The slope of each segment represents apparent accumulation rate.

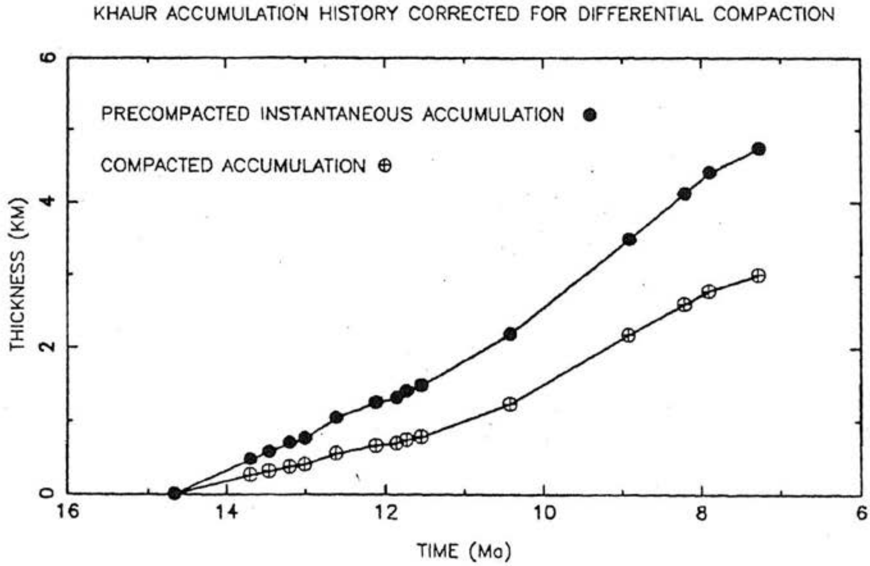


Fig. 6. Sediment accumulation versus time for Khaur. Note the greater thicknesses at Khaur than at Gabir (Fig. 5).

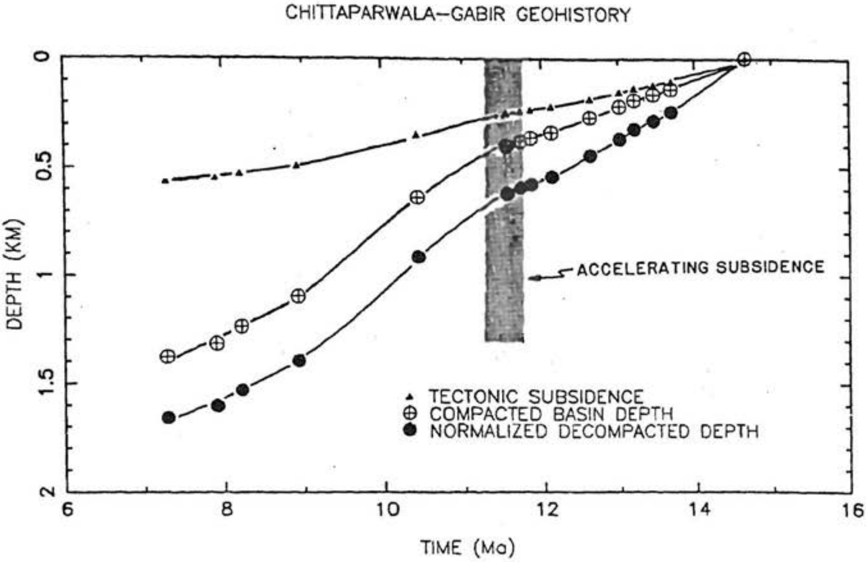


Fig. 7. Basin depth versus time curves for Chittaparwalla-Gabir. Data from Johnson et al., (1982, 1985); Tauxe and Opdyke (1982). Compacted basin depth calculated from observed magnetostratigraphies. Decompaction was carried out according to the method of Sclater and Christie (1980). Normalized decompacted basin depth curves are scaled to the present stratigrahic thickness of the basin, the beginning and ending points of these curves are coincident with those of compacted curves when basin histories are complete. Tectonic subsidence curves are calculated following the method of Johnson et al., (1983). The stippled area marks an interval of accelerated tectonic subsidence.

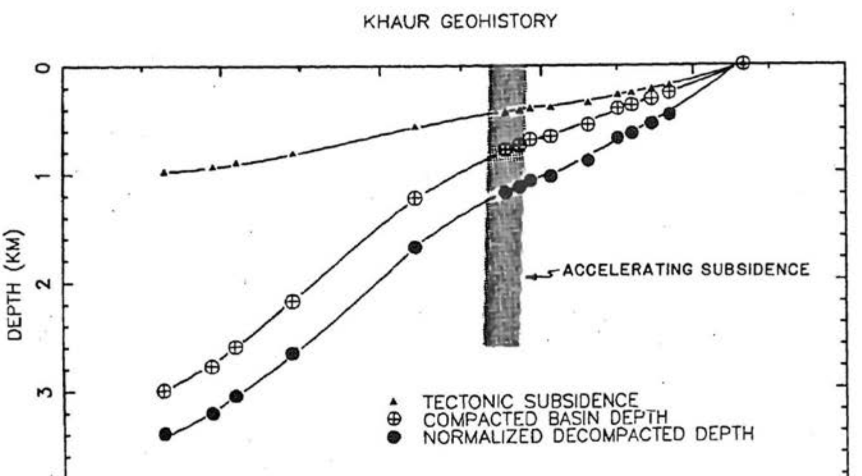


Fig. 8. Basin depth versus time curves for Khaur. Despite contrasts in absolute thicknesses, both Khaur and Gabir show very similar subsidence histories.

DISCUSSION

Models of flexural loading in foreland basins (Beaumont, 1981; Flemings and Jordan, 1987) indicate that, when an elastic plate is loaded, the maximum subsidence should occur beneath and adjacent to the load, and there should be a smooth decrease in the amount of subsidence until the peripheral bulge, an area of positive relief, is reached along the distal margin of the basin. Most models assume that the plate is unbroken and is uniformly strong. Depending on the coupling across fractures in a broken plate, the predicted smooth curve may be interrupted by fault-controlled steps. In such cases, the foreland basin may be dominated by "second-order" features, e.g., DeCelles, 1984. The very large scale surficial homogeneity that is displayed by the Himalayan foreland basin along the entire length of the range suggests that fairly uniform, strong crust is being flexed by Himalayan thrust loading. Therefore, despite the decreasing amount of the distal basin margin, flexural models predict that a pulse of tectonically induced subsidence should be experienced synchronously across the basin in response to thrust loading. If we compare the tectonic subsidence from Gabir on the south and Khaur on the north (Figs. 7 and 8), we can see that, whereas there is a predicted large difference in the absolute amount of subsidence the timing of the inflections in the curves toward a more rapid rate of subsidence is similar. These data suggest that a major episode of loading began around 11.5 Ma and that this caused a deepening of the foreland basin. Because Gabir and Khaur lie on a line that is essentially perpendicular to the orogenic front, it is possible to construct a basin-slope history that derives from the contrasting subsidence records from these two sites. Through consideration of common time points in the two magnetic polarity stratigraphies for these sequences and by hanging the subsidence curves on the same horizontal, depositonal surface for the two sequences, changes in the basement slope through time can be examined (Fig. 10). The results indicate that between 14 and 8 Ma there is both a progressive increase in the dip of the basement slope toward the north and a subtle inflection that occurs between 11.5 and 10.5 Ma in response to tectonic loading. Around 8 Ma, several sections show a decrease in the rate of sediment accumulation and subsidence (Figs. 5-9). Theoretical models of foreland basin evolution (Flemings and Jordan, 1987) suggest that when rates of erosive attack on a thrusted mass (i.e., the tectonic load) exceed the rate of growth of the load, subsidence rates in the foreland basin should diminish. Based on these models, the rate decrease observed at ~8 Ma may delineate the termination of the thrusting that began ~11.5 Ma.

CONCLUSIONS

Within the detailed temporal framework provided by magnetic stratigraphies, the geometry of former depositional surfaces in the Himalayan foreland of northern Pakistan has been reconstructed using paleocurrent and provenance data. In the region of the Potwar Plateau there appears to have been a persistent, semi-horizontal depositonal surface along which a longitudinal, but laterally shifting, drainage system developed during the middle and late Miocene. Based on burial depths, magnetostratigraphic ages, and lithologic characteristics, decompaction of several Miocene sequences has been used to develop more reliable subsidence and sediment accumulation histories than has heretofore been possible. Coherent patterns of subsidence are present at the subregional scale, whereas strong contrasts exist from north to south across the foreland basin. Despite contrasts in absolute amount of subsidence, there appears to be a synchronous response to tectonic loading as reflected by isochronous inflection points in the tectonic subsidence curves at ~11.5 Ma and 8 Ma.

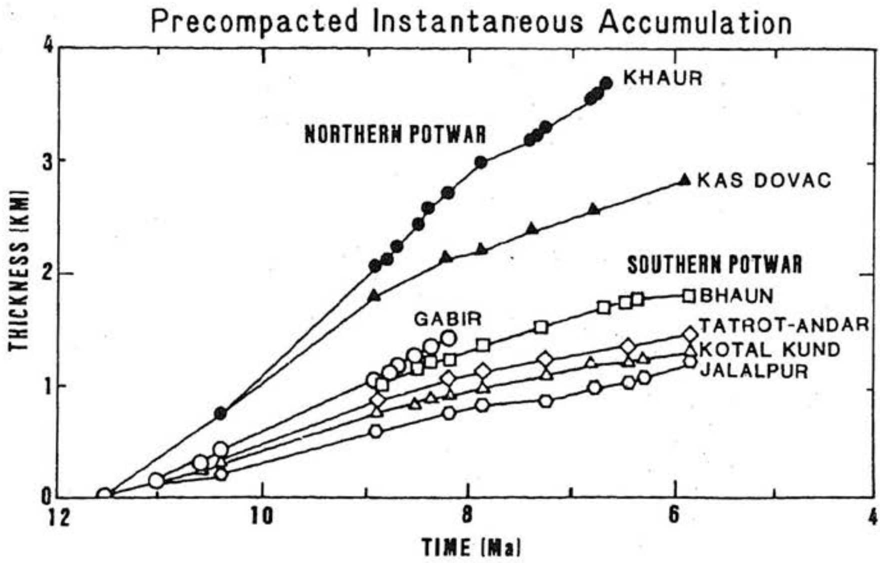


Fig. 9. Comparison of precompacted instantaneous accumulation for selected sections along the margins of the Potwar Plateau. Coherent record are evident in both the north and south, but there are distinct contrasts between the two groups. All sections exhibit a slowing in sediment accumulation at ~8 Ma

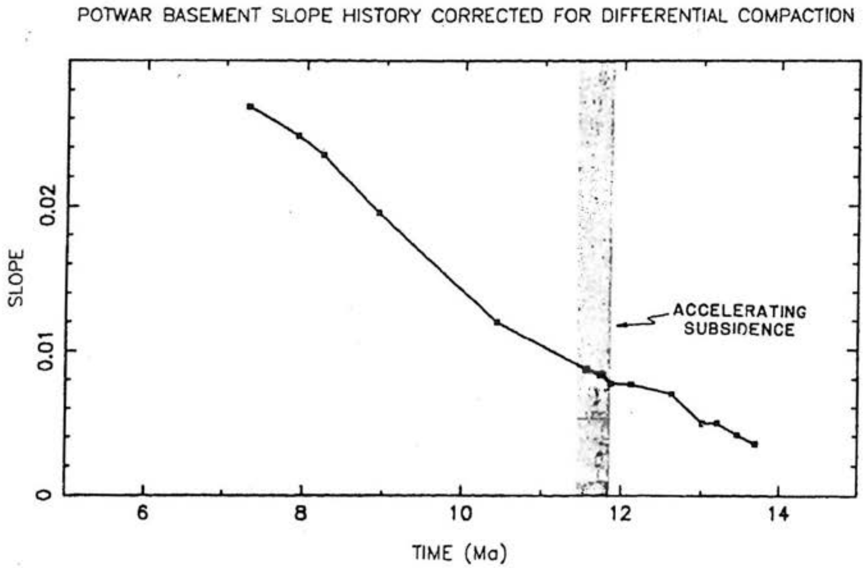


Fig. 10. Potwar basement slope history calculated from decompacted magnetostratigraphies normalized to total basin depth at Khaur (north) and Chittaparwalla-Gabir (south). The decompacted magnetostratigraphies are hung upon quasi-horizontal depositional surfaces documented by paleocurrent and provenance data. The stippled area marks an inflection in the basement slope curves, and at ~8 Ma, the rate of change in slope decreases.

These analyses are supportive of flexural models for foreland basin development in which an asymmetrically subsiding basin is created by tectonic loading during thrusting and in which subsidence-related responses to loading vary in magnitude but not in timing in different localities within the basin. The specific results shown here suggest a major episode of thrusting in northern Pakistan commenced at ~11.5 Ma and that erosion began to exceed the rate of thrusting by ~8 Ma, such that mean rates of subsidence diminished at this time.

Acknowledgments: Financial support for this research was provided by a Smithsonian Foreign Currency Program grant to Drs. David Pilbeam and John Barry, and by National Geograpic Society Field Research Grant 3677-87 and National Science Foundation Grant EAR-8720970 to D.W. Burbank. Logistical support was provided by the Geological Survey of Pakistan and by the Centre of Excellence in Geology at the University of Peshawar. Special thanks are extended to R.A.K. Tahirkeli, S.M.I. Shah, I.A. Khan, M. Hamilton, R. Raynolds, M. Raza, K. Sheikh, and M.G. Raza.

REFERENCES

Barndt, J., Johnson, N.M., Johnson, G.D., Opdyke, N.D., Lindsay, E.H., Pilbeam, D. & Tahirkheli, R.A.K., 1978. The magnetic polarity stratigraphy and age of the Siwalik group near Dhok Pathan Village, Potwar Plateau, Pakistan. Earth Planet. Sci. Lett. 41, 355-364.

Beaumont, C., 1981. Foreland basins: Jour. Royal Astronom. Soc. 65, 291-329.

Beck, R.A., Burbank, D.W., Shah, S.M.I. & Khan, I.A., 1987. Basin-scale isochronous paleocurrent study of Chron 9 polarity interval, Middle Siwaliks, Potwar Plateau, northern Pakistan. SEPM Annual Midyear Meeting Abstract 4, 6-7.

Berggren, W.A., Kent, D.V., Flynn, J.J. & Van Couvering, J.A., 1985. Cenozoic geochronology. Geol. Soc. Amer. Bull. 96, 1407-1418.

Cerveny, P.F., Naeser, N.D., Zeitler, P.K., Naeser, C.W. & Johnson, N.M. 1988. History of uplift, relief, and provenance of the Himalaya during the past 18 million years: Evidence from fission track ages of detrital zircons from Siwalik Group sediments. In: New Perspectives in Basin Analysis (K. Klenispehn and C. Paola, eds.). Springer-Verlag, 43-61.

DeCelles, P.G., 1984. Sedimentation and diagenesis in tectonic partitioned nonmarine foreland basins: Lower Cretaceous Kootenai Formation, south-west Montana. Unpub. Ph.D. dissertation, Univ. of Indiana, Bloomington, Indiana.

Flemings, P.B. & Jordan, T.E., 1987. Sedimentary response in a foreland basin to thrusting: A forward modeling approach. Geol. Soc. Amer. Annual meeting and expositon, Abst. with Programs, p. 644.

Harland, W.B. & others, 1982. A geologic time scale. Cambridge University Press, Cambridge, U.K. 131 p.

Johson, G.D., Johnson, N.M., Opdyke, N.D. & Tahirkheli, R.A.K., 1979. Magnetic reversal stratigraphy and sedimentary tectonic history of the Upper Siwalik Group, Eastern Salt Range and Southwestern Kashmir. In: Geodynamics of Pakistan (A. Farah and K.A. DeJong eds.). Geol. Surv. Pakistan, Quetta, 149-165.

Johnson, N.M., Stix, J., Tauxe, L., Cerveny, P.F. & Tahirkheli, R.A. K., 1985, Paleomagnetic chronology, fluvial processes, and tectonic implications of the Siwalik deposits near Chinji Village, Pakistan. Jour. Geol. 93, 27-40.

Johnson, N.M., Officer, C.B., Opdyke, N.D., Woodard, G.D., Zeitler, P.K. & Lindsay, E.H., 1983. Rates of late Cenozoic tectonism in the Vallecito-Fish Creek basin, western Imerial Valley, California. Geology 11, 664-667.

LaBreque, J. L., Kent, D.V. & Cande, S. C., 1977. Revised magnetic polarity time scale for Late Cretacoeus and Cenozoic time. Geology 5, 330-335.

Mankinen, E.A. & Dalrymple, G.B., 1979. Revised geomagnetic polarity time scale for the interval 0-5 m.y. B.P. Jour. Geophys. Res. 84, 615-626.

Opdyke, N.D., Johnson, N. M., Johnson, G.D., Lindsay, E.H. & Tahirkheli, R.A.K., 1982. Paleomagnetism of the Middle Siwalik Formations of Northern Pakistan and rotation of the Salt Range Decollement: Palaeogeography, Palaeoclimatlogy, Palaeoecology 37, 1-15.

Raynolds, R.G.H., 1980. The Plio-Pleistocene structural and stratigraphic evolution of the eastern Potwar Plateau, Pakistan. Unpub. Ph.D. dissertation, Dartmouth College, Hanover, N.H., 255 pp.

Sclater, J.G. & Christie, P.A.F., 1980. Continental stretching: An explanation of the post-mid-Cretaceous subsidence of the Central North Sea Basin. Jour. Geophys. Res. 85, 3711-3739.

Steckler, M.S. & Watts, A.B. 1978. Subsidence of Atlantic-type continental margin off New York. Earth Planet Sci. Lett. 41, 1-13.

Tauxe, L. & Opdyke, N.D., 1982. A time framework based on magnetostratigraphy for the Siwalik Sediments of the Khaur area, northern Pakistan. Palaeogeography, Palaeoclimatology, Palaeoecology 37. 43-61.

Turcotte, D. L. & Schubert, G., 1982. Geodynamics. John Wiley and Sons, 309-320.

Van Hinte, J. E., 1978. Geohistory analysis - application of micropaleontology in exploration geology. Amer. Assoc. Petrol. Geol. Bull. 62, 201-222.