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ACKNOWLEDGEMENTS We thank the Regional Sophisticated Instrumentation Centre, Indian Institute of Technology, Powai, Bombay, for the ESCA facility. KSR thanks Prof. B. Viswanathan, Department of Chemistry, Indian Institute of Technology, Madras, for stimulating discussions.

Received 27 March 1995; revised accepted 5 June 1995

Tectonic evolution of the Central Gujarat plain, western India

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The Quaternary basin of the Gujarat plain is formed due to the reactivation of Tertiary basement faults. The uplift as a horst of the Aravalli in the east and the Saurashtra peninsula in the west, comprising a culminating event of the post-Mesozoic rifting of the western continental margin, resulted in the Quaternary basin which was later filled up by alluvial sediments. The basin that received the fluvial sediments marked the end phase of the Cambay graben subsidence that was initiated in the Paleocene. The nature of variation in thickness of the Quaternary sediments in its different segments indicates that the basin comprised a series of horsts and grabens. Whereas the Early Quaternary tectonism gave rise to the differential basement topography, the tectonic events of the Late Quaternary were responsible for the present landscape development in Central Gujarat.

THE 300–800 m thickness of Quaternary fluvial and aeolian sediments resting upon the Tertiary rocks of the Cambay basin is the consequence of reactivation of pre-Quaternary basement faults. The Quaternary basin is delimited by marginal faults in the west and east. To the SE lies the Narmada–Son Lineament, and in the NE is the Aravalli horst (Figure 1). The basin comprises several fault-bound structural blocks[1] which continue up to Moho boundary[2]. The Gujarat Quaternary sediments have been studied by several workers (Allchin *et al.*[3], Chamyal[4], Chamyal and Merh[5], Merh and Chamyal[6] and Pant and Chamyal[7]); their emphasis, however, was mainly on the processes and agents of deposition, and on the paleoclimatic variations recorded in sediments. Recent work has demonstrated that successive tectonic events in the Gujarat region since Cretaceous[8] have also controlled the pattern of sedimentation and nature of the sediment body. The Cambay and Narmada basins, according to Biswas[8] opened up as a result of the counterclockwise rotation accompanying drift of the Indian plate.

The Gujarat plains, in the light of the overall Cambay basin tectonics, point to an important role played by differential movements along numerous structural lineaments in controlling the process of filling up of the Quaternary basin and sculpturing the present-day landscape. The movements along tectonic lineaments at various scales are significantly reflected in (i) the disruption of an ancient superfluvial system and its replacement by the existing drainage[9], (ii) development of ravines along various river courses indicating post-depositional fracturing, (iii) differential altitudes of river terraces, (iv) capturing of rivers (e.g. Rupen by Sabarmati, Orsang by Narmada), (v) differential uplifts along most major rivers giving rise to a distinct northward tilting of the respective left banks, and (vi) progressively increasing subsidence from south to north[10].

We have for the first time attempted to interpret the role of tectonics in the evolution of the Quaternary basin and its subsequent filling. Obviously, the Quaternary sedimentation is found to have been controlled by the same tectonic features which were responsible for the deposition of the Tertiaries. With the withdrawal of the Tertiary sea in this part, marine processes were replaced by fluvial sedimentation, marking the onset of the nonmarine continental depositional cycles. The marine sediments of Upper Tertiary show a transition[11] changing over to a period dominantly of fluvial sedimentation during the Quaternary.

The basin that received Quaternary sediments, obviously, comprised the more or less filled up Tertiary Cambay basin and marked the culminating phase of the Cambay and Narmada graben tectonics, though the tectonism preceding, during and post-dating the continental deposition was an integral part of the Cambay basin tectonism. ONGC investigations have adequately shown that the Cambay basin formed during Paleocene subsided episodically with varying rates and finally during Quaternary the rate of subsidence slowed down. It is however, not unlikely that the Quaternary basin experienced considerable reactivation of the pre-existing faults. These faults were an integral part of the Cambay basin rift phenomenon. It is possible that the advent of Pleistocene witnessed a renewal of tectonic activity and triggering of a new cycle of subsidence. This neotectonism coincided with the uplift of Aravalli in the east and northeast[12]. An uplift of the order of 300 m of the Aravalli has been envisaged by Ahmad[13] during Quaternary. To

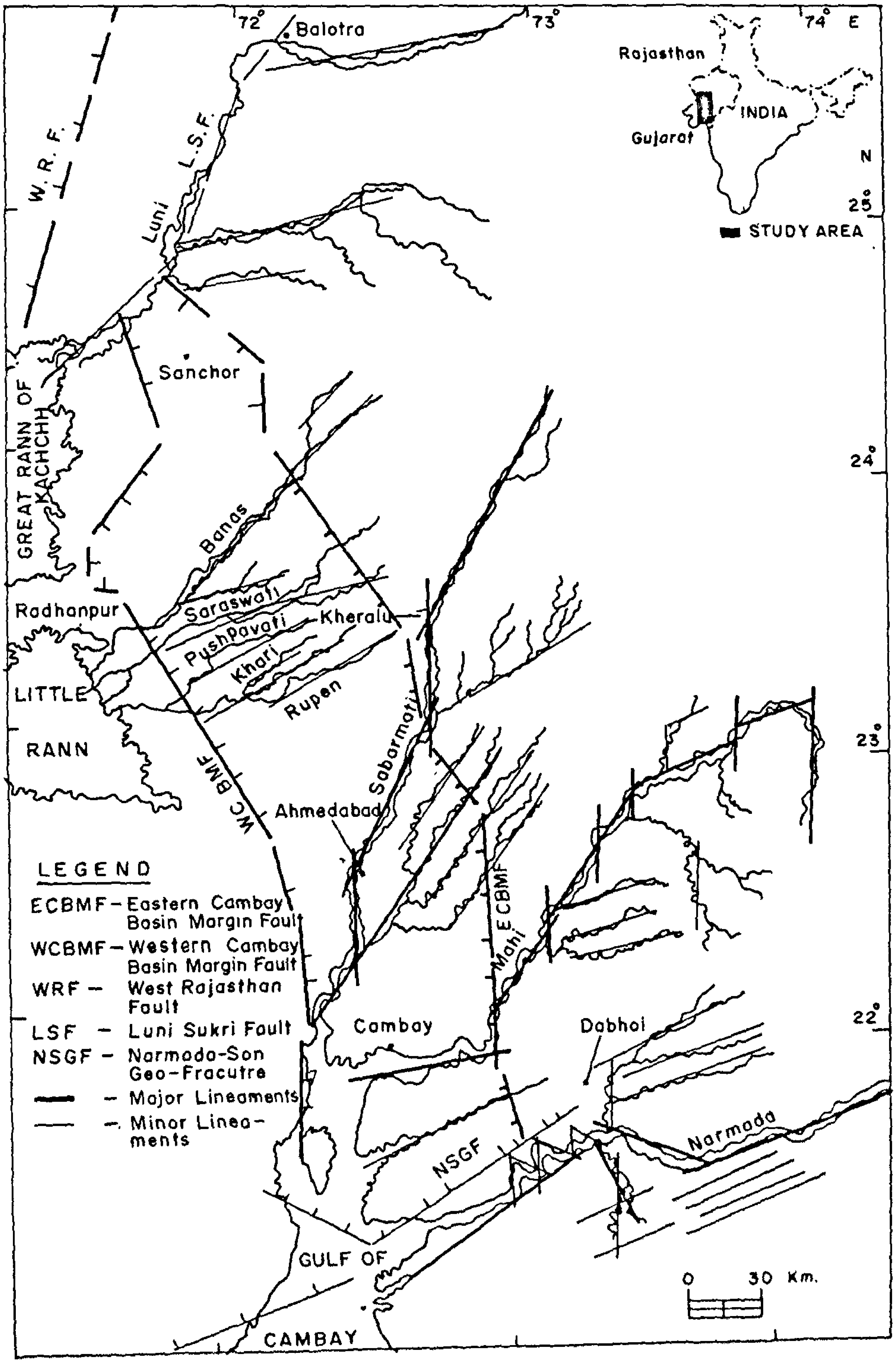

Figure 1. Tectonic map of the Gujarat alluvial plain superimposed over the tectonic map of Cambay basin[14].

the west, the Saurashtra peninsula formed an uplifted horst (Figure 2). This renewal of tectonic activity was essentially related to the Cambay basin faulting and the Narmada geofracture.

The development of a rift-related depression in front of a rising hill range provided an ideal site for the initiation of fluvial sedimentation. The exposed river sections as well as subsurface data provide clear and unequivocal evidences pointing to an enormous thickness varying from about 800 m in the south to 300 m in the north. The variation in thickness is controlled by basinal faults which were effective prior to and during the sedimentation. Significantly, colluvial deposits are absent and fluvial material is encountered right from the rocky fringes. Although the sediment thickness varies from block to block (Figure 3), in composition the fluvial sediments comprise gravels, coarse to fine sands, silts and clays, and point to their deposition in several instalments, depositional process punctuated by periods of nondeposition and pedogenesis. The sediment nature and thickness point to an overall basin subsidence, but one cannot be very sure about the variations in the movement and in the course of Quaternary too, it is not unlikely that inversions in movement directions did take place. Such a tectonic pattern has been established for the trappean highlands of South Gujarat by Alavi and Merh[10], and similar post-Tertiary tectonic activity can safely be visualized.

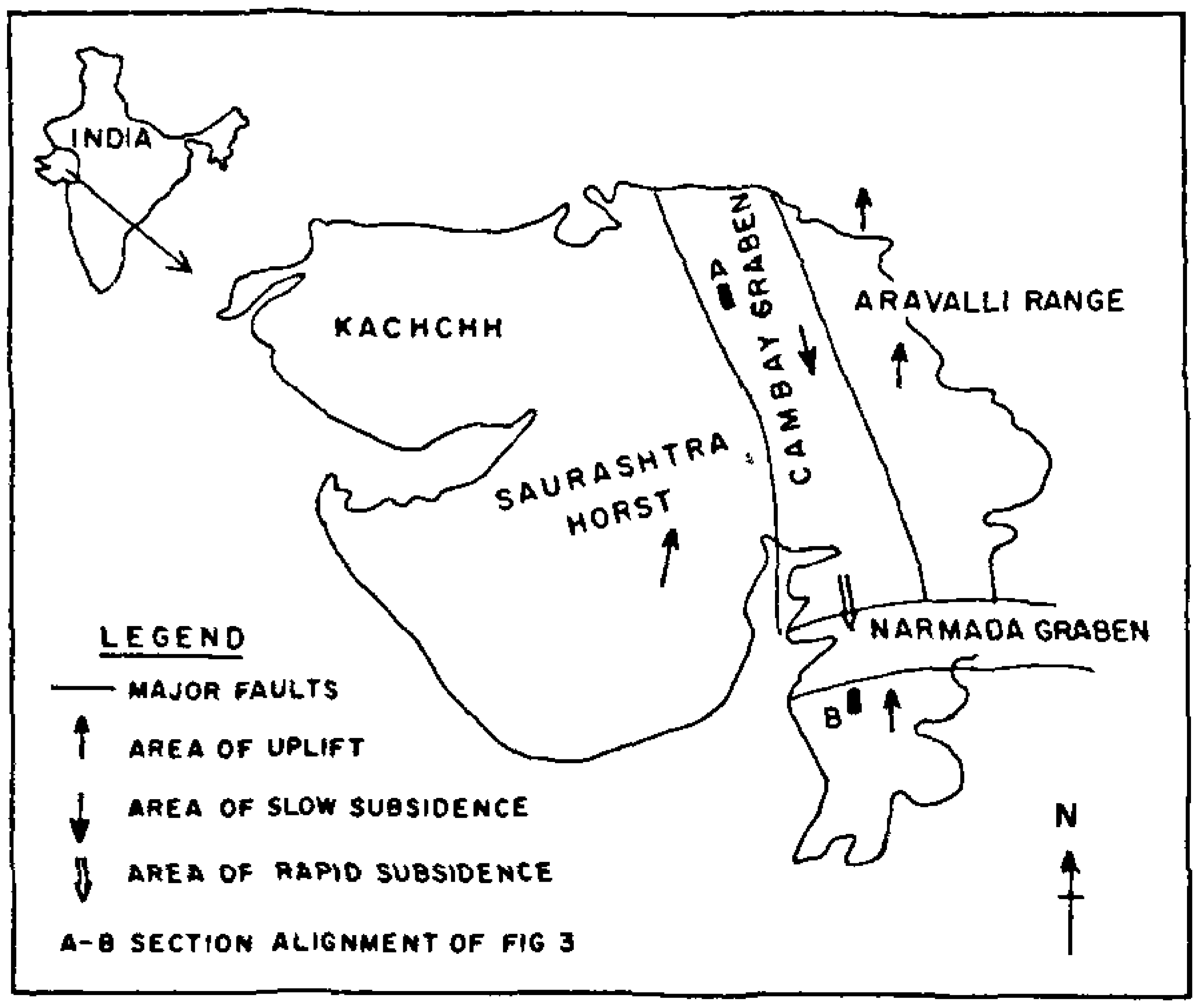

Figure 2. Sketch map of Gujarat showing major tectonic movements during Quaternary.

The cross-section prepared based on ONGC data clearly brings out the influence of the tectonic framework of the Cambay and Narmada basins along with their various tectonic blocks on the Quaternary sediments (Figure 3). The basin therefore, comprised series of horsts and grabens which were the direct manifestations of the various Tertiary structural blocks. These tectonic sub-basins were subjected to periodic uplifts and subsidences relative to each other, while overall the basin was subsiding. Whereas the ONGC workers have worked out in considerable detail the role of tectonics in Tertiary sedimentation, no information was provided by them on the Quaternary history. There is, however, little doubt that the Late Quaternary tectonism has been responsible for the present landscape development in Central Gujarat.

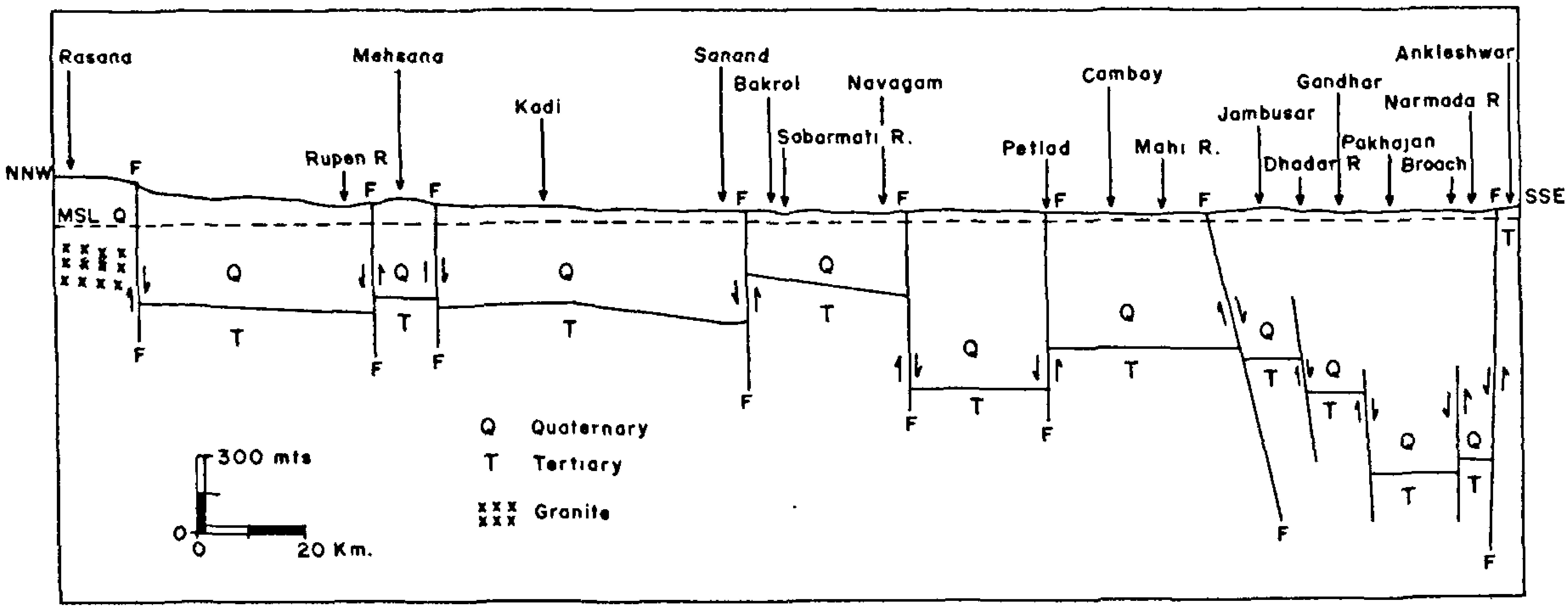

Figure 3. Schematic cross-section of the Quaternary basin (based on thickness data obtained from ONGC archives).

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ACKNOWLEDGEMENTS. We are indebted to Prof. K. S. Valdiya for critically going through the manuscript. Financial assistance provided by Department of Science and Technology is gratefully acknowledged.

Received 25 July 1994, revised accepted 14 August 1995

Occurrence and petrogenesis of Loda Pahar trondhjemitic gneiss from Bundelkhand craton, central India: Remnant of an early crust

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The occurrence and the geochemistry of the typical high-Al trondhjemitic gneiss intruding into the highly deformed basic host rocks from Loda Pahar, Kabrai area, northeastern part of the Bundelkhand massif is reported. This large relict of the early crust is intruded by various phases of Proterozoic calc-alkaline granitoids. The highly fractionated REE pattern with HREE depletion and concave upward shape at the HREE end of the Loda Pahar trondhjemitic gneiss (LPTG), besides the major and trace element chemistry, is typical of Archaean TTG suites reported from shield areas of other continents. The evolution of such trondhjemitic magma is considered to have played a significant role during early crustal growth and the LPTG provides the first convincing evidence to qualify the Bundelkhand craton as a typical Archaean terrain.

In recent years considerable work has been done to understand the nature and evolutionary trends in the formation of early crustal rocks, the relicts of which are exposed in shield areas of all the continents. The Archaean crust in general is comprised of granitoid gneisses, massive granitoids and greenstones in proportion of 6 : 3 : 1[1]. The evolutionary trends recognized in the granitoid rocks of the Precambrian terrains of the world contain two main associations, an older Na-rich tonalite–trondhjemite–granodiorite (TTG) suite and younger K-rich granodiorite–monzonite–adamellite–granite (GMAG) suite. The former predominates throughout the Archaean, but subsequently, the latter becomes significant. The chemical and isotopic characters of the two suites are distinct and provide a major temporal demarcation in continental evolution at the Archaean–Proterozoic boundary[1].

In India, evidence to reconstruct different stages of early crustal evolution have so far come from the cratonic nucleii of Dharwar, Singhbhum and very recently from Bastar. Though the Bundelkhand craton is being considered unique for representing an early crust, unaffected by Proterozoic and subsequent deformational events[2], there is no convincing geochemical or geochronological data to indicate the presence of an early crust from Bundelkhand craton except for the geochemical data of early Proterozoic Bundelkhand granitoids[3].

The authors initiated detailed petrochemical studies of the Bundelkhand craton and have identified different components (metabasic and metasediments with banded iron intruded by various phases of TTG) of the early crust into which the Proterozoic calc-alkaline granitoid suite intrudes. The present paper reports the occurrence of a large relict block of trondhjemitic gneiss in deformed Archaean crust intruded by undeformed early Proterozoic calc-alkaline granitoids from Loda Pahar, Kabrai area. It also discusses the geochemistry, petrogenesis and its implication to the evolution of the Archaean crust in the Bundelkhand craton of the Central Indian Shield.

Semicircular to triangular outcrop of Bundelkhand granite massif in the northern part of the Indian Shield is known to be comprised dominantly of granitoid plutons of various phases, younger basic dykes and quartz reefs, mainly the early Proterozoic magmatic events. The information on the nature of the Archaean crust into which the younger Proterozoic granitoids intruded is very much limited to the reported occurrences of numerous enclaves of schists, gneisses, banded iron, calc-silicates, mafic and ultramafic rock suites only[4].

Recently, Rahman and Zainuddin[3] identified five phases within the Bundelkhand massif and provided geochemical data to characterize their source rock from Mahoba area. The earliest phase of the hornblende-bearing granodiorite having metaluminous composition and Y depletion has been attributed to hydrous partial melting of hornblende- and/or garnet-bearing mafic source. The