

CHAPTER - III
REGIONAL GEOLOGICAL AND TECTONIC
FRAMEWORK

REGIONAL GEOLOGY

The Gujarat alluvial plains extending from NNW to SSE, tectonically lie within the Cambay basin, an intracratonic rift graben. The plains are bounded by the Aravallis in the NE and Deccan basalts in the east (Fig.3.1). Towards the west the basin is bounded by the Saurashtra horst. The rocks of the Mainland Gujarat range in age from Proterozoic to Recent. A striking feature of the geology of Mainland Gujarat is the total absence of Palaeozoic and a major part of the Mesozoic rocks. The oldest

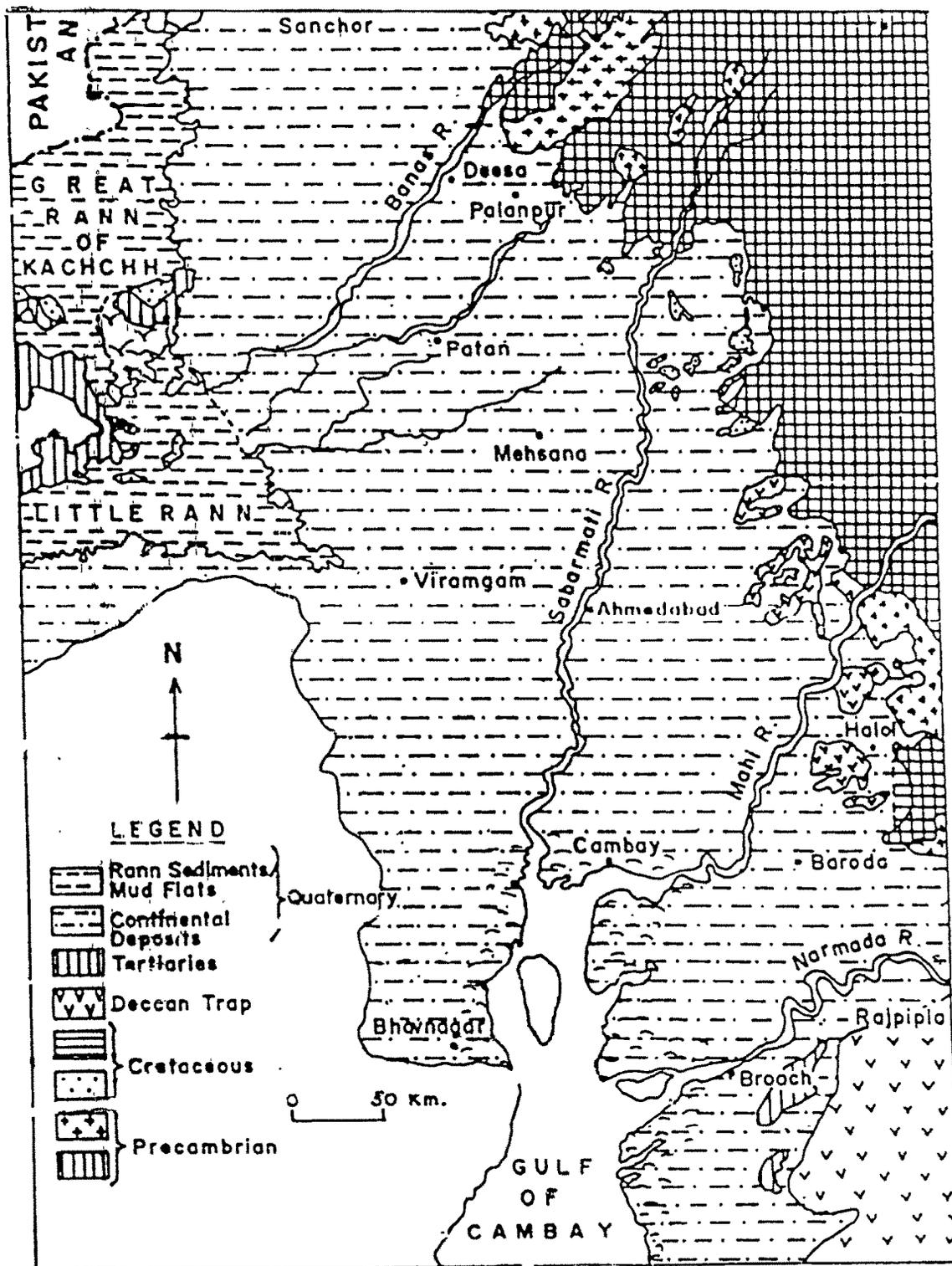


Fig. 3.1 Geological map of Mainland Gujarat.

strata that rest directly over the Precambrians belong to an age as late as Cretaceous. Surface exposures of Precambrian and Mesozoic rocks, Deccan basalts and Tertiary sediments occur in isolated localities on either side of the plains. The stratigraphic set up of Mainland Gujarat as given by Merh (1995) is as follows.

Continental sediments (fluviomarine, fluvial and aeolian)	Quaternary
Marine and fluvio-marine sediments	Tertiary
-----Unconformity-----	
Laterites	Palaeocene
Basalts of Deccan trap with associated differentiates and intrusive bodies	Upper Cretaceous to Lower Eocene
-----Unconformity-----	
Marine, Fluvio-marine and fluvial rocks (Himmatnagar, Bagh and Lameta)	Cretaceous
-----Unconformity-----	
Crystalline rocks (metasediments with associated granitic, mafic and ultramafics)	Precambrian (Proterozoic)

PRECAMBRIAN ROCKS

The Precambrian rocks of Gujarat have been described by several early workers (Middlemiss,1921; Coulson,1933; Heron and Ghosh,1938; Gupta and Mukherjee,1938; and Gupta et al., 1992). These rocks are divided into Aravalli and Delhi systems with associated mafic and granitic rocks. However, the Precambrian stratigraphy of Rajasthan and Gujarat have been radically revised during the last two

decades. The term 'system' has been replaced by 'Supergroup' and the rocks have been further classified into Groups and Formations.

Aravalli Super Group :

Only three groups of Aravalli Supergroup viz. Jharol, Lunawada and Champaner are encountered in Gujarat. The oldest Proterozoic rocks in Gujarat belong to Jharol group and are exposed in the Sabarkantha district extending into Rajasthan. The constituent rocks are phyllites, chlorite schists, garnet mica schist with intercalations of quartzites and minor bands of calc schists and crystalline limestones. These rocks very clearly show the imprints of Aravalli (E-W) and Delhi (NNE-SSW to NNW-SSE) deformational events.

The Rakhabdev ultramafic suite of Rajasthan is represented in Gujarat by the metamorphosed ultramafic rocks as strings of discrete rocks in Idar and Lunawada areas. They were emplaced during the closing period of Aravalli sedimentation when the deformation had just set in. The ultramafic belt of north Gujarat and South Rajasthan form a large regional antiform plunging due north whose limbs fall within Gujarat.

The Lunawada group, occupying parts of Sabarkantha and Panchmahals and form the uppermost sequence of Aravalli cycle. The constituent rocks are phyllite, quartzite, schist and dolomite. As a result of multiple folding, the quartzite ridges show a variety of interference patterns, refolded folds and domal structure. The rocks of Champaner group form an important and well developed Precambrian sequence of Gujarat. They are ideally exposed in the hilly areas NE of Baroda and occupy parts of

Chotaudepur, Shivrajpur and Panchmahals. These rocks are separated from the Lunawada group by granites and gneisses. The Champaner rocks unconformably overlie an older gneissic basement (B.G.C.). Lithologically they consist of meta-subgreywacke, metaconglomerate and manganiferous phyllite. The rocks have undergone one single major phase of deformation (E-W) and form an anticlinorium with west plunging antiforms and synforms.

Delhi Supergroup :

This supergroup is subdivided into several groups. Of these three groups viz. Gogunda, Kumbhalgarh and Sirohi are represented in Gujarat. The Gogunda group occupies the area to the east of Sabarmati river, NE of Khedbrahma. The rock types include quartzite, slate and calc schist. Between Shamlaji and Khedbrahma, the rocks of this group form tight plunging synclines and anticlines.

The Kumbhalgarh group is extensively developed in north Gujarat. It occupies large areas in the eastern parts of Banaskantha district comprising almost entire Danta Ambaji and Palanpur talukas. Lithologically, the group consists of calc schist, muscovite biotite schist, and ortho-amphibolites.

The Sirohi group comprises the youngest Delhis occurring within the limits of Gujarat along the northern extremity of Banaskantha district, north of Palanpur at the border with Sirohi district of Rajasthan. These rocks occupy the area around villages Kapasia and Amodra. This group is represented by rocks viz. phyllite, muscovite schist, and biotite schist with intercalated bands of calcitic marble and quartzite.

The intrusive mafic bodies are scattered all over the northern portions of Sabarkantha and Banaskantha districts within the Delhis. These form conspicuous linear exposures (sills and dykes) and also occur as plugs. The constituent rocks are olivine bearing dolerite and gabbro.

Considerable confusion prevails in literature about the various granitic events of north Gujarat and south Rajasthan. But a tentative chronology of the post Delhi granitic rocks has been proposed based on radiometric dates. It has been suggested that the granites of Godhra and its neighbourhood are slightly older than the Erinpura granite and the later is more or less coeval with the Malani igneous suite.

CRETACEOUS ROCKS

Rocks belonging to Paleozoic era are absent in Gujarat. The Cretaceous rocks directly lie unconformably over the Precambrian basement. They are also referred to as infra-trappeans as they are overlain by Deccan trap at many places. The Cretaceous rocks occurring around the study area are grouped as under

A. Mainland Gujarat

Himmatnagar Sandstone

Bagh formation

Lameta Formation

B. Saurashtra

Dhrangadhra formation

Wadhwan formation

The Himmatnagar Sandstone formation is ideally exposed around the town of Himmatnagar in Sabarkantha District on both the banks of the river Hathmati. It is well exposed along the Hathmati river and forms discrete outcrops spread over an area of about 200 sq km. The formation comprises an undisturbed near horizontal sequence varying in thickness from 30 to 60 m consisting of sandstone and shale and conglomerate. According to Biswas(1987), these form remnants of a last deltaic complex built up by the system of rivers flowing down the Aravallis into the sea in lower Cretaceous.

Within Gujarat the Bagh formation occurs as detached outcrops along the Narmada river. The exposures occur in abundance in Baroda and Bharuch districts forming conspicuous inliers with the basalts or form outliers over the the Proterozoic basement. In Gujarat, the Bagh formation is exposed as 17 outliers within the Precambrian and five inliers in the Deccan Trap north of Narmada while five inliers occur south of Narmada in Rajpipla area. Most of the outcrops show linear WSW-ENE trend and appear to be fault controlled.

The Lameta Formation mostly occurs below and along the fringes of the Deccan Trap and is stratigraphically younger than the Bagh Formation. This formation is well exposed in the districts of Kheda, Panchamhals, Sabarkantha and Vadodara. The constituent rocks are mainly limestone and sandstone of fresh water origin. Very good exposures of this formation are recorded near Balasinor in Kheda district.

In Saurashtra, the Cretaceous rocks comprise the older Dharangadhra Formation and the younger Wadhwan Formation and occupy a vast area in the northeastern part. The constituent rocks of Dharangadhra Formation are feldspathic sandstone, fine grained sandstone, quartzite, sandy clay with occasional thin coal bands. The beds are almost horizontal and point to a continental depositional environment.

The Wadhwan Formation overlies the Dharangadhra Formation more or less unconformably over which lie the basalts of Deccan Trap. The rocks comprise sandstones, sandy shale and layers of soft clay. It has been suggested that the deposition of the formation took place in a shallow marine environment.

All the Cretaceous rocks viz. the Himmatnagar sandstone, Songir sandstone, Nimar sandstone, Dharangadhra Formation and Bhuj Formation of Kutch are comparable in age.

Deccan Trap

The Deccan Trap is by far the most extensive geological formation in Gujarat. The outpourings of huge volume of basalts mark the Cretaceous-Tertiary boundary. The Deccan trap is bracketed within a short interval spanning the late Cretaceous to early Eocene with a major peak in eruptive activity around 60-65 my ago. During this period, the Indian plate was migrating northward at a rapid rate. Various circumstantial evidences place the eruptive sources in the western part of the Deccan province between Bombay and Khambhat areas.

The Deccan Trap Formation in Gujarat rest either over the Cretaceous sedimentary rocks or over Precambrian rocks. In the northern part these occur around Dahod and Jhalod along the eastern boundary of the state and scattered outcrops within the alluvial cover to the north of Baroda. Here basalts occupy an area of about 500 sq km forming a north south elongated occurrence with irregular boundaries, long narrow tongues of basalts stretch out from the main mass and rise as table topped hills. The main constituent rock is tholeiite. To the north of Baroda, the trappean inliers occur in the form of discrete outcrops around Timba, Savli-Samlaya, Sathamba, Dhansura and Modasa extending for about 100 km in N-S direction. The traps form a continuous occurrence beneath the soil cover. The Modasa inlier represents the northernmost limit of Deccan Trap in Gujarat.

In the central part lies the Pavagarh hill to the NE of Baroda and outcrops in SE of Baroda district. The Pavagarh hill about 60 km NE of Baroda rises abruptly from the low flat alluvial plain. The hill is about 5 km long and rises to about 857 m above msl. The hill represents a horst uplifted on account of NNW-SSE and WNW-ESE trending faults. The constituent rocks include varieties of basalt, rhyolite, pitchstone etc. The outcrops in the south Baroda district occupy an area of approximately 1500 sq km between the Unch river, a tributary of Heran and the Narmada that further extend eastward into Madhya Pradesh. Towards the west, beyond Garudeshwar and Naswadi, the traps go below the alluvium. The basalts and their variants here indicate explosive activity accompanied by emplacement of lava along rift related NNW-SSE and WSW-ESE faults. These form several conspicuous hills massifs. The prominent

ones being the Ambadongar hill, and the Phenaimata hill. The alkaline complex of Ambadongar is located within the Narmada rift zone and rises to over 600 m. The massif has been formed due to updoming of Bagh beds and overlying basalts. The Phenaimata hill is located on the left bank of Heran river is 3 km long and 2km wide with a plateau at about 425m. In Panwad- Kawant area, a large number and variety of dykes and plugs intrude the lava flows, Bagh sandstones and the Precambrians. These dykes show two trends ENE-WSW and NNW-SSE and comprise several varieties of alkaline rocks.

In the southern part, the exposures occur in upland areas around Rajpipla and highlands of Dangs district. The area is hilly and is characterised by E-W trending rows of hills that rise 20-30m above the ground. The constituent rocks are tholeiite and alkaline varieties. Upto Tapti and the highlands of Dangs district, The terrain is dominantly made up of basaltic flows continuing east and south into Maharashtra and are extensively intruded by younger dykes.

In Saurashtra, the basaltic rocks of Deccan trap cover a large area and are prominently exposed. The common rock type is a fine to medium grained compact greyish black basalt and their varieties. On the eastern side they are terminated by the Quaternary rocks. Numerous trap dykes cut the basalt and show three main directions ENE-WSW, E-W and NW-SE. These are structurally controlled and follow major fracture lineament trends.

Laterites

Laterites are important Palaeocene rocks of Gujarat. As compared to Kutch and Saurashtra, the laterites are less developed in mainland. Here they occur in a linear belt and form two groups of exposures, one in north Gujarat in the Sabarkantha (Bayad) and Kheda (Kapadvanj) districts and the other in Bharuch, Surat and Valsad districts. In north Gujarat these form low mounds rising a few meters above the ground level. Bentonite, Kaolinite and bauxite are important constituents of the laterite. These occurrences mark a major NNE lineament, a fault zone coinciding with the eastern flank of the Tertiary Cambay basin. In Saurashtra and Kutch the laterite occupies the eastern parts. All these laterites have been exclusively derived from the *in situ* decomposition of basaltic rocks, pyroclastic material or brecciated and fracture lava flows.

TERTIARY ROCKS

The exposed part of the Tertiary rocks form a very small area. A large part of the Tertiary rocks are buried below the thick alluvium of Gujarat alluvial plains. The Tertiary rocks are exposed in two patches between the Narmada and Tapti rivers. Most of the formations are in the subsurface and hence the exposed part is fragmentary. The Olpad, Ankleshwar, Kathana, Broach and Jambusar Formations occur in the subsurface only.

REGIONAL TECTONIC SETTING

The western continental margin of the Indian plate has evolved as a result of rifting along major Precambrian trends (Biswas, 1982). The Kutch Cambay and Narmada basins are the three major marginal rift basins bounded by intersecting sets of faults whose trends follow the three important Precambrian tectonic trends viz. the Aravalli, Dharwad and Satpura trends (Fig.3.2A). The Saurashtra occurs as a horst block between the rifts. The ENE-WSW Narmada-Son lineament which parallels the Satpura orogenic belt, is a major tectonic boundary (West, 1962; Mathur et al., 1968; Choubey, 1971) dividing the Indian shield into a northern peninsular block and a northern foreland block. The Dharwad trend parallels the faulted west coast of India (Fig.3.2B). The Cambay basin is the northward extension of this trend. The third important trend is the NE-SW Aravalli trend which splays out into three components at its south-western extremity (Biswas, 1987). The main NE-SW trend continues across the Cambay graben into Saurashtra as a southwesterly plunging arch. The northern component of the trend is the Aravalli orogen and Delhi fold belt, which swings to E-W and continues into the Kutch region across the Cambay graben. The Kutch basin rifted along this trend.

The geology of these basins show that each has its own history of development independent of the others. However, there is a synchronicity in the tectonic evolution of these basins and the major events of plate tectonics (Biswas, 1982). These basins opened up one after another from north to south (Fig.3.3) as the subcontinent drifted

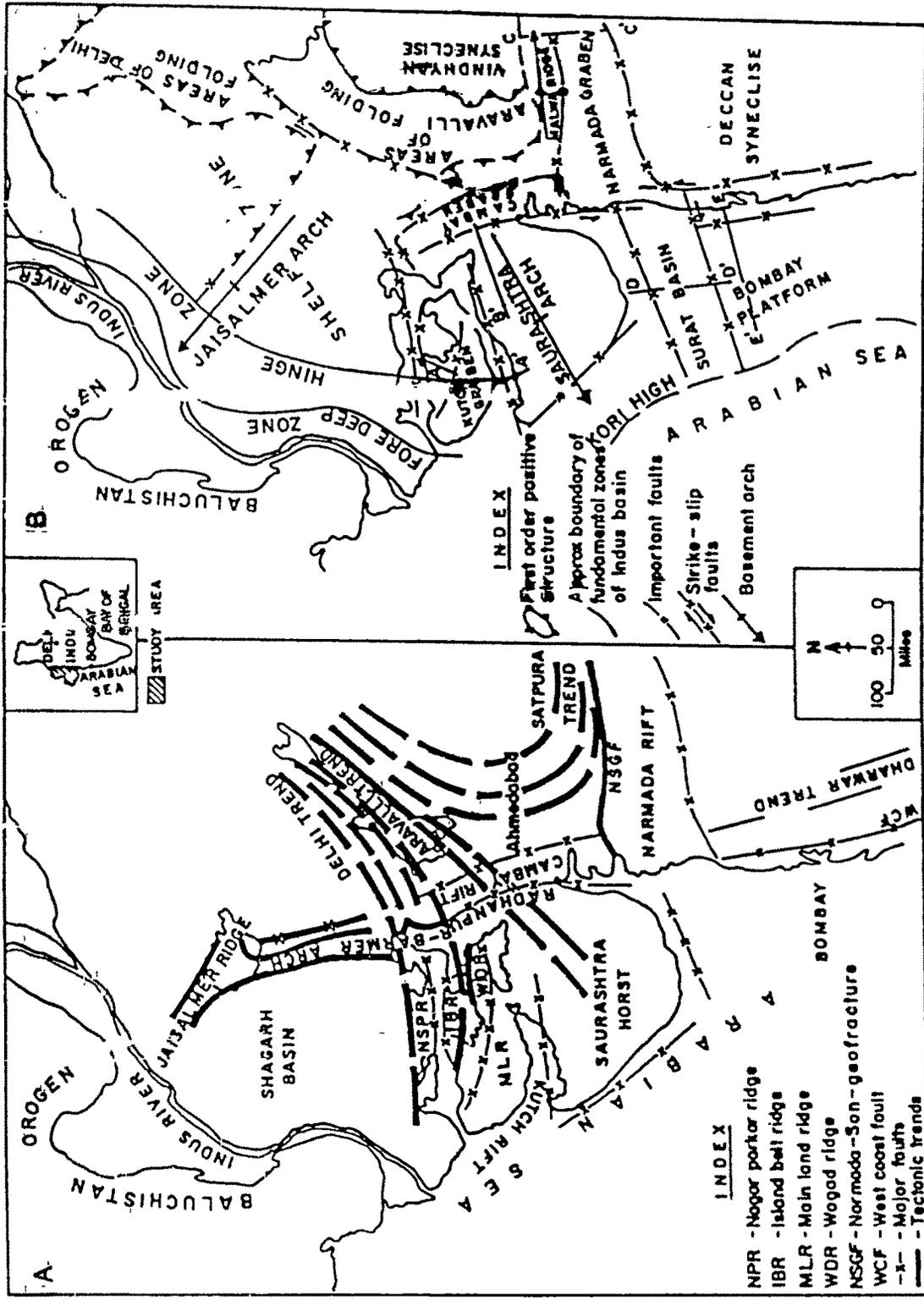


Fig. 3.2 A. Major tectonic trends in western India B. Regional tectonic framework of western continental margin (after Biswas, 1987)

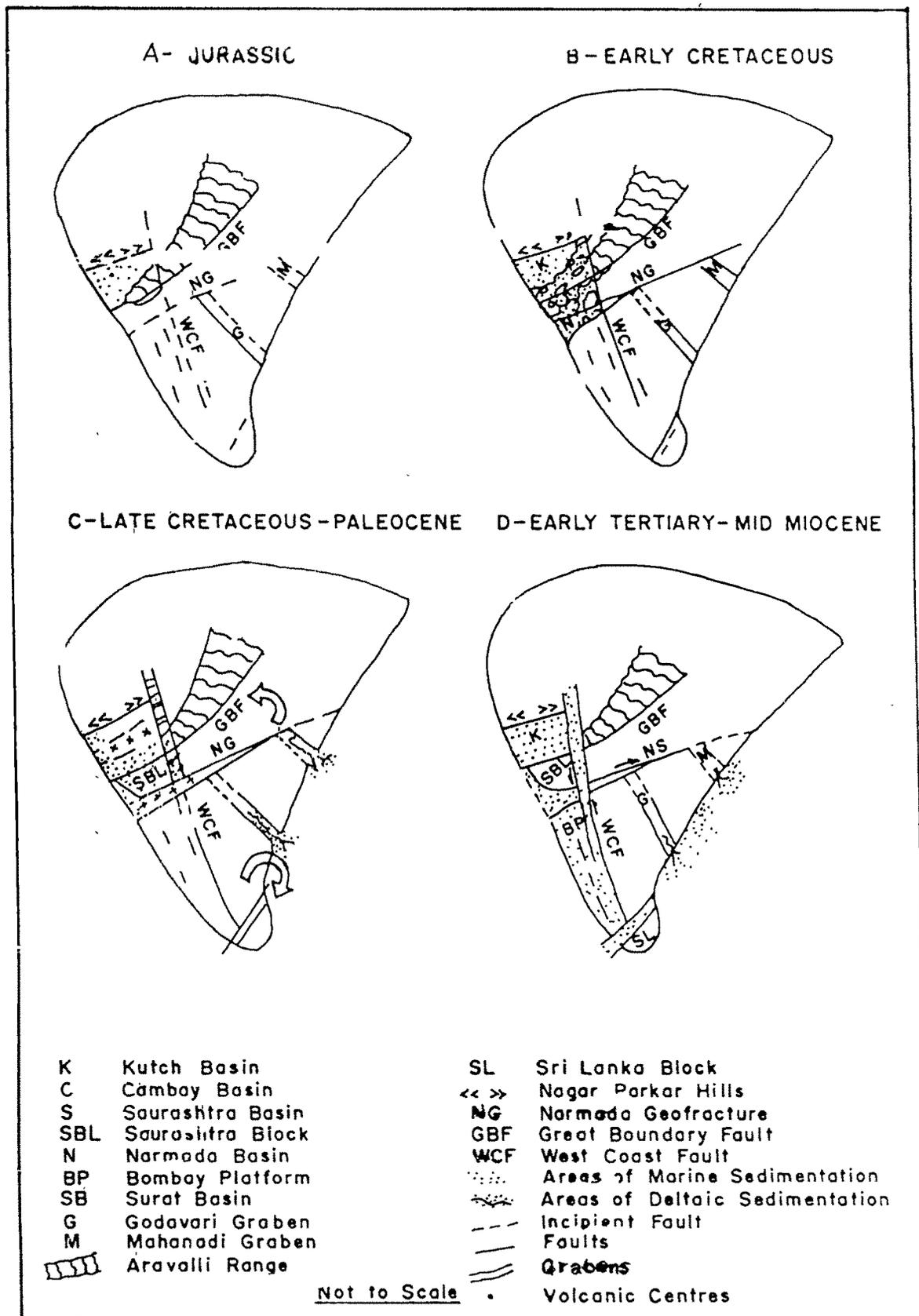
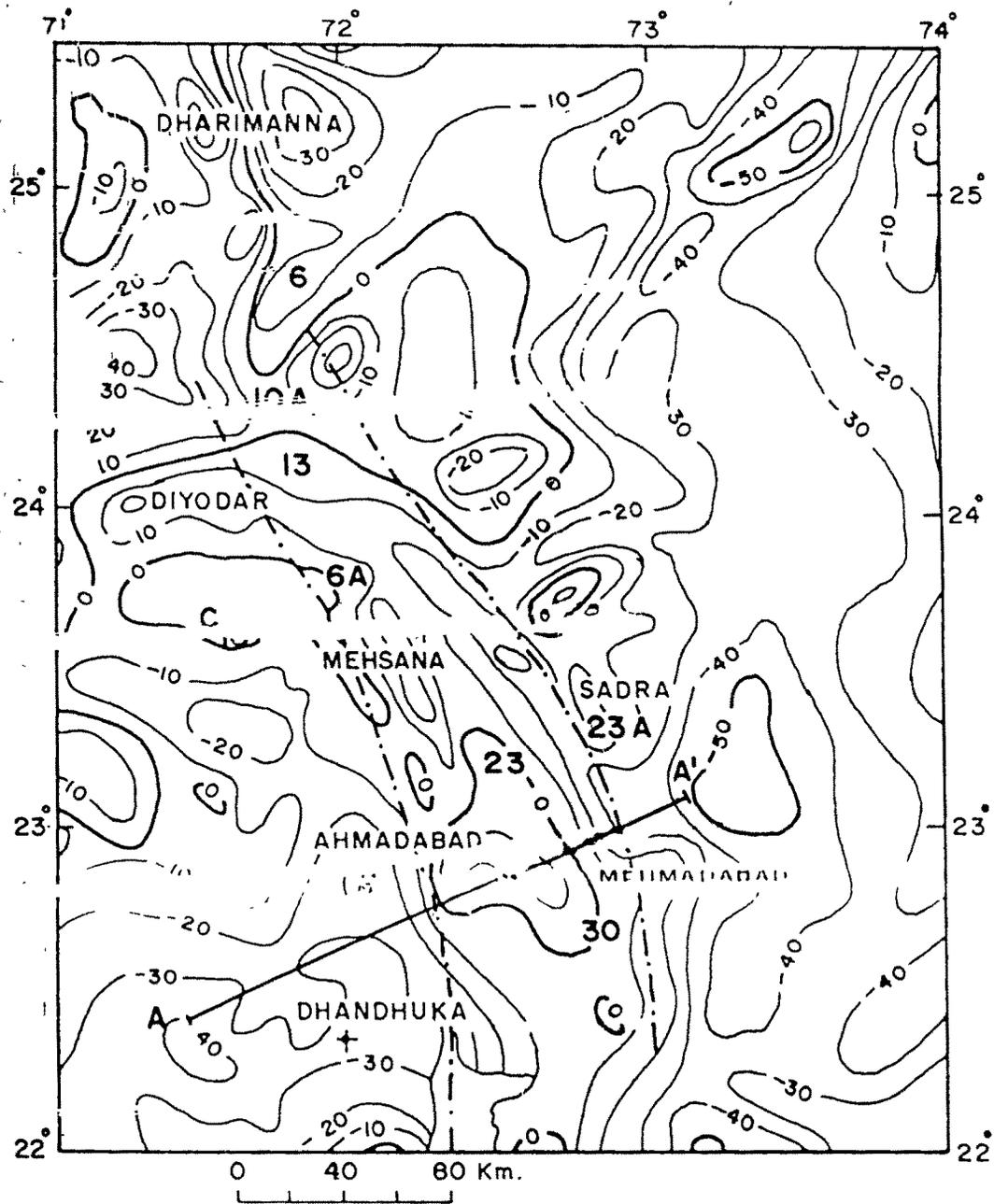


Fig. 3.3 Stages in evolution of rift basins in western India (after Biswas, 1982)

northward at an increasing pace and rotated counter-clockwise during the Mesozoic (Biswas, 1982). The basins developed seriatim, starting with the Kutch basin in the early Jurassic, Cambay basin in Early Cretaceous and Narmada basin in late Cretaceous. These three periods of basin formation are correlatable with the three important stages of the drifting history of the Indian subcontinent.

The evolution of the western marginal basins is related to the break-up of the Gondwanaland in the Late Triassic/Early Jurassic (Norton and Selater, 1979) and the subsequent spreading history of the Eastern Indian Ocean (Biswas, 1987). The main tectonic event took place in the Late Cretaceous (Biswas, 1987) when the drift motion was at its maximum at an average rate exceeding 15 cm/year (Powell, 1979). The three marginal basins evolved in four stages (Biswas, 1982) as depicted in the figure 3.3.

The Saurashtra horst remains as a foundered horst between the three intersecting rifts. It is a more or less square shaped block tilted to the SW. The Cambay basin occupies narrow NNW-SSE trending graben in the eastern part of the Saurashtra Kutch shelf. A linear positive feature of low magnitude indicated by the gravity map (Fig.3.4), separates the graben from the Kutch and Saurashtra (Biswas, 1987). This high known as the Radhanpur-Barmer arch extends along the western margin of the graben. Evidently this high is the result of the uplift of the western shoulder of the Cambay graben. This arch crosses the Nagar- Parkar Tharad ridge almost at a right angle near Tharad. The Aravalli and Delhi trends which cross the Cambay graben are seen as important cross trends within the graben in the



LEGEND

-  Bouguer Gravity Contours
In Mgals
-  Gravity Profiles
-  Basin Margins

Fig. 3.4 Gravity anomaly map of the area (after Tewari et al., 1991)

numerous transverse and oblique faults, uplifts and geomorphic lineaments (Biswas, 1987). The important river courses like the Banas, Saraswati and Sabarmati across the basin also illustrates such cross trends. These cross trends across the Cambay graben continue into Kutch where they form the major longitudinal trend (Biswas, 1987). The Cambay basin is bounded by enechelon faults paralleling the Dharwad trend and cuts across the Narmada and Aravalli trend (Biswas, 1982). The basin extends to the south as a narrow graben parallel with the coast, between Bombay high and Mainland (Biswas, 1982). The evolution of the Cambay basin during the Tertiary can be traced through four stages of development- formative, negative, oscillatory and positive, which characterize it as an aulacogen(Raju, 1968). Raju(1969) also described it as an aborted rift graben.

Both Cambay and Bombay regions have high geothermal gradients (Fig. 3.5) which are believed to be responsible for oil and gas generation in the sediments rich in organic mater. Gupta et al. (1970) attribute the high heat flow in Cambay basin to Miocene-Pliocene igneous intrusion in the crust beneath the basin. However the high heat flow regime is an extensive one encompassing Cambay and Bombay basins and it appears to be a regional phenomenon in the western margin (Biswas, 1982). The high heat regime, localization of eruptive centres and basic igneous complexes along the western margin and associated rifts (Biswas et al, 1973) and the fact that Cambay is an aborted rift or aulacogen (Milanovsky, 1972; Thompson, 1976; Raju, 1979) possibly indicates thinning of the lithosphere. Deep seismic sounding data indicate the depth of the mantle as 20-25 km near Surat north of Bombay (Kaila et al 1979).

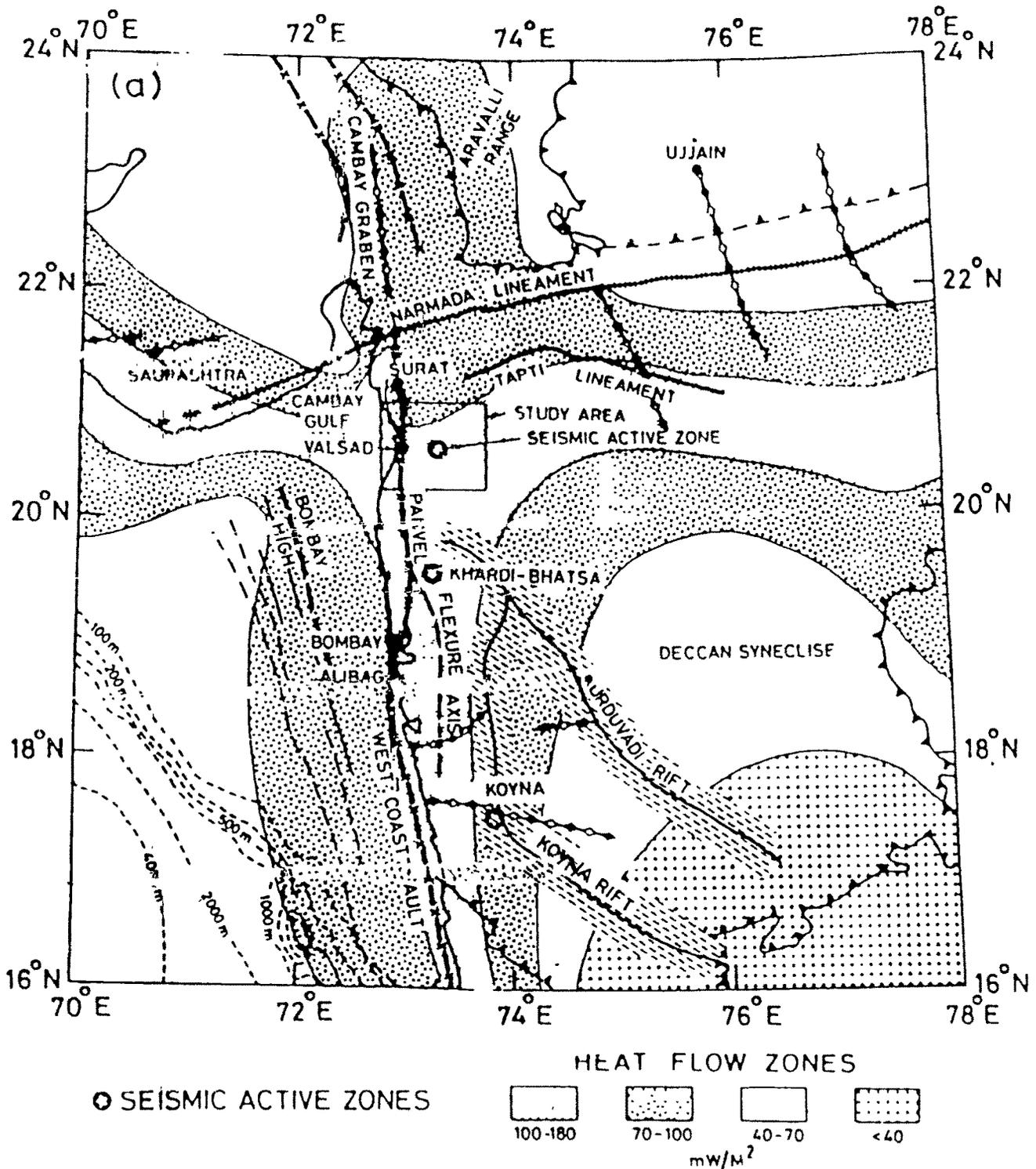


Fig. 3.5 Heat flow zones in Western India (after Arora and Reddy, 1991)

The thinning of lithosphere and consequent rise of asthenosphere (Royden et al 1980) seems to be the cause of the heat flow in this region. This might have happened at the time of rifting in Early Jurassic (Biswas, 1982). The present high geothermal gradient indicates that the marginal rifting is still active and thermal equilibrium by cooling of the lithosphere has not yet been attained (Biswas, 1982).

Both the Narmada, Tapi and the west coast tectonic belts are characterised by positive gravity anomalies, high thermal gradients, high heat flow and seismic activity (Kailasam et al., 1972; Quereshy, 1982, Gupta and Gaur, 1984, Ravishankar, 1988). An intense linear Bouger anomaly along the west coast is considered to be related to deep seated causes marking areas of crustal thinning and asthenospheric upwarping (Quereshy, 1981). This postulation has been largely substantiated by deep seismic sounding studies which indicates that the region from Surat to Bombay is of Moho upwarp (Kaila, 1986; 1988). The manifestation of thermal activity in the form of hot springs (Fig. 3.6) is taken by Murthy (1981) to indicate that magma beneath the west coast chamber has not cooled completely. Chadha (1992) established the relationship of hot springs to geological contacts, tectonic units and earthquakes. These thermal springs occur either near the contact of two geological units or along prominent tectonic units. These springs issue from Deccan traps or surficial deposits and none from Precambrian rocks (Snow, 1982).

The seismic results of Kaila et al. (1980) also indicate a shallow depth of the mantle 20-25 km near the junction of the Cambay and Narmada rifts. These two major conjugate rift systems cross each other in the Cambay gulf region and together with

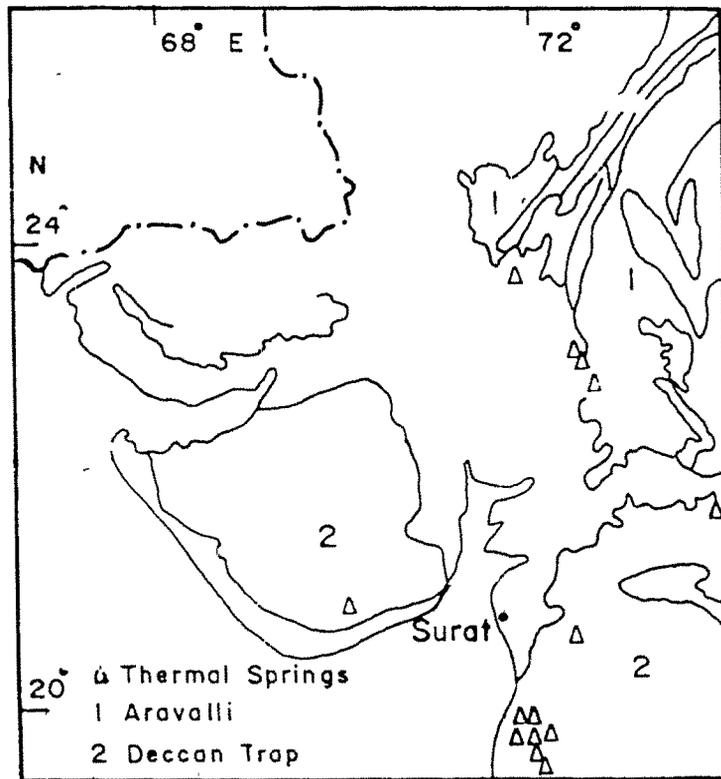


Fig. 3.6 Location of hot springs in Western India (after Chadha, 1992)

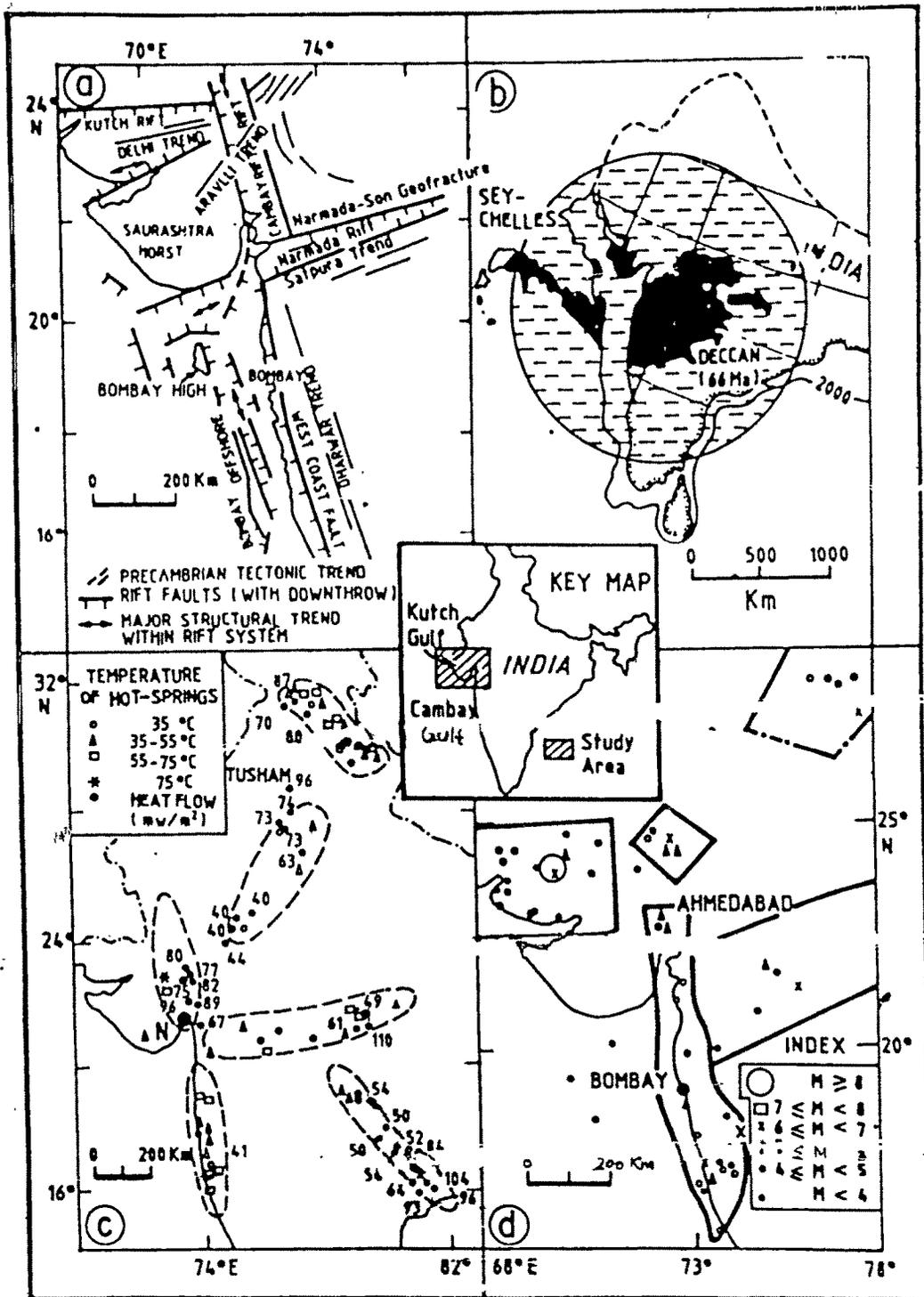


Fig. 3.7 Radial pattern of (a) tectonic trends (after Biswas, 1987) (c) heat flow and hot spring (after Gupta et al., 1989) (d) seismicity (after Khattri et al., 1984) after the out burst of (b) Reunion plume head near the Cambay node (Figure cf. Raval, 1995)

the west coast fault define an area which has been identified by many as a triple junction (Burke and Dewey, 1973; Bose, 1980). Burke and Dewey (1973) have attributed the Mauritius- Reunion plume to be the cause of this junction. This contention is further supported by a magnetisation map deduced from an inversion of the MAGSAT anomaly map (Singh et al., 1989) where the area of the triple junction is seen as a region of relatively low magnetisation, signifying a thin magnetic crust and form an elevated temperature at depth and high electrical conductivity (Adam, 1978). The geological and geophysical data thus clearly indicates that the region around the Cambay rift represents a region of Moho upwarp.

Biswas (1987) is of the opinion that the Cambay Graben is displaced westward by the right lateral Narmada tear fault, which continues southward parallel to the west coast. The ECBMF of this extended graben is reckoned to correspond to the west coast fault. The geophysical anomalies in the Gulf of Cambay region is reflected as a radial distribution of activity (Fig. 3.7) from the node (Raval, 1995). The electrical conductivity anomalies, the heat flow and seismicity observed over the subcontinent are in figure 3.7 and these may also reflect the plausible inferences of the collision dynamics. The figures show a preferential concentration of high heat flow, hot springs, seismicity, gravity, magnetic and electrical conductivity anomalies in the MA (mobile arm) and Delhi-Aravalli MA implying that the geodynamical forces are perhaps active within these mobile arms (Raval, 1995). According to him, the radial uplifts around the Cambay-Bombay node (triple junction) and the associated bounding fault systems are likely to be zones of higher seismic activity due to

compressional stress superposed by the convergence and possible presence of fluids. This is corroborated by the seismicity observed along the Satpura, Delhi-Aravalli, Nagar Parkar ridge, and Jaisalmer-Mari arch (Raval, 1995).