CHAPTER - VI

STRUCTURAL STYLE AND TECTONIC FRAMEWORK

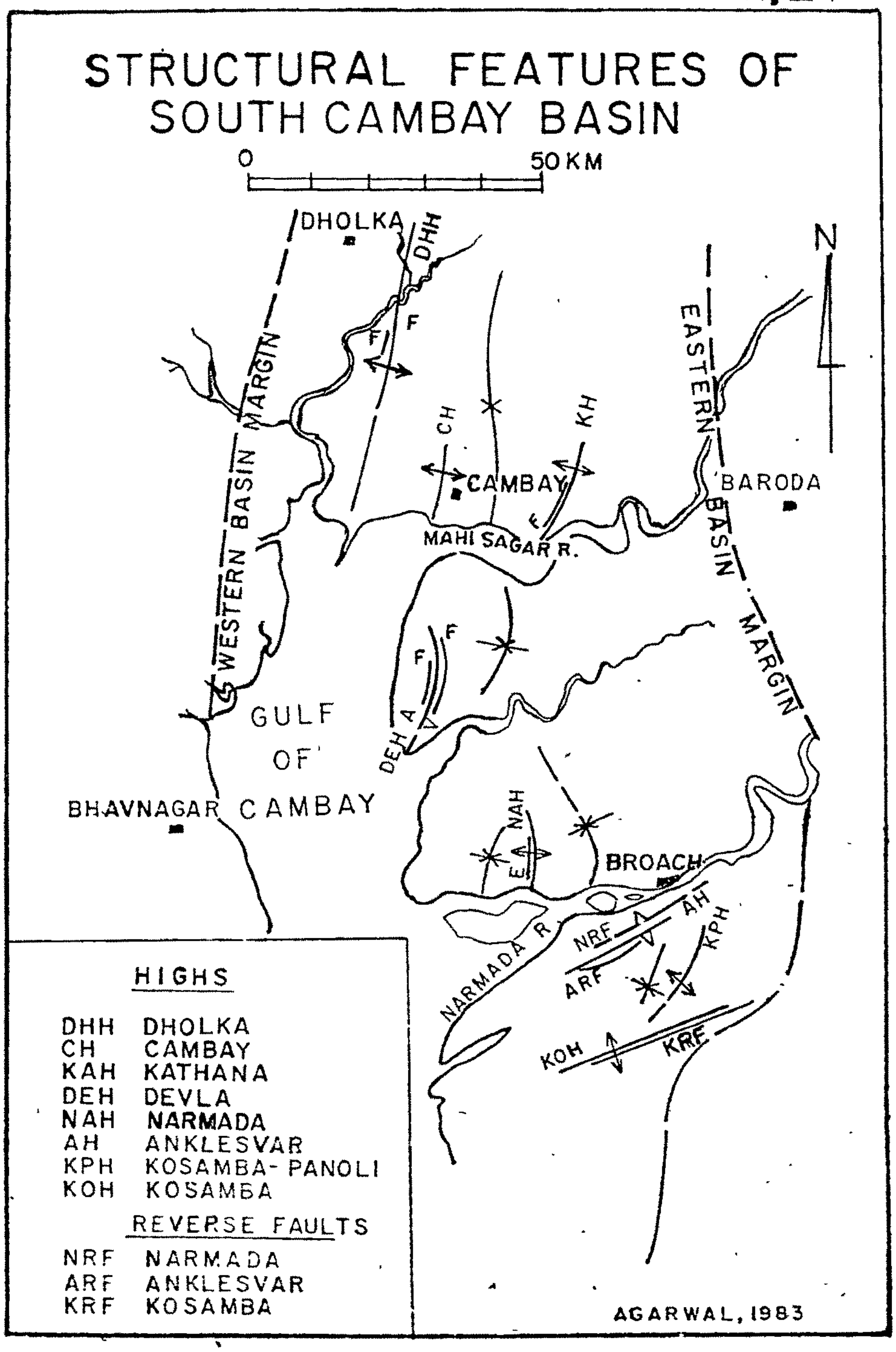
GENERAL

The Cambay basin is an intra-cratonic rift basin trending N-S situated between the Saurashtra peninsula to the west, the Aravalli ranges to the east, and the Deccan plateau to the SE. The basin extends southward through the Gulf of Cambay into the Arabian sea. The study area is located in the southern onland basinal part of the Cambay Tertiary basin. In the whole of Cambay basin the Tertiaries lie under the cover of Quaternary sediments excepting in the area of study, between the Narmada and Kim river, and in other two areas i.e. between the Kim and Tapti rivers and Bhavnagar coastal areas, where the Tertiaries were folded, faulted and uplifted. Regionally, the study area falls within the superimposed tectonic belt of the Narmada rift basin which trends SW in the Narmada valley and also across the Gulf of Cambay. Thus, the structural style of this part of the Cambay basin, within which the study area falls, is unique in many ways. Another important aspect, of the structural setup is that several tectonic phases have affected the study area.

The structural style of the study area is of great significance as it falls within that part of the Narmada tectonic belt that crosses the Cambay basin.

North of the Narmada river, the subsurface structural trends in the Tertiary sediments of the Cambay basin, are nearly N-S whereas south of the river, including the study area, the trends are SW to WSW, and the change is rather abrupt (Fig.VI.1). Further, the exposed Tertiaries of the study area exhibit linear anticlinal structures trending SW toWSW, plunging SW to WSW and invariably flanked by reverse faults along southeastern limbs. These anticlines also show a south-westerly plunge, and occasionally toward NE. The entire Tertiary sequence is folded and faulted and the overlying Quaternary sediments also show evidences of neo-tectonic

Fig VI·1


STRUCTURAL FEATURES OF
SOUTH CAMBAY BASIN
0
50 KM
N
DHOLKA
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BROACH
NARMADA R
NRF
AH
KPH
ARF
KOH
KRF
HIGHS
DHH DHOLKA
CH CAMBAY
KAH KATHANA
DEH DEVLA
NAH NARMADA
AH ANKLESVAR
KPH KOSAMBA-PANOLI
KOH KOSAMBA
REVERSE FAULTS
NRF NARMADA
ARF ANKLESVAR
KRF KOSAMBA
AGARWAL, 1983

activity, which had uplifted the Tertiaries and exposed them.

The latitudinal Narmada rift basin came into being possibly as a result of tension created by the counterclockwise rotation of the Indian plate (Biswas 1982), and its two northern and southern sub-plates across the Narmada geofracture, in mid-Jurassic (Agarwal,1984). The Late Mesozoic sediments, deposited in the Narmada rift basin and subsequently covered up by the Deccan Trap basalts during Late Cretaceous to Paleocene times, in the western part, were down-faulted as a part of the Cambay Tertiary rift basin along meridional tensional-faults.

The upliftment accompanied by folding and faulting of the Tertiaries in the area of the Cambay basin between the Narmada and Tapti rivers, falling within the Narmada tectonic belt, was possibly related to the Late Cenozoic tectonism, and the present author has explained by invoking it with the collision of the Indian plate with the Asian plate, narrowing the Narmada basin gap by the convergence of the two Indian sub-plates during the Late Cenozoic final welding of the Indian plate with the Asian plate.

<u>STRUCTURAL FEATURES OF THE STUDY AREA</u>

The Tertiaries in the study area have been folded into several narrow anticlinal structures separated by gentle synclinal lows. At times, the folds are well expressed by geomorphological characteristics also. The folds in the northeast of the study area are tight comparatively and faulted, the beds showing steep dips, whereas in the central and southwestern parts, their folds are gentle. Occasionally the beds near the faults exhibit higher dips. The southeastern limbs of the anticlines are almost invariably faulted, trending SW. A total of eleven anticlinal features have been mapped within the limits of the study area (Fig.IV.1). From NE to SW, they are: (1) Jhagadia, (2) Bhuri, (3) Padwania, (4) Gallyaphalla, (5) Hutiyapur, (6) Talodra, (7) Limet, (8) Vagadkhol, (9) Dungri, (10) Dinod, and (11) Kosamba. Out of these 11 anticlinal structures, 5 of them viz. Nos. 3,4,5,6 and 7 have been recognised on the geomorphic characteristics. The synclinal areas in between these anticlinal structures comprise very gentle lows and are not well defined. The northwestern part of the study area shows gentle dips due NW. In fact, it is observed that the various anticlines and synclines listed above, are superimposed over an originally NW dipping beds. The drainage pattern of the area and the occurrence of exposed cherry-red sandstones/agate conglomerates and foraminiferal limestones as linear outcrops within the cores of the anticlines have facilitated the mapping of these otherwise gentle flexures. To the south-east of Dinod and Dungri structures the presence of anticlinal highs and synclinal lows have been interpreted with help of geomorphic highs and the trend of stream courses following the lows. These features are viz. the Gondhwa low, Velacha high and the Kim low, identified only by geomorphic characteristics and have been dealt with in the following chapter (Chapter IX).

DETAILS OF INDIVIDUAL STRUCTURES

The detailed description of individual structures in respect of their trend, length, attitude of beds, stratigraphic sequences involved, nature of associated faulting and the overall relationship of the structures with the structural set up of the study area are given below:

(1) JHAGADIA ANTICLINE

This anticlinal structure is located in the NE part of the study area and extends between Rajpardi and Jhagadia towns (Fig.IV.1). It trends SW near Rajpardi and swings to a WSW trend near Jhagadia, and is 9 km long and 2 km wide. It is an asymmetrical anticline, plunging due WSW and faulted along it's SSE limb. The crest of the anticline runs close to the fault, terminating against it almost half way along its length. Further extension of the Jhagadia anticline to the NE close to the Rajpardi town and Sirsia rhyolite hill, gets covered by the alluvium. In all probability the anticline terminates against the N-S trending Trap rocks. From the outcrop pattern it appears as if the Sirsia rhyolite hill which trends SW and occurs in the anticlinal core of the Jhagadia anticline could as well be an inlier exposed due to an uplift and erosion.

In the core of the anticline the conglomerates of the Babaguru formation are exposed, overlain by Kand and Jhagadia formations. The hard and compact calcareous bands in all these formations, show high dips upto 60 degrees, and their differential erosion easily marked on the air-photos enabled the author to map the various bands in the field. The geological map of the area (Figure IV.1) clearly exhibits these bands and a pronounced WSW plunge beyond Jhagadia to the SW extension of this plunging anticline is obscured by the alluvial cover. A good stratigraphic section, anticlinal crest and the Jhagadia fault are very well seen in the Ratanpur Ni Nadi cutting 3 km east of Jhagadia town. The NW limb of the Jhagadia anticline abruptly ends up, and is represented by the left paleo-bank of the Narmada river flowing close by. As the alignment of the paleo-bank is parallel to the strike of the beds of Jhagadia anticline, it is most likely that a strike fault marks the boundary and lies concealed under the Narmada alluvium.

The WSW trending fault along the ESE limb of the Jhagadia anticline has its upthrown side toward NW. It is a reverse fault hading due NW. The older rocks of the upthrown side abut against the younger rocks as seen in the map (Fig.IV.1).

(2) BURHI ANTICLINE

The Burhi anticline occurs close to the Jhagadia anticline to the NE of study area (Fig.IV.1). The Burhi village is located along the axial part of the anticline, and trends SW. It is 5 km long and 1 km wide. It is a narrow structure and better recognised from the air-photos. The crestal part of the anticline is a near flat ground due to the exposures of variegated clays of the Vagadkhol formation, which has developed a good cultivable land amidst Ratanpur reserved forest. The Jhagadia reverse fault limits its NW extent. It shows a SW plunge and its NE extension seems to merge with the Jhagadia anticlinal axis, and the Sirsia rhyolite hillock to the NE appears to occur as an inlier along the merged anticlinal axes of the Burhi and the Jhagadia anticlines.

(3) PADWANIA ANTICLINE

Padwania anticline is situated in the eastern part of the study area adjoining the Deccan Trap (Fig.IV.1). It is a very gentle anticline trending WSW for a length of 3 km. The anticlinal features are well marked on air-photos, forms a gentle geomorphic high exposing the variegated clays of the Vagadkhol formation and the cherryred sandstones and conglomerates of the overlying Babaguru formation within its core. A WSW trending fault has been inferred along its SSE limb.

(4) GALLYAPHALIA ANTICLINE

This anticline is located south of the Padwania structure in the eastern part of the study area (Fig.IV.1). It is represented by a gentle flexure trending SW, and forms a gentle geomorphic high. Like the Padwania structure, it is also recognised on the air-photos by tonal anomalies. In the core of this anticline cherry-red sandstones and conglomerates of Babaguru formation are exposed. It is interesting to note that to the ENE of Padwania and Gallyaphalla structural highs, hillocks of Deccan Traps with Rampur and Kariya reserved forests are present. It is quite likely that like the Sirsia inlier these Trap hillocks might also have been uplifted along with the Tertiaries of these anticlines.

(5) HUTIYAPUR ANTICLINE

This structure forms a gentle geomorphic high and its outline is not well defined. On the basis of the geomorphic expression, its trend is SW to NE, the SW trending hills of Deccan Traps are seen near Koyali Vav village indicating the simultaneous uplift of Deccan Traps and Tertiaries together (Fig.IV.1). Near village Huthiyapur conglomerates, hard and compact, pebbly and gritty of Vagadkhol formation are exposed.

(6) TALODRA ANTICLINE

The anticline is located near the Talodra village and trends WSW (Fig.IV.1). It is 8 km long and nearly 2 km wide. It plunges due WSW and the NNE limb is gentler than the SSE limb. Near village Darmuda, the cherry-red sandstones dip 48 degrees due SSE. On air-photos WSW trending lineaments are seen close to the above described observation point suggesting presence of a fault along the SSE limb of the Talodra anticline. All along the gentle crestal part of the anticline cherry-red sandstones and agate conglomerates are exposed, and these rocks being resistant to weathering, form high mounds easily identifiable in the field as geomorphic highs.

(7) LIMET ANTICLINE

It is located south of Talodra anticline, and the village Limet is located near its anticlinal axis (Fig.IV.1). It trends WSW and has a length of 7 km and a width of one-and-a-half km. The anticline shows a plunge due WSW and a well marked fault designated as 'Limet fault' cuts its SSE limb just south of the Limet village. This fault is clearly seen as a lineament on the air-photos, and the conglomerate beds of Kand formation are seen as vertical beds along the right bank of the Amravati Nadi south of Limet village (Plate V.6.C). The fault is of reverse type, and the older cherry-red sandstones and agate conglomerates of Babaguru formation are faulted against the sandstones and conglomerates of Kand formation which are younger, and the fault hades due NNW.

(8) VAGADKHOL ANTICLINE

The anticline is located a little north of Vagadkhol village, trending SW, and the anticlinal crest, exposing the variegated coloured clays, agate conglomerates, lateritic agate conglomerates, and gritty sandstones are ideally seen to the NE of the village and along a small tributary of Amravati Nadi (Fig. IV.1). The Vagadkhol anticline is 4 km long and 1 km wide. One km east of Vagadkhol village, an exposure (1 km by 2 km) of variegated clays of yellow, pink and red colours is observed and it seems to form the SE limb of the anticline and represents the upper part of the Vagadkhol formation. The anticline is in a general alignment with that of Dungri anticline to the SW.

(9) DUNGRI ANTICLINE

The Dungri anticline is situated in the SE part of the study area and trends SW (Fig.IV.1). It is 10 km long and 1½ km wide. It is a narrow anticline flanked by the Quaternary sediments to the SE. It is a gentle anticline, marked by a distinct water divide forming a pronounced geomorphic high, in which foraminiferal limestones are exposed all along its crestal part. The gentle anticlinal flexure is clearly seen south of Valia town. The limestone quarries, near village Kanerav, show gentle dips of nearly 5° on either sides of the anticlinal axis and also a NE plunge. The overlying cherry-red sandstones and conglomerates of Babaguru formation are seen exposed to the NW of the Dungri anticline and good exposures representing cherry-red soil are seen along the road joining Siludi and Valia towns. The anticline plunges due SW and passes beneath the Quaternary sediments and Kim river alluvium. However, from geomorphic expressions, its further SW extension is marked as Velacha High, between the SW flowing Gondhwa and another small tributary of Kim river.

(10) DINOD ANTICLINE

The Dinod anticline is located in the southern part of the study area and trends SW-NE (Fig.IV.1). It is a pronounced doubly plunging anticline, and could be distinctly mapped from the air-photo. On the ground it has been mapped taking the help of bright bands on the air-photos, represented by the foraminiferal limestones which are very hard and compact. Good exposures of coquina limestones are seen along a small stream ½ km east of Dinod village. In the quarries, ½ km south of Dinod village yellow coloured limestones of Dinod formation are exposed. The anticlinal axis is also exposed in the quarries, and the NE and SW gentle dips on either sides of the axis are ideally seen here. The dip values range between 5° to 10°.

Although no fault on the SE side of the Dinod anticline could be recognised either from air-photo or by field mapping, but considering the general outcrop pattern and the abrupt end of limestones SE of the anticline, beneath the alluvial cover, the presence of a fault along the southeastern limit of the anticlinal outcrop is suggested.

(11) <u>KOSAMBA ANTICLINE</u>

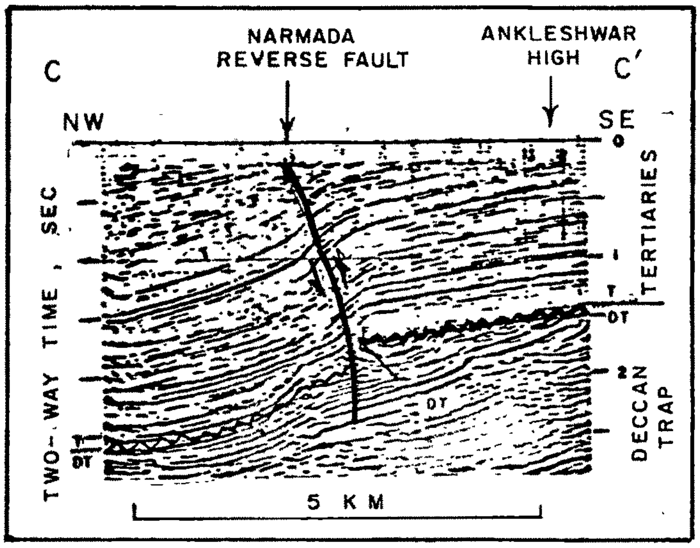
This structure is located to the SW of the study area, and trends SW (Fig.IV.1). It is a broad and gentle anticline showing a SW plunge. The NE-ward axis of the anticline passes through Nandav village and is seen to align itself with that of Dinod anticline (No.10). As such, the length of the Kosamba anticline, from the SW limit of Dinod anticline to the point where it crosses the Kim river and then gets covered up by the alluvium, is 18 km. The SE limb of the anticline is abruptly terminated against the Kim river alluvium due to a SW trending fault along the SE limb of the anticline. This fault designated as the 'Kosamba fault', is a reverse fault hading due NW. It is also clear from the known subsurface geological (Fig.VI.2.B) and geophysical data that it is a reverse fault (Agarwal,1984). The NW limb of the anticline is wide and has low dips. NW of Kosamba town, it gets concealed under the Quaternary sediments.

Regionally, the NW limb of the Kosamba anticline extends NE and forms the common limb of the Dinod anticline as well.

Fig. VI·2

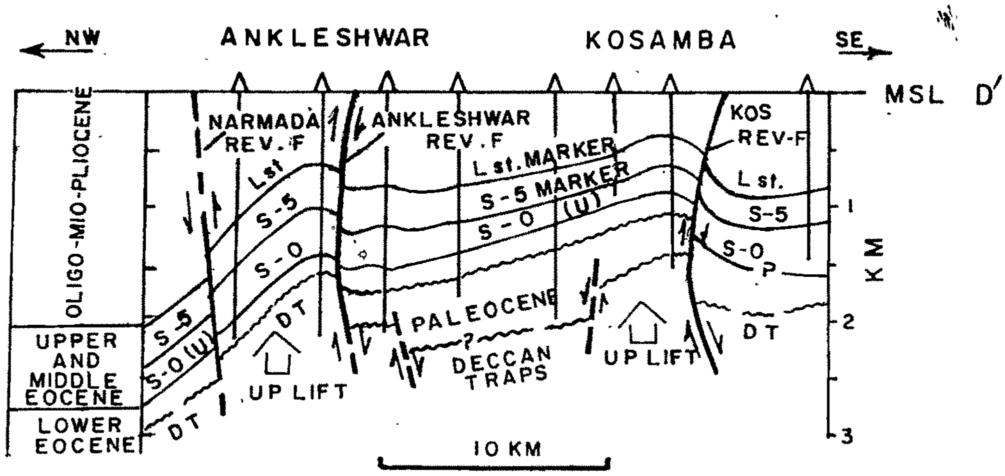
FOLDING AND REVERSE FAULTING OF TERTIARIES

A



NARMADA REVERSE FAULT IN SEISMIC SECTION (FOR LOCATION SEE Fig. IX-1)

B



Geological section across Kosamba and Ankleshwar structures

(For location see fig. IX-1)

AFTER AGARWAL, 1984

In other words, the Dinod culmination is along the same anticlineal axis as those of Kosamba and Dinod structures. Another small and partially exposed culmination is observed in between Kosamba and Dinod anticlines. A small patch of foraminiferal limestone is exposed along the Kosamba anticlinal axis near village Nandev overlain by the cherry-red sandstones and agate conglomerate of the Babaguru formation toward NW which are in turn overlain by Kand formation. The calcareous sandstones, conglomerates, and calcareous clays of the Kand formation forming the NW limb of the Kosamba anticline pass beneath the Quaternary sediments toward NW.

A good evidence of Kosamba fault is recorded along the right canal cutting a little south of village Nandev. Here, the limestone of Dinod formation dips steeply with an angle of 65 degrees due SE. This sudden steepening of dips is due to a steep flexure near the fault.

TECTONIC SETTING

The detailed study of individual structures described earlier in this chapter, has shown that their SW to WSW trends are generally bounded by reverse faults close to their SE limbs. The structures show a SW plunge excepting the Dinod and Dungri anticlines which are doubly plunging anticlines. Due to the SW plunge older rocks are exposed to the NE. It is interesting to record that to the north of the study area, across the Narmada river, the subsurface Tertiaries reveal structural trends which are at right angles to that of the study area. The tedtonic setting of the study area is such that the Tertiaries have been folded, uplifted and partially eroded, whereas in the north, they have remained tectonically undisturbed. The deformation of the Tertiaries of the study area has been interpreted as related to the Late Cenozoic tectonic activity effecting the Narmada tectonic belt within which the study area falls. Although, the Tertiaries of the area were forming part of the N-S trending Cambay rift basin, the WSW to SW tectonic trends of the Narmada basin must have also been present in this part of the Cambay basin. Subsequently, in Late Cenozoic, due to renewed tectonic activity in the Narmada tectonic belt, the Tertiaries of the area were subjected to differential vertical fault-block movement pushing the basement blocks against each other. This was due to the narrowing down of the Narmada rift basin by the push of the southern Indian sub-plate against the northern Indian sub-plate during Late Cenozoic.

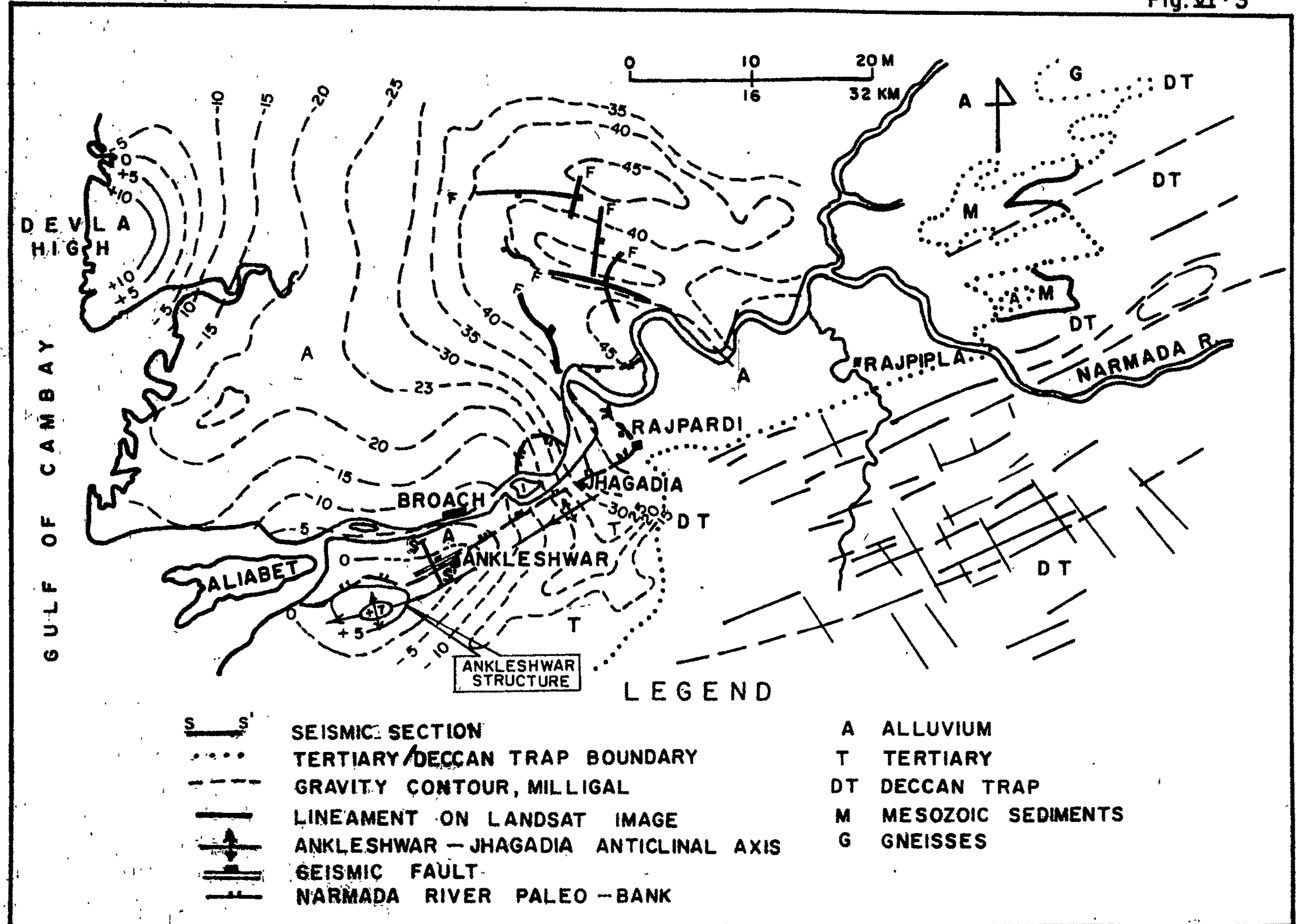
The differential uplift of fault blocks, in the study area, as a result of the tectonic activity, generated by the mechanism explained above, the Deccan Traps along with the overlying Tertiaries were deformed, fractured and uplifted. The geomorphic expression of this phenomenon is amply observed in the form of partly eroded linear ridges etc.

The gravity and magnetic highs observed over the Anklesvar anticline, and the axial trend continuing along the Jhagadia anticline, clearly indicate that the underlying Deccan Trap had also been uplifted along the SW trend (Agarwal,1983). The regional geological picture of Narmada valley further points to an overall tilting of fault blocks southwestward, thereby successively exposing older rocks toward NE.

MECHANISM OF STRUCTURAL DEFORMATION

The tectonic activity in the study area must have been as late as Late Cenozoic, and continuing in Recent times as the entire sedimentary sequence is involved in their structural deformation. The Tertiary sequence of the study area was thus involved in the tectonic activity which was obviously a part of the Narmada tectonic belt. The faults, associated with major structural features,extend in depth through the Deccan Traps underlying the Tertiaries, and even upto the Moho boundary as evidenced from the Deep Seismic Sounding surveys (Kaila,1981). The area north of the study area, across the Narmada river is down-faulted, forming a structural low known as 'Broach depression' with over 5000 m of Cenozoic sediments. From the composite Bouguer gravity anomaly data (Sengupta, 1967) it is observed that there is a major graben in Broach area, north of the Narmada river, and south of it, there is a major gravity high coinciding with the Anklesvar geomorphic high (Figure VI.3), and a gentle gravity high over Kosamba high also(Agarwal,1983).

Fig. VI · 3



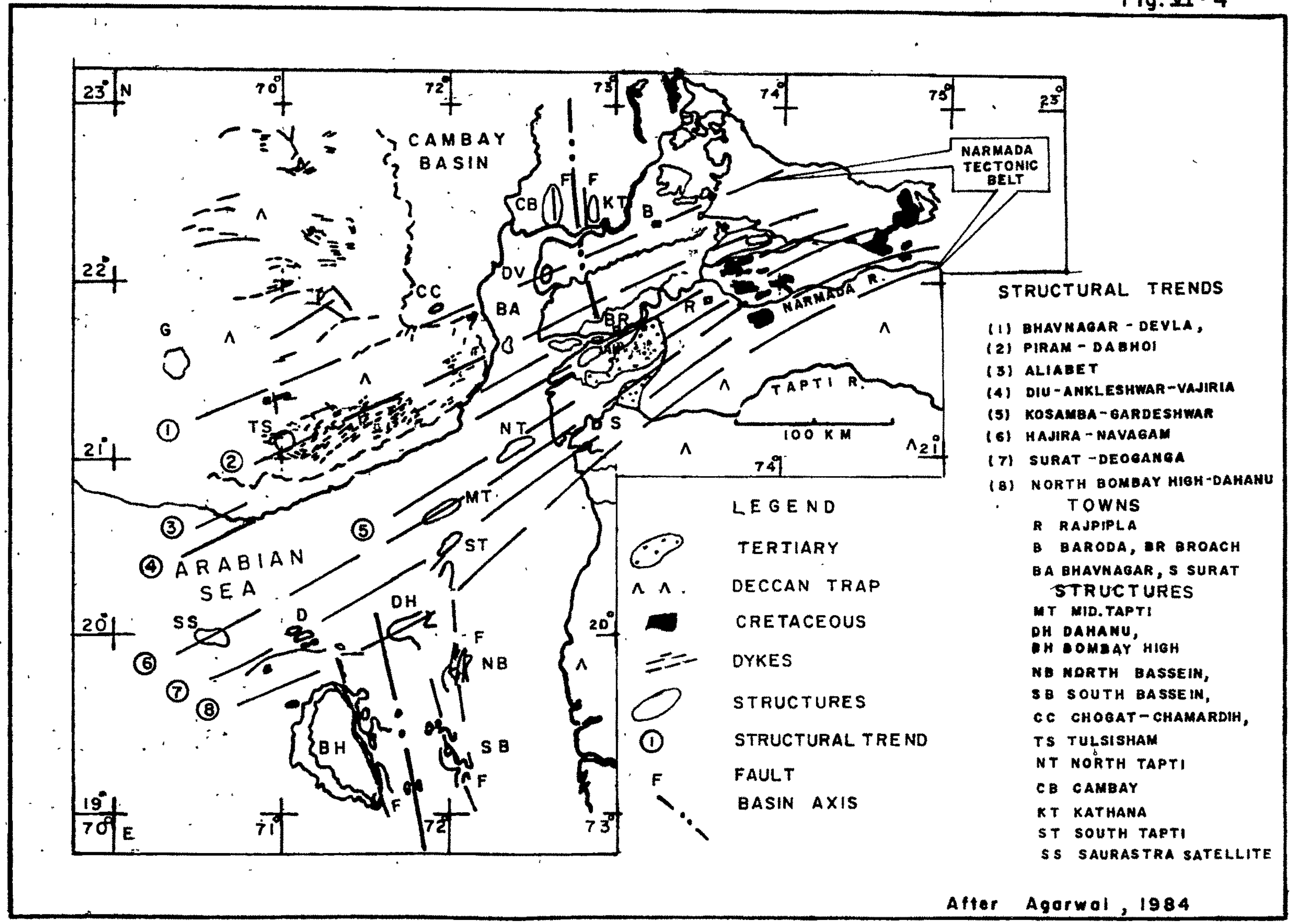
STRUCTURAL ELEMENTS ALONG NARMADA RIVER

The contrasting tectonics of the Tertiaries, south and north of the Narmada river, obviously reveal a significant control exercised by the Narmada geofracture. After Cretaceous sedimentation in the Narmada basin, Deccan Trap basalts flowed over a vast area covering the entire Narmada basin and Central India. At the end of Paleocene, Cambay basin rifting took place and simultaneously further rifting in the Narmada basin also took place. As such, during Tertiary sedimentation, there were two rifted basins i.e. that of Cambay trending N-S and of Narmada trending WSW-ENE, the former superimposed over the later in the study area. There were horst and graben features in both the basins with trends corresponding to the regional trends of the respective basins. Subsequent to the filling up of the lows, between the horsts, by the sediments which were essentially trap derivatives, a pronounced tectonic activity is envisaged along the Narmada basin resulting in the folding and partial erosion of early Tertiary sediments. This tectonic activity has been related by the present author to the first collision of the Indian plate with the Asian plate. The author envisages that the Narmada rift basin demarcates the northern Indian sub-plate from the southern Indian sub-plate. The Narmada basin, lying between the northern Indian sub-plate and the southern Indian sub-plate, experienced the first narrowing effect as a result of the push of the southern sub-plate against the northern sub-plate consequent upon the collision of the Indian plate with the Asian Plate. In Early Eocene the sediments of the study area, falling in the western part of the Narmada basin, were thus folded due to the compressional stresses experienced by SW to WSW trending fault blocks against each other. This was followed by a period of marine transgression which lasted till Lower to Middle Eocene. This transgression effected the entire area of Cambay basin and the western part of the Narmada basin and thereafter all over the subsequent sequence of Tertiary was deposited. However, during Late Cenozoic when the final drift and welding of the Indian plate with the Asian plate took place, once again the Narmada basin experienced a narrowing affect due to another push of the southern Indian sub-plate against the northern India sub-plate resulting in the differential vertical fault block movement in the study area. The resulting push of SW to WSW trending fault blocks, bordered by deep seated faults, developed compressional stresses which folded the incompetent Tertiary sediments and also releasing the stresses through reverse faults. It is further envisaged that during Early Cenozoic the horsts and grabens of the Narmada basin were bordered by normal faults due to tensional forces in vogue. Thereafter during the two major phases of tectonism in Early Eocene and Late Cenozoic wherein there was convergence and narrowing of the Narmada basin due to the push of northern and southern sub-plates, the normal faults were reactivated and turned into reverse faults due to the development of compressional stresses. The fault blocks had a tilt toward SW to WSW during early Tertiary, and as such, later on when the Tertiaries were folded they attained a SW to WSW plunges. This mechanism fully explains why all the structural features in the study area are aligned with the Narmada basin structural trend.

Extension of the folded and faulted Tertiary trend toward NE to ENE have been examined by the present author in the outcrop pattern of the inliers of Late Cretaceous sediments of Narmada valley to the ENE of the study area (Fig.VI.4). The Sirsia rhyolite hill, exposed along the axial part of the Jhagadia-Burhi anticlines and the Deccan Trap hills ENE of Padwania and Gallyaphalla anticlines also suggest that along with the folding and faulting of Tertiaries, the underlying Deccan Traps and Mesozoics were also deformed. That the structural trends of the study area extend further NE to ENE is further evidenced from the study of Landsat Image of the area. Prominent NE to ENE trending lineaments have been mapped from Landsat Images extending from the study area through Deccan Traps to the Mesozoic inliers NE of Rajpipla beyond Narmada river (Agarwal,1983, Fig.VI.3). From the study of drainage pattern and Landsat Image presence of geomorphic highs and major lineaments supporting the above conclusions have also been observed.

NARMADA TECTONIC BELT IN WESTERN INDIA

Fig. VI · 4



After Agarwal, 1984