Chapter – 4

Chapter 4

STRUCTURE

INTRODUCTION

Detailed mapping of major and minor structures was carried out. The area under investigation provided ample avenue to study a variety of tectonics features. By and large Mesozoic and Tertiary sediments are sub-horizontal to low-dipping, abundantly jointed and often dissected by faults. Normal as well as reverse faults are commonly encountered in the field. Normal faults are seen all over the area especially in Jurassic and Cretaceous rocks; also the hinge portion of folds and domes incorporate some. Whereas, reverse faults are seen mostly along the hill ranges. Structures related to compression such as flat-ramp-flat, asymmetric overturned, fault-propagation folds, out-of-syncline thrusts and mesoscopic detachment faults are encountered in the field.

As mentioned earlier in the Chapter 1, the framework of Kachchh Rift consists of an embayment closed by the Nagar Parkar Uplift (NPU) in the north, the Radhanpur-Barmer Arch in the east and the North Kathiawar Uplift (NKU) in the south (Fig. 1.2). The landscape of Kachchh region shows a complex structural pattern marked by uplifts and low-lying areas. Other than the rift shoulders mentioned here the region is characterised by three major uplifts namely Kachchh (Kutch) Mainland Uplift (KMU), Wagad Uplift (WU) and Island Belt Uplift (IBU) (Biswas, 1987 and Biswas, 2005). The chain of islands: Pachham, Khadir, Bela and Chorar Hills, is collectively addressed as Island Belt Uplift (IBU). The Uplifts are mainly confined along sub-parallel E-W striking major faults of the region ranging in length from 40 to 180 km. The major faults of the region from north to south are Nagar Parkar Fault (NPF), Allah Bund Fault (ABF), Island Belt Fault (IBF), Kachchh Mainland Fault (KMF), Katrol Hill Fault (KHF), South Wagad Fault (SWF) and Gedi Fault (GF) (Fig. 1.2). Apart from these regional faults a number of minor faults are present in the regions such as Goradongar Fault, Vigodi Fault Banni Fault etc. More recently Morino et al. (2008a) have recognized a reverse fault near Bhuj city, termed as 'Bhuj Fault'.

The uplifts and faults of study area are described here in detail. The investigations were extended outside the study area as well, to correlate between different structural features and their significance to regional geology, The main focus of this study is on the eastern part of Kachchh Mainland Fault and western part of South Wagad Fault as they appear to have played a pivotal role in shaping the structure and geomorphic features of the region. Additionally parts of western KMF near Jara, KHF, IBF and Gedi Fault are also investigated to collect evidences supporting the concepts proposed in this study.

GENERAL DISCRIPTION OF UPLIFTS AND ASSOCIATED STRUCTURES

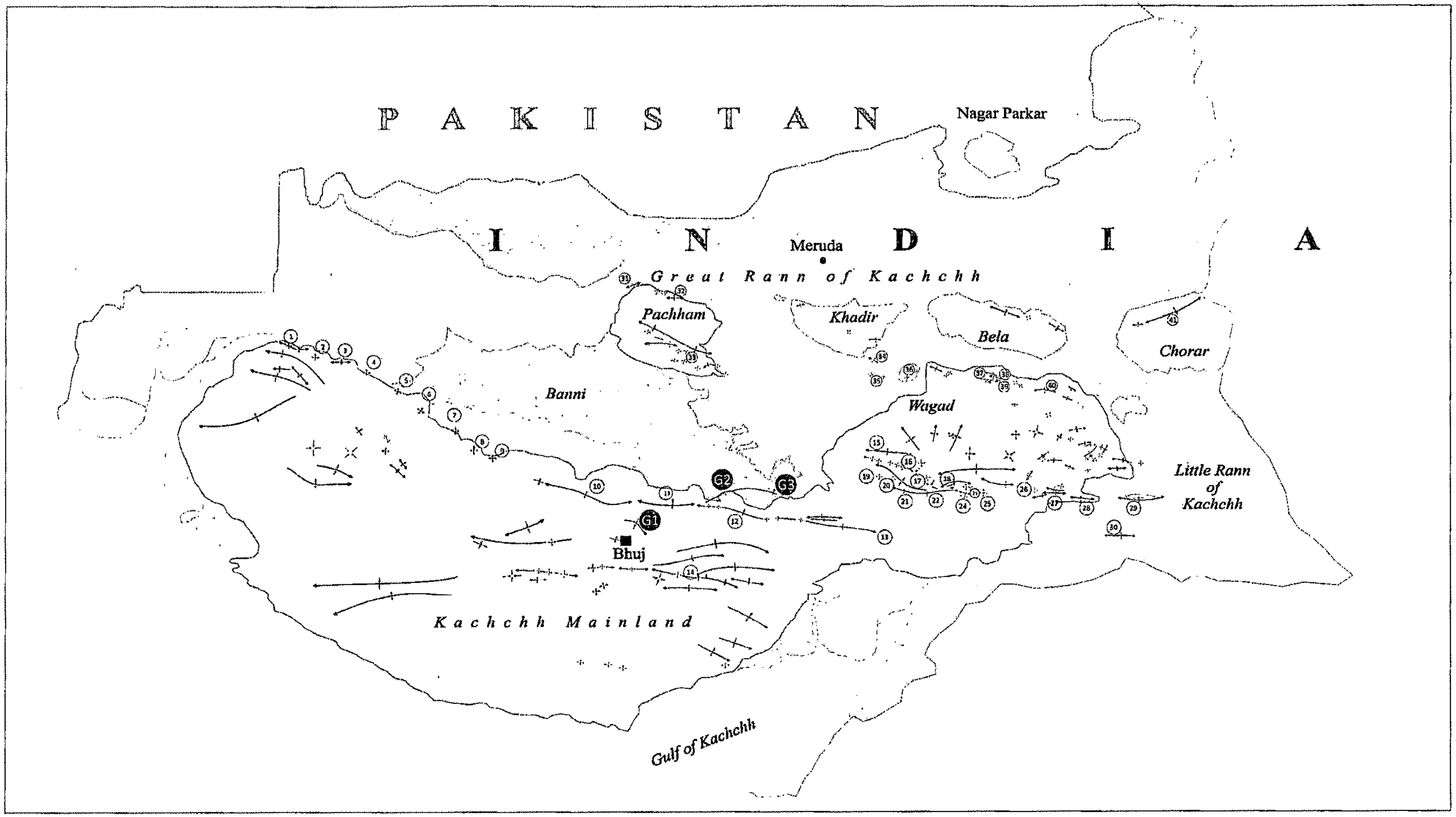
General configuration of the uplifts is of asymmetric, often overturned anticlines in the northern part and the southern part gradually merges with the plains. The narrow linear flexure zone along its faulted margin is recognisable in each of the uplift. The folds associated with the flexure zones typically face the basins with the forelimbs dipping 40°-90°, often overturned, and gentle back limbs dipping 5°-10°. Various structural features observed in the area correspond to the development of features that are commonly reported from fold-and-thrust belts when alternate layers of relatively more ductile shale and stiffer beds of sandstone of the region are subjected to compression.

All the uplifts, except for the Wagad, are characterised by faults or flexures along the northern margin. They are elongated in E-W direction and are asymmetric in nature with their steep limbs dipping due north. The Wagad uplift, however, has its flexure zone in the southern margin. The structures are further complicated by the presence of igneous intrusions. Characteristics of folds as interpreted during present study in light of new data, observations and concepts evolved by different authors in various parts Kachchh region are described below.

Mainland Uplift

Mainland Uplift is largest of all the uplifts. . Its southern boundary passes on to the depression of the Gulf of Kachchh, which separates it from the Kathiawar Uplift. The continental shelf of the Arabian Sea occurs to the west and an extension of Gulf of Kachchh basin occurs in the form of Little Rann to the east. It is separated from the Banni basin by Kachchh Mainland Fault from the north side. A narrow flexure zone characterised by numerous domes and doubly plunging anticlines occurs along the Northern Hill Range (Fig. 4.).

The Northern Hill Range is characterised by number of anticlines and domes from west to east namely Lakhpat Anticline, Ghuneri Dome, Mundhan Anticline, Jara Dome, Jumara Dome, Manjal Dome, Keera Dome, Chari Dome, Laiyari Dome, Jhurio Brachy-Anticline, Habo Brachy-Anticline and Kas Hill Anticline (Biswas 1993). The scope of the present study incorporates eastern part of Northern Hill Range which consists mainly of Habo anticline and Kas Hill anticline. The Kas Hill Anticline occupies major part of eastern half of the Northern Hill Range flexure. It is a long narrow anticline with chain of domes along its axis named from west to east as: a) Kas Hill Dome, b) Lotia (Lothia) Dam Dome, c) Wantra Dome, d) West Khirasara Dome, e) East Khirasara Dome, f) Devisar Dome, g) Dudhai Dome and h) Mamusa Pir Dome (Fig. 4.) (Biswas and Deshpande, 1983). The amplitude and size of the folds and domes are variable. The Jhurio fold is the biggest structure, Habo dome is the second largest whereas Mamusa Pir Dome is the smallest structure along the Northern Hill Range.



1 Lakhpat anticline, 2 Ghuneri dome, 3 Mundhan anticline, 4 Jara dome, 5 Jumara dome, 6 Manjal dome, 7 Keera dome, 8 Lyari dome, 9 Chhari dome, 10 Jhurio brachy-anticline, 11 Habo brachy-anticline, 12 Kas hill anticline,13 Bhachau nose, 14 Khatrod Hill anticline, 15 Chobari nose, 16 Kanthkot anticline, 17 Meman Wandh syncline, 18 Wasthawa dome, 19 Mae dome, 20 Wamka dome, 21 Halra anticline, 22 Adhoi anticline, 23 Shivlakha syncline, 24 Shivlakha anticline, 25 Chitrod dome, 26 Gagodar anticline, 27 Kanmer anticline, 28 Gon anticline, 29 Mardak Bet anticline, 30 Kesmari Bet anticline, 31 Kaur Bet dome, 32 Kala-dongar anticline, 33 Juna anticline, 34 Kakindia bet anticline, 35 Gorabir-Karabir anticline, 36 Gangta bet dome, 37 Desalpur anticlines, 38 Desalpur synclines, 39 Gedi syncline, 40 Fatehgadh anticline, 41 Chorar anticline.

Structures identified and proposed during present study: G1 Palara syncline, G2 Sravan dome, G3 Kharod anticline

Fig. 4.1: Structural map of Kachchh Region (modified after Biswas and Deshpande, 1983).

Though variable in sizes and shapes, all the domes in Mainland show more or less uniform structural geometry; they are strikingly asymmetric with short, steep, north-limbs and gentle south limbs. The individual folds and domes within the flexure zone are separated by saddles, and the north-flowing rivers surge through these saddle regions.

East-west trending longitudinal flexure zone similar to that of Northern Hill Range occurs in the central part of Mainland Uplift which is named as Chorwar Hill Range flexure, which abruptly abuts in the north against Bhuj plains along 'Katrol Hill Fault' and in the south it gradually merges with the coastal plains. These two zones of folding run parallel to each other within the Mainland Uplift. The structure of Chorwar Hill flexure zone is more or less similar to that of Northern Hill Range flexure zone. However, the complexity of structures in this zone is more than in Northern Hill Range flexure zone. A number of small folds and domes evolved along Katrol Hill Fault constitute a part of this flexure zone.

The forelimb of all folds and domes associated with this flexure zone face the Bhuj Low to the north (Fig. 1.2). Exposures of folds and low angle to subhorizontal auxiliary thrust faults are encountered along the geographic divide between the Katrol Hill range and Bhuj Plains (Fig. 4.22).

Between the Northern Hill Range and Chorwar Hill Range is situated structural low known as Bhuj Low.

Wagad uplift

Wagad uplift is the second largest uplift in the region. The structural orientation of this block is contrary to that of other uplifts. While all other blocks are bound by faults in the north, the southern part of Wagad uplift is bound by faults and associated flexures; the ramifying domes and anticlines are collectively referred as the South Wagad

Fault System. South Wagad Fault System is a complex arrangement of two crisscrossing faults. Accordingly two important flexure zones are associated with this fault system; an inner, Kanthkot-Dedarwa-Vekra flexure zone and an outer, Adhoi-Chitrod-Kanmer-Gon flexure zone. The inner zone is represented by the presence of a series of narrow idiomorphic anticlines and domes along the Kanthkot-Dedarwa fault zone, which borders the central zone of uplift within Wagad Uplift. This zone is more faulted and folded portion of Wagad uplift (Biswas 1993). The outer zone is represented by domes and tight symmetric/asymmetric anticlines along Adhoi-Chitrod fault zone. The fault shows segmented nature and each segment is named locally. Both the fault zones converge and bifurcate near Washatwa. As the faults converge and bifurcate the two flexure zones also tend to coalesce and branch off (see Fig. 4.).

The Inner Zone of Faulting is marked by Kanthkot Fault, which initiates near Chobari Village. The geomorphologic expression of this fault is conspicuous where domal hills and synclinal valleys (or structural basins) truncate abruptly along the line of faulting. The western tip of inner zone is marked by the presence of tiny Manfara dome, which is followed by Kakarwa anticline to the east. The Kakarwa anticline is characterised by near vertical to steeply south dipping forelimb and gently north dipping back limb (Fig. 4.2). The axial part of the anticline is completely eroded. The morphology of the anticline distinctly represents geometry of fault-propagation fold (the nature of fault-propagation fold is described in more detail later in this chapter).

Fig. 4.2: Field photo of Kakarwa anticline. Axial portion along with core part of anticline is eroded; South verging forelimb and gently north dipping back limb are preserved.

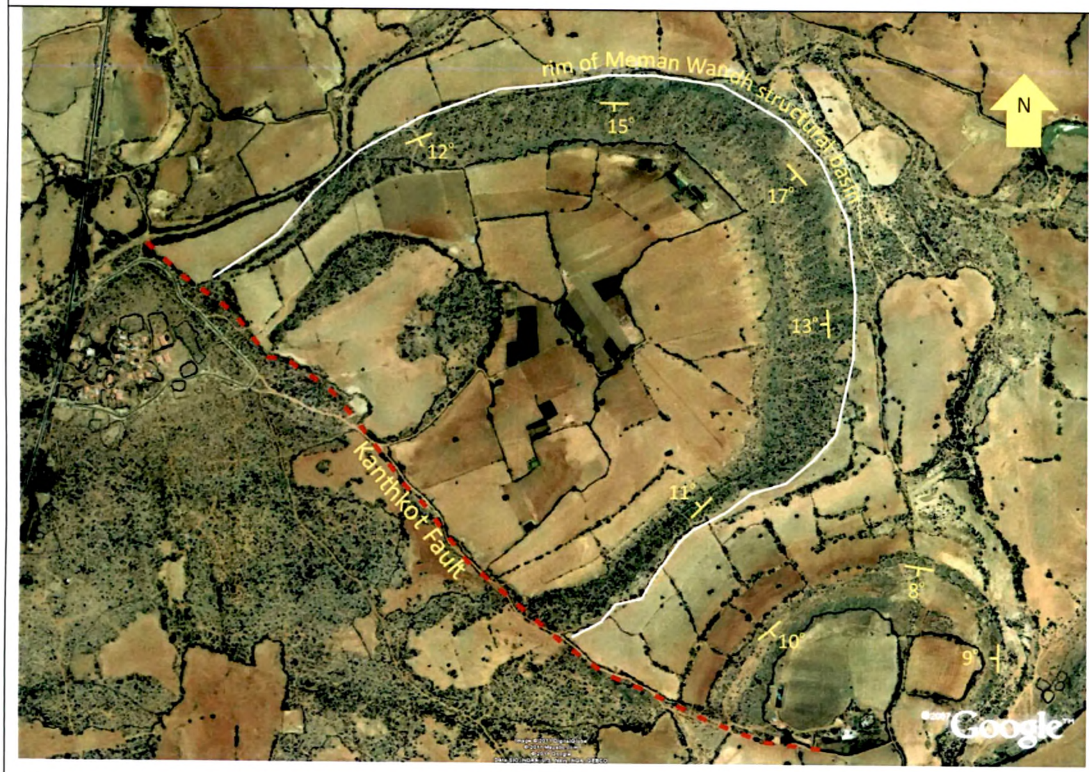


Fig. 4.3: Google image of Meman wandh structural basin.

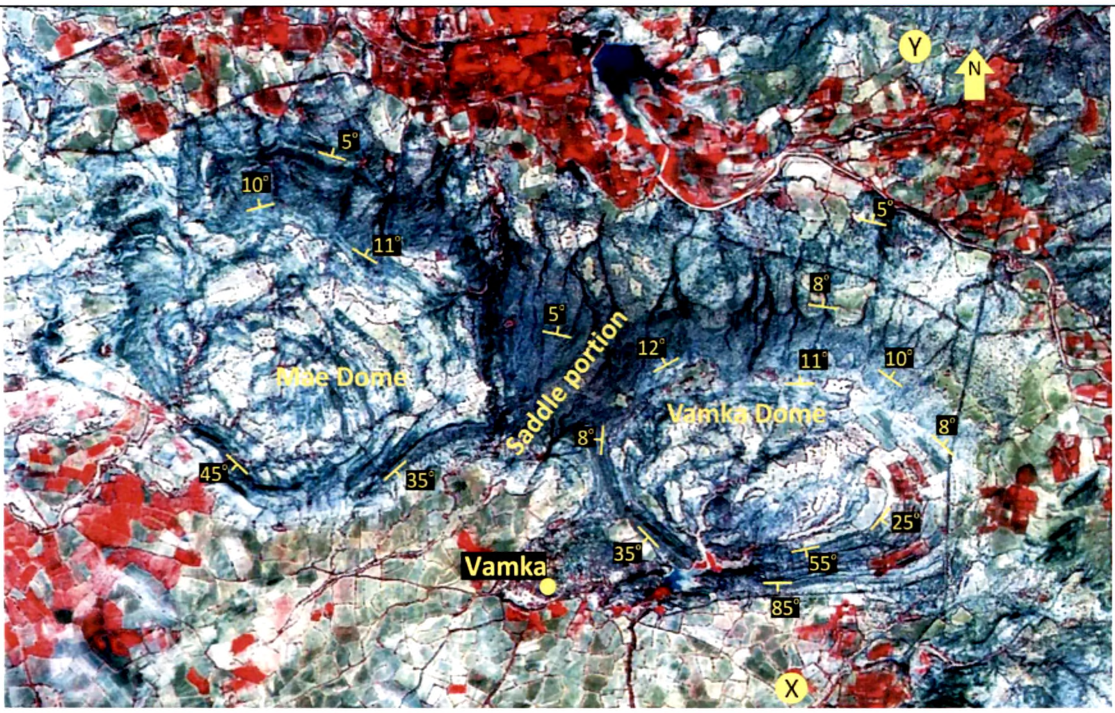


Fig. 4.4: LISS-PAN merged FCC satellite image depicting Mae and Vamka Domes along South Wagad Fault Zone.

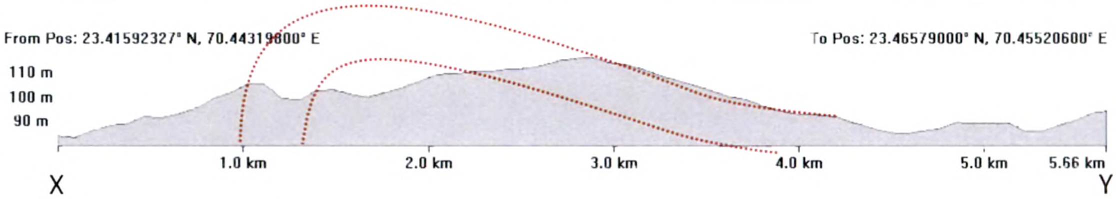


Fig. 4.5: Elevation profile along X-Y; across Vamka Dome. Bedding is imitated over it.

Fig. 4.6: Overturned beds of Jurassic age as observed south of Adhoi Anticline. (view towards east).

To the east, the Kakarwa anticline is followed by a chain of smaller domes collectively known as the Kanthkot anticline. South of it occurs Chobari Syncline, these structures are characterised by cuestas formed by the Astrata Bands (Deshpande, 1972). A peculiar structure named as Meman Wandh dome by Biswas (1993) is actually a structural basin in the line of same flexure zone, whose outer rim is marked by inward dipping beds (Fig. 4.3).

Fig. 4.7: Sheared and folded Tertiary rocks at Adhoi (view towards west).

The western tip of outer zone is marked by the Mae dome, which is followed by Vamka dome to the east. The Mae and Vamka domes are twin domes separated by a shallow saddle. These twin domes provide good examples of fault-propagation fold with slip deficit on the subsurface thrust (see Chapter 6 for discussion). (Fig. 4.4).

Fig. 4.8: Surface of Mardak Bet (Little Rann of Kachchh) covered with quartz and agate.

Fig. 4.9: Google image of domal structures and steeper south dipping beds of sandstone at Mardak Bet, Little Rann of Kachchh.

With a south step of 1.5 km the Halra Anticline occurs further east of Vamka dome. Halra Anticline is a narrow asymmetric anticline with axial length of 5.5 km trending nearly east-west along the Adhoi segments of outer fault zone. The Adhoi segments runs along the south-western border of Wagad Uplift. The presence of fault is evident from vertical beds of Mesozoic and Tertiray strata and sheared and brecciated rocks along Halra and Adhoi anticlines (Fig. 4.6 and Fig. 4.7). Biswas (1993) estimated throw of the fault near Adhoi approximately 200 m. Adhoi anticline is a long and narrow tight fold. Its southern limb dips 40°-80°, at both the ends it plunges sharply. To the east of it lies Shivlakha Anticline and Syncline. Adhoi Fault appears to terminate against Khanpur Fault near Washtwa where Inner Zone of faulting converges with Outer Zone of faulting; they are followed by Chitrod Dome to further east. Chitrod Dome is a broad-topped dome with low amplitude. The eastern part of this zone (east of Kidianagar fault) shows comparatively simple structural pattern (Biswas 1993). Gagodar dome and Kanmer, Gon & Mardak Bet anticlines constitute this zone of folding. These folds form a low range of hills bordering the south-eastern margin of the Wagad Highland and projecting into Little Rann of Kachchh. Flexure of Gagodar dome involves steeply south dipping Tertiary beds to the south. Kanmer Anticline is also a narrow asymmetric anticline, whose southern limb dips 70°-80° due south. At places beds are seen sub-vertical to overturned. The Gon Anticline is a, narrow oblong nearly symmetrical anticline; it forms a low ridge which projects into Little Rann of Kachchh. On the same axial line occurs the Mardakh Bet anticline, which is an isolated fold forming an island in the Little Rann. A portion of the surface of Mardakh Bet is seen completely covered with quartz and agate pebbles (Fig. 4.8). This anticline exhibits asymmetric fold geometry, where the dip of southern limb is steeper than the northern limb (Fig. 4.9).

The central zone of deformation in Wagad Uplift represents the highest elevated portion of the broad topped uplift of Wagad. It consists of two main structures Sarasla and Dabunda domes. The northern part of Wagad Uplift is characterised by Rav syncline, which is faulted by the Gedi Fault along which Bela Uplift has taken place. The Gedi Fault has brought up the Desalpur-Fatehgadh Ridge (Biswas 1993). The fault is defined by steeply south dipping to overturned Jurassic beds (Fig. 4.10 and Fig. 4.11). The Gedi Fault Zone is characterised by presence of many domal closures and plunging folds (Fig. 4.10).

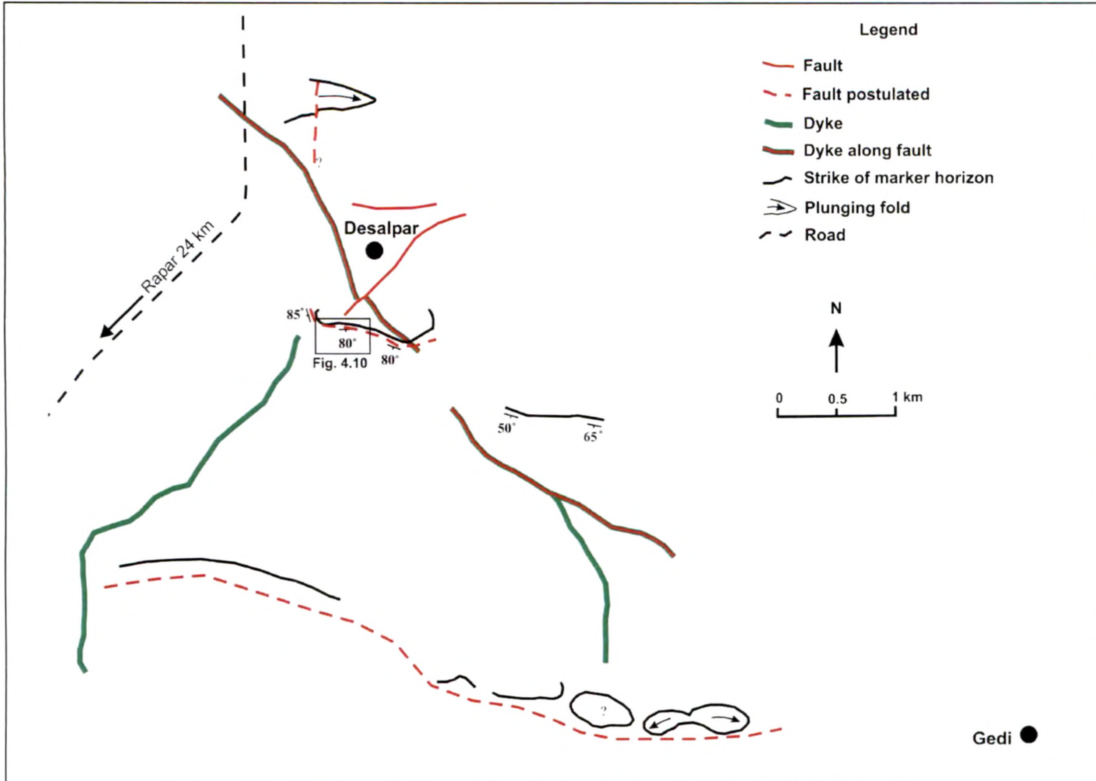


Fig. 4.10: Structural map of Gedi Fault Zone near Desalpar village.

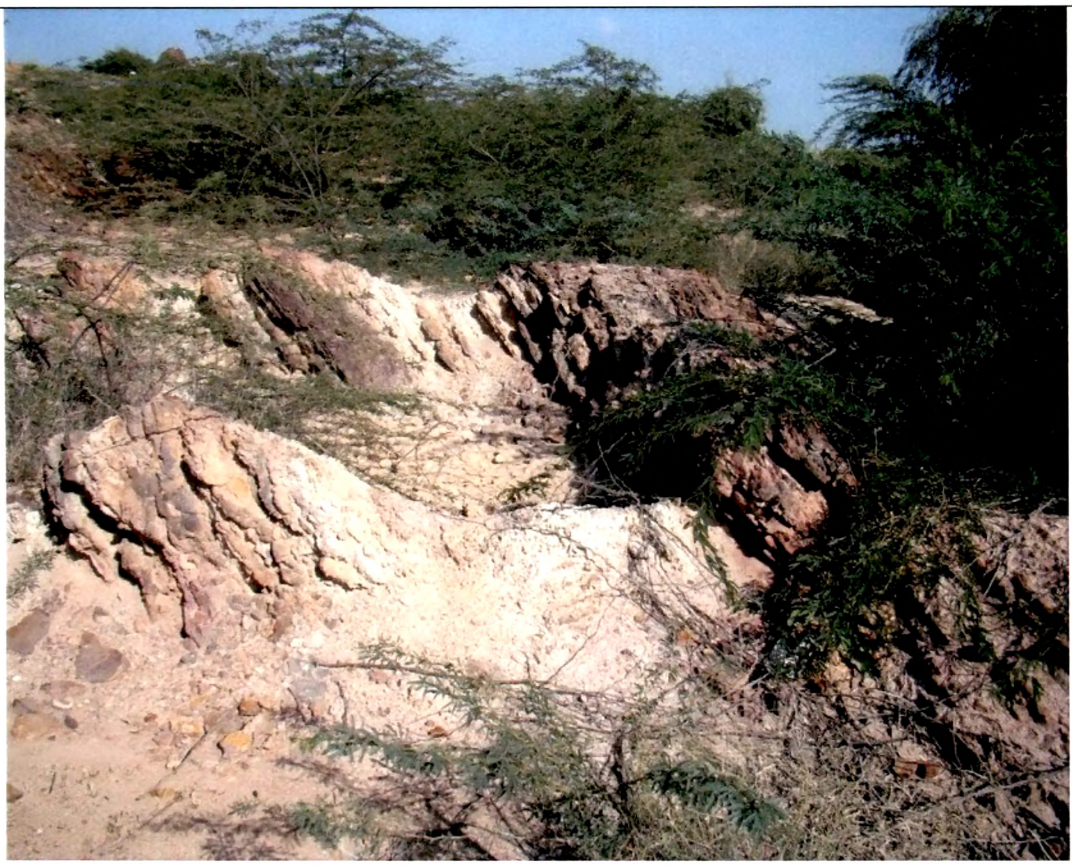


Fig. 4.11: Steeply south dipping beds near Desalpar village (Gedi Fault).

Island Belt Uplift

Island Belt Uplift (IBU) is characterised by four island-like blocks known as Pachham, Khadir, Bela and Chorar arranged in en-echelon pattern with each block shifted progressively towards the north from west to east. As mentioned in Chapter I, the uplifts emerge from unusually flat surface, described as the 'Great Rann of Kachchh'. During the rainy season the Rann is covered with knee-deep water and during dry season it forms a vast saltpan. A similar but smaller saltpan is located in the south-eastern part of Kachchh known as the 'Little Rann of Kachchh'. The northern part of each uplift is characterised by a chain of hillocks while the southern margins gradually merge with the plains. Pachham uplift is characterised by two hill-ranges; Goradongar hill-range in the south and Kaladongar hill-range in the north. Bela Uplift consists of a pair of flexures, Bela and Desalpur flexure zones, respectively along its northern and southern margin. Between Pachham -Khadir uplifts and Kachchh Mainland lies a slightly elevated stretch of land, not inundated by water during rainy season known as the Banni Plains. Excepting the Khadir uplift, all other major uplifts are defined by sharp monoclonal flexures with the accompanying fault on one side (Fig. 4.). Biswas (1993) considered the northern escarpment of Khadir to be a residual fault line scarp, where, according to him marginal flexure is buried under the Rann sediments. The northern margin of Pachham uplift is marked by an asymmetric anticline (Fig. 4.12). Along Goradongar at the eastern part of Pachham Island, a large-scale tight recumbent fold is seen to have developed (Fig. 4.13).

Several small auxiliary uplifts also occur along with the major uplifts, which are discussed here. To the north-west of Pachham Island occurs Kuar Bet Dome, In the line with the Desalpur flexure (south of the Bela Uplift) occur domes of Gangta Bet, Gora Bir, Kara Bir and Kakindia Bet (Fig. 4.).

Fig. 4.12: North dipping beds north of Kaladongar Hill (view to west).

Fig. 4.13: Recumbent fold observed near Juna, Goradongar Hill, Pachham (view to east).

Isolated anticline of Mardakh Bet in Little Rann of Kachchh (Fig. 4.) occurs on the same axis that of Kanmer-Gon flexure zone. A small islet Keshmari Bet represents an anticlinal uplift within Little Rann of Kachchh along the axis of Northern Hill Range of Kachchh Mainland Uplift. Based on the facies and thickness of sediments of Mesozoic rocks observed across Katrol Hill fault and Goradongar fault

FAULTS AND FAULT RELATED FOLDS

Morphology of Kachchh region is governed by fault related uplifts. All major faults types i.e. normal, reverse and strike-slip are observed in the region (Biswas 1993). However, reverse fault of the region are of greater importance, as from the present study it can be conceived that they controll presentday structural fabric. Whereas, normal and strike-slip faults are found to be of secondary origin. Reverse faults are mainly encountered along the mountain fronts. Asymmetric to overturned /recumbent folds are seen closely associated with reverse fault. By and large the strike of reverse faults is E-W with southerly dips. The amount of dip of reverse faults ranges from about 45° to sub-horizontal. Often they are found to be horizontal. In rare occasions the splays of thrusts are seen to dip northward due to subsequent folding of the sub-horizontal thrust sheet on account of persistent application of compressional stresses (Karanth 2003).

Kachchh Mainland Fault

Kachchh Mainland Fault is the largest fault in the region extending for nearly 190 km, right from Lakhpat in west to Bhachau in east and it forms main zone of weakness in the region. Normally, zone of faulting is marked by steeply north dipping beds (Fig. 4.14) within a width of 1 to 2 km. Within fault zone the beds are mostly vertical to sub-vertical, at times overturned and erratic (Fig. 4.15).

Fig. 4.14: Steeply north dipping/subvertical beds observed at northern boundary of Kas Hill Dome (Lothia Nala).

Fig. 4.15: Over turned beds north of Lothia-Nala Dam dome, Kas Hill anticline (view to east).

Most beds show thinning along northern limb of flexure associated with KMF. The fault has a prominent geomorphic expression; it is responsible for bringing up the Northern Hill Range (NHR) abutting against the Banni Plains. The fault is exposed in central part; where it has ruptured pediment zone to the north of Jhura Dome and Habo Brachy Anticline. To the east of Lodai the fault is either buried under the Recent cover or replaced by the marginal flexure. Again between Jhuran and Khirsara the fault is indicated by the highly plicated Tertiary beds. The fault appears to fadeout gradually to the east of Bhachau giving rise to Bhachau Nose near Vondh village.

The dip of fault is about 70° to 80° due south as observed north of Jhura Dome (Morino et al. 2008b). East of Jawahar Nagar the fault is dipping 80° to 85° towards south (Biswas 1993). In extream west the fault strikes north-west to south-east near Lakhpat. The strike of fault changes to east-west near Dudhai at its eastern extremity. From the thickness of the sediments as exposed in the Mainland (Biswas 1993) estimated the stratigraphic throw of the fault to be around 4000 ft.

The marginal flexure associated with it and its effects has already been discussed in previous section of this chapter. The steeply dipping Tertiary rocks are seen faulted against the folded Mesozoic rocks along the northern margin of Mainland Uplift demarcating zone of faulting. Fault plane is made up of several slip planes (Biswas 1993).

East of Lodai village a bifurcation from main the fault is reported by Biswas (1993). He named this fault as Kas Hill fault. According to him Kas Hill dome and Wantra anticline have resulted from the uplift of the block between Kas Hill fault and the master KMF.

Kharod Fault

So far it was believed that (Biswas and Deshpande, 1975; Biswas, 1993; p 309; GSI Kachchh District resource map, 2002) the Banni area is devoid of any rock exposure and hence geological information was lacking from this area. However, during present study a few outcrops of Tertiary rocks are encountered in Banni area. The exposure of folded and gently north dipping tertiary rocks observed about 7 km north of KMF near Kharod village hitherto remained unnoticed by all the previous workers (Fig. 4.16 and Fig. 4.17). The exposure consists of an east-west oriented small ridge hardly 2 m high with steep south slope and gentle dip-slope due north. The ridge is locally known as Kharod *mori* (ridge). The beds of 10-15 cm thick buff-coloured gently folded limestone are exposed in a small pond, excavated within this ridge. The fold in the limestone beds are plunging in NE direction while overall dip of the beds is due north. A continuation of Kharod ridge, to the western side, is observed in form of a chain of small domal exposures of gritty sandstones at the margin of Lotia Nala (River) Fan to the northwest of Khengarpar Village (Fig. 4.17). At western end, the trend of the chain of domal structures gradually changes from east-west to northeast-southwest. The changed orientation leads the exposures close to Northern Hill Range, the trend appears to match with that of Wantra Anticline (Fig. 4.17). A water spring also exists close to these outcrops.

Fig. 4.16: Folded Tertiary rocks observed at Kharod ridge, Banni.

Fig. 4.17: Domal exposures of Tertiary rocks in Banni, near Sravan shrine, north of Jawaharnagar.

Katrol Hill Fault

Katrol Hill fault occurs in the central part of Kachchh Mainland Uplift and extends for about 70 km. This fault runs nearly in E-W direction, parallel to Kachchh Mainland

Fault demarking the northern frontier of the Katrol Hill Range that forms main drainage divide in Mainland. The strike of fault is nearly east-west for entire length with some local variations. The plane of Katrol Hill Fault is very well defined and sharply marked by single fault plane or narrow zone of deformation (Biswas 1993). The fault plane is characterised by folded beds on hanging wall side. At places fault plane forms a prominent ridge marking geomorphic divide between Bhuj Low and Katrol Hill. Biswas (1993) reported that western half of KHF dips to the south and eastern half is north dipping to vertical. Based on stratigraphic record on either side of fault Biswas 1993 estimated maximum stratigraphic throw of 2400 ft for the fault. Hardas (1968) had reported that Katrol Hill Fault is a reverse fault (Fig. 2.1).

Sheared rocks are commonly observed in the core of folds associated with this fault (Fig. 4.18). At places bedding parallel slip between two brittle layers (sandstone/limestone) separated by ductile (shale) layers results in shearing of ductile layers (Fig. 4.19).

As mentioned earlier the Island Belt Uplift (IBU) portrays en-echelon arrangement of chain of islands, with their position shifted progressively towards the north from west to east. For this arrangement of uplifts, Biswas (1993), postulated presence of en-echelon transcurrent faults, oblique to main fault, along which strike-slip movement, have caused individual uplifts to shift northward.

Fig. 4.18: Sheared rocks in core of Katrol Hill.

Fig. 4.19: Drag folds developed in shale (less competent) beds sandwiched between sandstone (more competent) beds observed in Katrol Hill, 8 km south of Bhuj (portion shown in box is enlarged below).

Some of these faults are displaced by obliquely oriented transverse faults (Biswas 2005, Sohoni 2001). The general form of deformation along the uplifts is marked by domes and asymmetric anticlines (Malik et al. 2001a, Karanth 2003, Karanth and Gadhavi 2007).

Fault-propagation folding

Marginal flexures (anticlines and domes) along the uplifts exhibit obvious morphology of fault-propagation folding along the major faults of the region. Fault-propagation folds of the region are characterised by subhorizontal to gently dipping hinterland limbs and steeply dipping forelimbs.

At most places the hinges of these folds are seen to have been eroded and forelimb can be discerned merely by the traces of steeply inclined to vertical beds, at places the beds are seen to be overturned. Inner Zone of Faulting of SWF along Kanthkot Fault represents eroded fault-propagation fold. The Kanthkot Fault initiates near Chobari Village. The geomorphologic expression of this fault is conspicuous where domal hills and synclinal valleys truncate abruptly along the line of faulting. The western tip of inner zone is marked by the presence of tiny Manfara dome, which is followed by Kakarwa anticline to the east. The Kakarwa anticline is characterised by near vertical to steeply south dipping forelimb and gently north dipping back limb. The axial part of the anticline is completely eroded. The morphology of the anticline distinctly represents geometry of fault-propagation fold. Near vertical beds of fossiliferous sandstone-shale sequence (Upper Jurassic) forming forelimb of the anticline are observed resting on horizontally placed coarse grain sandstone (Cretaceous) near Kakarwa village (Fig. 4.20 and Fig. 4.21). To the east, the Kakarwa anticline is followed by a chain of smaller domes collectively known as the Kanthkot anticline.

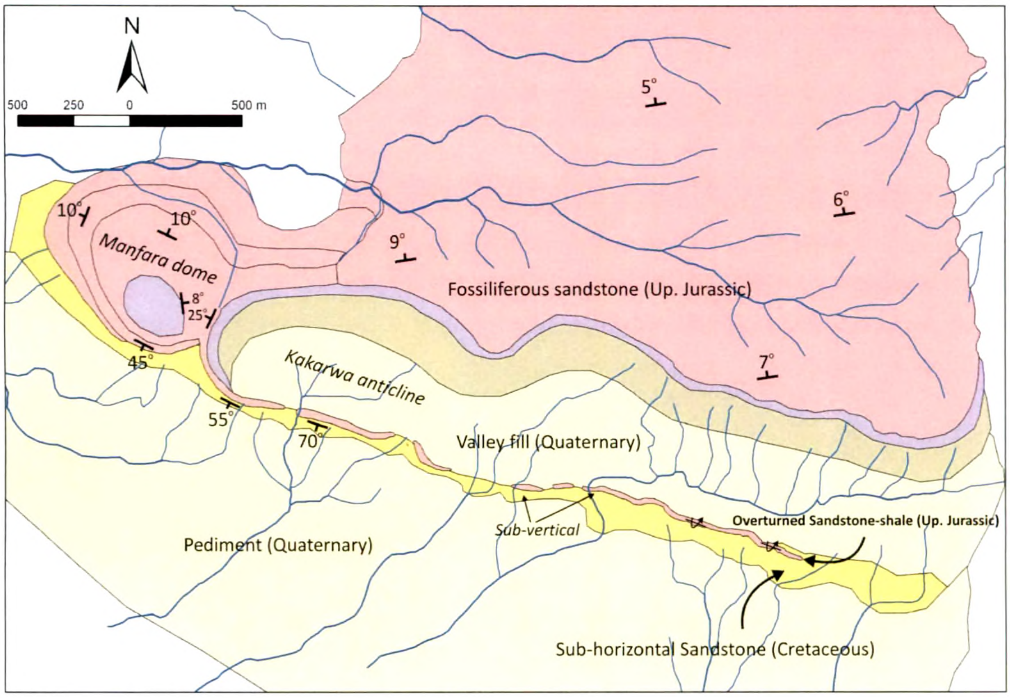


Fig. 4.20: Geology of Kakarwa anticline; note very thin outcrop of Jurassic rocks at southern margin of the structure.

Fig. 4.21: Overturned Jurassic beds resting over gently south dipping Cretaceous sandstone.

Northern Hill Range is also characterised by several domal structures of which Habo and Jhura domes are most prominent. These domes are seen intimately associated with igneous intrusive bodies at the core. The presence of intrusive stocks/plugs within the Mesozoic sediments appears to have interfered with the style of fault-propagation folding. Erosion of the envelop of incompetent (shale) layers alternating with competent (sandstone) layers superimposed by conjugate fractures developed on account of compressional stresses, has given rise to *'petal-like pattern of a lotus flower'* (Karanth 2003).

Exposure scale fault-propagation folds and sub-horizontal thrusts are encountered at number of places in field. Along the geomorphic boundary between Katrol Hill Range and Bhuj Low north verging sub-horizontal thrust is observed (Fig. 4.22). This structure exhibits recumbent folding of hanging wall of the thrust. The thrust is seen to ride over sub-horizontal beds of footwall.

Fig. 4.22: Sub-hrizontal thrust observed near geomorphic boundary between Katrol Hill Range and Bhuj Low.

Fig. 4.23: Low angle reverse faults observed at (a) Trambou and (b) Saraspar.

Near Trambou and Saraspar villages exposure scale low angle reverse faults are observed. These reverse faults have cut across shale-sandstone sequence along approximately 30° south dipping fault planes. It was observed here that reverse fault near Trambou village has less deformed footwall, whereas, fault observed near Saraspar is characterised by considerably sheared footwall (Fig. 4.23). Both faults indicate that the direction of tectonic transport is due north.

Out-of-syncline thrust

In Kachchh region popularly it is believed that folds are more or less restricted to the margin of uplifts. However, the present study reveals that the fault-related folds and other compression related structures also occur in the interior parts of the uplifts. Within Bhuj Low an easterly plunging syncline is observed south to the saddle between the Jhurio and Habo anticline, about 10 km north of Bhuj (Fig. 4. and Fig. 4.24). The northern limb at the margin of the syncline is characterised by low angle thrust and contractional wedge, which is named here as Saraspar thrust (Fig. 4.25). Saraspar thrust is an example of out-of-syncline thrust. Compression induced bedding parallel slip has resulted in localised uplift and out-of-syncline thrust. Southern margin of syncline, at a distance of about 1 km east of Palara Mahadev temple, is marked by steeply north dipping beds that are abutting against sub-horizontal to gently north dipping beds (Fig. 4.26). The structure as a whole is an assemblage of compression related structures such as flat-ramp-flat structure (Fig. 4.28) and fault-bend fold in association with localised uplift.

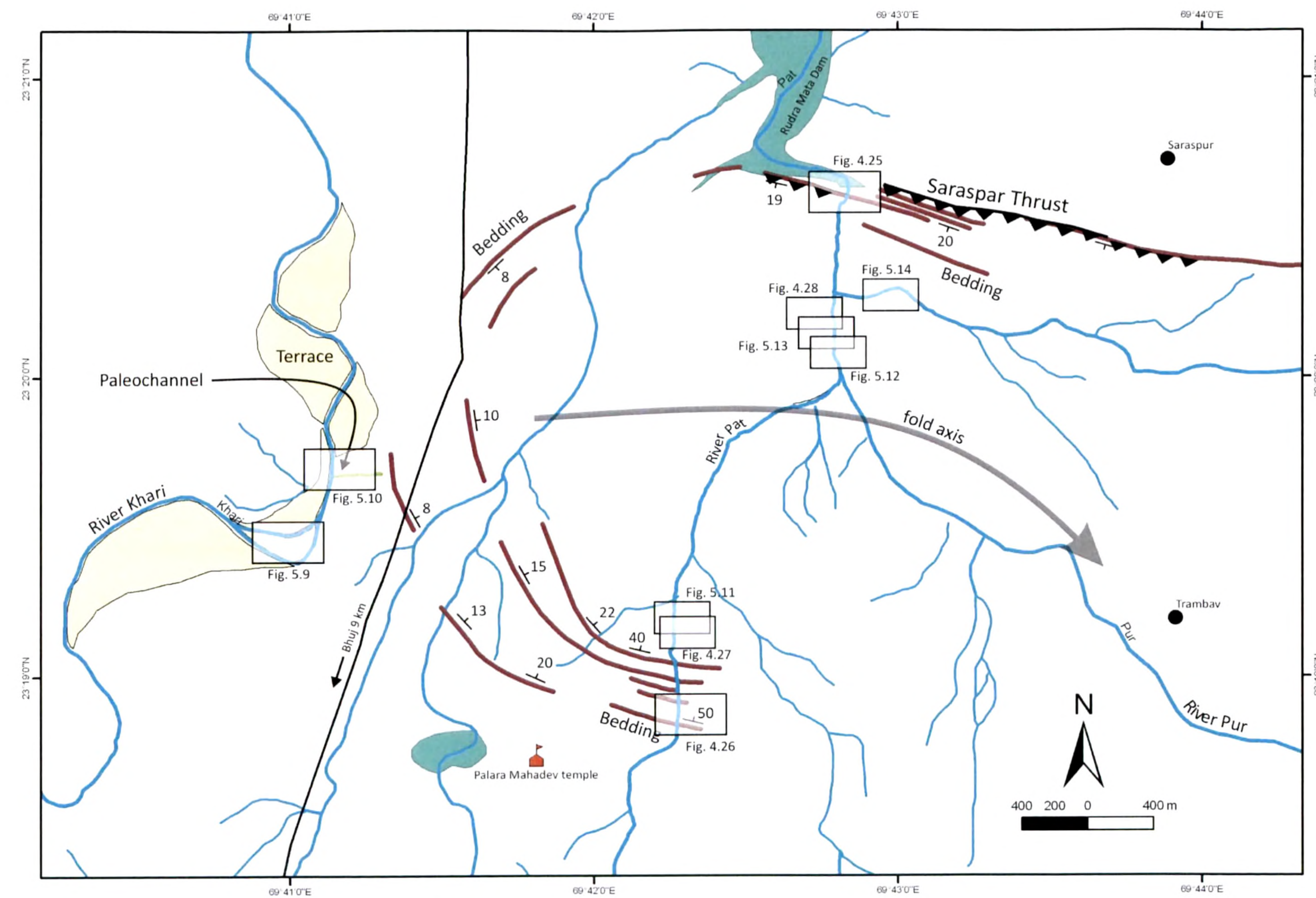


Fig. 4.24: Structural features of Palara syncline, Bhuj.

Fig. 4.25: Photo mosaic of Saraspar thrust.

Fig. 4.26: Southern margin of Palara Syncline; observe steeply north dipping beds abuting against sub-horizontal beds.

The structure is responsible for localised active deformation in the area. The northern boundary of this syncline is characterised by thrust fault, displacement along which has resulted in ponding, drainage reversal and paired strath terraces (these geomorphic features are discussed in detail in Chapter 5). The syncline is named here as Palara Syncline from name of Shiva temple situated just south of it (Fig. 4.24). It is also observed that, under the influence of horizontal compressive stresses, bedding confined inclined (around 30° in most parts of the region) conjugate joints in thick sandstone bed lying between shale beds above and below (Fig. 4.27) are facilitating formation of flat-ramp-flat structure (Fig. 4.28). Shearing is evident at the base of bedding parallel thrust sheet (Fig. 4.25) (Karanth 2003, Karanth and Gadhavi 2007). Commonly it is observed that shale layers are sheared at the base of bedding parallel thrust; whereas, brittle sandstone layers are displaced along thrust faults.

Fig. 4.27: Bedding confined inclined joints.

Fig. 4.28: Flat-ramp-flat structure observed within Palara syncline.

Opposite sense of relative displacement

An interesting structure was recorded near Nadapa, located within the hanging wall of Kachchh Mainland Fault. The structure reveals opposite sense of relative displacements in thin incompetent-shale layers on either side of a sandstone bed (Fig. 4.29). The structure is an example of lithologically heterogeneous strata subjected to bedding parallel compression.

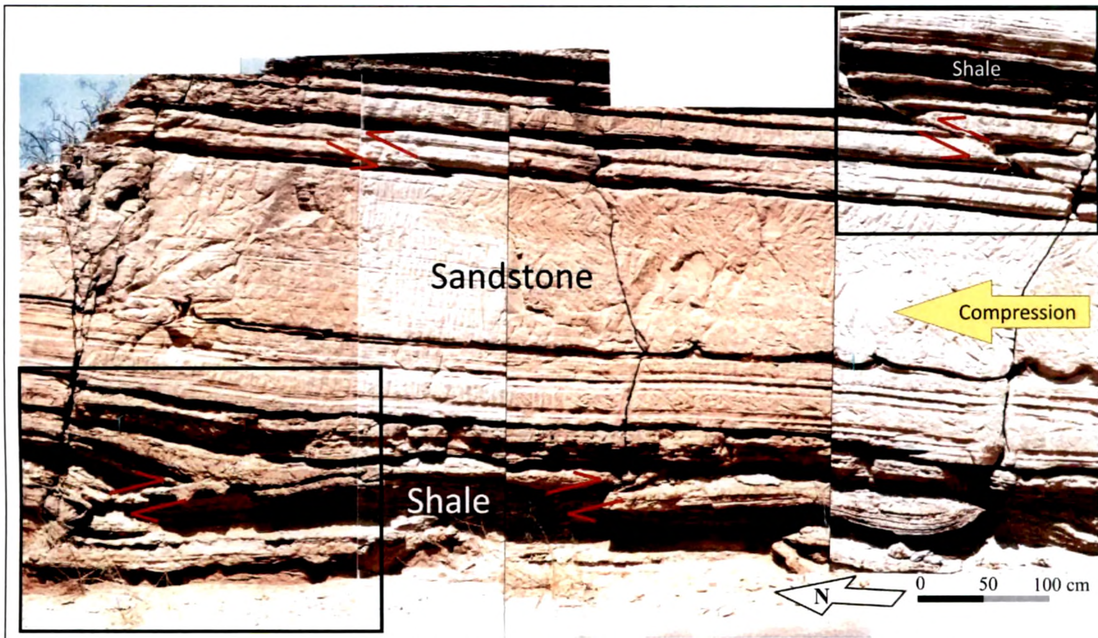
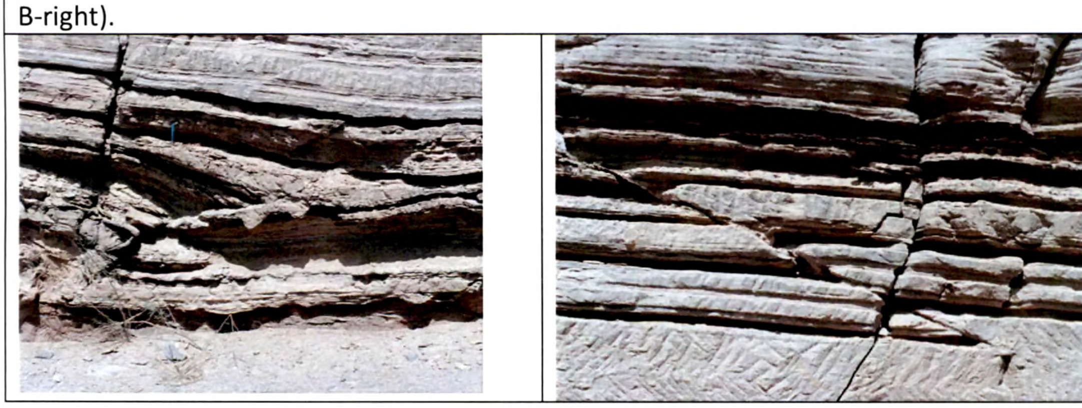


Fig. 4.29: Opposite sense of relative displacements in thin incompetent shale layers on either side of a sandstone bed; Portions shown in the rectangles are enlarged below (A-left; B-right).



Most structures observed in the field, as described above indicate that currently the region is under the spell of compressive regime. These aspects are discussed in detail in Chapter-6.