CHAPTER 3

GEOLOGICAL SETTING OF THE STUDY AREA

3.1. INTRODUCTION

Rocks of the study area belong to the Kadana Formation of the Lunavada Group and consist of quartzites and metapelites (chlorite schists, and garnet mica schists). The pelitic component contains frequent lenses and bands of calc silicate rock. This entire sequence, complexly folded by at least three deformational events, has been subsequently invaded by Godhra Granite. Though granites do not occur within the limits of the study area, their thermal effects are clearly seen. Metamorphic changes accompanying the successive fold events have impressed upon the rocks some very well defined mineralogical and textural changes. The various combinations in which successive deformational events have affected different parts of the area are well reflected in the overall outcrop patterns at the regional scale. This is quite obvious from the satellite imagery of the area (Fig. 3.1 a, b, c) and the geological map of the study area prepared by the author (Fig. 3.2). On account of isoclinal foldings, the area shows outcrops of linear as well as sinuous quartzite ridges with intervening low lying areas occupied by their softer counterparts (e.g. mica schists, chlorite schists etc.). Considering the scarcity of exposures and the fact that tight folding of more than one generation has been responsible for giving rise to alternating sequences of quartzites and metapelites, it is not practicable to work out

Fig. 3.1a. Photograph of satellite imagery (Indian Remote Sensing Satellite-False Colour Composite; Path-31, Row-51) of Aravalli Mountain Belt. The southeastern parts of the imagery occupy study area which is shown in Fig. 3.1b.

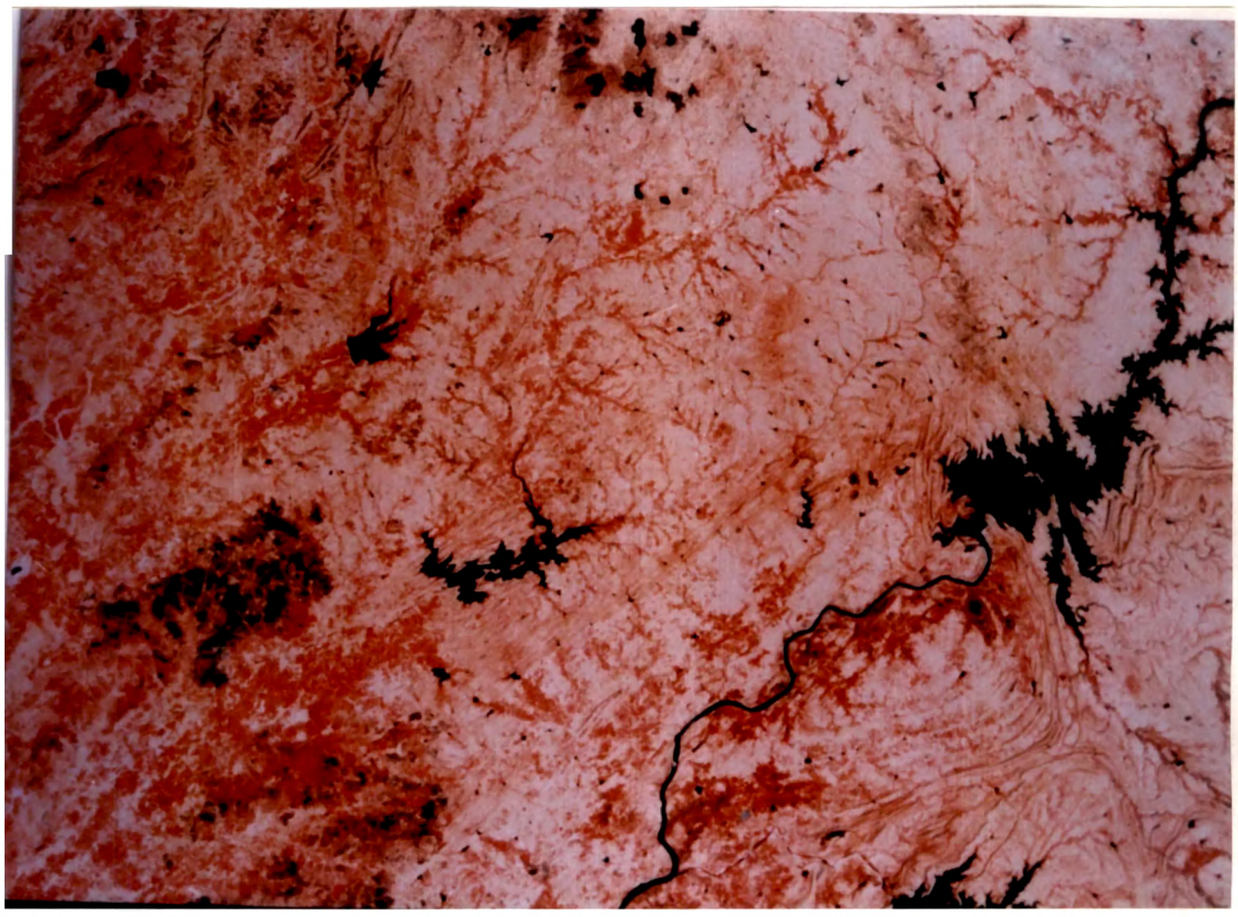


Fig. 3.1b. Satellite imagery showing the complex outcrop pattern of the study area.

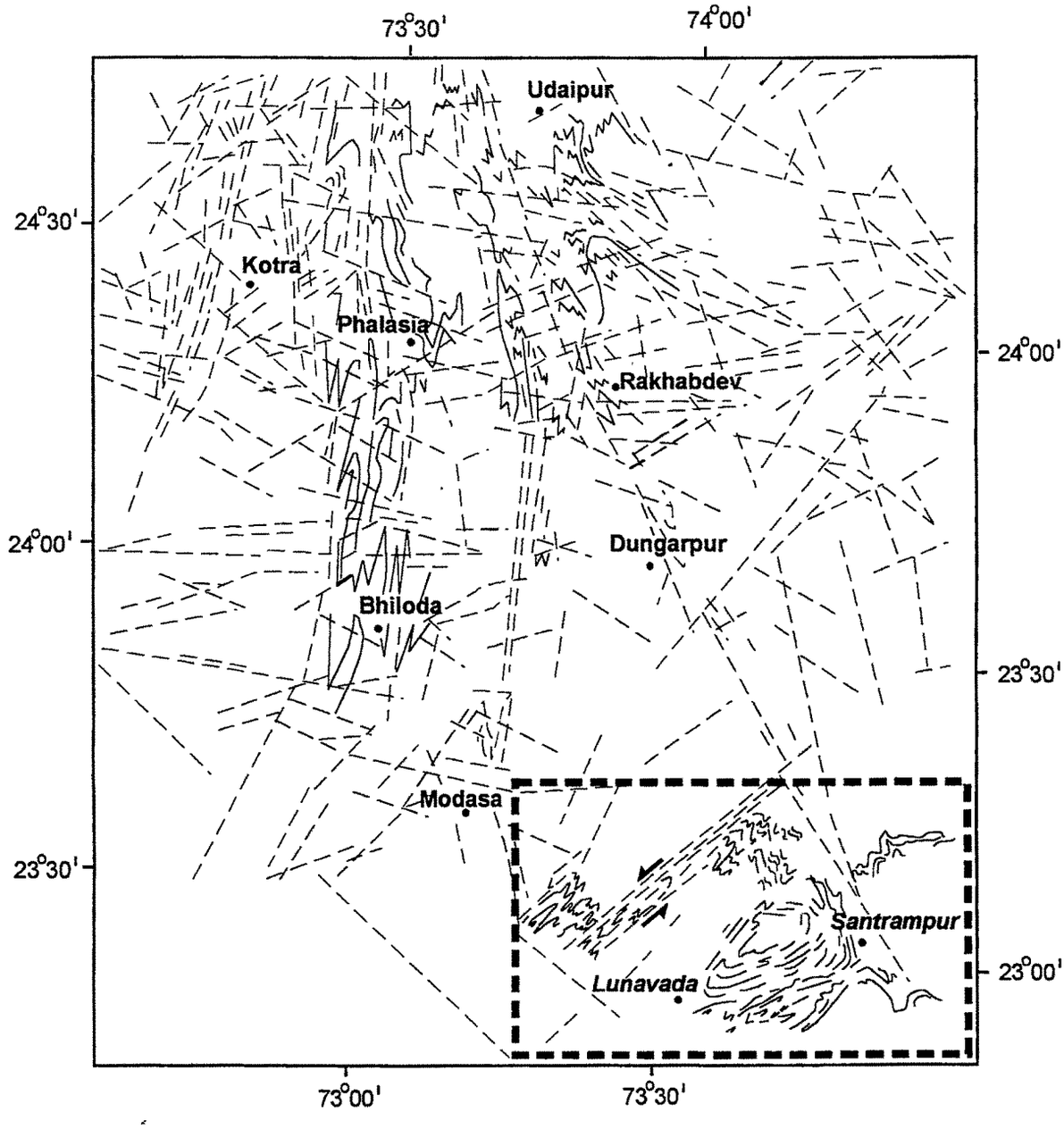
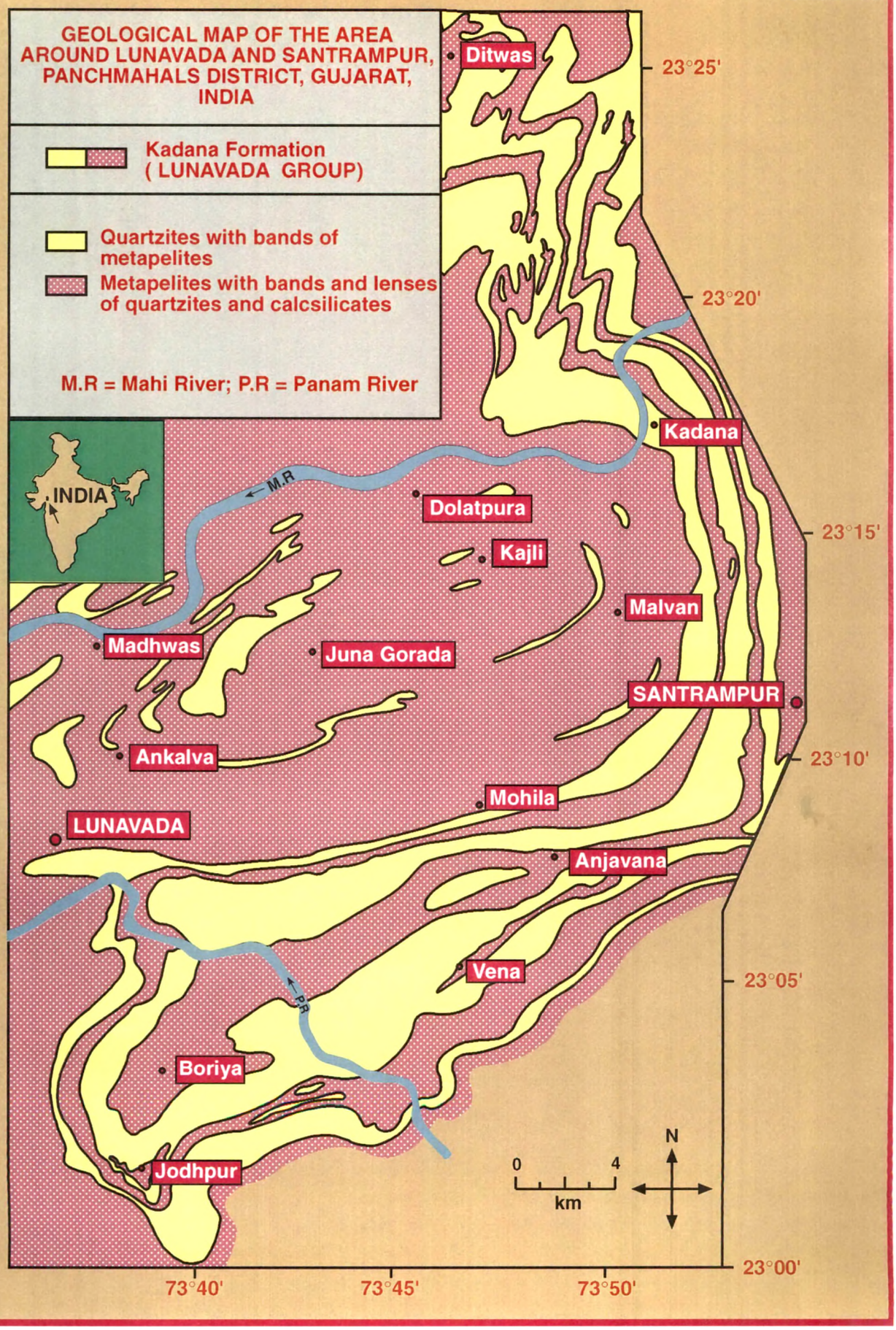


Fig. 3.1c. Tectonic map of the Aravalli Mountain Belt prepared from the satellite imagery (Fig. 3.1a). The study area lies in lower right corner of the diagram.

Fig. 3.2


GEOLOGICAL MAP OF THE AREA AROUND LUNAVADA AND SANTRAMPUR, PANCHMAHALS DISTRICT, GUJARAT, INDIA
Kadana Formation (LUNAVADA GROUP)
Quartzites with bands of metapelites
Metapelites with bands and lenses of quartzites and calcsilicates
M.R = Mahi River; P.R = Panam River
INDIA
M.R
P.R
Ditwas
Kadana
Dolatpura
Kajli
Malvan
Madhwas
Juna Gorada
SANTRAMPUR
Ankalva
Mohila
LUNAVADA
Anjavana
Vena
Boriya
Jodhpur
0
4
km
N
23°25'
23°20'
23°15'
23°10'
23°05'
23°00'
73°40'
73°45'
73°50'

the stratigraphic age relationship between the two rock types and it is difficult to conclusively state whether a single psammite-pelite sequence was repeatedly folded or there were several such sequences. Obviously, it is not feasible to suggest a stratigraphic classification. The author has therefore only to put forth the following generalized stratigraphic sequence for the study area:

Godhra Granite	Syn to Post- D3 deformation of Lunavada rocks (955 Ma); Pre-Erinpura
Quartzite intercalated with metapelites (chlorite schists, mica schists)	Kadana Formation (Lunavada Group)
Base (not exposed)	(?) B.G.C

3.2. FIELD DESCRIPTION

As it is not possible to describe the mode of occurrence and field characters of the various rock types of the area in stratigraphic order, the author has preferred to take into account the factor of outcrop pattern of the quartzite ridges and the degree of abundance and nature of various planar and linear structural elements to describe the geological setting of the area. Applying this criterion, the study area has been divided into three sub-regions - I, II and III, each characterized by its own distinctive outcrop pattern and structural characteristics (Figs. 3.1 and 3.2). The account of each sub-region essentially comprises description of different rock types as seen in the field and also the various field characteristics preserved in them. In this chapter, no attempt has been made to go into the details of the mineralogical, textural and structural complexities. These have been discussed at length in subsequent chapters.

Sub-Region-I : (Area to the north of Kadana-Dolatpura NE-SW trending tract

An area of about 150 sq. km around Kadana and to its north extending upto Ditwas village forms more or less a rectangle. The villages of Kadana, Madhwas, Dolatpura and Ditwas are located within this sub-region (Survey of India Topographical Sheets 46 E/15 and parts of 46 E/12; Fig. 3.2). The rocks consisting of intercalated quartzites and chlorite schists show linear NE-SW and N-S trending outcrops of quartzites. Topographically, this part of the study area is characterized by linear ridges of quartzites with intervening low ground which contain mostly chlorite schists. The quartzite ridges show heights ranging from 203 m to 261 m and extend for 25 km along the strike. The northernmost part constitutes a NE-SW trending ridge which is seen on the satellite imagery (Fig. 3.1 a, c). A major part of this ridge lies to the southwest, outside the limits of the study area. Whereas, quartzites are well exposed in the field, the chlorite schists which occupy the intervening low lying areas generally do not show any exposures, being covered by soils and alluvium; their presence is however conclusively observed in the numerous well sections (Figs. 3.3 a,b).

The quartzites are rather massive and dominantly yellowish white in colour. They do not show any significant preservation of sedimentary structures. As such, it is very difficult to record any bedding planes. By and large, the quartzites only occasionally have preserved folds of mesoscopic scale. The folding however can be established by taking into account the outcrop pattern of the closely spaced ridges and on the basis of a detailed structural analysis (discussed in chapter 4). The presence of tight folds is recorded at several places on the basis of a very careful and extensive indepth regional mapping. Small folds of the order of a few square

a

b

Fig.3.3.(a, b). Field photographs of well sections documenting the presence of quartzite alternating with chlorite schists. In the absence of good field exposures, such well sections are useful in determining the orientations of planar structures. The contact between the two lithologies is the bedding plane. Location: (a) Godhar (S of Ditwas); (b) Ditwas.

meters aerial extent are recorded at Kadana, on the banks of the river Mahi. Flexures in quartzites giving rise to culminations and depressions are also observed (Fig. 3.4, 3.5). The quartzites tend to assume a grey colour when they show transition towards chlorite schists.

The chlorite schists are only occasionally exposed on the surface but numerous well sections reveal their presence and nature. These intercalated rocks show greenish grey colour and are highly cleaved. The main cleavage (S_1) is essentially a product of the earliest folding of the alternating sequence and because of tight folding the trends of the quartzite ridges and that of the cleavage are more or less identical. It is observed that the cleavage marks the axial plane of the tight folds. Crenulation of the cleavage is obviously a phenomenon related to subsequent fold events. Some chlorite schists show a diagnostic b-lineation (cleavage-bedding intersection) pointing to the main fold axis of the area.

On the satellite imagery, the area of this sub-region is observed to comprise very closely spaced linear ridges and their dense population. Moreover, the satellite imagery also gives an impression that this region has undergone some shearing or movement resulting in stretching of pre-existing structures. Field studies have further revealed that the quartzites of this region are extensively fractured and sliced. NE-SW trending joints and fractures are prominent and these are very closely spaced; this joint spacing ranges from 5-12 cm. The quartzites showing such closely spaced joints are dominantly homogenous and fine grained (as observed under the microscope). Moreover, chlorite schists of this region show presence of a well developed crenulation cleavage. These chlorite schists possess small bands of

Fig. 3.4. Culminations and depressions related to F_3 folding in quartzites. Location: Kadana

Fig. 3.5. Fold hinge (F_2) in quartzite. The fold axis plunges moderately to the SW. Location: Munpur.

quartz rich layers which are seen to be offset along the crenulation cleavage planes. All the above features and characteristics point to the fact that this sub-region comprises rocks that underwent high strain and shearing.

Sub-Region-II : (Area to the south of Kadana-Dolatpura tract upto the Lunavada-Santrampur tract):

This part occupies an area of around 600 sq. km around the town of Santrampur and villages-Malvan, Kajli, Ankalva and Juna Gorada (Survey of India Topographical Sheets 46 E/12 and 46 E/16; Fig. 3.2). It consists of alternating horizons of quartzites and mica. The outcrop patter is rather interesting. The quartzites are generally yellowish in colour with lenses or bands of grey quartzites occurring at a few places. They are homogenous and rarely show any mesoscopic scale mineralogical banding (Fig. 3.6 a, b). Ridges of quartzites, some of which are 245 m high, form a rather regional elliptical outcrop pattern enclosing a slightly depressed area within which occur biotite mica schists; the latter interestingly pointing to a higher metamorphic equivalent of the chlorite schists encountered in sub-region I. On the whole the exposures are scarce and sporadic, the number of ridges are less but they very ideally show the overall outcrop pattern. The northwestern part has a set of broken ridges trending NE-SW whereas the southern part has a few conspicuous almost E-W trending ridges; the two sets of ridges more or less meeting at the western extremity ideally showing a macroscale fold closure. The eastern part also has a large scale fold closure formed by quartzite ridges. The overall outcrop pattern documents that the area represents a dome-basin structure, a product of cross folding. This aspect has been discussed in detail in chapter 4. As usual, the quartzites alternate with mica schists and except for the quartzites, there

Fig. 3.6 (a, b). Ridges of homogenous jointed quartzite. Location: Santrampur.

is scarcity of good exposures. Quartzites do not show any worthwhile small scale folds in this sub-region except at Dolatpura where recumbent folds were encountered (Fig. 3.7). Moreover a minor flexure in quartzite is also present to the N of Lunavada along the Lunavada-Modasa road (Fig. 3.8).

Exposures of schists on the surface are scarce, but the samples collected from well sections provide vital information. Schistose rocks of this area are grey in appearance and show porphyroblasts of biotite. A few samples have preserved a primary lithological layering. It is observed that in hand-specimens the schistose rocks comprise alternating horizons of phyllosilicate-rich and phyllosilicate-poor layers. Whereas the former has a lesser percentage of quartz, the latter has a higher percentage of quartz. At a few places, the alternating sequence of such phyllosilicate rich and phyllosilicate poor layers ideally show cleavage bedding relationship. Bedding is characterized by the mineralogical variations whereas the mica flakes which are oblique to the former point to the axial plane cleavage. The intersection of cleavage and bedding forms a lineation which is parallel to one of the early folds (F_2 axis). Garnet biotite schists alternating with quartzites are encountered in Ankalva area which lies on the western tip of the *eyed-structure* . Here the junction between the two rock types is taken as the bedding plane and the schistosity is sub-parallel to the bedding plane (Fig. 3.9). Schists from well sections in this region show presence of crenulation cleavage in thin sections. This phenomenon indicates folding of an earlier cleavage, thus implying a complex fold history.

Fig. 3.7. F_2 fold hinge of a recumbent fold in quartzite. The fold axis trends NE-SW. Location: Dolatpura.

Fig. 3.8. F_2 fold in quartzite. The fold axis plunges gently to the NE. Location: Limbodhra crossing (N of Lunavada on Lunavada-Modasa highway).

Sub-Region-III (Area to the south of Lunavada-Santrampur tract)

The rock exposures to the south of the Lunavada-Santrampur line comprising an area of 400 sq. km provides many interesting details. Towns of Lunavada and Santrampur and the villages - Boriya, Anjavana and Vena, fall within this sub-region (survey of India Topographical Sheets 46 E/12 and 46 E/16; Fig. 3.2). Lithologically, the rocks of this area, as usual consist of quartzites and schists. Quartzites form ridges of massive, homogeneous rock; the ridges range in height from 186 to 281 m and extend continuously for a length of 35 km between Lunavada and Santrampur towns. The quartzites are devoid of any indication of original bedding though some colour banding is well preserved in localities like Gada (south of Lunavada) which could be used in deciphering the bedding plane (Fig. 3.10). The colour of these quartzites varies from yellow to brown. The quartzites alternate with garnet mica schists; these schists have a distinct spotted appearance in the field on account of the presence of porphyroblasts of garnet and biotite. Sporadically occurring lenses of calc silicate rock rich in actinolite are intervened with the quartzites and schists to the south of Lunavada. The outcrop pattern as revealed by very sinuous and complex trends of massive quartzite ridges is suggestive of a complex fold interference pattern which on a regional scale resembles a distorted closed structure, a product of superimposition of at least three fold episodes. This area is most revealing and has preserved numerous evidences which have enabled the author to work out the deformational and metamorphic history.

Mapping in this area has revealed that there is pinching of the outcrop pattern around Kotvad, Falva and Umber areas which form the northeastern extremity of this sub-region. Contrary to the above, the western part of the region has a inflated or

Fig. 3.9. Photograph documenting sub-parallel relationship between schistosity and bedding plane. The bedding plane is marked by the contact between quartzite and schist. Locality: Ankalva.

Fig. 3.10. Field photograph showing presence of lithological variation (colour banding) in quartzites. Such exposures are useful in recognizing the bedding plane in quartzites. Location: Gada (S of Lunavada).

swollen outcrop pattern. The entire region to the south of Lunavada and Santrampur can be likened as an east-west trending oblong balloon which was pinched out (due to two limbs of a fold coming closer) at the eastern end and a resultant bloating at the western limit, on account of the effect of an open cross flexure.

Compared to the other two subdivisions, this region has a better presence of mesoscopic folds. Reclined folds are exposed in quartzite - schist assemblage along a 100 m long nala cutting (canal cutting) at Anjavana (18 km southwest of Santrampur; Figs. 3.11 to 3.14). Garnet porphyroblasts as well as crenulation cleavages are absent in the schists of this exposure. Axial plane cleavage and bedding relationships are well observed here. The axial plane cleavage strikes NW-SE and dips to the NE. It maintains a constant orientation throughout this exposure, while the strike and amount of dip of the bedding plane keeps on varying from the limbs to hinges of the fold. The dip of the bedding plane on limbs of the folds is same as the plunge of the fold axis which is due NE. The bedding and axial plane cleavage are parallel to each other on the limbs. Moreover, in the nose area of the fold, the bedding plane is vertical and the axial plane cleavage is perpendicular to the bedding (Fig. 3.13). All the above characteristics typically point to the reclined nature of the folds.

Some of the well sections in the Anjavana, Charada, Falva and Kotvad areas lying to the southwest of Santrampur have garnet-biotite schists which under the microscope show a well developed crenulation cleavage. Obviously, this crenulation is a manifestation of the superimposed deformation. However, mesoscopic superposed folds are not observed in the region. Exposures along the road cuttings

Fig. 3.11. Reclined F_1 fold in quartzite-schist assemblage exposed along a canal cutting. Location: Anjavana (SW of Santrampur).

Fig. 3.12. Axial plane cleavage developed due to reclined folding in quartzite-schist sequence. Location: Anjavana (SW of Santrampur).

Fig. 3.13. Field photograph showing presence of vertical bedding plane (marked by white quartz rich bands parallel to the pen in photograph) on the nose portion of reclined fold. The axial plane cleavage is perpendicular to the bedding plane. Locality: Anjavana (SW of Santrampur).

Fig. 3.14. Hinge of the F_1 reclined fold. The axis plunges moderately to the NE. Location: Anjavana (SW of Santrampur).

through the E-W trending quartzites ridges like the one at Vena crossing (18 km southeast of Lunavada) show quartzites alternating with schists. Rock assemblages at such places exhibit well defined cleavage-bedding relationships. The bedding and cleavage lie sub-parallel to slightly oblique to one another and obviously, such E-W trending linear ridges form the limbs of a macroscopic fold.

Mineral lineations are prominent in this region. They lie at a high angle to the fold axis of the reclined folds at Anjavana. These mineral lineations plunge due NNW and are strongly developed in schists of the area to the south of Lunavada and Santrampur (Fig. 3.15). They represent an "a" lineation which appears to have developed on account of slipping along the foliation plane during folding. At a few places to the south of Lunavada, schists exposed on the banks of the river Panam show kinks with the kink axis trending in WNW-ESE direction (Fig. 3.16). Mineral lineation on the foliation plane is deformed on account of this late kinking which is obviously related to a later deformation (D_3). Quartzites rarely show any lineations. However, good exposures of b-lineations in homogenous, massive yellow quartzites are observed at Kotwal Dungar (south of Lunavada) where the lineation is characterized by fold axis of several minor flexures in quartzites plunging due NW (Fig. 3.17). Slickensides have developed on joint planes in quartzites at Gada and Jodhpur (south of Lunavada) (Figs. 3.18 a, b). These imply local movement along joint planes.

The Godhra Granite is exposed to the S and W beyond the study area and to the west of sub-region III. Although the granite is not encountered in the study area, veins of quartz pegmatites and associated quartzo-feldspathic pegmatites are

Fig. 3.15. Mineral lineation on foliation plane (S_2) in schist. The lineation plunges gently to the NNW. Location: Banks of river Panam, S of Lunavada town.

Fig. 3.16. F_3 kinks in schist. The kink axis (parallel to the blue pen in photograph) is sub-horizontal and has a WNW-ESE trend. There is a NNW-SSE trending mineral lineation on the foliation plane (parallel to white pen in photograph) which is deformed by the F_3 kinks. Location: Banks of river Panam, S of Lunavada town.

Fig. 3.17. Lineations (mesoscopic F_3 fold axes) in quartzites plunging due NW. Location: Kotwal Dungar (S of Lunavada).

a

b

Fig. 3.18(a, b). Slickensides on joint planes in quartzite implying local movement. Location: (a) Jodhpur, (b) Gada.

observed to intrude the quartzite-schist assemblages to the south of Lunavada around Boriya-Chari area (Fig. 3.19). Some pegmatites are seen exposed on the surface around Bhaiyasar (south of Lunavada). However, the intrusive relation of the pegmatites and country rocks are generally observed better in the well sections around Boriya and Chari. Tourmaline crystals have developed in schists lying in the vicinity of the pegmatites.

3.3. OVERVIEW

It is seen from the above description that the study area around Lunavada, Santrampur and Kadana which constitutes the Kadana Formation of the Lunavada Group, comprises a dominantly monotonous lithology. The entire region is characterized by prominent ridges of quartzites which are intercalated with pelitic layers .The rock types occurring in the study area as described in the three sub-regions provide a good overview of their structural complexity. The regional outcrop pattern so ideally seen on the map of Gupta and Mukherjee (1938) and also on the satellite imagery conclusively points to interference fold patterns of several generations. The complexity of the fold pattern is very well seen in the regional outcrop pattern, but most previous workers were unable to investigate the details of the deformational history and sort out the fold interference pattern. This was mainly because of the relative scarcity of mesoscopic or small scale folds in quartzites and paucity of outcrops of softer rocks.

The investigations by the present author have enabled him to record at many places small folds and linear and planar structures related to successive fold events.

Fig. 3.19. Well section showing quartz-pegmatites associated with Godhra Granite intrusion. The pegmatites intrude through the foliation planes of the schists. Location: Boriya (SE of Lunavada).

It will be seen from the above description that a close relationship exists between the geometry of the successive fold events and the behaviour of quartzite ridges. In fact, the field data collected by the present author provided very important guideline, not only for understanding the structural history of the area, but also enabled him to establish its relationship with metamorphic changes.