CHAPTER 9

STRUCTURAL ANALYSIS

The Wagad hills form one of the six major uplifts of the Kutch basin. The Wagad uplift is bounded by high angled normal fault to its S. This upthurst fault has been termed as the 'South Wagad fault' (Biswas and Despande, 1970, fig. 2) and is associated with a flexure zone to its N - the upthrown side of the fault. Such a flexure zone which comprises asymmetrical anticlines and domes related to faulting have been referred to as 'Bruchfaulten' or 'fault folds' (Prucha, Graham and Nickelson, 1965, p.974, Biswas, 1971). The south

Wagad fault shows approximately an E-W regional strike. A few important faults which show a regional trend sub-parallel to that of the South Wagad fault occur close to it, and which have been called as the Kanthkot fault, Kharoi fault, and the Dedarwa fault from W to E respectively (Figs. 1.4 and 9.1). These faults in turn, show associated flexure zones on their upthrown side. In all, there are three major flexure zones in the structurally disturbed southern part of the Wagad hills and these have been termed as the south Wagad flexure zone, Kanthkot flexure zone and the Dedarwa flexure zone. These zones are characterised by several asymmetrical anticlines and domes with intervening synclines. Besides these flexure zones of the southern part, the northern part of the Wagad is also marked by several anticlines, domes and corresponding synclines. These northern structures are associated with minor faults only and are quite gentle, broad and of open type. However, these northern structures occupy far more extensive areas than those of the southern part.

SOUTH WAGAD FLEXURE ZONE

The southern chain of structures flanking the South Wagad fault has been grouped into the south Wagad flexure zone, and includes, the Mae dome, Wamka dome, Adhoi anticlinal complex, Washtawa dome, Chitrod dome, Shivlakha domes, the Bedarwa anticline and Mewasa dome from W to E respectively.

It appears that the Kanthkot fault is an offshoot of the South Wagad fault and the bifurcation probably takes place in the area south of village Washtawa. The Washtawa dome is thus flanked by the South Wagad fault to the S, the Kanthkot fault in the W and the Kharoi fault in the E. Since the South Wagad fault is the most important amongst them, the Washtawa dome has been included in the South Wagad flexure zone. Similarly, the Bedarwa domes which are almost in physical continuity with the Mewasa dome, have also been included in the South Wagad flexure zone. The Bedarwa fault along which the Bedarwa anticline occurs is also a bifurcation of the South Wagad fault.

The western Mae and Wamka domes show roughly oval shaped closures and these closures are conspicuously displayed by the Upper Astarte band. The southern flanks of these dome are quite steep where the dips vary between 50° to 80° due S, while the northern flanks show dip variations around 10° - 15° only. The longer axes of both these closures are about 1½ to 2 miles in length.

The Adhoi anticline occurs in the area extending from Halrae in the W to Washtawa in the E, a distance of about 8 miles. It is a doubly plunging narrow elongated, sharp asymmetrical anticline with an approximate E-W axis. The village Adhoi is situated on the axial part. The anticline is marked by several local closures and the westernmost amongst them is the most prominent and termed as Halrae dome. The Upper Astarte band which fringes the entire Adhoi anticline except in the eastern part, very clearly shows the westward plunge of the structure near village Halrae. The configuration of the Adhoi structures is clearly revealed by the Lower and the Upper Astarte bands. The saddle part between the Halrae dome and the Adhoi anticline is marked by a conspicuous kink or a drag. The entire length of the anticline shows a sharp asymmetric nature such that the southern flank dips steeply due S, or at places it is almost vertical or even inverted dipping due N. The northern flank however dips at only 10° to 15° due N. In the northern part of the area, the Upper Astarte band typically shows a broad 'U' shaped swing towards W characterising the Gamdau syncline. The eastern part of this syncline shows an approximate E-W axis while in the western half it is WNW-ESE. The shift of the axis between Wamka and Halrae probably is due to a cross fault. A few bands within the Gamdau Formation in the eastern half of this synclinal area around Gamdau village show a complete closure indicating a structural basin. The Kanthkot fault in the N forms an abrupt limit of this syncline where the younger Gamdau or the Upper Kanthkot rocks are in juxtaposition with the older Washtawa or the Lower Kanthkot rocks.

The Washtawa dome which comprises the central part of the South Wagad flexure zone, forms the most important structure of the Wagad hills so far as the degree of uplift is concerned. It is an oblong shaped dome with E-W longer axis of about 7 miles length. The core of the Washtawa dome exposes the oldest rocks of the entire Wagad succession. The shape of this dome is ideally brought out by the fossiliferrous mudstone band which encircles the entire structure except in the eastern part. As in the case of other structures the Washtawa dome also shows steeper southern limb with gentle northern limb. It is an interesting feature to note that a narrow chain of plunging anticlines and domes occur in between the Washtawa dome and the south Wagad fault in the south eastern part. These smaller structures (Ghantodia domes) also have their axis roughly E-W oriented and are asymmetric in nature.

In the area E of the Washtawa dome, exists a chain of small half domes along the Kharol fault showing a NE-SW orientation, and have been termed as Kharol domes.

The Chitrod dome which occurs ESE of the Washtawa dome is oval shaped and characteristically asymmetrical. The northern limb is gentle dipping at 3° to 4° due N while the southern one dips at 60° is almost vertical.

The conglomeratic mudstone band that encircles this dome ideally shows its geometry. A narrow chain of domes similar to the Ghantodia domes occurs in the area between Shivlakha and the Chitrod domes. These domes have been designated as Shivlakha domes.

The Mewasa-Dedarwa structure is another eastward plunging, narrow, asymmetrical anticline made-up of several small domal closures. The total length of this anticline is about 8 miles. The eastern part which occurs along the South Wagad fault including the Mewasa dome has an E-W axis while the western part occurring along the Dedarwa fault shows WNW-ESE axis. Several bands traced in this area clearly reveal this structural pattern. To the NE of the Mewasa dome occur two small structures bordering the South Wagad fault. These are the Jadawas dome and the Kidianagar structural basin.

The area N of the Washtawa, and the Chitrod domes and the Dedarwa-Mewasa structures is marked by a synclinal low. This E-W regional syncline occurring between the Northern Range structures and the Southern flexure zone can be divided into three units viz. the

Badargadh syncline, Khirai structural basin and the Kidianagar syncline including the Kidianagar structural basin. The Badargadh syncline has WSW-ENE axis while in case of the Kidianagar syncline it has an E-W orientation. Both the Badargadh and the Kidianagar synclines are of symmetrical type and 6 and 8 miles long respectively.

KANTHKOT FLEXURE ZONE

Structures occurring along the Kanthkot fault in the southwestern part of the area have been grouped under 'Kanthkot flexure zone'. These include from W to E the Manfara dome, Kakarwa anticline, Kanthkot domes, Wandh Moman synclines and the Nara dome (Figs. 1.4 and 9.1).

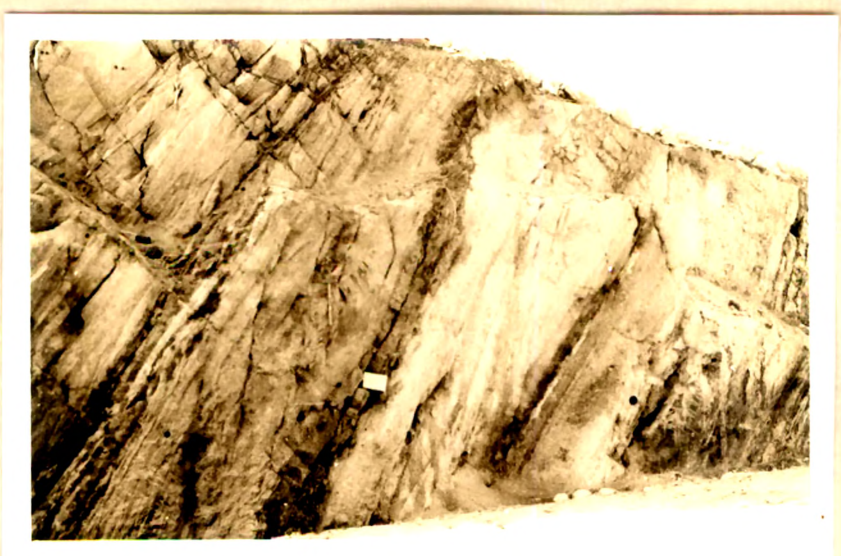
Of all the structures of this flexure zone, the Nara and the Kanthkot domes show maximum degree of uplift.

The Manfara dome is a small structure occurring in the westernmost part of the area and it exposes the Upper Astarte band in its core. The Kakarwa anticline is a narrow, asymmetrical, plunging anticline with a WNW-ESE axis. As in case of other structures, the

PLATE 26

Kakarwa anticline showing steep southerly dips (of ridge towards right) along the Kanthkot fault and gentle northerly dips of extreme left background hill.

PLATE 27



Steeply dipping Fort sandstone near South Wagad fault. Locality: southern flank of Chitrod dome.

Kakarwa anticline also shows very steep southern limb and a gentle northern limb. The plunge direction is towards WNW. The Upper Astarte band which makes an impressive scarp all around the structure shows a sharp northerly swing in the north easten part of the anticline.

The Kanthkot domes which occur about 3 miles east of the Kakarwa anticline do not show complete domal closures and are semicircular in shape. The fossiliferous mudstone band which has been traced in the area clearly reveals the geometry of these domes.

The Mamma Wandh Synclines are two semicircular, gentle structures. It appears that these were originally structural basins, the southern parts of which have been cut-off by the Kanthkot fault. It is interesting to note that a small dome called the Torania dome occurs in between these two synclinal structures. All these synclines appear to be a continuation of the Badargadh synclinal low.

The Nara dome which is the easternmost extension of the Kanthkot flexure, is an oval shaped structure with roughly NE-SW axis. The fossiliferous mudstone band exposed in this dome perfectly show its shape.

THE NORTHERN RANGE STRUCTURES

The structures of the Northern Range are not associated with any particular major fault and do not show any preferred orientation. The structures are quite broad and gentle and occupy extensive areas of the Wagad. These includes:

(1) The Chobari Nose (2) The Ramwao low
(3) The Tramau anticline (4) The Narada dome
(5) The Wagad anticline (6) The Dabunda dome
(7) The Rapar syncline (8) The Sonalwa dome
(9) The Hamirpur dome (10) The Bhutakia syncline
(11) The Bhimasar anticline (12) The Umarpur domes.

The most important structure of this group occurring in the central part of the Wagad is obviously the Wagad anticline. It is a broad arch shaped doubly plunging anticline having an E-W axis. Its both flanks show gentle dips of 3° to 4°. This anticline is fringed all around by the fossiliferrous mudstone band. The eastern extension of this structure shows a separate local closure which has been termed as <u>the Dabunda dome</u>. This dome is associated to its E and N by two faults - Sai and Dabunda faults. The mudstone band abuts against the Sai fault. The Chobari nose, the Ramwao low and the Tramau anticline having respectively E-W, NW-SE and N-S axes are the subsidiary structures which are apparently the extensions of the Wagad anticline.

The Narada dome is a gentle, elongated, oval shaped dome having NW-SE axis and occurs in the north central part of the area.

The Sonalwa and Hamirpur domes are of broad and gentle type, and are cut by numerous minor faults. The area between these two domes is marked by a synclinal low termed as Bhutakia syncline having roughly a NNW-SSE axis.

The Bhimasar anticline having roughly E-W axis and plunging towards E is the eastern most structure of the area.

A narrow E-W trending chain of minor structures occurs in the east central part of the area. These half domes and anticlines occur along the Vekra fault (Fig. 9.1) and have been termed as Umarpur domes, the name derived from the nearest village.

PLATE 28

South Wagad fault. Vertical Mesozoic beds in contact with horizontal Tertiaries forming large plains. Locality: S of Mewasa dome.

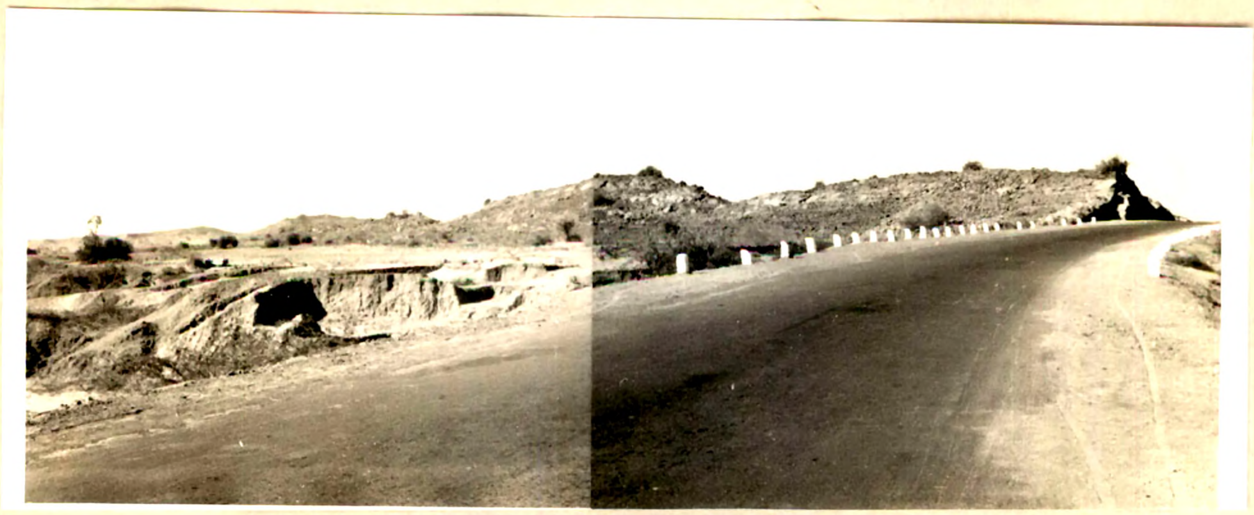
FAULTS

Though the area is marked by a number of faults, only a few major faults have been described here.

The South Wagad Fault

This fault is the most important of all the dislocations and marks the southern limit of the Mesozoic outcrops of Wagad. It extends from Mae in the W to Jadawas in the E. It is a high angled to almost vertical normal fault having a general E-W, strike, though actually from W to E, the strike swings from WNW-ESE to NE-SW. This fault is ideally exposed in the eastern parts of the area especially S of the Mewasa and the Chitrod domes where the younger Tertiaries are seen in contact with the Mesozoic rocks to the N. It appears that the Vekra fault and the Bhimasar fault are the eastern extensions of the South Wagad fault. This fault is cut by several cross faults giving rise to corresponding shifts of the fault plane. In the western half of the area to the S of Adhoi anticline, and the Wamka and Mae domes, the fault does not outcrop and it appears that this fault passes through

PLATE 29



South Wagad fault. Ridge comprising sandstones of Lower Kanthkot Formation in contact with low lying Tertiary clays of foreground. Locality: southern flank of Chitrod dome.

the vertical dip zones of these structures. The maximum stratigraphic throw of this fault has been calculated to be about 2000' in the eastern parts. The Dedarwa and the Kharel faults in the E having respectively NW-SE and NE-SW strikes are perhaps branches of the South Wagad fault, each having caused vertical displacement of about 800'.

The Kanthkot Fault

The Kanthkot fault occurs in the south western part of the area and strikes approximately WNW-ESE. It has brought in juxtaposition the older Washtawa and the Kanthkot rocks (in the N) against the Gamdau rocks (to the S). The fault extends for a distance of about 16 miles from Manfara in the W to a little E of village Nara in the south central Wagad. It has a maximum stratigraphic throw of the order of 1000' around the Kanthkot and Nara domes. The fault plane dips at angles varying between 60° to 80° due SSW. At a few places viz. S of the Kanthkot dome, it is almost vertical. A few good outcrops of the fault can be cited as those S of the Kakarwa anticline, Kanthkot domes and the Nara dome. In the area between the Adhoi anclino and the Washtawa dome, this fault appears to die out, no appreciable effect of the fault is seen on the surface. The Lower Astarte band has been continously traced from Adhoi to Washtawa in this area and does not show any shifting.

The Dabunda Fault, Sai Fault and the Kidianagar Fault

These three are high angled normal faults encountered in the eastern part of the area. The Dabunda fault which could be traced for about 6 miles from S of Rapar to Dabunda is a dislocation having roughly WNW-ESE strike, and occurs within the Lower Kanthkot Formation. The Sai fault shows a NNE-SSW strike in the N and NNW-SSE strike in the S. The northern half of the fault limits the eastern extensions of the Washtawa rocks of the Dabunda dome. The Kidianagar fault which extends from Kidianagar in the N to Sae in the S, a distance of about 6 miles, also occurs within the Lower Kanthkot Formation and offsets the south Wagad fault. This fault is also associated with a dyke in its southern part.

Many more faults that show small amounts of displacements, have been traced in the field. Majority

PLATE 30

Dabunda fault. Locality: W of Dabunda.

PLATE 31

A minor fault in Lower Kanthkot Formation.
Locality: S of Bhutakia.

PLATE 32

High angled Dedarwa fault. Fort sandstones (right) in contact with shales of Kharol Member. Locality: about 1/2 mile S of Chitrod railway station.

of these show strikes that vary from NNE-SSW to E-W. The rose diagrams (Fig. 9.2) shows the strike directions and relative frequencies of all the major and minor faults recorded from the eastern and the western halves of the Wagad hills.

INTRUSIVE BODIES

Though numerous dykes and sills of local nature are met with in the area, only a few major ones are described. The Badargadh dyke extends from the area N of the Kakarwa anticline in the W, through the Wagad anticline, the Badargadh syncline, and upto the Mewasa dome in the E, for a distance of about 24 miles. It strikes WNW-ESE and is seen intruding through all the formations.

The Lilpur dyke occurs in the area E of Tramau, and passes through Lilpur southward for a distance of over 6 miles. The northern half of this intrusive body shows a NW-SE strike, while the same swings to N-S in its southern part and progressively intruding the Washtawa and the Lower Kanthkot Formations. The Khirai dyke occurs in the southern part of the

Dabunda dome within the Washtawa Formation and shows a semicircular shape.

Several other dykes and sills have been mapped. A number of them occur along fault planes in the eastern half of the area.

DISCUSSION

In conformity with the other structural uplifts of the Kutch basin, the Wagad uplift is also bounded by a fault to its S (the South Wagad fault). The main Wagad uplift comprises several chains of big and small domes, anticlines and synclines; and a most striking feature of these structures is that in most of the cases they are bordered by one or the other fault. The various major faults of the area are typically flanked by chain of domes to their north. These domal and anticlinal structures, characteristically asymmetrical in nature and comprise narrow and linear zones. Obviously their origin is closely related to the movement along these faults.

As already stated, the South Wagad fault is a block fault along which major vertical uplift has taken place. Obviously, the fault is an expression of the movement of a basement block. Prucha et al. (1965, p.969-970, fig. 4 and 5) have ideally shown that the attitude of the fault plane of such an upthrust varies from base to top, such that at the bottom of the block it is nearly vertical, but upward it passes through a high angled to low angled reverse fault near the surface. Prucha et al. (1965, p.969-970) who called such faults as upthrusts have divided the fault profile from deeper portions upwards towards the surface into three segments viz. vertical fault segment, high angled reverse fault segment and the low angled reverse fault segment. Beloussov (1962, p.147-148) has also favoured a wider genetic concept of upthrust to include all the faulted structures produced by upward movement of a portion of the earth's crust relative to another parts.

It is thus apparent that the South Wagad fault and the associated faults e.g. the Kanthkot, Dedarwa, Kharel, and Vekra, are upthrust faults. The attitude of these faults include high angled normal, vertical and high angled reverse at different localities indicating the difference in the present erosion level. The exact shape of the fault profiles seen in the field is thus obviously a combined function of (1) level of observation relative to the corresponding structural segment of the fault, (2) the thickness of the sedimentary column above the basement, (3) the type of the rocks involved, (4) the magnitude of the discontinuity in the basement, and (5) the topographic effect produced by faulting etc. Prucha et al. (1965, p.971) have further said that as one would expect in nature, the steep segments of upthrusts are more commonly found than to the flat upper segments.

The various faults of the Southern hill range, typically indicate the effect of basement uplift, reflected in relatively thinner stratigraphic column. Thus the upthrusts seen at various places (= levels) vary from high angle normal to reverse fault.

The various flexure zones associated with the faults are mainly controlled by these faults. The strong asymmetric nature of the folds with narrow linear zones of steep dips (varying from 70° to vertical or even inverted) along the faults support this view. These linear zones of asymmetrical flexures, typically illustrate the bending or draping of the sediments over the margins of the basement blocks on the upthrown sides of the faults. This phenomenon is a function of depth of erosion relative to the structural level of displacement and the plasticity of the beds. Prucha et al. (1965, p.982-83) have explained that when a vertical displacement occurs on the basement surface, the lowermost sedimentary beds adjust to the structural relief produced. If the beds cannot be folded, they will be faulted, when the deformation exceeds some critical intensity beyond which the sedimentary beds can no longer adjust by folding. The lower beds adjacent to the rigid basement blocks will be thus more susceptible to displacement by faults rather than folds, while for the beds higher up the uplift may manifest only as a flexure (Prucha, Graham and Nickelsen, 1965, p.975-84, figs. 12,23 and 24). Beloussov (1962, p.529) has classified folds that result from the upward directed and locally manifested tectonic forces as 'block folds'. It is thus obvious that the South Wagad and the Kanthkot flexure zones are typically the 'bruchfaulten' or 'fault folds'. The relationship between the rupturing and folding is so close that the upthrusts and fault folds may merge into each other. In fact it is the rupturing of the steeper limbs of such folds that gives rise to a fault on the surface.

Thus, the various upthrust faults in the area showing conspicuous displacement of sediments at most places quite frequently change over to folds and do not show any fracture and displacement. Such a phenomenon is typically seen S of the Adhoi anticline, and the Wamka and Mae domes, where the south Wagad fault is replaced by a steep asymmetric flexure.

The structures of the Northern Range area of Wagad are associated with several small faults and do not show any preferred orientation. These structures can be grouped under 'idiomorphic or discontinuous' folds of Beloussov (1962, p.119-130), who has defined such folds as those originated from dislocation of relatively 'rigid masses' and occur as numerous isolated, unconnected, variously shaped uplifts in the area of horizontally lying beds. The discontinuous or the isolated nature is clearly exhibited by the Narada dome, Daubunda dome, Sonalwa dome, and the Hamirpur dome. There is a complete absence of linearity among these structures. Besides, there seems to be unequal development of anticlines and synclines resulting in the development of residual depressions.

So far as the mafic igneous activity is concerned, a majority of dykes are seen to have intruded into the Washtawa, Lower and the Upper Kanthkot Formations, indicating their post Upper-Kanthkot age. It may be noted that there are no intrusive bodies present in the core or axial parts of various domes and anticlines. The important ones like the Badargadh dyke, a Lilpur dyke, do not show any conformity with the structures and mostly occur within the synclines or on the flanks of major anticlines. It is thus clear, that the intrusive phase was not related to the tectonic episode of the Wagad. It represents a separate post-Wagad tectonic, igneous activity. The author thinks that this intrusive phase can be assigned to the second cycle of igneous activity of the Kutch Mainland - a post-Kutch tectonic phase and pre-Deccan Trap volcanicity (Biswas and Deshpande, 1971).