Chapter 5

Structural Geology

5.1 Regional Structure

Regional structure and associated metamorphism are attributed to the Eburnean tectonothermal event *(Taylor et al., 1988; Hirdes et al., 1992; Milesi et al., 1992; Vidal and Alric, 1994)* that affected the entire West African Craton. This orogeny is characterized by isoclinal folding as well as intrusion of pre-, syn-, and post-tectonic granites. Overall, the southern Ashanti belt has a synclinal structure (Fig. 2.3) with the Tarkwaian Group (Table 2.1 and Fig. 2.5) in the core of the syncline *(Eisenlohr and Hirdes, 1992; John et al., 1999).*

Bedding in the southern Ashanti belt typically has a steep dip and have a consistent strike trend to the NE (Fig. 2.3). The dominant trend is apparently folded around an approximate E-W trend. The NW margin of the Ashanti belt is strongly tectonised and displays a well-developed cleavage and steeply plunging stretching lineations *(Eisenlohr and Hirdes, 1992; Hirdes and Nunoo, 1994).* An axial planar cleavage (S_1) parallel to the bedding is attributed to the folding event *(Eisenlohr and Hirdes, 1992).* A weak second foliation (S_2) is developed locally *(Blenkinsop et al., 1994).*

To the west of the Tarkwaian the Birimian strata are overturned in a series of overturned synclines and anticlines that are associated with westerly dipping thrust faults (Fig. 2.4).

5.2 Mine Scale Structure

The geological map of the Nsuta manganese deposit is presented (Fig. 5.1A) and should be used in conjunction with the three dimensional cross-section (Fig 5.1B) to assist in understanding the general structure and geometry of the mine. This map is based on data from the mine supplemented by new information obtained during this study. Major features to be noted are:

- Isoclinal folding with axial planes generally dipping to the east.
- Thrust duplication of strata by a westward verging thrust fault.
- Two generations of faulting; E-W normal faults crosscut by a younger NNE-SSW trending normal fault.

The entire concession (Fig. 5.1A) is dissected by NNE-SSW and E-W fault systems. This dissection by faulting has led to naming the different segments from Hill A in the south to Hill E in the north. Hills C and D are centrally situated and are subdivided into northern and southern units, namely Hill D north and Hill D south and Hill C north and Hill C south.

5.2.1 Folds

The general structure of the deposit is a series of faulted anticlines and synclines. Two synclinal structures are evident in the field, namely at Hill A and in the northern part of Hill D north (Fig. 5.1A and B). Both have fold axes plunging NNE. The fold axial plane of the syncline at Hill D north dips approximately 50^{O} E (Fig. 5.2).

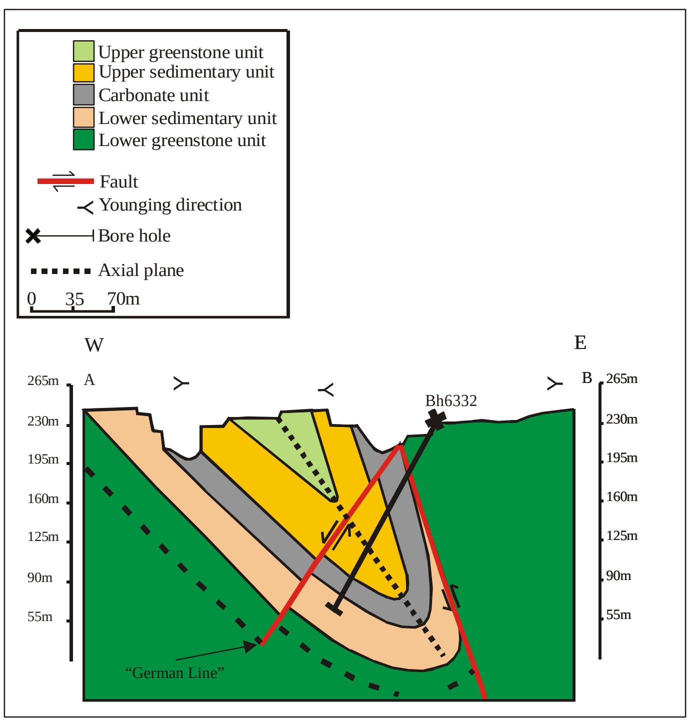

Figure 5.2. Cross-section A-B (Fig. 5.1A) across the northern part of Hill D north.

Other major fold structures include anticlines identified at Hill D south and in the southern part of Hill D north (Figs. 5.1A and B). These anticlines have younging directions away from the anticlinal core and also have fold axes that plunge NNE. The wavelength of these folds (anticlines and synclines) is about 640m.

In the field it is evident that there has been a weak second folding event although data presented in this chapter is insufficient for an accurate and meaningful interpretation. On a regional scale, however, evidence of a second folding event is presented on aeromagnetic surveys of the southern Ashanti belt. These images (Fig. 2.10B and 2.11B) indicate form-lines (produced by F_1) that have been folded with fold axes generally oriented in a NW-SE direction. First phase folds are the dominant structures at Nsuta and are defined as F_1 while second phase folds (cross folds) are defined as F_2. Cross folds (F_2) were especially noted at Hills B, C south, C north and E and have a maximum wavelength of about 30 m. Where open-pit geometry permitted measurement of these structures, it was noted that their axes plunge steeply at about 35^{O} towards the east (Figs. 5.3a, 5.3b, and 5.3c). Cleavage is well developed locally at Hill D south and Hill B (Fig. 5.4a). This cleavage is usually defined by an alignment of sericite and/or chlorite, and is more obvious in greenstones than in siliciclastic sediments.

5.2.2 Faults

Locally, strata have been offset by faults that have variable strike length and displacements. A NNE-SSW fault system exists and can be divided into two sub-systems, namely:

- a NNE-SSW thrust fault system and
- a NNE-SSW normal fault system

The thrust fault is difficult to note in the field although field evidence does indicate its existence in the southern part of Hill D north (Fig. 5.1A) where the lower greenstone unit is thrusted over the upper sedimentary unit (Fig. 5.5). The thrust fault is projected down the center of the concession and is apparently offset by younger east-west striking normal faults (Fig. 5.1A).

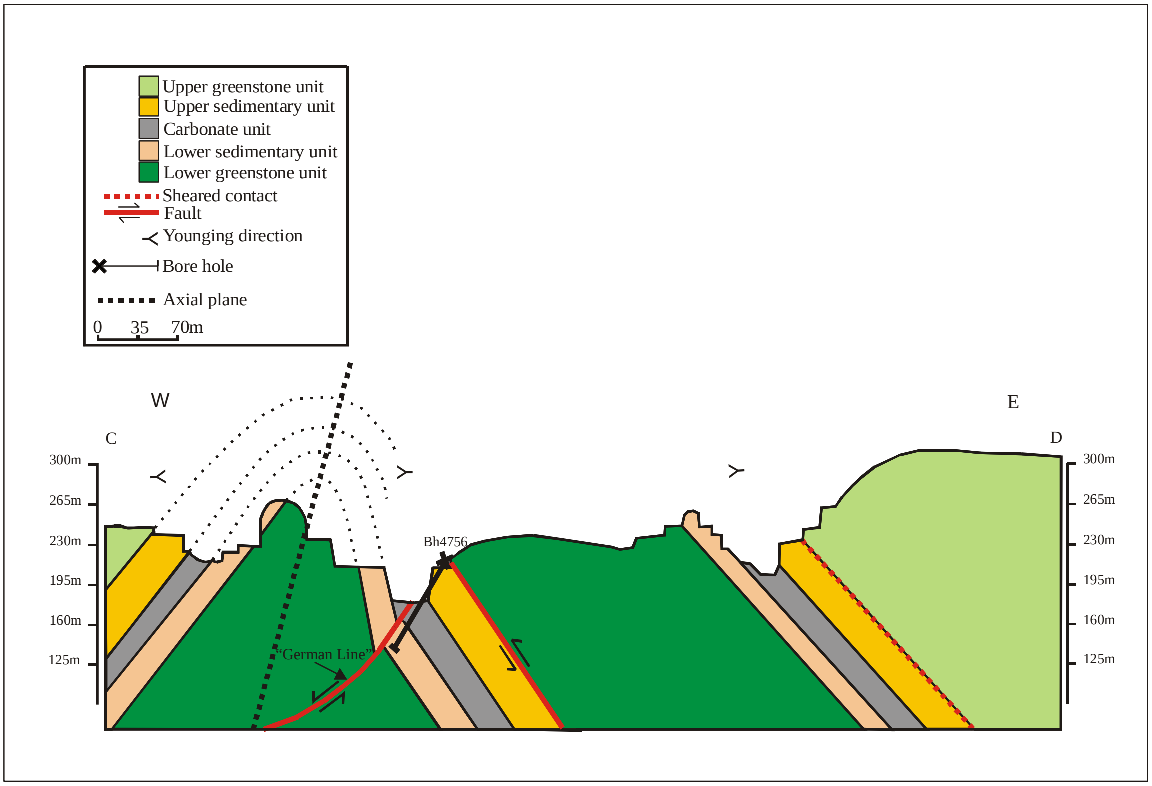

Figure 5.5. Cross-section C-D along the southern part of Hill D north indicating the effect of the "German Line" and thrust faulting.

The NNE-SSW striking normal fault system indicated on the map (Fig 5.1A), is referred to as the "German Line" on the mine. Evidence of its existence is present on the eastern limbs of Hill D north and Hill D south (Fig. 5.1A and B). This fault is oriented at $033^{O}/57^{O}$ W. In the southern part of Hill D north and at Hill D south this fault apparently becomes listric and is responsible for rotation of the anticlinal structures (Fig. 5.5). Listric faulting has changed the orientation of the fold axial plane from dipping east to dipping steeply towards the west (Fig. 5.5). Rotation related to the listric fault similarly changed the orientation of the strata in the western limb of southern Hill D north which now dip at about 51^{O} to the west whilst the eastern limb dips either steeply east or west (Fig. 5.4b).

The E-W striking normal fault system displaces the sequence at irregular intervals along strike (Fig. 5.1A) and controls the distribution of the orebody. These faults also displace the thrust fault. One of the E-W faults displaced a syncline next to an anticline in Hill D north (Fig 5.1A). Plotted survey points indicate significant dextral displacement between the various hills (Fig. 5.1A).

Based on stratal relationships on the geological map it is concluded that the relative ages for faulting took place in the order of thrust faulting followed by east-west normal faults in turn followed by NNE-SSW normal listric faulting (Fig. 5.1A).

An additional structural feature that was mapped is a shear plane along the contact between the upper sedimentary unit and the upper greenstone unit (Figs. 5.1A and B). It was observed at Hills A, B, and C south (Fig. 5.6a and b) and was extrapolated to Hills C north and E because poor outcrop prevented delineation of the structure in the field. Also, because of poor exposure, the sense of shear along the fault could not be determined.

5.3 Structure of Individual Open Pits

5.3.1 Hill A

Hill A is situated in the southern-most part of the mining concession (Fig. 5.1A), where manganese oxide ore was initially discovered *(Service, 1943)*. The structure appears to be a synclinal fold with fold axis plunging at $345^{O}/57^{O}$ (Fig 5.7). On the eastern flank of the syncline the strata have an average strike of 24^{O} and dip at an average of 59^{O} to the west. These measurements were all taken on highly weathered greywacke beds where bedding planes were still intact. Strata on the western flank of the syncline dip at an average of 75^{O} W and strike at an average of 183^{O} (Fig. 5.7). In the nose of the fold, small-scale folds with fold axes plunging at about $351^{O}/57^{O}$. The small-scale folds are best expressed by bedding-parallel quartz veins (Fig. 5.8).

Poles to planes of bedding produce an average great circle whose constructed fold axis virtually plots on the same point as the small-scale fold axes i.e. $350^{O}/61^{O}$. Looking north from the southern part of Hill A, it becomes obvious that the contact between the upper sedimentary unit and the upper greenstone unit is

Figure 5.8. Small-scale folds (related to F_1) expressed in bedding parallel quartz veins; southern extremity of Hill A.

sheared. This contact is marked by a sudden change from dark greywackes and argillites to highly weathered light coloured greenstones (Fig. 5.6a).

5.3.2 Hill B

Hill B (Fig. 5.1A) is structurally simple and is characterized by warped NNE-SSW striking strata dipping at an average of 63^{O} to the east (Fig. 5.9). The easterly dipping beds are warped along strike with fold axes oriented E-W. Plotted poles to planes are spread along the western side of the stereoplot. This indicates a variation in the dip and strike of the beds which is conveniently explained by the second (F_2) fold event as well as by late faulting which locally affects the strata. Warping of the beds becomes more intense towards the northern part of the pit.

Hill B is the only locality on the mining concession where the normal contact between the lower greenstone unit and the lower sedimentary unit is exposed i.e. in the center of the western wall of the open pit (Fig. 5.10). The orebody attains a thickness of approximately 40 m in the central part of Hill B but thin considerably to the north and south.

A well-developed cleavage was noted in the upper sedimentary unit (Fig. 5.4a). This is a very localized cleavage and is either absent or not mesoscopically

noticeable in other stratigraphic units of Hill B. The structure of Hill B is further marked by a number of small-scale faults. The majority of these faults trend east-

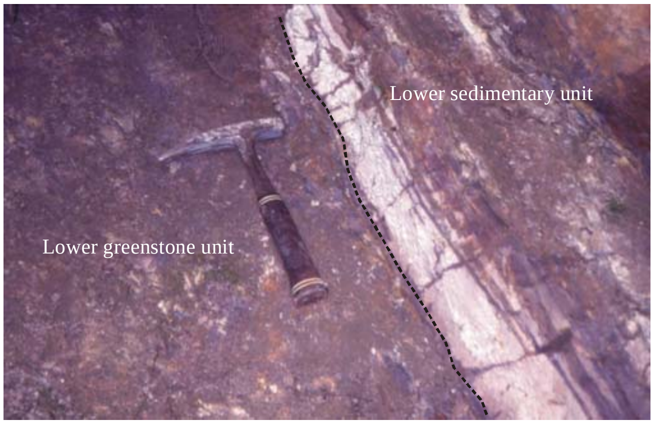

Figure 5.10. An apparently conformable contact between lower greenstone unit and lower turbidite unit. Western side of Hill B.

west. The faults cause displacement of a few meters in the orebody and is often not recognized by miners and surveyors on the property. This results in sudden lateral changes in ore grade from high-grade (35 wt% Mn) to very low-grade (< 20 wt% Mn) ore. Detailed mapping of the pit on a regular basis as mining proceeds could solve this problem and lead to better mine planning and less removal of waste on the mine.

5.3.3 Hill C South

Only limited outcrop is available in the southern part of Hill C south (Fig. 5.11) because of flooding of pits. However, there seems to be a major change in dip of beds in Hill C south compared to Hills A and B. The bedding dips at a much lower angle (average dip is 37^{O} E). Stereonet projections of poles to bedding planes are in support of this. Small-scale cross-folds with E-W oriented fold axes are well developed in the upper sedimentary unit (Fig. 5.3b). As in Hill A, the contact between the upper sedimentary unit and the upper greenstone unit is sheared and well exposed in the pit (Fig. 5.3c).

5.3.4 Hill C North

In Hill C north dips are quite variable between 40^{O} and 80^{O} essentially in an easterly direction (Fig. 5.12). Small-scale cross folding as well as local faulting have evidently had a strong influence on bedding orientation. The cross folds have steeply plunging fold axes (~40^{o}) to the east. These secondary folds are especially well exposed in the lower sedimentary unit in the open pit.

The orebody in the northern part of Hill C north is terminated by a fault with apparent dextral movement, displacing strata to the east. E-W striking normal faults with minor (< 2 m) displacement are abundant. The orebody is about 35 m thick in the southern part of the pit but is faulted out along the northern boundary of the pit (Fig. 5.12).

5.3.5 Hill E

This region of the concession (Fig. 5.1A) appears to be structurally simple. In the southern part, the upper sedimentary unit dips to the west at an average of 61^{O}, but further north the beds dip at an average of 36^{O} to the east (Fig. 5.13). Cross folding (F_2) of the northern parts of the concession appears to be more intense than in the southern parts of the concession. The effect of faulting is not obvious. The lower sedimentary unit has a consistent dip to the east, averaging about 53^{O}.

The stereonet projection of poles to planes indicates a presence of two fold events. Cross folds noted in other parts of the concession are smaller scale structures than those observed at Hill E. Plotted survey points during the mapping exercise reveal the spatial orientation of the cross folds, and have a fold axis plunging ENE (Fig. 5.13).

5.3.6 Hill D North

This is structurally the most complex part of the mine (Fig. 5.14) consisting of an F_1 anticline next to an F_1 syncline with a normal fault in between. Stereonet plots display a broad spectrum of bedding orientations caused by folding and faulting in the area. The western limb of the anticline dips to the west at 52^{O} while the

eastern limb is overturned and dipping steeply at 80-84^O to the west (Fig. 5.4b). The core of the anticline consists of highly weathered greenstone from the lower greenstone unit. The limbs are formed by the upper and lower sedimentary units and the carbonate unit.

The northern part of the Hill consists of a tightly folded F_1 syncline (Fig. 5.2) that is separated from the anticline by an east-west trending normal fault. In the vicinity of this fault a multitude of small-scale faults are developed and have have varying strikes, ranging from E-W, N-S and NE-SW. These small-scale faults are only locally developed and do not appear to have a significant influence on the regional distribution and grade of the orebody.

A normal fault, informally referred to as the "German Line" at the mine, is situated along the eastern limb of the two folds (anticline and syncline) and has displaced the carbonate orebody in both these structures. On surface the "German Line" dips at an angle of approximately 55^O-57^O to the west. Very poor outcrop prevented data from being collected in the syncline.

5.3.7 Hill D South

Lack of outcrop and flooding of the open pit resulted in very little data collection in this region (Fig. 5.15). In the exposed central part of the pit, a large-scale anticlinal fold was observed with fold axis plunging at 31^O in an east-north-easterly direction (Fig. 5.16a). The bedding planes change strike from NE-SW to NW-SE and the measured fold axis is in agreement with the constructed fold axis.

It is assumed that the anticline of Hill D north and that of Hill D south is one and the same. The fold axes do differ somewhat in orientation, but this is due to the east-west striking oblique-slip fault that separates the two hills (Fig. 5.1A). This fault may become listric at depth resulting in Hill D south to represent a half-graben structure. Later listric faulting along the "German Line" resulted in Hill D south to be rotated slightly towards the east. The effect of listric faulting along the

"German Line" is clearly demonstrated in this open pit as it brought the upper greenstone unit in direct contact with the carbonate unit. Microstructures (related to thrusting and/or the "German Line") observed in greywacke and upper greenstone samples include sigmoidal structures (Fig. 5.16b), foliation (Fig. 5.16c), and pure shear flattening (Fig. 5.16d).

A strong, consistently orientated cleavage ($040^{O}/49^{O}$ NW) is present in the upper greenstones but appears to be unrelated to either of the folding events.

A detailed discussion and interpretation is presented in Chapter 6.