Chapter 2

Geological Setting

2.1 Introduction

The Nsuta manganese deposit is located on the West African Craton in the Western Region of Ghana and is situated on the eastern side of the southern Ashanti Belt in the Birimian Supergroup (Fig. 2.1). The West African Craton consists of an Archaean core, the so-called Man Shield and a Paleoproterozoic domain with relics of Archean basement *(Milesi et al., 1989)* (Fig 2.2). The latter domain is essentially composed of volcanic belts and intervening sedimentary basins across a ~1000 km wide region between the Dahomeyide front in the east and the Sasandra fault to the west (Fig. 2.2).

Individual volcanic belts stretch for ~500 km in a NE-SW direction and are separated from one another by metasedimentary basins up to ~200 km wide (Fig 2.1). The volcanic belts consist mostly of metamorphosed volcanic rocks of tholeiitic to calc-alkaline composition, whereas the metasedimentary basins contain metamorphosed volcaniclastics, wackes and argillitic sedimentary rocks *(Kesse, 1985).* These volcanic belts and associated sedimentary strata are widely known as the Birimian Supergroup *(Attoh and Ekwueme, 1997).* Major stratigraphic units in the geology of Ghana are tabulated in Table 2.1. From this it is seen that the Nsuta manganese deposit is associated with ~2.2 Ga metasediments of the Birimian Supergroup (Fig. 2.1).

According to Hirdes et al. *(1992)*, the Ashanti Belt which hosts the Nsuta manganese deposit, has a U-Pb zircon age of 2172±2 Ma. It is bordered by the Kumasi Basin to the NW and by the Cape Coast basin to the SE, both filled with Birimian sedimentary rocks (Fig. 2.3). Regional metamorphism and structural deformation are commonly 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. Overall, the southern Ashanti belt has a synclinal structure (Fig. 2.4) 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).*

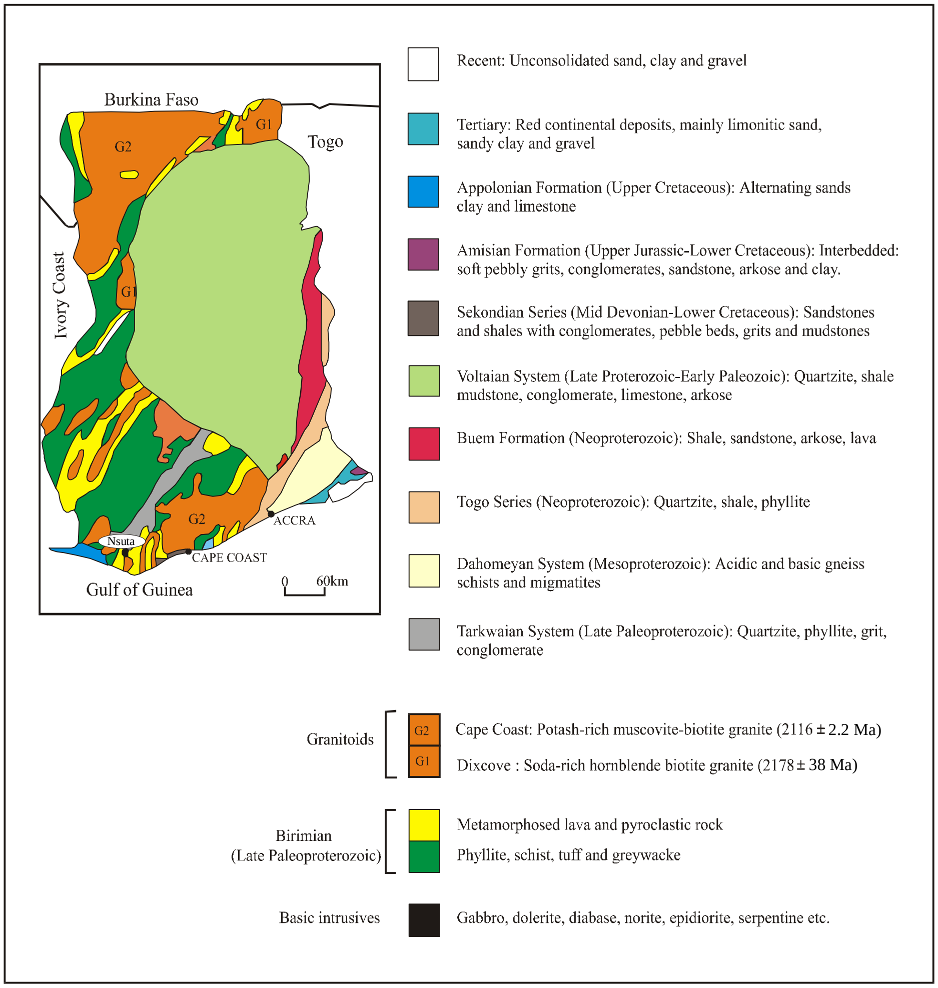

Figure 2.1. General geology of Ghana (after Kesse, 1985).

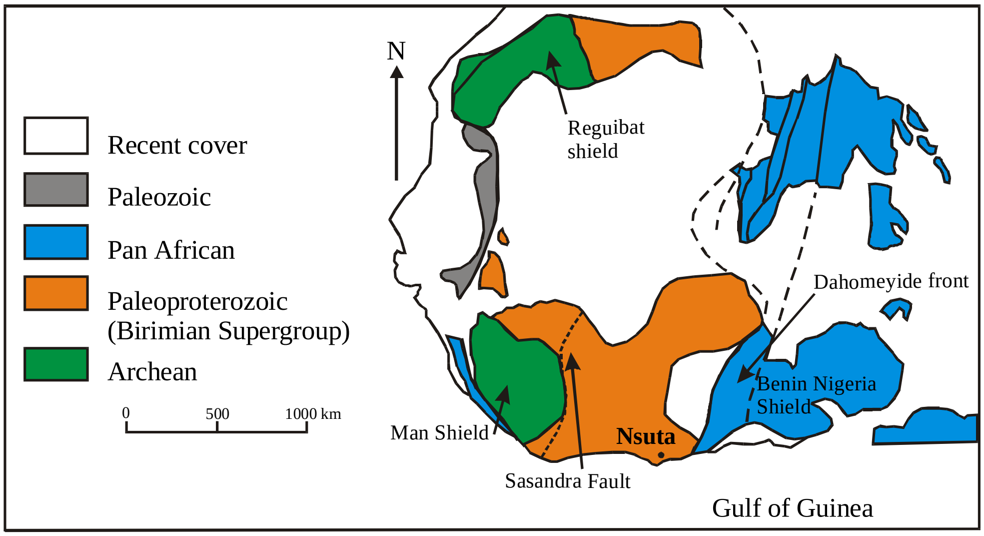

Figure 2.2. Precambrian geology of West Africa with the Archean Man Shield bordered on the west by the Birimian Supergroup (after Milesi et al. 1992).

Table 2.1. Generalised stratigraphy of Ghana. Compiled from references indicated in the Table.

Age	**Reference**	**Orogeny**	**Formation/Series/ System**	**Description**
Upper Cretaceous	Kesse (1985)		Appolonian Formation	Alternating sands, clay and limestone
Upper Jurassic/Lower Cretaceous	Kesse (1985)		Amisian Formation	Interbedded soft pebbly grits, conglomerate, sandstone, arkose, clay
Middle Devonian/Lower Cretaceous	Kesse (1985)		Sekondian Series	Sandstone, shales, conglomerate, pebble beds, grits, mudstones.
Early/Mid Devonian	Kesse (1985)	PAN AFRICAN	Accraian Series	Alternating shales, sandstone, mudstone, pebble grits
Late Proterozoic/Early Paleozoic	Kesse (1985)		Voltaian System	Quartzite, shale, mudstone, conglomerate, limestone, arkose
Mid/Late Precambrian	Kesse (1985)		Buem Formation, Togo Series, Dahomeyan System	Shale, sandstone, arkose, lava
1.97 Ga	BHP Minerals (Ghana) *(1992)*			Undeformed mafic dykes
2058 ± 6 Ma	Oberthür et al. 1998; Pigois, op.cit.)		Post peak metamorphism gold mineralization	Shear zone and quartz vein-hosted mineralization
2061 ± 438 Ma	Kesse (1985)		Tarkwaian deposition	Quartzite, grit, conglomerate, phyllite
2116 ± 2.2 Ma	Eisenlohr & Hirdes (1992)	EBURNEAN	Cape Coast Granitoids	Potash-rich, muscovite-biotite granite
2132 ± 3 to 2097 ± 2 Ma	Hirdes & Davis (1998)		Formation of Tarkwaian depositories and infill.	Quartzite, grit, conglomerate, phyllite
2166 ± 66 Ma	Hirdes & Davis (1998)		Birimian tholeiites	
2178 ± 2.3 Ma	Eisenlohr & Hirdes (1992)		Dixcove granitoids	Soda-rich hornblende biotite granite. Early phase of thrusting?
2172 ± 2 Ma	Hirdes et al. (1992)		Synvolcanic tonalitic granodioritic belt granitoids and volcanics	
2189 ± 1 Ma	Hirdes & Davis (1998)		Extrusive volcanism in Birimian	
2195 Ma	Hirdes & Davis (1998)		Felsic volcanics	
~2200 Ma	Eisenlohr & Hirdes (1992)		Deposition of Birimian metasedimentary rocks & metavolcanics **(Nsuta Mn- deposit)**	Meta lava and pyroclastic rock, phyllite, schist, tuff, greywacke, chemical sediments, Mn-carbonate, and chert
>2500 Ma			Archean basement?	

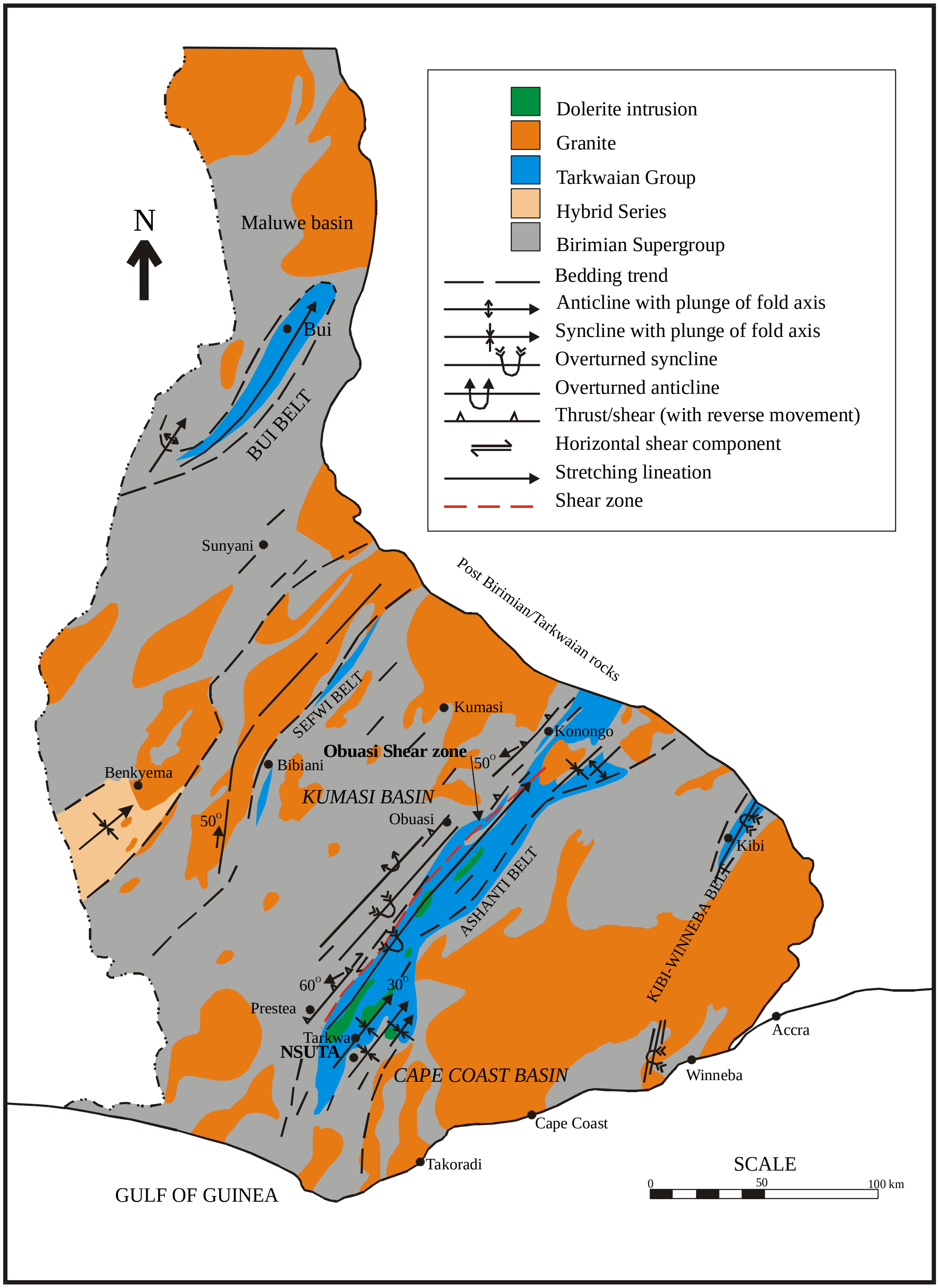

Figure 2.3. General geology and structure of the southern Ashanti Belt, Western Ghana (modified after Eisenlohr and Hirdes, 1992)

Strata in the southern Ashanti Belt typically has a steep dip and strikes are consistently oriented to the northeast (Fig 2.3). The northwestern margin of the Ashanti Belt is strongly tectonised and displays a well-developed cleavage and steeply plunging stretching lineations; here the Birimian rocks are thrusted over the Tarkwaian Group in an oblique manner (Fig. 2.4) *(Eisenlohr and Hirdes, 1992; Hirdes and Nunoo, 1994).*

Folding in the Tarkwaian Group does not appear to be consistent as it is isoclinally folded in the NW parts *(Hirdes and Nunoo, 1994)* but openly folded around Tarkwa and Prestea *(Hirdes and Nunoo, 1994)*. These folds open towards the core of the Ashanti Belt where they are locally overturned, forming a series of antiforms and synforms that plunge moderately to the northeast *(Hirdes and Nunoo, 1994)* (Figs. 2.4 and 2.5). Birimian rocks outcropping in the core of the Ashanti belt display a conformable folding relationship *(Eisenlohr and Hirdes, 1992).* 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).*

With reference to fold and thrust structures in the Birimian Supergroup, it is known that the Nsuta deposit is situated in an area of northwards plunging synclinal and anticlinal structures that are pre- and post-Tarkwaian in age (Fig 2.3). 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).

2.2 Review of the Birimian Supergroup

Birimian rocks derive their name from the Birim River valley in Ghana, where Kitson defined and described the typical rock formations in 1918 *(Kesse, 1985)*. The Birimian Supergroup (~2.2 Ga) is an economically important source of gold, diamonds and manganese *(Kesse, 1985).* Chemical sedimentary rocks are common constituents in the sedimentary successions of the Birimian Supergroup and include manganese carbonates, and chert *(Attoh & Ekwueme, 1997).* The manganese deposit of Nsuta is related to one of the manganese carbonate units (Table 2.1).

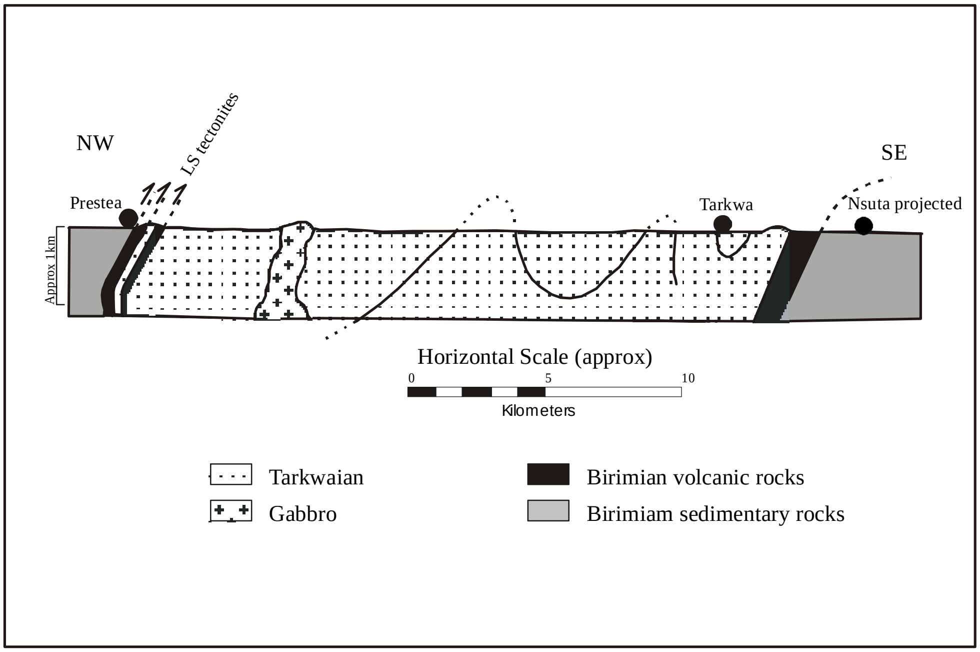

Figure 2.4. Schematic cross-section across the Ashanti belt in the Prestea-Tarkwa area (modified after Eisenlohr & Hirdes 1992).

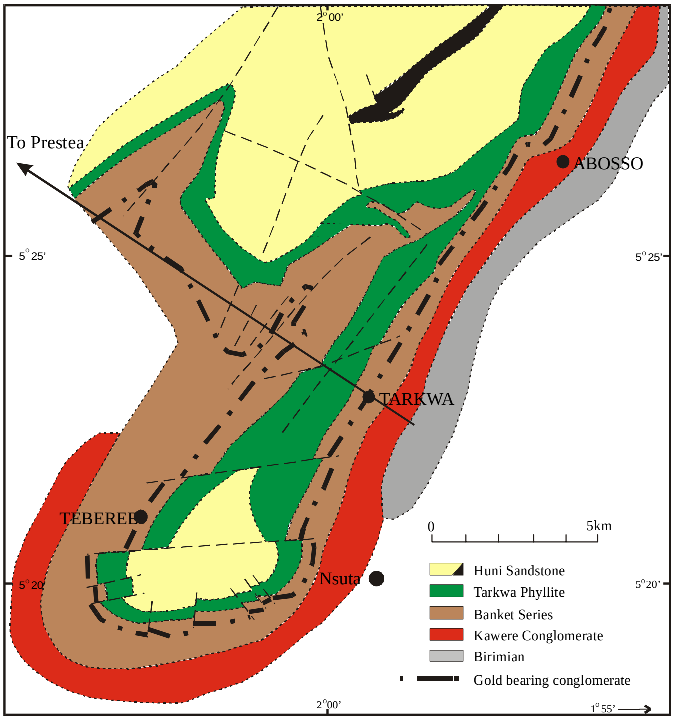

Figure 2.5. Geological map of the Tarkwa area (modified after Hirdes & Nunoo, 1994)

As a lithostratigraphic unit, Birimian rocks occupy the southern part of the West African Craton (Fig. 2.1). Birimian strata were deformed and metamorphosed during the ~2.2 Ga Eburnean Orogeny *(Nyame, 1998)*. This orogeny is characterized by isoclinal folding as well as intrusion of pre-, syn-, and post-tectonic granites *(Eisenlohr and Hirdes, 1992)* (Fig. 2.3).

The Birimian Supergroup can be subdivided into two major lithological units. The first is predominantly mafic volcanic; with pyroclastics, hypabyssal intrusives, phyllites and greywackes as common constituents. The second is characterized by a predominance of immature or volcaniclastic sediments, including argillites, tuffs and greywackes *(Junner, 1940)*. The Nsuta manganese deposit forms part of the latter lithological unit. The spatial and temporal relation between these two units has long been a topic of debate *(Mortimer, 1992)*. Two "schools of thought" have emerged, the one dominated by French researchers, the other by German geologists.

The German school of thought assumes contemporaneous volcanism and sedimentation, as indicated by a transition from volcanic rocks to sedimentary rocks along strike, and interbedding between the two rock types. In contrast the French school is opposed to the idea of contemporaneity between sedimentary rocks and volcanics *(Junner, 1940; Cahen et al. 1984; Milesi et al. 1989, Davis et al., 1994)*. They favor a model in which volcanic activity preceeds sedimentary basin infill. This model is largely based on extensive field work.

Recent geochronological and geochemical data appear to favour the German school of thought with contemporaneous volcanism and sedimentation. Sm-Nd isotopic dating of samples from the Birimian volcanic and sedimentary rocks by Taylor et al. *(1988)* for example confirmed the suspected contemporaneity of Birimian sedimentary rocks and volcanics. Model ages for eight samples of Birimian sedimentary rocks range from 2.01 Ga to 2.31 Ga *(Eisenlohr and Hirdes, 1992; Davis et al., 1994)*; they differ very little from the analysed

Birimian volcanic rocks dated at 2189 ±1 Ma *(Hirdes and Davis, 1998).* Detrital input into the Birimian sedimentary basins from ancient crustal sources has thus been insignificant; instead a derivation of clastic sediments from contemporaneous igneous activity in the volcanic belts is confirmed by isotopic data *(Leube et al., 1990).* Mortimer *(1992)* also contests the division of the Birimian Supergroup into older and younger units, suggesting that the existence of simultaneous deposition of volcanic ejecta in proximal and distal environments has not been considered by the French school.

The Birimian Supergroup is unconformably overlain by coarse fluvial sedimentary rocks referred to as the Tarkwaian Group (Fig 2.3) which contains auriferous conglomerates (Banket Series). Most authors *(Junner, 1940; Service, 1943; Kesse, 1985)* regard the Birimian and Tarkwaian as two separate entities, but Cahen et al. *(1984)* include the Tarkwaian Group within the Birimian Supergroup.

The Tarkwaian Group has been well studied in the region of the Tarkwa goldfield. The Group consists of a thick series (1800 - 3000m) of argillaceous and arenaceous sedimentary rocks with two well-defined zones of auriferous conglomerates in the lower formations of the succession *(Junner, 1940).* These Precambrian conglomerates are believed to be alluvial fan deposits with associated braided stream channels *(Hirdes and Nunoo, 1994).* Four coalescing fans are delineated based on thickness variations, facies and crossbedding directions in the conglomerates, with dispersal from the east and southeast *(Hirdes and Nunoo, 1994).* Conglomerate beds tend to become thinner and also decrease in number downcurrent, while it is apparent that erosion and reworking of sediments was active in upstream parts of the four fans *(Sestini, 1973).*

Various stratigraphic subdivisions have been proposed for the Tarkwaian Group *(Junner, 1940; Kesse, 1985; Hirdes & Nunoo, 1994).* The latest subdivision that was officially accepted by the Geological Survey of Ghana is that of Hirdes and Nunoo *(1994)* (Table 2.2).

Table 2.2. Stratigraphic subdivision of the Tarkwaian Group in the Tarkwa mine area (modified by Hirdes & Nunoo, 1994, after Junner, 1940).

Series	Thickness (m)	Composite lithology
Huni Series	1370	Sandstones, grits and quartzites with phyllites.
Tarkwa Phyllite Series	120 – 400	Huni sandstone transitional beds and green- and greenish-grey chloritic and sericitic phyllites and schists.
Banket Series	120 – 160	Tarkwa phyllite transitional beds and sandstones, quartzites, grits, breccias and auriferous conglomerates
Kawere Series	250 – 700	Quartzites, grits, phyllites and conglomerates.

The source area from which Tarkwaian sediments of the Ashanti Belt were derived was located east and southeast of the Tarkwa depository. This hinterland consists of Birimian tholeiitic volcanics and sedimentary rocks (volcaniclastics, wackes, argillites) as well as Dixcove-type and Cape Coast-type granitoids. Based on the study of detrital zircon populations, Hirdes and Davis *(1998)* suggest that the formation of Tarkwaian depositories and their sedimentary infill took place between 2132 ± 3 Ma and 2097 ± 2 Ma. Seventeen of twenty investigated detrital zircon grains from the Tarkwaian depository investigated by Hirdes and Davis *(1998)* fall within the age range of 2194 Ma to 2155 Ma. This confirms that the principal provenance of the Tarkwaian zircons in the Ashanti Belt was the Birimian Supergroup *(Leube et al., 1990; Taylor et al., 1992).* These ages of 2155-2194 Ma most probably also reflect the age of the Nsuta manganese deposit.

2.3 Review of the Eburnean Orogeny in Ghana

The accretion of the Birimian Supergroup onto the Man Shield during the Late Paleoproterozoic is referred to as the Eburnean Orogeny *(Attoh and Ekwueme, 1997).* It involves the accretion of volcanic arcs, deformation and intrusion of granitoids. Granitic intrusives present in both Tarkwaian and Birimian rocks either pre-date (i.e. Dixcove granites) or coincide with (i.e. Cape Coast granites) or immediately postdate (i.e. Bongo granites) the Eburnean tectonothermal event (Table 2.1) and resulted locally in high-grade contact metamorphic aureoles in the surrounding Birrimian and Tarkwaian strata. The exact timing and duration of the Eburnean Orogeny is not entirely clear at present. Milesi et al. *(1992)* do, however, suggest that compressional deformation commenced at ~2.1 Ga with an early phase of low-angle thrusting and folding. This phase of deformation is well represented at Nsuta as shall be shown in this dissertation. This phase is thought to precede the deposition of the Tarkwaian siliciclastics. Two later phases of deformation (sinistral and dextral strike-slip faulting) occurred after deposition of the Tarkwaian *(Milesi et al. 1992).*

Rocks of the Birimian Supergroup were affected by upper greenschist facies regional metamorphism *(Eisenlohr and Hirdes, 1992; Mortimer, 1992; Davis et al., 1994; Kleinschrot et al., 1994, Hirdes et al., 1996).* According to Kleinschrot et al. *(1994),* P-T conditions reached upper greenschist facies (maximum of 500^{O} C and 5 kbar). In contrast, John et al. *(1999)* suggest that regional metamorphism was as high as amphibolite facies (500 - 650^{O} C and 5 - 6 kbar) and that the greenschist facies metamorphism only represents a retrograde event associated with large-scale aqueous fluid infiltration (Fig. 2.6). *In the Nsuta mining area no evidence could be found for amphibolite facies metamorphism and it would appear as though the strata only experienced greenschist facies metamorphism.*

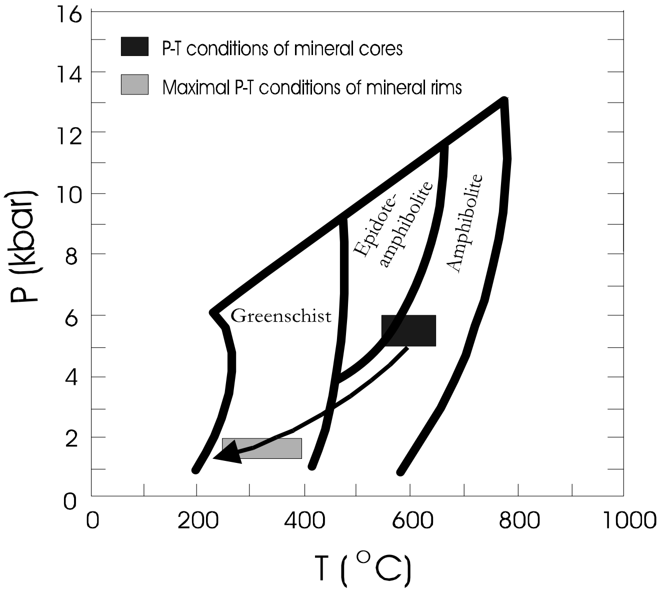

Fig. 2.6. P-T path and the relevant metamorphic facies fields (John et al., 1999).

Large-scale aqueous fluid infiltration took place into Birimian strata along major late tectonic shear zones and smaller associated faults. One such shear zone is is the NE-SW trending Obuasi shear zone to the west of the Nsuta manganese mine (Fig. 2.3). It is a major strike-slip shear with dominant sinistral movement *(Oberthur et al., 1994).*

Hydrothermal Au mineralization associated with the Obuasi shear zone is post peak metamorphic and was dated at 2058±6 Ma *(Oberthur et al., 1998).* This constrains the age and duration of the Eburnean tectonothermal event between 2.17 and 2.06 Ga, a period of 110 Ma, comparable to typical time periods envisaged for one half of a plate tectonic Wilson cycle *(see for example Prothero and Schwab, 1996).*

2.4 Review of Granitic Intrusives

The Birimian Supergroup and Tarkwaian Group are intruded by three types of granitoids that comprise distinct geochronological and geochemical suites. An understanding of the origin and geotectonic position of these different types of intrusives is essential to understand the tectonic evolution of the West African Craton. The three different granitoid suites present in Ghana are referred to as the Dixcove (G1), Cape Coast (G2) and Bongo (G3) granitoids *(Eisenlohr & Hirdes, 1992)*. Leube et al. *(1990)* and Eisenlohr and Hirdes *(1992)* provide the following distinguishing characteristics of the different granitoids:

- Dixcove-type granitoids (2178 ± 2.3 Ma): These are small, unfoliated plutonic bodies that intrude Birimian belt volcanics. This suite consists of quartz diorite, tonalite and trondhjemite, granodiorite, adamellite, and to a lesser degree, granite.
- Cape Coast-type granitoids (2116 ± 2.2 Ma): Large, syntectonic, foliated granitoid batholiths that typically intrude the Birimian sedimentary strata. Typical lithologies include quartz diorites, tonalities and trondhjemites, granodiorites, adamellites and granites. The Cape Coast granitoids have

extensive contact metamorphic aureoles with mineral assemblages that indicate pressures of at least 4 kb and temperatures around 500^{O} C.

- Bongo-type granitoids: These bodies intrude Tarkwaian sediments in the Bole-Navrongo belt, and show unusually high K-concentrations. These granitoids lack foliation i.e. they are post-tectonic in origin and are petrographically characterized by pink phenocrysts of alkali feldspar.

2.5 Local Geological Setting

A map by Service *(1943)* of the Nsuta region indicates that the manganese-bearing sedimentary unit is very extensive, interbedded with greenstone above and below (Fig. 2.7). The unit is also clearly deformed, folded and unconformably overlain by the Tarkwaian Group in the northwestern part of the area (Fig 2.7). Beds dip regionally rather steep to the east at 55°-90° with general strike in a NNE-SSW direction.

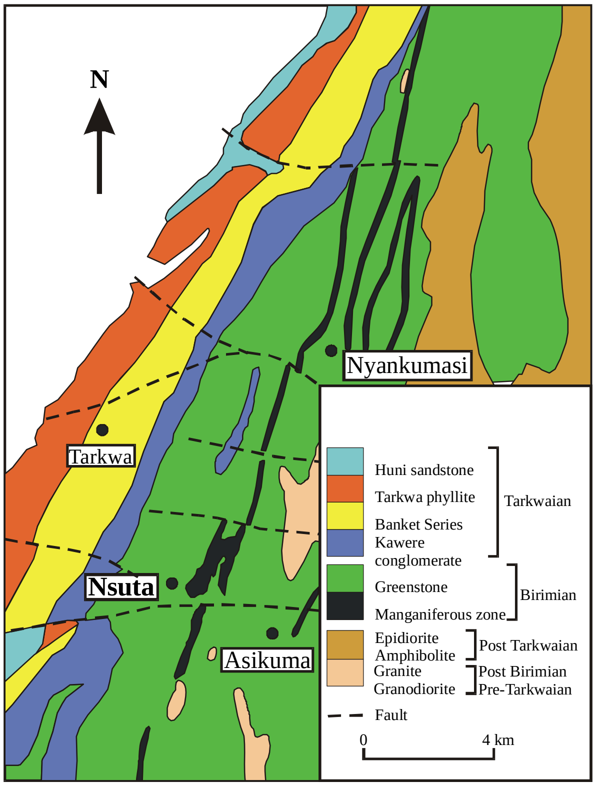

Figure 2.7. Local geology surrounding Nsuta. Note the E-W trending faults and the unconformably overlying Tarkwaian Group (modified after Service, 1943).

On a regional scale outcrops are very poor due to dense rainforest cover. However, on the mine itself outcrops are of an acceptable standard due to open pit mining. Some of the older open pits are densely overgrown and flooded so that they are not accessible. However, sufficient outcrops are available aided by drillcore information, so that a geological map could be constructed (see Chapter 5).

In the mine concession the succession is composed of a basal lower greenstone unit, consisting predominantly of volcaniclastic material, overlain by a sedimentary succession which is in turn overlain by an upper greenstone unit composed of altered lava and possibly altered fine volcaniclastics (Fig. 2.8). The sedimentary unit is subdivided into a) a lower sedimentary unit, consisting of greywacke interlaminated with argillites and subordinate bands of phyllite that have a well-developed foliation, b) a manganese-rich carbonate unit which hosts the manganese ore bed, and c) an upper sedimentary unit of greywacke, argillite, and phyllite (Fig. 2.8).

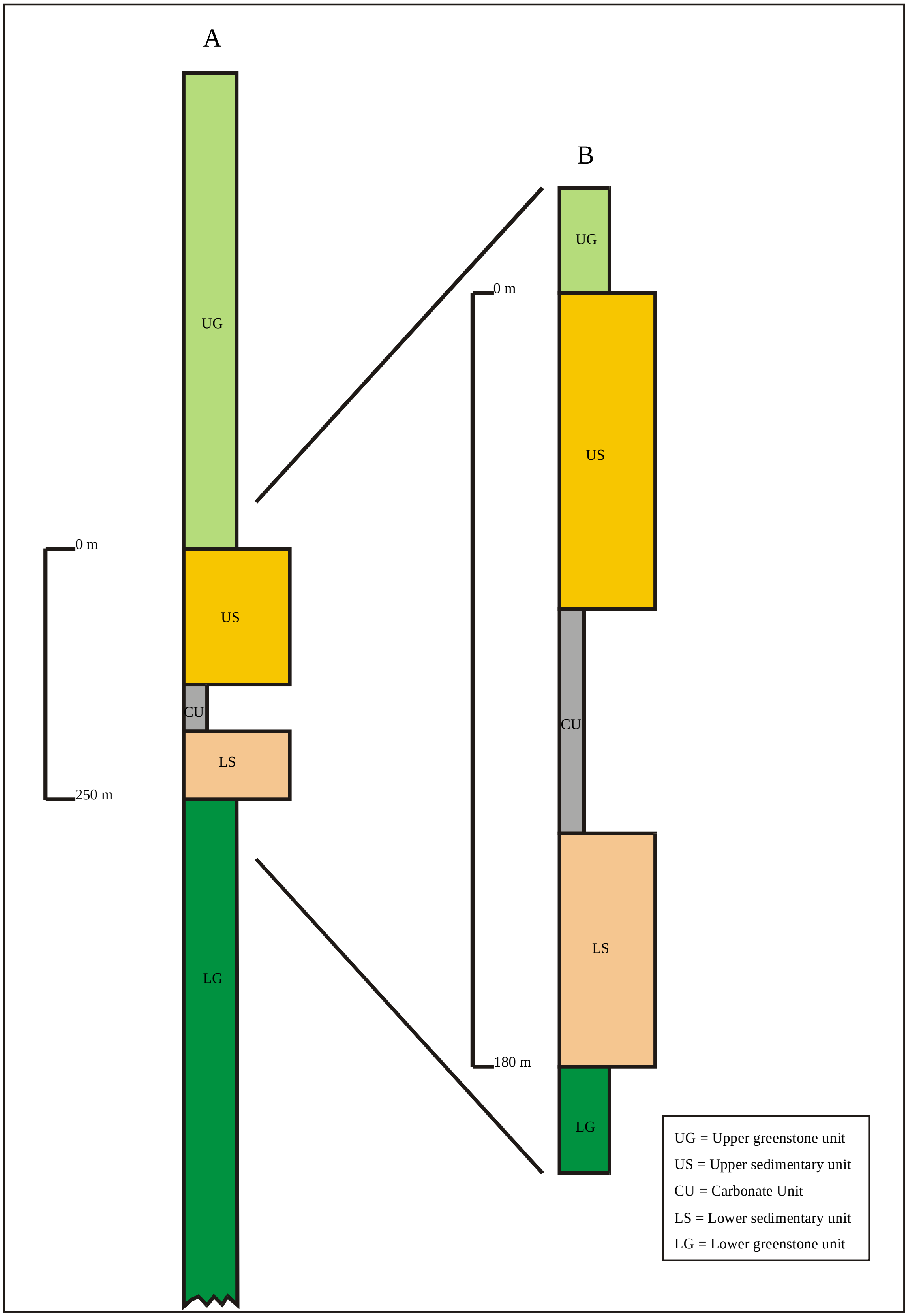

Figure 2.8. Simplified stratigraphic profile of the succession at Nsuta.
Profile "A" is that reported by Kesse (1985); profile B is based on the results of the present study.

A simplified geological map produced during this dissertation indicates the major structural features that influence the Nsuta manganese deposit (Fig. 2.9). The first obvious feature is a series of anticlines and synclines that are cross-faulted and dislocated from one another. Another important feature is a thrust fault situated more or less along the center of the concession. This is accompanied by a younger normal fault in the same orientation as the thrust fault and which is locally known as the "German Line".

Because of dense forest cover in the region, very little is known about the geology of the Birimian Supergroup immediately outside the Nsuta mining area. In an attempt to obtain more information, regional geophysical data i.e. airborne magnetic surveys of the southern Ashanti Belt for the Nsuta area were made available by BHP Minerals (Cape Town, South Africa). The data reveal several important regional structural trends, most of which can be identified at Nsuta:

- Thrust faults (Fig 2.10A and Fig 2.10B). This is known from mapping, drilling and mining in the Tarkwa gold field.
- Form (strike) lines indicate two periods of deformation (folding). The first oriented about a NE-SW axis and the second about a NW-SE axis (Figs 2.11A and B).
- Either a fault or a shear parallel to the Obuasi shear zone situated immediately to the west of Nsuta (Figs 2.10A and B).
- Dolerite dykes, dated at 1.97 Ga, intruding Tarkwaian and Birimian rocks *(BHP minerals (Ghana), 1992).*
- Late faults with two principal directions being E-W and NE-SW (Fig. 2.10A and B).

Nsuta itself does not stand out or show any specific significance on airborne magnetic images (Figs. 2.10B and 2.11B).

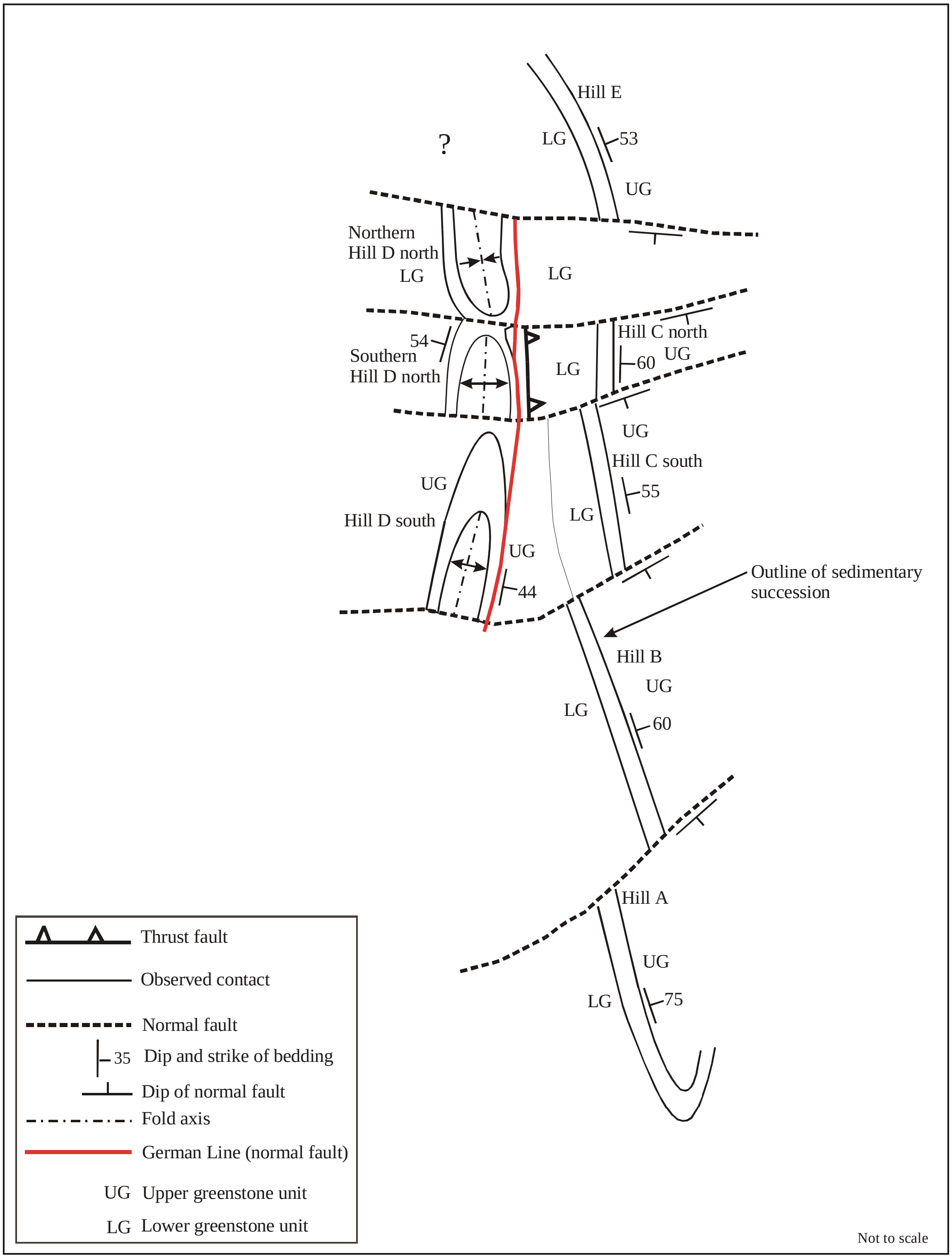

Figure 2.9. Plan view sketch map of the structural geology of the Nsuta deposit.

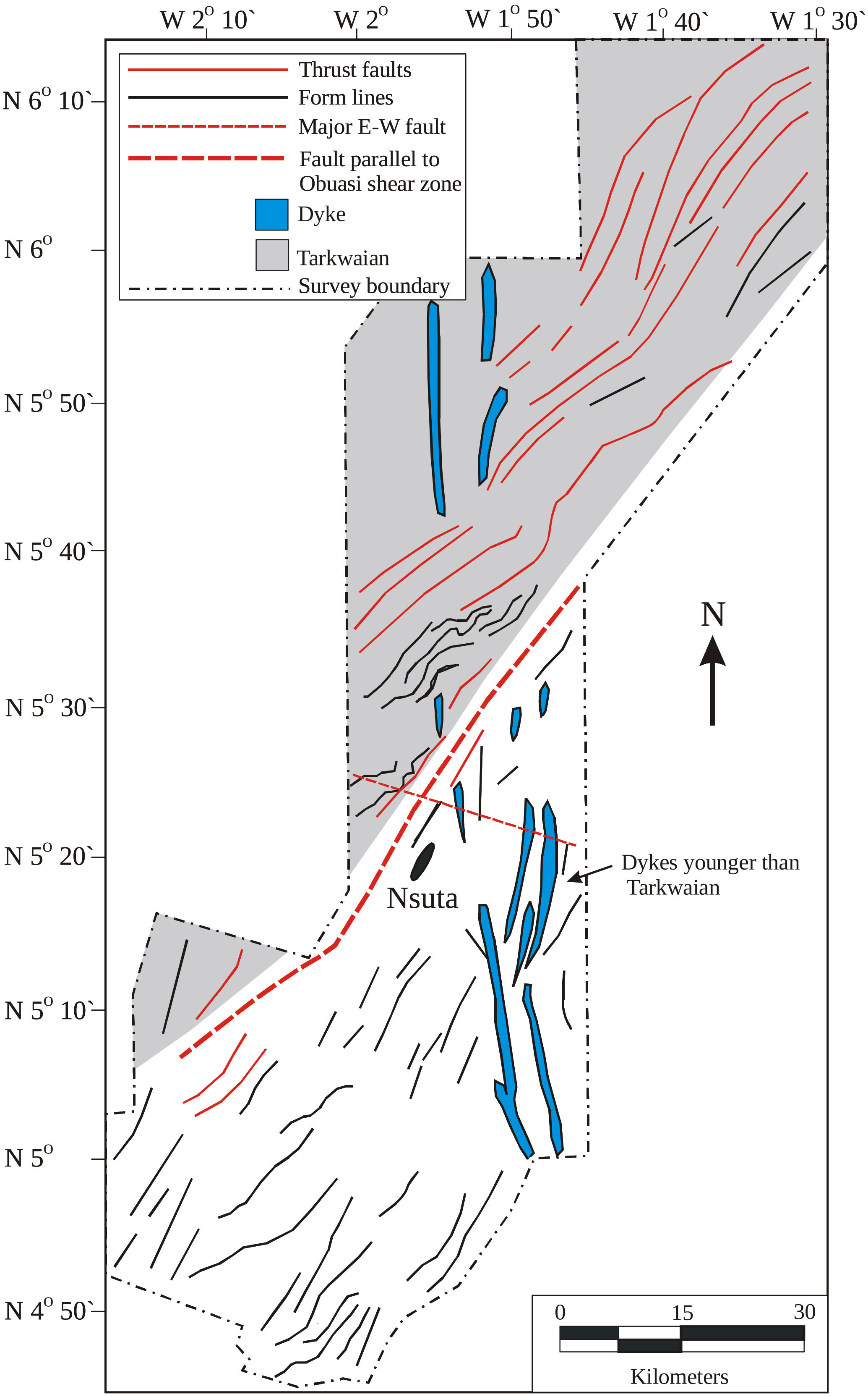

Figure 2.10B. Interpretation of Total Magnetic Intensity image. Note NE-SW striking thrust system parallel to the Obuasi shear zone. Note Tarkwaian cover on map.

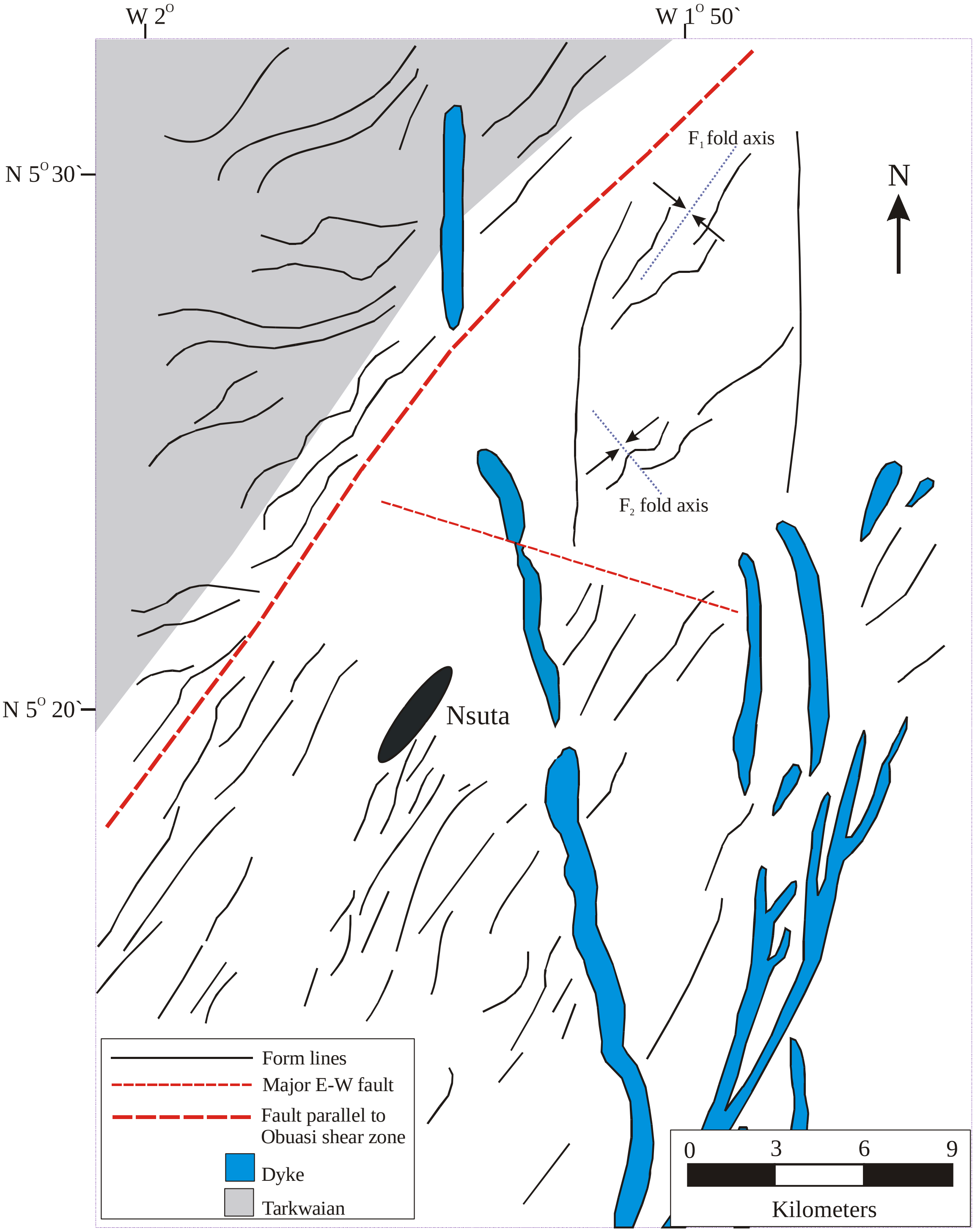

Figure 2.11B. Interpretation of Total Field Magnetics image. Note the NE-SW trend of form lines, major fault parallel to the Obuasi shear zone, and location of the smaller E-W fault system. Note Tarkwaian cover on map.