Chapter 3

Lithofacies Description

3.1 Introduction

A problem with describing the succession at Nsuta is that different authors use different names for the same rock type *(eg. Junner, 1940; Service, 1943; Kesse, 1985*; *Nyame, 1998)*. Often genetic names are also used which are based on interpretation and do not represent the lithologies as directly observed in the field (Table 3.1). For example, the sedimentary rocks that host the manganese carbonate orebody are referred to as either phyllite, tuff, or carbonaceous schist by various authors. The Collins Dictionary of Geology *(Lapidus, 1987)* defines these terms as follows:

- Tuff: *a pyroclastic rock composed mainly of volcanic ash (fragments <2mm in diameter).*
- Phyllite: *a regional metamorphic rock, light silvery-grey in colour, intermediate in metamorphic grade between slate and schist. They are derived from argillaceous sedimentary rocks.*
- Schist: *a metamorphic rock that is not defined by mineral composition, but by the well-developed parallel orientation of >50% of the minerals present, particularly minerals such as mica and hornblende (a* carbonaceous schist is thus a schist that contains a significant amount of organic carbon).

During this study no justification could be found for using terms like "tuff" and "schist" for the strata hosting the Nsuta manganese orebody. It was also found that what has previously been described as tuffs and phyllites, in actual fact represent low-grade metamorphosed greywackes in which original textures and structures are well preserved (Table 3.1). For the sake of simplicity, the term "greywacke" will be used instead of "metagreywacke". In addition it was found that what was previously defined as "carbonaceous schist" or "phyllite" is much more accurately described as "carbonaceous (meta)argillite" which includes both (meta)siltstones and (meta)mudstones. The term "phyllite" is reserved for (meta)argillites that

developed a strong cleavage associated with faulting and/or intense folding in certain parts of the deposit. Thus, in this dissertation the following rock types (lithofacies) are recognized (see appendix for sample localities and mineral content):

- Argillite: Dark grey to black (carbonaceous) fine-grained metamorphosed shale.
- Greywacke: Metamorphosed immature greywacke. Ranges from very coarse with argillite intraclasts.
- Phyllite: Light grey, sheared (foliated) meta-argillite.
- Greenstone: Either sheared or unsheared volcanic and volcaniclastic rock. Unsheared volcaniclastic varieties have preserved sedimentary textures.

3.2 Argillite

a) Macroscopic description

Argillite occurs as interbeds closely associated with greywacke or as massively textured layers up to about 10 m thick. Argillites are typically compact and dark grey to black in colour and are composed mostly of silt-sized detrital particles. In places they are finely laminated (Fig. 3.1a). Samples that occur close to the transition into the carbonate orebody and the sedimentary unit commonly contain abundant spessartine garnet. Diagenetic pyrite cubes are often present and vary in size from 1mm to 10mm in diameter. Abundant quartz veins crosscut laminae in argillite.

b) Petrography

Petrographic and XRD analyses of three representative samples revealed the presence of the mineral phases presented in Table 3.2.

Table 3.2. Mineralogy of representative argillite samples.

Sample #	Locality	Major minerals	Minor minerals
DC2	US, Hill A	quartz, kutnahorite	albite, chlorite, muscovite
FS54	LS-CU transition, Hill C south	kutnahorite, quartz	spessartine
DC8	CU, Hill A	quartz, muscovite	albite, kutnahorite

Abbreviations: US = Upper sedimentary unit, LS = Lower sedimentary unit, CU = Carbonate unit.

The most prominent petrographic feature of the argillites is spessartine garnet porphyroblasts (150-600μm diameter), occurring either as clusters (Fig. 3.1b) or as isolated euhedral crystals (Fig. 3.1c). EDS analysis confirmed that the garnets have a spessartine composition. Spessartine porphyroblasts have well-defined crystal outlines and usually contain inclusions of carbonate minerals and/or quartz that appear to define a crude radial pattern (Fig. 3.1d).

The garnets are hosted by a carbonate-rich matrix. This matrix is composed of manganiferous carbonate microconcretions that are ellipsoidal or irregular spherical in shape and 30 - 70μm in diameter. Larger ones display a Brewster cross under the microscope, suggesting a radial fibrous internal texture as described by Nyame *(1998)*. The microconcretions carry a distinct dark rim constituted by organic matter (kerogen). Carbonate microconcretions are hosted in a matrix of pseudo-sparitic carbonate (<70μm diameter). Within this matrix, small irregular shaped pods of mono- or polycrystalline quartz (<100μm diameter) appear randomly distributed. These may represent segregations of SiO_2 mobilized during metamorphism.

Two generations of veins (composed of quartz and/or carbonate) are present. First generation veins are sigmoidal infills and of pre-compressional origin (Fig. 3.1e). Second generation veins, in contrast, are found to crosscut spessartine garnet porphyroblasts suggesting a post peak metamorphic origin. These veins are fracture-hosted and usually symmetrically banded, with an outer band of fine-grained carbonate and quartz as a central infill (Fig. 3.1f). Carbonate grains in the veins attain sizes of up to 20μm while quartz grains reach a size of 50μm and have abundant carbonate inclusions.

3.3 Phyllite

a) Macroscopic description

Thin phyllitic units occur throughout the sedimentary succession and are preferentially developed between thick greywacke beds. Bed thicknesses vary from 30cm to ~1m. A very well developed bedding-parallel cleavage suggests that these beds have accommodated strain (Fig. 3.2a). Phyllite beds are especially abundant in outcrop at Hill B, but the lateral continuity of these beds is uncertain because they are less abundant or conspicuous in Hills A and D. Hand samples are silver-grey in colour with development of abundant sericite on foliation planes.

b) Petrography

Phyllites are typically composed of a submicroscopically fine-grained matrix of quartz, muscovite (sericite), chlorite and albite (Table 3.3). Bedding-parallel quartz stringers occur in this matrix, and are filled with fibrous quartz inclined at approximately 45^{O} to the bedding (Fig 3.2b). These stringers are in some cases surrounded by thin seams of sericite.

Table 3.3. Mineralogy of two representative phyllite samples.

Sample #	Locality	Major minerals	Minor minerals
DC4	CU, Hill A	quartz, muscovite	chlorite, albite
FS6	LS, Hill B	quartz, muscovite	albite

Abbreviations: CU = Carbonate unit, LS = Lower sedimentary unit.

3.4 Greywacke

a) Macroscopic description

Greywackes are very abundant in the upper and lower sedimentary units at Nsuta. They can be described as grey-coloured, poorly sorted, and very immature sandy sedimentary rocks composed predominantly of sand and silt-sized detritus (Fig. 3.3a). Grain sizes vary from very fine sand to granule size. Detrital quartz grains show variable degrees of rounding and are set in a matrix that accounts for >15% of the rock volume.

The greywacke beds contain argillaceous rip-up clasts derived from the immediately underlying beds, in their lower parts. The greywacke beds also often display normal graded bedding (Fig. 3.3b). They have sharp basal contacts and gradational upper contacts into argillite or phyllite. Thick greywacke units (>120 cm) are usually massive and display no internal sedimentary structures. Large (1mm to 10mm diameter) euhedral pyrite cubes often cut across the sedimentary bedding (S_0) (Fig. 3.3c). Fracture-hosted quartz veins crosscut bedding as well as pyrite cubes.

b) Petrography

Greywackes are poorly sorted and composed of a variable mineral assemblage, including Mn-carbonates, quartz, chlorite, albite, muscovite and tourmaline (Table 3.4).

Table 3.4. Mineralogy of seven representative greywacke samples.

Sample #	Locality	Major minerals	Minor minerals	Trace Minerals
DC3	US, Hill A	quartz, kutnahorite	albite, chlorite	muscovite
DC7	LS, Hill A	quartz, chlorite	albite, kutnahorite, muscovite	
DC28	US, Hill D north	quartz, kutnahorite	albite	muscovite
DC25	US, Hill D north	quartz, kutnahorite, chlorite, albite		
DC12	US, Hill C south	quartz, muscovite	kutnahorite, chlorite, albite	tourmaline
DC15	US, Hill C south	quartz, kutnahorite, muscovite	albite	
DC23	US, Hill D north	quartz, albite, chlorite	muscovite, kutnahorite	tourmaline

Abbreviations: US = Upper sedimentary unit, LS = Lower sedimentary unit.

Rip-up clasts (4-50 mm) and detrital grains (up to 600μm in diameter) are hosted in a fine-grained matrix predominantly composed of carbonate. Rip-up clasts are composed of carbonate-rich argillite derived from argillaceous beds immediately underlying the greywacke beds and are most commonly oriented parallel to the sedimentary bedding.

The majority of the detrital grains are of sand to silt size and were originally composed of plagioclase feldspar identified by its characteristic

albite and Karlsbad twinning, and monocrystalline or polycrystalline quartz (Fig. 3.3d). Quartz and feldspar grains usually have poorly defined grain outlines and display variable degrees of rounding. They are invariably partly replaced by carbonate that seems to invade the grains from outside inwards. Euhedral carbonate porphyroblasts, of up to 600μm in size, replace matrix as well as rip-up clasts and detrital grains. Nyame *(1998)* identified these carbonates as Mn-dolomite. Some of the porphyroblasts (Mn-dolomite) contain inclusions of slightly altered, well-defined feldspar grains (250μm) that display Karlsbad twinning (Fig. 3.3e). SEM-EDS analysis identified the feldspar grains as albite. Not only replacement by carbonate (Fig. 3.3f) but also sericitization of albite along cleavage planes is evident.

The matrix of the greywackes is composed of very fine-grained and intimately intergrown carbonate, sericite, quartz and minor amounts of chlorite. Fracture-hosted quartz-carbonate veins crosscut matrix, clasts and carbonate porphyroblasts. As observed in argillites, such veins are filled by fine-grained carbonate along the vein selvages and coarser-grained quartz in the central part of the vein. Other fracture-hosted quartz stringers appear to be syndeformational in origin and are arranged parallel to the foliation. Quartz microstructures define the foliation and indicate pure shear flattening (Chapter 5).

3.5 Manganese carbonate ore

a) Macroscopic description

Hand samples of manganese carbonate ore are dark to light grey, with a finely laminated to massive appearance. Very fine-grained dark carbonate ore can easily be confused with argillite (Fig. 3.4a). The dominant carbonate mineral throughout the carbonate unit is rhodochrosite, with or without kutnahorite. This fine-grained carbonate rock is locally enriched by hydrothermal alteration that is expressed by an abundance of crosscutting veins of coarse-grained rhodochrosite (Fig. 3.4b) or as

massive replacement bodies as observed in drill-core. The recrystallised rhodochrosite has a pink or grey colour and is similar in appearance to coarse-grained marble. Parts of the orebody that contain abundant recrystallised rhodochrosite are of especially high-grade.

b) Petrography

Petrographic studies by Nyame *(1998)* revealed three textural types of carbonate, namely:

- Microconcretionary (Fig. 3.4c and d)
- Granular (Fig. 3.4e)
- Granoblastic (Fig. 3.4f)

According to Nyame *(1998)* the distribution of these three types appears to depend on location on the mine and stratigraphic position. Granular carbonates, composed of kutnahorite and rhodochrosite, are predominant in central parts of the carbonate unit at Hills A, B, E, and to some extent, C. Granular carbonate thus accounts for the bulk of the manganese carbonate ore resource.

Microconcretionary carbonates appear to be confined to the transition zones between carbonate ore and the surrounding sedimentary rocks. Nyame *(1998)* described the size of the microconcretions as ranging between 30 and 110µm (Fig. 3.4c and d). The microconcretions show an irregular rounded to elliptical shape and display a crude concentric zonation (Fig 3.4a). The concentric zones vary in composition from rhodochrosite to kutnahorite *(Nyame, 1998)*. The microconcretions are cemented by microcrystalline chert/quartz and carbonate which show little evidence of compaction, thus suggesting that cementation took place during early diagenesis. It is important to note that carbonate-rich argillites described in this thesis contain very similar Mn-carbonate microconcretions.

Granoblastic textured carbonate appears to be restricted to Hill D south. It appears to be a product of intense hydrothermal alteration and recrystallization of the primary ore to form granoblastic rhodochrosite. Concurrent deformation is indicated by twin lamellae and bent cleavages in anhedral carbonate grains that may be up to several mm in size. Further evidence for intense alteration is provided by the occurrence of minor and trace minerals such as alleghanyite, alabandite, pentlandite etc. (Table 3.5) in the granoblastic rhodochrosite ore *(Nyame, 1998).*

Table 3.5. Mineralogy of texturally different carbonate ores after Nyame (1998).

Sample #	**Locality**	**Major minerals**	**Minor minerals**	**Trace minerals**
DC21 Granular carbonate	Lower part of CU	rhodochrosite, quartz		
FS54 Microconcretionary carbonate	LS-CU transition	kutnahorite, quartz	spessartine	
Microconcretionary carbonate	Boundary CU	quartz, rhodochrosite		
Granular carbonate	Central CU	quartz, rhodochrosite	kutnahorite	
Granoblastic carbonate	Central CU, Hill D south	quartz, rhodochrosite	kutnahorite	alleghanyite, rutile, mangano-cummingtonite, alabandite, molybdenite, pentlandite, millerite, linneite and sphalerite.

Abbreviations: CU = Carbonate unit, LS = Lower sedimentary unit.

3.6 Greenstone:

The upper and lower greenstones at Nsuta have distinctly different characteristics, both on macroscopic and microscopic scale. Samples from the upper greenstone unit are intensely sheared, whereas samples from the lower greenstone unit are massive and appear relatively undeformed.

a) Macroscopic description

Greenstones from the upper greenstone unit (UG) typically have a well-developed cleavage and a dark green to khaki colour. Generally the rocks are fine-grained, probably representing true metalavas rather than volcaniclastic material. However, textural preservation is usually very poor in the intensely foliated UG. Post-tectonic and post-metamorphic cross-cutting quartz veins are common, as well as abundant secondary pyrite, usually in the form of small isolated cubes or thin veinlets (Fig. 3.5a).

Samples of the lower greenstone unit (LG) are typically light-green to light grey in colour. They have a well-preserved fragmented (volcaniclastic) texture and display no evidence of foliation. Large porphyroblastic carbonate crystals are recognizable in chlorite-rich samples. Cross-cutting quartz veins are common, as is pyrite; the latter usually in the form of small isolated cubes and less commonly in the form of veinlets. The lower greenstone unit (LG) can thus be described as a massive poorly sorted volcaniclastic unit with clasts ranging from sand to medium pebble size (Fig. 3.5b); cobble-sized clasts are exclusive to the contact between the lower greenstone unit and lower sedimentary unit (Fig. 3.5c).

Although two greenstone units are distinguished, the LG does display clastic textures and is thus considered to be a precursor to the lower sedimentary unit.

b) Petrography

X-ray diffraction analysis indicated that quartz, ankerite, albite and chlorite are major mineral phases in the greenstones with plagioclase, muscovite, calcite, epidote and biotite as minor phases (Table 3.6):

Lower Greenstone

Samples of the LG were always found to be completely altered to a dense and fine-grained metamorphic mineral assemblage. No trace of the original igneous mineralogy is preserved. Two mineralogical varieties of LG occur, namely one rich in actinolite, and another rich in carbonate and chlorite (Table 3.6).

Table 3.6. Major, minor, and trace minerals identified by petrography and XRD analysis.

Sample #	**Locality**	**Major minerals**	**Minor minerals**	**Trace Minerals**
FS57	LG, Hill D south	quartz, ankerite	plagioclase, muscovite, calcite	
FS56	LG, Hill D south	quartz, ankerite	albite, muscovite	
DC36	LG, Hill D south	quartz, ankerite, chlorite	biotite	
DC11	LG, Hill A	quartz, chlorite	muscovite	
FS59	LG, Hill D north	quartz, albite, chlorite, ankerite	muscovite, epidote	rutile
FS57B	UG, Hill D south	quartz, chlorite	albite, apatite, ankerite	
HE01*	LG, Hill E	quartz, chlorite, ankerite	calcite, epidote, biotite	apatite
DC19	LG, Hill C north	quartz, calcite, muscovite, chlorite, albite	epidote	tourmaline
DC23	LG, Hill D north	actinolite, quartz	epidote, tourmaline, biotite, albite	apatite, ankerite, chlorite

Abbreviations: LG = Lower greenstone unit, UG = Upper greenstone unit.
* Courtesy, Frank Nyame.

Actinolite-bearing samples have volcanic clasts set in a dense massively textured matrix composed of finely intergrown actinolite, biotite, albite, epidote and tourmaline with trace amounts of carbonate and chlorite. Actinolite-rich samples are marked by an abundance of minute sub- to euhedral needles of actinolite (~150µm), often arranged in brush-like or radial aggregates that are densely intergrown and predominate the matrix. Interstices between the actinolite needles are filled by submicroscopically fine-grained quartz or albite. Small subspherical grains of granular epidote (max. 25µm) are quite abundant and scattered throughout the matrix. Few large subhedral to euhedral grains of brownish-green tourmaline appear to be randomly dispersed (~60µm). Biotite is fairly abundant and also finely dispersed in the rock. It occurs in the form of booklets that attain sizes of 100 - 140 µm.

Volcanic clasts (small pebble size) set in a dense matrix, have a coarser grained internal texture but an identical mineralogy to the surrounding matrix. Clasts in samples DC19 (Hill C north) and DC23 (Hill D north) exhibit a fine planar fabric (possibly laminae of sedimentary origin) that does not extend into the surrounding matrix. There is an abundance of long prismatic needles of actinolite (120-160µm). These needles grow randomly across the planar fabric in the clasts. Minor amounts of biotite occur in the form of small clusters. Albite and quartz make up the bulk of the remaining mineralogy, but are very fine-grained and thus difficult to distinguish using a normal petrographic microscope.

Quartz veins which crosscut the matrix, are post-metamorphic in origin as metamorphic minerals do not transect the vein selvage and no reactions between vein quartz and surrounding matrix are observed. Carbonate, if present, lines the vein selvages with a central infill of quartz.

Carbonate and chlorite-rich samples, in contrast, are dominated by an abundance of porphyroblastic ankerite *(Nyame, 1998)* that often displays twin lamellae. Sparitic carbonate veins pre-date peak metamorphism as suggested by chlorite that overgrows the vein selvage (Fig. 3.5d). Albite crystals which display albite and Karlsbad twinning, have poorly developed outlines and abundant inclusions of epidote (Fig. 3.5e).

Dark green chlorite abounds in these samples and occurs as dense, fibrous clusters. Small amounts of light green chlorite, in the form of booklets, occur in the matrix and in clasts (80-120µm). Nyame *(1998)* identified trace amounts of sub- to euhedral apatite in chlorite-rich greenstone samples from the LG.

Electron microprobe analyses were carried out on chlorite, biotite, and feldspar. Chlorite can be classified as ripidolite or pycnochlorite (Fig. 3.6A), biotite falls into the field between annite and phlogopite (Fig. 3.6B), and the feldspar in the field of pure albite (Fig. 3.6C).

Upper greenstone

The presence of a well-developed foliation is characteristic for samples from the UG. Most samples are sheared to the extent that no primary

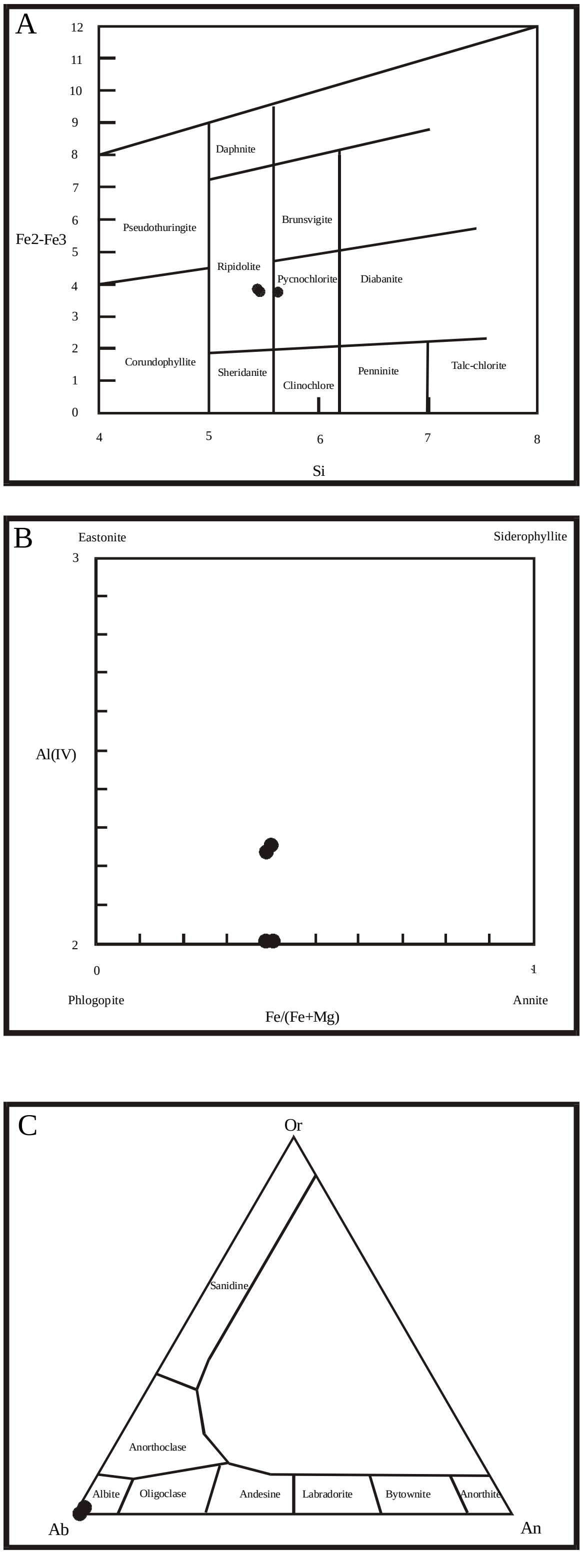

Figure 3.6. Mineral chemistry of chlorite (A), biotite (B), and albite (C) identified in greenstone lithofacies.

textures are recognizable. The mineral assemblage is often too fine-grained to be recognised by optical microscopy, but XRD reveals it to be composed of quartz, albite and ankerite, with minor amounts of muscovite and epidote. Chlorite platelets usually define the foliation (sample FS57B) which suggests a syndeformational origin for the chlorite. Granular quartz fills interstitial spaces between chlorite clusters.

One sample (FS59) has a better preserved texture than most samples examined from the UG; with microscopic textures indicating that it may be of volcaniclastic origin similar to samples from the LG. Euhedral ankerite porphyroblasts (~400µm) are set in very fine intergrowths of quartz and albite. Chlorite (30-40µm) and syntectonic quartz stringers define the foliation. The formation of quartz stringers are thought to pre-date peak metamorphism as chlorite grains are found to crosscut them. Minor amounts of apatite are present in the matrix.

An interesting feature in the matrix is the occurrence of large pre-deformational ankerite porphyroclasts (100µm - 1mm) that have evidently been entrained by tectonic deformation. They constitute the core of sigmoidal structures delineated by chlorite and submicroscopically fine-grained quartz and/or albite. Two generations of ankerite porphyroclasts are present. The first generation (~40µm diameter) has well defined crystal outlines, and appears very clear sparitic with few or no inclusions. Second generation carbonate porphyroblasts (200µm-1mm diameter) engulf the smaller first generation porphyroblasts. The second generation porphyroblasts contain many submicroscopically fine-grained (fluid?)inclusions and has only poorly defined crystal boundaries.