IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 3, Issue 5 Ver. I (Sep. - Oct. 2015), PP 16-29
www.iosrjournals.org

Provenance, tectonic setting and diagenesis of the Mn-Fe coated terrigenous clastsfrom the modern soil profiles, North West Province of South Africa: a case study of theCarletonville area.

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Abstract: *The arkosic and subordinate quartz-arenitic Mn-Fe coated terrigenous clasts were discovered to occur in association with manganese nodules hosted by weathered Mn-Fe rich alluvial-fluvial sediments of the Tertiary period in Carletonville area. The weathered Mn-Fe rich alluvial-fluvial sediments form the modern soil profiles in the study area. The Scanning Electron Microscope and petrographic studies of the terrigenous clasts indicated elevated content of manganese oxide precipitated in pore spaces between the framework grains as well as forming surface coatings on hand specimen. These clasts are mined with manganese nodules in the study area. The manganese nodules were formed from in situ concentration of Mn-oxide due to surficial weathering of the underlying Mn-rich dolomites of the Malmani Subgroup and then concentrated as Mn-rich residues, encircling rock fragments in soil profile. In contrast, Mn-Fe coated terrigenous clasts and the alluvial-fluvial sediments were sourced from older geological basins. Therefore, the purpose of the study were to construct a possible source area of Mn-Fe coated clasts and Mn-rich alluvial-fluvial sediments which hosted Mn-nodules in the mine area and from the results deduce the overall source of manganese that is mined in the area. On the basis of framework compositional analysis, the sediments were found to have been sourced from metamorphic and granitic origins in a cratonic interior to recycle orogen and sedimentation occurred in low plain, temperate, humid to subhumid climate. The sediment sources resembled the properties of the Archean granites and gneisses of the Witwatersrand Supergroup and Rand Anticline ridge (quartzite formation) exposed far off along the northern part of the study area on a high topographic mountain.*
Key words:*Diagenesis, Carletonville area, Mn-Fe coated terrigenous clasts, provenance, tectonic setting*

I. Introduction

This paper was aimed at studying the tectonic-provenance, diagenesis and nature of Mn-Fe coated terrigenous clasts which were firstly identified by Van Niekerk et al. (1999) to be of Aeolian depositional environment while studying ferromanganese wad deposits at Klipkuil, Wes Wits Mine, Houtkoppies and Ryedale Mine. This also includes studying the source areas for Mn-Fe rich alluvial-fluvial sediments hosting Mn-nodules which are associated with high silica content that is found in manganese ore. Understanding the source areas of the host sediments will enable a conclusion to be made on whether the Mn-source was only from the dolomites or there was addition from continental sources. The word coating used in naming the terrigenous clasts in this article refers to Mn and Fe concentric layers which encircled the nucleus and not the cement coatings around individual framework grains (Fig.1). Jafarzadeh and Hosseini-Barzi (2008) described the combination of geochemical and petrological data of the sedimentary rocks playing a critical role in uncapping the nature of source regions, tectonic setting of sedimentary basins, and the palaeoclimatic conditions that prevailed during the formation of sedimentary rocks. Provenance terranes and associated basins of deposition can be classified based on their tectonic settings (Dickinson et al, 1983). Many various studies are used to reconstruct the provenance for clastic sedimentary rocks. These include grain size analysis, heavy mineral separation (Ludwig, 1874; Meunier, 1877; Michel Levy, 1878), modal composition analysis (Pettijohn et al, 1987). This paper however, based its core on petrology and modal composition studies for sediment tectonic-provenance studies.

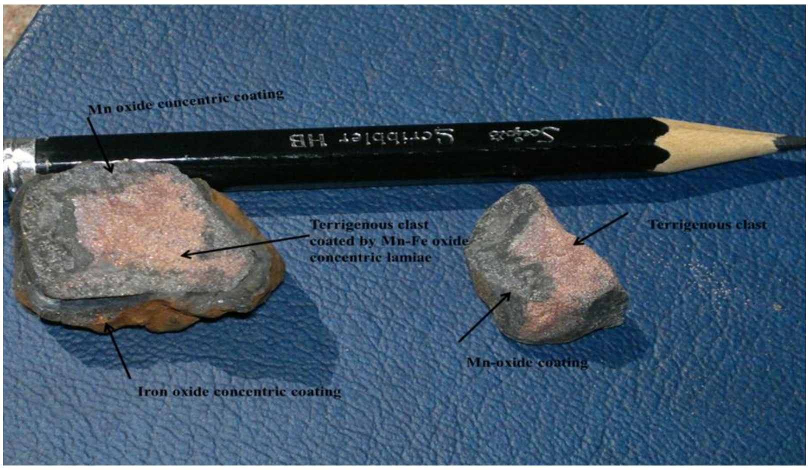


Figure 1: Manganese and iron coated terrigenous clast which occurs in association with manganiferous nodules in the soil profile.

1.1 Location of the study area

The area under investigation is located in Carletonville area, North West Province of the Republic of South Africa. The study was carried out at the General Nice Manganese Mine where there are open exploration boreholes and trenches which make it easy to carry out profile measurements, pit logging and sampling. The overall area under investigation is estimated to be 1543.2 km^2 in extent and it lies between longitudes 27^o 10' E and 27^o 25' E and between latitudes 26^o 15' N and 26^o 05 N' (Fig. 2). Accessibility of the area from Carletonville commercial town is fairly easy along the tarred R500 road that runs towards Ventersdorp which in turn off-ramps to a gravel road along the way that leads to Boons, and then the mine is on the left of the gravel road before reaching Boons. The area under investigation is characteristically having a flat terrain and comprises of few visible outcrops occurring on small scale due to thick Quaternary sand cover with great scale observed where there are trenches, open pits and sinkholes (Fig. 3).

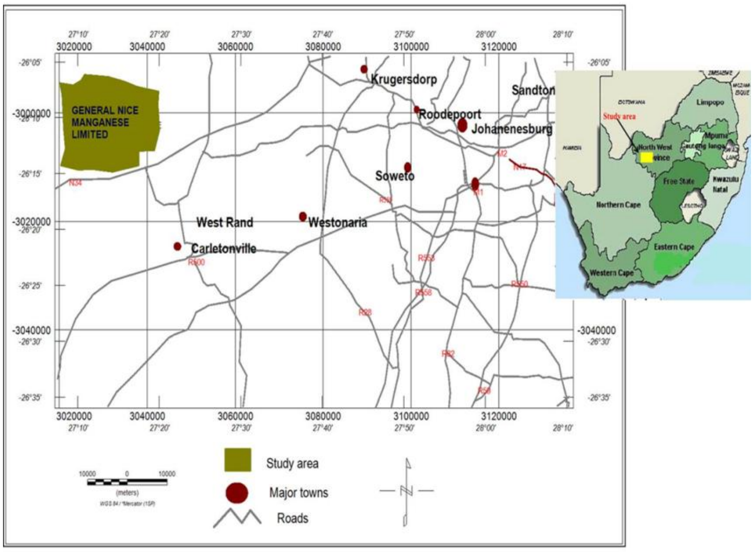


Figure 2: Traffic map displaying the location of the study area in Carletonville, West Rand District of North West Province, Southern Africa.

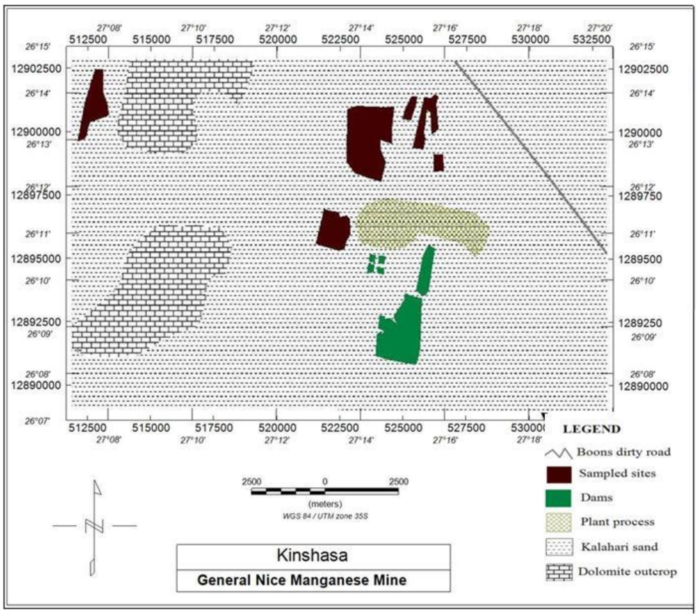


Figure 3: Locality map of the mine area indicating sampled sites and rock outcrops.

II. Geological Setting

The area under investigation is stratigraphically belonging to the Tertiary alluvial-fluvial sediments of the modern soil profile and is underlain by Malmani Dolomite Subgroup forming the bedrock. The stratigraphic profile setting in the mine area characterized of basal Mn-bearing stromatolite, which in turn overlain by alluvial-fluvial sediments hosting manganese nodules. The whole succession is capped on surface by Quaternary soil also known as top soil (Fig. 4).

Figure 4: An open exploration borehole showing the profile setting in the mine area. GPS coordinates (S 26^{o} 8' 5.8"; E 27^{o} 15' 32" and elevation: 1554 m).

The Mn-Fe coated terrigenous clasts are found in this area densely concentrated at the uppermost zones of the weathered alluvial-fluvial sediments, forming the soil profile and towards the contact with the Quaternary sand (Top soil) cover (Fig. 5). The soil profile was subdivided into variety of zones on the basis of zonal mineralogical composition and nodule grain sizes. Zone 1 characterizes of silt soil representing the Quaternary sand which caps the stratigraphic section in the mine area. Zone 1 is further below underlain, with sharp conformable contact by Zone 2 which comprises of elevated content of Mn-Fe coated terrigenous clasts which forms the core of this study, with distributed patches of calcretes. The underlying Zone 3 comprises of coarse to medium grain Mn and Fe bearing nodules with big angular to subrounded fragments of Mn and Fe bearing fragments reaching up to 5cm in size. This zone also consists of extensive amount of calcrete fragments and thin bed of up to 55cm thick manganiferous wad, overlying stromatolitic pinnacle at the base.

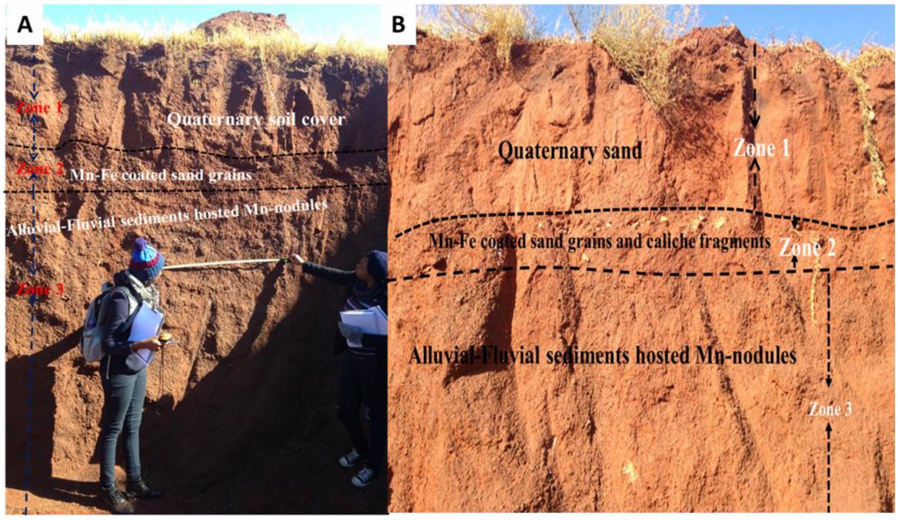


Figure 5: Soil profile setting in the mine area subdivided into three varieties of zones (Zone 1, Zone 2 and Zone 3) on the basis of difference in mineral composition and macroscopic constituents.

The deep brownish colour in A) is associated with the presence of organic material and accumulation of Mg, Ca, Na and K bearing minerals. The deep reddish colour in B) is due to intense chemical weathering of Fe-bearing mineral close to the tropical regions. GPS coordinates (S 26^{o} 8' 50.4"; E 27^{o} 15' 31" and elevation: 1563 m).

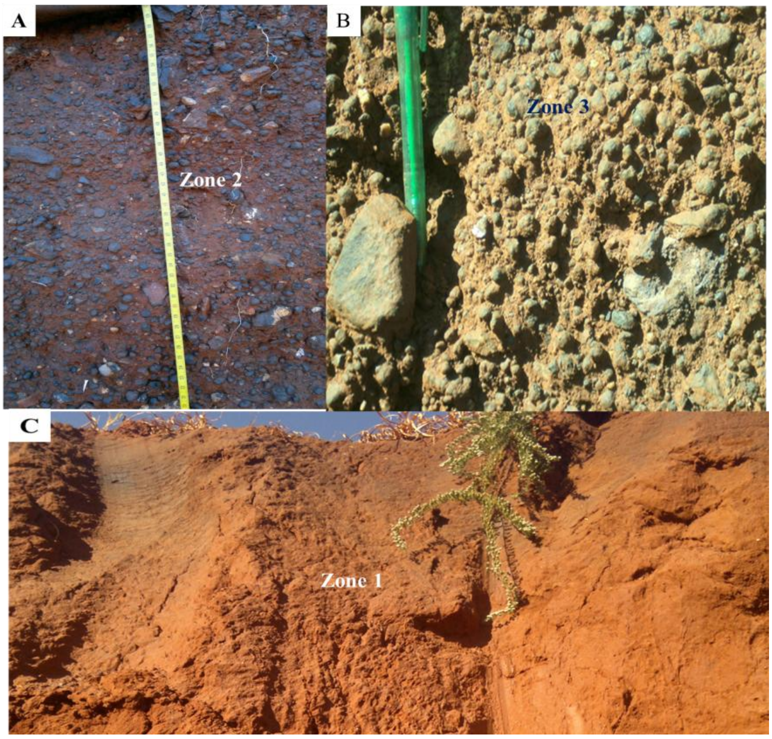


Figure 6: Clear identification of the three delineated zones of the profile with their components on large scale. a) Zone of Mn-Fe coated terrigenous clasts. b) Zone of manganese nodules and c) Zone of silty soil of Quaternary age.

The underlying Chuniespoort group of the Transvaal Supergroup which comprise the source beds of the Mn oxides which is been mined in the area under study was defined by Eriksson and Reczko (1995) as an intracratonic sag basin dominated by thermal subsidence which continues the structural style of the preceding Black Reef Formation. The Black Reef and Chuniespoort Basins are separated by stage of tectonic tilting, which changes the tilt of the depositional surface from north to south. Much of the Chuniespoort strata in the study area reflect a continuous aggradation within a marine environment which indicates a stage of sea level rise probably related to the intracratonic thermal subsidence (Eriksson and Reczko, 1995). The alluvial-fluvial sediments were deposited on top of Malmani dolomites on a continental setting, following the depositional style of the underlying Chuniespoort and Black Reef sediments.

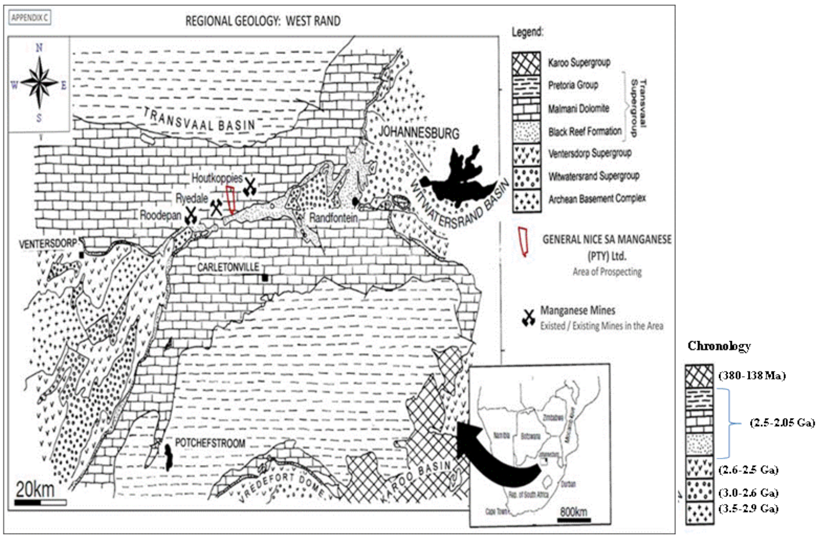


Figure 7: Regional geological map of the study area showing the location of the General Nice Manganese Mine (modified after Pack et al., 2000).

III. Sampling And Methodology

Several exploration boreholes and open pits were opened in the mining area during the phase 1 exploration. Twenty five samples were collected from eight representative sites of the ten selected exploration pits.Fifteen thin sections for petrography studies and ten polished sections to be subjected to Scanning Electron Microscopy (SEM)were prepared from the twenty five representative samples.The prepared thin sections were photographed and examined under both plane and cross-polarized light on Olympus polarizing microscopy with a built in camera, equipped to computer monitor at University of Fort Hare.Polished sections were cleaned, glued on a glass slide for 24 hour-period and were then carbon coated using Cressington Carbon Coater 108Carbon/A combined with a pumping system and thickness monitor into an area of approximately 42 cm x 60 cm. These samples were then subjected to Scanning Electron Microscopy undertaken on JEOL JSM-6390 LV model withEnergy dispersive X-ray spectroscopy (EDS) link at University of Fort Hare with operating conditions at 15kV and 15 mA on cobalt standard.

The data was then used to study clays, cements/matrix, morphology and textural relationship among grains. This paper based its core on the studies of detrital framework modes of sandstone suites to provide information about the tectonic setting of basins of deposition and associated provenances. Modal compositional analysis of manganese and iron coated terrigenous clasts were carried out on ten thin sections, and each section was accounted for at least 300 grains encompassing mineral type-identification and calculation of grain percentages through the use of gridiron screen monitor attached to an optical microscope with built in camera.

The Gazzi Dickinson's point count method was employed for quantitative compositional analysis. During the point counting, grains were grouped as Qm (Monocrystalline quartz), Qp (Polycrystalline quartz), P (Plagioclase feldspar), K (Potassium feldspar), Lv (Volcanic or metavolcanic lithic fragments) and Ls (Sedimentary or metasedimentary lithic fragments). The detrital grains were then recalculated to 100%, excluding matrix, cement, micas, heavy minerals and carbonates (Dickinson, 1985). The point counted data was then used to determine the nature of the terrigenous clasts, tectonic-provenance settings, source rocks and semi-quantitative weathering index based on ancient climate. This was achieved through the use of various discrimination plots. The Q-F-L plots by Pettijohn (1975) and Folk (1980) were used to discriminate the nature of the sand clasts based on the percentage of quartz, feldspar and lithics. The 1n (Q/F) vs. 1n (Q/RF) binary plot by Weltje et al. (1998) was used to determine the sediments semi-quantitative weathering index with relation to ancient climate. The Q_t-F-L and Q_m-F-L_t plots by Dickinson et al. (1983) and Q-F-L plot by Yerino and Maynard (1984) were used to discriminate the sediment tectonic setting. Stunner et al. (1981) ternary plot was used to determine the parent source rocks.

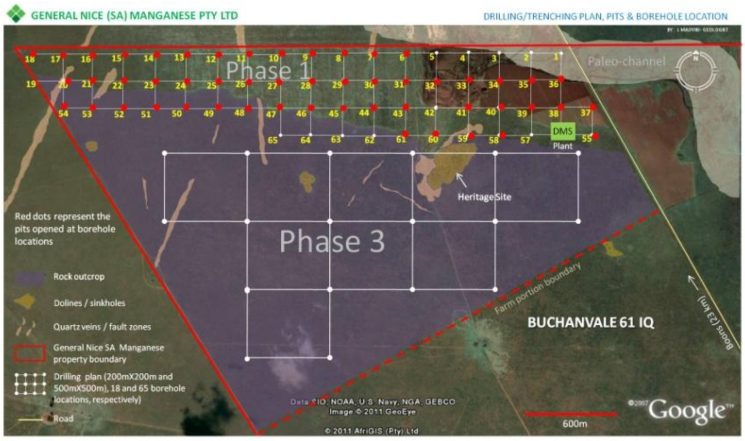


Figure 8: Exploration plan map showing open pits and borehole location in the mine area.

IV. Results And Discussion

4.1 Petrography

The petrographic studies of the Mn-Fe coated terrigenous clasts indicate the analysed samples having moderately to coarse and subrounded to well-rounded grains with moderate to slightly well sorted texture. Various types of grain major contacts including long, point, concave-convex and sutured contacts were noted. The detrital framework grains of the Mn-Fe coated terrigenous clasts composed mainly of monocrystalline quartz (Qm), polycrystalline (Qp), feldspars and lithic fragments. Monocrystalline quartz grains, comprising average percentage of 83.04 % total grain predominates the sand grains. Both plagioclase and potassium feldspars comprise of 10 % total framework grains. Lithic fragments comprised 4 % with the remaining 3 % comprised of polycrystalline quartz grains.

Sandstone classification was made from Folk (1980) and Pettijohn (1975) classification scheme. Based on these classification schemesMn-Fe coated terrigenous clasts were found to be mostly subarkosic with subordinate quartz arenites.

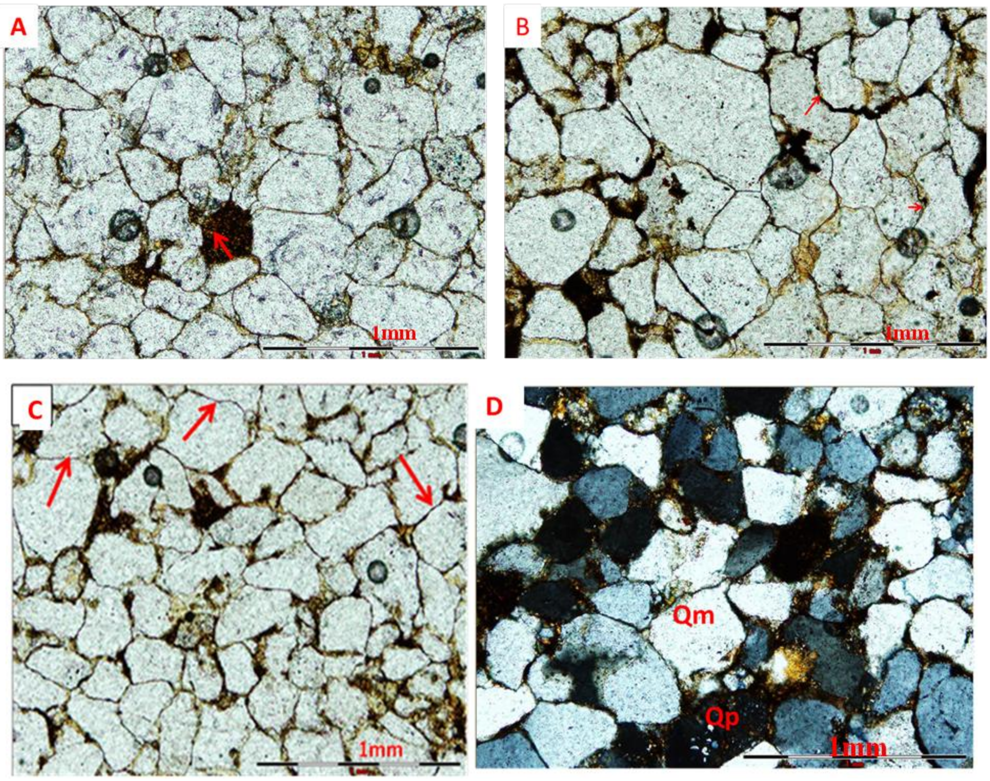


Figure 9: Photomicrographs for Mn-Fe coated terrigenous clasts in mining area, arrows for indications. a) Volcanic lithic fragment. b) Concave-convex contacts between neighboring framework grains. c) Long and embayed contacts between framework grains indicating a moderate degree of compaction and d) Monocrystalline (Qm) and polycrystalline (Qp) quartz grain captured under cross polarized light.

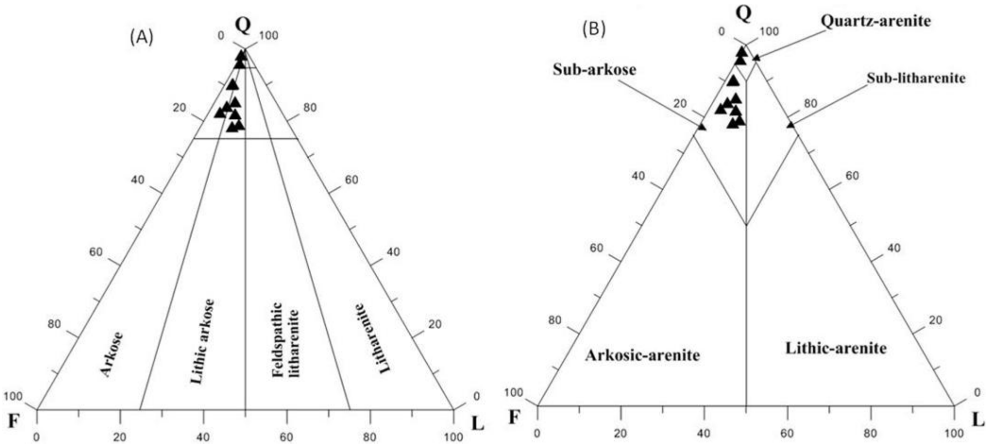
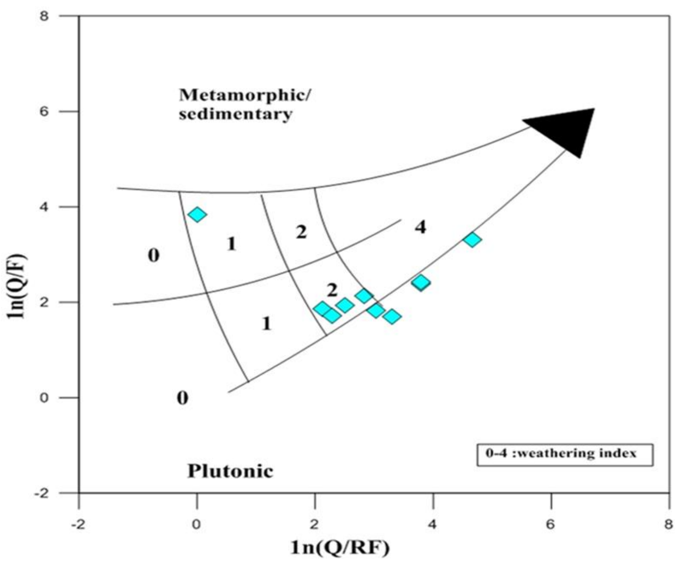


Figure 10: Classification of sandstone composition from the petrography of the Mn-Fe coated terrigenous clasts based on schemes proposed by a) Pettijohn (1975) and b) Folk (1980). Standard plots: Quartz, Feldspar, Lithic grains (Q, L, F), indicates:a) Arkoses to lithic arkoses and b) Sub-arkoses to quartz arenites reflecting the nature for the Mn-Fe coated terrigenous clasts in the area under study.

4.2 Provenance

An elevated percentage of quartz grains (79-96 %), moderately to well sorting, subround to rounded framework grains, low percentage of feldspars (2-14 %) and rock fragments (0-8 %) indicates that sediments were transported for long distance from their source. Samples plot under cratonic interior and recycled orogen, with the high content of monocrystalline quartz grains representing, according to Basu et al (1975) sediments derived from granitic sources.In contrary, the samples indicated metamorphic sources under humid conditions on Suttner et al (1981) discrimination plot.

Based on the log-ratio plot proposed by Weltje et al (1998) in Fig.11samples plot in the field number 2 and on the vicinity of field number 4, suggesting sedimentation either in a low plains with a temperate and subhumid climate or on tropical, humid conditions within an area of moderate relief, and low relief and tropical, humid climatic conditions respectively. The long distance transportation and recycling of sediments shifts the data towards humidity rather than arid regions (Zaid, 2013).Dabbagh and Rogers (1983) on the other hand explains the abundance of monocrystalline quartz in sandstone as ascribed to the attrition and abrasion processes of polycrystalline grains during the sediment transportation from metamorphic terranes.However, the low percentage of feldspars and rock fragments and their absence in some samples implies the cratonic region (Zaid, 2012). Based on the above observations, the studied samples reflect their source region in cratonic interior and a long transportation distance to the current depositional basin which supports sediment derivation from the Archean granites of the Kaapvaal Craton and Rand Anticline quartzitic formations of the Black Reef Formation which are found exposed along the northern extent of the study area on high topographic mountain.



Semi-quantitative weathering index			Relief		
			High mountains 0	Moderate hills 1	Low plains 2
Climate precipitation	Semi-arid and Mediterranean	0	0	0	0
	Temperate Subhumid	1	0	1	2
	Tropical humid	2	0	2	4

Figure 11: Log-ratio plot after Weltje et al. (1998). Q: quartz, F: feldspar, RF: rock fragments. Fields 1–4 refer to the semi-quantitative weathering indices defined on the basis of relief and climate as indicated in the table.

The values 0, 1 and 2 represents sediments from semi-arid and Mediterranean, temperate subhumid and tropical humid climatic condition, and high mountain (0), moderate hills (1) and low plains (2) relief. In semi-quantitative weathering index values in range of 0-4 represents unweathered, slightly weathered, moderately weathered and intensely weathered sediments respectively, with minima corresponding to areas below relief or climate thresholds and maxima to humid tropical lowlands. The Mn-Fe coated terrigenous clasts indicate source regions from tropical humid climates and low plain reliefs and are moderately to intensely weathered.

Table 1: Framework parameters of detrital modes (Ingersoll and Suczek, 1979; Tucker, 2001).

Parameter	Explanation
Q	Quartz (Qm + Qp)
Qm	Monocrystalline quartz
Qp	Polycrystalline quartz
Qt	Total quartzose grains (Qm + Qp)
P	Plagioclase feldspar
K	Potassium feldspar
F	Total feldspar grains (P + K)
Lv	Volcanic- metavolcanic rock fragments
Ls	Sedimentary rock fragments
Lm	Metamorphic rock fragments
Lsm	Metasedimentary rock fragments
L	Unstable (siliciclastic) lithic fragments (Lv +Ls +Lsm)
Lt	Total siliciclastic lithic fragments (L + Qp)

Table 2: Modal compositional analysis (%) for the Mn-Fe coated terrigenous clasts in mining area.

Sample No	Qt	F	L	Qm	Qp	Lt
NS 1	82.7	13.3	4.0	79.7	3.0	7.0
NS 2	78.7	12.2	9.0	76.0	2.7	11.7
NS 3	85.0	10.0	5.0	83.3	1.7	6.7
NS 6	98.0	2.1	0.0	96.3	1.7	1.7
NS 8	81.7	11.7	6.7	79.3	2.3	9.0
NS 11	78.0	14.1	7.9	76.7	1.3	9.2
NS 13	95.6	3.5	0.9	91.1	4.5	5.4
NS 23	89.6	8.3	2.0	85.3	4.3	6.3
NS 28	82.0	15.0	3.0	78.0	4.0	7.0
NS 30	90.0	8.0	2.0	84.7	5.3	7.3

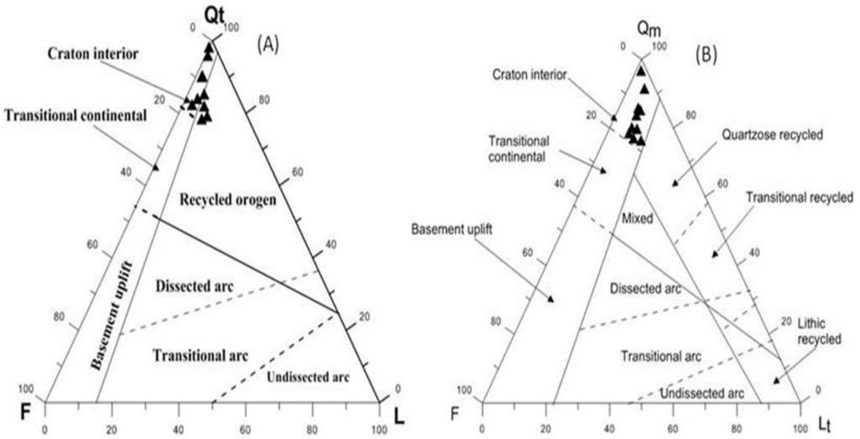


Figure 12: Ternary plots for interpreting the provenance for the terrigenous clastsafter Dickinson et al. (1983). a) Total quartz, feldspar and lithic fragments (Q_t, F and L) and b) Monocrystalline quartz, feldspar and total lithic grains (including polycrystalline quartz) (Q_m, F and Lt).

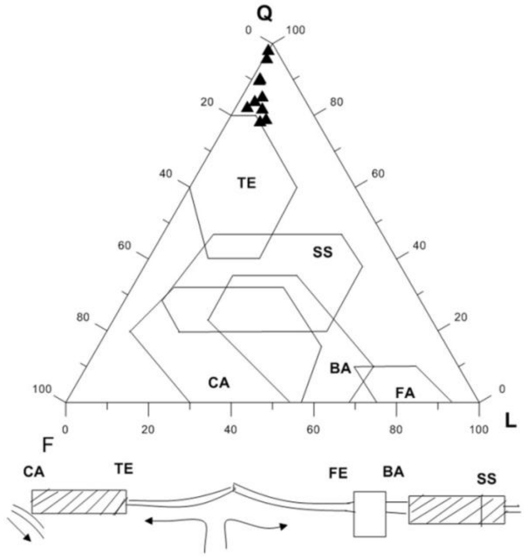


Figure 13: Q-F-L tectonic provenance diagram for studies rock samples, after Yerino and Maynard (1984). Samples plot near the TE field close to Q apex. TE: trailing edge (also called passive margin), SS: strike slip, CA: continental margin arc, BA: back arc to island arc, FA: fore arc to island arc.

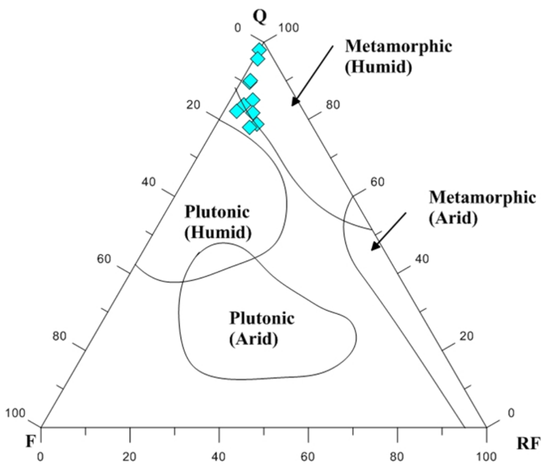


Figure 14: The effect of source rock on the composition of the Mn-Fe coated terrigenous clasts using Suttner et al (1981) ternary plot. The samples plot under metamorphic, humid source rock which implies recycling and long distance transportation of sediments from metamorphic source regions (Zaid, 2013).

4.3 Diagenesis

The major diagenetic factors observed in studied samples are: (1) compaction, (2) iron oxide cementation, (3) silica cementation and carbonate dissolution, (4) kaolinite and illite cementation, (5) Mn- oxide cementation and quartz overgrowths.

4.3.1 Compaction

Clastic sediments are subjected to compaction as a result of the weight of overlying sediments during progressive burial in the process of diagenesis. This is noticeable from reduction in primary porosity due to close packing of detrital framework grains. Compaction is also evidenced from concave-convex and sutured contacts between framework grains (Fig.9). Long and embayed contacts are also present indicating moderate degree of compaction as opposed to intense concave-convex contacts for high compactional regime.

4.3.2 Iron oxide cementation

Iron oxide occurs in all samples as a cement coating around detrital grains and to lesser extent as patches between framework grains filling pore spaces. The weak iron oxide coatings as seen in (Fig. 15a) where there are grain contacts suggests diagenetic origin for iron oxide, not an oxidized rim of detrital grains (Zaid, 2012). Iron oxide (hematite) as one of predominant cementing minerals in the samples of the area under investigation may have been derived in solution from weathering of iron rich minerals such as biotite, magnetite, siderite, pyroxenes and hornblende from the surrounding quartzitic and iron formation rocks which tend to release their iron under an oxidizing diagenetic environment. The iron was then precipitated as hematite or as goethite precursor oxide and subsequently turned to hematite. Some of the iron cement occurred during the uplift stage under oxidizing environment.

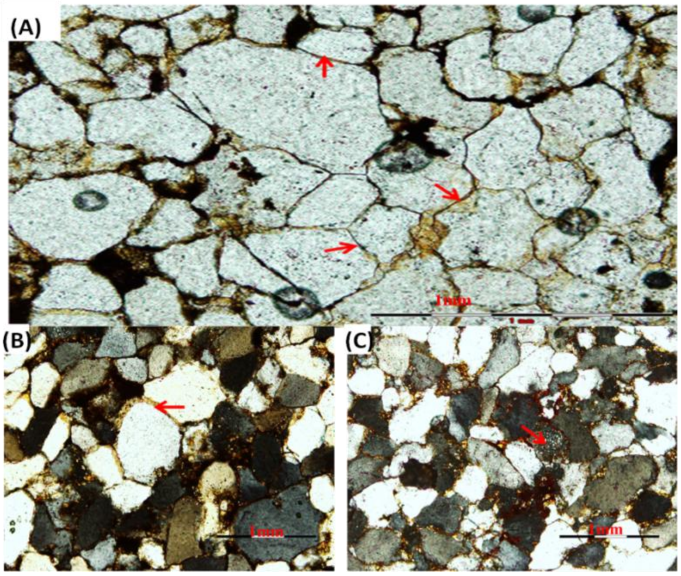


Figure 15: SEM-EDX image and photomicrographs of theMn-Fe coated terrigenous clasts, arrows for indications. a) Weak to absence of hematite coating at grain contact as an indication of diagenetic origin for iron oxide.b) Clearly discernible iron oxide coating forming a ring round detrital quartz grain.c) A bright speck indicating alteration of feldspar grain.

4.3.3 Silica cementation and carbonate dissolution

Early precipitation of silica cementation in the studied samples occurred during early-mid diagenesis due to progressive grain packing and pore water chemistry, which resulted in dissolution of unstable silicate framework grains forming silica cement. The chemistry of the interstitial fluid grew strongly acidic and saturated with silica in the mid-late stages of diagenesis resulting in the formation of quartz overgrowths (Fig. 16a). The scarcity of quartz overgrowths in Mn-Fe coated terrigenous clasts may be related dissolution due to change in chemistry of the interstitial pore fluid, becoming more alkaline upon the interaction with dissolved Malmani dolomites. The early formed carbonate cements include the unstable aragonite and high Mg-calcite which were later dissolved to form the stable form of carbonate such as siderite and calcite as witnessed in the samples (Fig. 16b and c).

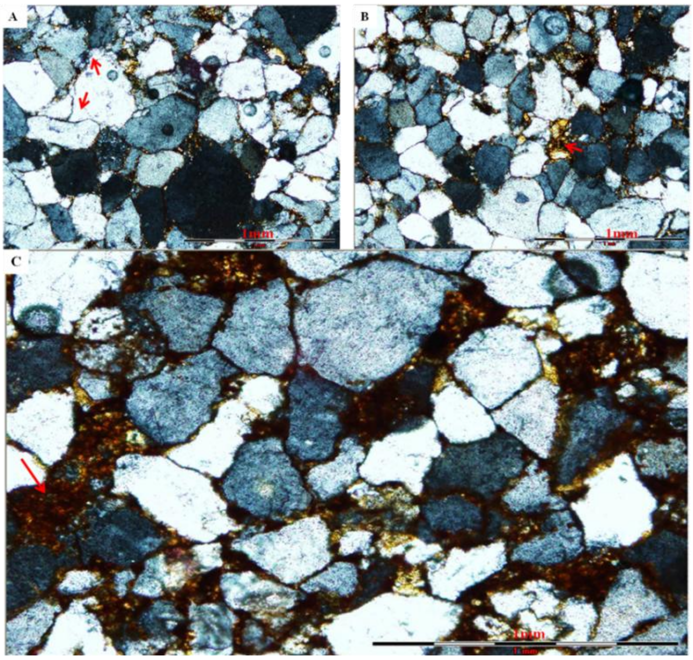


Figure 16: Photomicrographs for Mn-Fe coated terrigenous clasts with red arrows to indicate. a) Diagenetic quartz overgrowth. b) Calcite cements reflecting high bright yellow interference colour under cross polarized light. The whole bar represents 1mm for a scale.

4.3.4 Mn-oxide cementation

The manganese oxide cement occurs predominantly as filling pore spaces between the framework grains in all samples and sometimes replacing unstable detrital grains. These cements occurred during mid and upliftdiagenetic stage engulfing the early formed cements and replacing the detrital grains as seen on (Fig. 18) where the chert grain is completely (yellow arrow) and partially (red arrow) replaced by Mn-oxide. SEM studies has shown honeycomb morphology of cryptomelane indicating pseudomorphic texture grading into massive texture as cryptomelane fills cavities that were previously occupied by clay minerals (Fig. 17). The Mn-oxide cement entirely comes from dolomites dissolution.

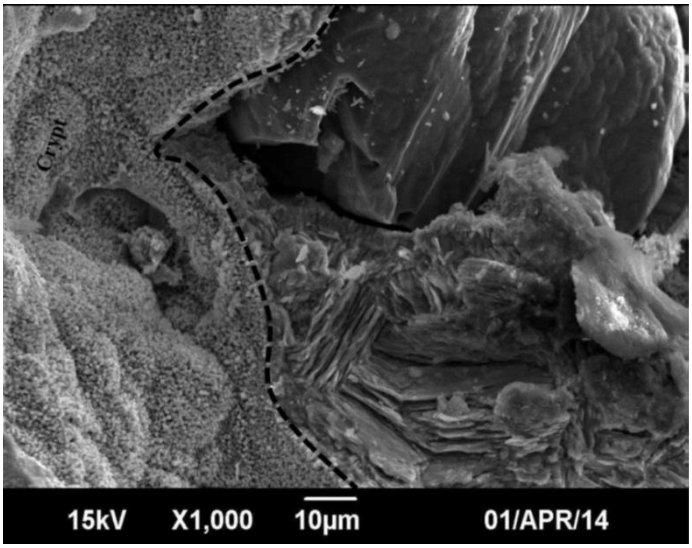


Figure 17: SEM photomicrograph of manganese bearing nodule indicating the pseudomorphic texture of cryptomelane in cavities after replacement of clay minerals.

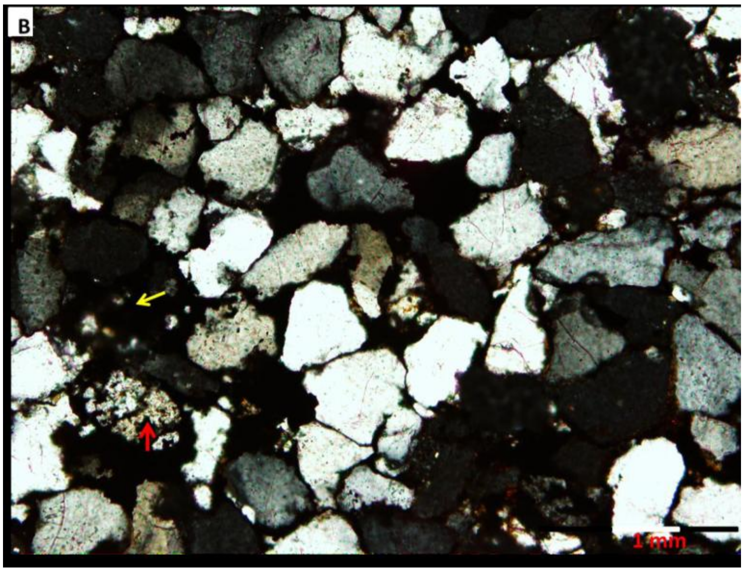


Figure 18: Photomicrograph shows Mn-oxide coated clast and also shows framework grains floating in the Mn-oxide cement. Red arrow indicates chert partially replaced by Mn oxide, and the yellow arrow indicates a grain was nearly completely replaced by Mn-oxide, remaining only little part.

4.3.5 Kaolinite and illite cementation

Kaolinite exists as a pore filling aggregates in the studied samples derived mostly from weathering of feldspar grains. Fig. 19c indicates a feldspar grain partially dissolved and replace by greyish colour cement representing kaolinite, red arrow. Illite cement is also seen in the samples derived from both mica dissolution (Fig. 19b) and smectite-kaolinite groundmass during illitization. Illite pellets intergrading on smectite and kaolinite groundmasses are common in the studied samples which indicate the change in chemistry of pore fluids promoting mineral recrystallization. The occurrence of clay cements was continuous during mid and uplift stage as the feldspar grains suffered an extensive continually alteration and therefore postdate quartz overgrowths. These cements, more especially kaolinite forms a thin laser in soil profile.

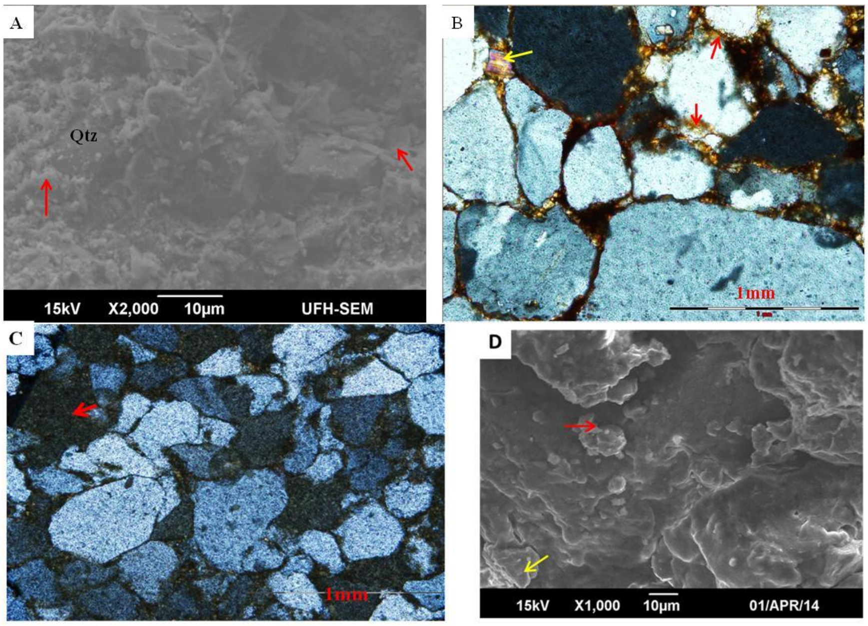


Figure 19: SEM images and photomicrographs ofFe-Mn coated terrigenous clasts. a) Kaolinite cement formed as filling aggregates in pore spaces between silica grains and postdates quartz overgrowth. b) Illite showing yellowish colour (red arrows) between quartz grains after muscovite alteration (yellow arrow) and smectite illitization. c) Kaolinite from alteration of detrital feldspar grain. d) Illite pellets growing from the groundmass of kaolinite during illitization.

4.4Paragenesis of Mn-Fe coated sand grains in the study area.

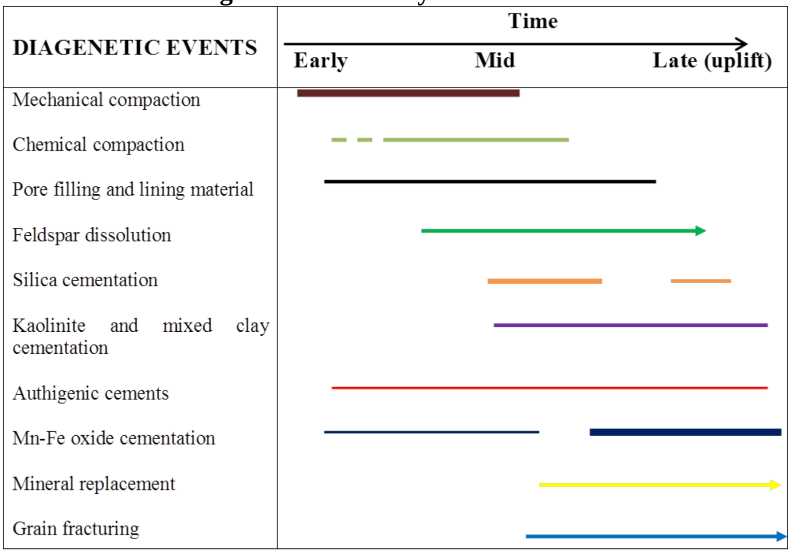


Figure 20: Diagenetic pathway for the formation of minerals in rocks found in the study area.

During early diagenesis, sediments underwent slight mechanical compaction as a result of progressing grain packing and to a greater extent, grain and cement dissolution. As a result of subsequent burial compaction extended into second stage of diagenesis (mid- early late stage) which characterized mostly of reduction of pore spaces, dissolution of unstable mineral phases and precipitation of their stable counterparts due to change in environmental conditions. Pore filling and lining material formed from precipitation of dissolved mineral phases. Quartz overgrowths in Mn-Fe coated terrigenous clast samples were rarely observed and thus iron oxide and manganese oxides formed at a late stage probably during the latest stage of mid diagenesis to the late (uplift) stage engulfing kaolinite.

V. Conclusions

The studies of modal compositional analyses conducted on Mn-Fe coated terrigenous clasts which were found to occur in association with manganiferous nodules in the mine area indicated their nature of arkoses to lithic arkoses with subordinate quartz arenites on the proposed Q-F-L sandstone classification schemes. These sediments indicated their source regions falling under cratonic interior to recycle orogen on Q_t - F-L and Q_m -F-L_t tectonic-provenance classification scheme. The point counted data also shows that the samples plot in the field number 2 and other samples on the vicinity of field number 4, suggestion sedimentation either in a low plains with a temperate and subhumid climate or on tropical , humid conditions within an area of moderate to low relief and tropical humid climatic conditions respectively. These are the prevailed climatic conditions in the study area which favoured soil profile formation.

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The enrichment of quartz grains, comprising an average of up to 86.13% with feldspar grains comprising up to 10% total framework grains, supports the long distance transportation notion from the cratonic interior and intense weathering, with dissolution from the tropical-humid climatic conditions at an area of low relief. The diagenesis of the clasts were divided into 3 stages i.e. early, mid and uplift diagenetic stage. These include sediment consolidation also known as the early stage which characterized of cementation and mineral neomorphism in sediments. This period was subsequently followed by mid (burial diagenesis) stage which brought about an increase in tightness of grain packing, loss of pore spaces and bed thinning mainly due to extended weight of the overlying sediments and selective dissolution of framework grains. Compaction, recrystallization and mineral overgrowth are the major diagenetic changes in this stage. In the uplift diagenetic stage, rocks were uplifted, weathered and unroofed by erosion bringing mineral assemblage including newly formed diagenetic minerals into environment of low temperate and pressure, and high oxygen environment. Therefore much of oxidation, dissolution and replacement diagenesis occurred in this stage. The dominance of Mn-Fe oxides and carbonate cementation indicate sediments deposition in littoral marine environment which is in contrast with the previous studies that suggested sediment deposition in aeolian depositional environment. Petrological and diagenetic studies indicated Mn-Fe oxides as predominant cements. Fe-oxides occur, mostly as coating cement around detrital framework grains. Mn-oxide on the other hand occurs predominantly as pore filling and lining between framework grains engulfing early formed cements. Clay cements especially kaolinite and illite forms secondary predominant cements from K-feldspar alteration, considering the low content of feldspars in the studied sediments. Quartz overgrowths as indication of change in pore water chemistry and deep burial are witnessed to have occurred in late diagenetic stage.

In conclusion, the Mn-Fe coated terrigenous clasts were derived from the weathering of Archean granites and gneisses as well the quartzitic formations of the Black Reef in a cratonic interior and recycle orogenic belt of the Rand anticlines along the north-north west direction. These rock facies have no trace of manganese and has never been tested to contain manganese in them and therefore cannot be potential source of manganese which is been mined in the form of nodules in Carletonville area. This then deduced that manganese oxide precipitation in and around sand grains occurred after their deposition in the present basin and the source still correlates with the weathering of the underlying Mn-rich dolomites of the Malmani Subgroup. These sediments were deposited in a basin of low-moderate relief under tropical and humid climatic conditions which is where they experienced the diagenetic processes resulting in the formation of manganese oxide and iron oxides contained in them.

Acknowledgements

The first author would like thank Council for Geosciences for financing the stay, tuition and the field excursions whilst at the university. Professor Liu is thanked for his assistance and constructive comments and editing tirelessly. My gratitude goes to the General Nice Manganese Mine (SA) Manager Dr Dong for granting me the access to the mining lease area.

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