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STRATIGRAPHY, TECTONIC SETTING, AND MINERALIZATION OF THE EARLY PROTEROZOIC MAGONDI SUPERGROUP, ZIMBABWE: A REVIEW

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by

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ABSTRACT

The Magondi Supergroup is a mainly metasedimentary succession, with minor mafic and intermediate to felsic metavolcanics, which is found in the early Proterozoic Magondi Mobile Belt of western Zimbabwe. It is subdivided into the Deweras, Lomagundi and Piriwiri groups, which were deposited between c.2.1 and 2.0 Ga (Pb-Pb, Rb-Sr). In addition, lithologies of the Dete-Kamativi Inlier of NW Zimbabwe are also part of the Magondi Supergroup. The Magondi Supergroup was deformed into a thin- and thick-skinned fold-thrust belt and metamorphosed from greenschist to granulite facies during the c.2.0-1.8 Ga (Rb-Sr, K-Ar) Magondi Orogeny, and was also affected by the Irumide and Pan-African Zambezi orogenies. The Deweras Group, which unconformably overlies the granite-greenstone terrane of the Archaean Zimbabwe craton, comprises a redbed sequence, up to 1.3 km thick, of meta-arenites, rudites, pelites and minor carbonates and evaporites, together with enriched sub-alkaline mafic lavas and pyroclastic rocks. In the southern outcrop area, the Deweras Group is subdivided into the Njerere, Munyati, Copper Pot, Nyachechene and Nyamachena formations, and in the northern outcrop area, it is subdivided (where best developed) into the Mangula, Norah, Suiwerspruit and Chimsenga formations.

The Lomagundi Group, which overlies the Deweras Group unconformably, is subdivided into three formations. The Mcheka Formation consists of basal conglomerates, grits and quartzites, followed by stromatolitic dolomites, phyllites, pockmarked quartzites, argillites and banded iron-formations. The Nyagari Formation consists of striped slates, sandstones and intermediate volcanics, while the Sakurgwe Formation consists predominantly of greywackes. The overlying Piriwiri Group, which can be considered the contemporaneous distal facies equivalent of the Lomagundi Group, is subdivided into three formations. The Umfuli Formation consists of basal graphitic and pyritiferous slates with narrow bands of cherty manganiferous quartzite, followed by argillites and phyllites with minor interbedded greywackes. The Chenjiri Formation consists of phyllites and greywackes, with minor quartzites, chert, felsites, tuffs, agglomerates and andesites. The Copper Queen Formation consists of a monotonous sequence of phyllites and micaceous feldspathic quartzites, with a ferruginous marble near the base together with major stratiform Zn-Pb-Cu-Fe-Ag massive sulphides.

The Dete-Kamativi Inlier consists of granodioritic orthogneisses, granites, and highly deformed and metamorphosed supracrustal sequences which have been subdivided into four formations. The Malaputese Formation consists of pink paragneiss with minor intercalated calc-silicate leucogneisses, metapelites with minor graphitic and calcareous rocks, and mafic metavolcanics with intercalated metasediments. The Inyantue Formation is composed of garnetiferous gneisses and schists with intercalations of calcareous, graphitic, magnesian and arenitic rocks. The Kamativi Formation consists of tightly folded muscovite schists, subordinate fine-grained biotite schists, and minor arkosic psammites. The Tshontanda Formation is composed of garnetiferous mica schists and subordinate sillimanite gneisses, with local intercalations of impure quartzite. The lithologies of the Dete-Kamativi Inlier correspond in great detail with those of the Deweras, Lomagundi and Piriwiri groups, with which they are correlated. The Magondi Supergroup may also be correlated with sequences in eastern Zambia and adjacent parts of Mozambique and Malawi, and also with sequences in Botswana and the northern Cape Province of South Africa.

The Deweras Group was deposited in rift-related continental alluvial fan, braided stream, playa flat, playa lake and volcanic environments. The lithological sequence of the Lomagundi Group is characteristic of marginal marine and shallow shelf settings. The Piriwiri Group was deposited in deep euxinic waters, possibly in continental slope, submarine fan and abyssal plain environments. Volcanogenic hydrothermal emanations on the sea floor may have given rise to the abundant cherts, manganese-rich beds, and minor iron-formations. The Lomagundi and Piriwiri groups resulted from a marine transgression over the continental sediments of the Deweras Group, and represent the thermal subsidence phase of the developing Magondi rift basin. The intermediate to felsic volcanic and pyroclastic rocks of the Lomagundi and Piriwiri Groups were inputs into the basin from a contemporaneous magmatic arc to the west, represented by granodioritic intrusions in the Dete-Kamativi and Kariba areas, as well as the calc-alkaline plutonic rocks of the Zambian basement.

A plausible tectonic environment in which the Magondi Basin could have developed, is in a transtensional continental back-arc setting behind an Andean-type magmatic arc located to the west. In this setting, back-arc rifting is related to plume generation above a subducted oceanic slab, and if the rifting proceeds to an advanced stage, this leads to the generation of a marginal oceanic basin. In the case of the Deweras Group, the rifting did not proceed beyond a thinning of the continental crust, and the rift basin was floored by continental crust at all times. A continental back-arc setting explains the asthenospheric upwelling responsible for the enriched Deweras volcanics, the subsequent limited amount of extension, coupled with a large amount of intermediate volcanic and pyroclastic inputs into the basin, and basin destruction and inversion soon after formation. The lack of advanced rifting is explained by the onset of the Magondi Orogeny, which followed soon after sedimentation of the Magondi Supergroup, most likely in response to collision of the magmatic arc with a continental mass to the west of it (Kasai-Congo craton), after consumption by subduction of the intervening oceanic crust. The arc terrane overrode the western part of the Magondi Basin, producing granulite facies metamorphism, and caused easterly-directed thrusting of the basin sequences onto the adjacent Zimbabwe Archaean craton.

The mineralization of the Magondi Supergroup occurred at various times in the history of the basin. Iron-formations and cherty manganiferous horizons were probably formed by syngenetic exhalations. Stratabound sediment-hosted Cu-Ag-(Au-Pt-Pd-U) mineralization in the Deweras Group (Mangula, Norah, Shackleton/Avondale and Angwa mines), and the Cu-Ag mineralization of the Shamrocke Mine in the Lomagundi Group, was formed diagenetically by saline basin brines. The major Sanyati stratiform Zn-Pb-Cu-Fe-Ag massive sulphide deposits in the Piriwiri Group were probably "sedimentary exhalative" deposits which formed diagenetically during basin evolution. Minor Cu-Au occurrences of the "Piriwiri mineral belt" are related to the intermediate volcanics and pyroclastic rocks in the Piriwiri Group. The Cu deposits of the Gwaai River mine and other prospects in the Malaputese Group, the Silverside Mine in the Deweras Group, and the Alaska Mine in the Lomagundi Group, are vein and stratabound metamorphogenic deposits formed syntectonically during the Magondi Orogeny. Other metamorphogenic mineral deposits formed during the Magondi Orogeny include the graphite, kyanite and minor gold deposits of the Piriwiri Group. Tin-tungsten mineralization in the Kamativi area occurred late in the Irumide cycle, while the muscovite- and semi-precious stone-bearing pegmatites of the Mwami area are related to granitoids intruded into Piriwiri schists during the Pan-African Zambezi Orogeny.

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INTRODUCTION

The Magondi Supergroup is a mainly metasedimentary succession, with minor mafic and intermediate to felsic metavolcanics, which is found in the early Proterozoic Magondi Mobile Belt of western Zimbabwe (Figs. 1 and 2). It is subdivided into the Deweras, Lomagundi and Piriwiri Groups, which were deposited between c.2.16 and 2.0 Ga (Pb-Pb, Rb-Sr). In addition, lithologies of the Dete-Kamativi Inlier of NW Zimbabwe are also part of the Magondi Supergroup. The early Proterozoic rocks of the Magondi Belt, formerly grouped under the "Lomagundi System", outcrop in the northwestern part of Zimbabwe, and are bounded to the north and west by the Zambezi rift valley, in the east by the granite-greenstone terrane of the Zimbabwe Craton, and in the south they disappear under Mesozoic and Cenozoic cover until they reappear to the southwest in the Dete-Kamativi Inlier (Fig. 1). The Magondi Supergroup was deformed into a thin- and thick-skinned fold-thrust belt and metamorphosed from greenschist to granulite facies during the c.2,0-1,8 Ga (Rb-Sr, K-Ar) Magondi Orogeny, and was also affected by the Irumide and Pan-African Zambezi orogenies. The rocks of the Magondi Supergroup are host to a large variety of economically important mineral deposits, including base metals (Cu, Zn, Pb, Sn, W, Ta, Nb, Fe, Mn, Mo, U), precious metals (Ag, Au, Pt, Pd), industrial minerals (muscovite mica, beryl, graphite, kyanite, dolomite), and gemstones (aquamarine, tourmaline, euclase, garnet, topaz), which were formed at various times during a complex geological history. A proper appreciation of the tectonic setting, and the stratigraphic, sedimentological and structural history of the Magondi Supergroup in the Magondi Mobile Belt, is essential for understanding the processes of crustal evolution and continental assembly of Central and Southern Africa in the early Proterozoic.

PREVIOUS WORK

The "Lomagundi System" was originally defined by Molyneux (1919). The subsequent evolution of stratigraphic nomenclature has been quite complex, with new schemes being proposed by virtually everyone who has mapped the "Lomagundi System". Various stratigraphic subdivisions have been discussed by J.B.E.Jacobsen (1962), Stagman et al. (1964), W.B.G.Jacobsen (1969), Thole (1974), Tennick and Phaup (1976), Newham (1986), and Leyshon and Tennick (1988). Much stratigraphic confusion has resulted from an inadequate understanding of the complex structural relationships, coupled with the lack of exposures in critical areas. This led Lightfoot (1928a) to talk about the "Lomagundi Puzzle", a theme that was taken up by Haughton (1969). Following the recommendations of Bliss (1968), the Geological Survey adopted a lithostratigraphic approach to stratigraphic subdivision of the former "Lomagundi System", which was composed of the Deweras, Lomagundi and Piriwiri Groups (Fig. 2). The term "Magondi Supergroup" was coined by Treloar (1988) and Leyshon and Tennick (1988) to encompass the three abovementioned groups, and this terminology is retained here. In addition, the Malaputese, Inyantue, Kamativi and Tshontanda Formations of the Dete-Kamativi Inlier (Fig. 1) are also here regarded as being part of the Magondi Supergroup. The basin in which the rocks of the Magondi Supergroup were deposited has long been informally referred to as the "Lomagundi basin". In view of the now restricted application of the name "Lomagundi" to the Lomagundi Group, it is here proposed that the name "Magondi Basin" be used instead.

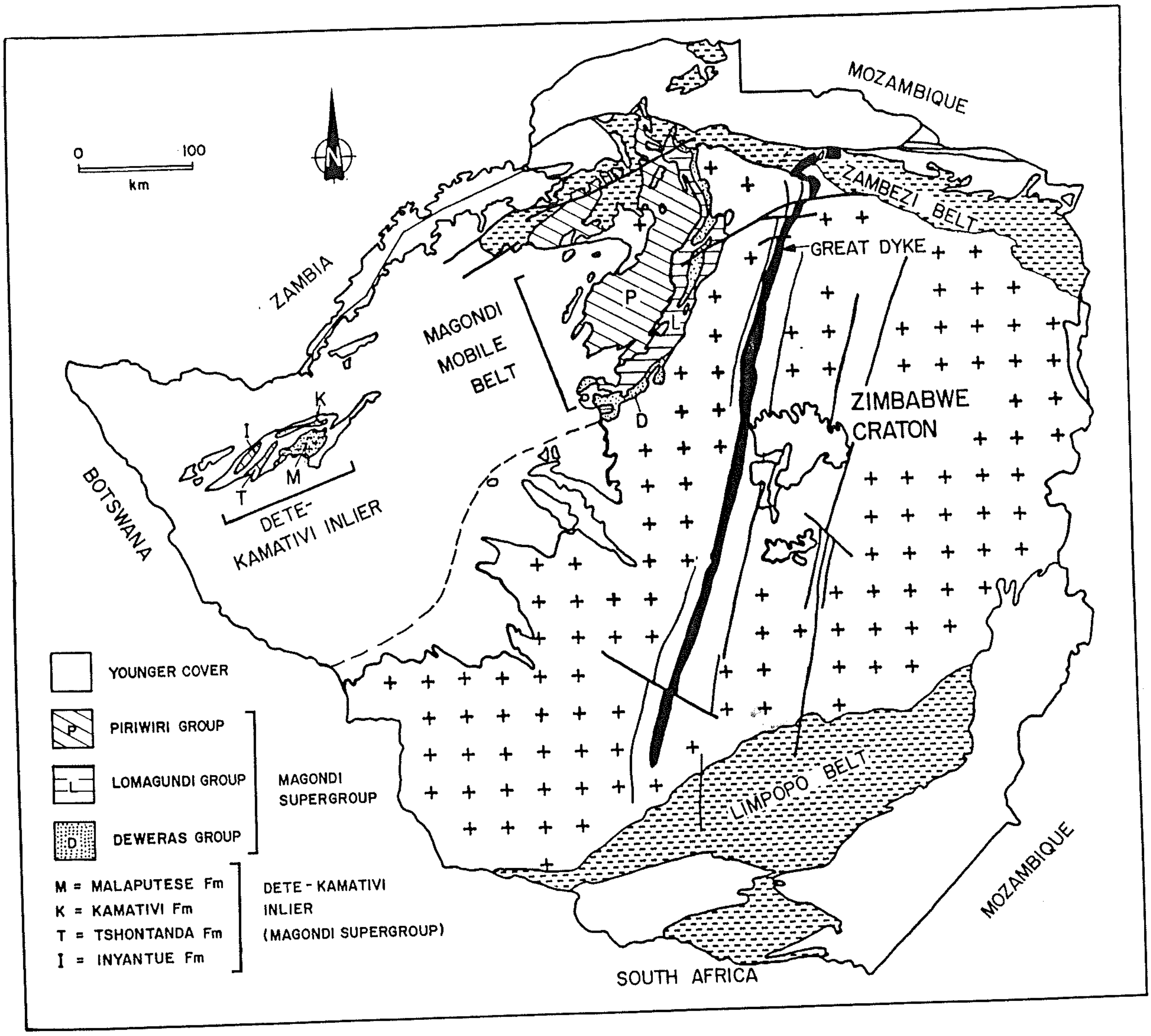


Figure 1: *General map of Zimbabwe, showing the Magondi Mobile Belt in relation to the Archaean Zimbabwe Craton and the Limpopo and Zambezi Mobile Belts. Note the fracture system on the Zimbabwe Craton, occupied by the Great Dyke and its satellite intrusions, which is parallel to the trend of the autochthonous Deweras Group in the Magondi Basin.*

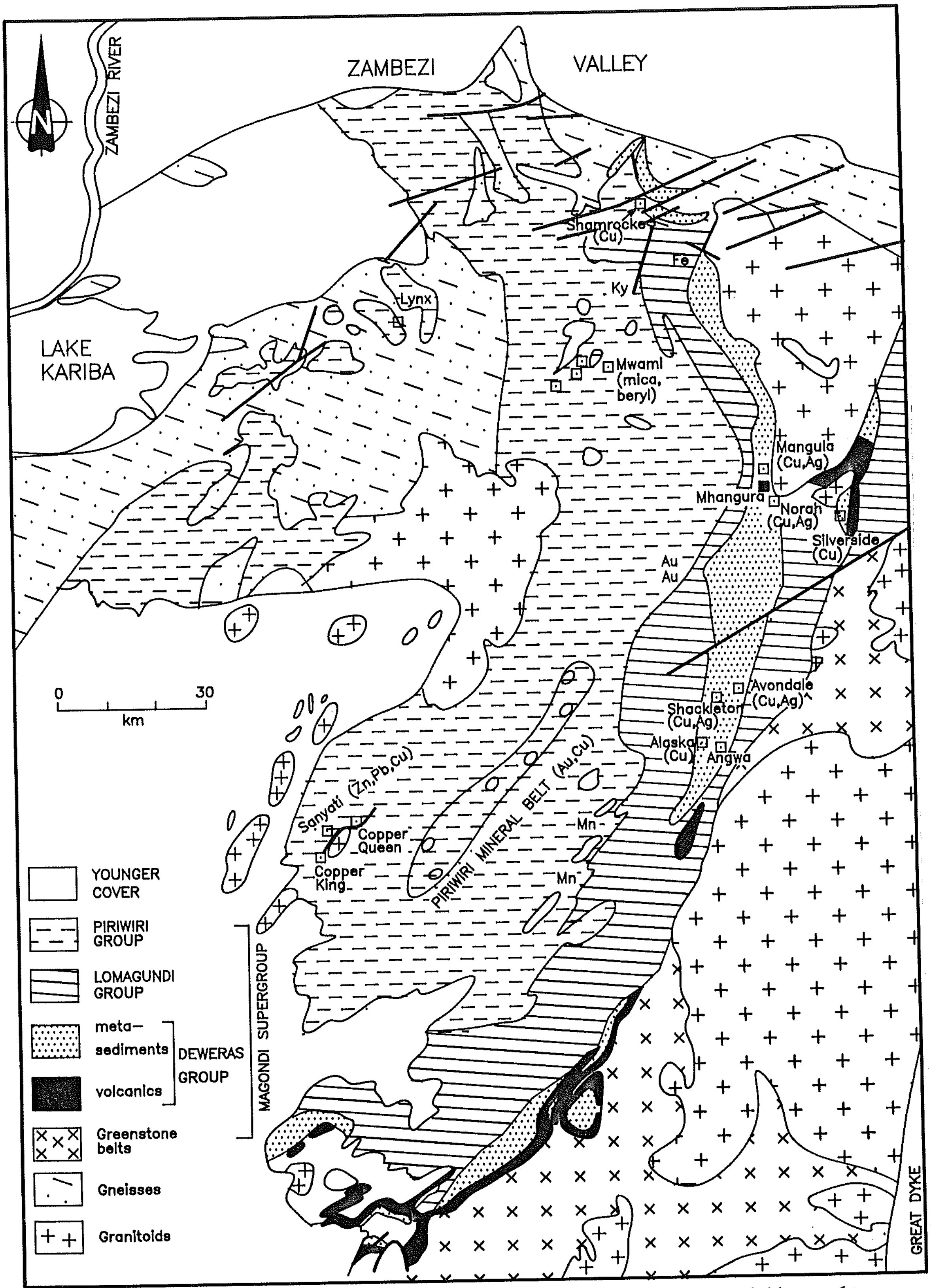


Figure 2: Detailed map of the northern part of the Magondi Mobile Belt, showing main lithostratigraphic units and the location of the principal mines and mineral deposits hosted by rocks of the Magondi Supergroup.

Mapping of the rocks of the Magondi Basin was initiated by the Geological Survey in the late 1910's. The first description of these rocks was by Molyneux (1919, 1922) and Maufe et al. (1923). The area around Mangula Mine was first mapped by Macgregor in 1931. The Deweras Group was defined by Phaup and Dobell (1938) from the type locality in the Mupfure (Umfuli) River area. Regional mapping of almost the entire outcrop area of the Magondi basin has subsequently been carried out by Stagman (1955, 1959, 1961a, 1962, 1964), Wiles (1961a,b), Leyshon (1969a,b), Bliss (1970), Kirkpatrick (1976), Tennick and Phaup (1976), Broderick (1976, 1980, 1981, 1982), Sutton (1979), and Fey and Broderick (1984). The results of their mapping are presented in Figure 2. Regional overviews on the geology of the Magondi area were given by Maufe (1938), Haughton (1969), Stagman (1978, 1981), Stowe (1983a) and Hartnady et al. (1985). The area north of Mhangura was mapped by Workman (1961) and by geologists of Rhodesian Copper Ventures (Rogers, 1963). This area is being remapped by the Geological Survey (Bartholomew, in prep.; Hahn et al., in prep.). The area around Shamrocke Mine was mapped by geologists of Rand Mines (Bichard, 1961), by Kyle (1972) and by Thole (1974), and has been remapped by Fey and Broderick (1984; in press). Jacobsen (1962) mapped a large portion of the Magondi Basin, but his ideas on stratigraphy (Jacobsen, 1964) were challenged by all the other workers in the area (Stagman et al., 1964). The stratigraphy and sedimentology of the Deweras Group has been discussed by Bliss and Tennick (1964), Bliss (1965, 1971), Tennick and Phaup (1976), Sutton (1979), Cooper (1978), Master (1984, 1989a,b, 1991) and Master et al. (1985). Jacobsen (1969) and Hahn et al. (in prep.) have re-interpreted the stratigraphy of the area around Silverside Mine. Rocks of the Sijarira Group in the Urungwe Klippe area were mapped by Stagman (1962), Harper (1970) and Mann (1970, 1979), and their significance assessed by Shackleton et al. (1966) and Schidlowski et al. (1976).

Aspects of the metamorphism of the rocks of the Magondi Basin have been described by Workman and Cowperthwaite (1963), Wiles (1961a,b; 1964), Workman (1966), Vail (1966, 1968), Harper (1973), Cheshire (1976), Treloar (1986, 1988), Treloar and Kramers (1989) and Munyanyiwa et al. (1990a,b). Structural studies of selected areas have been made by Leyshon (1969b, 1973), Stowe (1978) and Master (1989c). Small areas have been mapped in detail by Rowlands (1964), Stidolph (1964), Stocklmayer (1964), Ireland (1965), Lee (1965), Shoko (1985), Vinyu (1985), Mugumbate (1987), Mundondo (1987), Revitt (1987) and Wills (1987). Regional syntheses on structure and metamorphism of the area have been published by Treloar (1988) and Leyshon and Tennick (1988). Geochronological studies on rocks from the Magondi Basin have been carried out by Wilson et al. (1954), Vail and Dodson (1969), Clifford et al. (1967), Vail et al. (1968), Vail and Snelling (1971), Thole and Robinson (1976), Treloar and Kramers (1989), Master et al. (1989), Master (1991) and Höhndorf et al. (in prep.). Recalculated ages using modern decay constants are listed in Cahen et al. (1984). Isotopic studies of Lomagundi schists and carbonates were done by Eichmann and Schidlowski (1975), Junge et al. (1975) and Schidlowski et al. (1975, 1976), and preliminary accounts of Deweras and Lomagundi carbonates and evaporites were reported by Master (1987) and Master et al. (1990).

Regional metallogeny has been discussed by Jacobsen (1965a,b) and Newham (1986). The copper-silver deposits of the Magondi Basin, here named the "Magondi Copperbelt", have been studied or discussed by Brackenbury (1906), Molyneaux (1919), Maufe et al. (1923), Macgregor (1931), Ostle and Taylor (1954), Tyndale-Biscoe and Stagman (1958), Anon (1960, 1961, 1962a,b. 1967), Stagman (1959, 1960), Viljoen (1961, 1962), Dechow and Jensen (1962), J.B.E. Jacobsen (1962, 1964, 1965a,b), W.B.G. Jacobsen (1963, 1964, 1965, 1969), Garlick and Green (1965), Kyle (1974), Thole (1974, 1976), Thole and Robinson (1976), Kirkpatrick (1976), Tennick and Phaup (1976), Anhaeusser and Button (1976), Cooper (1977), Mallenson (1978), Von Rahden and De Wet (1975a,b, 1984), Tsomondo (1980), O'Shann (1981), King (1982), Maiden et al. (1984, 1986a,b,c), Walters (1984), Newham (1986), Maiden and Master (1986a,b), Master and Maiden (1986a,b), Master and Tredoux (1987), Matanga (1987), Muchenje (1987), Mapeto (1988), Master (1984, 1986a,b, 1988, 1989a,b, 1990a,b, 1991), and Master et al. (1989, 1990). Geobotanical investigations, comparing soil copper contents with tree and shrub distribution, have been carried out at Mangula Mine (Jacobsen, 1967), and at Silverside Mine (Jacobsen, 1968; Howard-Williams, 1968; Wild, 1969). Deposits of minerals other than copper (mica, graphite, kyanite, manganese, tungsten, lead-zinc, gold) have been described by Maufe (1920), Wiles and Tatham (1962), Muchemwa (1987), Workman and Cowperthwaite (1963), Harrison (1972), Cunningham et al. (1973), Bahnemann (1957, 1961), Horrell Clark (1964), Nutt (1984, 1987), Kalbskopf and Nutt (1986), and Nutt and Carr (1988).

Despite the large amount of work that has been done in the past 70 years or so, there has been no detailed synthesis of the stratigraphy and sedimentology of the Magondi Supergroup, and no serious attempt to work out its plate-tectonic setting in a broad regional context. The most recent reviews on the Magondi belt by Treloar (1988) and Leyshon and Tennick (1988) deal mainly with the deformation and metamorphism suffered by these rocks during the Magondi Orogeny. Treloar (1988) did not examine the broader regional context of the Magondi Orogeny and how it related to plate tectonics at that time. Leyshon and Tennick (1988) concluded that the Magondi Orogeny was entirely ensialic, and that there was no evidence of modern-style plate-tectonic processes having taken place. This conclusion was disputed by Stowe (1989, 1990). The present review, dealing with the stratigraphy, sedimentology, tectonic setting and mineralization of the Magondi Supergroup, is intended to be exhaustive in its scope, putting together for the first time a large amount of information from all available published and unpublished sources since the earliest work began. The reference list is thus the most complete bibliography to date on the geology of the Magondi Mobile Belt.

GEOCHRONOLOGY

The general geochronological framework of the Magondi Supergroup has been discussed by Vail et al. (1968), Cahen et al. (1984), Leyshon and Tennick, (1988) and Treloar (1988). The only dating from the Deweras Group is a whole-rock Rb-Sr isochron age obtained on Deweras lavas. This age, obtained by A.Höhndorf (unpubl. data, 1985; T.J.Broderick, pers.comm., 1985), was initially reported as between 2170 ± 100 Ma and 2150 ± 100 Ma (Treloar, 1988; Leyshon and Tennick, 1988; Master, 1989b). However, after rejecting certain anomalous points from altered lavas, a new regression of the data has yielded an age of 2060 ± 100 Ma (J.D.Kramers, pers.comm., 1989; Höhndorf et al., in prep.), which is the currently accepted age of the Deweras Group.

Galenas from the Copper Queen massive sulphide deposit in the Piriwiri Group have yielded model ages of c.2,1 Ga (J.D.Kramers, pers. comm. to Treloar, 1988), which is taken as the age of sedimentation. Since the Piriwiri Group is regarded as the facies equivalent of the Lomagundi

Group, which overlies the Deweras Group unconformably (Leyshon and Tennick, 1988), it implies that the Deweras Group is at least 2,1 Ga old. Therefore, taking the errors on the Rb-Sr whole-rock age into consideration, the age of the Deweras Group is likely to be between 2160 and 2100 Ma.

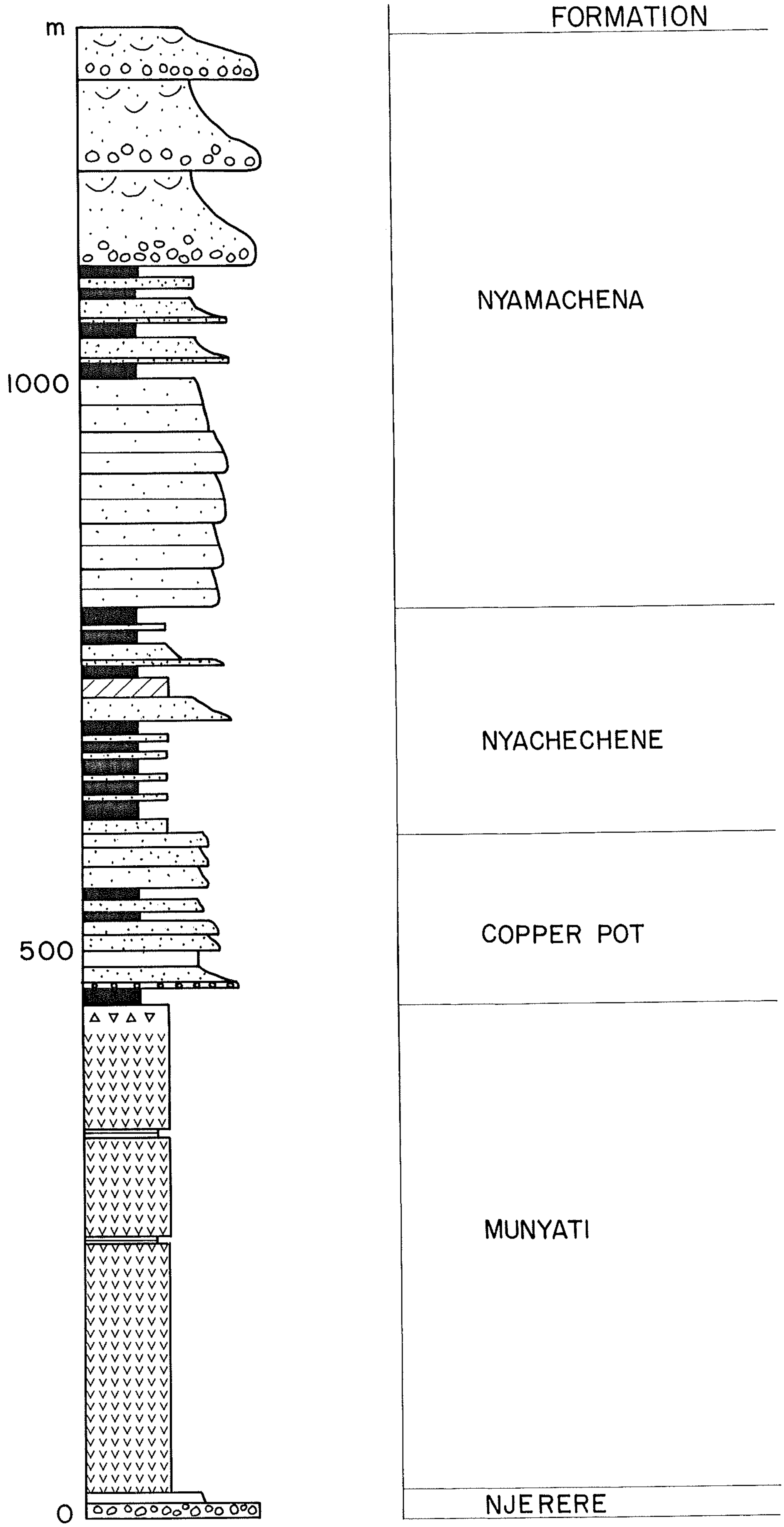
Rb-Sr whole rock ages of 1890 ± 260 Ma and 1780 ± 280 Ma, obtained from Piriwiri granulites, record the high-grade peak of the Magondi Orogeny (Treloar, 1988; Treloar and Kramers, 1989). Vail et al. (1968) obtained comparable K/Ar ages from Piriwiri phyllites (1753 ± 65 Ma, 1659 ± 50 Ma), and from Lomagundi Group Striped Slates (1905 ± 70 Ma, 1974 ± 70 Ma). The deposition of the Magondi Supergroup thus occurred between 2,16-2,0 Ga, while the Magondi Orogeny occurred between c.2,0-1,75 Ga.

DEWERAS GROUP

The Deweras Group, which is a mainly arenaceous redbed sequence with subordinate mafic volcanics, was first defined by Phaup and Dobell (1938) in the Mupfure (Umfuli) River area. In the area around Chinhoyi, arkosic rocks were assigned to the "Angwa Plains Series" by Molyneux (1919). At Mhangura, the arkosic rocks were regarded as the basal part of the Lomagundi System by Macgregor (1931) and Stagman (1959). Subsequently, Stagman (1961a) placed the arkosic rocks in the Deweras Group, and this practice has been followed by the Geological Survey after the recognition of the unconformity between the arkosic rocks and the overlying Lomagundi Group. There are two main areas of outcrop of the Deweras Group, a southern area around the Munyati and Mupfure rivers, and a northern area stretching from south of Alaska to Shamrocke. The northerly outcrop area is subdivided here into the Central, Mhangura, and Northern areas. In addition, there is an outlier of Deweras Group rocks in the Silverside area 15 km ESE of Mhangura. The Deweras Group in the southern area was formerly subdivided into the "Lower Arenite", "Volcanic" and "Upper Arenite" Formations (Bliss, 1970; Sutton, 1979). In order to conform to internationally acceptable codes of stratigraphic nomenclature (SACS, 1980), the "Lower Arenite" and "Volcanic" Formations have been renamed (after their type localities) the Njerere and Munyati Formations respectively, and the "Upper Arenite Formation" has been subdivided into three separate formations, the Copper Pot, Nyachechene and Nyamachena Formations (Master, 1991) (Figure 3).

In the Mafungabusi area, Sutton (1979) recognised three subdivisions in what he termed the "Upper Arenaceous Formation". Different successions are present in two separate areas. In the east-central area of Sutton's map, the succession consists of a "Greywacke Member" (here renamed the Copper Pot Formation), followed by an "Argillite Member" (Nyachechene Formation) and an "Arkose Member" (Nyamachena Formation). In the northern part of Sutton's map area, the succession consists of a "Lithic Greywacke Member" (Copper Pot Formation) overlain by an "Arkosic Wacke Member" (Nyamachena Formation). The rocks of the Deweras Group overlying the Munyati Formation in the Kadoma area have been termed the "Arenaceous Formation" by Bliss (1970), who subdivided them into a "Lower Arkose", a "Middle Shale" and an "Upper Arkose". These subdivisions correspond to the "Greywacke Member", "Argillite Member" and "Arkose Member" that Sutton (1979) recognised in the Mafungabusi area. These subdivisions are also redesignated as the Copper Pot, Nyachechene and Nyamachena Formations, respectively. In the area north of the Mupfure

DEWERAS GROUP (Southern Facies)



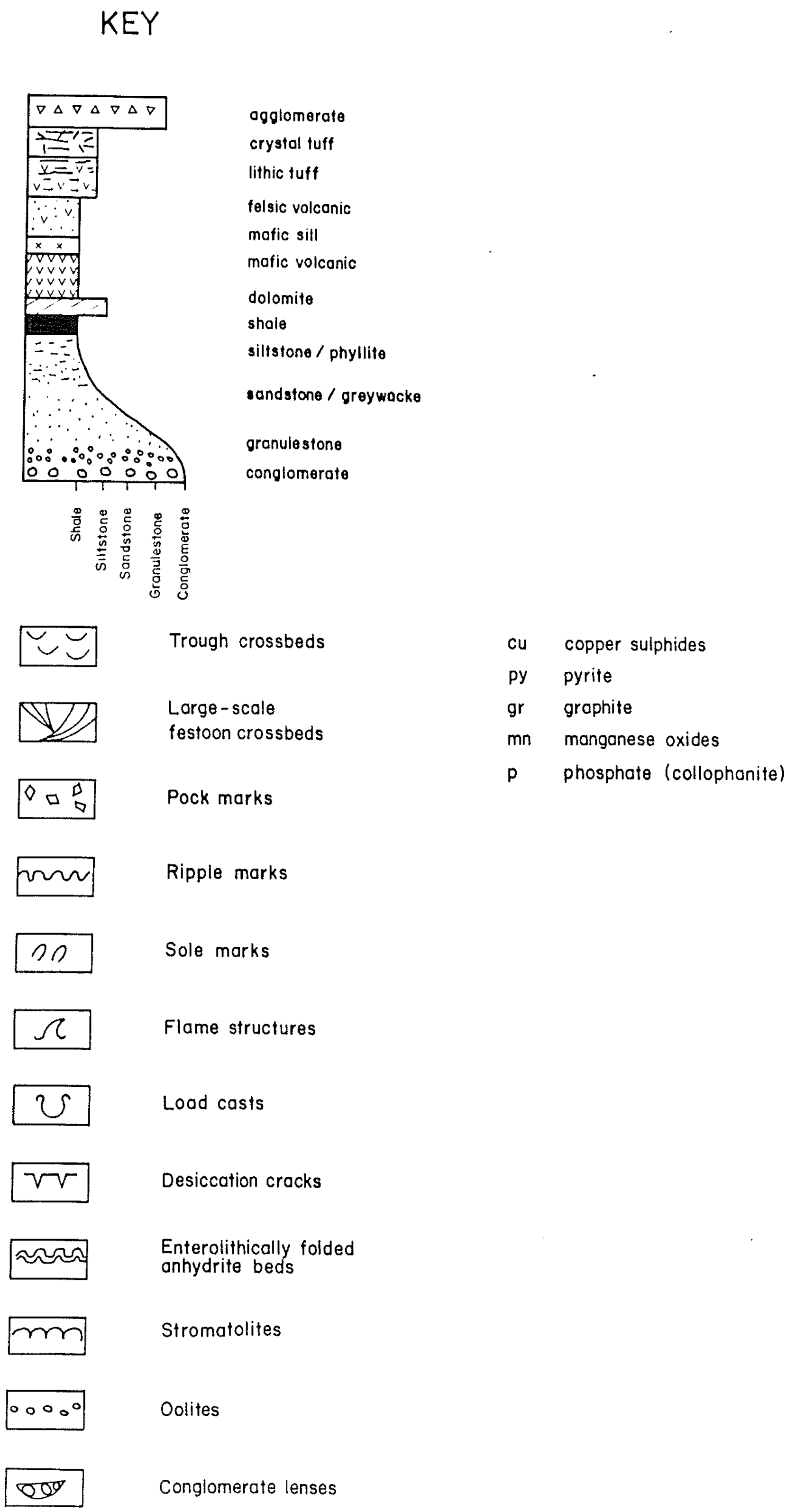


Figure 3: *Generalised lithostratigraphy of the southern part of the Deweras Group. Key the same for interpreting Figures 3, 4, 7, and 8.*

(Umfuli) River, the "Arenaceous Formation" and its subdivisions of Bliss (1970) were also recognised by Tennick and Phaup (1976). The "Arenaceous Formation" here consists of a persistent basal main conglomerate horizon (here assigned to the Copper Pot Formation), and a large thickness of medium-grained arkoses, shales and minor conglomerate bands (here assigned to the Nyamachena Formation).

STRATIGRAPHY

Southern Outcrop Belt

Njerere Formation

The Njerere Formation (formerly the Lower Arenaceous Formation) in the Mafungabusi area consists of an impersistent sequence of conglomerates, arkosic arenites, grits and interbedded silty mudstones, up to 20m thick, which overlie tonalites and andesitic lavas of the Archaean Basement Complex (Sutton, 1979). The conglomerate contains pebbles and cobbles of vein quartz and rare banded jaspilite from 2,5 to 10cm in diameter, in a matrix of green cherty material which is in part gritty in texture (Sutton, 1979). The arkoses and mudstones are pink or brown, and are red beds coloured by the presence of hematite. The Njerere Formation is impersistent, and is absent further north in the Kadoma area, where the volcanics of the Munyati Formation rest directly, with an angular unconformity, on Archaean rocks of the Basement Complex (Bliss, 1970).

Munyati Formation

In the Kadoma (Gatooma) area, the Munyati Formation (formerly the Volcanic Formation) is 300-600m thick, and consists of a single differentiated lava flow overlain by an agglomerate (Bliss, 1970). The lower portion of the flow consists of an ophitic-textured basalt, interpreted as a basal differentiate, which contains a few amygdales. The main part of the flow consists of porphyritic but non-ophitic basalt which passes upwards into massive or amygdaloidal and vesicular basalt. The lava displays well-developed columnar jointing, with the columns starting in the basal ophitic zone and continuing into the main part of the flow (Bliss, 1971). The agglomerate consists of rounded and sigmoidally shaped fragments of scoriaceous and amygdaloidal lava embedded in a fine-grained quartz-rich sedimentary matrix (Bliss., 1970). According to Bliss (1970), the lava is a tholeiitic basalt.

In the Mupfure (Umfuli) River area north of the area mapped by Bliss (1970), a similar subdivision of the Munyati Formation has been recognised (Tennick and Phaup, 1976). A basal ophitic lava is succeeded by a porphyritic phase followed by the main lava which is massive or amygdaloidal. Near the base of the main lava, pillow structures have been recognised (Phaup and Dobell, 1938; Tennick and Phaup, 1976). The agglomerate at the top of the sequence is only sporadically developed. In the type Munyati River area, Sutton (1979) also recognised the basal ophitic-textured differentiate, up to 150m thick, which passes upwards into porphyritic lava. However, Sutton (1979) described several lava flows, separated by interflow sediments, within the main lava overlying the porphyritic phase. The interflow sediments consist of haematite-speckled sericite and chlorite aggregates with rounded grains of quartz and microcline. The upper part of the Munyati Formation is rich in ropy, vesicular and frothy lavas. The agglomerate or volcanic breccia is also present at the top of the volcanics in this area, and consists of fragments of vesicular basalt up to 0,5m across. The composition of the lavas is that of tholeiitic basalts and andesites, according to Sutton (1979), but more extensive chemical analyses (Höhndorf et al., in prep.) show the volcanics to be sub-alkaline basalts. Prehnite, epidote, and chlorite are common constituents of the lavas and their vesicles, indicating a metamorphic grade in the prehnite-pumpellyite facies (Liou et al., 1983).

Copper Pot Formation

The basal beds of the Copper Pot Formation in the type Mafungabusi area consist of lateritic purple argillites overlying an extensive laterite, up to 3m thick, developed on the top of the underlying Munyati Formation. The argillites contain scattered dolomite rhombohedra, and in places incorporate quartz amygdales derived from the underlying lavas. Arenaceous rocks are sporadically developed in the basal beds, and consist of well-bedded gritty lithic wackes and quartz wackes with cherty fragments. The main part of the Copper Pot Formation consists of purplish medium-grained graded beds of greywacke consisting of quartz, plagioclase and lithic fragments up to 1cm across, set in a chlorite-sericite matrix. Argillite beds are commonly intercalated with the finer grained greywackes, and fragments of shale are incorporated in the coarser grained greywackes. In the northern area, the basal beds of the lithic greywackes of the Copper Pot Formation consist of boulder and cobble conglomerates interstratified with crossbedded grits, up to 150m thick. The conglomerates contain cobble-sized clasts of many Archaean basement lithologies, including felsic lavas, amphibole-porphyry felsites and tonalites, as well as spheroidally weathered Deweras lavas, set in a gritty matrix consisting of rock fragments. The conglomerates are overlain by medium to coarse grained greenish-grey lithic greywackes that contain rounded granite and felsite cobbles and occasional thin conglomerate lenses especially developed towards the base. The conglomerates and overlying lithic greywackes were deposited in proximal alluvial fan and braided stream environments, while the argillites and greywackes of the east-central area represent a facies change to more distal fan and playa-type environments (Sutton, 1979).

The Copper Pot Formation ("Lower Arkose") in the Kadoma area (Bliss, 1970) consists of conglomerate, arkose, sub-greywacke, and ferruginous quartzitic arkose. The conglomerate is generally massive and matrix-supported, with local stratification caused by grit bands. The clasts are mainly cobble sized with a high degree of rounding, and consist of granite, gneiss, Dewera basalt, Bulawayan greenstone, quartzite, and vein quartz. The matrix is sand sized with a distinctly gritty texture and green colour, and consist of fragments of granite and basalt with quartz and plagioclase grains. The impersistent conglomerate has a facies change to a coarse-grained sub-greywacke lithologically similar to the conglomerate matrix. The sub-greywacke is overlain by and changes laterally to a ferruginous purple-red quartzitic arkose. A succeeding grey arkose comprises arkoses and sub-greywackes with a few bands of intraformational breccia. The main conglomerate of the Copper Pot Formation in the Mupfure River area is matrix-supported and consists of cobble- and pebble-sized clasts of granite, gneiss, Deweras lava, Archaean greenstones, quartzite, and vein quartz (Tennick and Phaup, 1976). The matrix consists of sandy, arkosic material composed of quartz, feldspar, volcanic fragments, chert, quartzite, and chlorite.

Bliss (1965, 1970, 1971) suggested that the Copper Pot Formation conglomerate originated as a result of flash floods depositing unsorted material in an alluvial fan at the foot of an uplifted area. The succeeding shales and arkoses of the Nyachechene and Nyamachena Formations were deposited in shallow-water fluvial conditions alternating with periods of local emergence in a continental environment. The abundance of igneous and metamorphic quartz grains, vein quartz, granitic and felsic rock fragments all support the source as being the Basement Complex to the east. Bliss and Tennick (1964) suggested that much of the material was derived from a desert source. Fragments of basalt derived from the Munyati Formation are scarce except in the basal beds of the Arenaceous Formation, suggesting that the Deweras volcanics were only available for erosion in the early part of the cycle (Bliss, 1970).

The sequences of the Copper Pot, Nyachechene, and Nyamachena Formations in both the east-central and northern areas exhibit an upward increase in 'granitic' components, with better sorted, more mature arkoses; and a decrease in abundance of mafic fragments, especially those of Deweras lava. This is interpreted to reflect removal of a cover of Deweras volcanic rocks by sustained uplift and erosion exposing the granitic basement, resulting in an 'inverted stratigraphy' in the Deweras Group (Sutton, 1979).

Nyachechene Formation

The Nyachechene Formation in the east-central Mafungabusi area consists of a varied succession of steel-grey to mauve and purplish-red argillites interbedded with mudstones and greywacke-type siltstones and sandstones, as well as coarse grits which have numerous argillite fragments. There is a common development of thin, fine-grained, ripple-marked, impure arkosic quartzites. In one area there are thin beds up to 30cm thick of fine-grained pink dolomite interbedded among grey slates, together with silty argillites with thin grit bands and cross-bedded greywackes. These dolomites are highly enriched in 13C (Schidlowski et al., 1976; Master and Verhagen, unpubl. data), and are similar to the dolomites of the Norah Formation. In the interbedded shale/ laminated arkose/siltstone sequences, some common sedimentary features include complex diapiric structures, disruption of bedding, and sand-filled mudcracks (Sutton, 1979). The Nyachechene Formation represents playa-lake deposits in the centre of a basin bounded by alluvial fans (Sutton, 1979). The Nyachechene Formation ("Middle Shale") in the Kadoma area consists of grey-green and red fine-grained shales and siltstones (Bliss, 1970).

Nyamachena Formation

The Nyamachena Formation of the east-central area is divided into three zones, a lower arkose zone 200m thick, overlain by a mixed arkose and argillite zone 100m thick, overlain in turn by an upper conglomerate at least 210m thick. The lower zone arkose consists of a zone of flaky-bedded grey arkoses. The mixed arkose-argillite zone consists of mauvish flaggy-bedded gritty arkoses which contain thin argillite intercalations and a few beds of pebble conglomerate. These are overlain by purplish-pink, flaggy, gritty arkoses with purple siltstones and mudstones. The upper conglomerate zone forms the bulk of the Arkose Member, and consists of pinkish-purple, coarse-grained, cross-bedded arkosic grits with pebbly and cobbly horizons. Thin argillites up to 5m thick are developed in places. In the northern area, the Nyamachena Formation consists of pinkish granitoid arkosic wackes which, aside from their colour, are texturally similar to the underlying greenish-grey lithic wackes. The arkosic wackes are medium- to coarse-grained massive or cross-bedded rocks with occasional conglomerate lenses containing cobbles of pinkish-grey albite-leucotonalite. The Nyamachena Formation is interpreted to have been deposited in braided stream and alluvial fan environments (Sutton, 1979).

The arkoses of the Nyamachena Formation in the Mupfure area are typically cross-bedded, and some are ripple marked. Conglomerate similar to the main conglomerate is found interbedded with arkoses near the top of the succession. Tennick and Phaup (1976) interpreted the sedimentary depositional environment of the "Arenaceous Formation" to have been a relatively narrow, shallow-water depository in which rapid deposition took place of mechanically immature detritus from an arid, granitic source area. The Nyamachena Formation ("Upper Arkose") in the Kadoma area consists of a lower succession of ripple-marked, friable, red-flaggy arkoses, overlain by red, splintery, trough cross-bedded quartzitic arkoses (Bliss, 1970).

Northern Outcrop Belt

Central Area

The Central Area of the Deweras Group outcrop comprises the inliers exposed in the Mazongororo and Kamwa anticlinoria (Tennick and Phaup, 1976). The Kamwa anticlinorium contains most of the exposure, and stretches towards Mhangura for a length of about 62km (Stagman, 1961a). The Shackleton/ Avondale, Angwa and Hans mines, and various other copper prospects, are located within the Deweras Group rocks exposed in the Kamwa anticlinorium. The Deweras Group in this area, which consists of metasediments with an intercalated volcanic formation, has not been formally subdivided, and is described informally in the following sections. The lower arenites and carbonates are the equivalents of the Mangula and Norah Formations in the Mhangura area, while the volcanic formation and the upper arenites are the equivalents of the Suiwerspruit and Chimsenga Formations, respectively.

Lower arenites and carbonates

The lower arenites in the Central Area consist mainly of arkoses together with subordinate conglomerates and minor argillites and dolomitic beds (Mallenson, 1978; Tennick and Phaup, 1976; Cooper, 1977). The arkoses are generally medium-grained, massive, greyish to pinkish coloured, and are plane-bedded or trough crossbedded. The conglomerates vary from pebble bands to massive boulder conglomerates, and contain clasts of a variety of rock types, including granitoids, greenstones, metasediments, vein quartz, pegmatites, lavas and banded iron-formations (Tennick and Phaup, 1976).

Volcanic Formation

The most extensive (but poorly exposed) occurrences of the Volcanic Formation in the central area are in the core of the Mazongororo anticlinorium (Tennick and Phaup, 1976). The Volcanic Formation here consists mainly of sheared, schistose, carbonated and silicified greenstones, and appears to be stratigraphically higher than the volcanics in the southern area. Massive or amygdaloidal varieties are found occasionally. A dark green altered agglomerate with fragmental pyroclastic texture has been recorded (Tennick and Phaup, 1976).

Upper arenites

On the western limb of the Mazongororo anticlinorium, a sequence of rocks overlying the volcanics has been described by Tennick and Phaup (1976). The sequence consists of a 5m-thick band of dolomite, followed by a 45m-thick sequence of conglomerates with intercalated arenaceous bands, and a 300m-thick zone of mixed rock types including dolomites, calcareous sandy phyllites and narrow lenses of conglomerates. The conglomeratic unit resembles lithologies of the Mangula Formation, while the mixed unit resembles the Norah Formation.

Mhangura Area

The Deweras Group in the Mhangura area was first differentiated by Stagman (1959). The rocks were previously included in the Lomagundi System (Macgregor, 1931). Stagman (1959) did not recognise any subdivisions of the sedimentary rocks of the Deweras Group at Mhangura. Jacobsen (1963) differentiated the rock-types at Mangula and Norah mines into various units, but did not formally propose any stratigraphic subdivisions. Master (1984) grouped the lithologies at Mhangura into the Mangula and Norah Formations, which are separately mappable units with differing rock types and depositional environments. Master (1991) recognised two additional formations in the Mhangura area, the volcanic Suiwerspruit Formation and the sedimentary Chimsenga Formation (Figure 4).

Mangula Formation

The Mangula Formation, which comprises the lowermost portion of the Deweras Group at Mhangura, and unconformably overlies the Mangula Granite (Master et al.,1989; Master, 1991), is a clastic sedimentary sequence, up to 200m thick, which consists mainly of trough crossbedded and plane bedded meta-arkosic red-beds, together with conglomerates, wackes, argillites and a pelitic-matrix boulder conglomerate. The lithofacies are arranged in two upward-fining cycles or cyclothems, each commencing with rudites and granulestones at the base, followed upwards by arenites, siltites and calc-argillites.

The lithofacies of the Mangula Formation are typical of alluvial fan and braided stream environments (Miall, 1977; Master, 1984, 1989b, 1991). The vertical arrangement of facies, from coarse-grained conglomerates, through trough-crossbedded and plane-bedded arkosic arenites, to calc-argillites and wackes is indicative of a transgressive sequence going from proximal alluvial fan to medial fan to distal fan environments. The basinward migration of facies recorded in the vertical profile could have been produced by a relative lowering of the base level (eg. by continued block rotation following initial rift faulting), or by stream avulsion and fan switching (Master, 1991). The two stacked upward-fining cyclothems were probably sedimentary responses to resurgent faulting on the basin margins. The pelitic-matrix boulder conglomerate is a deposit of a debris-flow which coursed over the distal part of the alluvial fan, and which may have been trigerred by a flash flood or an earthquake.

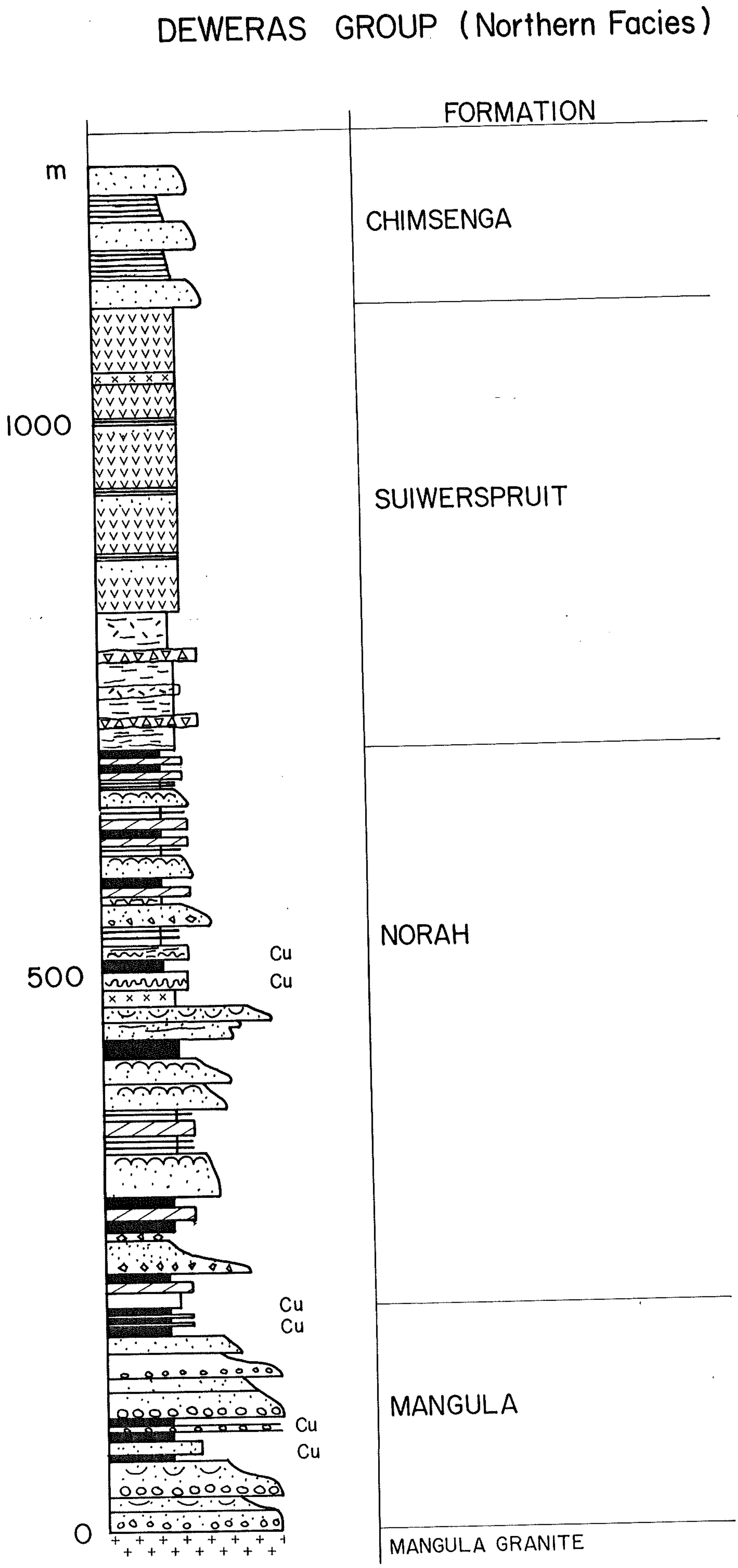


Figure 4: Generalised lithostratigraphy of the northern part of the Deweras Group.

Norah Formation

The Norah Formation, defined by Master (1984, 1991), comprises a sequence of clastic and chemical metasedimentary rocks, up to 500m thick. It consists mainly of thinly bedded anhydrite-bearing dolomites and argillites with interbeds of pink graded-bedded and ripple-marked arkosic arenites. The impersistent Norah Orebody Subformation, found intercalated with the dolomitic argillites, consists of pink gritty to conglomeratic trough crossbedded and plane bedded arkosic granulestones overlain by grey reduced plane bedded chloritic quartz wackes and chlorite-calcite schists with thin interbedded evaporitic beds consisting of anhydrite, barite, celestite, chlorite, tourmaline and copper sulphides. The evaporite beds of the Norah Formation are the oldest preserved evaporites in Africa, and are among the oldest in the world (Master, 1990c). The carbonate rocks of the Norah Formation are among the most isotopically anomalous carbonates in the world in terms of 13C, with an average del 13C value of +11.15 permil PDB, n=23 (Master et al., 1990). The rocks of the Norah Formation were deposited in playa flat and playa lake environments (Master, 1989b, 1990b, 1991), and are regarded as the correlatives of the Nyachechene Formation ("Argillite Member" of the "Upper Arenaceous Formation"; Sutton, 1979) in the southern part of the basin.

The lithofacies of the Norah Formation are representative of distal alluvial plain, playa flat and playa lake environments (Master, 1984, 1989a). The graded arenite units are interpreted as having been deposited by unchannelised sheet floods, coming off alluvial fan aprons, which coursed over exposed evaporitic playa mudflats, and in the process incorporating rip-up clasts of curled and dessicated flakes of the underlying argillite and dolomite. The ripple-marked arkoses are interpreted as having been deposited on the shores of a playa lake which occupied the lowest and most distal part of the depository. The trough-crossbedded granulestone was deposited in a distal braided stream which regressed over the playa mudflat, and which may have fed the playa lake which then filled up and transgressed over the mudflat (Master, 1989a). The chloritic quartz wackes, together with laminated carbonate and anhydrite beds, were deposited within the playa lake. In contrast to the red, oxidised nature of the ripple-marked and trough-crossbedded arenites, the chloritic quartz wackes and chlorite-calcite schists are green and reduced, as indicated by the presence of graphite, magnetite and pyrite. They are thus interpreted as having been deposited in the reducing bottom waters (hypolimnion) of a stratified organic-rich playa lake. A similar environmental setting has been proposed for the mineralized organic-rich greywackes at Mufulira Mine, Zambia (Clemmey, 1978). When the playa lake shrank again, the playa mudflat regressed over the lacustrine wackes and evaporites. The thin lava flow found interbedded with the Upper Multicoloured Schist Member of the Norah Formation is the first indication of the volcanism represented by the Suiwerspruit Formation.

Suiwerspruit Formation

Until very recently, the volcanic formation of the Deweras Group was thought to be absent at Mhangura. However, in January 1990, a thick, vertically dipping succession of mafic volcanics and pyroclastics was recognised in Borehole N44, drilled on Suiwerspruit Farm, 2km west of Mhangura. The volcanics in this borehole are stratigraphically above the Norah Formation, and are here called the Suiwerspruit Formation. They consist of a series of mafic lava flows separated by thin interflow sediments (at least 142m thick in borehole; probably 470m thick in total), which overlie a mafic pyroclastic sequence of tuffs, volcaniclastics and agglomerates, about 130m thick. The pyroclastic rocks are strongly cleaved chlorite schists, and include ash-fall lithic tuffs, plagioclase crystal tuffs, and lapilli tuffs. The mafic lavas are intruded by some blastophitic-textured dolerite intrusives with chilled margins. Both lavas and intrusives contain altered clumps of plagioclase phenocrysts pseudomorphed by epidote and albite (blastoglomeroporphyritic texture). A common magma for both the lavas and intrusives is thereby implied, with the intrusives possibly being high-level subvolcanic sills intruded into the lava pile. The volcanics and pyroclastics intersected in Borehole N44 occupy a position that is shown on Stagman's (1959) map as "doleritic rocks". This original identification was based entirely on soil colour, since there are no outcrops. Stagman (1959) shows a band of "dolerite", up to 600m thick, stretching northwards from Mhangura towards the Umboe Claims, for a distance of about 16km. Most of this basic material is likely to be volcanics of the Suiwerspruit Formation rather than mafic dykes. The Suiwerspruit Formation at Mhangura corresponds in stratigraphic position to the Volcanic Formation around the Angwa and Hans mines in the Alaska area, and is thus different from the volcanics at Silverside, which are at the base of the Deweras Group.

The Suiwerspruit Formation, with its basaltic lava flows, sub-volcanic metagabbroic sills, and pyroclastic rocks, represents the culmination of the ascent of an enriched asthenospheric mantle plume which was emplaced at a more advanced stage of rifting than is represented by the early volcanics of the Mupfure and Munyati areas.

Chimsenga Formation

The Chimsenga Formation consists of the poorly exposed arkoses that overlie the volcanics of the Suiwerspruit Formation. It forms the uppermost part of the Deweras Group around Mhangura. The only exposures of these rocks are in the Chimsenga River drainage area about 10 km north of Mhangura (Macgregor, 1931; Stagman, 1959). The lithologies consist of white fine- to medium-grained arkoses (e.g. in the vicinity of Umboe Claims), and well-bedded pelites and siltites which form coarse-grained slaty phyllites (e.g. about 1 km S of Chimsenga drift; Macgregor, 1931). No petrographic or sedimentological work has been done on these rocks, but they seem to resemble the distal rocks of the Norah Formation, rather than the coarser-grained proximal rocks of the Mangula Formation. Because of complicated folding and poor exposure, it has not been possible to estimate the thickness of the Chimsenga Formation. The Chimsenga Formation represents renewed sedimentation after the cessation of volcanism, possibly due to continued tectonism on the rift margins.

Basic intrusions

Basic intrusions in the form of dykes and sills are common in the Deweras Group at Mhangura, and consist of metadolerites (called "epidiorites" by Stagman, 1959). They are variably textured medium to coarse grained rocks, consisting of a typical greenschist-facies assemblage of albite, actinolite, chlorite, epidote, sphene and magnetite. Fine-grained chill zones to some of these intrusives contain aligned feldspar microlites and chlorite pseudomorphs after an idioblastic ferromagnesian mineral, probably olivine, set in a groundmass of skeletal magnetite and chlorite. A thin (20cm thick) fine-grained igneous rock, thought to be a lava flow, intersected in three surface boreholes at Norah Mine, exhibits the same textures and mineral assemblages as the chill zones of the dykes and sills, which may have been feeders to the volcanic Suiwerspruit Formation.

Silverside Area

Silverside Volcanic Formation

The Silverside Volcanic Formation in the Silverside area occurs at the base of the Deweras Group, and consists of sheared tholeiitic lavas which rest unconformably on steeply dipping amphibole schists and felsic schists of the Shamvaian Group (Stagman, 1959). There are several lava flows separated by impersistent interflow sediments consisting of pyritic quartz-sericite schists (Hahn et al., in prep.). The lavas have flat MORB-normalised trace element patterns, in contrast to the enriched patterns of the Deweras Group volcanics farther west (D.S.Bartholomew, pers.comm., 1989).

The lavas unconformably overlie folded Shamvaian rocks of the Chinhoyi Greenstone Belt, and are in turn unconformably overlain by the diamictites of the Deweras Group which transgress onto the Shamvaian rocks farther south. The Silverside Volcanic Formation is thus an unconformity-bounded sequence, and its correlation with the Deweras Group is only tentative, and unproven. The field relations, and the differences in chemistry between the Silverside volcanics and other volcanics in the Deweras Group suggest, instead, that the Silverside lavas may be older than the Deweras Group. They may be the only remnants of flood basalts that were the extrusive equivalents of the magmas that produced the Great Dyke.

Diamictite

At Silverside, a diamictite containing boulders and cobbles of various greenstone lithologies, including mafic and felsic volcanics, porphyries, banded ironstones, and granitic rocks, is developed with an unconformity on the Silverside Volcanic Formation. The diamictite, which is highly deformed, is matrix supported, with a chlorite- and quartz-rich matrix. It was interpreted by J.B.E. Jacobsen (1962) and W.B.G.Jacobsen (1969) as a glacial tillite, and by Newham (1986) as a volcanic agglomerate. Master (1986) considered it to be a debris flow deposit formed in an alluvial fan environment.

Dolomitic metasediments

Thinly bedded dolomites and argillites comprise the bulk of the sedimentary rocks in the Deweras Group at Silverside. The rocks closely resemble the playa flat and playa lake lithologies of the Norah Formation, with which they are correlated. An impersistent graphite schist horizon, about a metre thick, is found just south of the open pit at Silverside Mine.

Northern Area

The northernmost part of the Deweras Group outcrop is in the Shamrocke Mine area. Here the Deweras Group comprises a 2,2 km thick sequence of arkoses and arkosic grits with minor quartzites, mica schists, amphibolites and tremolite schists (Thole, 1974). The succession was divided by Thole (1974) into the three formations recognised by Bliss (1970) in the southern part of the basin, namely the "Basal Sedimentary", "Volcanic" and "Arenaceous" formations. Since the northern part of the Deweras Group has recently been remapped by Bartholomew (in prep.), the revised stratigraphic nomenclature awaits the publication of his bulletin.

Basal Sedimentary Formation

The "Basal Sedimentary Formation", although recognised further southeast by Workman (1961), does not occur as a mappable unit in the Shamrocke area (Thole, 1974). At one locality, Thole (1974) found conglomeratic arkoses and grits at the base of the Deweras Group, which he assigned to the Basal Sedimentary Formation. The pebbles in the conglomerate, up to 2cm in diameter, are composed of quartzite, vein quartz, arkose and granite, and are derived from the basement complex to the east (Thole, 1974).

Volcanic Formation

The only possible Deweras Group volcanic rocks in the Shamrocke area are tremolite schists which occur as conformable units up to 30m thick (Thole, 1974). The dark green tremolite schists, which consist of tremolite, minor plagioclase and opaque minerals, and ellipsoidal ocelli (deformed amygdales), are interpreted as metamorphosed picritic basalts (Thole, 1974). Other metabasic rocks in the area are amphibolites, most of which are cross-cutting, and interpreted as metadolerite dykes, though Thole (1974) suggested that some of them may have been basaltic lavas.

Arenaceous Formation

The "Arenaceous Formation" in the Shamrocke area is characterised by predominant massive to flaggy amd schistose arkoses, interbedded with narrow bands of grey, fine-grained massive quartzites, biotite and anthophyllite-tremolite-actinolite schists, and local conglomerates (Thole, 1974). There is a considerable lateral variation in composition and thickness of the beds over short distances. The schists represent metamorphosed pelites and calcareous siltstones.

VOLCANIC GEOCHEMISTRY AND PETROGENESIS

The Deweras volcanics have undergone greenschist facies metamorphism (Höhndorf et al., in prep.), and consequently may have suffered some allochemical changes in their whole-rock chemistries. The volcanics are therefore classified using their immobile trace elements (data from Höhndorf et al., in prep.; T.J.Broderick, pers.comm., 1985), according to the methods of Winchester and Floyd (1976, 1977), and plotted in Figure 5. The diagrams show that most of the Deweras volcanics can be classified as sub-alkaline basalts, with just a few analyses (8% of the total) plotting in the field of andesites. On a chondrite-normalised diagram, all the Deweras volcanics show an enrichment in LREE, with no significant Eu anomaly (Höhndorf et al.,in prep.). Although the Deweras volcanics have yielded whole-rock Rb-Sr and Pb-Pb ages of c.2 Ga, lavas from one locality have yielded a well-defined Sm-Nd isochron of 2,5 Ga, and similar Nd model ages prevail throughout the suite (Kramers et al., 1989). Kramers et al. (1989) discounted crustal contamination as a determining factor for these ages, and considered it likely that the Nd system dates the consolidation of the subcontinental lithosphere keel, coeval with

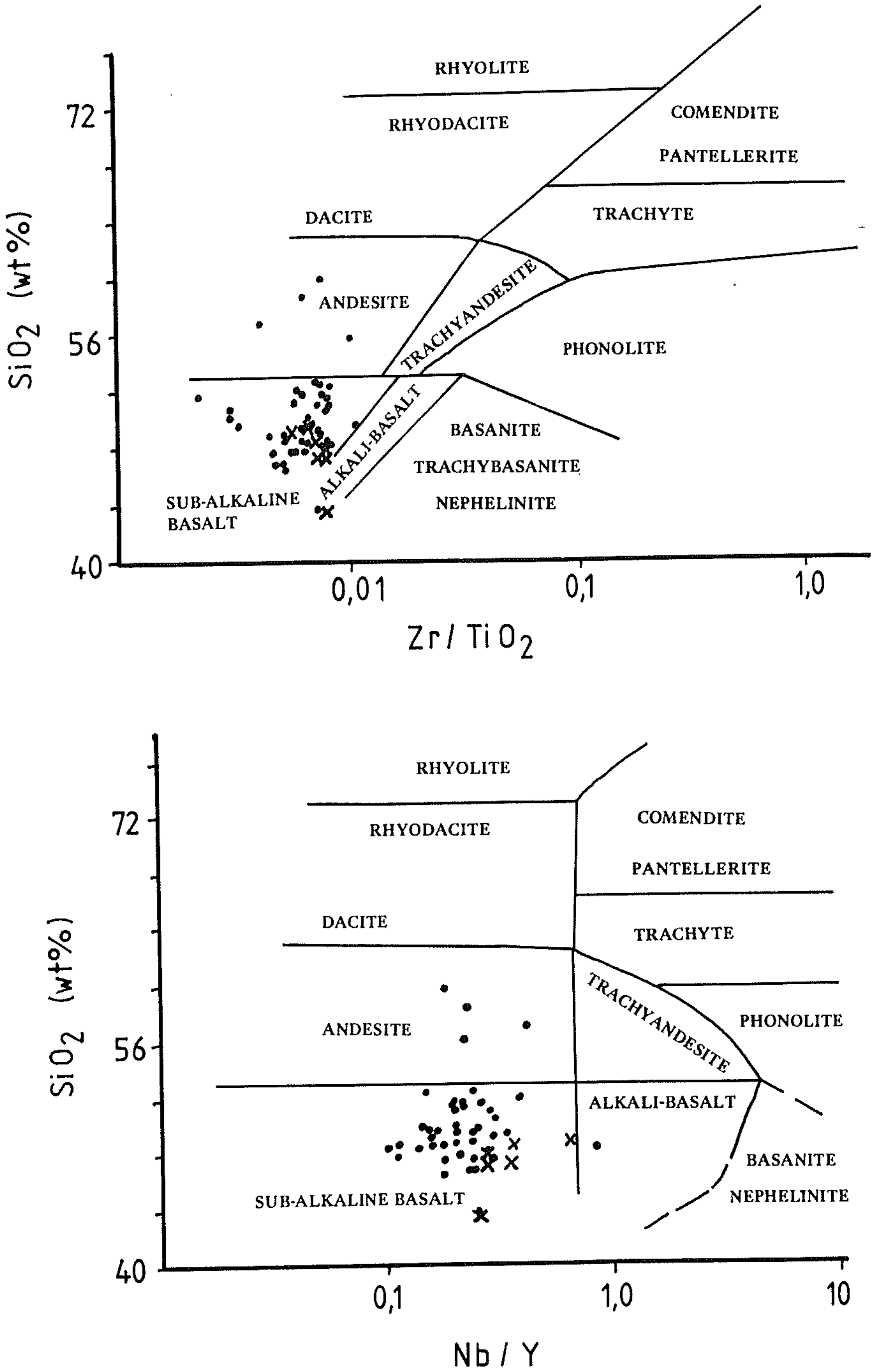


Figure 5: *(a) Zr/TiO_2 vs SiO_2 and (b) Nb/Y vs SiO_2 classification diagrams for volcanics (after Floyd and Winchester, 1977). The Deweras Group volcanics plot mainly in the field of subalkaline basalts. Lavas from the Munyati Formation in the southern outcrop belt are plotted as dots. Lavas from the Alaska area (Suiwerspruit Formation equivalents) in the northern outcrop belt are plotted as crosses.*

cratonization at the end of the Archaean. It is felt here that significant crustal contamination cannot be ruled out at this stage, since there is a considerable mantle-normalised enrichment in the light rare earth elements La and Ce (Fig. 6), and may include Sm and Nd.

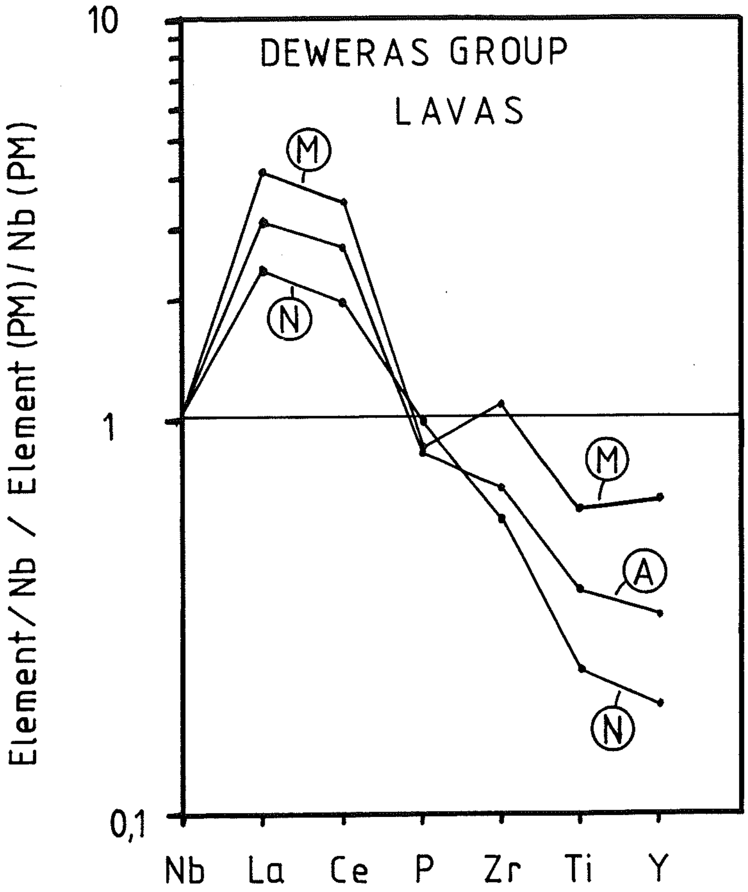


Figure 6: *Nb- and mantle-normalised immobile incompatible trace element spidergram for Deweras Group volcanics (after Myers et al., 1987). M = Munyati Formation lavas, A = Alaska lavas, N = lavas in Norah Formation. Note the extreme enrichment of La and Ce in all the volcanic suites.*

Myers et al. (1987) developed a niobium-normalised spidergram plot using the elements Nb, La, Ce, P, Zr, Ti and Y in order to fingerprint the source characteristics of volcanic suites on the Kaapvaal Craton in South Africa. These elements were chosen because they are all relatively immobile during alteration; because in the crust these elements are all held in refractory minerals and hence will not partition into the melt with small degrees of partial melting; and because they are all highly incompatible in basaltic magmas, and their ratios will be largely unaffected by fractionation of olivine, pyroxenes and plagioclase (Myers et al., 1987). In the spidergram plot of Myers et al. (1987), the elements are normalised against their concentrations in the "primordial mantle" of Wood et al. (1979), and are further normalised against the Nb values in the sample, in order to minimise the effects of variation produced by fractional crystallization (Myers and Breitkopf, 1989). Nb was chosen, because in extensive studies of oceanic basalts, the Nb/Zr ratio was shown to be an effective discriminant between enriched and depleted mantle sources. In their study of the South West Indian Ridge, Le Roex et al. (1983) were able to define a spectrum of compositions produced by mixing of two end-member source compositions, one depleted and the other enriched with respect to "primordial mantle", on a plot of Nb versus Zr. When plotted using the Myers et al. (1987) spidergram format, the enriched (plume) and depleted (normal MORB) end member compositions are clearly separated, with the transitional types occupying intermediate positions on the graph.

Volcanic suites from different tectonic settings, eg. calc-alkaline subduction-related magmatic arc volcanics, and rift-related continental alkaline volcanics, have different patterns on the spidergram plot, corresponding respectively to depleted and enriched source characteristics. Some continental alkaline volcanics are characterised by enrichment in La and Ce, which is generally ascribed to the effects of crustal contamination (Dupuy and Dostal, 1984). The Deweras Group volcanics are plotted on a Myers et al. (1987) spidergram in Figure 6. All the samples show a considerable enrichment in the light rare earth elements La and Ce, indicating a significant amount of crustal contamination. The patterns from Norah and Lion's Den show similarities with the enriched (plume-type) source of Le Roex et al. (1984), and with continental alkaline volcanics from Nigeria and Scotland (Myers et al., 1987). The patterns for the stratigraphically lower Mupfure and Munyati volcanics from the southern part of the basin, particularly the positive slope between P and Zr, and the flat slope between Ti and Y, are similar to the transitional-type MORB of Le Roex et al. (1984), as well as to some of the volcanics from the western Matchless Belt in Namibia (Breitkopf, 1989), produced by mixing of enriched plume material with more depleted mantle.

Whereas Kramers et al. (1989) and Höhndorf et al. (in prep.) interpret the source region of the Deweras volcanics, on the basis of Nd systematics, to be subcontinental lithospheric mantle formed at c.2,5 Ga, coeval with late Archaean cratonization, an alternative model is presented here which takes into account the temporal and stratigraphic variations in magma and source characteristics. From the primordial mantle- and Nb-normalised incompatible immobile trace element spidergram pattern for the Deweras volcanics (Fig. 6), it appears that there is a temporal evolution from an early transitional-MORB-type (partially enriched) mantle source region (Mupfure and Munyati lavas), to a later enriched (plume-type) mantle source region (Alaska and Norah lavas). The transitional-type source region is believed to be the subcontinental lithospheric keel that was formed in the late Archaean under the Zimbabwe craton, and the source for the old (2,5 Ga) Nd model ages found in some (not all) of the Deweras volcanics. This source region interacted and mixed with an enriched asthenospheric mantle plume, giving rise to the enriched Alaska and Norah lavas with disturbed Nd isotope systematics. In contrast to the situation in many pre-drift rift basins (East Africa, Brazil continental margin, Sardinia, California; Thompson et al., 1983; Fodor and Vetter, 1984), which do not have much crustal contamination and LREE-enrichment, the Deweras Group volcanics are considerably enriched in LREE. This implies considerable interaction of the mafic magmas with continental crust, through underplating and sill intrusion in the crust.

The sequence of events involved in the generation of the Deweras volcanics is inferred to be as follows: (i) early transtensional rifting influenced by the activity of an enriched mantle plume, which veined and mixed with a partially-depleted subcontinental mantle (produced by crust extraction in the late Archaean; Kramers, 1987), giving rise to transitional-type magmas which rose through continental crust, in the process of which they assimilated partial melts of continental crustal material leading to alkali and light rare earth element enrichment; and

(ii) with continued rifting, the influence of the mantle plume became dominant, and the magma source was more enriched. Although crustal contamination was still ongoing, the amount of La and Ce assimilation decreased with time, probably due to depletion during the early rifting.

STRUCTURE AND METAMORPHISM

The Deweras Group has been affected by at least three phases of deformation during the Magondi and Pan-African Zambezi orogenies. The last (Zambezi) deformation phase only affected the northern part of the basin, and has not been recognised further south. The earliest structural mapping was done by J.B.E.Jacobsen (1962) who found evidence for two phases of deformation. More detailed mapping by Bliss (1970) and Sutton (1979) also showed that the Deweras Group rocks have suffered two phases of deformation. In the Mafungabusi area in the south, Sutton (1979) found an early set of folds trending 065° to 055°, which were affected by crossfolds trending at 140°. The early folds have an axial planar cleavage, which is a slaty cleavage in argillaceous rocks, and a fracture cleavage in psammitic rocks. The metamorphic grade in the southern part of the basin is lower greenschist facies (quartz-muscovite-chlorite-albite subfacies), and the presence of prehnite in volcanics indicates a transition from prehnite-pumpellyite facies conditions. In the central part of the Deweras Group outcrop area, around Alaska, two deformations are recognised. An early 055o-trending fold set is affected by later 010o-trending folds. In the Mhangura area, Master (1984) found three phases of folding affecting the Deweras Group rocks, the third phase being E-W Zambezi crossfolding, which reversed the plunges of earlier N-S Magondian folds. Master (1991) showed that there may be a fourth (Irumide) deformation event which took place between the Magondi and Zambezi orogenic episodes. The metamorphic grades around Mhangura are of greenschist facies, and peaked with the incoming of biotite. Northwards from Mhangura, the metamorphic grades increase to amphibolite facies (Workman, 1966), and the intensity of the Zambezi deformation phase increases markedly (Thole, 1974, 1976; Fey and Broderick, 1984).

LOMAGUNDI GROUP

The Lomagundi Group overlies the Deweras Group unconformably, and in places also transgresses onto the Archaean basement (Stagman, 1961; Tennick and Phaup, 1976; Stowe, 1978). In some areas the contact between the two groups is a thrust (Sutton, 1978; Treloar, 1988). The Lomagundi Group consists of the Mcheka, Nyagari and Sakurgwe Formations (Fig. 7).

STRATIGRAPHY

Mcheka Formation

The Mcheka Formation is the lowermost unit of the Lomagundi Group, and was defined by Tennick and Phaup (1976). It overlies the Deweras Group unconformably, and in places it lies with a thrust contact on Archaean basement rocks. It comprises basal pebbly grits overlain by a lower dolomite, phyllites, quartzites, upper dolomite, and sandy argillites. Rocks equivalent to the Mcheka Formation were grouped under the "Sinoia Caves Formation" by Kirkpatrick (1976). This name is discarded because it is superfluous, and the name "Sinoia" has been changed to Chinhoyi. The dolomites of the Lomagundi Group are among the most

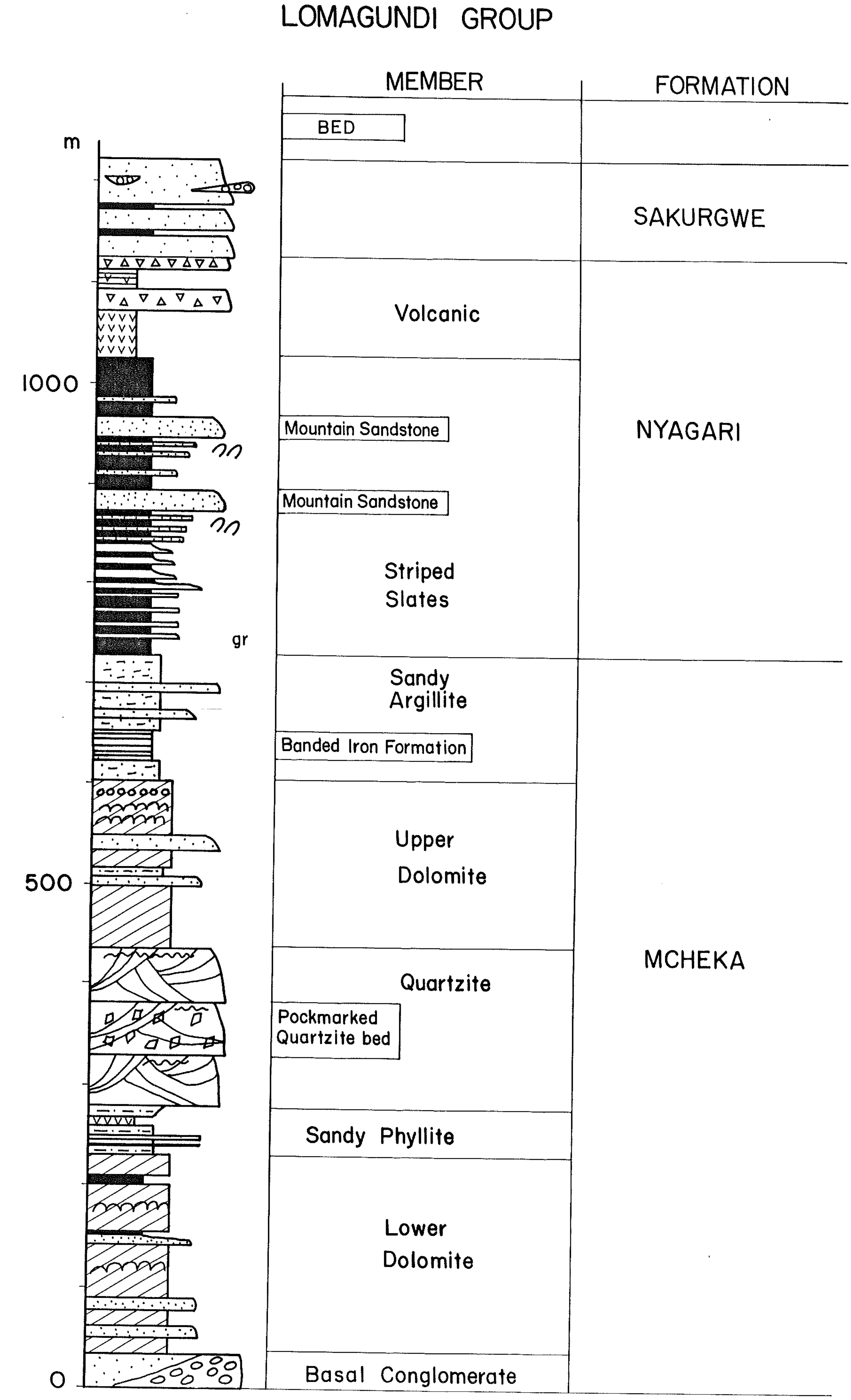


Figure 7: Generalised lithostratigraphy of the Lomagundi Group.

anomalous in the world in terms of carbon isotopes, having an average del 13C value of +8,2 permil PDB, n=67 (Schidlowski et al., 1975, 1976). Dolomites underlying the Karoo Supergroup have been intersected in a borehole in the Sawmills district NW of Bulawayo (Thompson, 1975). They have a similar 13C-enriched carbon isotope signature to the Lomagundi Group carbonates, and they have been correlated with the Mcheka Formation (Thompson, 1975).

Basal Conglomerate, Grit and Quartzite

The basal unit of the Mcheka Formation consists of a conglomerate (up to 30m thick) which changes laterally in places to a grit (granulestone) and a schistose quartzite. The conglomerate contains clasts of vein quartz, Deweras arkoses and lavas, quartzite, jaspilite, and a dark phyllitic schist (Tennick and Phaup, 1976; Stowe, 1978). Rare clasts of microsyenite have also been found (Stagman, 1961). The clasts indicate that the basal conglomerate of the Lomagundi Group was derived from the underlying Deweras Group, and from Archaean greenstone belt lithologies which outcrop to the east. According to Stagman (1961), there are thin bands of dolomite interbedded with the grits. These dolomite bands are indistinguishable from the main dolomite bands in the Mcheka Formation, and indicate an interfingering of facies in the gradation to the overlying Lower Dolomite.

Lower Dolomite

The Lower Dolomite is a mainly dolomitic unit (up to 200m thick) which is impersistent along strike. It consists of whitish-pink mottled dolomite, with thin argillaceous and arenaceous interbeds. Small domical stromatolites were noted by Stowe (1978).

Sandy Phyllites

The Sandy Phyllites overlie the Lower Dolomite horizon, and are typically pinkish-grey in colour with a schistose, sometimes sandy, texture (Tennick and Phaup, 1976). They vary from very fine grained schistose sericitic phyllonites, to coarser grained massive arkosic arenaceous varieties. There are rare lenses of iron-stained quartzite. Schistose pebble-conglomerates form narrow lenses within the sandy phyllites. They have a micaceous quartzo-feldspathic groundmass, and clasts composed of vein quartz, porphyry, granite, quartzite and plagioclase feldspar.

A very rare occurrence of haematitic lava interbedded with the sandy phyllites to the south of Nevada copper-lead prospect has been reported by Tennick and Phaup (1976). The weathered lava consists of feldspar phenocrysts completely altered to sericite and chlorite, set in an unresolvable groundmass of dendritic interlocking iron ore.

Pockmarked Quartzite

A thick quartzite unit is developed between the Sandy Phyllites and the Upper Dolomite. A lower and an upper undifferentiated quartzite is separated by a pockmarked quartzite. All three quartzite varieties display similar types of sedimentary structures, including large-scale crossbedding and ripple marks. The pockmarked quartzite contains pink to grey-coloured pock marks, 2 to 12 mm in diameter, which are concentrated along bedding. The pocked cavities generally contain quartz grains which are loosely cemented by ferruginous material. Tennick and Phaup (1976) suggested that they may result from the weathering out of original anhydrite crystals or cement. On the other hand, it has been suggested by Macgregor (1947) that they result from removal of rhombic carbonate grains, an idea supported by a strain analysis on the pockmarks by Stowe (1978). The quartzite unit has been repeated three times by thrusting (Tennick and Phaup, 1978; Treloar, 1988; Leyshon and Tennick, 1988).

Upper Dolomite

The Upper Dolomite, which overlies the quartzites, shows great variation in texture, crystallinity and colour, and contains bands of biotitic phyllite and sericitic and feldspathic grits and chloritic quartzite. It contains two bands of stromatolites which include both domical and columnar varieties (Jacobsen, 1962; Bond and Bliss, 1964; Bond, 1973; Tennick and Phaup, 1976; Stowe, 1978). An oolitic horizon is present in the upper dolomite (Stowe, 1978), and has also been found in the Mawiru Hills area (Tennick and Phaup, 1976). A sedimentary breccia containing both dolomite and shale clasts (partly replaced by tourmaline) has been recorded in a thrusted outlier of Lomagundi dolomite north of Mhangura (Bartholomew, in prep.).

Sandy Argillites

The Sandy Argillites, which overlie the upper dolomite, are generally light coloured, fine-grained laminated or massive rocks which have occasional coarser-grained more sandy interbeds. There are locally developed arkosic grits which contain vein quartz and feldspar clasts. The argillites consist of fine-grained quartz and phyllosilicates (biotite, sericite, chlorite), together with accessory iron-oxides and tourmaline.

Iron Formations

Although no iron-formations were found by any of the previous workers who mapped the Lomagundi Group (Stagman, 1959, 1961a; Workman, 1961; Thole, 1974; Tennick and Phaup, 1976), outcrops of banded iron-formations were recently discovered in the northern part of the Magondi basin, in the Shamrocke area, and in the NW limb of the Rusere syncline area. The Shamrocke example is a banded oxide-facies iron-formation, up to 2m wide and 1,5 km long, consisting of alternating quartz-rich and magnetite-rich layers, which are believed to be developed in the argillites above the dolomites (H.Simpson, pers.comm., 1988). The Rusere example is a coarse-grained metamorphosed silicate-facies iron-formation, up to 50m wide and at least 750m long, consisting of grunerite, garnet, quartz and possibly other iron silicates, and lies immediately above a biotitic metasiltstone adjacent to the dolomites (D.S.Bartholomew, pers.comm., 1988). The iron-formations may extend at least as far south as Chirombozi just west of Mhangura, where they may be responsible for a strong linear magnetic anomaly associated with the Pockmarked Quartzites, which are thrust over them in this area.

<u>Nyagari Formation</u>

The Nyagari Formation consists of argillaceous sediments (striped slates and graphitic shales) and the interbedded Mountain Sandstone and arkosic grits, overlain by a volcanic sequence consisting of andesitic lavas and pyroclastic rocks with associated cherts. The Nyagari Formation of Tennick and Phaup (1976) was called the "Zhonzhi Formation" by Kirkpatrick (1976). The latter name is superfluous, and priority is given to the former name as it was coined earlier.

Striped Slates

The Striped Slates are composed mainly of striped slates and graphitic shales with subordinate horizons of graded, upward-fining sandy argillite and phyllite. The striped appearance of the slates is due to a slight difference in colour, texture or composition. The colour varies from greyish-purple in fresh rocks to purplish-pink or reddish-brown in weathered rocks. Non-striped slates locally become more sandy in texture, especially in proximity to a band of Mountain Sandstone, and contain sole markings and flute clasts. The soft graphitic shales display alternate bands of dark and grey material which may be graded, and often contain pyrite. Tennick and Phaup (1976) suggested that the argillaceous sediments of the Nyagari Formation were probably laid down in a barred depository under reducing and anaerobic conditions in which there was stagnant but not necessarily very deep water.

Mountain Sandstone

The Mountain Sandstone is a dark grey massive, very poorly bedded medium-grained quartzite which often contains pyrite and clay pellets (Tennick and Phaup, 1976). Two bands of Mountain Sandstone, which are interbedded with the Striped Slates, are developed mainly in the northern part of the Lomagundi Group outcrop area, and occur only as scattered small discontinuous lenses in the south. The coarse-grained arkosic grit is of local development, and is found as thin bands interbedded with the argillites or dolomite lenses.

Volcanics

In the uppermost part of the Nyagari Formation, porphyritic andesitic lavas are associated with pyroclastic rocks (agglomerates and welded tuffs). The agglomerates are greyish-green in colour with a typical fragmental texture, and contain very angular fragments of andesitic lava and carbonate material (Tennick and Phaup, 1976). Some agglomerates contain flattened black fragments of spherulitic devitrified glass set in a cherty groundmass. Some of the tuffs contain fragments of amygdular or scoriaceous lava fragments. Many varieties of agglomerates and tuffs, some of which may be epiclastic (containing sedimentary clasts) are described by Tennick and Phaup (1976). The pyroclastic rocks indicate the proximity of an explosive volcanic source (andesitic volcano) during deposition of the Nyagari Formation.

Sakurgwe Formation

The Sakurgwe Formation consists of a monotonous succession of poorly bedded medium- to fine-grained greywackes, with the occasional narrow intercalated shale or feldspathic quartzite horizon (Leyshon, 1969a; Bliss, 1970; Tennick and Phaup, 1976). The poorly sorted greywackes are compositionally and texturally immature, and contain angular quartz, plagioclase and lithic fragments as well as chlorite and sericite.

STRUCTURE AND METAMORPHISM

The Lomagundi Group has been extensively deformed and metamorphosed during the Magondi Orogeny (Stagman, 1961; Jacobsen, 1962; Tennick and Phaup, 1976; Kirkpatrick, 1976). In the northern part of the Magondi basin, the Lomagundi Group has also been affected by the Pan-African Zambezi Orogeny (Thole, 1974, 1976; Thole and Robinson, 1976). At least three phases of deformation have been recorded. In the Chinhoyi Caves area, the first phase involved NE-striking eastward-verging folds, which were then refolded about NW-striking F2 folds (Stowe, 1978). A localised F3 deformation produced a NE-striking cleavage. In the Mcheka ranges further south, the Lomagundi Group has been repeated three times through thrust duplication in a thin-skinned thrust duplex (Tennick and Phaup, 1976; Leyshon and Tennick, 1988; Treloar, 1988). The metamorphic grades in the Lomagundi Group range from greenschist facies in the south (Tennick and Phaup, 1976), to amphibolite facies in the north (Workman, 1961, 1965; Thole, 1974), where the dolomites have been converted into tremolitic marbles.

PIRIWIRI GROUP

INTRODUCTION

The Piriwiri Group consists of phyllites, greywackes, black graphitic and ferruginous slates, cherty quartzites and subordinate volcanic and pyroclastic rocks (felsites, tuffs, agglomerates and andesites). The stratigraphic position of the Piriwiri Group has been the result of much debate and controversy (Lightfoot, 1929a; Haughton, 1969). Stagman (1959, 1961) and Kirkpatrick (1976) regarded the Piriwiri Group as being older than the Deweras and Lomagundi Groups, but their reasons for this (higher metamorphic grades, differences in metallogeny) are inconclusive. On the basis of detailed mapping, Tennick and Phaup (1976) concluded that the Piriwiri Group overlies the Lomagundi Group conformably. Leyshon (1969a) and Leyshon and Tennick (1988) suggested that because of extensive facies changes both along and across strike, the Lomagundi and Piriwiri Groups are roughly contemporaneous. Leyshon (1969a,b) and Tennick and Phaup (1976) subdivided the Piriwiri Group into the Umfuli, Chenjiri, and Copper Queen Formations. Kirkpatrick (1976) subdivided it into the Kanyaga and Chitena Formations. The Chitena Formation is equivalent to the Umfuli Formation, while the Kanyaga Formation is equivalent to the Chenjiri and Copper Queen Formations. Kirkpatrick's nomenclature is superfluous and confusing, and the older tripartite subdivision is retained here (Fig. 8).

STRATIGRAPHY

Umfuli Formation

The basal part of the Umfuli Formation consists of black graphitic slates and breccias and pyritiferous slates with narrow bands of cherty quartzite. The greater part of the Umfuli Formation consists of argillites and phyllites with minor interbedded greywackes (Tennick and Phaup, 1976).

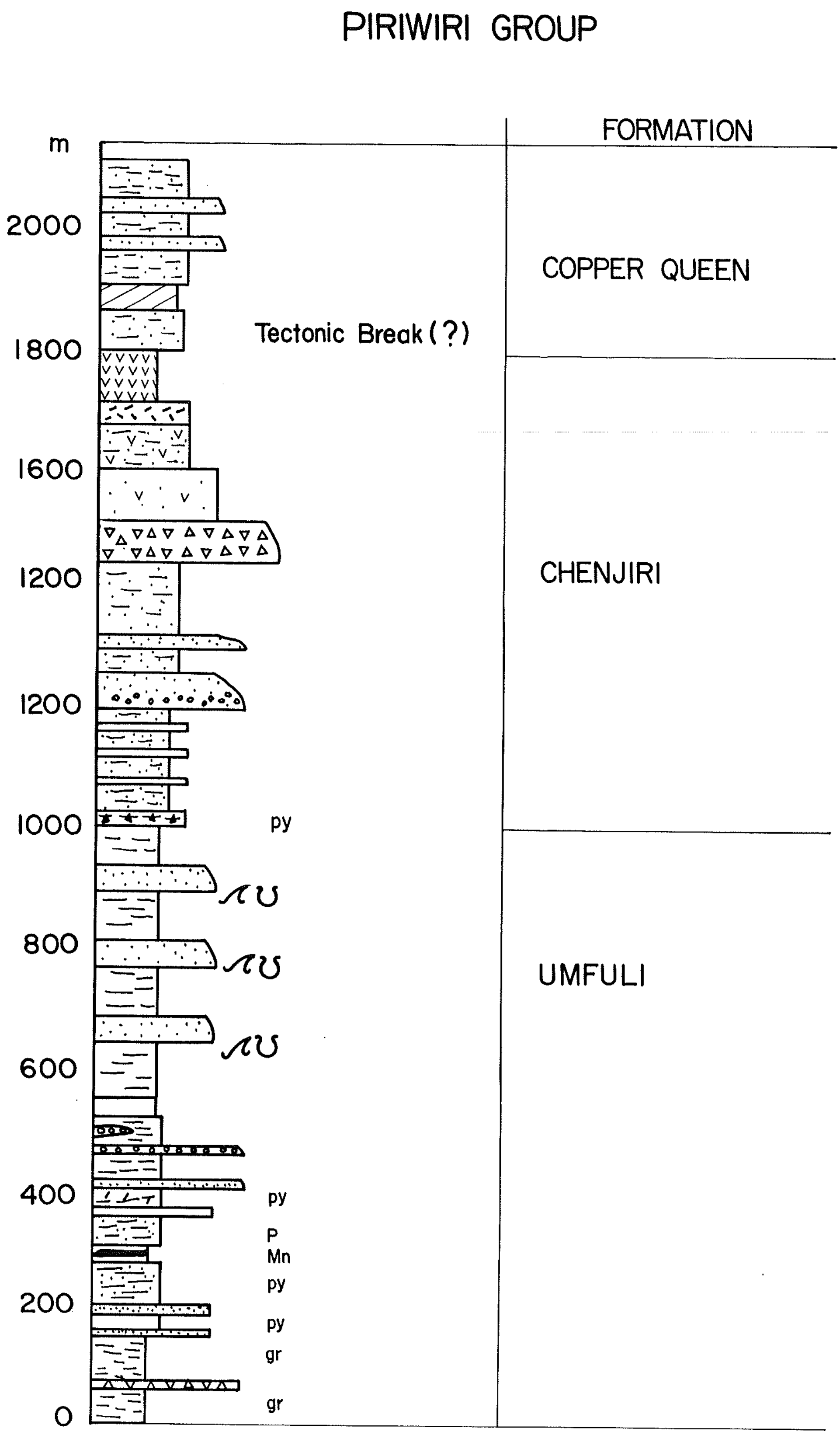


Figure 8: Generalised lithostratigraphy of the Piriwiri Group

Graphitic slates and breccias

The graphitic shales are extremely fine-grained, soft, black rocks which are very finely laminated. The graphitic breccia is a highly carbonaceous shale with a brecciated appearance, and contains stilpnomelane (Tennick and Phaup, 1976).

Cherty quartzites

The cherty quartzites, which are interbedded with pyritiferous, siliceous slates, are hard, dense, creamy-grey to black, microcrystalline quartzose rocks. The darker colour of some quartzites is due either to manganese, or to iron oxides and graphite. The chemical composition, areal extent, and interbedding with black graphitic and pyritic slates indicates that the cherty quartzites are bedded deposits inorganically formed from a primary precipitate of silica gel in a restricted basin (Tennick and Phaup, 1976). Tennick and Phaup (1976) also suggested the possibility that the cherty quartzites may be altered tuffs, because of their fragmental appearance, colloform structures, shards of devitrified glass, and ovoid perlitic or spherulitic textures.

Pyritiferous slates

The pyritiferous slates, which are interbedded with the cherty quartzite bands, are fine-grained, siliceous, hard, reddish-grey to greyish green pyrite-rich rocks that are manganiferous in places. They are locally associated with lenses of thinly-bedded phosphate-bearing shale. The phosphate is collophanite which consists of fluorapatite and quartz (Tennick and Phaup, 1976).

Conglomerates, grits and quartzites

Thin discontinuous bands of schistose conglomerate are found interbedded with the cherty quartzites and pyritiferous slates. The matrix-supported conglomerates contain clasts of quartz, quartzite, chert, devitrified glass and argillaceous rock fragments set in a poorly-sorted matrix of quartz and micas (Tennick and Phaup, 1976). Dark-grey ferruginous-to-feldspathic quartzite occurs as thin beds intercalated with phyllites and fine-grained greywackes. Locally developed grit bands are similar to very coarse-grained greywackes. The conglomerates, quartzites and grits of the Umfuli Formation show a strong lithological resemblance to, and may represent a lateral facies interfingering with, equivalent rock types of the Nyagari Formation of the Lomagundi Group.

Phyllite and interbedded greywacke

The bulk of the Umfuli Formation comprises a sequence of fine-grained argillites, phyllites and slates, with intercalated horizons of fine-grained greywacke and calcareous and feldspathic quartzites (Tennick and Phaup, 1976). The argillaceous rocks, which predominate, show considerable variations in colour, grain-size and texture, and consist mainly of quartz, muscovite, chlorite, feldspar, biotite, and iron oxides. The greywackes are greyish-green fine- to medium-grained poorly-sorted rocks consisting of angular to subrounded grains of quartz, plagioclase, and microcline, set in a fine-grained clayey matrix of quartz, feldspar, mica, iron oxides, and pyrite. Sedimentary structures in the greywackes include load-casts, flame structures, and sand volcanoes, which are all indicative of rapid sediment loading (Tennick and Phaup, 1976).

Chenjiri Formation

The Chenjiri Formation consists of phyllites and greywacke, with minor quartzites, chert, felsites, tuffs, and agglomerates, and is separated from the underlying Umfuli Formation by a long, thin, bed of pyritiferous slate (Tennick and Phaup, 1976). Leyshon (1969a) has subdivided the lithologies of the Chenjiri Formation into the Argillaceous, Arenaceous, and Volcanic Members.

Argillaceous Member

The Argillaceous Member, which is widespread in the Chenjiri Formation, is composed of fine-grained greyish-green to brown phyllites, together with black, fine-grained massive or schistose graphitic rocks. The phyllites, which are identical to those in the Umfuli and Copper Queen Formations, are composed of quartz and muscovite, with minor chlorite and iron oxides (Leyshon, 1969a).

Arenaceous Member

Quartzites and grits

Quartzites and grits of the Chenjiri Formation are interbedded with phyllites and graphitic rocks. They are clastic-textured rocks consisting of recrystallised quartz together with chert grains and phyllitic fragments, and minor graphite, iron oxides, and muscovite (Leyshon, 1969a). There is a complete gradation between the quartzites and the coarse-grained grits.

Feldspathic quartzites

The feldspathic quartzites are generally finer grained and more flaggy than the normal quartzites, and consist mainly of quartz, with minor feldspar and graphite. Micaceous varieties also contain muscovite, chlorite and iron oxides, and are similar to rocks in the Copper Queen Formation (Leyshon, 1969a).

Chert

The cherts are fine-grained black or banded black and white rocks which occur as long, continuous, beds up to 20 km long, and as thin, discontinuous bands interbedded with phyllites and graphitic rocks (Leyshon, 1969a). They consist of very fine-grained quartz together with graphite and iron oxides.

Volcanic Member

The Volcanic Member consists of agglomerates, felsites and tuffs. Outcrops of these rock types are found in several places in a linear belt over a strike length of 85 km. They have been referred to as "volcanic centres" by Leyshon (1969a), Tennick and Phaup (1976) and Kirkpatrick (1976). These "volcanic centres" are the Hova, Godzi, Piriwiri, Montana, Crescent, Kameno, and Nyamakari centres, which all have very similar lithologies. Outcrops of altered mafic greenstones, which occur along the same general strike as the main "centres" (Kirkpatrick, 1976) have been mapped as andesites by Molyneux (1919) and Macgregor and Dobell (1937).

Agglomerates

The agglomerates are coarse, fragmental volcanic breccias composed of angular fragments of scoriaceous felsite, from 3 to 50 cm across, with fewer fragments of tuff and crystal tuff set in a matrix of crystal tuff and small rock fragments. The matrix is composed of subhedral laths of plagioclase, together with abundant magnesian calcite and minor quartz. The agglomerates may be massive or bedded.

Felsites

The felsites are fine-grained pyritiferous rocks which consist of aggregates of plagioclase (albite-oligoclase), quartz and calcite, with accessory pyrite, tourmaline, iron oxides, apatite, and chlorite. They are regarded as extrusive volcanic or volcaniclastic rocks (Leyshon, 1969a).

Tuffs

The tuffs are of two types, lithic tuffs, with felsite rock fragments, and crystal tuffs, with plagioclase cryastal fragments. The lithic tuffs are generally medium- to fine-grained well-bedded banded rocks which may display graded bedding. The crystal tuffs, which also form the matrix to the agglomerates, are grey well-bedded rocks consisting of subhedral plagioclase crystals and felsite fragments set in a matrix of feldspar, quartz and iron-stained calcite.

Discussion

Although the agglomerates were thought to be vent breccias (Leyshon, 1969a; Kirkpatrick, 1976), no proof of this has been given by the above authors. On the contrary, from their descriptions, the agglomerates appear to pyroclastic rocks interbedded with tuffs. The outcrops of the Volcanic Member appear to be confined to a closed boat-shaped doubly plunging syncline (Tennick and Phaup, 1976; Kirkpatrick, 1976), and the various "centres" can be regarded as merely the exposed outcrops of what may be a fairly continuous unit of volcanic and pyroclastic rocks. In this regard, it may be significant that the "centres" seem to be located at the intersections of the regional northeasterly striking beds with north-westerly striking F3 fold hinges (Leyshon, 1969a). The volcaniclastic rocks are conformably enclosed by the country rocks, and have been deformed with them. The Nyamakari centre is apparently enclosed by Striped Slates of the Mcheka Formation (Lomagundi Group), though these rocks are difficult to distinguish from lithologies of the Piriwiri Group (Kirkpatrick, 1976). The pyroclastic rocks of the Volcanic Member thus appear to transgress facies boundaries between the Lomagundi and Piriwiri groups. Mapping of the Crescent, Hova and Nyamakari centres (Wills, 1987; H.Simpson, pers.comm., 1989) shows that part of the stratigraphy is inverted due to tight folding. If the structural and stratigraphic interpretation is correct, then the Volcanic Member may form the uppermost stratigraphic unit in the Piriwiri Group (H.Simpson, pers. comm., 1990).

Copper Queen Formation

The Copper Queen Formation consists of a monotonous sequence of phyllites and micaceous feldspathic quartzites, with a ferruginous marble near the base. The coarse-grained, vitreous, micaceous feldspathic quartzites are dark grey-green in colour, and are composed of rounded quartz grains set in a quartzo-feldspathic mosaic together with muscovite and rare biotite. The phyllites are fine-grained, greyish-green rocks and consist of an interlocking mosaic of quartz and muscovite, with minor chlorite and iron oxides. The marble, which is exposed around the Copper Queen and Copper King domes, is composed of tremolite, actinolite, ankerite, and calcite (Bahnemann, 1957, 1961; Leyshon, 1969a).

STRUCTURE AND METAMORPHISM

The Piriwiri Group was deformed and metamorphosed during the Magondi Orogeny, and has undergone three main phases of folding (Leyshon, 1969a,b). In addition, the Piriwiri Group in the northern part of the Magondi Basin has experienced deformation and metamorphism during the Pan-African Zambezi Orogeny. The F1 deformation, which was the most intense and widespread, produced tight folds with axial planes striking NE-SW, with fold axes plunging NE and SW. The F2 deformation produced asymmetric folds with axial planes striking NE and NNE. The F3 deformation produced open folds with NW-striking axial planes, and was responsible for large swings in strikes produced by earlier deformations (Leyshon, 1969a). Regional metamorphism of greenschist facies affected Piriwiri rocks in the southern part of the basin (Leyshon, 1969a,b). The metamorphic grades increased to amphibolite and granulite facies to the north and northwest (Wiles, 1961,1964; Broderick, 1976; Treloar, 1988; Treloar and Kramers, 1989). Treloar and Kramers (1989) described the Rukomeche granulites from the Piriwiri Group. Munyanyiwa et al. (1990) studied the thermobarometry and CO_2-rich fluid inclusions of the Nyaodza enderbites near Kariba. They estimated peak granulite facies metamorphism to have taken place at temperatures of 750-800°C, and pressures of 5-7 kb, with a pressure-temperature-time (P-T-t) path which involved cooling at high pressure, followed by a rapid pressure decrease at nearly constant temperature. In the Miami (Mwami) area, syn- to late-kinematic muscovite and biotite granites (the Miami Granites) intruded sillimanite-grade schists (Wiles, 1961,1964). Leyshon (1969a) and Kirkpatrick (1976) described a zone of garnet-mica schists confined to a linear belt incorporating the Copper King and Copper Queen domes, which they ascribed to contact metamorphism produced during the emplacement of the domes.

DETE-KAMATIVI INLIER

INTRODUCTION

The Dete-Kamativi Inlier is a sequence of Precambrian metamorphic rocks which are exposed through Phanerozoic cover in western Zimbabwe. The rocks consist of granodioritic orthogneisses, granites, and highly deformed and metamorphosed supracrustal sequences which have been subdivided by Lockett (1979a,b) into the Malaputese, Inyantue, Kamativi, and Tshontanda Formations (Lockett, 1979a,b) (Fig. 1, Table 1).

MALAPUTESE FORMATION

Stratigraphy

The Malaputese Formation, consisting of metasedimentary and mafic rocks, is exposed over much of the south-east portion of the Dete-Kamativi Inlier, and is divided into two stratigraphic domains (Lockett, 1979a,b).

Table 1: Stratigraphy of the Dete-Kamativi Inlier, N.W. Zimbabwe

FORMATION	LITHOLOGY	CORRELATION
-	postkinematic granites (2000+/-80 Ma, Rb-Sr W.R.)	
Kamativi	muscovite and biotite schists, minor psammites.	Piriwiri Group
Tshontanda	garnet-mica schists, sillimanite gneisses, impure quartzites.	
Inyantue	garnetiferous gneisses, arenites, calcareous and graphitic rocks.	Lomagundi & Deweras Groups
Malaputese	pink arkosic psammites, calc-silicates, metapelites, mafic metavolcanics, quartzites.	
-	granodioritic orthogneisses (2159+/-100 Ma, Rb-Sr W.R.)	

The Western Domain consists of pink paragneiss at the base with minor intercalated calc-silicate and pyroxene leucogneisses, followed by a sequence of metapelites with minor graphitic, calcareous and mafic rocks, with quartzites forming the top of the succession. The Eastern Domain consists of quartzite at the base, followed by a succession of metapelites with graphitic schist interbeds, and by a sequence of mafic rocks with intercalated metasedimentary schists and quartzites. The rocks were metamorphosed to upper amphibolite and granulite facies, and the metapelites contain cordierite, sillimanite and andalusite. Retrograded schists consist of chlorite, sericite and quartz. The pink paragneisses are interpreted as metamorphosed continental arkosic red-beds (Lockett, 1979a). The quartzites are interpreted to have formed on a shallow marine shelf by a marine transgression over a stable cratonic platform. The metapelitic schists are interpreted to have been deposited in a shallow marine or lagoonal depository, while the intercalated graphitic schists are regarded as metamorphosed black shales indicating strongly reducing, anoxygenic conditions of deposition (Lockett, 1979). The mafic rocks are hornblende-andesine amphibolites, and are chemically classified as subalkaline basalts, which Lockett (1979a) compared with continental olivine-tholeiite plateau-basalts. The schists intercalated with the metabasalts consist of calcareous marbles and calc-silicate-rich rocks, anthophyllite-cordierite rocks, and thin-bedded, fine-grained quartzites, and are interpreted to be metamorphosed interflow sediments. They are hosts to stratabound copper mineralization at the Gwaai River Mine and other prospects in the area (Lockett, 1979a; Bahnemann and Lockett, 1979).

Structure

Rocks of the Malaputese Formation were affected by three fold phases, F1, F2 and F3, recognised from small-scale and regional structures (Lockett, 1979a). The first deformation produced NE-trending F1 isoclinal folds and some recumbent structures in the quartzites. The second deformation produced SE-trending F2 folds, which were overprinted by NNE-trending F3 folds, producing regional dome and basin, arcuate and lobate interference structures outlined by the Malaputese quartzites (Lockett, 1979a,b).

INYANTUE FORMATION

The Inyantue Formation is composed of garnetiferous gneisses and schists with intercalations of calcareous, graphitic, magnesian and arenitic rocks (Lockett, 1979a). The garnetiferous gneisses and schists, making up 95% of the sequence, have been divided into four varieties: (i) sillimanite-cordierite-garnet-biotite gneiss; (ii) garnetiferous gneiss with a leucosome phase; (iii) speckled, augen and banded gneisses; and (iv) veined biotite schist. Narrow bands of tremolite, epidote and diopside-bearing siliceous calc-silicate rocks are ubiquitous in the gneisses and schists. Graphitic horizons, 1-20m wide, may occur singly or in groups of three or more bands, and may have associated coarse-grained diopsidic rocks. An impersistent quartzite horizon is found interbedded with the schists. Thin bands of magnesian chlorite-tremolite, tremolite-talc, and chlorite-talc rocks occur in biotite schists. Scattered outcrops of medium-grained grey biotite-hypersthene granulites are also found.

The garnetiferous gneisses and schists are interpreted, on the basis of their modal composition, to be metamorphosed argillaceous sediments (Lockett, 1979a). The graphitic horizons, with diopsidic rocks, are interpreted to have been carbonaceous shale with lenticular beds of impure dolostone. The siliceous calc-silicate bands were probably calcareous sandstone or siltstone intercalations, and the talc-tremolite-chlorite rocks were probably dolomitic marls. The biotite-hypersthene granulites, which contain accessory graphite, are interpreted as metamorphosed greywackes. The recrystallized quartzite is interpreted to have been a lenticular quartz-arenite horizon (Lockett, 1979a).

KAMATIVI AND TSHONTANDA FORMATIONS

Stratigraphy

The Kamativi and Tshontanda Formations are found in two elongated belts that were formerly thought to be continuous (Lockett, 1979a). The Kamativi Formation consists of tightly folded muscovite schists, subordinate fine-grained biotite schists, and minor arkosic psammites. The muscovite schists are medium-grained, strongly foliated rocks which contain garnets, schorl, and in some varieties, retrograde andalusite porphyroblasts with sillimanite inclusions. There are rare remnants of sillimanite-bearing schists. The biotite schists form intercalations in the muscovite schists, ranging in width from a few centimetres to over 100m. The fine-grained biotite schists range from sheared, flaggy types to more massive, poorly cleaved varieties, and they commonly display a fine compositional banding parallel to the schistosity. The schists consist mainly of quartz, plagioclase, and biotite. Minor meta-arkose, which is a grey, medium-grained, granoblastic garnetiferous quartz-andesine rock with a biotite-rich fabric, forms psammitic intercalations in the schists.

The Tshontanda Formation is composed of garnetiferous mica schists and subordinate sillimanite gneisses, with local intercalations of impure quartzite. The garnet-mica schists are medium- to coarse-grained and consist of muscovite, biotite, quartz, garnet, chlorite, and tourmaline (Lockett, 1979a). Fine-grained semipelitic biotite schists with interlaminated more psammitic layers form banded intercalations in the muscovite schists. The sillimanite gneisses range from garnetiferous metapelites to more psammitic sillimanite-biotite-quartz gneisses. Alternations of biotite-rich and psammitic layers impart a banding to these rocks. The impure quartzites are grey, fine-grained, massive to finely banded quartz-oligoclase-mica rocks which form lenticular horizons, 1-30m wide, in the semipelitic biotite schists and the more psammitic sillimanite gneisses (Lockett, 1979a).

The modal compositions and layering of the rocks of the Kamativi and Tshontanda Formations suggest that their protoliths consisted of micaceous shales interlaminated with subordinate silty shales and siltstones, and incorporating thin sandy horizons of arkose and feldspathic quartzite. According to Lockett (1979a), the lack of associated clean quartzites and calcareous rocks suggests a deeper water origin than for the Inyantue Formation. Lockett (1979a) did not recognise any turbidite sequences, however, and considered that a deep-water geosynclinal environment was unlikely.

Structure

The rocks of the Kamativi and Tshontanda Formations have been intensely deformed and attenuated into long thin linear or slightly arcuate belts. The schists are isoclinally folded with a steeply dipping fabric, and are cut by numerous shear zones. Lockett (1979a) proposed that the deformation took place under sinistral simple shear, based on the "drag direction to swept back schist protrusions into granitic rocks along the northern margins of the Kamativi and Tshontanda belts". However, examination of the geological map (Lockett, 1979a) indicates that the sigmoidal shape of the schist belts is due to regional NE-SW dextral transpressional shear, which would also explain the NNE orientation of F3 folds in the Malaputese Formation.

GEOCHRONOLOGY AND CORRELATION

The rocks of the Dete-Kamativi inlier were dated by Priem et al. (1972). They obtained Rb-Sr whole-rock ages on three intrusive granites and gneisses of 2159 ± 100 Ma, 2000 ± 80 Ma, and 2574 ± 400 Ma (recalculated using modern 87Rb decay constant). The last age is very poorly constrained and may or may not be geologically meaningful, while the other two ages reflect magmatic episodes on the western side of the Magondi Basin pre- or syn-kinematic (granodioritic gneisses), as well as postkinematic (unfoliated granites), with respect to the Magondi Orogeny. The granodioritic gneisses represent a calc-alkaline magmatic arc, while the granites represent post-collisional crustal melts following granulite-facies metamorphism and migmatite formation. The tourmaline-bearing pegmatites are related to this early Proterozoic phase of granitic magmatism. Galena from the Elbas Mine in the Inyantue Formation was analysed by Bate and Kulp (1955), Holmes and Cahen (1957) and Russell and Farquhar (1960), and was recalculated by Vail and Dodson (1969) to give model ages of 1250 ± 39 Ma, 1310 ± 30 Ma and 1360 ± 38 Ma respectively. The economic tin-bearing pegmatites have been dated at 969 ± 15 Ma, and may be related to the Choma-Kalomo batholith in Zambia, which contains tin mineralization (Legg, 1972).

Lockett (1979a) correlated the metapelitic rocks of the Dete-Kamativi inlier with the Piriwiri Group, but Watson (1962) suggested that they could also be correlated with the older Hurungwe paragneisses in the Kariba area. Watson (1962) correlated the Malaputese Formation with the Lomagundi Group, but Lockett (1979a) pointed out that in order satisfy lithological requirements, the Deweras Group would have to be included in the correlation, and would account for the pink paragneisses (meta-arkoses) and the meta-volcanics. Lockett (1979a) rejected the suggested correlation between the Malaputese Group and the Deweras and Lomagundi Groups, on the sole basis that there was an unconformity between the latter two groups, whereas he did not recognise one within the Malaputese Group. He also cited the presence of Lomagundi Group lithologies in the Sawmills borehole 130 km to the southeast of the Dete-Kamativi inlier (Thompson, 1975) as evidence that the Lomagundi basin passed well southeast of the Malaputese Group outcrops, and could not therefore be a correlative.

It is felt here that Lockett's (1979a) objections to the correlation of the Dete-Kamativi inlier lithologies with those of the Magondi Supergroup are weak, and disregard their very close lithological similarities. The Deweras-Lomagundi-Piriwiri Group sequence of copper-bearing arkoses, sub-alkaline basalts, orthoquartzites, dolomites, slates, graphite-bearing schists and wackes is mirrored closely by the copper-bearing pink paragneisses, sub-alkaline amphibolites, metaquartzites, marbles, alumino-silicate-bearing and graphite-bearing schists and gneisses of the Malaputese-Inyantue-Kamativi-Tshontanda Formations of the Dete-Kamativi inlier. This remarkable lithological correspondence, together with the similarities in terms of age, leads to the inescapable conclusion that the metasedimentary and metavolcanic rocks of the Dete-Kamativi inlier are the high-grade metamorphosed equivalents of the Deweras, Lomagundi and Piriwiri Groups which outcrop in the northern part of the Magondi Basin. As regards the lack of lateral strike continuity between the two areas, it is postulated here that the Dete-Kamativi inlier rocks were deposited on the <u>western</u> side of the Magondi rift basin. During the Magondi Orogeny, this western flank of the basin was overthrust by the basement/magmatic arc terrane to the west, resulting in granulite grade metamorphism of the Malaputese Group. In contrast, farther north along strike, the western edge of the basin, together with the flanking Hurungwe gneisses/magmatic arc, was itself uplifted and involved in thrusting over the central part of the basin (filled with Piriwiri Group rocks). This led to granulite facies metamorphism of the Piriwiri Group, and the complete erosion of the Deweras and Lomagundi Group/Malaputese Group equivalent rocks of the northwestern flank.

NORTHERN EXTENSIONS OF THE MAGONDI BELT

ZAMBIA

In view of the fact that the Great Dyke extended into Mozambique (Real, 1962; Master 1990), it seems certain that the original extent of the Archaean Zimbabwe Craton was much larger. The Magondi Basin may also have extended much farther northwards than the presently accepted limits which end at the Zambezi escarpment. North of the Zambezi Valley, there is a sequence of gneisses, schists, and marbles in the Eastern Province of Zambia (Fig. 9), which have great lithological similarities with the

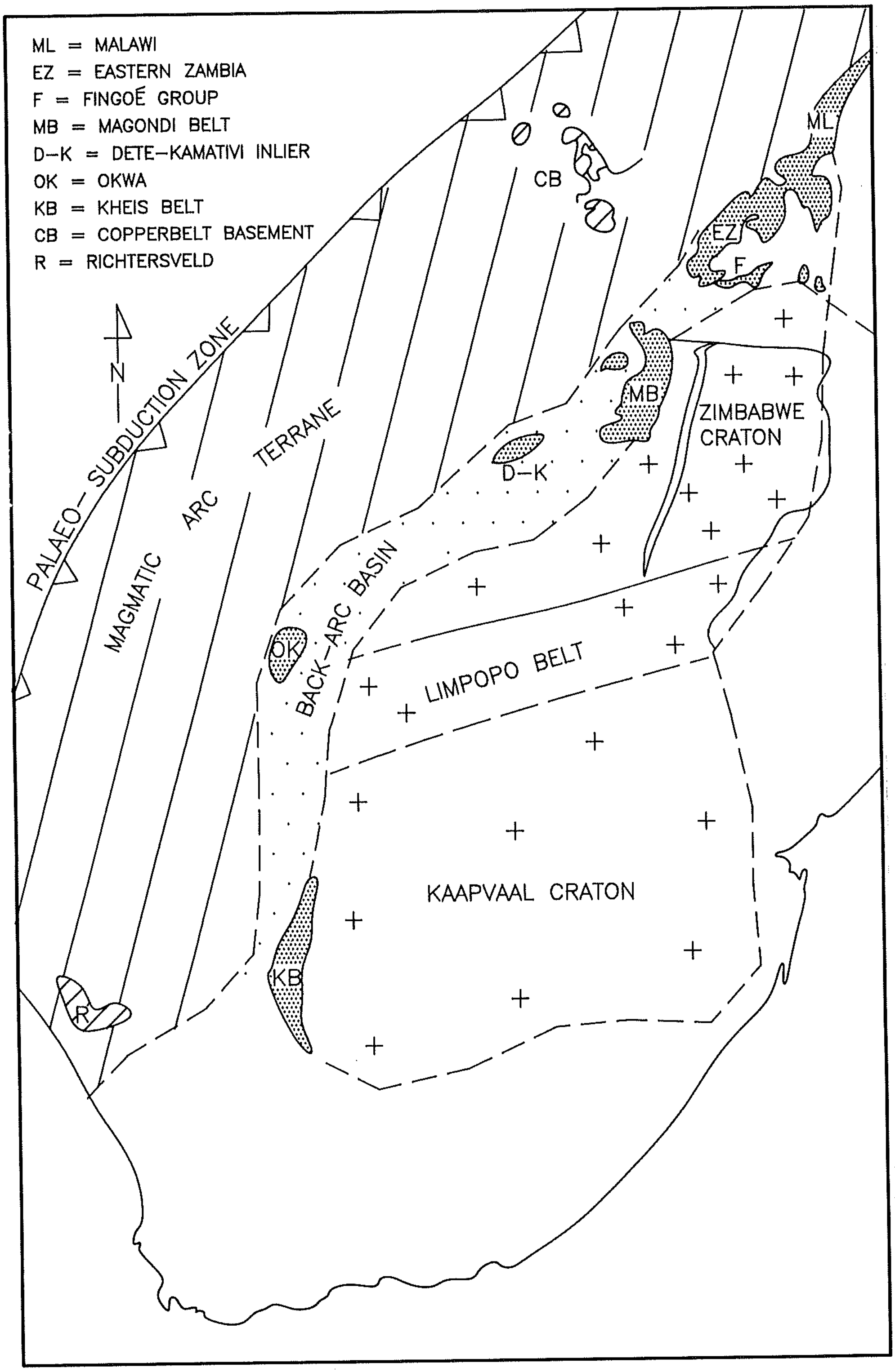


Figure 9: Schematic plan showing position of Magondi Supergroup and correlative sequences in a continental back-arc basin, with respect to the postulated magmatic arc terrane, palaeo-subduction zone, and the combined Zimbabwe-Limpopo-Kaapvaal continent (after Master, 1990d, 1991).

Deweras, Lomagundi and Piriwiri Groups of Zimbabwe (Mountford, 1982).

In a recent review of the stratigraphic and structural framework of eastern Zambia, Johns et al. (1989) synthesised the findings of several workers in the area, and concluded that there are three main stratigraphic sequences which can be broadly correlated with the "Ubendian" or "Magondi" (c.2 Ga), the "Muva Supergroup" (post-1.8 Ga), and the Lufilian-Zambezi or Pan-African (c.0.9-0.5 Ga) events. Phillips (1961) divided the Precambrian rocks of the "Chindeni Mobile Belt" (Petauke area) into the Nyanji orthogneiss, overlain by the Sinda, Lusandwa, Mvuvye, and Sasare Groups. The porphyroblastic Nyanji gneiss, which varies from granite to tonalite/granodiorite in composition, forms the basement on which the metasedimentary sequences were deposited. The Sinda Group consists of quartzofeldspathic paragneisses (meta-arkoses), which contain minor interbedded metapelites and thin banded marble and calc-silicate horizons (metadolomites), as well as amphibolite sills. The Lusandwa Group is an allochthonous structural unit with similar lithologies to the Sinda Group, with which it is correlated. The Mvuvye Group consists of calcareous and calc-silicate-rich marbles, quartzites, and graphitic and biotitic semi-pelitic gneisses (Phillips, 1961), which contain widespread disseminated and massive iron-copper-zinc sulphide mineralization (Skowronski and Sliwa, 1986), as well as graphite deposits (Drysdall, 1960). The Sinda, Lusandwa and Mvuvye groups were all metamorphosed to granulite facies. They are unconformably overlain by the Sasare Group, consisting of basaltic and andesitic lavas and pyroclastic rocks overlain by quartz-pebble conglomerates and quartzites, which have undergone greenschist facies metamorphism.

In the Chipata area farther east, Vavrda (1974) described complexly folded, polymetamorphosed basement rocks, the "Lutembwe River Granulites", which are overlain by the weakly metamorphosed psammitic and metapelitic Mwami Group. The granulites consist of the high-grade metamorphosed equivalents of arkose, pelite, semi-pelite, orthoquartzite, and dolomitic marls, which display great lithological similarities with the rocks from the Petauke area to the west. Rb-Sr geochronological studies on the Lutembwe River Granulites by Haslam et al. (1986) produced an unreliable "errorchron" due to wide scatter of data points. A regression line for leucocratic quartzofeldspathic gneisses yielded a poorly constrained age of 1866 ±582 Ma, which dates the granulite metamorphism.

MALAWI

The gneisses of eastern Zambia continue eastwards into Malawi (Fig. 9), where they are referred to as the Dedsa, Misuku and Nyika gneisses (Thatcher, 1973). Amphibolite facies paragneisses and schists make up much of the Malawi Basement Complex, and comprise widespread semipelitic biotite-gneisses, cafemic gneisses, ferruginous and graphitic gneisses, psammites, and pelites, as well as abundant marbles and calc-silicate granulites (Bloomfield, 1968). The Mafingi and Mchinji Groups of central and northern Malawi are the equivalents of the Sasare and Mwami Groups (Bloomfield, 1968; Fitches, 1971), and may be correlatives of the Muva Supergroup of western Zambia (Daly and Unrug, 1983).

MOZAMBIQUE

The Fingoé Group of the Zambezia Province, northwestern Mozambique (Fig. 9), consists of clastic metasediments (arkoses, conglomerates, greywackes, impure and ferruginous quartzites), dolomitic and tremolitic marbles (with associated stratabound copper mineralization), mica schists, and amphibolites (Vail and Pinto, 1965; Real, 1966).

CORRELATIONS WITH THE MAGONDI SUPERGROUP

The meta-arkosic rocks of the Sinda and Lusandwa Groups, together with their interbedded metapelites and marbles, and amphibolite sills, are almost identical lithologically to the Deweras Group, with which they are here correlated. The Mvuvye Group lithologies of marbles, quartzites, and graphitic schists, together with base-metal sulphide mineralization, correspond very closely to the lithological sequence in the Lomagundi and Piriwiri Groups, with which they are correlated. The Lutembwe River Granulites are lithologically correlated with the Deweras and Lomagundi Groups of the Magondi Belt, and their poorly constrained metamorphic age corresponds to the Magondi Orogeny. Similar correlations may be made with the gneisses of the Basement Complex in Malawi. Vail and Pinto (1965) correlated the Fingoé Group with the Mafingi Group, but considering the position of the Fingoé Group between the northern extension of the Magondi Belt, and the Chipata and Dedsa regions of Zambia and Malawi, it is felt here that a much better correlation can be made with the Deweras and Lomagundi Groups, especially with regards to the dolomites, quartzites, and stratabound copper mineralization.

POSSIBLE EXTENSION INTO BOTSWANA AND SOUTH AFRICA

The southward continuation of the Magondi Belt is obscured by Mesozoic and Cenozoic deposits of the Kalahari Basin in Botswana. In the Okwa region of south-central Botswana (Fig. 9), a gneissic granite basement inlier has been dated by Key and Rundle (1981) at 1.8 Ga (U-Pb), which is the same age as the Magondi Belt. The Xade and Tshane mafic complexes occur to the northeast and southwest of the Okwa inlier (Stowe, 1990). The Okwa terrane continues southwards along the `Kalahari Line' of high linear gravity anomalies (Reeves and Hutchins, 1975; Hutchins and Reeves, 1980) and emerges as the Kheis Belt of the northern Cape Province (Hartnady et al., 1985; Stowe, 1989, 1990). Cooper (1978) originally proposed that the Deweras Group was deposited in a large rift basin that extended as far south as the Kheis Belt.

The Kheis Belt (Fig. 9) consists of metasediments and metavolcanics of the Olifantshoek Sequence, which were deformed during the c.2.0-1.8 Ga Kheis Orogeny (Stowe, 1983b, 1986). The Olifantshoek Sequence has been divided into the Mapedi, Lucknow, Hartley, Matsap, Brulsand, and Groblershoop Formations (SACS, 1980; Stowe, 1986; Beukes and Smit, 1987). The Gamagara Formation, formerly thought to be part of the underlying Griqualand West Sequence, has been shown to be a thrust-duplicated equivalent of the Mapedi Formation (Beukes and Smit, 1987). Red-bed quartzites, shales, siltstones, and minor dolomites of the Mapedi, Lucknow, Matsap, and Brulsand Formations, together with the Hartley basalts, were deposited in rift-related fluvial, deltaic and near-shore tidal environments, while the lavas, greywackes and chloritic argillites of the Groblershoop Formation were deposited in offshore passive-margin-type shelf environments (Stowe, 1990). The Hartley Basalt Formation (Cornell, 1987) has been dated at 2070 ± 90 Ma (recalculated Rb-Sr whole rock isochron) by Crampton (1974), and is interpreted to be the age of extrusion. Armstrong (1987) obtained a younger Rb-Sr whole rock age of 1893 ± 48 Ma, which is interpreted here as the age of resetting of the lavas during the Kheis Orogeny. Coward and Potgieter (1983) suggested that the Kheis Belt followed the 'Kalahari Line' to join up with the Magondi Belt in Zimbabwe. The Kheis and Magondi Belts were interpreted by Stowe (1990) to be the products of 'rift', 'drift' and 'collisional' stages of a plate-tectonic cycle affecting the western continental margin of the combined Kaapvaal and Zimbabwe Cratons.

TECTONIC SETTING OF THE MAGONDI SUPERGROUP

DEWERAS GROUP

The palaeoenvironments of the Deweras Group (alluvial fans, playa lakes, volcanics) indicate that it was deposited in a continental rift basin (Bliss, 1970; Cooper, 1978; Sutton, 1979; Master, 1991), which had a faulted margin with the Archaean basement to the east (Maiden et al., 1984). Good modern analogues for the depositional environments of the Deweras Group are the alluvial fans and playa lakes of Death Valley in California, the Dead Sea graben of Israel and Jordan, the eastern arm (Gregory Rift) of the East African Rift System (Miall, 1981), and playa-lake basins of Texas and New Mexico (Wood and Osterkamp, 1987). Ancient analogues have been described from the Upper Triassic Blomidon redbeds of Nova Scotia (Hubert and Hyde, 1982), the Torridonian of Scotland (Turner, 1979), and the Eocene Green River Formation, Wyoming (Eugster and Hardie, 1975; Smoot, 1978, 1983).

The architecture of the Deweras basin was in the form of an elongate, fault-bounded trough, which was parallel to the sinistral strike-slip faults which traverse the Archaean Zimbabwe Craton. The basin fill pattern was one of transverse alluvial fans and transverse braid plains, with central distal playa lakes (basin fill model 1 of Miall, 1981). Consideration of the trends of en-echelon synsedimentary folds indicates that the Deweras trough was undergoing left-lateral wrench deformation during or shortly after sedimentation (Master, 1991). Modern analogues of such a strike-slip basin are the Salton Sea Trough, California (Crowell, 1974), and the Dead Sea basin, Israel. The Deweras Group volcanics are subalkaline basalts, which are typical of continental flood basalts, and they show considerable LREE enrichment, which indicates crustal contamination. The temporal evolution of the Deweras volcanics indicates the involvement of an enriched mantle plume, probably due to asthenospheric upwelling during progressive rifting (McKenzie, 1978; Bhattacharji and Koide, 1987).

A plausible tectonic environment in which the Deweras rift basin could have developed, is in a transtensional continental back-arc setting behind an Andean-type magmatic arc located to the west. In this setting, back-arc rifting is related to plume generation above a subducted oceanic slab, and if the rifting proceeds to an advanced stage, this leads to the generation of a marginal oceanic basin like the Sea of Japan, or with considerable transtension, a strike-slip oceanic basin like the Gulf of California. In the case of the Deweras Group, the rifting did not proceed beyond a thinning of the continental crust, and the rift basin was floored by continental crust at all times.

LOMAGUNDI AND PIRIWIRI GROUPS

The Lomagundi Group, which overlies the Deweras Group unconformably, has a lithological sequence which is characteristic of marginal marine and shallow shelf settings. The orthoquartzite-dolomite succession of the Mcheka Formation is typical of marginal marine sequences.

The dolomites were deposited in shallow water, in the shallow intertidal to subtidal zones, as is required by the presence of stromatolites and oolites. The orthoquartzites were deposited in intertidal and subtidal environments, as well as in supratidal aeolian sand dunes. The minor iron formations and the Striped Slates were deposited in deeper subtidal environments, while the greywackes of the Sakurgwe Formation were distal turbidites. The lithological sequence is very similar to the succession in the Transvaal Sequence of Griqualand West (Beukes, 1986).

The Piriwiri Group can be considered the distal facies equivalent of the contemporaneous Lomagundi Group (Leyshon and Tennick, 1988). The graphitic and pyritic argillites, cherts, and greywackes were deposited in deep euxinic waters, possibly in continental slope, submarine fan and abyssal plain environments. Volcanogenic hydrothermal emanations on the sea floor may have given rise to the abundant cherts, manganese-rich beds, and minor iron formations. The Lomagundi and Piriwiri Groups represent a marine transgression over the continental sediments of the Deweras Group. This implies subsidence of the rift fill below sea level. Most rifts initiate with an upwelling of hot asthenospheric material, which then cools and contracts, leading to a phase of thermal subsidence (McKenzie, 1978; Sclater and Célerier, 1987). The Lomagundi and Piriwiri Groups thus represent the thermal subsidence phase of the developing Magondi rift basin.

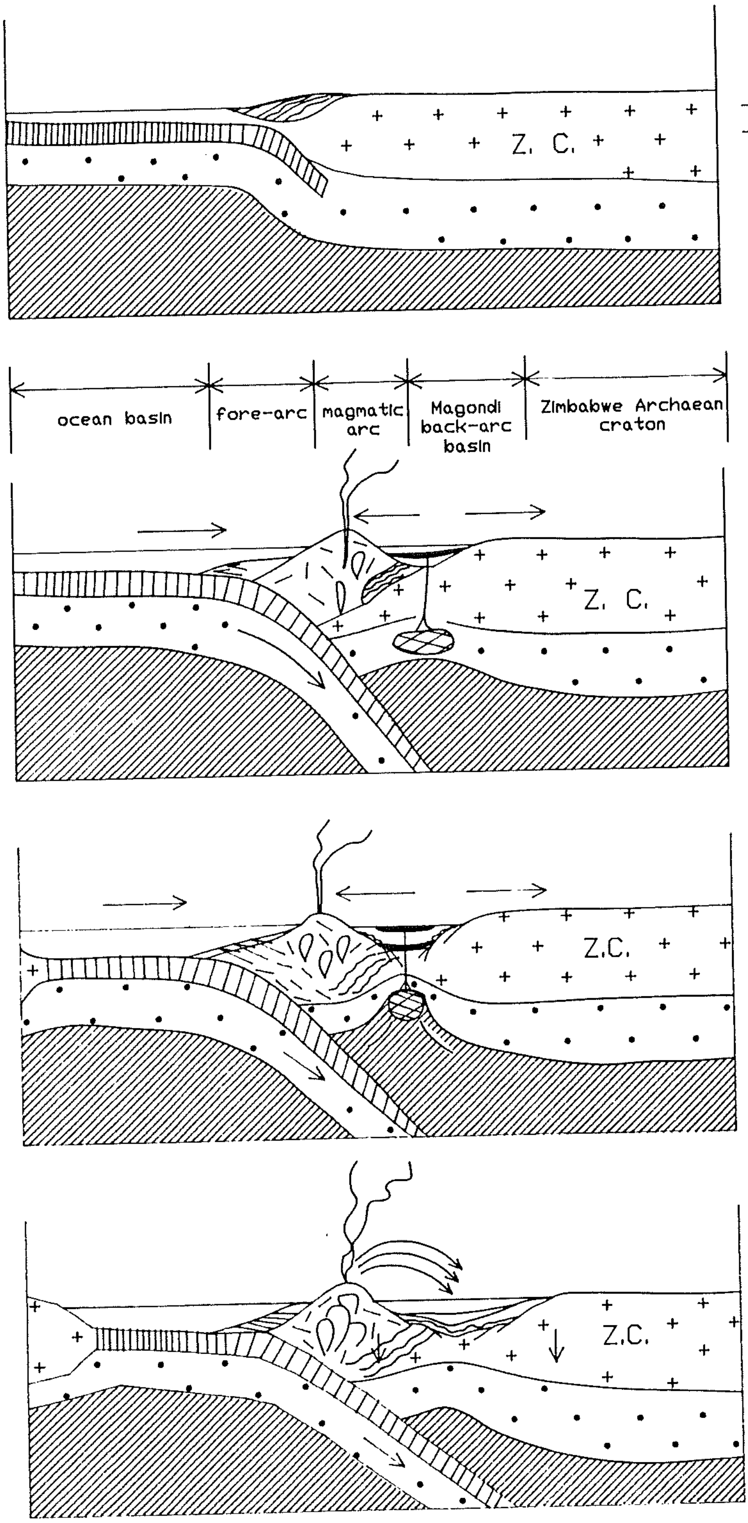
DISCUSSION

Rift basins that undergo very large amounts of extension eventually become floored by oceanic crust, and the rift shoulders develop into passive margins (McKenzie, 1978; LePichon and Sibuet, 1981; Sclater and Célerier, 1987). However, passive margins, in contrast to active continental margins, do not contain acid-intermediate volcanics, which are normally associated with magmatic arcs (Latin and White, 1990). The Magondi basin was regarded by Stowe (1990) as a typical "rift-drift" basin, with the Lomagundi and Piriwiri Groups representing a passive margin. However, the Magondi Basin appears to have been floored at all times by continental crust (Hurungwe gneisses, and gneisses of the Dete-Kamativi area), and there is absolutely no evidence whatsoever for the former presence of oceanic crust. In addition, the supracrustal sequences of the Dete-Kamativi Inlier appear to have been deposited on the western margin of the Magondi Basin, which thus did not undergo much extension.

The volcanics are of critical importance in determining the tectonic setting of the Lomagundi and Piriwiri groups. The presence of pyroclastic rocks (felsites, agglomerates, tuffs) and andesites indicates that active explosive volcanism (acid to intermediate type) was going on during sedimentation. The c.2.05 Ga granodioritic rocks from the Dete-Kamativi Inlier, as well as c.2.06 Ga granitoids from the Kariba area (Loney, 1969), were emplaced contemporaneously with the sedimentation in the Magondi Basin, and would have formed a magmatic arc which was the source of the volcanic and volcaniclastic rocks in the Lomagundi and Piriwiri Groups. Samarium-neodymium studies on granitoids of the Choma-Kalomo block in Zambia (immediately west of the Magondi Belt), indicates that their crustal precursors, even if derived from a depleted mantle, could not have formed much earlier than 2 Ga ago (Hanson et al., 1988). This implies a lack of Archaean crust in that region, and a crust-forming event at c.2 Ga. The Mufulira granite of the Zambian Copperbelt, and the Mokambo granodiorites, monzogranites and granites have been dated at c.2,018 Ga (Cahen et al., 1970; Musengie and Makutu, 1987), while muscovite from a pegmatite cutting basement rocks at Mindola Mine was dated at c.2,02 Ga (Cliff and Clemmey, 1976). It thus appears that the c.2 Ga magmatic arc extended at least from western Zimbabwe to the Zambian Copperbelt (Fig. 9). On the basis of regional considerations, it is postulated that the extensive magmatic arc, representing juvenile crust, was produced as a result of the subduction of oceanic lithosphere beneath the Zimbabwe Craton in an easterly dipping subduction zone (Master, 1990d). The Magondi Basin was formed in a back-arc setting with respect to the magmatic arc, and a similar setting is postulated for the correlative sequences in the Kheis belt, and in Zambia, Mozambique and Malawi (Fig. 9). Similar back-arc basins with calc-alkaline volcanism include the Palaeozoic Welsh back-arc basin (Bevins et al., 1984; James, 1987), and the Cenozoic Rio Grande rift, New Mexico (Ramberg and Morgan, 1984; Olsen et al., 1987).

In a major compilation and review of early and middle Proterozoic supracrustal sequences, Condie (1982) showed that such sequences can be grouped into three contrasting lithologic associations: (i) quartzite-carbonate-shale; (ii) bimodal volcanics-quartzite-arkose; and (iii) continuous (tholeiitic and calc-alkaline) volcanics-greywacke. The respective tectonic settings of these assemblages were considered to be (I) stable continental margins or intracratonic basins, (II) lithosphere-activated continental rifts or aborted mantle-activated rifts, and (III) mantle-activated cratonic rifts or basins associated with convergent plate boundaries (Condie, 1982). Using this tripartite scheme, Condie (1982) assigned the Deweras Group to a class (II) tectonic setting (rift), and citing Swift (1961), he regarded the Lomagundi and Piriwiri Groups to be a simple quartzite-shale-carbonate sequence which was assigned a class (I) tectonic setting (stable continental margin). However, the lithological sequence in the Piriwiri Group (greywackes, shales, intermediate volcanics) is of type (III), implying association with a convergent plate boundary. The quartzite-carbonate-shale assemblage may also form on the continental side of a back-arc basin, as has been suggested for the Epworth Basin in the Coronation geosyncline, Canada (Hoffman, 1973; Hoffman and McGlynn, 1977). The lithological associations of the Magondi Supergroup can thus be interpreted to imply an early continental rift phase (Deweras Group), followed by a subsidence phase with development of a marginal basin influenced by a convergent plate boundary, ie. a continental back-arc basin.

A continental back-arc setting would explain the asthenospheric upwelling responsible for the enriched Deweras volcanics (with high La and Ce due to crustal contamination), the subsequent limited amount of extension, coupled with a large amount of intermediate volcanic and pyroclastic inputs into the basin, and basin destruction and inversion soon after formation. The lack of advanced rifting is explained by the onset of the Magondi Orogeny, which followed soon after sedimentation of the Magondi Supergroup, most likely in response to collision of the magmatic arc with a continental mass to the west of it (Kasai-Congo craton), after consumption by subduction of the intervening oceanic crust (Master, 1990d). The arc terrane overrode the western part of the Magondi Basin, producing granulite facies metamorphism, and caused easterly-directed thrusting of the basin sequences onto the adjacent Archaean Zimbabwe Craton (Treloar, 1988). Various stages in the evolution of the Magondi Basin, from the initiation of back-arc rifting to the Magondi Orogeny are summarised in Figure 10.



c. 2.2 Ga

Initiation of Subduction

Thrusting and accretion of Kariba paragneisses on craton margin.

c. 2.1 Ga

Early back-arc rifting

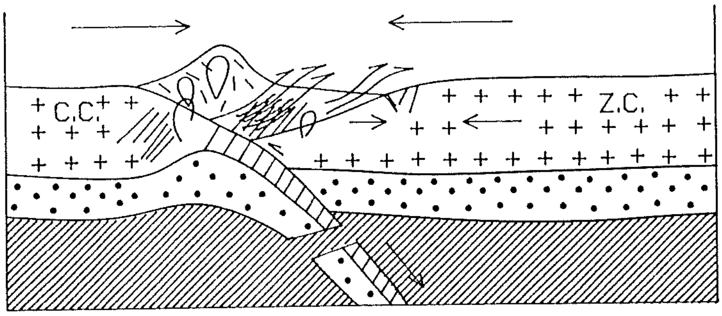
Deweras Group basalts with I-type-MORB characteristics (mixed lithospheric source)

Later rifting

Deweras Group basalts with P-type-MORB characteristics (asthenospheric mantle plume source)

Thermal subsidence stage

Lomagundi & Piriwiri Group deposition.
Calc-alkaline volcanic and pyroclastic input into basin from magmatic arc.



c. 1.8 Ga

Collisional stage

Magondi orogeny. Magmatic arc thrust over back-arc basin. Back-arc basin sequence thrust onto Zimbabwe craton.

//// = granulite metamorphism

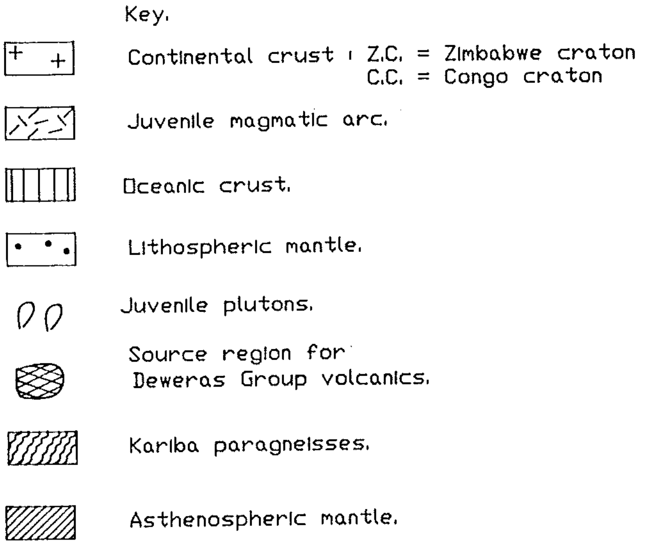


Figure 10: *Schematic summary of the evolution of the Magondi Basin between 2,2 to 1,8 Ga, from the initiation of back-arc rifting, and the deposition of the Deweras, Lomagundi, and Piriwiri Groups, to the Magondi Orogeny.*

MAGONDI OROGENY

The Magondi Orogeny was defined by Leyshon (1969a,b) from structural work in the Copper Queen area. The term was applied to the tectonometamorphic event that was responsible for the intense deformation and metamorphism of the Piriwiri and Lomagundi Group rocks of the Magondi Belt. The first regional study of the belt was by Jacobsen (1962), who equated the Lomagundi System and its deformation with the Damarides-Katangides of Namibia and Zambia. Jacobsen (1969) called the fold belt the "Lomagundides". There have been attempts to correlate the Magondi deformation with events in Zambia, in particular with a N-S trending "Tumbide" event (De Swardt et al., 1965; Vail, 1968; Vail et al., 1968). Recently, two regional syntheses of the Magondi Mobile Belt have been published (Treloar, 1988; Leyshon and Tennick, 1988). In the south, the belt is a typical fold-thrust belt, with imbricate stacks of Magondi Supergroup rocks thrust southeastwards onto the Archaean Zimbabwe Craton, while in the north the structural style is of a more thick-skinned type, with basement gneisses imbricated within the sedimentary sequence (Leyshon and Tennick, 1988; Treloar, 1988). The metamorphism in the north, which increased from greenschist to granulite facies, was explained by thermal relaxation following overthrusting of hot "early Proterozoic" gneisses (Late Archaean (?) Hurungwe gneisses, Master, 1991), which effectively sandwiched the Magondi rocks between the Archaean cratonic basement below, and the gneissic basement above (Treloar, 1988; Treloar and Kramers, 1989).

MINERALIZATION

DEWERAS GROUP

The Deweras Group is host to several stratabound copper-silver deposits which are currently being mined, or have been exploited in the past. The deposits ocur in two main areas, around Mhangura (Mangula, Norah and Silverside mines) and around Alaska (Shackleton/ Avondale, Angwa and Hans mines). In addition to the economic deposits, there are a host of minor sub-economic copper occurrences, both stratiform and vein-type, which have been investigated in numerous claims and Exclusive Prospecting Orders (Morrison, 1974, 1975).

Mangula Mine

Mangula is by far the largest known deposit in the basin. Mining commenced in 1957, and its original size is estimated to have been 60 mt at an average grade of 1.2% copper and 20 g/t silver (Maiden et al.,1984). Important by-product gold, platinum and palladium are recovered from the ores. Copper mineralization occurs over a stratigraphic thickness of about 200m in the basal part of the Deweras Group, hosted by arkoses, conglomerates and semipelitic schists deposited in alluvial fan, braided stream and distal flood plain environments (Master, 1989a). For mining purposes, the deposit is divided into eight parallel tabular orebodies separated by subgrade mineralization or barren zones, and extending along strike for 2km. Most of the orebodies coalesce at depth and extend down-dip to about 900m below surface.

The main ore minerals are chalcocite and bornite, with subordinate chalcopyrite and pyrite, minor molybdenite and native silver, and trace argentite, wittichenite, uraninite, and native gold. Silver also occurs as a lattice-substitution in copper sulphides. There is no galena or sphalerite. The orebodies are zoned both vertically and laterally, having chalcocite cores surrounded by bornite-rich zones, passing out into narrow fringes of chalcopyrite and then into wide pyritic zones containing very minor sparsely disseminated pyrite. Sulphur isotope values in the sulphides have a range in del ^{34}S of -2.3 to -16.0 permil (Von Rahden and De Wet, 1984a).

Copper mineralization occurs in several forms: (i) as even, banded or cloudy disseminations in arkose and schist; (ii) as a replacement of detrital iron-titanium oxides on crossbed foreset laminae; (iii) as syntectonic quartz-microcline-sulphide (-hematite-carbonate) veins occupying brittle fractures in competent lithologies (Master and Maiden, 1986b); and (iv) as cleavage-parallel syntectonic quartz-microcline-sulphide veins in semi-pelitic schists.

The ore textures are interpreted as the result of partial remobilization of pretectonic disseminated mineralization during polyphase deformation and metamorphism. Alteration in and around the orebodies is characterized by the development of quartz, microcline and haematite. A major zone of intense alteration is found in arkosic redbeds between the two largest orebodies. In this zone, sedimentary structures such as cross-bedding are completely destroyed, and replaced by stratiform zones of haematite and magnetite bands and ellipsoids which are parallel to both bedding and cross-bedding. The magnetite-rich ellipsoids also contain uraninite, and structural analysis has shown that they are true strain ellipsoids, and formed by deformation of originally spherical diagenetic reduction spots in the arkosic red-beds. Oxidising metamorphic fluids generated by pressure solution during the first phase of deformation were responsible for very similar haematite-microcline alteration, especially around faults and veins.

The stratabound mineralization at Mangula Mine, and the accompanying alteration, was produced by saline, slightly alkaline oxidising basin brines, which evolved through reaction with evaporites in the sequence (Master, 1990c), and which leached metals out of the red beds, especially from detrital components like titanomagnetite, chromite, zircon, apatite and labile ferromagnesian minerals (Master, 1991; Master and Tredoux, 1987). The high copper and silver contents of the ores, the relatively low gold and platinoid contents, and the absence of lead and zinc are explained by the respective solubilities of these metals in the postulated ore fluids (Master, 1991). Sulphide precipitation occurred where mineralizing fluids encountered reduced beds and/or reduced fluids, and through replacement of pre-existing pyrite and magnetite.

Norah Mine

The Norah Mine is situated 6 km south of Mangula Mine and was opened in 1972. Disseminated copper-silver mineralization is hosted by a reduced chloritic quartz wacke, with an interbedded evaporitic rock that contains anhydrite, calcite, barite, celestite, tourmaline and sulphides, and in the upper part of an underlying oxidised pink gritty arkose. The ore zone straddles a redox interface between the oxidised permeable footwall sediments (braided stream deposits) and the less permeable reduced chloritic quartz wacke and evaporites (playa lake deposits). The lithologies of the ore zone are enclosed within a thick sequence of anhydrite-bearing dolomitic argillites and ripple-marked arkoses which were deposited in a playa-flat environment (Master, 1989b). These rocks overlie, and are the lateral facies equivalents of, the alluvial fan lithologies that host the Mangula deposit.

The orebody is tabular and up to 10m thick. It tapers gradually from its thickest development and thins out along strike in both directions over a restored strike length of about 1.5km. The orebody is faulted out at depths of between 300 and 500m by a compressional wrench fault. The main ore minerals are bornite and chalcopyrite, with subordinate chalcocite and pyrite. The mineralized zone has a sharp hanging-wall contact in the chloritic quartz wackes, and a diffuse contact in the underlying gritty arkose. The ore minerals are zoned stratigraphically from the top to the bottom in the sequence chalcocite-bornite-chalcopyrite-pyrite, with considerable overlap between the various zones. Sulphur isotopes in the disseminated sulphides show a considerable spread in del ^{34}S values, from +20.9 to -22.3 permil, probably indicating biogenic sulphide formation (Von Rahden and De Wet, 1984a). A significant amount of mineralization is present in axial-planar quartz-carbonate-microcline veins in a metadolerite sill that intruded the competent quartz wacke. Xenoliths of sulphide-bearing metasediment in the metadolerite, and textural evidence, including contact metamorphic actinolite replacing copper sulphides, indicate that the sill was emplaced subsequent to the disseminated mineralization in the wallrock metasediments; structural relationships show that the sill predates the first cleavage-forming deformation event. There were several episodes of syntectonic remobilization of sulphides into veins occupying brittle fractures, especially in the sill. The orebody has been intensely folded and severely disrupted by wrench, normal and thrust faults, and occurs as several discrete blocks.

Other Deposits in the Deweras Group

Silverside Mine

About 15km ESE from Mhangura is the Silverside deposit, occurring in an outlier of Deweras Group rocks on the eastern edge of the basin. The rock sequence comprises a basal mafic volcanic unit consisting of lava flows separated by pyritic interflow sediments, overlain by a diamictite, arkosic, pelitic, and semipelitic schists, graphitic schist, and thinly bedded anhydrite-bearing dolomites. The sequence is interpreted as volcanic and volcaniclastic, alluvial fan, lacustrine and playa deposits formed in a fault-bounded sub-basin. The rocks have been extensively thrust faulted. The orebodies are related to fracture systems, usually marked by quartz-carbonate veining and silicified breccia zones (Jacobsen, 1969).

The mineralogy is complex due to supergene enrichment, but the main primary sulphides are chalcocite, bornite, and chalcopyrite. The orebodies and their associated fracture zones are contained within envelopes of quartz-carbonate alteration with an outer hematite zone. There are minor zones of stratabound replacement mineralization in the interflow sediments, where syntectonic chalcopyrite replacement of pyrite has occurred, accompanied by quartz-carbonate-epidote alteration. The Silverside fracture systems, and hence the mineralization, are related to the Magondi deformation event.

Alaska group of deposits

In the Alaska area, about 50 km south of Mhangura, there is a cluster of small copper-silver deposits, ranging up to 6mt in size, at an average grade of around 1.5% Cu. Individual orebodies may have much higher grades- the L3 orebody at Shackleton Mine was running at 8.88% Cu, 182 g/t Ag and 3 g/t Au. Descriptions of the deposits have been given by Newham (1986). At the Angwa deposit, an upper orebody is developed in trough-crossbedded arkoses below a persistent argillite horizon and a lower orebody is hosted largely by conglomerate. The Avondale deposit is hosted by arkoses sandwiched between two argillite horizons. The small Hans deposit is hosted by arkoses overlain by volcanics, and occupies the crest of an anticlinal structure. At the Shackleton deposit, there are up to 16 stacked orebodies hosted by cyclic units of conglomerate and trough-crossbedded arkoses separated by barren argillites. The ore-bodies, which have been likened to saddle-reefs, straddle a fault which occurs in the axial plane of an anticline, and which is occupied by a post-ore metadolerite dyke (Newham, 1986).

The deposits consist mainly of disseminated chalcocite and bornite with subordinate chalcopyrite and minor pyrite. Silver occurs in the lattice of copper minerals, preferentially in chalcocite, as shown by electron microprobe. Some mineralization occurs along bedding plane shears and in cleavage-parallellenticles. Along dyke margins there has been partial remobilization into quartz-sulphide veins occupying brittle fractures. Hematitic alteration is found in red-beds associated with most of the individual orebodies. Sulphide sulphur isotopes from Shackleton Mine (and the smaller deposits) show a broad range of del^{34}S values, from +10.6 to -16.3 permil, and have been interpreted to indicate biogenic influence on sulphide precipitation (Von Rahden and De Wet, 1984a).

LOMAGUNDI GROUP

The Lomagundi Group contains copper and gold mineralization which have been exploited in the past. There is a dolomite quarry near the Chinhoyi caves which supplies the Alaska smelter. Traces of lead mineralization have been found at three localities (Stagman, 1961), but very little prospecting has been done for these metals, and only one prospect is known, the Dambudzoko Claims. Two economic copper deposits (Alaska and Shamrocke mines), and a few copper claims have been found in rocks of the Lomagundi Group. The only gold producer was the Lovel Mine. Slate has been quarried from the Striped Slates of the Mcheka Formation (Stowe, 1978).

Alaska Mine

The Alaska Mine, which is very old, was worked for copper by the indigenous population (Brackenbury, 1906; Molyneux, 1919; Maufe et al., 1923; Anon, 1962b, Summers, 1969). The mineralization occurs in highly sheared dolomites and intercalated sandstones and siltstones, and consists mainly of oxidised malachite ore, with some hypogene chalcocite which occurs as pseudomorphs after pyrite, and minor chalcopyrite (McCann, 1928; Stagman, 1961; Newham, 1986). Sulphur isotopes of the sulphides range in del^{34}S from +8.1 to -2.0 permil (Von Rahden and De Wet, 1984). The malachite occurs as paint-like films along cleavage planes and fractures. Other oxide minerals recorded are chrysocolla, cornetite, plancheite, shattuckite, dioptase, cuprite and tenorite. Native copper occurs as dendritic crystals, and as sheets along fractures and faults. J.B.E. Jacobsen (1964) described the geology of the deposit, and interpreted the host rocks to be part of an allochthonous nappe that was bounded at the base by a major breccia zone. The nappe consisted of several imbricately stacked thrust sheets, in what would today be termed a duplex structure. Newham (1986) reinterpreted the structure to be a simple syncline, as shown in his idealised cross-section of the deposit. This is at total variance with the detailed mapping of Jacobsen (1964), as well as with maps produced by the mine in 1970.

Examination of a sample from the sandstone orebody, which contains 'chalcocite' pseudomorphs after pyrite, revealed convincing evidence for the timing of the mineralization. The 'chalcocite' was shown by XRD to be the closely related mineral djurleite ($Cu_{31}S_{16}$). The djurleites, pseudomorphous after cubic pyrite, are deformed into parallelepipeds, and appear diamond-shaped in cross section. The host rock is a highly sheared metasiltsone, which has shear planes with talcose partings, and which have a strong slickensided striation lineation, with steps at right angles to this. Fibrous minerals growing in the lee of the slickenside steps are oriented parallel to the lineation. The long axes of the deformed djurleite pseudomorphs are also aligned parallel to the lineation, and they appear to have stretched during simple shear. The djurleite pseudomorphs have quartz-rich pressure shadow fringes, indicating that the replacement took place after these fringes had formed around the earlier euhedral pyrites. If the djurleite replacement had taken place before any deformation, there would be no pressure shadows around the djurleites, but instead, because of the low grain boundary energy and strength of chalcocites (Davies, 1965), they would have been totally flattened into parallelism with the cleavage. The deformed pseudomorphs with pressure shadows indicate that the replacement must have happened syntectonically (Ferguson and Harte, 1975). A first increment of deformation produced a schistosity in the rock, and formed quartz pressure shadows around rigid pre-existing pyrite crystals. The rock was then infiltrated syntectonically by copper-bearing solutions moving along permeable cleavage and fracture planes, which replaced the pyrite by djurleite. The djurleites, with their inherited quartz pressure shadow fringes, then underwent further deformation, in which they behaved plastically, and suffered rotation and flattening by simple shear (Etchecopar and Malavieille, 1987). A similar example of chalcocite pseudomorphs after euhedral pyrite has been recorded from the Klein Aub Mine in Namibia (Borg, 1987), but in this case the replacement was post-tectonic, since the chalcocites, with their quartz pressure shadows, are undeformed.

Shamrocke Mine

The Shamrocke deposit, which is situated about 50 km north of Mhangura, has been described by Kyle (1972), and Thole (1974, 1976). The rocks in this area are more highly deformed, and were subjected to amphibolite grade metamorphism. The orebody is confined to a fine-grained calcareous biotite-oligoclase rock (meta-arkose) which forms discontinuous lenses within a unit of graphitic schist (Thole, 1976). A nearshore shallow-water depositional environment is interpreted. The sulphides are disseminated through the meta-arkose, and consist mainly of chalcopyrite and pyrrhotite with minor arsenopyrite, sphalerite, and pyrite. Ore textures show that the sulphide mineral assemblage has been subjected to the same deformation and metamorphic events as the host rocks. Sulphur isotopes in the sulphides have del^{34}S values ranging from -1.9 to +14.8 permil, with a mean of +8 permil (Thole and Robinson, 1976). There is a strong zonation of del^{34}S values across the orebody, with the values getting lighter from the footwall to the hangingwall of the mineralized zone.

Lovel Mine

The Lovel Gold Mine, from which 64 kg of gold was recovered between 1920 and 1939, is situated in the Lower Dolomite of the Mcheka Formation, Lomagundi Group (Tennick and Phaup, 1976). The ore was in vuggy quartz veins which contained abundant hematite, calcite, red ochre, and minor copper sulphides. In the zone of supergene enrichment, coarse gold, some of it well crystallized, was present in vugs in the vein quartz. Gold mineralization was also associated with veins next to a schist horizon interbedded with the dolomite. The gold occurred in the vein, as well as in the schist and dolomite, which had a reddish alteration in the mineralized zones. A report by Anon (1931) in the Rhodesian Mining Journal compared the gold mineralization at Lovel Mine with the Sabie-Pilgrims Rest goldfield in the eastern Transvaal, where similar mineralization is found associated with shales interbedded with the Malmani dolomite, Transvaal Sequence.

PIRIWIRI GROUP

The Piriwiri Group is the host to metallic mineralization (massive base metal sulphides, manganese, gold-copper) as well as deposits of industrial minerals (graphite, kyanite, muscovite, beryl) and gem minerals (tourmaline, aquamarine, topaz, etc.). The most important deposits are undoubtedly the massive sulphide Zn-Pb-Cu-Ag deposits of the Sanyati area.

Sanyati Zn-Pb-Cu-Ag Massive Sulphide Deposits

The Sanyati polymetallic Zn-Pb-Cu-Ag massive sulphide deposits are situated about 100 km SW of Chinhoyi. They are expressed on surface as a line of spectacular malachite-stained ferruginous gossans which extend from the Copper King Dome to the Copper Queen Dome, over a strike length of about 25 km. The deposits, including the Copper Queen, Copper King, Copper Joker and Copper Straight prospects, which are all developed along the same strike, were first pegged in 1910, and briefly worked for copper in 1918-1919. Their subsequent history is given by Leyshon (1969). The only prospect that has been drilled and developed underground is the Copper Queen prospect (J-Lines), where about 15 mt of ore at about 7% combined metals was proven. The mineralization is closely associated with a band of tremolitic ferruginous dolomite marble which is surrounded by phyllites, schists, and feldspathic quartzites. The marble was regarded as a "skarn" by Bahnemann (1957, 1961). The hypogene ore minerals consist mainly of pyrrhotite, sphalerite, chalcopyrite, galena, arsenopyrite, and pyrite, with minor magnetite, cubanite, valeriite and marcasite (Bahnemann, 1957,1961). Rare rammelsbergite has also been reported. In the oxidation zone, a variety of secondary minerals, including hemimorphite, cornwallite, legrandite and duftite, have been identified by XRD (Kalbskopf, 1987). In addition, pyromorphite, mimetite, anglesite, pharmacosiderite, bayldonite, and levandulan have been provisionally identified (Kalbskopf, 1988).

Structural interpretations by McCann (1928) and Bahnemann (1957) indicated that the orebodies have been tightly folded. Preliminary investigations by the author of an underground adit indicates that the orebodies may have been repeated up to three times by thrusting. Bahnemann (1957,1961) suggested that the Sanyati deposits were skarn deposits related to emplacement of the Copper Queen and Copper King domes, but the style of mineralization shows great similarities with the class of sediment-hosted massive sulphide deposits referred to as "sedimentary exhalative" or "sedex" deposits (Lydon et al., 1981). The question of the origin of these highly deformed and metamorphosed deposits must be deferred until more detailed studies have been carried out. The continuity of the gossans over 25 km indicates that the Sanyati deposits have the potential to be a major ore district (up to 200 mt of ore), which could be comparable with other giant early Proterozoic deposits like Broken Hill (NSW), Mt.Isa, and McArthur River (Queensland).

"Piriwiri Mineral Belt" Au-Cu Deposits

Minor vein-type copper-gold occurrences are associated with the various "volcanic centres" of the Volcanic Member of the Chenjiri Formation. These occurrences have been referred to as the "Piriwiri Mineral Belt" by Molyneux (1919). The main prospects were located at the Montana, Crescent, Gondia and Northern Star mines. The mineralization consists of gold-rich copper-sulphide-bearing quartz-carbonate veins that were emplaced in andesites or phyllites (Gondia Mine). In addition to these occurrences related to the volcanics, there are small gold mines and prospects along the Angwa River, of which the largest is the D Troop Mine (Kirkpatrick, 1976; Nutt, 1984). These deposits consist of quartz veins situated in phyllitic sandy argillites. Further north, at the Redwing Mine, gold mineralization is associated with a skarn on the contacts of an ultramafic talc-magnetite intrusive (Nutt, 1987; Kalbskopf and Nutt, 1986; Nutt and Carr, 1988). Other minor gold occurrences (Kuyu and Chihambe Mines) occur at the base of the Umfuli Formation, where gold-bearing quartz stringers are associated with highly pyritiferous graphitic slates interbedded with greywackes and phyllites (Tennick and Phaup, 1976). Nutt (1984) listed a total of 52 small gold mines in the Piriwiri Group which had declared a production of 1587,48 kg of Au between 1890 and 1977.

Manganese

Some of the cherty quartzites interbedded with graphitic schists of the Umfuli Formation are extremely enriched in manganese, and have been exploited in a few places (Tennick and Phaup, 1976; Kirkpatrick, 1976). Macgregor (1937) mapped a 0,15- to 6,0-m-thick bed of dark-grey, pyrolusite-bearing banded quartzite in graphitic shales, which extended over a strike length of about 16 km. In other places, eg. Morocco claims, manganese oxides are associated with quartz veins in argillaceous country rock (Kirkpatrick, 1976). Harrison (1972) examined manganese ores of the Sheffield Claims, which occur as discontinuous lenses of dark grey, compact pyrolusite and manganite in a 20m-wide silicified and ferruginous zone over a strike length of 250m, enclosed within graphitic and pyritic slates. The ores contain up to 22% Mn (average 9,24%, n=12), and are also significantly enriched in copper (average 1078ppm, maximum 0,52%), nickel (average 1128 ppm, maximum 0,1%), cobalt (maximum 375ppm) and zinc ("up to several thousand ppm"; Harrison, 1972).

Graphite

The graphitic schists of the Piriwiri Group have in places been highly deformed and metamorphosed to high grades, and the resulting flake graphite has been exploited at the Lynx Graphite Mine and in several smaller prospects (Muchemwa, 1987). The mineralization at Lynx Graphite Mine is confined to a horizon of graphite schist which is interbedded with sillimanite and biotite gneisses and feldspathic psammites (Armstrong, 1975). The graphitic horizon has been traced geophysically and by trenching for a strike length of over a kilometre (Davies, 1982; Muchemwa, 1987).

Kyanite

Wiles (1961) mapped a belt of kyanite pseudomorphs after chiastolite, developed in Piriwiri schists, near the Angwa River. The kyanites occur in a variety of crystal habits, from pure pseudomorphs after chiastolite, to neomorphic "christmas-tree" intergrowths replacing the andalusite (Workman and Cowperthwaite, 1963). On Masterpiece Farm, there are large (0,5 Mt), high-grade kyanite deposits formed by in situ eluvial concentration in the top 0,5m of the soil profile, through weathering and removal of the friable graphitic schist matrix.

Pegmatite Deposits

In the Mwami (Miami) area, a large number of pegmatites, originating from the Miami granites, are found intruded into Piriwiri Group schists. The pegmatites consist of quartz, alkali feldspars and muscovite, with lesser tourmaline and beryl. They have been exploited in the past as a source of industrial muscovite in the "Miami Mica Field" (Maufe, 1920; Wiles, 1961; Wiles and Tatham, 1962). Some industrial beryl and minor tantalo-columbite has also been produced. Wolframite has been found in one small area, the Honey claims. The pegmatites are also mined on a small scale for gem minerals, which include tourmaline (elbaite), aquamarine, blue topaz, chrysoberyl (cymophane) and deep blue euclase (Kanis, 1962). Rare grandidierite has also been found (Warner, 1972). Gem-quality almandine garnets are recovered from the country-rock garnet-mica schists. In the Nyaodza area near Kariba, the Piriwiri Group is invaded by numerous muscovite-mica-bearing pegmatites and minor quartz-wolframite veins, which are related to a hydrous retrograde event following granulite facies metamorphism during the Magondi Orogeny (Broderick, 1976). In the granulites, sillimanite-bearing gneisses may be a potential source of industrial sillimanite.

DETE-KAMATIVI INLIER

Malaputese Formation

Although copper staining is widespread in the Malaputese Group, significant copper sulphide mineralization is restricted to rocks of the Eastern Domain, mainly in association with the mafic amphibolites. There was one operating mine in the area, the Gwaai River Mine, and many small claims and workings. At the Gwaai River Mine, there are three ore shoots in the form of elongate cigar-shaped pods which are restricted to the noses of fold closures, and which plunge parallel to co-linear F1 and F3 deformation structures. There are two types of copper occurrences: in shears and fractures within tremolite and cummingtonite-anthophyllite amphibolites which are enclosed in hornblende amphibolites; and in siliceous and calc-silicate-rich interflow metasedimentary intercalations in the mafic sequence. The sulphides consist of chalcopyrite, pyrite, and pyrrhotite. At the Adder shoot at Gwaai River Mine, coarse sulphides occur together with vein quartz filling breccias in calc-silicate rocks in the nose of a fold. At the Puff Adder Shaft, finely disseminated sulphide mineralization is localized within bands of vitreous grey quartzite grading outwards into calc-silicate rocks. Enrichments of coarse sulphides are found in quartzites adjacent to small cross-cutting veins and blows of quartz. The orebody varies from 3 to 15m in width, and has a strike length of 400m, and a down-dip extent of at least 470m (Lockett, 1979a). Other copper claims and prospects in the Malaputese Group are all restricted to the mafic amphibolites, and also appear to be of the two types of occurrence seen at Gwaai River Mine (Lockett, 1979a).

The ores appear to have been metamorphosed to high grades, and then retrograded. Ore minerals are intergrown with metamorphic minerals like almandine garnet, cordierite, tremolite, cummingtonite, anthophyllite, and epidote. The ores predate regional granitic events, as they are cut by undeformed granitic intrusions. Bahnemann and Lockett (1979) attributed the origin of the Gwaai River Mine mineralization to syngenetic volcanic exhalations next to fumarolic vents, or to a final degassing of the lava pile. These volcanogenic deposits were then metamorphosed, stretched and deformed into the shape seen today.

An alternative explanation of the origin of these deposits, which is considered much more likely, is that they were generated by metamorphic fluids which leached copper from the volcanic pile during the first deformation and high-grade metamorphic event. The alteration of mafic volcanics is a good potential source of copper, and may have provided the metal in many copper districts (Haynes, 1972; Jolly, 1974; Borg and Maiden, 1987). The metamorphic fluids were channelled along permeable pathways, such as the interflow sediments intercalated with the volcanics, as well as along faults, shears, and brecciated fracture zones in the noses of folds. The copper-bearing fluids would have replaced early-formed pyrite to produce chalcopyrite in these permeable zones, giving rise to the elongate shapes of the orebodies. Pyrrhotite may have formed during the metamorphism by desulphidation of pyrite. The same metamorphic fluids would have given rise to the very widespread, but uneconomic, veins and hydrothermal fracture fillings that cut all the Precambrian rocks of the area (Lockett, 1979). The copper deposits in the Malaputese Group should thus be regarded as metamorphogenic or "metamorphic" rather than "metamorphosed" according to the distinction made by Mookherjee (1970).

Kamativi and Tshontanda Formations

The schists of the Kamativi and Tshontanda Formations are extensively invaded by tin-, tungsten- and lithium-bearing quartz-feldspar-muscovite pegmatites, which are concentrated in five clusters (Lockett, 1979a). The pegmatites, which contain cassiterite and wolframite, as well as minor tantalite-columbite, amblygonite, lepidolite, spodumene, and petalite, have been mined at the Lutope and Kamativi tin mines, and the RHA tungsten mine, descriptions of which have been given by Ewart (1960), Fick (1960), Pilaar (1960), Bellasis and Van der Heyde (1962), Watson (1962), Rijks and Van der Veen (1972), Garaba (1976), Lockett (1979a) and Rusike (1985). The undeformed tin-bearing pegmatites cut across an earlier generation of deformed tourmaline-bearing pegmatites (Lockett, 1979a). Cunningham et al. (1973) briefly referred to a 10 to 20m-thick wolframite and scheelite-bearing tourmalinised schist horizon heavily invaded by pegmatites in the Kamativi belt, which they claimed was syngenetic, but it is suggested here that the tungsten was introduced by the magmatic fluids which were responsible for the pegmatites. Lockett (1979a) showed that at Kalinda in the Kamativi belt, wolframite and scheelite-bearing quartz-microcline-muscovite pegmatites also contain cassiterite. He regarded the tungsten-bearing veins as representing a late hydrothermal phase of the magmatism responsible for the lithium and tin-bearing pegmatites. Minor lead-silver mineralization, in the form of argentiferous galena in quartz veins, has been exploited in the Elbas mine (Lockett, 1979a).

DISCUSSION

The mineralization of the Magondi Supergroup occurred at various times in the history of the basin. Iron-formations and cherty manganiferous horizons were probably formed by syngenetic exhalations. Stratabound sediment-hosted Cu-Ag-(Au-Pt-Pd-U) mineralization in the Dewers Group (Mangula, Norah, Shackleton/Avondale, and Angwa Mines), and the Cu-Ag mineralization of the Shamrocke Mine in the Lomagundi Group, was formed diagenetically by saline basin brines. The major Sanyati stratiform Zn-Pb-Cu-Fe-Ag massive sulphide deposits in the Piriwiri Group were probably "sedimentary exhalative" deposits which formed diagenetically during basin evolution. Minor Cu-Au occurrences of the "Piriwiri mineral belt" are related to the intermediate volcanics and pyroclastic rocks in the Piriwiri Group. The Cu deposits of the Gwaai River Mine and other prospects in the Malaputese Group, the Silverside Mine in the Deweras Group, and the Alaska Mine in the Lomagundi Group, are vein and stratabound metamorphogenic deposits formed syntectonically during the Magondi Orogeny. Other metamorphogenic mineral deposits formed during the Magondi Orogeny include the graphite, kyanite, garnet, sillimanite, muscovite, and minor gold deposits of the Piriwiri Group. Tin-tungsten mineralization in the Kamativi area occurred late in the Irumide cycle, while the muscovite- and semi-precious stone-bearing pegmatites of the Mwami area were intruded into Piriwiri schists during the Pan-African orogeny. Table 2 gives a summary of the stratigraphic positions of metals and minerals in the Magondi Supergroup, and the styles and timing of the mineralization.

CONCLUSIONS

The Magondi Supergroup was deposited at c.2.1-2.0 Ga in an ensialic back-arc basin, which initiated with rifting represented by the alluvial-fan and playa-lake sequences and volcanics of the Deweras Group and part of the Malaputese Formation (pink paragneisses and amphibolites). The rift-stage volcanism was characterised by sub-alkaline basalt flows, which have high La and Ce values indicative of crustal contamination, and which show a temporal evolution from early intermediate types to later enriched types, due to the activity of an enriched asthenospheric mantle plume. Following the rifting stage, thermal subsidence resulted in a marine transgression (Lomagundi and Piriwiri Groups; quartzites and marbles of the Malaputese Formation; Inyantue, Kamativi, and Tshontanda Formations) over the continental alluvial fan sequences of the Deweras Group. The marginal marine and aeolian quartzites, stromatolitic dolomites and striped shales of the Lomagundi Group were the near-shore facies equivalents of the deeper marine graphitic shales, turbiditic wackes and cherts of the Piriwiri Group. Acid- to intermediate-type explosive volcanism, represented by andesitic lavas, agglomerates, felsites and pyroclastic rocks, was going on during deposition of the Lomagundi and Piriwiri Groups. These volcanics and volcaniclastic rocks were derived from an Andean-type magmatic arc to the west of the Magondi Basin, represented by contemporaneous granodioritic and granitic intrusions in the Dete-Kamativi and Kariba areas, and in the basement of the Zambian Copperbelt. The Magondi Supergroup may be correlated with sequences in eastern Zambia and adjacent parts of Mozambique and Malawi, and also with sequences in Botswana and the northern Cape Province of South Africa. The Magondi Orogeny, which took place between c.2.0-1.8 Ga, occurred in

Table 2: Summary of mineralization in the Magondi Supergroup in relation to stratigraphy and basin evolution

STRATIGRAPHIC POSITION	MINERALIZATION Metals/Minerals	Style	Timing
Piriwiri	Muscovite mica, Beryl, Tourmaline, Chrysoberyl, Euclase, Topaz, Ta, Nb, W.	Pegmatites	Syn-D3 (Pan-African) c.550 Ma
Kamativi, Tshontanda	Sn, W, Li, Ta, Nb.	Pegmatites	Late/post-D2 (Irumide) c.970 Ma
Inyantue	Pb, Ag	Veins	Syn-D2 (Irumide) c.1,3 Ga
Kamativi, Tshontanda	Tourmaline	Pegmatites	Syn-D1/M1 (Magondi) c.2-1,8 Ga
Piriwiri	Muscovite mica, Wolframite.	Pegmatites	Syn-D1/M1 (Magondi) c.2-1,8 Ga
Piriwiri	Graphite, Kyanite, Garnet, sillimanite.	Stratabound	Syn-D1/M1 (Magondi) c.2-1,8 Ga
Piriwiri, Lomagundi	Au	Veins	Syn-D1/M1 (Magondi) c.2-1,8 Ga
Lomagundi	Slate	Stratiform	Syn-D1/M1 (Magondi) c.2-1,8 Ga
Malaputese, Lomagundi, Deweras	Cu (Ag, Au, Mo)	Veins, strata-bound replace-ments	Syn-D1/M1 (Magondi) c.2-1,8 Ga
Piriwiri	Zn, Pb, Cu, Ag, Au	Stratiform	Diagenetic, sediment-ary exhalative c.2,1 Ga
Piriwiri	Au, Cu	Disseminated, veins	Syngenetic volcano-genic c.2,1 Ga
Lomagundi	Cu (Ag, Pb, Zn)	Stratabound	Diagenetic, sediment-hosted c.2,1 Ga
Lomagundi	Fe, Mn, Dolomite	Stratiform beds	Synsedimentary c.2,1 Ga
Deweras	Cu, Ag (Au, Pt, Pd, U, Mo)	Stratabound	Diagenetic, sediment-hosted c.2,16-2,1 Ga

response to the collision of the magmatic arc with a continent to the west. The magmatic arc terrane overrode the western part of the back-arc basin, while the eastern part of the back-arc basin was thrust onto the Zimbabwe Craton.

The mineralization of the Magondi Supergroup occurred at various times during the history of the Magondi Basin, from synsedimentary accumulations of iron and manganese, through diagenetic base- and precious-metal deposits and metamorphogenic gold, base metal and industrial mineral deposits formed during the Magondi Orogeny, to pegmatites intruded during later orogenies.

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