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Geology and correlation of the central Irumide belt

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Abstract

The Irumide Fold belt of Zambia consists of a Palaeo to Mesoproterozoic complex of gneisses and granite gneisses and a supracrustal sequence of quartzites and pelites. Although no direct correlation is possible, the metasedimentary sequence is tentatively equated with the Manshya River Group described in the NE. The basement to the Irumide belt consists of the Bangweulu Granites to the North, and the Mkushi gneiss basement (MGB) to the Southwest. Age constraints on the Bangweulu Block are limited, but the Mkushi Gneiss has been dated at ~2050 Ma. A detrital provenance study on a quartzite of the Manshya River Group near Mkushi indicates derivation from terranes of up to 3180 Ma, with a maximum age for the Manshya River Group set by the youngest detrital grain at 1941 Ma. Detrital cores from paragneisses and migmatites in the Serenje area indicate a more uniform detrital source for the sedimentary protolith of 2050–2000 Ma. A more direct age constraint on the Manshya River Group has been provided through an age of 1880 Ma on a concordant rhyolite in the metasedimentary sequence near Chinsali. The Manshya River Group consists of a succession of four pelite and four quartzite Formations. The granitoids, which make up a large portion of the Irumide belt, can be subdivided into an older suite of leucocratic gneisses and biotite-granites, and a younger suite of alkaline, often porphyritic K-feldspar granites. Oversimplified lithostratigraphic division of the "crystalline basement" in the southwest of the Irumide belt has lead to an overestimation of the Palaeoproterozoic basement (MGB). The extent of the Palaeoproterozoic basement awaits re-evaluation through fieldwork.

The main structural trend of the Irumide belt is northeast and is related to extensive crustal shortening during the main stage of the Irumide orogeny. Tectonic transport is directed towards the northwest, with southwest directed backthrusting locally developed to define a double verging overall structure. The compressional stage is characterised by amphibolite grade metamorphism and accompanied by widespread granite magmatism and anatexis.

Keywords: Mesoproterozoic; Palaeoproterozoic; Kibaran; Irumide; Zambia; Muva

1. Introduction

The northeast–southwest trending Irumide belt is a Mesoproterozoic and/or Palaeoproterozoic terrane occupying most of central-eastern Zambia. The Pan-African Zambezi belt to the southwest separates the Irumide belt from the broadly coeval Choma–Kalomo Block. The Lufilian belt to the west overprints the Irumide structures, such that the nature of the Irumide basin below the Lufilian belt is not well known. To the northeast the Irumide belt is bound by the Palaeoproterozoic Ubendian belt, which was reactivated during the Meso and Neoproterozoic. The polycyclic Mozambique belt occurs to the east and southeast while to the north the Palaeoproterozoic rocks of the Bangweulu Block occur (Fig. 1).

The Irumide Belt was first described by Ackermann (1950) and Ackermann and Forster (1960) to consist of an older granitic complex (Die Mkushi Gneisse) and a younger metasedimentary sequence called the Muva Supergroup. Successive mapping by geologists of the Zambian Geological Survey Department from the early 1960s to 1994, referenced herein, has shed more light on the geology of the Irumide belt (Fig. 2; Stillman, 1965; Smith, 1966; Moore, 1967; Cordiner, 1968, 1977; Cvetkovic, 1972; Page, 1973; Daly, 1986; Harding, 1993; Kerr, 1993; Klinck, 1993; Mosley, 1993; Mosley and Marten, 1994; Mapani and Moore, 1995; Van De Velde and De Waele, 1997; Smith and Kerr, 2000).

The northern and northwestern part of the Irumide belt consists of unmetamorphosed clastic sedimentary

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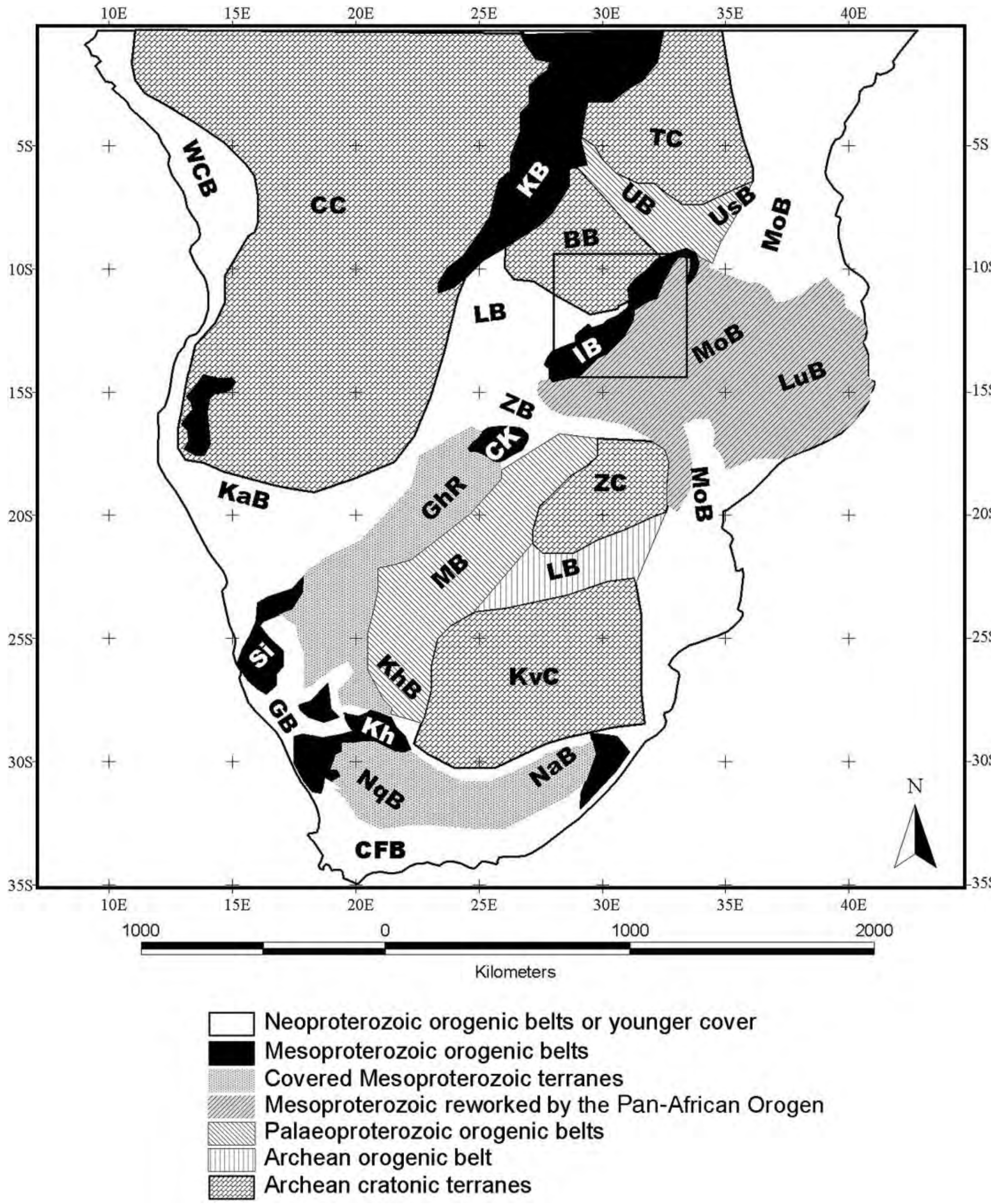

Fig. 1. Major cratons and tectonic belts of the southern African subcontinent.

rocks, which constitute the foreland of the belt (Daly and Unrug, 1982). Further east and in the central part of the belt, the deformation becomes complex and the metamorphic grade increases from lower greenschist to amphibolite facies in the central part of the belt. The central part of the belt (Fig. 2) is characterised by highly deformed basement gneisses and metasedimentary rocks overlain by younger metasedimentary rocks that preserve sedimentary features. The Irumide belt is characterised by the lack of extensive carbonates as those present in the Lufilian, Zambezi and Mozambique belts. The only recorded carbonate bed, occurs at the top of the Manshya River Group (Daly and Unrug, 1982). The lack of thick carbonate sequences and predominance of clastic metasedimentary rocks in the Irumide belt implies that the basin never attained a stable character during deposition.

Previously the belt was considered to have recorded little crustal shortening (Shackleton, 1973; Kröner, 1977; Onstott and Hargraves, 1981). However subsequent work has shown that there is considerable crustal shortening in the Irumide belt both in the foreland region (Daly, 1986) and in the central part of the belt (Daly et al., 1984; Mapani, 1992).

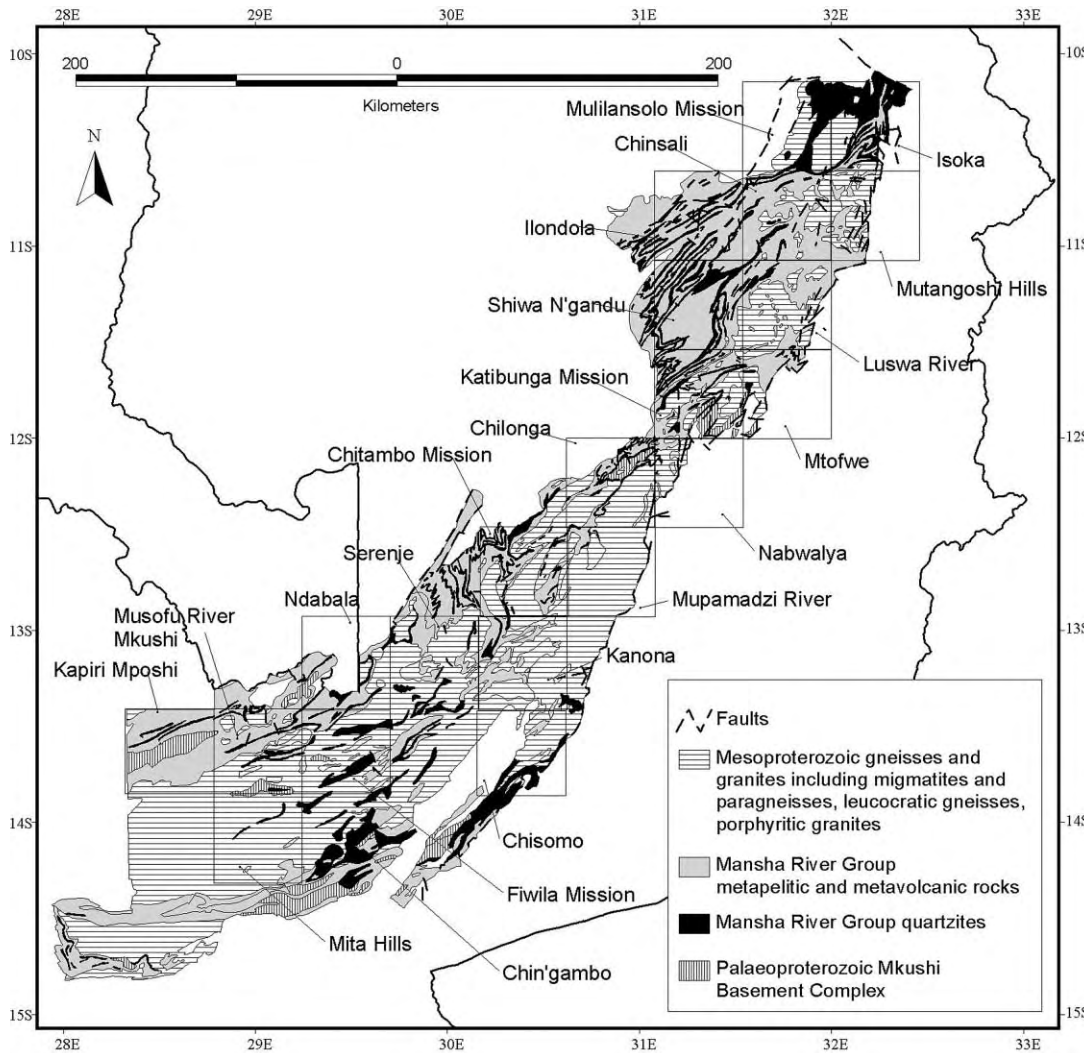

Fig. 2. Overview of the Irumide belt of Zambia, showing mapped areas and generalised geology.

2. Review of age data in the Irumide belt

There is limited and sparse radiometric data in the Irumide belt, most of which are K–Ar and Rb–Sr dates (Cahen et al., 1984). Recent U–Pb SHRIMP ages have been obtained from across the belt, providing a more robust geochronological framework for the belt (De Waele et al., 2001). The oldest U–Pb ages are detrital monazite ages from Irumi hill (Irumi quartzite) in Mkushi, where Snelling et al. (1964) (Vail et al., 1968) record a date of 2720 ± 24 Ma and the Changwena hill quartzite, south west of Serenje in the Ndabala area which records an age of 2720 ± 20 Ma (Snelling et al., 1964). The source of these detrital monazites is thought to be to the northwest of the Irumide basin, where sedimentary material came into the basin from the Congo Craton. More recent detrital work was done by Armstrong et al. (1999) who dated detrital zircons from a quartzite of the Manshya River Group near Mkushi. These detrital U–Pb SHRIMP ages yielded an oldest grain of 3180 Ma, and youngest zircon (and thus maximum age for the Manshya River Group) of 1940 Ma. U–Pb zircon SHRIMP dating of the Mkushi Gneiss yielded an age of 2049 ± 6 Ma, while aplite intruding the gneiss yielded cores of 2036 ± 22 Ma with a rim of 1088 ± 159 Ma (Armstrong et al., 1999). SHRIMP ages of magmatic unzoned zircons in the Serenje area and 100 km to the northeast of Serenje indicate intrusion ages of 1038 ± 10, 1025 ± 10, 1024 ± 13, 1022 ± 12 and 1018 ± 6 Ma for an extensive suite of porphyritic granites (De Waele et al., 2001, 2002). A conventional U–Pb date was obtained from the Kaunga granite, near Chinsali, where Daly (1986) records an emplacement age of 970 ± 5 Ma, which is interpreted as the intrusion age of the granite. The Mutangoshi gneissic granite, which yielded a Rb–Sr whole rock date of 1407 ± 39 Ma (Daly, 1986), has now been dated using U–Pb SHRIMP, and yielded an age of 1021 ± 3 Ma for the mesocratic, fine-grained unit, and an age of 1053 ± 7 Ma for the coarse-grained felsic phase. An older set of granitoids occurs in a narrow region in the Serenje area, and yields SHRIMP U–Pb ages of 1661 ± 8 and 1647 ± 10 Ma (De Waele et al., 2002). SHRIMP analysis on an extensive suite of biotite granite near Chinsali (Mutangoshi Granite or Grey Granite of Daly (1986)) yielded an emplacement age of 1009 ± 12 Ma (De Waele, unpublished data). Magmatic zircons of a conformable metarhyolite in the Muva sediments to the southwest of Chinsali yielded 1880 ± 12 Ma (De Waele, unpublished data).

3. Lithostratigraphy

An older basement gneiss complex, the Mkushi Gneiss, has been described (Stillman, 1965) and dated (Armstrong et al., 1999) from the southwestern part of the Irumide belt. Granitoids, para and orthogneisses have been attributed to the same basement in adjacent areas (Smith, 1966; Cordiner, 1968, 1977; Cvetkovic, 1972; Page, 1973; Kerr, 1993; Mosley, 1993; Mosley and Marten, 1994; Smith and Kerr, 2000). Mapping by Mapani and Moore (1995) has however shown that the porphyritic granite, locally deformed into porphyroblastic gneiss, is clearly intrusive into the metasedimentary rocks as well as a suite of leucocratic biotite gneisses. U–Pb SHRIMP dating of the different granitoids in the Serenje area indicates that no ~2050 Ma Mkushi Basement Complex crops out further northeast, and that the granite-gneisses can be subdivided into an older (pre-tectonic) ~1650 Ma and a younger (syn-late-kinematic) ~1040–1000 Ma suite. Occurrence of large metasedimentary rafts in all the granite-gneisses indicates that the metasedimentary rocks predate the granitoid precursors to all gneisses northeast of Mkushi (Table 1). A SHRIMP age of 1880 ± 12 Ma on a metarhyolite within the metasediments in the Chinsali area confirms this and places the sedimentation into the Irumide basin at the same time as the deposition of the Mporokoso Group to the North of the Bangweulu Block. The metasedimentary rocks of the Irumide belt have been given a multitude of local names, and have been equated to the Manshya River Group in the northeast. Owing to a gap in outcrop towards the center of the Irumide belt (Mupamadzi River area), no direct correlation on a bed-by-bed basis is possible, and inferences are made on lithological and stratigraphical similarities alone.

3.1. Mkushi basement complex

The Mkushi Group (Stillman, 1965) consists of the Mkushi gneiss complex and associated granites, and is taken as the Palaeoproterozoic basement to the Irumide belt in the southwest. We propose a new term for the Mkushi Group as the "Mkushi basement complex" (MBC) to include the observed complexity of the basement gneisses and granites. In the Mkushi, Musofu and Ndabala areas, the MBC was considered by Stillman (1965) and Smith and Kerr (2000) to consist of the basal Mkushi Gneiss Formation, and an upper Irumi Quartzite Formation, which consists of quartzites and quartz–muscovite, biotite and garnet–biotite schists. The Irumi Quartzite Formation is overlain by metasedimentary rocks of the Manshya River Group. However work by subsequent authors (Ng'ambi et al., 1986; Kerr, 1993; Mapani, 1992) has suggested that the Irumi Quartzite Formation represents the lowest unit of the Manshya River Group. We have in this paper taken the Irumi Quartzite Formation to be at the base of the Manshya River Group, following observations in the Fiwila and Ndabala areas (Kerr, 1993; Smith and Kerr, 2000) where it is shown to unconformably overly the MGC gneiss unit, and to be conformably overlain by quartzite of the Kalonga Formation.

According to Stillman (1965) the Mkushi Gneiss is an extensive and complex unit composed of coarse- and medium-grained granoblastic gneisses, fine-grained, banded gneisses and a unit he called a "porphyroblastic gneiss or foliated granite". Evidence for igneous parentage of the porphyroblastic gneisses is given by the mantling of oligoclase by microcline–perthite through partial recrystallisation of a pre-existing feldspar and by the presence of xenoliths. Porphyroblastic gneiss units are often found to be enclosed by banded fine-grained gneisses indicating that the porphyritic granites are intrusive into the fine-grained banded gneisses. The occurrence of xenoliths of banded gneiss and quartzite in the porphyroblastic gneisses in the Fiwila, Chitambo, Chilonga, Chisomo, Serenje, Kanona and Mupamadzi areas, confirms that the porphyroblastic gneisses are younger than the banded gneisses, and younger than the Mkushi gneiss basement (MGB) (De Waele, 1997). The porphyroblastic gneiss is the predominant rock type north of the Mita hills area where Cvetkovic (1972) observed them to be in "gradational" contact with the banded gneisses. In places however, the porphyroblastic gneisses take on an intrusive character, with xenoliths of banded gneiss, again suggesting them to be younger than both the MBC, the banded gneisses and the Manshya River Group. Porphyritic and banded gneisses in the Serenje area, equivalent to the ones described in Mkushi, yielded U–Pb SHRIMP Zircon ages of 1040–1020 and 1665–1650 Ma, respectively (De Waele et al., 2001, 2002). Other outcrops, described as part of the MBC occur in domes of the Ndabala area, flanked by basal Manshya River Group quartzites. These domes generally consist of coarse quartz–feldspar–biotite gneisses and porphyritic foliated granites. A similar granite dome (Sasa Granite), consisting of leucocratic

Table 1
Lithostratigraphy and correlation of the Irumide belt in the Musofu, Mkushi, Fiwila, Ndabala, Serenje, Kanona, Chitambo, Mupamadzi, Chilonga, Nabwalya and Katibunga areas

Age (Ma)	Musofu river and Mkushi	Fiwila mission	Ndabala	Serenje and Kanona	Chitambo mission	Mupamadzi river	Chilonga mission	Nabwalya	Katibunga mission
1000–1040	Porphyritic granite (described in the Mkushi Group)	Porphyritic granite (described in the Mkushi Group)	Porphyritic granite	Porphyritic granite	Porphyritic granite	Porphyritic granite (Kamanga Gr.)	Porphyritic granite (Mayenze Fm.)	Porphyritic granite (Granite gneiss Fm.)	
1650					(Chibobo Gr.)	(Momboshi Gr.)	(Mayenze–Escarpment Fm.)	(Granite-gneiss Fm.)	(Lubanga–Itanga Fm.)
			Leucocratic gneiss	Leucocratic gneiss	Granite- and banded-gneiss	Lukula gneiss Chifuma gneiss	Granite gneiss Banded gneiss	Gneiss Banded gneiss	Biotite gneiss Banded gneiss Leucocratic gneiss
1800	Manshya River Group (Kalonga–Musofu–Irumi Fm.)	Manshya River Group (Kalonga–Irumi Fm.)	Manshya River Group (Kalonga–Irumi Fm.)	Manshya River Group (Serenje–Kanona Gr.)	Manshya River Group (Kanona Fm.)	Manshya River Group (Ishilankuni Gr.)	Manshya River Group (Chilonga–Swankali Fm.)	Manshya River Group (Mpala Fm.)	Manshya River Group (Manshya River Gr. Ibangwe Fm.)
	Schist	Upper pelite	Upper pelite	Upper pelite	Wakawaka quartzite	Upper pelite	Pelite	Upper pelite	Pelite
	Quartzite	Upper quartzite	Quartzite	Upper quartzite	Kipamakunja quartzite	Quartzite	Quartzite	Quartzite	Psammite
	Pebbly quartzite	Middle siltstone	Pelite	Middle pelite	Nsalu quartzite	Pelite	Pelite	Pelite	Pelite
	Conglomerate	Middle quartzite	Quartzite	Middle quartzite	Ikuli pelite member	Quartzite	Quartzite	Quartzite	Quartzite
		Lower quartzite	Pelite	Lower quartzite	Lavusha conglomerate	Pelite	Lower pelite	Pelite	Pelite
		Lower siltstone	Lower quartzite	Basal conglomerate		Lower quartzite	Psammitic schist	Lower Quartzite	
		Basal quartzite					Metaquartzite		Pillow lava
									Tuff-agglomerate
				Migmatite		Migmatite		Migmatite	Migmatite
2050	Mkushi gneiss basement	Mkushi gneiss basement	Mkushi gneiss basement	Mkushi gneiss basement					

Original lithostratigraphic names are given in brackets (Stillman, 1965; Cordiner, 1977, 2000; Page, 1973; Harding, 1993; Kerr, 1993; Mosley and Marten, 1994; Mapani and Moore, 1995; Van De Velde and De Waele, 1997; Smith and Kerr, 2000).

biotite granite, has been dated in the Serenje area, and gave a U–Pb SHRIMP Zircon age of 1018 ± 6 Ma (De Waele et al., 2001, 2002).

In conclusion it seems clear that the extent of the MBC has been grossly exaggerated in the Irumide belt. The lithological and structural similarity of the Mkushi basement gneisses with the younger suites of granite gneisses makes it difficult to demarcate the MBC at present. More geochronological work is underway along two traverses through the southwestern portion of the belt to better define the Palaeoproterozoic Basement in the southwest.

3.2. The Manshya River Group

We propose here to use the Manshya River Group, described in the northeastern part of the belt by Daly (1986) and Marten (1968) to include all metasedimentary rocks in the Irumide belt. The Manshya River Group therefore includes the rocks of the Kanona Group, Serenje Group, Musofu Formation, Kalonga Formation and all correlatives in the southeast (Table 2). The Manshya River Group has been correlated with the Mitoba River Group of the Kasama area (Daly and Unrug, 1982) and the Mafinga Group of the Mafinga Hills area in the extreme northeast (Fitches, 1968). Earlier division of the sedimentary rocks in the Mkushi area, into a lower Musofu Formation and an upper Kalonga Formation (Ackermann and Forster, 1960; Stillman, 1965) has been abandoned, as it is purely based on differences in metamorphic grade, and spatial distribution. High metamorphic grades at the base of the metasedimentary sequence, locally give rise to anatectic gneisses.

Based on well-exposed successions in the Mkushi, Serenje and Nabwalya areas (Stillman, 1965; Harding, 1993; Mapani and Moore, 1995), the Manshya River Group comprises four quartzite and four pelite members making up an estimated total thickness of 4800 m.

3.2.1. Anatectic equivalents of the Manshya River Group

Strong deformation, and deep burial of the Muva sedimentary rocks, during the main episode of the Irumide Orogeny, gave rise to partial melting and anatexis of the Manshya River Group. S-type granites and paragneisses described throughout the foldbelt, share a close structural and compositional relationship with the metasedimentary rocks. Along strike, the metasedimentary rocks show gradational contacts with paragneisses and migmatites. Towards the southeastern parts of the belt, where upper amphibolite facies conditions prevailed, these paragneisses and migmatites form elongate NE–SW trending complexes.

Stillman (1965), Cvetkovic (1972) and Kerr (1993) did not recognise any paragneisses in the Mkushi, Mita and Fiwila areas, respectively. However, the fine-grained banded gneisses of the Mkushi and Musofu areas are observed to continue laterally eastwards into the Ndabala area where they grade into schists of the Kanona Group (Smith and Kerr, 2000). A similar gradation of pelitic rocks into high-grade gneisses and migmatites is also clear in the Serenje area where rocks of greenschist facies metamorphism in the north of Serenje, can be traced southeastwards where they grade into high grade schists and migmatites (Mapani, 1992). In the Katibunga mission area (Fig. 2) the basal unit is the Itanga Paragneiss Formation (Mosley and Marten, 1994) which consists of a migmatitic and paragneissic complex. The migmatites include restitic biotite–hornblende–quartz–plagioclase and leucocratic neosomes of quartz, microcline, plagioclase and minor biotite. The paragneissic complex consists of metapsammites and feldspathic banded gneisses in which sillimanite, garnet, quartz, microcline and fibrolite are often present. Page (1973) describes the paragneisses and migmatites of the Escarpment Gneiss as almandine–quartz–hornblende–gneisses and banded plagioclase–quartz–perthite gneisses with accessory almandine, apatite, zircon and xenotime. The granites of the Escarpment Gneiss are generally foliated but not banded. Their emplacement

Table 2
Revised stratigraphy of the Manshya River Group

Name of formation	Lithology
Carbonate	Calc-silicate rock and marble
Upper quartzite	Sericitic quartzite, quartzite, recrystallised in places. Primary structures often preserved
Upper pelite	Metasiltstone, slate and phyllite Schist at higher grades
Middle quartzite	Micaceous quartzite, metasiltstone, sandstone Sugary quartzite and minor schist at high grades
Lower pelite	Flaggy metasiltstone, slate and phyllite Schist and gneiss where metamorphosed to high grades
Lower quartzite	Quartzite, interbedded with ferruginous bands Schist, fine-grained quartzite, occasionally current bedded
Basal pelite	Epidote, andalusite, kyanite, garnet and biotite schist
Basal quartzite	Ferruginous muscovite quartzite

was accompanied by pegmatites, the field relationships and orientation of which suggests synkinematic emplacement during the main Irumide deformation event. Such rocks have been described from the south of the Serenje area, where the pegmatites form an important source of beryl-tourmaline mineralisation (Nkemba et al., 2000). In the Nabwalya area, Harding (1993) recognised the Granite Gneiss Formation as a unit of coarse-grained quartz–microcline–plagioclase gneiss with accessory hornblende, titanite and, in places, sillimanite. The gradational contact between this gneiss and the metasediment any rocks of the Manshya River Group (Mpala Formation), together with the occurrence of metasedimentary pods in the gneiss, suggests that the gneiss is the migmatised equivalent of the Manshya River Group, and therefore correlates with the other paragneisses and migmatites described above. Diopside- and tremolite-bearing calc-silicate rocks are described in the Lubanga Gneiss of the Katibunga area, where they coexist with paragneisses (Mosley and Marten, 1994), implying more stable conditions of deposition in the northeastern part of the Irumide basin. A marble member has been described from the Kasama area, and occurs at the top of the Manshya River Group, confirming the presence of a carbonate member at the top of the sequence.

3.2.2. The metasedimentary succession of the Manshya River Group

The Manshya River Group was first described by Marten (1968) in the Chalabesa River area (Fig. 2). In this type section, neither the base nor the top of the sequence is seen. The Manshya River section consists of three pelitic and two quartzitic units. The sequence starts with a sequence of slates and phyllites (Lower Pelite Formation), with minor quartzitic horizons. It gradually passes into a sequence of fine and coarse quartzites with subordinate laminated siltstones (Lower (Mukonkoto) Quartzite Formation). This quartzite is in turn overlain by a thick unit of slates and phyllites, with minor quartzite and hematite–quartzite units (Middle Pelite Formation). The Nkwale Quartzite Formation (Middle Quartzite Formation) is composed of ferruginous and pure quartzites, which in turn grade into an Upper Pelite Formation of slates and phyllites with subordinate quartzite horizons. Important additions can be added to the base and top of the sequence, based on observations in the Isoka area. There, the Lower Pelite Formation is underlain by another Pelite–Quartzite pair (Basal Pelite Formation and Nkanza Quartzite Formation), which we propose as the Basal Pelite and Basal Quartzite Formation. Another addition can be made to the top of the sequence where in Isoka, the Nkanza Quartzite Formation overlies the Upper Pelite (Nkanka Pelite Formation), and an isolated occurrence of a small meta-carbonate horizon (Mpangala Marble) is recognized at the very top of the sequence. The complete Manshya River Group thus consists of four alternating pelitic and quartzitic units, with at the very top a carbonate unit.

The Irumi Formation (type locality, Irumi Hill) is interpreted as the Basal Quartzite Formation in the Mkushi area. It forms a continuous outcrop traceable from the Kapiri–Mkushi area into the Ndabala and Fiwila mission areas. Some isolated ridges of quartzite and quartzo-feldspathic schists in the Mita Hills area are also assigned to the Irumi Formation. It has not been recognized farther to the east, where it is incorporated at the base of the Manshya River Group. The Irumi Formation is characteristically a ferruginous muscovite quartzite grading into schists. Depending on regional metamorphic grade the schist are biotite, andalusite–garnet, sillimanite–garnet, or kyanite schists (Stillman, 1965; Cvetkovic, 1972; Kerr, 1993; Smith and Kerr, 2000). In the Mkushi area, the Irumi Formation occurs along a sheared contact with the Mkushi Gneiss Formation. In the Fiwila area, a gradational and conformable contact is recognised between the pelites of the Irumi Formation and the overlying quartzite (the Irumi quartzite) of the Manshya River Group (Kerr, 1993). This confirms that the Irumi Formation of Stillman (1965) is actually the basal member of the Manshya River Group. In Mkushi, the overlying metasedimentary sequence (Kalonga Formation) contains three quartzite members, and three pelite members. The overall sequence of Irumi and Kalonga Formations therefore correlate well with the Manshya River Group, which is described as a sequence consisting of four pelite and four quartzite members. We propose here to rename the Quartzite member of the Irumi Formation the "Basal Quartzite Formation", and the upper pelitic member the "Basal Pelite Formation" (Table 2).

The Basal section is overlain by a conglomerate-quartzite, which is laterally extensive and is recognised in the Mkushi, Musofu, Fiwila, Ndabala, Serenje, Kanona and Chitambo areas (Stillman, 1965; Kerr, 1993; Mapani, 1992; Cordiner, 1977, 2000; Smith and Kerr, 2000) (Table 2). We propose to name this unit the "Lower Quartzite Formation", which consists of a conglomerate at the base, passing into a pebbly quartzite and finally into a fine-grained, pure quartzite. The pebbles of the conglomerate are generally flattened and petrologically resemble quartzites of the Basal Quartzite Formation. The conglomerate generally has a dark matrix of schistose (Musofu area) or talcose (Serenje area) appearance (Stillman, 1965; Mapani and Moore, 1995). The matrix of the conglomerate is usually psammitic and is composed of quartz, muscovite, talc and minor hematite. Higher in the Formation, several other quartzite horizons occur, which are ferruginous at the base and pure at the top. Thin pelitic bands within the Lower Quartzite Formation contain the high-pressure assemblage kyanite–garnet–quartz, which has been retrogressed to lower pressure andalusite- and/or staurolite-bearing assemblages. The pelitic bands often grade into impure kyanite quartzites. Above the Lower Quartzite Formation, the succession is characterised by alternating quartzite and metapelitic horizons, which we attribute to the Lower Pelite Formation (Table 2). The metapelitic members of the Lower Pelite Formation include slates, phyllites and schists, while the arenaceous units are sericitic and micaceous quartzites (Stillman, 1965). The metapelitic members consist of flaggy metasiltstones, slates and phyllites with a sericite–chlorite–quartz mineralogy, often spotted with chloritoid. It grades upwards through metasiltstones and fine-grained quartzites into the Middle Quartzite Formation. In this Formation, white quartzite passes upward into slightly micaceous quartzite, which makes up the greater part. The quartzite grades into the Middle Pelite Formation at the top. The Middle Pelite Formation is similar to the lower one, in that it consists of slates, phyllites and metasiltstones. White or buff quartzites, sericitic–chloritic quartzites and slates make up the Upper Quartzite Formation. The Upper Quartzite Formation is overlain by the Upper Pelite Formation, which consists of slates, phyllites and metasiltstones (Table 2). These quartzites are characterised by cross-bedding, festoon bedding and posses ripple marks where tectonic overprinting was not intense. These structures suggest a fluvial type and/or shallow marine depositional environment. Large-scale low-angle cross-beds may indicate aeolian dune deposits, and the extreme sorting and purity of the quartzites is taken to indicate deposition in shallow marine and shoreline environments.

The thickness of the Manshya River Group, is calculated from a continuous succession in the Mkushi area to be 4800 m. The same sequence attains a thickness of 4900 m in the Isoka area indicating that the Manshya River Group is of relatively uniform thickness over its full strike-length. Although many quartzite ridges can be traced over large distances, outcrop of the Manshya River Group disappears towards the central part of the belt (Mupamadzi River area), making direct correlation of the units from the southwest to the northeast impossible. Although the quartzite formations are relatively similar, only the Upper Quartzite Formation displays large- and medium-scale cross-bedding, defined by fine layers of magnetite, detrital hornblende and tourmaline.

The Ibangwe Group of the Katibunga area (Mosley and Marten, 1994) consists of deformed pillow lavas, tuffs and agglomerates at the base, followed by schists, with metaquartzites at the top. The metavolcanic rocks include quartz, plagioclase, chlorite, actinolite or hornblende, epidote and pyrite (Mosley and Marten, 1994). Chlorite-rich "greenschists" are abundant within the sequence and are probably of mixed sedimentary and volcaniclastic origin (Mosley and Marten, 1994). The exact stratigraphic position of the Ibangwe group cannot be ascertained, as it occurs in a fault bounded terrane. However, the presence of pillow lavas, tuffs and agglomerates similar to the andesitic rocks of the Mporokoso Group of Andersen and Unrug (1984), and the occurrence of the Manshya River Group above it, suggests that the Ibangwe Group is an equivalent of the Mporokoso Group of the Bangweulu Block.

3.3. Biotite granite-gneisses and leucocratic gneisses

New U–Pb SHRIMP dating in the Serenje area has revealed a roughly northeast trending terrane of granite gneisses giving ages of 1661 ± 8 and 1647 ± 10 Ma (De Waele et al., 2001, 2002). These gneisses and foliated granites were considered to be syntectonic with respect to the Irumide orogeny, based on their strong northeast directed foliation at the margins of intrusive bodies, and largely undeformed megacrystic character towards the core. In contrast to the porphyritic granites, the biotite granite-gneisses show that a roughly northeast-directed foliation predates the main Irumide trends. The Irumide event therefore imparts a strong crenulation, which is often close to parallel to the older structural grain. Based on this, Mapani and Moore (1995) regarded the biotite granite gneisses to predate the porphyritic granites. Two main varieties have been described in Serenje (Mapani and Moore, 1995), a medium-grained, in places megacrystic, biotite granite-gneiss and a medium-grained pink, leucocratic biotite gneiss. In Serenje, the $\sim$1650 Ma granitoids form several elongate domal terranes, flanked by, and containing large pods of metasedimentary rocks of the Manshya River Group. In Daly's model (1986), the $\sim$1650 Ma granite-gneisses occur in a steep zone of double vergence, indicating that they may have represented a cool and rigid rock-body accommodated fore- and backthrust movements on either side. A similar tectonic model in the Mkushi area has been explained as a pop-up structure (Daly, 1986) Whether the terrane of $\approx$1650 Ma granite gneisses represents an accreted terrane or a pre-Irumide magmatic front remains an open question.

3.4. Porphyritic granites and porphyroblastic gneisses

Various authors (Stillman, 1965, Smith, 1966; Cordiner, 1968, 1977; Cvetkovic, 1972; Page, 1973; Kerr, 1993; Mosley, 1993; Mosley and Marten, 1994; Smith and Kerr, 2000) have described widely distributed porphyritic granites and porphyroblastic granite-gneisses in the Irumide belt, and regarded them as being part of the basement to the Manshya River Group. The presence of xenoliths of quartzite, microgranite, microsyenite and biotite gneiss, as well as inherited igneous banding and flow structures, suggests that they intrude the Manshya

River Group. The majority of geological mapping in the Irumide belt did not distinguish these younger granite-gneisses from an older gneiss group. We now propose a Porphyritic Granite suite to include all younger porphyritic granite-gneisses throughout the Irumide belt. Various porphyritic granites have been dated using SHRIMP and define an age-range of 1038 ± 10–1022 ± 12 Ma (De Waele et al., 2001, 2002).

4. Structure

Ackermann and Forster (1960) distinguished an older Tumbide orogenic event that produced recumbent and isoclinal structures along northerly axes, with widespread migmatisation. A second deformation episode, called the Irumide orogenic event, was considered by Ackermann and Forster (1960) to be concentrated along northeast to east–northeast axes and characterised by shallow-plunging, open to isoclinal upright folds. Careful mapping of structures across the strike of the belt in the Serenje area reveals folds facing northwest in the northwest, upright in a central zone, and southeast facing in the extreme southeast. Regionally constant mineral lineations developed both in gneisses and the Manshya River Group indicates northwest-directed thrust transport in the northwest, with some southeast directed backthrusting in the southeast. The northwest facing attitude of the foreland thrusts and fold-nappes to the northwest of Serenje, supports overall northwest directed thrust transport. In the foreland zone, hinge-lines are often rotated towards parallelism with the regional mineral lineation indicating recumbent folds to have a sheath geometry. The occurrence of large granite bodies within this terrane during the fold and thrust events gave rise to locally deflected axial surfaces, and north–south foliations. To the southeast, the northwest directed, bedding-parallel structures have been affected by a later D_2 event, producing northwest–southeast steep plunging fabrics with a vergence towards the southeast. The D_2 event produced upright, tight to isoclinal folds, and was preceded by emplacement of quartz veins during D_1, which have been affected by the S_2 crenulation cleavage. A D_3 event followed the compressional tectonics, and produced some extensional faulting and crustal collapse. During D_4 numerous granitoids (porphyritic granites) are emplaced, and locally steepen, rotate or deflect earlier structures.

A structural cross-section across the Shiwa N'gandu and Luswa area reveals much the same structural pattern. A D_1 event of subhorizontal ductile thrusting followed by crustal shortening and buckling produces a series of thrust nappes and tight to isoclinal recumbent folds, displaying northwest facing tectonic transport. In Shiwa N'gandu, the axial traces are along northeast–southwest direction, with variable plunges to southwest and northeast. Towards the center of the belt, the isoclinal fold patterns take on an upright attitude. No evidence of backthrusting is observed in the northern Irumide belt. The extensional collapse event D_3 produces large normal faults and extensional imbricates, and provides an environment for the intrusion of the numerous granitoids. Post-kinematic granitoids occupy regional antiforms and have little effect on the structural patterns of the belt, while syn-kinematic intrusives cause disturbance of regional patterns, and develop a strong internal fabric. A general overview of structures described in the various areas is given in Table 3.

5. Metamorphism

An attempt to constrain metamorphic patterns in Zambia was made by Ramsay and Ridgeway (1977), who outlined metamorphic facies boundaries based on thin section analysis and unpublished data from the Zambian Geological Survey. From their work, it is clear that the Irumide belt displays a consistent increase in metamorphic grade from greenschist facies in the NW to amphibolite, and in places granulite facies, in the SE. Although similar patterns are described for various mapsheets in the Irumide belt, a lot of confusion still exists, and no attempt to synthesise metamorphic assemblages into a meaningful model has been done. Table 4 presents a reinterpretation of assemblages described for various areas in the SW Irumide belt. The main metamorphic event, which reached amphibolite (and in places granulite) grades in the SE, is characterised by quartz–microcline–plagioclase–biotite assemblages in granitoids and gneisses. Paragneisses, and migmatites are characterized by quartz–plagioclase–garnet–sillimanite assemblages, while metapelitic assemblages include quartz–muscovite–kyanite–biotite–garnet or quartz–muscovite–garnet–sillimanite–biotite. A marked decrease in grade of the M_1-event is clearly seen in the Serenje area, where assemblages change from quartz–chlorite–muscovite $\pm$ talc in the NW, over quartz–muscovite–biotite–garnet–staurolite schist, to quartz–garnet–sillimanite schists in the SE. Assemblages were described to contain quartz–garnet–sillimanite–cordierite. Sillimanite does not indicate high-pressure. A series of calc-silicates in the Chisomo area contain diopside–garnet–zoisite–plagioclase at higher grade in the SE, and diopside–edenite–scapolite–biotite–plagioclase at lower grades in the NW. The assemblage quartz–muscovite–kyanite–biotite–garnet is only described from the SW part of the belt and disappears towards the NE. Stillman (1965), Kerr (1993), Mapani and Moore (1995) and Cordiner (2000) describe a localized retrograde event ($M_{1'}$) expressed as a replacement of sillimanite (and kyanite) by andalusite, or the occurrence of quartz–cordierite–plagioclase assemblages.

Table 3
Structure in the Musofu River, Mkushi, Mita Hills, Fiwila Mission, Ndabala, Serenje, Kanona, Chitambo Mission, Mupamadzi River, Chilonga Mission, Nabwalya and Katibunga Mission areas

	Musofu river amp; Mkushi	Mita hills	Fiwila mission	Ndabala	Serenje and Kanona	Chisomo	Chitambo mission	Mupamadzi river	Chilonga mission	Nabwalya	Katibunga mission
D_4	Granite intrusion	Granite intrusion	Granite intrusion	Granite intrusion	Granite intrusion	Granite intrusion	Granite intrusion	Granite intrusion	Granite intrusion	Granite intrusion	Granite intrusion
D_3	Extensional faulting	Extensional faulting	Large-scale NW–SE gentle upright folds. Extensional faulting	Large-scale NNW open upright folds and extensional faulting	Open NW upright folds and extensional faulting	Open NW oriented upright folds and extensional faulting	Large-scale open folding	Large-scale tight and upright NS oriented folds and extensional faulting	Open upright folds with WNW axes. Accompanying shearing and extensional faulting		Open upright folds and doming
D_2	ENE foliation. F_2 folds close-tight, overturned to N, steep plunging vertical axes	NE foliation, tight folding, overturned to N Anatexis of sediments	ENE foliation, Tight gently plunging folds	NE foliation, tight isoclinal folds, overturned towards N	NE foliation. Tight isoclinal NE folds with steep to vertical axes Vergence changing from N in Serenje to S in Kanona. In Kanona backthrusting to SE	NE foliation. Tight upright folds along NE axes	NE foliation through tight to isoclinal NE oriented folds	Tight-isoclinal steeply plunging NE trending folds. Strong NE foliation	Upright isoclinal NE trending folds	NE foliation and tight upright folds	NE foliation and tightening of earlier NE folds. Ductile shearing and mylonitisation
D_1	NS–NNW banding and foliation	ENE foliation and remnant banding		ENE foliation	Large-scale, open to tight, shallow, doubly plunging folds and N banding	NNW foliation	Weak EW foliation	Weak EW foliation	NW trending large-scale folds	NE foliation and isoclinal folding axial planar to bedding	Isoclinal NNE upright folds and NE foliation

Original structural data re-interpreted from Stillman (1965), Cvetkovic (1972), Cordiner (1977, 2000), Page (1973), Harding (1993), Kerr (1993), Mosley and Marten (1994), Mapani and Moore (1995), Van De Velde and De Waele (1997), Smith and Kerr (2000).

Table 4
Overview of metamorphic assemblages described from various areas in the SW Irumide belt

	Musofu river and Mkushi	Fiwila mission	Ndabala	Serenje and Kanona	Chisomo	Chitambo mission	Mupamadzi river	Chilonga mission
M_2 ↓	Metapelites q–ms–chl–cl q–ser–chl–ms–gt	Metapelites q–ms–chl–cl	Metapelites q–ser–chl–ms	Metapelites q–chl–ser–tlc	Metapelites q–bt–chl–ser	Metapelites q–mc–gt–chl–bt	Metapelites q–chl–ser	Metapelites q–chl–ser q–chl–cl–ms–ser
$M_{1'}$ ↓	Metapelites q–and–bt–ms	Metapelites g–and–bt–ms–chl		Metapelttes q–pl–cor	Calc-silicates bt–diop–eden– scap–pl			
M_1 ↑	Gneisses q–ms–bt–mc	Gneisses q–mc–pl–bt–ms	Gneisses q–mc–pl–bt q–ms–bt–gt	Gneisses q–ms–gt–bt	Gneisses q–mc–pl–bt–ms	Gneisses q–pl–mc–bt–ms	Gneisses q–mc–pl–bt–ms	Gneisses q–pl–mc–ms–bt–gt
	Metapelites q–ms–ky–bt–gt q–ms–gt–sill–bt	Metapelites ms–gt–sill	Metapelites q–pl–gt–sill	Metapelites q–pl–gt–sill q–ky–chl q–st–gt	Metapelites q–st–gt q–pl–gt–sill q–ms–gt–bt	Metapelites q–st–gt–ms	Metapelites q–ms–st	Metapelites q–ms–st
					Calc-silicates diop–gt–zois–pl			

M_1, M_2 and M_3 denote metamorphic events (arrow up = prograde, arrow down = retrograde). q = quartz; ms = muscovite; chl = chlorite; cl = chloritoid; ser = sericite; mc = microcline; and = andalusite; bt = biotite; ky = kyanite; gt = garnet; sill = sillimanite; pl = plagioclase; st = staurolite; tc = talc. Data taken and reinterpreted from Stillman (1965), Cordiner (1968, 1977, 2000), Page (1973), Kerr (1993), Klinck (1993), Mapani and Moore (1995), Van De Velde and De Waele (1997), Smith and Kerr (2000).

These retrogressive "events" may however represent locally lower conditions of the M_1 event, as no replacements or in situ descriptions of mineral reactions have been described. Relaxation of the Irumide belt after the main deformation, gave rise to widespread retrogressive assemblages of quartz–chlorite–chloritoid–sericite and quartz–chlorite–chloritoid–muscovite. This M_2 event appears to be pervasive across the Irumide belt, and is characterised by widespread chloritisation and sericitisation.

6. Discussion

It is clear that, although much of the Irumide belt has been mapped extensively by various authors, it remains difficult to establish a coherent lithostratigraphic succession for the belt. Interpretation of geological information available from geological reports is hampered essentially by the fact that mapping was done over a wide time span, by various geologists, with minimal initial efforts being made to correlate the data into a regional model. This results in adjacent maps not fitting together and lack of lithostratigraphical consistency between adjacent areas.

The belt is characterised by an older (basement) foliated granite, granite gneiss and banded gneiss, called the MGB, which is overlain by the Manshya River Group, consisting of a complex lithology of metapelites and quartzites. The Manshya River Group consists of four pelitic and quartzitic formations with an estimated thickness of 4800–4900 m as estimated from continuous sections in Mkushi and Isoka respectively. The very low abundance of meta-carbonates in the succession suggests that the Manshya River Group deposited in a basin that never attained a stable character. The lateral continuity, purity and large-scale, shallow-angle cross-bedding observed in the upper quartzites of the Manshya River Group support a shallow marine to coastal deposition model for the quartzites, while the metapelites represent slightly deeper off-shore deposits, starved of detrital influx. The purity of the quartzites is explained through repeated reworking of detritus along a shoreline, while large-scale, shallow-angle cross-beds relate to dunal landforms in an offshore environment. The presence of pillow lavas, associated with arenaceous and pelitic units of the Ibangwe Group, and the occurrence of metarhyolitic tuffs within the Manshya River Group, indicates that volcanism occurred during the deposition of the Manshya River Group. An age of 1880 ± 12 Ma obtained on a conformal metarhyolite sets back the timing of deposition for the Manshya River Group to the Palaeoproterozoic, and makes the Manshya River Group coeval with the Mporokoso Group to the North of the Bangweulu Block. Numerous granitoids intrude the belt, and broadly group into an older suite (~1650 Ma, only recognized so far in the Serenje area) and a younger suite (~1040–1000 Ma). High grade metamorphism in the SE portions of the belt gave rise to various anatectic gneisses and migmatites. Peak metamorphism, which produced metamorphic rims on zircons in high-grade gneisses and migmatites in the Serenje area, was constrained at ~1000 Ma.

The metamorphic grade increases from northwest to southeast indicating that the tectonic front lies to the NW and the internal domain lies to the SE. The exact position of the tectonic front is concealed by Katangan strata to the NW, and increased Pan African overprint obliterates the Irumide belt to the SE. Both boundaries of the Irumide Belt therefore remain uncertain.

Structurally the Irumide Belt is characterised by at least four deformation events. The earliest event (D_1) is a weakly defined banding and bedding-parallel foliation, which produced gentle, upright F_1 folds. The main Irumide deformation D_2 is expressed in the prominent northeast–southwest structural grain, open to isoclinal northeast–southwest folding and was accompanied by widespread migmatisation and a well-constrained M_1 event. The Irumide (F_2) folds show a double vergence from NW to SE across the belt. Thrust geometries are observed to accommodate NW directed thrusting in the NW and SE directed back-thrusting in the SE. This geometry corresponds to a pop-up structure, and is well constrained in the Mkushi area (Daly, 1986).

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