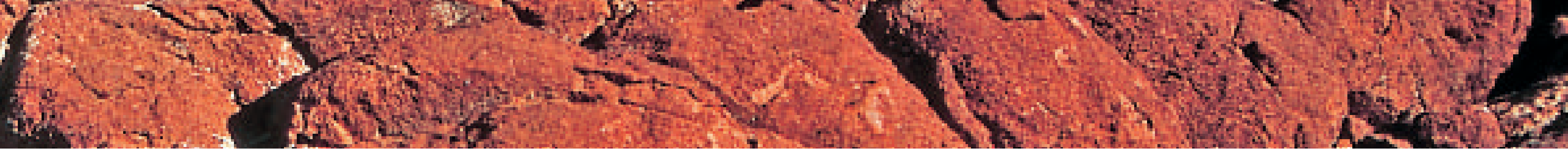


Participants; Drs S.A. Pisarevsky, M.T.D. Wingate (TSRC), D.P Gladkochub, T.V. Donskaya, A.M. Stanevich, A.M. Mazukabzov (Institute of the Earth's Crust, Irkutsk, Russia), L. Natapov (Macquarie University), V. Pavlov (Institute of Physics of the Earth, Moscow, Russia), K.M. Konstantinov (ALROSA, Russia), V. Vernikovsky, A.E. Vernikovskaya (Institute of Geology, Novosibirsk, Russia).

Michael Wingate enjoying a hot meal during sampling of Paleoproterozoic sedimentary rocks and dolerite sills in the Olenek uplift of northern Siberia. [Photo: K.M. Konstantinov]

Project 2.4: Assembling Gondwana

Project Co-ordinators: Ian Fitzsimons and Alan Collins

Aims:

The overall objective of this project is to constrain the sequence and timing of Gondwana assembly, and determine the roles played by late Mesoproterozoic and late Neoproterozoic orogens in this evolution.

When the TSRC was established in 1997, it was widely believed that Gondwana assembled by the collision of East and West Gondwana along the late Neoproterozoic East African Orogen, although the timing of collision and precise location of the suture or sutures remained unknown. It was thought that East and West Gondwana had themselves assembled by the collision of older fragments along late Mesoproterozoic "Grenville" or "Kibaran" orogens, and that regions of late Neoproterozoic "Pan-African" tectonism within East and West Gondwana were sites of intracratonic reworking that were of little importance in continental reconstructions. Since 1997, the TSRC has been at the forefront of a revolution in our understanding of Gondwana assembly. New data have constrained the timing of collision and location of potential oceanic sutures within the East African Orogen [TSRC Publications # 65, 75, 125, 159, 172, 178, 209]. They have demonstrated that other regions of Pan-African tectonism (namely the Pinjarra and Zambezi orogens) involved significant horizontal displacements and quite possibly ocean closure, and are likely to have been just as significant as the East African Orogen for Neoproterozoic Gondwana assembly [TSRC Publications # 5, 95, 114, 126, 150, 155, 184, 218, 224]. They have also emphasized that many of the late Mesoproterozoic orogens previously regarded as a coherent framework of equivalent collisional belts actually represent a collage of different late Mesoproterozoic collision zones truncated and juxtaposed by the Pan-African orogens [TSRC Publications # 95, 114, 218]. Some of this work and its implications form the core of the recent volume published by the Geological Society, London, on "Proterozoic East Gondwana: Supercontinent Assembly and Break up", and it is clear that TSRC results are forcing significant changes in our understanding of Gondwana formation.

Our work has shown that previous models for Gondwanaland assembly are invalid, but data collected so far are insufficient to propose a new model. The aim of this project is to fill the most prominent gaps in our knowledge of Gondwana assembly, and develop an all-embracing model for the Proterozoic evolution of the southern continents. Such a model is a pre-requisite for any reconstruction of Rodinia, since the continental blocks that assembled to form Gondwana are the fragments produced by Rodinia breakup. Our work will constrain the size, shape and geological character of the Neoproterozoic pieces from which we must reconstruct the Rodinia puzzle, and therefore lies at the core of the TSRC's goals.

This project focuses on relationships in Australia, Antarctica, India and southern Africa (see Figure 1). There are four core sub-projects with TSRC funding, two of which represent continuations of projects commenced before the 2003–2005 triennium (Project 2.4.1 in East Africa and Project 2.4.2 in Madagascar) and two of which are new project areas whose importance has been highlighted by recent TSRC research (Project 2.4.3 in southern India and Project 2.4.4 in the Pinjarra Orogen of Western Australia). In addition, work is progressing in a number of related non-core projects without direct TSRC support (Usagaran Orogen of Tanzania, Vibaran belt of Central Africa, Cuddapah Basin of India, Prince Charles Mountains of Antarctica, Mount Barren Group of Western Australia, and Musgrave Complex of central Australia).

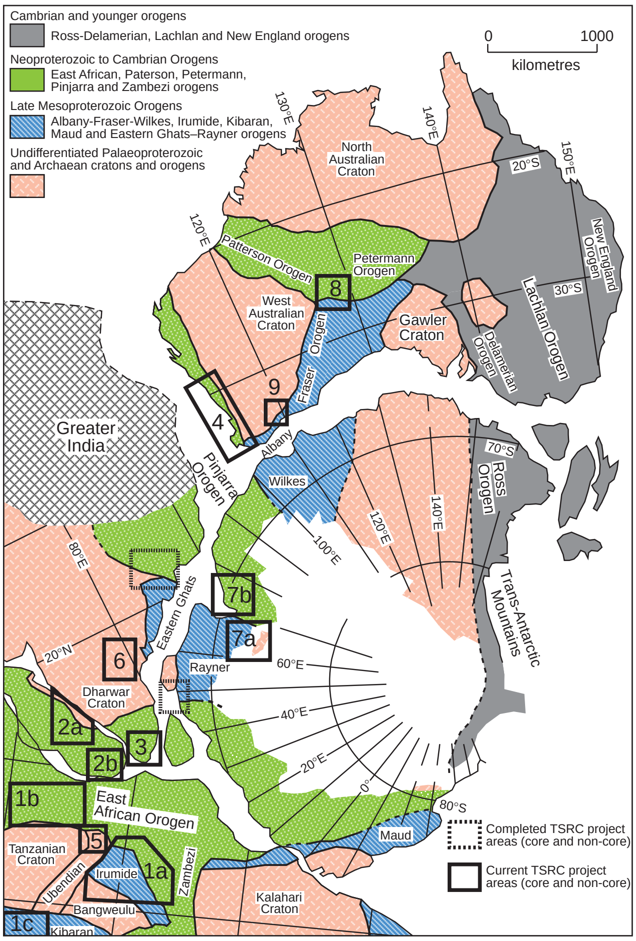
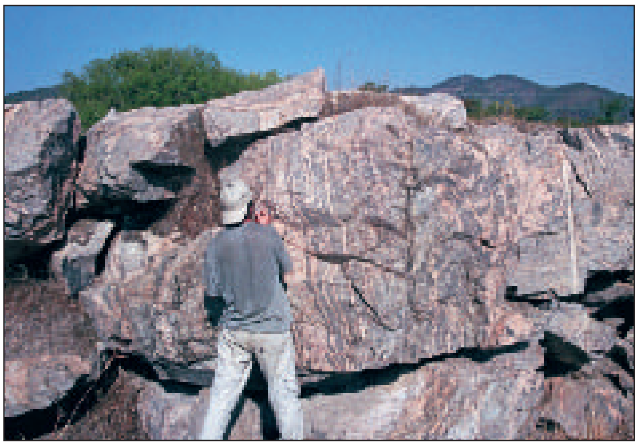


Figure 1: Gondwana reconstruction showing TSRC project areas for Project 2.4, 2.4.1, 2.4.2, 2.4.3 and 2.4.4.

Project 2.4.1: The Irumide Belt of Zambia

Project Co-ordinator: Ian Fitzsimons

The Congo Craton lies at the centre of Africa, and this project is concerned with the Proterozoic events responsible for the consolidation of the eastern margin of this craton and its incorporation into greater Gondwana. This project has been split into three components. Sub project 2.4.1a is concerned with the Irumide Belt which lies at the south eastern margin of the Congo Craton and records a significant period of late Mesoproterozoic orogenesis, overprinted to the south and east by Neoproterozoic events associated with the Zambezi Belt and East African Orogen respectively (area 1a in Figure 1.). This area is critical for understanding the tectonic relationships between the Congo Craton and the Kalahari Craton to the south. Sub project 2.4.1b is concerned with Neoproterozoic tectonism along the eastern margin of the Congo Craton during the assembly of the East African Orogen (area 1b in Figure 1, also known as the Mozambique Belt). This region records the collision of the Congo Craton with the Dharwar Craton of India to the east. Sub project 2.4.1c is concerned with the Kibaran Belt (area 1c in Figure 1), a Mesoproterozoic orogen that divides the Congo Craton into two sectors (the Bangweulu Block and Tanzanian Craton the east, and the Kasai Craton to the west). This area is critical for understanding the evolution of the Congo Craton prior to Gondwana assembly.

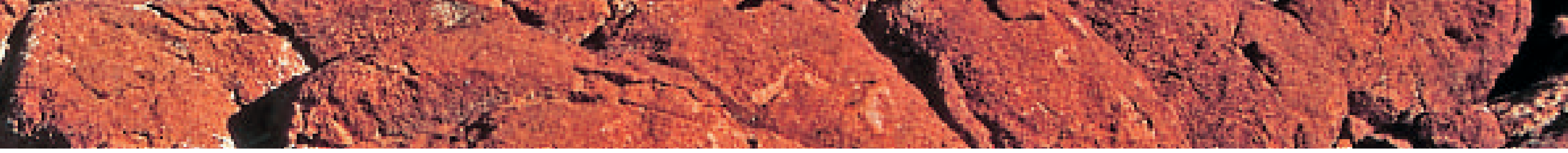


Simon Johnson looks at charnockite. Taken in the Lutembwe River Granulites, SE of Chipata, Eastern Province of Zambia (near the Malawi border). The rock is a charnockitic gneiss with a protolith of ca 1050 Ma. [Photo: B. De Waele]

(a) The Irumide Belt of Zambia

Aims:

The Mesoproterozoic Irumide Belt (project area 1a, Figure 1) occupies a central position in an intersecting network of



orogenic belts that characterizes south-central Africa, and it provides a unique opportunity to study the tectonic history of the "African" margin of the Mozambique Ocean prior to its closure during the Neoproterozoic East African Orogeny. The belt trends northeast-southwest and comprises various suites of granitoids and deformed metasedimentary rocks of the Muva Super group. It is truncated to the northeast by the reactivated Palaeoproterozoic Ubendian Belt, and to the southwest by the Neoproterozoic Lufilian Arc and Zambezi Belt terranes, whilst to the northwest the granite, metavolcanic rock and undeformed Muva Supergroup rocks of the Bangweulu Block are assumed to represent a foreland to the orogen. The Irumide Belt has previously been correlated with other Mesoproterozoic metamorphic belts of central Africa on the basis of equivocal and imprecise isotopic age data, and these correlations have been used to argue that much of the Proterozoic tectonism in Africa is intracratonic in nature.

The aim of this project is to determine the tectonic setting, internal structure, and tectonothermal evolution of the Irumide Belt and its Bangweulu foreland, and use these data and data from adjacent geological provinces to develop new models for the tectonic architecture of south-central Africa.

Progress:

- Bert De Waele finished writing up his PhD during the first half of 2004, submitting in July. The thesis is entitled "The Proterozoic Geological History of the Irumide Belt, Zambia" and summarises all of the project results, including SHRIMP U–Pb zircon crystallisation ages for 50 samples of pre-, syn-, and post-tectonic granitoid and three samples of volcanic rock from within the Muva Supergroup. In addition, detrital zircons were dated from four samples of the Muva Supergroup to constrain sedimentary provenance, 108 granitoid and volcanic samples were analysed for major and trace element geochemistry and 17 granitoid and volcanic samples for Sm/Nd isotope geochemistry. The results of these analyses provide the first quantitative time framework for the tectonic evolution of the Irumide Belt and have been summarized in previous reports. Key findings are as follows:
- The Muva Supergroup was deposited at c. 1850 Ma, approximately synchronous with the end of Palaeoproterozoic orogenesis in the nearby Ubendian Belt. It is dominated by Palaeoproterozoic detritus eroded from relatively local sources in the Congo Craton, including the Bangweulu Block and Ubendian Belt.
- Pre-tectonic basement granitoids in the Irumide Belt include Archaean to Palaeoproterozoic components of identical age to similar rocks in the Congo Craton foreland, and a previously unrecognised c. 1650-1550 Ma igneous suite.
- Major tectonism in the Irumide Belt occurred at 1020 Ma, at least 150 million years younger than believed previously.

Outcomes: The results of this project have been presented as papers at a number of international conferences, including one presentation at the Mike Coward Memorial Meeting, London, May 2004, three presentations at the 20th Colloquium of African Geology in Orléans, June 2004, three presentations at Geoscience Africa, July 2004, Johannesburg, and one presentation at the 32nd International Geological Congress, Florence, August 2004. A review paper on the Irumide Belt is in press in an IGCP 418 special volume on the Mesoproterozoic of southern Africa [TSRC Publication # 257], and three other papers have been published. The first of these is a paper on the Zambezi Belt of Zambia, which has some input from De Waele's work [TSRC Publication # 299] The second details a geochemical database for part of the Copper Belt of NW Zambia [TSRC Publication # 302] and the third is a review on the Meso- to early Palaeozoic evolution of south-central Africa by Johnson et al. [TSRC Publication # 305]. One paper was accepted on the metamorphic evolution of the Irumide Belt [TSRC Publication # 322], while several papers are in advanced stages of preparation. The results presented in these papers and conference presentations are providing a robust geochronological framework for the various Palaeo- to Mesoproterozoic belts responsible for the assembly of the Congo Craton. The age of tectonism in these belts was previously very poorly constrained, and our new data are leading to significant revisions of earlier correlations between the Congo Craton and other continental blocks.

Aims for 2005:

De Waele has commenced a Lu/Hf isotopic study of Irumide granitoid and volcanic samples with Simon Johnson, and has arranged a Rb/Sr and Sm/Nd study of the same lithologies with Jean-Paul Liégeois (Museum for Central Africa, Belgium). This work will be completed during 2005, and yield new results that will complement the existing dataset collected with other isotope systems. De Waele and Johnson have also embarked on a regional geological/geochronological study of the southeastern extension of the Irumide Belt in eastern Zambia, work which will hopefully help define the tectonic makeup of this part of the orogen.

(b) The Mozambique Belt of Kenya and Tanzania

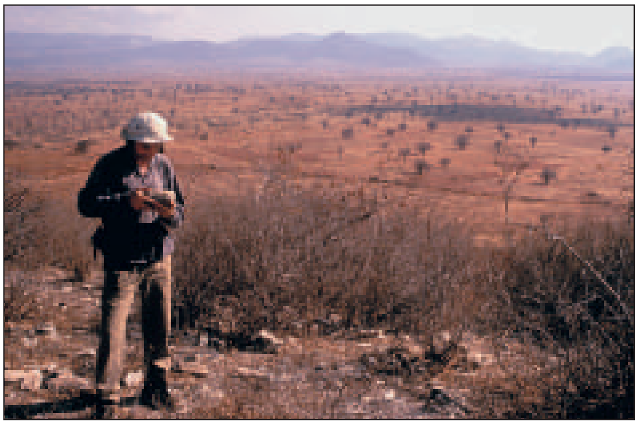
Aims:

The eastern margin of the Congo Craton records collisional processes during the Neoproterozoic amalgamation of Gondwana in the Mozambique Belt of Kenya and Tanzania. The aim of this sub-project is to compile all published geological data for the Mozambique Belt into a spatial database as a basis to develop new tectonic models for this part of the East African Orogen and provide a case study of the application of GIS and database technology in tectonic modelling.

Progress:

Neoproterozoic tectonism along the eastern margin of the Congo Craton has been studied by Huntly Cutten, who submitted his PhD in November 2004. The thesis is entitled "Development of a GIS/Access Database Research Tool and its use to synthesise the Proterozoic history of the Mozambique Belt, eastern Africa" and presents a database of geologic data from the Tanzanian and Kenyan sectors of the East African Orogen (project area 1b, Figure 1), comprising ArcView™ digital maps and Access™ attribute data compiled from TSRC research and other published literature. Key findings are as follows:

- The western Mozambique Belt in Tanzania and Kenya comprises reworked Congo Craton (Archaean) and Usagaran (Palaeoproterozoic) basement rocks. SHRIMP U–Pb analysis of zircon cores and rims from granitoid gneisses indicate that the protolith plutons were emplaced at ~2.7 Ga, and metamorphosed to the granulite facies at ~2.6 Ga. Neoproterozoic Pan-African tectonism deformed these rocks within an imbricate thrust zone under upper amphibolite-facies conditions.
- Granulite-facies rocks in the central and eastern Mozambique Belt, known as the "Eastern Granulites", comprise a series of thin sheets, thrust westwards over the western Mozambique belt basement in Tanzania. Meta-igneous rocks in these thrust sheets have a geochemistry consistent with a magmatic arc origin and igneous crystallisation ages of ~750 Ma to 650 Ma. Nd isotope systematics indicate that these rocks were sourced dominantly from juvenile crustal material with minor input from some older, possibly Archaean, crust. Two periods of granulite-facies metamorphism at ~640 Ma and ~550 Ma suggest two periods of continental collision.
- The thrust contact between these eastern and western terranes was uplifted from lower crustal depths by isostatic rebound following the collisions.



Simon Johnson at Mautia Hill, Tanzania, with the Western Mozambique Belt in the middle ground and the Tanzania Craton in the background [Photo: H. Cutten]

Outcomes: Project participants gave one presentation at the 17th Australian Geological Convention in Hobart, February 2004 and one at the 20th Colloquium of African Geology in Orléans, June 2004. Huntly Cutten has submitted a paper for publication in Precambrian Research, proposing a new tectonic model for the Mozambique Belt in Eastern Africa, and is currently preparing an additional publication together with Bregje Hulscher and Simon Johnson on integrated data for the

Mozambique Belt and its counterpart in Madagascar. A further publication on the development of the database is also in preparation.

(c) The Kibaran Belt of Zambia

Aims:

The Kibaran Belt of central Africa is a Mesoproterozoic orogen that separates the Tanzania Craton and Bangweulu Block of eastern and south-central Africa, from the remainder of the Congo Craton in central Africa. Despite recent advances in our understanding of this orogenic belt, the debate on its intracratonic versus collisional nature has remained unresolved. This sub-project utilises excellent research links with the Museum for Central Africa in Tervueren, Belgium, to embark on a modest geochronological exercise to help constrain the tectono-thermal evolution of the northeastern Kibaran Belt of Burundi and Rwanda.

Progress:

In cooperation with Drs. Luc Tack, André Tahon and Fernandez-Alonso of the Museum for Central Africa, Belgium, Wingate and De Waele have embarked on a regional geochronological study of granitoids in the NE Kibaran Belt of Burundi and Rwanda (project area 1c, Figure 1). The new zircon U-Pb SHRIMP results clearly show that the previously accepted multiphase tectonothermal framework, largely based on whole-rock Rb-Sr data, is incorrect. The new analyses demonstrate the presence, at least locally, of a basement with an age of c. 1.98 Ga, intruded by S-type granitoids between 1.38 and 1.37 Ga. Similar ages have recently been obtained from the Kibaran Belt type area in the Democratic Republic of Congo, demonstrating a synchronous development of these S-type granitoids along the entire strike-length of the belt. Shear-controlled A-type granitoids, previously dated using bulk zircon U-Pb method at c. 1.25 Ga, yielded an age of 1.20 Ga. One post-kinematic Sn-bearing granite yielded an age of c. 990 Ma, and represents the first reliable constraint on the granitoid magmatism accompanying the large Sn-Ta province in the region.

In a separate cooperation between Cutten and De Waele and the same team at Tervueren, SHRIMP U–Pb zircon analysis of supracrustal samples from the northeast Kibaran Belt have been undertaken. Detrital zircon ages from the supracrustal rocks indicate a similar provenance to metasedimentary rocks in the Irumide Belt, both being dominated by Palaeoproterozoic to Archaean detritus and correlated with the ancient core of the central African Congo Craton.

Outcomes: Results of the detrital study of Kibaran metasedimentary rocks have been presented at the 20th Colloquium of African Geology in Orléans Two papers are in various stages of preparation: one will present the zircon U-Pb SHRIMP and 40Ar-39Ar data on the granitoids and gneisses of the NE Kibaran Belt, while another will present the detrital provenance and age of the NE Kibaran Belt sedimentary rocks.

Bert De Waele and Willy Nundwe (second from left) consult a topographic map together with local villagers near Luangwa Bridge, Eastern Zambia [Photo: S. Johnson]

Participants (projects 2.4.1a, b and c): Drs. Huntly Cutten and B. De Waele (finished PhD students), Drs D. Evans, I. Fitzsimons, A. Nemchin, K. Sircombe, M. Wingate and Professor Mark Barley (UWA), Drs. M. Fernandez-Alonso, J.-P. Liégeois, L. Tack and A. Tahon (Museum for Central Africa, Tervueren, Belgium), Dr J. Jacobs (University of Bremen), Dr S. Johnson (Japan Marine Science and Technology Centre), Professor A. Kampunzu (University of Botswana), Mr C. Katongo (University of Zambia), Professor

A. Kröner (University of Mainz), Dr B. Mapani (University of Namibia), Professor S. Muhongo (University of Dar es Salaam, Tanzania), Professor T. Rivers (Memorial University of Newfoundland, Canada), Dr F. Tembo (University of Zambia).

We report with sadness the recent deaths of Mr C. Katongo and Professor A. Kampunzu, both of who have had significant input into this project.

Simon Johnson, taking notes in the bed of the Chakwenga River, Lower Zambezi National Park, south-central Zambia.
[Photo: B. De Waele]

Project 2.4.2: Tectonic Profile through Madagascar
Project Co-ordinators: Ian Fitzsimons and Alan Collins

Aims:

Madagascar has a critical position in Gondwana reconstructions, lying between the cratons in central Africa and India that collided to form the East African Orogen as the intervening Mozambique Ocean closed during the late Neoproterozoic. The East African Orogen represents the culmination of the transformation from Rodinia to Gondwana, but remains poorly understood with little consensus on the time of collision or the location of the suture that separates crust of essentially African origin from that of Indian origin. Madagascar provides the best-preserved section through the eastern margin of this broad orogenic zone, and is a key area for understanding the evolution of the orogen as a whole.

This project aims to identify and characterize the major lithotectonic units present along an east-west profile through the Malagasy basement rocks, constrain their age of amalgamation, and develop a comprehensive model for the evolution of the East African Orogen.

Progress:

Bregje Hulscher is in the final months of her PhD project on central Madagascar (project area 2a, Figure 1). During 2004 she has focused on data synthesis, and the interpretation of previously completed U–Pb geochronology (14 samples), 40Ar-39Ar geochronology (11 samples), geochemistry, Landsat/Aster analysis and (micro) structural and petrological analysis. Key conclusions of this work are as follows:

- Combined geochemical, geochronological and field data clearly demonstrate the existence of a continental magmatic arc in Madagascar at c. 800 Ma.
- A U–Pb titanite age of c. 750 Ma is believed to date pervasive deformation in the basement of central Madagascar, perhaps reflecting arc-continent accretion.
- A weakly deformed stratoid granite cross-cut by undeformed 545–528 Ma plutons contains 570–540 Ma anatectic zircon produced by partial melting of the granite precursor. The intrusive age of this precursor is unclear, but it cuts basement rocks with a penetrative foliation, indicating that pervasive ductile strain in the basement of central Madagascar must be older than 570 Ma, consistent with the titanite age.
- Late syn-tectonic granite plutons in central Madagascar dated at 545–528 Ma were emplaced into discrete sinistral strike-slip dominated shear zones, while high-grade metamorphism and anatexis in western Madagascar dated at c. 540 Ma occurred during pervasive shearing in the hanging wall of a regional east-vergent thrust. The different structural styles of these synchronous events indicates that transpressional strain in Madagascar during the final stages of Gondwanaland assembly was partitioned, with pervasive E–W shortening in the west and N–S directed escape tectonics in the east.

Fitzsimons and Hulscher have developed a two-stage model for the Neoproterozoic assembly of Madagascar [TSRC