

Annual Report of IGCP Project No. 440

IGCP project short title: **RODINIA ASSEMBLY AND BREAKUP**

Duration and status: 1999-2003, active

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2. Summary of major past achievements of the project

During the first year of the project (1999), we established the project structure, including setting up regional working parties and country working groups. We also established cooperation with other IGCP projects including 368, 411, 418, 419, and 420. There are also plans to hold future joint meetings with IGCP 453. We organised four symposia or field workshop, including one on *Mesoproterozoic Continental Assembly and Subsequent Break-up* during the 10th European Union of Geosciences conference, one field workshops in Kitwe, Zambia jointly with IGCP 418 and 419, an international symposium and field workshop on *Geodynamic and Tectonic Evolution of China and Related Gondwana Crustal Fragments* in Yichang, China, jointly with IGCP 368 and 411, and a symposium on *The role of supercontinents in earth history: Assembly and dispersal of the Rodinian supercontinent (1300?-750 Ma), and impacts on the Proterozoic biosphere, hydrosphere and crust-mantle system* at the Geological Society of America Annual meeting in Denver, Colorado, USA. Many scientific ideas were exchanged and new collaborative research projects set up during those meetings.

During 2000, a significant number of scientific contributions by project members appeared in international journals. These include a special issue of *Precambrian Research* entitled *Neoproterozoic of Australia* (Guest Editor: Malcolm R. Walter, Vol. 100, published in March 2000), in which 17 scientific articles/reviews were devoted to the latest progress in understanding the Neoproterozoic successions in Australia and their global correlations, Neoproterozoic palaeoenvironment, new high-quality palaeomagnetic results from both Australia and China, and implications for Rodinia configuration and breakup. A special issue of *Gondwana Research* (Vol. 4, No. 1, Jan. 2001) on *Crustal Evolution in South and Southeast Asia* has been published (Co-editors: S. Hada, M. Yoshida, Z.X. Li, and X. Wang)..

During 2000, we progressed well in developing the legends for the Rodinia maps, and co-organised special sessions/symposia in three major international meetings: (1) a special session on *Assembly and Dispersal of Rodinia and Gondwana Supercontinents in Western Pacific* (sessions T31B and 32A) at the AGU Western Pacific Geophysics Meeting, Tokyo, Japan, (2) a special symposium on *Precambrian Supercontinents* at the 15th Australian Geological Congress, Sydney, Australia, and (3) sessions at the 31st International Geological Congress, Rio de Janeiro, Brazil.

The project has made some scientific breakthroughs between late 2000 and 2001. One is the emerging evidence arguing against a coherent East Gondwana during Rodinia time. The other is new palaeomagnetic evidence indicating that the SWEAT fit could not have existed at ca. 1.07 Ga.

In addition to a large number of individual papers in international journals, two *Precambrian Research* special issues and one *GSA Special Paper* were published in 2001 reporting latest research related to Rodinia. One Precambrian Research Special

Issue was co-edited by the late C.McA. Powell (the late Project co-leader) and J. Meert (Vol. 110), and a special issue (Vol. 111) on *Rodinia and the Mesoproterozoic earth–ocean system* was edited by L.C. Kah and J.K. Bartley. R.E. Ernst and K.L. Buchan, co-edited a GSA Special Paper Series (volume No. 352) on *Mantle plume: their identification through time*.

The project also made progress in the making of the Rodinia maps. It was decided that the project will produce continental tectonic maps, at 1:2 million scale where possible, but with the main focus being the production of the 1:10 million GIS-based Rodinia map.

The project sponsored a number of successful international conferences/symposia during 2001, at which members exchanged their latest results and ideas: (1) *The Irkutsk field workshop on "Assembly and breakup of Rodinia", held in Irkutsk, Russia, between 23 July and 4 August, 2001*, (2) *The Chris Powell Memorial Symposium on "From Mountains to Basins: Rodinia at the Turn of the Century", held at the Tectonics Special Research Centre, Perth, Australia between 30 September and 2 October 2001*, (3) *The international symposium on "The evolution of Rodinia and Gondwanaland and the formation of Asia", held at Osaka between 26 and 30 October, 2001* (co-sponsored by IGCP Projects 386, 411 and 440). In addition, IGCP 440 was involved in a chiefly IGCP 418-sponsored field symposium in Durban, South Africa, between 8-21 July.

More discoveries and generalizations in some of the Rodinian blocks were made in 2002 – Baltica, Siberia, Australia, Antarctica, South China, Tarim, West Gondwana blocks. New studies revealed that convergent tectonic regimes along both the southern and northern margins of the Yangtze craton persisted until ca. 900 Ma. With 1000-900 Ma metamorphic events widely reported in other Grenvillian orogenic belts around the world, it is possible that the assembly of Rodinia did not finish until ca. 900 Ma. Field and analytical studies in southern Sweden, Bornholm, Poland, Lithuania and Belarus show that syn-kinematic intrusions were emplaced along with EW-trending shear zones/lineaments, demonstrating compressional tectonics and heating of the crust over a large part of the craton. This is interpreted as a result of a collision between Baltica and another continent, possibly Amazonia. The Laurentia-Baltica configuration in Rodinia was verified with new early Neoproterozoic palaeomagnetic data from Baltica. Series of studies along Siberian margins suggested that most of this craton was surrounded by oceans in Meso- to Neoproterozoic. New AUSMEX Laurentia-Australia fit was proposed on the basis of the palaeomagnetic and geochronological studies in Western Australia. An extensional tectonic regime started from at least ca. 830 Ma in the region, including South China, Tarim, and part of Korea. Continental rifting and associated bimodal magmatism widely occurred between ca. 830-750 Ma, and they are temporally comparable to those in many other parts of Rodinia such as Australia, Laurentia, India and southern Africa. It has been speculated that these events may be related to a Rodinian superplume that led to the breakup of the supercontinent at ca. 750-700 Ma.

The project sponsored a number of successful international conferences/symposia during 2002, at which members exchanged their latest results and ideas: (1) *Sessions on the GAC-MAC Saskatoon conference (27-29 May 2002) and the post-conference field trip to the southwestern Grenville Province (30 May – 7 June 2002): Aspects of Rodinia assembly exemplified in the Grenville province*, (2) *A joint field meeting*

organised by the project leaders of IGCP 418 and IGCP 440 in Windhoek (Namibia) at the end of July 2002, followed by a fieldtrip through the Mesoproterozoic Sinclair and Namaqua sequences in southern Namibia, (3) Rodinia map compilers workshop, Perth, 11-15 November 200, (4) China Working Group national symposium on the positions of Chinese blocks in Rodinia, Tianjin, 11-13, Jan., 2002, (5) A special session on “Planet Earth—structure and dynamics: Supercontinents through geological times” (Conveners: W. Cavazza, I. Dalziel and T. Torsvik) at EGS XXVII General Assembly, Nice, France, April 200, (6) Nordic Working Group meeting, May 2002; (7) The PPO-Asia Symposium, Sapporo, Japan, 5-7 September 2002.

3. Achievements of the project this year

3.1 List of countries involved in the project (please *indicate the countries active this year)

Argentina, Australia*, Austria, Belgium*, Botswana*, Brazil*, Canada*, China*, Congo-DRC, Denmark*, Finland*, France*, Germany*, India*, Ireland, Japan*, Republic of Korea*, Kuwait, Madagascar*, Malaysia, Mexico*, Mongolia*, Namibia*, New Zealand, Norway*, Russia*, South Africa*, Spain, Sri Lanka*, Sweden*, Switzerland, Taiwan*, Tanzania*, The Netherlands*, U.K.*, USA*, Vietnam*, Zambia*, Zimbabwe*.

3.2. General scientific achievements (including social benefits)

With the rapidly accumulating new scientific results by the over 300 members, it is extremely difficult to summarise all scientific achievements in this brief report. Following are just a few scientific highlights achieved by some major working groups/working parties.

New models of the Rodinia assembly and break-up were proposed and tested. The one by Pisarevsky et al. (2003) features a detailed analysis of the up-to-date geological, geochronological and palaeomagnetic information from all continental blocks and their boundaries. The configuration of Rodinia (1000 – 750 Ma) in this model is different from the previous ones, and the new model for the initial break-up along the western Laurentian margin is analogous to the Northern Atlantic. Another feature of this model is that some continents (India, Congo/São Francisco) may not have been parts of Rodinia.

The main achievements in understanding the building blocks of Rodinia were summarized in the topical session on “Testing Rodinia using new maps compiled for each craton through IGCP 440” at the Geological Society of America annual meeting in Seattle (see below).

Baltica (compilers S. Bogdanova, V. Pease, and Nordic Group). The East European Craton (ProtoBaltica) had a complex evolution history between 1.7 and 0.9 Ga. In western ProtoBaltica, pulses of convergent tectonics and accretion of the crust occurred at ca. 1.7, 1.6, 1.45-1.42 and 1.2 Ga, which created a complex combination of blocks of different tectonic origins separated by major shear zones. These blocks were mostly juxtaposed together at ca.1.2 and 1.03-0.95 Ga along the Sveconorwegian collisional belt. Generally, active continental margin settings can be attributed to the Mesoproterozoic evolution of western ProtoBaltica. Semi-simultaneously with the orogenies in the west, discontinuous sedimentary covers with rare volcanics were repeatedly formed in the central parts of the craton. That

development was interrupted by rifting of the crust, and the formation of grabens and aulacogens which were most characteristic of the “anorogenic” periods at ca. 1.4-1.2 and 0.9- 0.7 Ga. The former was a consequence of mantle plume-induced tension in the lithosphere. The latter rifting was connected both with the post-Sveconorwegian destruction of the crust and the Rodinia break-up. In contrast to western ProtoBaltica, the eastern edge of the craton developed after ca. 1.65 Ga as a continuous passive continental margin. In northern Scandinavia, Timan and the Polar Urals, such evolution commenced later and continued into the Neoproterozoic. Here, it was marked by transition with time from shallow - to deepwater sedimentation and the formation of an ophiolite complex towards the northeast. It appears that ProtoBaltica was completely surrounded by oceans by about 700 Ma, as recorded by the preserved ophiolites and LIP provinces in NW Scandinavia, Poland and Ukraine. The dramatic changes in the evolution of the craton occurred at the end of the Neoproterozoic, between 620 and 540 Ma ago when almost all passive margins of ProtoBaltica were reworked by the Timanian/Cadomian orogenic processes and became active margins. This is seen best along the northern, northeastern and eastern margins of the craton. Elsewhere, rifting and the creation of oceans in the Late Cambrian and Early Ordovician have disrupted the evidence.

Siberia (*compilers D. Gladkochub, S. Pisarevsky, E. Sklyarov, L. Natapov, A. Mazukabzov, T. Donskaya*). Recent geological and palaeomagnetic data from Siberia suggest the possible survival of some minor cratonic assemblage after the breakup of an unknown Paleoproterozoic supercontinent. This assemblage, probably included Siberia and Laurentia, became the core of the Rodinia. We suppose the direct or indirect connection between the southern part of the Siberian craton and north Laurentia in this core. The absence of any traces of large-scale Grenville-age collision in Siberia supports this model. The mantle-derived ultramafic complexes near the southern margin of Siberian craton were probably related to the mantle plume that later caused the breakup of Rodinia. During the early Neoproterozoic numerous dikes and sills were intruded into the eastern (about 1000 Ma) and southern (740-780 Ma) parts of the Siberian craton. The latter may be related to the Franklinian magmatic event in north Laurentia. At this stage the passive continental margin, marking the opening new oceanic basins were developed along its southern (Sayan- Baikal) margin. We suppose that the complete separation of Siberia from Rodinia happened at about 700 Ma.

At least seven alternative reconstructions of the Laurentia-Siberia connections in this supercontinent were published in recent years. Some previously proposed Laurentia-Siberia reconstructions may be dismissed, whereas other models are permissible with minor modifications and conservative assumptions about recent geochronological data from Siberia. An analysis of the Riphean sedimentary successions along the margins of the Siberian craton, together with recent geochronological and palaeomagnetic data from Siberia, suggest that most of Siberian margins faced oceans in Rodinia times. A comparison of Laurentian and Siberian apparent polar wander paths between 1050 and 1000 Ma show s a striking similarity. However, if Siberia was part of Rodinia, it was probably not contiguous with the Laurentian craton. In this scenario northern and southern (Stanovoy block) margins of Siberia are possible candidates for conjunction with the rest of Rodinia. We propose a new reconstruction of Laurentia and Siberia at ca. 1050 – 1000 Ma.

South America (*compilers R.Fuck, Brito de Neves, and C. Schobenhaus*). Compilation of available geological maps allows new insights into Rodinia amalgamation and subsequent break-up as recorded in the South American

continent. Three main domains related to Rodinia evolution were recognized: i) the most complete record appears in northern South America, within the Amazon Craton. In its southwestern portion the craton displays Mesoproterozoic fold belts (from 1.5 up to 1.1 Ga) and corresponding foreland exposures, with coeval intracratonic intrusions and cover successions. ii) In eastern South America small crustal fragments of inferred Rodinia ascent were variably reworked during Neoproterozoic Brasiliano orogenic events, rendering it difficult to recognize and map Meso -Neoproterozoic (Grenvillian) mobile belts. So far only the Punta del Este, Uruguay, terrain and the Cariris Velhos, northeastern Brazil, area seem to bear evidence of being related with the final events of Rodinia amalgamation. iii) The third domain comprises a number of scattered basement exposures within the Andean Cordillera, from Venezuela and Colombia (Guajira, Santa Marta) to northwest Argentina (Pampia, Occidentalia). Although deeply reworked and fragmentary in exposure, these basement exposures seem to represent the largest litho-structural record of the Meso-Neoproterozoic orogenic collage in South America, apparently making up the western border of the South American Platform.

African cratons (*compilers H. Kampunzu, J.P., Milesi, and Y., Deschamps*). The Mesoproterozoic Kibaran orogenic system of Africa has been ignored in most Rodinia reconstruction scenarios. This orogenic belt extends for >3000 km and is >400 km wide in Africa. It is the result of the convergence of Paleoproterozoic/Archaean cratonic blocks forming the Congo craton to the north and a mosaic including the Kalahari, Bangweulu, Tanzania and West-Nilian cratons (hereafter Kalahari craton) to the south. The orogenic system includes several segments with local names (from north to south): Karagwe-Ankolean, Burundian, Kibarides, Irumides, Choma-Kalomo, Ngamiland, Namaqua-Natal and Lurio belts. These segments define two major groups: (1) provinces affected by a long-lived Mesoproterozoic plate convergence between ~1.4-1.0Ga. They host sedimentary basins affected by contractional deformation for the first time during the Mesoproterozoic. The supracrustal sedimentary units are intruded by large batholiths with peak magmatism/deformation at ca. 1.39-1.35 Ga (subduction) and 1.1-1 Ga (continental collision). Geochemical characteristics of 1.39-1.35 Ga mafic rocks suggest an active continental margin, although an ophiolitic complex formed in an oceanic arc has been documented. Strongly peraluminous Sn - Nb-W-REE bearing collisional granites were emplaced at ca. 1-0.96 Ga. (2) Archaean to Paleoproterozoic provinces representing older crust of the converging plates strongly reworked during the 1.1-1 Ga continental collision. Thin-skinned folds-thrusts define the main physiography of this orogen in centraleastern Africa and control the NE-SW structural grain of the belt. The above new geological and geochronological data and interpretations suggest the convergence between the Kalahari craton and a composite Congo-Laurentia craton during the assembly of Rodinia, generating the Kibaran-Grenvillian-Llano belts. IGCP 440 geological and paleomagnetic data will be used to further constrain this interpretation.

Antarctica (*compiler J. Jacobs*). A comparison of geological, geochronological and aerogeophysical data in Dronning Maud Land (East Antarctica) highlight a number of important structural discontinuities, that were probably significant elements during the amalgamation of Gondwana. In Dronning Maud Land an Archaean cratonic fragment, the Grunehogna craton, is exposed, that is rimmed by the c. 1.1 Ga Maud Belt. The Maud Belt is characterised by high-amplitude, elongate magnetic anomalies, that are parallel to the craton margin and coincide with craton-parallel

shear zones. These anomalies can be correlated with similar anomalies in the Mesoproterozoic Natal Metamorphic Province of southern Africa, to which this part of East Antarctica was attached during the Mesoproterozoic. In Dronning Maud Land, these elongate anomalies terminate sharply at the Heimefront Shear Zone in western Dronning Maud Land. This dextral transpression zone coincides with Grenville-age Ar-Ar and K-Ar cooling ages to the W and Pan-African cooling ages to the E. The dextral sense of shear of this major shear zone contrasts with the overall sinistral transpressional character of the East African/Antarctic Orogen. East of the Heimefront shear zone, the basement has been pervasively reworked, and the degree of reworking and the grade of metamorphism increases E -wards. Since on either side of the Heimefront Shear Zone Grenville-age rocks are exposed, this structure is interpreted as the orogenic front of the southern continuation of the East African Orogen into East Antarctica. It is unlikely that this structure represents a suture. Laterally, the East African/Antarctic Orogen in Antarctica probably terminates in an escape tectonic regime, similar to the present situation in SE Asia. Lateral extrusion was associated with large transpressional shear zones such as the Heimefront Shear Zone. These shear zones were reactivated during Gondwana break-up and resulted in a characteristic microplate pattern within the Natal embayment during break-up. The molasse of the East African/Antarctic Orogen is preserved in shear zone bound pull-apart basins in e.g. SE Africa (Natal Group) and western Dronning Maud Land. For any Mesoproterozoic continent reconstruction, it is important to fully restore this Late Neoproterozoic/Early Paleozoic escape tectonics.

India (*compiler M. Pandit*). Neoproterozoic felsic magmatic events in NW India are unique in terms of diversity in tectonic setting despite a close temporal and spatial association. The Sendra granitoids (intrusive into the metasediments of Delhi Supergroup) are tonalitic to granodioritic in composition, however, the predominant component is essentially granitic (granite gneiss) which has yielded a U – Pb zircon age of 967 Ma and seems to be related to the 1 Ga collisional event. A younger event comprises of variably deformed granodiorite – tonalite – granite to granite gneiss, popularly known as Erinpura Granite. The granite gneiss component has yielded 830 Ma age and has been considered to mark the end of Delhi orogeny. The most voluminous of the Neoproterozoic felsic magmatic events, Malani Igneous Suite, is characterized by an initial felsic (bimodal at places) volcanism followed by emplacement of granites and felsic to mafic dykes. These rocks are undeformed and unmetamorphosed and show well-documented intrusive relationship with the older Delhi metasediments and Erinpura granite. Occurrence of conglomerate units and their linear disposition suggest that the volcanic activity took place along roughly N – S and subparallel fracture systems. The Sindreth bimodal volcanics which have long been considered as part of Delhi Supergroup are undeformed and show resemblance with Malani rocks. The U - Pb zircon ages indicate a 20 Ma span for Malani felsic volcanics and granites (770 – 750 Ma). The felsic magmatic events in NW India appear to be the manifestation of amalgamation of Rodinia at ~1 Ga and its breakup at ~750 Ma. The 770 -750 Ma Malani magmatism (non orogenic) appears to be consistent with coeval events recorded in Seychelles and Madagascar, substantiating their spatial association prior to Gondwanic break-up. The trio formed the western margin of the Rodinia which also raises the possibility of a ‘subduction’ setting for the Malani magmatism.

Laurentia (*compilers A. Davidson, K. Karlstrom, J. Sears, D. Holm, M. Williams, J. Wooden, R. Hatcher, C. Finn, R. Price, C. Miller, and P. Berquist*). Pre-Grenvillian

Laurentia (PGL) was established as a major continental block by the end of the Paleoproterozoic (1.6 Ga). Continental sedimentary cover of exhumed Archean and Paleoproterozoic orogenic rocks spanning this time boundary (Athabaska, Thelon, Hornby Bay) have continental character, were probably connected, and may once have covered much of PGL; coeval rocks along the present western margin (Wernicke, Musqua) have passive margin attributes. Continental to shelf -type character is maintained by early to mid-Mesoproterozoic groups (Sibley, Dismal Lakes-Coppermine, Bylot, Fury and Hecla, Sims), some accompanied by continental flood basalt related to extensive diabase dyke swarms; other magmatic activity during this time is restricted to small, widely scattered, generally alkalic intrusions, with the exception of voluminous anorogenic anorthosite and related granitoid magmatism in Labrador-NE Quebec, itself coeval with anorthosite and granite-rhyolite magmatism in midcontinental USA. The Belt- Purcell at the W margin appears to have a provenance other than PGL. The Grenville Province along the present SE margin of PGL resulted from compressive tectonics presumed to have been related to the assembly of Rodinia. Composed mainly of reworked PGL crust, in places once doubled in thickness, it preserves an early Mesoproterozoic history (1.5–1.35 Ga) of continental magmatic arc activity (Pinware, Wakeham, Britt). Also preserved are remnants of volcanic arc and back-arc deposits (Montauban, Grenville), with attendant TTG-suite (1.35–1.23 Ga), that formed mainly on PGL crust but may possibly include obducted rocks from marginal volcanic arcs that preceding terminal continent-continent collision at ca. 1.2 Ga. Post-collisional development of the Midcontinent Rift (1.1 Ga) does not coincide with any major event recorded in the Grenville orogen, although compressive tectonism and plutonism continued there until 1.0–0.95 Ga. Early Neoproterozoic sedimentary rocks in NW Laurentia (Shaler, Mackenzie Mountains) contain Grenvillian detritus, indicating continental bypassing via huge river systems, and mid- Neoproterozoic rift sediments deposited on the exhumed Grenville orogen in Labrador (Double Mer), the W Laurentia margin (basal Windermere), and younger diabase dyke swarms (0.6 Ga) relate to breakup of Rodinia.

Numerous reconstructions of the Proterozoic supercontinent of Rodinia have been proposed, but there little agreement exists on firm piercing points, between any two continental blocks, for any time between 1700 and 500 Ma. Continued efforts at resolution of this issue can be considered an international challenge to merge geologic and refined palaeomagnetic data to: 1) understand the pre-Pangeans configurations of continents, and 2) understand secular changes in Earth's tectonic regimes. The IGCP 440 compilation of 1:10 M maps of all the Rodinia components offers a chance for discussion of the best portrayal of tectonic elements for different cratons, then an evaluation of the best piercing points between cratons. Laurentia is proposed to have been at the core of Rodinia because it is rimmed by Neoproterozoic rifted margins. The length of these rifted margins is comparable to the combined length of rifted margins for rifted Pangea, hence many Rodinia continents must have nestled against Laurentia prior to 750 Ma. Laurentia also offers one of the most complete geologic, geophysical and isotopic data sets of any continent and hence provides a template to test piercing points. Compilation of pre-Neoproterozoic tectonic belts in southern Laurentia is aided by extensive geochronology and isotopic crustal model ages and aeromagnetic data that show structural trends in the sub-Phanerozoic basement. We attempt to show all pre-750 Ma tectonic elements that may be useful for reconstructions. Rifted margins, because they are thinned and modified during extension are invariably overprinted by younger orogens, hence the importance of the isotopic data combined with geologic studies (e.g. for the Mojave province and pre-Appalachian rifted margin). Also, the map will attempt to

palinspastically restore post- Neoproterozoic displacements using structural and geophysical data. Detrital zircon and monazite studies, including “fingerprinting” of zoning patterns using monazite, locally provides information about provenance outside Laurentia. Dike patterns and compositions and palaeomagnetism offer potential to identify piercing points that formed from mantle magmatic events whose scale transcends that of cratons. The integrated understanding of the geologic history of a craton ultimately will provide the best confidence in linking once-adjacent blocks.

South China (*compiler Z.X. Li*). South China may hold some key clues for understanding the assembly and break-up of Rodinia. On the assembly and configuration of Rodinia, recent work confirm the existence of ca. 1430 Ma granitoids and 1300-1000 Ma amphibolite-facies metamorphism in the Hainan Island, at the southwestern end of Cathaysia. The presence in southern Yangtze craton of ca. 1000 Ma granitoids, and similar-aged clastic rocks likely sourced from Cathaysia, suggest that the collision between Cathaysia and Yangtze likely peaked at ca. 1000 Ma in western Sibao Orogen. However, the presence of ca. 970 Ma adakitic granites along southeastern Yangtze craton indicates that subduction was still ongoing at that time, and 900 Ma arc volcanism on both northern and southeastern margins of the Yangtze Craton could represent the youngest rocks formed during the continental collision/accretion. Further considering that the Neoproterozoic rift history of South China is almost identical to that of eastern Australia, South China is geologically plausible to be between southern Laurentia and eastern Australia in Rodinia. If this was the case, it would imply that major segments of Rodinia did not come together until after 1000 Ma, and possibly as young as ca. 900 Ma. This could explain some geological mismatches in various Australia-East Antarctica-Laurentia fits. However, other configurations are also feasible, such as having South China adjacent to India and western Australia. Currently available paleomagnetic data permit both configurations. On the break-up of Rodinia, recent work identified largely coeval anorogenic magmatism in central and western Rodinia that spread over 100 My but fall mostly within two major episodes: one at ca. 830-795 Ma, and the other at ca. 780-745 Ma. Both episodes have mafic rocks of mantle plume origin (e.g., in western Laurentia, South China, Australia and southern Africa), and the pre-rift start of the first episode argues against the possibility of them being decompressional melt of a stretched and thinned continental lithosphere. It has thus been proposed that there was a mantle superplume beneath Rodinia which caused anatexic magmatism from at least ca. 830 Ma, and continental rifting from ca. 820 Ma within the supercontinent. This eventually led to the break-up of Rodinia at around the time of the Sturtian glaciation.

Tarim (*compiler S. Lu*). A number of supercontinent-related events were developed from the terminal Mesoproterozoic to the early Paleozoic (mainly in the Neoproterozoic) in Tarim. The most important events include the assembly and breakup of Rodinia, the extreme cold climate (Snowball Earth), biota development and formation of Gondwanaland, which resulted in the great change of the earth system, such as lithosphere, biosphere, hydrosphere and atmosphere at that time. The supercontinental events are not only preserved at the larger cratons, such as Laurentia, Baltica, East Gondwana, Kalahari, Amazonia et al, but also in some smaller block, for example the Tarim and Yangzi Cratons. There is a marvellous similarity of the Neoproterozoic history between the Tarim and Yangzi blocks based on a number of stratigraphic and event geological data, especially new U-Pb ages. The similarity is illustrated by the feature, sequence and ages of thermo-tectonic

events of the Neoproterozoic, the cratonic progress, bi-layer structure composed of pre-Nanhua metamorphic basement and sedimentary cover, the stratigraphic sequence from the Nanhua to Sinian System of Neoproterozoic, and the stratigraphic markers-glaciogenic beds within the Nanhua System. These features, sequence and time framework of the Neoproterozoic thermo-tectonic events of the Tarim and Yangzi Cratons are quite similar and the events took place from the terminal Mesoproterozoic to early Neoproterozoic. In addition, rifting basins, dyke swarms, bimodal volcanics, continental flood tholeiites, and A-type granites during the period between 810 Ma to a little older 700 Ma are well preserved in the two cratons and their margins. An unconformity between pre-Nanhua metamorphic basement and the Nanhua-Sinian sedimentary cover is preserved in the two blocks. Above the unconformity, the sequence, sedimentary characteristics and date from the Nanhua to Sinian Systems are nearly same in the cratons. Typical tillites are exposed in the Tarim and Yangzi Cratons. They are well exposed in the Nanhua System (0.80 - 0.68Ga, based on the new Chinese Stratigraphic Time Scale). According to the abovementioned similarities, a hypothesis on the Yangzi - Tarim connection or neighborhood is proposed.

It is planned that the complete Rodinia map be displayed at the 32nd IGC at Florence in August 2004.

3.3. List of meetings with approximate attendance and number of countries

3.1. International Symposium and Field Workshop on "The Role of Sri Lanka in Rodinia and Gondwana Assembly and Break-up and the LEGENDS Proposal for a N-S Seismic Traverse Across Southern India and Sri Lanka" (Kandy, Sri Lanka, March 29 to April 3, 2003)

The event was organised by Dr Wilbert Kehel-pannala at the Institute of Fundamental Studies (IFS), Kandy, Sri Lanka. It was sponsored by the IFS, UNESCO-IUGS-IGCP 440 and the LEGENDS Program. About 20 scientists from six countries, including Australia, China, Germany, India, Japan and Sri Lanka, participated in the event.

Indoor symposium

Twenty-three papers were submitted for presentation during the indoor symposium held in the IFS on 29 March. Major topics covered include:

1. Grenvillian and Pan-African events in Sri Lanka and Southern India (contributors: M. Yoshida, Y. Osanai and others, Japan; I. Braun, L. Kriegsman, R. Kleinschrodt and W. Pouillon, Germany; G.W.A.R. Fernando and others, Sri Lanka; A.S. Janardhan, T.R.K. Chetty and Y.J. Bhaskar Rao, India).
2. Tectonics and magmatism in Rodinia and Gondwana (contributors include: A. Kröner and others, Germany; P.R. Reddy, India; A.S. Collins, S.A. Wilde and others, Australia; M. Owada and others, Japan; Fuyuan Wu, China).
3. Geological and tectonic evolution of China (contributors include: Songnian Lu, Gouchun Zhao, Zhihong Chen, Fukun Chen and others, China).

The extended abstracts of the symposium were published as a Centenary Publication of the Geological Survey and Mines Bureau, Sri Lanka, and full papers will be published in a special issue of the following special issue of the Journal of Asian Earth Sciences on "The role of Sri Lanka and associated continental blocks in the

assembly and break-up of Rodinia and Gondwana” (guest editors Kehelpannala, K.V.W. and Collins, A.S.).

Field Workshop

The field workshop, which was held from 30th March to 3rd April 2003 and led by K.V.W. Kehelpannala, A. Kröner and B. Prame, was organized to show the participants Palaeoproterozoic and Grenville-age rocks and Pan-African structures and deep crustal processes in Sri Lanka. Four excursions were scheduled, and fourteen persons from six countries, including Australia, China, Germany, India, Japan and Sri Lanka participated in the field workshop. A total of some 25 major outcrops covering the three major crustal blocks in Sri Lanka, namely, the Wannai Complex (WC), the Highland Complex (HC) and the Vijayan Complex (VC) were visited. Localities visited during the first three days covered outcrops near the upper part of the Highland Complex or in the Wannai Complex. During the last two days of the excursion, the participants examined typical HC quartzites containing Archaean to Palaeoproterozoic detrital zircons, metamorphosed and deformed Pan-African (670 Ma) granitoid of the HC near Jayanthipura, the nature of the strongly sheared and migmatized rocks at the contact shear zone between the HC and the VC and well-layered ortho- and paragneisses of the Highland and Vijayan Complexes. After seeing the lithologies and structures in the three lithotectonic units of Sri Lanka and their tectonic boundaries, the participants discussed various possible correlation schemes between these crustal units and the other Gondwana fragments around Sri Lanka.

The Excursion Guide of the field workshop was published as a Centenary Publication of the Geological Survey and Mines Bureau, Sri Lanka.

3.2. Field workshop “Magmatism at the passive margins of Rodinia” (Ufa, Southern Urals, Russia, July 22 to August 3, 2003)

The workshop was organized by Dr Viktor Puchkov of the Institute of Geology, Ufimian Scientific Centre of Russian Academy of Sciences. A one-day technical session in Ufa (23.07. 2003) was followed by a 10 day field trip in the Southern Urals (the Bashkirian anticlinorium). Sixty scientists attended the technical session.

Indoor technical session (July 23, 2003)

One of the talks which attracted the main attention and questions of the audience was the presentation of S. Bogdanova (Lund University, Sweden) and co-authors, who gave a comparative analysis of the Meso- and Neoproterozoic development of the eastern and western margins of the East European Craton with its interiors. V. Puchkov (Institute of Geology, Ufa) analyzed the pros and cons of the idea that the eastern part of the East European Craton contains relics of a Rodinian passive margin. R. Ernst (Geological Survey of Canada) reviewed the current understanding of Large Igneous Provinces (LIPs), and highlighted some recent discoveries.

Field excursion (July 24 to August 2, 2003)

A 10-day field trip was the major event of the workshop. The aim of the excursion was to collect representative materials for isotope dating, petrological and geochemical characterization, and a paleomagnetic study of the volcanic and intrusive rocks along the Uralian margin of EEC. The results should provide a better understanding of the position of the East European Craton during the assembly of Rodinia and also after breakup of that supercontinent. One specific goal is to test

whether the Bashkirian anticlinorium belonged to a passive margin of Rodinia between 1350 and 1000 Ma ago.

The main outcrops visited include:

1. The metamorphic Archean-Paleoproterozoic Taratash complex (amphibolite- with relics of granulite facies) cut by diabase dikes (Radashny quarry);
2. Mesoproterozoic volcanics of the Ai formation on the Bolshoi and Malyi Miass Mountains and close to the mouth of the Navysh river. Dikes and sills in the Mesoproterozoic Satka (the town of Kusa) and Bakal (the Irkuskan and Tsentralny quarries) formations.
3. The Berdyaush massif of rapakivi granites (ca. 1350 Ma) close to the Berdyaush railway station. In contrast to typical rapakivi granites, these rocks have a mantle, not crustal derivation (based on Rb/Sr isotopic data). Diabase dikes cut the granites.
4. The volcanogenic-sedimentary Mesoproterozoic Mashak Formation (Bolshoi Shatak Range in the area of Matveev Zaalavok, Kapkatash Mt. and Bolshoi Kliuch creek).
5. Neoproterozoic (Lower Vendian) mafic and intermediate volcanics of the Arsha formation to the North of Tirlyan settlement.
6. Gabbro-dolerite dikes and sills cutting Suran, Yusha (Mesoproterozoic) and Inzer (Neoproterozoic) sedimentary formations along with the Beloretsk-Ufa highway.

3.3. The SGTSG meeting in Kalbarri, Western Australia (22-26 September, 2003)

IGCP 440 supported the successful SGTSG meeting in Kalbarri, western Australia, organised by Drs S. Reddy, P. Cawood, A. Collins, I. Fitzsimons (all from the TSRC) and others. It is participated by over one hundred scientists, including many members of the project.

3.4. South China field symposium on Assembly and Breakup of Rodinia (Hangzhou, 9-18 October, 2003)

This was probably the last of a series of successful IGCP 440 international field symposia, organised by Professors X.H. Li (Chinese Academy of Science), Z.X. Li (TSRC, University of WA), J. Wang (China Geological Survey) and S. Zhang (China University of Geosciences, Beijing). The symposium covered many aspects of Rodinia assembly and breakup, with special focus on the East Asia region.

Indoor symposium (10-11 October)

A one-and-half day indoor symposium was held in the city of Hangzhou. It was participated by over 60 scientists from five countries, including numerous postgraduate students. Papers presented covered the topics of (1) Late Precambrian orogenic belts and crustal history of China, Australia, Africa, Canada and Korea and the assembly of Rodinia; (2) Neoproterozoic magmatic and basin history and mechanism for the breakup of Rodinia (e.g., mantle plumes/superplume); (3) testing the position of the South China Block in Rodinia/Gondwana using palaeomagnetism; and (4) evidence of plume activities in Mars and comparison with the Rodinian superplume. In addition, draft tectonic maps of Australia, Canada and various blocks of China produced following the IGCP 440 legend were displayed and discussed during the symposium.

Field workshop (12-18 October)

Field trip started from central Zhejiang, through northeast Jiangxi, and finished at the Huangshan City of southern Anhui. It was participated by over 30 people including

seven from outside China. Along with the beautiful sceneries and food, participants enjoyed the exciting geological traverse covering: (1) possible ca. 1 Ga ophiolitic complexes and schists formed during the ≥ 900 Ma Sibao orogeny, possibly related to Rodinia assembly, (2) the ≥ 900 Ma Shuangxiwu and Zhangcun arc complexes and 970 Ma adakitic granite (experienced blue-schist facies metamorphism), (3) possible back-arc deposits along southern Yangtze block (the Shuangqiaoshan Group and equivalents), and (4) ca. 830-820 Ma bimodal intrusions 820-740 Ma rift successions possibly formed during the early stage of the Rodinia breakup (plume-related?). Most participants chose to finish off the trip by climbing the spectacular Huangshan Mountain (a ca. 1840 m-high mountain of Cretaceous granites).

A 100 page monograph entitled “From Sibao orogenesis to Nanhua rifting: Late Precambrian tectonic history of eastern South China — An overview and field guide” was published by the Geological Publishing House, Beijing (2003).

3.5. A topical session on “Testing Rodinia using new maps compiled for each craton through IGCP 440” at the Geological Society of America annual meeting and exposition (Seattle, 2-5 November 2003)

The oral and poster sessions, chaired by Professors K.E. Karlstrom and S.V. Bogdanova and held on 3-4 November, were highly successful. There were 12 oral and over 20 poster presentations. Draft Pre-700 ma tectonic maps for seven continents/cratons were also displayed and discussed on. Different Rodinia reconstructions were debated in light of new geological and geophysical information obtained by members. At a business meeting members suggested minor modifications to the Rodinia Map legend, and set out the work plan for 2004.

3.4. Educational, training or capacity building activities

The project continue to encourage and support students to participate all aspects of its activities, including international collaborative primary research, all national and international meetings and workshops, field trips, and map compilation.

Numerous doctoral theses related to Rodinia were defended in 2003, including:

Emma F. Rehnstrom "Geography and Geometry of pre-Caledonian western Baltica: U-Pb geochronology and Palaeomagnetism. 2003. LITHOLUND theses, no.1, Dept of Geology, Lund University, Sweden.

Oskar Paulsson. U-Pb geochronology of tectonothermal events related to the Rodinia and Gondwana supercontinents - observations from Antarctica and Baltica. 2003. LITHOLUND theses, no.2, Dept of Geology, Lund University, Sweden.

3.5. Participation of scientists from developing countries

This project has now over 300 registered participants from 40 countries (see section 3.1), with a majority coming from developing countries. A significant proportion of the project funds for 2003 were used to support the involvement of scientists from developing countries (some Asian, African and Latin American countries, plus India and Russia etc.) to participate in the projects activities.

3.6. List of most important publications (including maps)

Members continued to produce an increasing body of literature on the assembly and breakup of Rodinia. An incomplete list is being updated annually at the TSRC web site (<http://www.tsrc.uwa.edu.au>, under IGCP 440).

IGCP 440-sponsored Journal Special Issue:

- 1) A *Geological Society of London Special Publication* 206 on “Proterozoic East Gondwana: Supercontinent Assembly and Break-up” (Editors M. Yoshida and B.F. Windley).
- 2) A *Precambrian Research* special issue (v.122) on “Precambrian Tectonics of East Asia and Relevance to Supercontinent Evolution” (Guest Editors Z.X. Li, M. Cho, and X.H. Li) (being final-edited by the Editor-in-Chief)
- 3) A *Tectonophysics* special issue (v.375) in honour of the late Professor Chris Powell on a wide range of issues reflecting Chris’ broad interests (Editors K. Sircombe and M.W. McElhinny).
- 4) A *Gondwana Research* special issue (v.6) on “Assembly and Break-up of Rodinia and Gondwana: Evidence from Eurasia and Gondwana” (Guest editors Yoshida, M., Kampunzu, A.B., Z.X. Li, Watanabe, T.).

IGCP 440 Field guides & abstract volumes

Li, Z.X., Wang, J., Li, X., Zhang, S. From Sibao Orogenesis to Nanhua Rifting: Late Precambrian Tectonic History of Eastern South China---An Overview and Field Guide. Geological Publishing House, Beijing 2003. p1-100.

The role of Sri Lanka in Rodinia and Gondwana assembly and break-up. Proceedings of the IGCP 440 and LEGENDS International Symposium and Field Workshop. K.V. Wilbert Kehelpannala (ed). Kandy, Sri Lanka 2003, p1-78.

Book edited by members

None

Refereed journal articles

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3.7. Activities involving other IGCP projects or the IUGS

The project continued to organise international activities in collaboration with other IGCP projects. For instance, the Namibia field symposium was jointly organised with IGCP 418, the PPO-Asia Symposium at Sapporo was jointly organised with IGCP 411 and 420. The project is also jointly publishing journal special issues with other IGCP projects.

4. Activities planned

4.1 General goals

The main tasks for the project in 2004 are:

- Continue to obtain and publish high-quality data (e.g., in geochronology, petrology, palaeomagnetism, structural and basin history etc.) in relation to the assembly and breakup of Rodinia, and
- Complete the 1:10 million map of Rodinia.

4.2. Specific meetings and field trips (please indicate participation from developing countries)

The project wish to seek for a one-year extension without UNESCO funding for 2004 in order to finish the Rodinia mapping project. At the business meeting held in Seattle, it was decided that we should aim to finish the compilation of the GIS-based 1:10 million Rodinian tectonic maps by the end of February 2004, and have all the digital maps gathered at the TSRC in Perth. A small workshop of the map compilers will be held in Perth (or an alternative place) during mid-May 2004 to finalize the maps and the configuration used for making the Rodinia map, so that a complete Geodynamic map of Rodinia will be made available by the time of the 32nd IGC in Florence (20-28 August, 2004).

A topical symposium (T-31.02) entitled “The evolution of Rodinia: Mesoproterozoic assembly and Neoproterozoic breakup” has been planned for the 32nd IGC in Florence, Italy (<http://www.32igc.org>) as the concluding meeting for IGCP 440. The deadline for abstract submission is 28 January 2004, and online registration is available.

4. Project funding requested

None (presume that no fund is available for projects beyond five years).

5. Request for extension, on-extended-term-status, or intention to propose successor project

The project wish to seek for a one-year extension without UNESCO funding for 2004 in order to finish the Rodinia mapping project and write a review paper of the main results of the project (see item 4.2).

6. Attach any information you may consider relevant

Cover pages of journal special issues, books, abstract volumes, and field guides sponsored or co-sponsored by the project.