Precambrian Research 234 (2013) 257–278

Contents lists available at ScienceDirect

Precambrian Research

journal homepage: www.elsevier.com/locate/precamres

Late-Tonian to early-Cryogenian apparent depositional ages for metacarbonate rocks from the Sør Rondane Mountains, East Antarctica

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ARTICLE INFO

Article history:
Received 1 March 2012
Received in revised form 20 October 2012
Accepted 24 October 2012
Available online 2 November 2012

Keywords:
Chemostratigraphy
Metacarbonate
Strontium isotopes
Carbon and oxygen isotopes
Sør Rondane Mountains

ABSTRACT

The Sør Rondane Mountains (SRM), located in the Neoproterozoic to Early Cambrian East African-Antarctic collisional orogen is composed of medium- to high-grade metasedimentary, metaigneous and intrusive rocks of diverse composition. Within the metasedimentary rocks, the metacarbonate rocks are considered to have deposited chemically in the so-called the "Mozambique Ocean" that separated the continental blocks that amalgamated to form Gondwana and possibly record geochemical signatures of contemporaneous seawater. Here we attempt to constrain the apparent age of sedimentation of metasedimentary sequences using strontium isotope chemostratigraphy of the least altered metacarbonate rocks. Pure metacarbonate samples, collected during the 51st Japanese Antarctic Research Expedition from different regions throughout the SRM, were selected based on careful screening using multiple geochemical parameters, such as carbon and oxygen isotopic composition and trace and rare earth element contents. We could successfully test the extent of alteration for the Sør Rondane metacarbonate samples, using Mn/Sr ratios, which show a positive correlation with $^{87}Sr/^{86}Sr$ ratios. After a rigorous geochemical screening in terms of post-depositional alterations, 18 samples were identified as least altered. These samples collectively gave regional initial $^{87}Sr/^{86}Sr$ ratios between 0.70566 and 0.70630, from Balchen, Brattnipene, Menipa and Tanngarden regions of the SRM, with the exception of Perlebandet region. These Sr isotopic ratios reflect seawater compositions of late-Tonian and early-Cryogenian age (880–850 Ma and 820–790 Ma), when compared with the evolution of Sr isotopes in the Neoproterozoic Oceans. Furthermore, these estimates are consistent with the carbon isotope chemostratigraphic curves of Neoproterozoic. The estimated apparent depositional ages of carbonate rocks in the SRM are also conformable with the reported detrital and metamorphic ages for this region. Carbonate rocks in the Perlebandet region shows low initial Sr isotope ratio (0.70482), suggesting that these rocks may have deposited earlier than other carbonate rocks in the SRM. Our results can be correlated with the chemostratigraphic depositional ages reported for carbonates from the Montepuetz Complex, Mozambique, suggesting the presence of contemporaneous platform environment on both sides of the possible suture. The finding of late-Tonian and early-Cryogenian carbonate deposition, potentially points toward a platform environment surrounding the tonalitic continental arc in the SW region of the SRM, prior to the amalgamation of Gondwana. The results obtained need to be tested with similar studies on metacarbonate sequences from the surrounding regions, which would help to resolve the processes and sequence of collision events that finally amalgamated Gondwana.

1. Introduction

One of the most common applications of carbonate geochemistry is chemostratigraphy, which helps us in correlating sequences as well as determining the apparent depositional ages of sedimentary rocks using a variety of geochemical proxies (Trønnes and

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http://dx.doi.org/10.1016/j.precamres.2012.10.016

Sundvoll, 1995; Melezhik et al., 2001; Halverson et al., 2010). In addition, carbonate geochemistry, especially the isotopic ratios of carbon and strontium, is widely used for understanding the chemical composition of paleo-oceans and its evolution through time and space (Veizer et al., 1999; Melezhik et al., 2001; Halverson et al., 2010). When compared with other elements, strontium has a long residence time (~2.4×10^6 yr; Jones and Jenkyns, 2001) relative to a short mixing time of the ocean water (~10^5 yr; Kump, 1991; Jacobsen and Kaufman, 1999), and therefore ocean is relatively homogenous with respect to its $^{87}Sr/^{86}Sr$ composition (Halverson et al., 2007). Moreover, carbonate minerals contain high concentrations of Sr (few hundreds to thousands of ppm on average) and very low contents of Rb (ppb levels). Sr isotope ratios in carbonate minerals can thus directly reflect sea water composition even in geologically older formation and therefore best suited for chemostratigraphic application. Compared with strontium, carbon behaves differently and is a proxy for a variety of environmental factors that controls the biogenic-abiogenic carbon balance in the Earth's surface processes (Knoll et al., 1986; Kaufman et al., 1997). Although secular trends in carbon isotope ratios can be applied for chemostratigraphic purpose for shorter time spans (few tens of millions of years) in the Neoproterozoic, recent studies also indicate decoupling from a simple biologically controlled isotopic excursions and other possible mechanisms are debated (Rothman et al., 2003; Knauth and Kennedy, 2009; Derry, 2010). Halverson et al. (2010) reported that the fluctuation of $^{87}Sr/^{86}Sr$ ratios from Early Neoproterozoic to early-Cambrian shows unidirectional-increasing shifts. They have also compiled the variations observed in carbon isotopic composition and demonstrated the secular trends which markedly shift during the global glaciation events. If strontium and carbon isotope ratios of carbonate rocks record the chemical compositions of coeval seawater, then these secular variations can be utilized to estimate an apparent age of carbonate deposition. Furthermore, recently, isotope chemostratigraphy has been successfully applied for indirect dating and correlation of high-grade metacarbonate sequences as well (e.g. Melezhik et al., 2005, 2008; Satish-Kumar et al., 2008).

Metasedimentary sequences preserved in orogenic belts provide key information about the paleo-oceans that existed between continents. The cycle of orogenesis initiates with rifting and opening up of oceans, where clastic sedimentary sequences are deposited and record information on the provenance of source rocks that span a wide range of geologic time and continue until the closure of the oceans. Radiometric dating (such as U-Th-Pb) of key horizons, such as volcanic layers, helps us in direct determination of age of sedimentation in weakly to unmetamorphosed sequences. However, such information is obliterated in high-grade metamorphic terrains, where in most cases the dating of detrital zircons can only lead to an upper limit (youngest detrital age) and lower limit (earliest metamorphic event) for constraining the age of deposition. Accurate determination of age of sedimentation is thus difficult in many of the orogenic belts. Continental collisions are, in general, preceded by closure of oceans and, therefore, the final stages of oceanic closure are marked by the abundance of clastic and carbonate facies sediments that have been deposited in a continental platform setting. Therefore, the carbonate sediments and their age of deposition are vital in understanding the tectonic developments in collisional orogenesis.

The Sør Rondane Mountains (SRM) located between 22° and 28° E and 71.5° and 72.5° S form one of the largest mountain chains in the Eastern Dronning Maud Land, East Antarctica. This region is a part of the Latest Proterozoic to Early Cambrian collision zone in the southern domain of the north–south trending East African-Antarctic Orogen (EAAO; Jacobs et al., 2003) that includes high-grade terranes of Mozambique, Madagascar, Sri Lanka and southern India (Fig. 1A). Recent studies have suggested that the east–west trending "Kuunga" orogeny passes through Eastern Dronning Maud Land and it is highly likely that multiple collision and accretion of smaller continental fragments have resulted in the final amalgamation of Gondwana rather than a single East- and West-Gondwana (Meert, 2003). In this context, the Dronning Maud Land is considered to be the western extremity of the Mozambique Ocean that existed between different cratonic blocks that finally amalgamated to form the Gondwana supercontinent. Similar to many other collisional orogenies, carbonate rocks from an integral part of the thick pile of metasedimentary sequences of the SRM suggesting that they were possibly deposited in the Mozambique Ocean. Considering a late Cryogenian to early Paleozoic (750–530 Ma; Meert, 2003, Boger, 2011 and references therein) orogenic event that resulted in the final amalgamation of Gondwana, the sediments should have been deposited chemically from the seawater prior to it, in the Proterozoic era. In the SRM, most of outcrops of metacarbonate layers are conformable with the adjoining metasedimentary sequences and several of them are composed of pure carbonate minerals. Therefore, these rock units can be ideal for yielding geochemical information of the paleo-oceans. However, carbonate rocks of the SRM are metamorphosed and may not essentially retain the chemical characteristics at the depositional time. The aim of this study is to identify pristine depositional geochemical signatures of metacarbonate rocks and to estimate the apparent depositional age for the metasedimentary sequences in the SRM, East Antarctica, by using strontium and carbon isotope chemostratigraphy.

Earlier geochronological studies in this region, based on zircon U-Pb SHRIMP and Nd model age data, have placed broad constraints on the age of deposition between middle- to late-Proterozoic for the metasediments (e.g. Shiraishi et al., 2008). This broad constraint is not sufficient to discuss the tectonic development of this region as well as the SRM's significance in a broader collisional regime. The chemostratigraphic approach we have undertaken in this study permits to obtain more stringent depositional age constraints for the metasedimentary rocks in the SRM, and not only helps us to reveal the timing and tectonic development of the region but also provides further insights on Gondwana amalgamation.

2. Geological background and field relationships

2.1. Geological outline of the Sør Rondane Mountains

The SRM forms part of the Neoproterozoic to Cambrian collisional orogenic belt in the Eastern Dronning Maud Land, East Antarctica (Fig. 1B). This region comprises of highly deformed medium- to high-grade metamorphic rocks in association with various igneous rocks. Field, petrologic and geochemical studies carried out in the late 1980s and early 1990s by the Japanese Antarctic Research Expeditions (JARE 25th to 32nd) in this region recognized two distinct terranes based on lithology and metamorphic grade, named as the Northeastern and the Southwestern terranes separated by a high strain zone (Osanai et al., 1992). However, based on recently obtained geological and geochronological data, Osanai et al. (2013) proposed that these terranes are separated by most important collision tectonic boundary (Main Tectonic Boundary), a possible candidate for suture between Maud-Natal Belt in the Kalahari craton and the Coats Land Block in Antarctica.

Geological structure of the Northeastern terrane (the NE terrane, here after) is characterized by the distribution of north-dipping low-angle faults trending WNW–ESE which are subparallel to the metamorphic foliations except for southeastern part where the faults are oblique to the metamorphic foliations with NNW–SSE strikes. Geologic structures generally strike E–W to ENE–WSW and dip steeply south, while those along the faults are overturned and