Precambrian Research 214–215 (2012) 172–184

Contents lists available at SciVerse ScienceDirect

Precambrian Research

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

A Neoproterozoic continental rift succession: The volcano-sedimentary Koivib Mountains deposits of Namibia

C. Pilote[a], P.L. Corcoran[a,*], W.U. Mueller[b,1]

[a] Department of Earth Sciences, University of Western Ontario, London, Ontario, Canada N6A 5B7
[b] Sciences de la terre, Universite du Quebec a Chicoutimi, Chicoutimi, Quebec, Canada G7A 2B1

ARTICLE INFO

Article history:
Received 30 June 2011
Received in revised form
16 September 2011
Accepted 14 October 2011
Available online 25 October 2011

Keywords:
Continental rifting
Adamastor Ocean
Pan-African Orogeny
Neoproterozoic
Volcano-sedimentary succession

ABSTRACT

Neoproterozoic volcanic and sedimentary rocks compose the 750 m thick Koivib Mountains succession, which forms part of the Rosh Pinah Formation of southwest Namibia. Detailed sedimentary facies analysis and physical volcanology enabled determination of four lithofacies and component twelve facies that record subaqueous deposition in a tectonically controlled shallow sea. The mafic volcanic lithofacies is composed of mafic: (1) flow, (2) volcaniclastic, and (3) intrusive facies characteristic of seamount building by effusive volcanic processes. The felsic volcanic lithofacies containing felsic: (4) flow and (5) volcaniclastic facies displays features characteristic of proximal to distal and marginal regions of subaqueous dome–flow complexes. The siliciclastic lithofacies composed of (6) shale, (7) thin- to medium-bedded sandstone, (8) thick-bedded sandstone, and (9) sedimentary breccia facies is consistent with a submarine fan environment in which subaqueous density current and turbidity flow processes were predominant. The silicilastic–carbonate lithofacies, which contains (10) massive bedded carbonate, (11) laminated to cross-bedded calcarenite, and (12) graded bedded calcarenite, formed mainly through erosion of primary carbonate and transport of material from a platform to a slope setting. The overall stratigraphy, combined with geochemical results indicating bimodal volcanism in a within-plate tectonic setting, signifies that the Koivib Mountains succession developed as part of a continental rift sequence associated with Neoproterozoic break-up of the Rodinia supercontinent. The structural geology of the Koivib Mountains revealed two generations of folds, including (i) NW trending tight, isoclinal folds (F1) and (ii) NNW trending open folds (F2). The second deformation event refolded F_1 folds, producing periclinal structures. The deformation features are consistent with SE transpression associated with the continental collision that occurred during closure of the Adamastor Ocean and formation of Gondwana.

1. Introduction

Volcano-sedimentary successions deposited in continental rift basins are important records of the processes that occur during continental break-up. Rift basins are complex, elongated crustal depressions bounded by normal faults and uplifted flanks (Withjack et al., 2002), which control sedimentation and magmatism in both subaerial and subaqueous environments. In the past, continental rifting has led to the break-up of supercontinents, including Rodinia. Evidence supporting the existence and splitting-apart of the Rodinia supercontinent is provided in rock successions globally, although the internal configuration of continents remains enigmatic (Hoffman, 1991; Moores, 1991; Li et al., 2008). The Rodinia supercontinent formed at approximately 1100–1000 Ma during the Grenvillian Orogeny (Dalziel, 1997) and began to break apart at 850 Ma (Li et al., 2010) as a result of plume-related extension (Li et al., 1999). Chronostratigraphy of individual Neoproterozoic belts has enabled recognition of connections between the South American and southwest African orogenic systems (e.g. Porada, 1989; Basei et al., 2005; Saalmanna et al., 2005). These belts evolved along the margins of the proto-Atlantic Adamastor Ocean, which formed as a result of the rifting of Rodinia. In some areas, such as Brazil and western Africa, tectonic inversion occurred and the volcano-sedimentary sequences were deformed and metamorphosed during subsequent ocean closure and formation of Gondwana. Although some of the primary sedimentary and volcanic structures are obscured by metamorphism and deformation, the volcano-sedimentary successions contain key information toward our understanding of the evolution of continental rifts during the Neoproterozoic era.

The Gariep belt, located along the southwest coast of Africa in Namibia (Fig. 1), represents a strategic area for studying the evolution of a rift-related volcano-sedimentary succession because it

* Corresponding author. Tel.: +1 519 661 2111x86836; fax: +1 519 661 3198.
E-mail address: pcorcor@uwo.ca (P.L. Corcoran).
[1] Deceased.

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doi:10.1016/j.precamres.2011.10.014

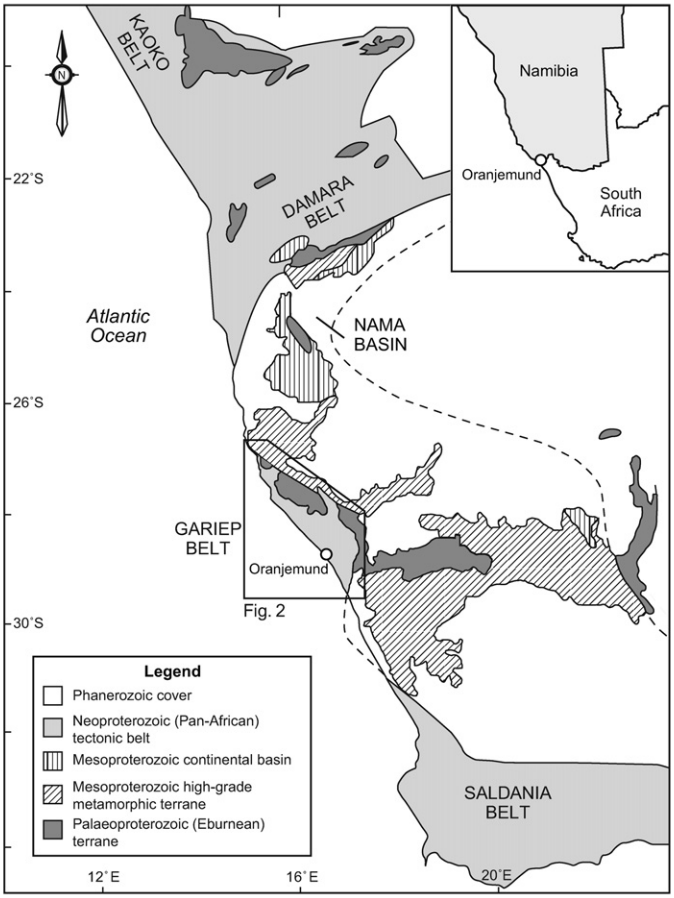

Fig. 1. Distribution of Proterozoic tectonic units/terranes in southwest Africa, showing the location of the Neoproterozoic Gariep belt.

Modified from Frimmel et al. (2004).

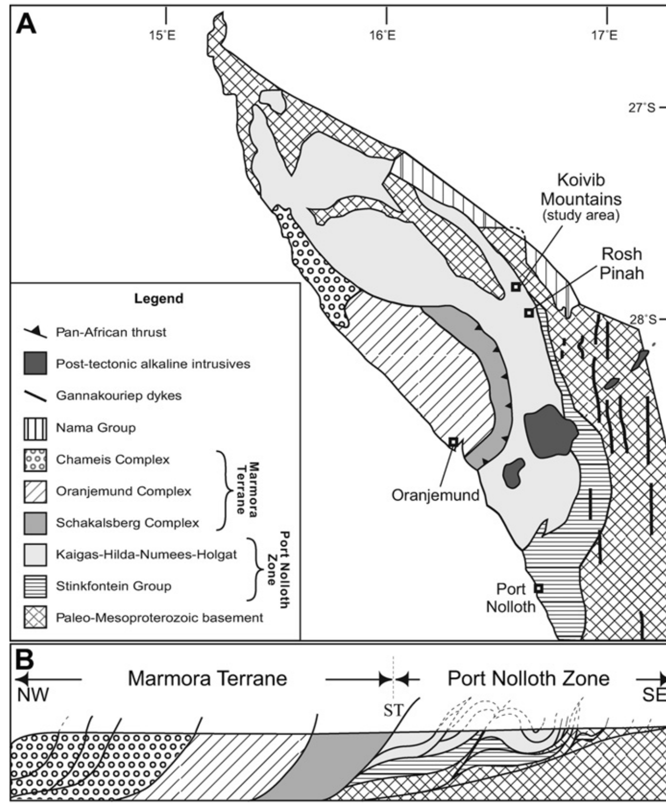

Fig. 2. (A) Simplified geological map of the Gariep belt showing the distribution of tectono-stratigraphic units. The location of the Koivib Mountains study area is indicated. (B) Geological cross-section through the Marmora Terrane and Port Nolloth Zone.

Modified from Frimmel and Frank (1998).

developed during the Pan-African extension event related to the break-up of Rodinia. The southeast portion of the orogenic belt is characterized by the para-autochthonous Port Nolloth zone, which contains evidence of an early phase of continental rifting (Frimmel et al., 1996a). The only volcanic assemblage within this zone forms part of the Rosh Pinah Formation, for which reviews of the lithostratigraphy and age constraints proximal to Rosh Pinah mine are provided in Frimmel et al. (2002) and Alchin et al. (2005). The Koivib Mountains comprise part of the Rosh Pinah Formation over an area of approximately 4 km × 9 km, 15 km northwest of Rosh Pinah mine (Fig. 2). This area is of great interest because of the proximity of two important base metal deposits, the Skorpion and Rosh Pinah Mines. Lithofacies mapping and detailed descriptions of the Koivib Mountains volcano-sedimentary sequence had not been conducted prior to this study. The aim of this project was to conduct detailed physical volcanology, sedimentary facies analysis and structural geology, which, combined with geochemical results from Pilote (2006) would enable determination of the stratigraphy, depositional environment, tectonic setting and deformation of the zone on the flanks of a major rift.

2. General geology

The Neoproterozoic Gariep Belt (ca. 770–550 Ma; Frimmel et al., 2002) is composed of two major tectonic divisions (Frimmel and Hartnady, 1992), (1) the Port Nolloth Zone, which represents the evolution from rift environment to passive margin and (2) the Marmora Terrane, which was predominantly oceanic. These units are separated by the Schakalsberg thrust fault, which tectonically emplaced the Marmora Terrane over the Port Nolloth Zone during Adamastor Ocean closure, indicating a southeast thrusting direction (Davies and Coward, 1982). The Port Nolloth Zone (PNZ), located in the eastern part of the Gariep Belt, rests unconformably on basement rocks composed of the Paleoproterozoic Eburnean terrane and the Mesoproterozoic Namaqualand high grade Metamorphic Complex. Three tectonic stages of basin evolution were recognized by Frimmel et al. (2002) (Fig. 3). The *M1* continental rift phase occurred from 770 to 740 Ma, and is represented by alluvial fan to alluvial plain and fan delta deposits (Stinkfontein Subgroup); fluvio-glacial deposits (Kaigas Formation); and bimodal, but predominantly felsic volcanic rocks (Rosh Pinah Formation). The *M2* passive margin development phase took place from 740 to 580 Ma, and is characterized by shallow marine carbonates of the Pickelhaube Formation, and a regressive siliciclastic succession (Wallekraal Formation) deposited proximal to the shoreline. Glacio-marine deposits of the overlying Numees Formation are correlative with the Marinoan glaciation (Frimmel et al., 2002), which is considered the most widespread "Snowball Earth" glaciation episode. The final *M3* phase consists of post-glacial carbonates and syn-orogenic flysch deposits (Holgat Formation).

The allochthonous Marmora Terrane, composing the westernmost part of the Gariep belt, contains three tectono-stratigraphic units, the Schakalsberg, Oranjemund and Chameis Subterranes (cf. complexes, Fig. 2). In contrast to the predominantly sedimentary Port Nolloth Zone, the Marmora Terrane contains a relatively large portion of mafic volcanic rocks, is characterized by the absence of basement, and represents volcanism and sedimentation during oceanic island formation and ocean floor spreading (Frimmel et al., 1996a,b). Detailed study in the Schakalsberg Mountains reveals that