Journal of South American Earth Sciences 58 (2015) 309–317

Contents lists available at ScienceDirect

Journal of South American Earth Sciences

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

Tectonic setting of basic igneous and metaigneous rocks of Borborema Province, Brazil using multi-dimensional geochemical discrimination diagrams☆

Sanjeet K. Verma*, Elson P. Oliveira

Department of Geology and Natural Resources, Institute of Geosciences, PO Box 6152, University of Campinas–UNICAMP, 13083-970 Campinas, SP, Brazil

ARTICLE INFO

Article history:
Received 19 March 2014
Accepted 31 August 2014
Available online 19 September 2014

Keywords:
Discrimination diagrams
Tectonic setting
Basic and ultrabasic rocks
Borborema Province
Log-ratio transformation
Geochemistry

ABSTRACT

Fifteen multi-dimensional diagrams for basic and ultrabasic rocks, based on log-ratio transformations, were used to infer tectonic setting for eight case studies of Borborema Province, NE Brazil. The applications of these diagrams indicated the following results: (1) a mid-ocean ridge setting for Forquilha eclogites (Central Ceará domain) during the Mesoproterozoic; (2) an oceanic plateau setting for Algodões amphibolites (Central Ceará domain) during the Paleoproterozoic; (3) an island arc setting for Brejo Seco amphibolites (Riacho do Pontal belt) during the Proterozoic; (4) an island arc to mid-ocean ridge setting for greenschists of the Monte Orebe Complex (Riacho do Pontal belt) during the Neoproterozoic; (5) within-plate (continental) setting for Vaza Barris domain mafic rocks (Sergipano belt) during the Neoproterozoic; (6) a less precise arc to continental rift for the Gentileza unit metadiorite/gabbro (Sergipano belt) during the Neoproterozoic; (7) an island arc setting for the Novo Gosto unit metabasalts (Sergipano belt) during Neoproterozoic; (8) continental rift setting for Rio Grande do Norte basic rocks during Miocene.

1. Introduction

The Borborema Province of NE Brazil is made of several Precambrian fold belts, domains, massifs, or terranes, and Phanerozoic sedimentary covers. The province contains units with ages protruding from the Archean to the Neogene time (Almeida et al., 1981; Brito Neves et al., 2000; Van Schmus et al., 1995, 2008; Santos et al., 2008). The Precambrian basement was shaped mainly during the Neoproterozoic Brasiliano/Pan-African orogenesis, which resulted from the convergence of major "cratonic" blocks such as the West Africa–São Luiz and the Congo–São Francisco, during the amalgamation of West Gondwana (Brito Neves et al., 2000; Arthaud et al., 2008; Neves et al., 2012).

As a contribution to the understanding of the geotectonic domains and their tectonic setting, researchers have used several geological constrains. The most used ones were field relationship, high-resolution geochronology, isotope geology, thermobarometry, and geochemistry (Oliveira and Tarney, 1990; Van Schmus et al., 2008; Martins et al., 2009; Oliveira et al., 2010; Amaral et al., 2011; Knesel et al., 2011; Araujo et al., 2012; Castro et al., 2012; Neves et al., 2012). However, in several cases the proposed tectonic settings were not unambiguous, demanding new data or new approaches. For instance, on the basis of field relationship and structural geology D'el-Rey Silva (1995) suggested an extension-related origin for the Sergipano belt in the southernmost part of Borborema Province. On the other hand Araujo et al. (2003), Van Schmus et al. (2008), and Oliveira et al. (2010) using field relationships combined with geochronology, isotope geochemistry and whole rock geochemistry demonstrated that the Sergipano belt had a complex evolution with ocean basin opening, collision, post-collision indentation and foreland basin formation. Thus, controversies exist about the origin of the Sergipano belt as well as about other areas in the Borborema Province, and very often to resolve contentions new approaches are required. Therefore, the novelty of our approach lies in the multi-dimensional solution of geochemical data as a complement to try to decipher tectonic settings. The limitation with the use of these new multi-dimensional diagrams include post-emplacement

☆ Manuscript Submitted to: Journal of South American Earth Sciences, Special issue on "Tectonic evolution of the Borborema Province, NE Brazil: From the Archean to the latest stages of the Brasiliano Orogeny", March 19, 2014; revised following reviewers' comments August 18, 2014.

* Corresponding author.
E-mail addresses: sanjeetverma@ige.unicamp.br, sanjeetverma@gmail.com, sanjeet_vrm@yahoo.com (S.K. Verma), elson@ige.unicamp.br (E.P. Oliveira).

http://dx.doi.org/10.1016/j.jsames.2014.08.010
0895-9811/

changes especially those related to metamorphism and hydrothermal alteration; analytical data quality, appropriate radiometric dates of geochemically analyzed samples; significant differences in the origin of basic, intermediate and acid magmas from a given area such as mantle versus crustal origin; imprint of multiple tectonic events; and unavailability of data for a sufficiently large number of samples from a given area.

Fifteen new multi-dimensional discrimination diagrams for a wide range of ultrabasic to basic magmas to infer their tectonic settings have recently been proposed from linear discriminant analysis of natural logarithm transformed ratios of chemical data (Verma et al., 2006; Agrawal et al., 2008; Verma and Agrawal, 2011), and were used in this work. These diagrams involve coherent statistical treatment of compositional data consisting of log-ratio transformation as a fundamental requirement for such data handling (Aitchison, 1986; Egozcue et al., 2003; Pawlowsky-Glahn and Egozcue, 2006; Verma, 2010, 2012a; Buccianti, 2013; Parent et al., 2013).

The set of five diagrams by Verma et al. (2006) requires the availability of a complete data set of all major elements. These diagrams have four tectonic settings that could be discriminated for basic and ultrabasic magmas from 10 (DF1–DF2) discriminant function equations (summarized in Table S1; see the Supplementary Material file taken from Verma et al. (2014a,b) compilation of all DF1–DF2 type equations). The other two sets by Agrawal et al. (2008) and Verma and Agrawal (2011) are based on the availability of concentration data for the so-called relatively immobile elements (La, Sm, Yb, Nb, and Th for the first set and Nb, V, Y, Zr, and $(TiO_2)_{adj}$ for the second set). The respective DF1–DF2 equations are summarized in Tables S2 and S3. These diagrams have been successfully evaluated by several authors, such as Sheth (2008), Bailie and Rajesh (2012), Polat et al. (2009, 2011), Polat (2013), Pandarinath (2014), Pandarinath and Verma (2013), Verma and Oliveira (2013), Verma (2009, 2012b, 2013), Verma et al. (2011).

Here, we have applied these new tectonic setting geochemical discrimination diagrams to selected mafic-ultramafic igneous or

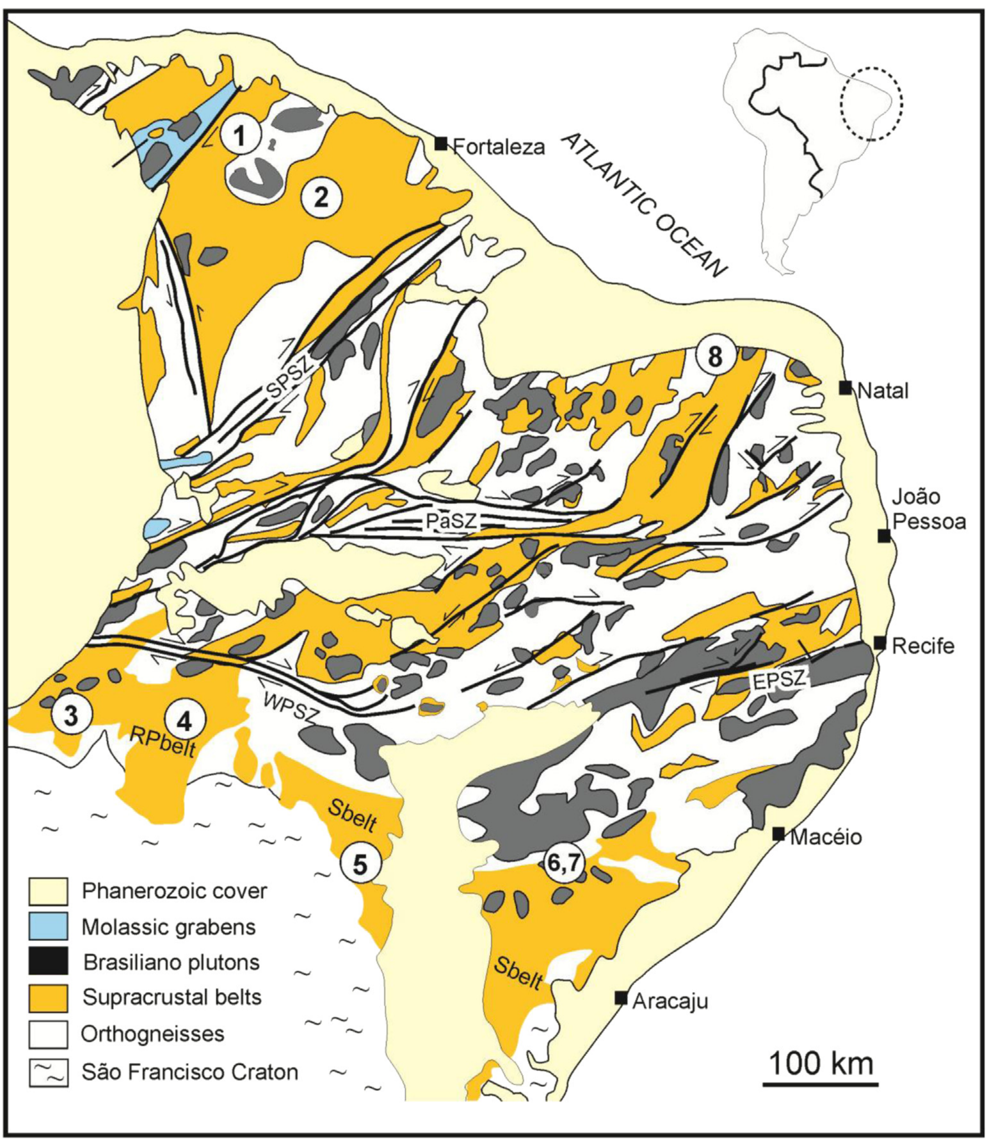

Fig. 1. Location Map of investigated basic rocks in the Borborema Province. 1 – Forquilha eclogite zone; 2 – Algodões amphibolites; 3 – Brejo Seco metavolcanic rocks; 4 – Monte Orebe metabasaltic rocks; 5 – Vaza Barris gabbroic/diabase intrusions; 6 – Gentileza unit amphibolites-diorites; 7 – Novo Gosto unit metabasaltic rocks; 8 – Miocene alkaline basaltic rocks of Rio Grande do Norte. Sbelt – Sergipano Belt; RPbelt-Riacho do Pontal belt; WPSZ and EPSZ, stand respectively to west and east Pernambuco shear zone; PaSZ – Patos shear zone; SPSZ-Senador Pompeu shear zone. Modified after Neves et al. (2009).