Journal of South American Earth Sciences 56 (2014) 468–484

Contents lists available at ScienceDirect

Journal of South American Earth Sciences

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

Tectonomagmatic origin of Precambrian rocks of Mexico and Argentina inferred from multi-dimensional discriminant-function based discrimination diagrams

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ARTICLE INFO

Article history:
Received 10 July 2014
Accepted 19 October 2014
Available online 23 October 2014

Keywords:
Tectonomagmatic diagrams
Tectonic setting
Arc
Rifting
Collision
Within-plate

ABSTRACT

Several new multi-dimensional tectonomagmatic discrimination diagrams employing log-ratio variables of chemical elements and probability based procedure have been developed during the last 10 years for basic-ultrabasic, intermediate and acid igneous rocks. There are numerous studies on extensive evaluations of these newly developed diagrams which have indicated their successful application to know the original tectonic setting of younger and older as well as sea-water and hydrothermally altered volcanic rocks. In the present study, these diagrams were applied to Precambrian rocks of Mexico (southern and north-eastern) and Argentina. The study indicated the original tectonic setting of Precambrian rocks from the Oaxaca Complex of southern Mexico as follows: (1) dominant rift (within-plate) setting for rocks of 1117–988 Ma age; (2) dominant rift and less-dominant arc setting for rocks of 1157–1130 Ma age; and (3) a combined tectonic setting of collision and rift for Etla Granitoid Pluton (917 Ma age). The diagrams have indicated the original tectonic setting of the Precambrian rocks from the north-eastern Mexico as: (1) a dominant arc tectonic setting for the rocks of 988 Ma age; and (2) an arc and collision setting for the rocks of 1200–1157 Ma age. Similarly, the diagrams have indicated the dominant original tectonic setting for the Precambrian rocks from Argentina as: (1) with-in plate (continental rift-ocean island) and continental rift (CR) setting for the rocks of 800 Ma and 845 Ma age, respectively; and (2) an arc setting for the rocks of 1174–1169 Ma and of 1212–1188 Ma age. The inferred tectonic setting for these Precambrian rocks are, in general, in accordance to the tectonic setting reported in the literature, though there are some inconsistence inference of tectonic settings by some of the diagrams. The present study confirms the importance of these newly developed discriminant-function based diagrams in inferring the original tectonic setting of Precambrian rocks.

1. Introduction

Mesozoic and Cenozoic sedimentary and volcanic rocks cover most parts of Mexico; much older rocks (Precambrian age) are very scarce and exposed only at some places. A Precambrian–Paleozoic composite terrene, Oaxaquia, extends beneath Mesozoic and Cenozoic rocks in the north-eastern and southern parts of Mexico. Oaxaquia comprises the basement rocks of Oaxaca, Juarez, Sierra Madre, and major parts of the Maya and Coahuila terranes (Ortega-Gutierrez et al., 1995). The rocks of Oaxaquia were exposed at the surface at Ciudad Victoria, Molango, Oaxacan Complex, and La Mixtequita of the eastern and southern Mexico (Lawlor et al., 1999). Among these surface exposed Precambrian rocks, Oaxaca Complex of southern Mexico is one with the larger area and forms part of the basement of Oaxaquia (Lawlor et al., 1999; Keppie et al., 2001). The original rocks (protoliths) of the Oaxaca Complex of southern Mexico consist of volcanic arc lavas and sediments intruded by rift-related granite, which were undergone granulite facies metamorphism at ~1 Ga. Geochronology data suggest a peak granulite facies metamorphism at 988 ± 5 Ma (Keppie et al., 2001).

Precambrian rocks are located at several places in central, western and north-western Argentina. The main orogenic activities in the crystalline basement of Argentina (central and western parts) have taken place during the Late-Proterozoic to Early-Paleozoic. The basement of Laurentian-derived terrenes consists of the Grenvillian-age rocks in the central and western Argentina (Sato et al., 2000). Grenville refers to rocks with ages of ~1300 to

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http://dx.doi.org/10.1016/j.jsames.2014.10.004
0895-9811/

~950 Ma that are contemporaneous with the North American Grenville province basement. Kay et al. (1996) have reported the similarity in isotopic signatures of these basement rocks and those of the North American Grenville Province.

Recently developed tectonomagmatic discrimination diagrams for basic (Agrawal et al., 2004, 2008; Verma et al., 2006; Verma and Agrawal, 2011), intermediate (Verma and Verma, 2013), and acid (Verma et al., 2013) volcanic rocks were highly successful in deciphering the original tectonic setting of the region. The first set of these diagrams are based on the discriminant function on the concentrations of major elements (Agrawal et al., 2004) and others are based on log-ratios of different combinations of major and trace elements of volcanic or plutonic rocks (Verma et al., 2006; Agrawal et al., 2008; Verma and Agrawal, 2011; Verma and Verma, 2013; Verma et al., 2013). Extensive evaluations of these diagrams have indicated the original tectonic setting of the region from which the studied rocks were sampled (Verma et al., 2006, 2010, 2011; Sheth, 2008; Verma, 2010; Verma et al., 2012; Pandarinath and Verma, 2013). Recently these discrimination diagrams have been successfully applied to know the original tectonic setting of igneous rocks of different types and ages: (1) altered rocks from the Indian Ocean (Sheth, 2008); (2) younger and older on-shore rocks as well as seawater altered deep-sea rocks off northwest Mexico (Pandarinath and Verma, 2013); (3) hydrothermally altered volcanic rocks derived from different depths of the drilled wells of several geothermal fields of the world (Pandarinath, 2014); (4) Precambrian rocks from several countries except Brazil and Mexico (Verma et al., 2014a); and (5) Precambrian rocks from several localities of Brazil (Verma and Oliveira, 2013, 2014; Verma et al., 2014b).

Sheth (2008) evaluated some of the diagrams (Verma et al., 2006) with data of ocean-island, arc and mid-ocean ridge lavas from the Indian Ocean and reported that the log-ratio transformation and linear discriminant analysis appear to be powerful methods in tectonomagmatic discrimination studies. Pandarinath and Verma (2013) have applied these tectonomagmatic discriminant function based diagrams to basic rocks from northwest Mexico and are of the opinion that these discrimination diagrams may successfully discriminate the original tectonic setting of comparatively younger and older on-shore rocks as well as seawater altered deep-sea rocks and dredged material. Similarly, Pandarinath (2014) has reported that these diagrams may be successfully applied to infer the original tectonic setting of hydrothermally altered rock samples derived from the geothermal wells.

Verma et al. (2014a) have applied these new multi-dimensional diagrams to decipher original tectonic settings for Precambrian belts in Canada, the USA, Poland, Finland, Jordan, Democratic Republic of Congo and Zambia, China, and India. The results of different sets of diagrams for basic-ultrabasic, intermediate, and acid magmas were generally consistent. They have reported that these new multi-dimensional diagrams perform better than the conventional bi-variate and ternary diagrams. However, they have also reported that there are still certain weaknesses in thee diagrams which may be related to the use of a sample group of mixed ages because of their uncertainties, extreme element mobility caused by metamorphism especially of high-grade type, analytical data quality, and different petrogenetic processes for basic to acid magmas such as mantle versus crustal origin. Verma et al. (2014b) have applied multi-dimensional discrimination diagrams (Agrawal et al., 2004, 2008; Verma et al., 2006; Verma and Agrawal, 2011) for Precambrian basic rocks for the data compiled from different locations of Brazil (for example, Amazonian Craton, Geraldes et al., 2004, Barros et al., 2009; Scandolara et al., 2013a; 2013b; Tocantins Province, Kuyumjian and Jost, 2006; São Francisco craton and marginal belt, Oliveira et al., 2011, 2013; Rosset et al., 2007; etc.) to infer the original tectonic origin of these rocks. They have reported that the application of these diagrams generally provided consistent results with the tectonic settings proposed by the authors based on field relationships and geochemical data. However, they have observed some limitations in applications of these diagrams and reported that these diagrams do not work well for some within-plate (continental) mafic dykes and basalts.

In this article, these recently developed and highly successful multi-element discriminant function based discrimination diagrams for basic-ultrabasic, intermediate, and acid rocks are applied for very old (988–1232 Ma; Precambrian) rocks of Mexico (southern and eastern parts) and Argentina (800–1212 Ma) to identify their tectonic origin.

2. Database

Based on the availability of the required complete geochemical data set in the literature, 77 rock samples from southern and north-eastern parts of Mexico (62 from the Oaxaca Complex of southern Mexico and 15 from north-eastern Mexico) were selected for this work from Lawlor et al. (1999), Keppie et al. (2001, 2003) and Ortega-Obregon et al. (2003). Similarly, 36 rock samples from Argentina were also selected for this study from Las Matras tonalitic–trondhjemitic pluton, central Argentina (Sato et al., 2000), Puncoviscana folded belt, northwestern Argentina (Omarini et al., 1999), and the Western Sierras Pampeanas, Argentina (Casquet et al., 2008; Colombo et al., 2009). Locations of the studied areas are shown in a schematic diagram (Fig. 1). A computer program SINCLAS (Verma et al., 2002, 2003) was used to classify the rocks into different magma and rock types. Thus, the database consists the following: (1) 29 rocks of basic-ultrabasic type (16 from Mexico and 13 from Argentina); (2) 27 rocks of intermediate type (21 from Mexico and 6 from Argentina); and (3) 57 rocks of acid type (40 from Mexico and 17 from Argentina). Recently developed discrimination diagrams are applied for these three types of rocks to know their original tectonic setting. The chemical composition data required for these diagrams are presented below.

The discrimination diagrams of basic and ultrabasic magmas of Agrawal et al. (2004) and Verma et al. (2006) are based on adjusted major element concentration data (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O and P_2O_5) and their log-ratios, respectively. The output from the SINCLAS program is required because the diagrams are based on both oxidation varieties of Fe and the sum of all oxides as 100%. The diagrams of basic and ultrabasic magmas of Agrawal et al. (2008) require immobile trace element data (La, Sm, Yb, Nb, and Th). Finally, the diagrams of basic and ultrabasic magmas of Verma and Agrawal (2011) require data of high field strength elements (TiO_2, Nb, V, Y, and Zr).

The discrimination diagrams of Verma and Verma (2013) for intermediate rocks require the availability of major elements (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O and P_2O_5), immobile major and trace elements (TiO_2, MgO, P_2O_5, Nb, Ni, V, Y, and Zr), and immobile trace elements (La, Ce, Sm, Yb, Nb, Th, Y, and Zr). Similarly, the discrimination diagrams of Verma et al. (2013) for acid rocks are based on log-ratios of major elements (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O and P_2O_5), immobile major and trace elements (TiO_2, MgO, P_2O_5, Nb, Y, and Zr) and immobile trace elements (Yb, La, Ce, Sm, Nb, Th, Y, and Zr). These multi-dimensional diagrams were developed by applying: (1) several chemical parameters simultaneously that show the highest separations among the different tectonic groups; and (2) the LDA technique to the worldwide database for obtaining the two discriminant functions DF1–DF2 for each combination of three tectonic groups at a time. Each tectonic setting appears in four of these five diagrams. Each diagram is a plot of two discriminant functions, DF1 and DF2, respectively in *x*- and *y*-axes. More details