Journal of African Earth Sciences 126 (2017) 159–175

Contents lists available at ScienceDirect

Journal of African Earth Sciences

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

Chemostratigraphic and sedimentologic evolution of Wajid Group (Wajid Sandstone): An outcrop analog study from the Cambrian to Permian, SW Saudi Arabia

Mohamed A. Yassin*, Osman M. Abdullatif

Geosciences Department, College of Petroleum Engineering & Geosciences, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

ARTICLE INFO

Article history:
Received 25 February 2016
Received in revised form
24 November 2016
Accepted 26 November 2016
Available online 28 November 2016

Keywords:
Geochemistry
Provenance
Tectonic setting
Wajid Group
Saudi Arabia

ABSTRACT

The Paleozoic age succession in Saudi Arabia represents one of the most prolific petroleum producing systems in the Arabian Peninsula. This succession is also considered important for unconventional tight gas and shale gas reservoirs. The Wajid Group (Wajid Sandstone) in SW Saudi Arabia consists of four formations, namely, Dibsiyah (Lower and Upper), Sanamah, Khusayyayn and Juwayl from bottom to top. This study investigates the major oxides, trace and rare earth elements for the Wajid Group formations in southwestern Saudi Arabia. We characterize and compare the sandstone types, provenance, tectonic setting, and climate. Moreover, we applied the chemostratigraphic technique for stratigraphic differentiation. Concentrations of certain elements indicate that Wajid Group was deposited in a passive continental margin. The geochemical analysis reveals that Wajid Group sediments were likely derived from the upper and bulk continental crust and mafic igneous provenance. The elemental geochemical data has been applied in this study to improve the stratigraphic subdivision and correlation. Using selected elements, geochemical vertical profiles, binary, and ternary diagrams allow clearly distinguishing between Wajid Group formations. Thus supports the established formation boundaries that constructed using lithostratigraphy and sedimentology. The geochemical elements variation between formations can be related to differences in rock-forming minerals, facies change, climate, and provenance. The results of this study may help in constraining and correlating complex facies strata and can be used as a guide for stratigraphic correlations in the subsurface within the Wajid basin and other equivalent stratigraphic successions within Saudi Arabia.

1. Introduction

The primary objective of this study is to use the elemental geochemistry of Wajid Group in southwestern Saudi Arabia for provenance signatures, tectonic setting determination, climate, and stratigraphic subdivisions. Moreover, the objective is to integrate the elemental geochemical results with the sedimentological results including lithofacies description, and petrographic analysis. The results of this study may contribute to hydrocarbon and water resource exploration and development by helping to solve geological challenges related to facies, paleoenvironments and paleogeography in relation to potential reservoir targets in complex geological settings (Al-Mahmoud and Al-Ghamdi, 2010; Briner et al., 2010). The sedimentary rocks chemical composition is dependent on numerous factors, such as weathering, source of sediments composition, transportation, sorting and diagenesis (Akarish and El-Gohary, 2008; Bhatia, 1983; Hussain, 2007; McLennan, 1989; Middleton, 1960; Yang et al., 2008). Some key trace elements are important for understanding sedimentary processes, (provenance, weathering, sorting, diagenesis, and recycling) (Hiscott, 1984). Trace elements which were used to discriminate the tectonic setting in this study are La, Th, Sc. The ratios of some elements were used by other authors to discriminate the tectonic setting e.g. Co/Th versus La/Sc used by (Gu et al., 2002); La/Sc/HF used by (Floyd and Leveridge, 1987); Th/Sc/Zr used by (Wanas and Abdel-Maguid, 2006); and La, Th, Sc used by Yan et al. (2007).

Integration of petrographic analyses with geochemical data will help to understand and reveal aspects of sedimentological and stratigraphic development. Moreover, several trace elements are used for the discrimination of tectonic settings and provenance

* Corresponding author. P.O. Box 8646, Dhahran 31261, Saudi Arabia.
E-mail address: mohamedgadir@kfupm.edu.sa (M.A. Yassin).

http://dx.doi.org/10.1016/j.jafrearsci.2016.11.029
1464-343X/

because of their moderately low mobility during sedimentary processes. Trace elements are utilized more than major elements to determine the tectonic setting and provenance (Bhatia and Crook, 1986). Elemental geochemistry has been applied for stratigraphic subdivisions and for chemostratigraphic correlation in different lithology and depositional environments (Craigie, 2015; Pearce et al., 1999; Racey et al., 1995; Ratcliffe et al., 2010).

Lower Paleozoic age outcrops are present in three main areas in Saudi Arabia from north to south; the Tayma/Tabuk regions, the Qasim area and the Wajid Plateau. Stratigraphically equivalent formation also occurs in the Gulf region. The type section of Wajid Group is located at Jabal A1 Wajid between longitudes 44° 25' E and 44° 35' E and latitudes 19° 51' N and 20° 50' N in the southern part of the Arabian Peninsula. At this location, the outcrops are composed of approximately 900-m-thick medium-to coarse-grained, cross-bedded quartz arenite of possible fluvial to shallow marine origin (Powers et al., 1966). The Wajid Group also crops out continuously for approximately 300 km from Wadi Ad Dawasir (latitude 20° 3074 and longitude 44° 30'E) to Najran (latitude 17° 3574 and longitude 44° 45'E). It is also exposed as small isolated outcrops along the southwest, where it caps the hilltops of the Precambrian Shield, and extends south to Yemen. The study area is located in southwest Saudi Arabia within the Wadi Tathlith Quadrangle, near Wadi Ad Dawasir (Fig. 1). It is bounded by latitude 20° 00' and 21° 00'N and longitude 43° 30' and 45° 00'E. The Wajid outcrop belt, which covers approximately 22,000 km^2, is exposed in the study area.

Commonly, the Phanerozoic rocks in southwestern Saudi Arabia lie non-conformably on the Arabian Shield Proterozoic rocks, and the contact is concealed by debris. However, the overall Paleozoic strata along the southern border of the Arabian Platform are composed almost exclusively of clastic sediments dipping gently to the east and northeast (Rub Al-Khali Basin) at dips of approximately 1° (Evans et al., 1991). The Wajid Group in Rub Al-Khali Basin represents a hydrocarbon province and a major aquifer in Saudi Arabia and some other Gulf countries (Evans et al., 1991).

This study was carried out at the Wajid Group in southwestern Saudi Arabia (Fig. 1). The study area is located between Wadi Ad Wasir in the north and Najran in the south. The area is covered by outcrops representing Lower Dibsiyah (LD), Upper Dibsiyah (UD), Sanamah (S), Khusayyayn (K) and Juwayl (J) formations (Figs. 1 and 2). Previous studies assigned Permian age and older or Cambrian-Ordovician age, to southwestern Saudi Arabia (Evans et al., 1991; Kellogg et al., 1986; Powers et al., 1966). The thickness of the Wajid Group ranges from 153 m to approximately 550 m. In these areas, the Wajid Group is underlain by igneous and metamorphic Basement Complex rocks and overlain by Khuff Formation. Kellogg et al. (1986) divided the Wajid Group into four members: Dibsiyah, Sanamah, Khusayyayn and Juwayl, from older to younger. The Wajid Formation was upgraded to the Wajid Group by (Stump and Eem, 1995), and all Wajid members were upgraded to formations. The depositional environment of the Wajid Group includes continental fluvial, braided stream channel/bar sequences, glacial aeolian and shallow marine near-shore environments (Vaslet et al., 1986). Hussain et al. (2004) studied the tectonic setting and provenance of Wajid Sandstone in Abha-Khamis Mushayt Area, Southwest Saudi Arabia using heavy mineral analysis (Hussain, 2007). studied the provenance of the Wajid Sandstone in an effort to correlate the results to the outcrops of the Saq Formation and relate strata in the northern outcrop belt of the Kingdom. Wanas and Abdel-Maguid (2006) studied the Wajid Group, concentrating on the petrography and geochemistry of the group (Knox et al., 2007). studied the entire succession of the Wajid Group with respect to its provenance using heavy mineral assemblages. Recent studies on the Wajid Group in southwest Saudi Arabia conducted by Abdulkadir et al. (2010); and Abdulkadir and Abdullatif (2013) described the sedimentology and petrophysical parameters of the Dibsiyah, Khusayyayn and Juwayl members in the area south of Wadi Adwasir in southwest Saudi Arabia (Al-Dabbagh, 2013). studied the tectonic growth of the Arabian shield and its effects on the Paleozoic succession in Saudi Arabia (Al-Ajmi et al., 2015). studied the sedimentology and stratigraphy of the Wajid Sandstone in outcrops southern Saudi Arabia.

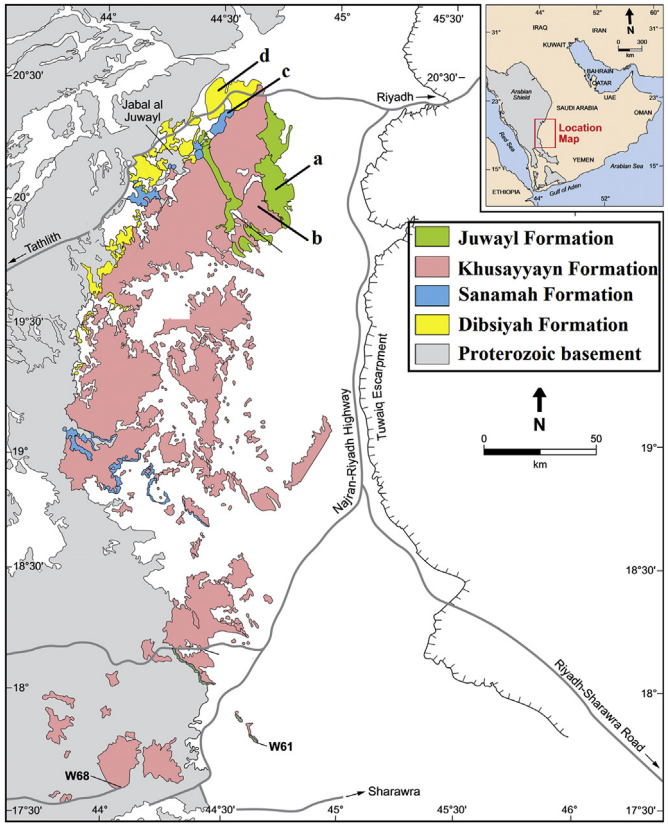

Fig. 1. Location map showing the study area and Wajid Sandstone Group. Vertical profiles description and Samples collection from Juwayl (a), Khusayyayn (b), Sanamah (c), Dibsiyah (d). (modified from Al-Husseini, 2004).

2. Materials and methods

The methods of the study included field, laboratory, and office investigations. The fieldwork investigated four outcrops representing the four formations of the Wajid Group south of the town of Al-Khamasin in the Wadi Adwasir area. These formations are the Dibsiyah (lower and upper), Sanamah, Kussayyan and Juwal formations. Four lithostratigraphic sections were measured, and facies types were described, identified and sampled. From the outcrop sections, a total of 64 samples representing the four formations were collected for laboratory examinations. Rock samples were collected from bottom to top of each section representing the various lithofacies present in the section. Petrographic analysis, bulk mineralogy analysis using polarized microscopy, Powder X-Ray using Jeol Diffractometer for (XRD) analysis and the Jeol Scanning Electron Microscope and Energy-dispersive X-ray spectroscopy (SEM-EDS) for SEM and micro elemental analyses (Tucker, 1991).

Quantitative geochemical analyses for major oxides, trace, and REE elements were carried out using a commercial lab (ALS Lab, Canada). In this study, we selected analytical package combining a