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Salt domes of the UAE and Oman: Probing eastern Arabia

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ABSTRACT

The emergent salt domes of the United Arab Emirates (UAE) have been investigated in detail and examples from central Oman have been studied for comparison. The salt domes contain exotic clasts of igneous, sedimentary and low-grade metamorphic rocks of the Arabian basement that have been brought to the surface from depths of over 8 km. The clasts thus provide an opportunity to examine the lithology, geochemical composition and age of the "basement" underlying this part of eastern Arabia, where no other outcrops are available for direct study. Five volcanic rocks give consistent latest Ediacaran U-Pb zircon crystallisation dates of ca. 560–545 Ma, with Neoproterozoic, Palaeoproterozoic and Neoarchaean ages of inherited zircons. These rocks, although strongly altered, preserve geochemical characteristics compatible with formation in a within-plate, extensional setting along the northern edge of Gondwana, adjacent to Prototethys. U-Pb analyses of detrital zircons in sedimentary and low-grade metamorphic rocks indicate deposition younger than ca. 597 Ma in UAE and <734 Ma in Oman. The two UAE sedimentary rocks may correlate with the Shuram and Khufai Formations of the Nafun Group (Huqf Supergroup) in Oman. Like the volcanic rocks, the two sedimentary samples from the UAE show derivation from the erosion of Neo-, Palaeoproterozoic and Neoarchaean sources. These sources could be from the Arabian basement itself or from other basement blocks such as those embedded in present-day Iran and Afghanistan, the precise whereabouts of which in Neoproterozoic times remains somewhat uncertain. The zircon age spectra of samples from the UAE show Neoproterozoic age peak characteristics of sources from both the western and eastern Arabian basement blocks, indicating that the two segments were juxtaposed by about 597 Ma, the maximum age of their deposition.

1. Introduction

The emergent salt domes of eastern Arabia which form the subject of this study are exposed in two clusters in the Arabian Gulf offshore of the United Arab Emirates (with one exposed on the adjacent mainland) and in the desert of central Oman (Peters et al., 2003). Two domes are also exposed in the territorial waters of Qatar (e.g. Nasir et al., 2003, 2008) and several hundred are identified in Iran (e.g. Kent, 1970, 1979; Edgell, 1996; Motamedi et al., 2011; Taghipour et al., 2012). The salt domes of UAE and Oman were intruded mainly in the Miocene, as evidenced by localised deformation of Miocene sediments (Thomas et al., 2012, 2014). They are sourced from a thick sequence of deeply buried Ediacaran-Cambrian ("Infracambrian") evaporites known as the Hormuz salt, which underlies much of the Gulf region of eastern Arabia and which formed along the northern margin of Gondwana (Husseini and Husseini, 1990; Smith, 2012) in a palaeo-latitudinal belt between 20 and 30° S (Allen, 2007).

It has long been known that the salt domes of eastern Arabia are made up largely of a halitic breccia ("Hormuz breccia"). The breccia typically contains a wide variety of exotic clasts of igneous, sedimentary and rare metamorphic rocks carried up from depth by the rising salt diapirs, with the most common clasts being carbonates of the "Infracambrian" Ara Group (e.g. Kent, 1970, 1979). Some clasts contain Cambrian fossils such as trilobites and many of the igneous rocks have been assumed to be Precambrian in age. Detailed work on the microbial limestone clasts of salt domes in Oman has established their latest Neoproterozoic-Cambrian age and investigated their depositional enviroments (e.g. Mettraux et al., 2014).

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However, no clasts have been dated by modern U-Pb zircon techniques.

The age of clasts in salt domes can be constrained to some extent by what they might reasonably could be expected to include: (1) materials incorporated from strata overlying the salt bed; (2) materials derived from strata immediately beneath the salt; (3) materials tectonically juxtaposed with the salt; (4) magmatic rocks intruding salt. In the case of the UAE and Oman salt domes there is no evidence that situations 3 and 4 are applicable.

As part of a contract between the UAE Ministry of Energy (Department of Mineral and Energy Resources) and the British Geological Survey, we mapped in detail seven of the nine exposed salt domes in the UAE. Geological maps at 1: 25,000 scale and detailed descriptions can be found in Thomas et al. (2012). Particular attention was paid to the wide variety of exotic clasts entrained within the salt domes. This study presents the results of dating and geochemical analysis of the igneous rocks, together with detrital zircon ages of siliciclastic sedimentary rocks and the very rare low-grade metamorphic carbonate rocks, in order to determine the maximum ages of deposition and age-provenance. We visited all the exposed salt domes of central Oman, only one of which contains exotic igneous and sedimentary rocks (other than the ubiquitous Ara Group carbonate clasts). This paper provides information on the lithological nature, composition and age of the deeply buried "basement" beneath NE Arabia and discusses wider implications for Arabian and Gondwana development.

2. Arabian basement architecture

The Arabian Peninsula comprises Precambrian basement rocks, extensively covered by up to 10 km of late Neoproterozoic to Phanerozoic sedimentary and volcanic rocks (Fig. 1). The Arabian plate is tilted northeastwards from the Red Sea uplift, so the cover rocks thicken gradually in that direction towards the Arabian Gulf States and Oman. The Precambrian basement crops out principally adjacent to the Red Sea uplift and adjacent interior along the SW side of the plate, and forms part of the Arabian Shield. Related outcrops in North Africa west of the Red Sea together make up the Arabian-Nubian Shield, itself representing the northern part of the enormous East African Orogen (referred to as forming a "Transgondwanan Supermountain" by Squire et al., 2006), which stretches fully 8000 km down the eastern side of Africa to Mozambique (Jacobs and Thomas, 2004). While the geology and nature of the exposed Arabian Shield are well known, the basement to the east is far less well understood due to lack of outcrops, except for a few isolated areas in Oman. A comprehensive review of the architecture of the Arabian plate is given by Stern and Johnson (2010) and detailed accounts of the geology of the Arabian Shield and its complex geological evolution are available (e.g. Johnson, 2003; Hargrove et al., 2006; Stern et al., 2010).

The major part of the Arabian basement was formed in the Neoproterozoic, after about 1 Ga, although there are remnants of older, Palaeoproterozoic to Neoarchaean rocks preserved in southern Saudi Arabia and Yemen (Whitehouse et al., 2001; Fig. 1). The older rocks of Yemen are considered to belong to part of a poorly exposed cratonic mass that included rocks in the Horn of Africa. Together these constitute the Somali craton, which may have formed, along with the Archaean rocks of Madagascar, a cratonic fragment known as Azania that was involved in the amalgamation of Gondwana (Collins and Pisarevsky, 2005). From outcrops in Oman and geophysical data it is clear that the Arabian Shield region in the west is fundamentally different from that of the east. The ca. 700+ Ma accreted island arcs and ocean crust of the Arabian-Nubian shield (Stoeser and Camp, 1985) are quite unlike coeval basement rocks in Oman (Mercolli et al., 2006). Therefore, in this paper we will refer to the "Western" and "Eastern" Arabian basement blocks. A major magnetic feature (the Central Arabian Magnetic Anomaly; Fig. 1) possibly coincides with the boundary between the two crustal segments, although this is disputed by other researchers (e.g. Cox et al., 2012) who suggest that the boundary may lie much further east, along a "Western Deformation Front" in southwestern Oman (see discussion in Allen, 2007). The timing of the accretion of the eastern basement with the western part of Arabia and Africa also remains open to further debate.

The Eastern basement has a quite different history from that of the Western basement. The oldest rocks are best exposed in the small inlier of Mirbat in southern coastal Oman (Fig. 2) (Mercolli et al., 2006). Here, the oldest rocks are metasedimentary gneisses with Mesoproterozoic protoliths (ca. 1300 Ma), that were deposited at <1000 Ma and intruded by early Cryogenian meta-igneous rocks at about 820 Ma and accompanied by high-grade metamorphism. The complex was intruded by various calcalkaline granitoids including tonalite at around 795 Ma and various granodiorites and granites up to about 720 Ma, as well as a NW-SE dyke swarm dated at 750–?700 Ma, with a second phase at ca. 600 Ma (Worthing, 2005). A similar history is recognised in the few other areas of basement outcrop, such as the Al Hallaniyat Islands and Jabal Ja'alan, where older studies utilising Rb-Sr and K-Ar techniques are available (see references in Mercolli et al., 2006). At Mirbat, the basement was rapidly exhumed and unconformably overlain by the (presumed) Upper Cryogenian clastic Mirbat Formation (Rieu et al., 2007). Acid volcanic rocks and granodiorite, considered to form the basement in the Huqf inlier at Al Jobah (Fig. 2), were dated at around 825 Ma (Bowring et al., 2007).

The crystalline basement is overlain by a thick sequence of Cryogenian to Ediacaran volcano-sedimentary rocks (the Huqf Supergroup), most extensively exposed and studied in the Huqf inlier in eastern Oman and in borehole cores from the surrounding region. Here, the unconformity between igneous basement and sedimentary cover probably dates from about 725 Ma (Allen, 2007). In the Jabal Akhdar region of northern Oman, the sedimentary succession contains glacial diamictites of the Abu Mahara Group. These were formed in two main phases of deposition with dates of ca. 713 Ma and <650 Ma, which may correlate with the putative Sturtian and Marinoan global events (Bowring et al., 2007). Sedimentation took place in extensional grabens (orientated N–S in present day coordinates), whereas uplifted rift shoulders were erosional and did not accommodate Cryogenian sediments (Allen, 2007). The overlying, post-Cryogenian sedimentary rocks of the Nafun Group in Oman are extensive, burying basement highs, and lack evidence of structural confinement. In Oman, the Nafun Group in general increases in depositional water depths from the south (Mirbat) to the north (Jabal Akhdar). There is therefore reliable evidence of crustal extension between 720 and 640 Ma, followed by widespread but slow subsidence unaffected by tectonics from 640 to 547 Ma, which is best explained by a model of continental stretching (Bowring et al., 2007).

Sedimentation of the Huqf Supergroup continued into the Cambrian, with the Cambrian-Precambrian boundary lying within the lower part of the carbonate-evaporite sequence of the Ara Group (the local name for the Hormuz Salt), the distribution and evolution of which is reviewed by Smith (2012). During the Cambrian, the extensive basin occupied by the Nafun Group was fragmented by tectonics, locally associated with volcanism in northern Oman (ignimbrites of the Fara Formation, and ash-beds in the time-equivalent Ara Group) (Allen, 2007; Bowring et al., 2007). Contemporaneous igneous activity in central Iran at 547–525 Ma (Ramezani and Tucker, 2003) suggests subduction of proto-Tethyan crust beyond the continental margin, which converted the Oman and UAE regions into a retro-arc setting on the NE Arabian margin.