Elsevier Editorial System(tm) for Precambrian Research
Manuscript Draft

Manuscript Number: PRECAM4226

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Article Type: Research Paper

Keywords: Arabia, Salt diapir, Neoproterozoic, Gondwana, U-Pb geochronology

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Salt domes of the UAE and Oman: probing eastern Arabia

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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 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 (ñInfracambrianò) 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^{o}S (Allen, 2007).

It has long been known that the salt domes of eastern Arabia are made up largely of a hyaloclastic breccia (ñHormuz brecciaò). 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 ñInfracambrianò 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 have established their latest Neoproterozoic-Cambrian age and depositional enviromnets (e.g. Mettraux et al., 2014). However, no clasts have ever been dated by modern U-Pb zircon techniques.

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. (2013). We paid particular attention to the wide variety of exotic clasts entrained within the salt domes, and this study presents the results of dating and geochemical analysis of the igneous rocks along with detrital zircon ages of siliciclastic sedimentary rocks and the very rare low-grade metamorphic carbonate rocks, in order to determine their maximum ages of deposition and their 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). We provide information on the lithological nature, composition and age of the deeply buried ñbasementò beneath NE Arabia and discuss any 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. This outcrop is known as 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 ñTransgondwanan Supermountainò by Squire et al., 2006), which stretches fully 8000 km down the eastern side of Africa to Mozambique. 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 ñWesternò and ñEasternò Arabian basement blocks. A major magnetic feature (the Central Arabian Magnetic Anomaly; Fig. 1) possibly forms the boundary between the two crustal segments, although this is disputed by other researchers (e.g Cox et al., 2012) and some researchers place it much further east, along a ñWestern Deformation Frontò 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 controversial.

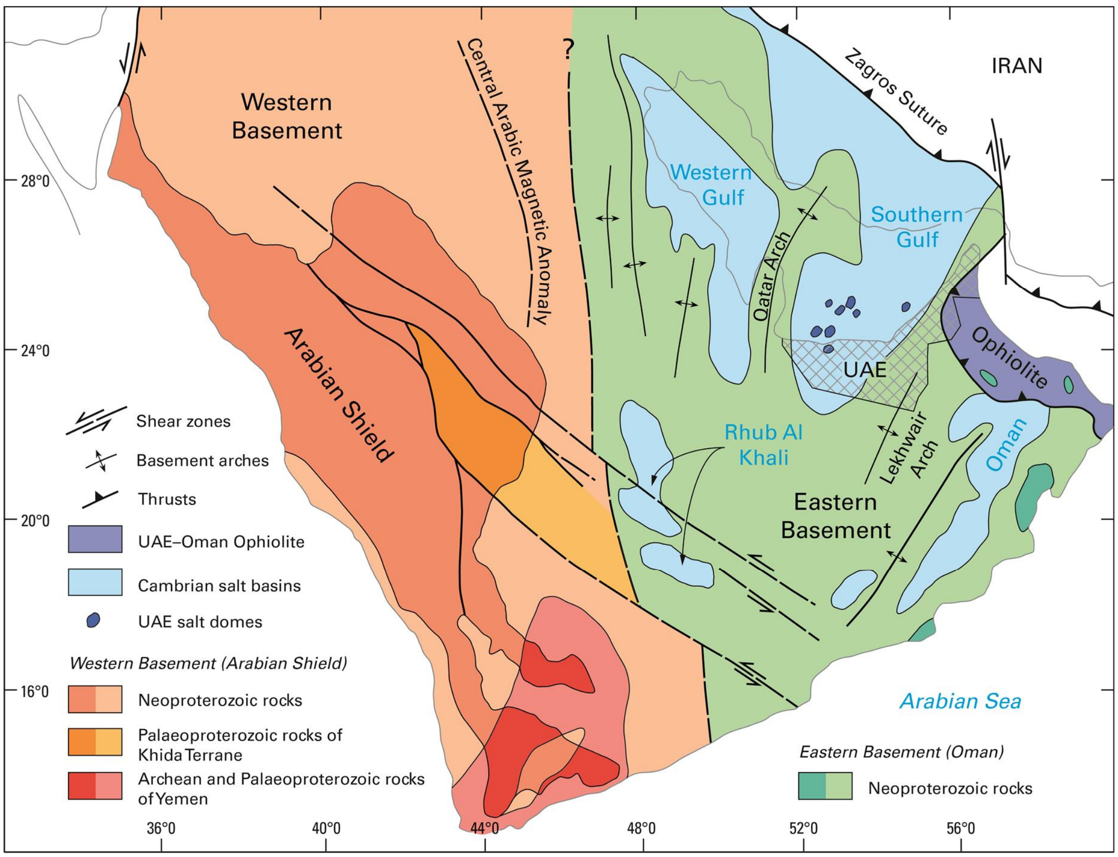

Fig. 1. The architecture of southern Arabia, modified after Stern and Johnson (2010) and the geological setting of the emergent salt domes of UAE and Oman. CAMA = Central Arabian Magnetic Anomaly. The darker shades indicate areas of outcrop.

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), where a detailed study has been made by 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, 2006). This history is typical of the few other outcrop areas such as the Al Hallaniyat Islands and Jabal Jaôatan, 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, 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 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 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 720-640 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.

Sedimentation of the Huqf Supergroup continued into the Cambrian, with the Cambrian-Precambian 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). The extensive Nafun basin was fragmented by tectonics, locally associated with volcanism in northern Oman (ignimbrites of the Fara Formation) (Bowring et al. 2007). Contemporaneous igneous activity in central Iran at 547 to

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. Thick evaporites and black shales were deposited in a number of ósaltô basins while structural highs focussed carbonate deposition. The structural highs are orientated N-S in present coordinates (the óArabian trendô) and continued to control sedimentation throughout the Phanerozoic (Fig. 2).

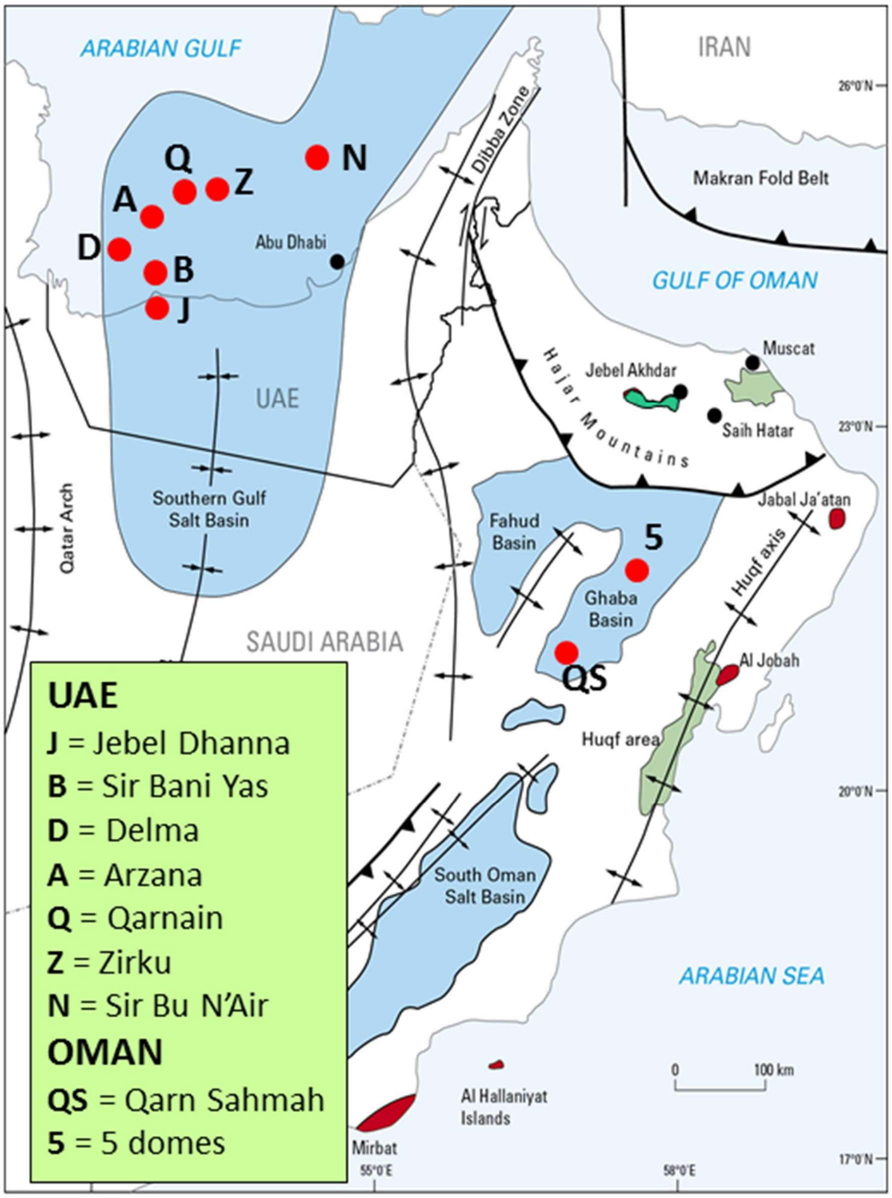

Fig. 2. Geology of the eastern part of Arabia after Allen (2007). Neoproterozoic basement outcrops are shown in red. They are unconformably overlain by Neoproterozoic sedimentary and minor volcanic rocks shown in green. The areas in blue are the subsurface known extent

of the Cambrian Hormuz salt. The red circles are the studied emergent salt domes of UAE and Oman, which are named in the legend. The white areas represent post-Hormuz salt cover rocks. The northern group of five domes in Oman only contain Ara Formation clasts.

The principal differences between the Western and Eastern basement blocks are summarised in Table 1.

Western basement (Arabian Shield)	**Eastern basement**
Comprises some Archaean and Palaeoproterozoic igneous and metamorphic rocks amongst a collage of Neoproterozoic high-grade juvenile accreted arc-terranes. Several stages of post-accretion basin development 650 to 570 Ma including late pull-apart basins and stitching granitoids (Johnson, 2003).	Comprises Early Neoproterozoic (Tonian/Cryogenian), metamorphosed volcano-sedimentary sequences and granitoids unconformably overlain by Late Neoproterozoic (Cryogenian/Ediacaran) to Phanerozoic rocks
Stabilised only at ca. 550 Ma	Stabilised by ca. 750 Ma
Thin Phanerozoic cover	Thick Phanerozoic cover
Bouyant, more deeply eroded; probably a positive feature throughout most of Phanerozoic	Gently subsiding throughout most of Phanerozoic
Moho at 35 to 40 km depth	Moho at 40 to 45 km depth

Table 1. Comparison of the main features of the Western and Eastern Arabian basement, following Stern and Johnson (2010).

It is clear that due to the sparse outcrops and thick cover, the Eastern basement of Arabia is far less well known than the Arabian Shield segment in the west. North of Oman, towards the Gulf States, there are no outcrops to study the Eastern basement - only those rocks brought up in unroofed salt diapirs which are the subject of our study.

3. UAE salt domes

The emergent salt domes of the UAE are exposed on a number of offshore islands in the Arabian Gulf. Jebel Dhanna, in the Western Region of Abu Dhabi Emirate is the only on-land breached example (Fig. 3a). The on-land salt dome at Jebel Ali, south of Dubai, has not been breached to expose its core and therefore cannot be studied from the surface. The entire area is underlain by Miocene bedrock, which forms the surface ñcountry rockò to the salt domes. The term ñsalt domeò is something of a misnomer in the UAE, in that none of the domes presently contain significant amounts of salt (halite) at outcrop; it has been leached away during sub-aerial exposure and denudation to leave residual gypsum. Salt is still present in fairly large volumes in at least two of the Oman domes.

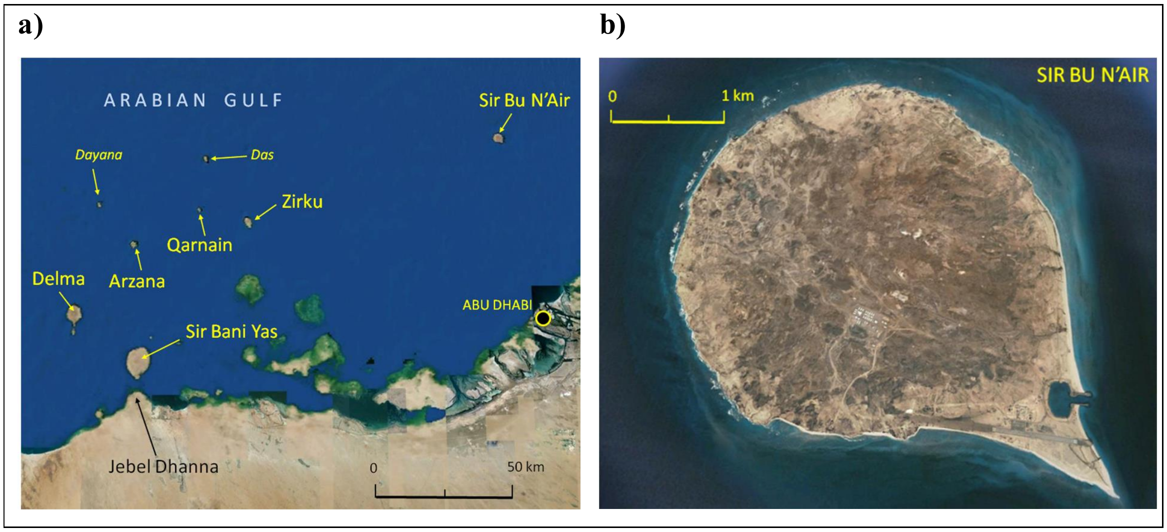

Fig. 3. Salt domes of the UAE. a) the seven salt domes studied are shown in large font; b) Satellite image of the island of Sir Bu Nô Air. The mottled appearance of the island is due to the megaclasts of different lithologies. (Images courtesy of © 2013 Google, Image © 2013 Digital Globe).

During diapiric ascent, the salt has plucked large clasts of the rocks which now lie about 10 km deep, and borne them to the surface. The salt domes have thus sampled the foundations of the UAE and can be viewed as natural probes into the crust. The mechanism by which the rising salt diapirs have incorporated rocks from below their source, the Cambrian Hormuz salt sequence, (with remarkably few from the country rocks on their ascent) is poorly understood.

The salt domes are sub-circular to elliptical in plan view and range from about 2 km (Zirku, Arzana) to 6 km (Delma) in diameter. The smaller, sub-circular bodies are simple, single domes, whereas the more elliptical forms have multiple superimposed phases of diapirism, such as at in Delma (two phases) and Jebel Dhanna (three phases). The 3D geometry of some of the salt domes can be broadly ascertained from seismic data that can image them down to depths of up to about 10 km. They appear to be essentially vertical, regular cylindrical to slightly down-tapering diapiric bodies of similar diameter to the surface outcrop and surrounded by shallow rim synclines where the bedding in the country rocks curves up adjacent to the contacts. At depth, seismic reflection profiles suggest that at least some of the diapirs, such as Jebel Dhanna, appear to be in continuity with the source salt beds, whereas Sir Bu NôAir, for example, may have separated from its source (Fig. 4).

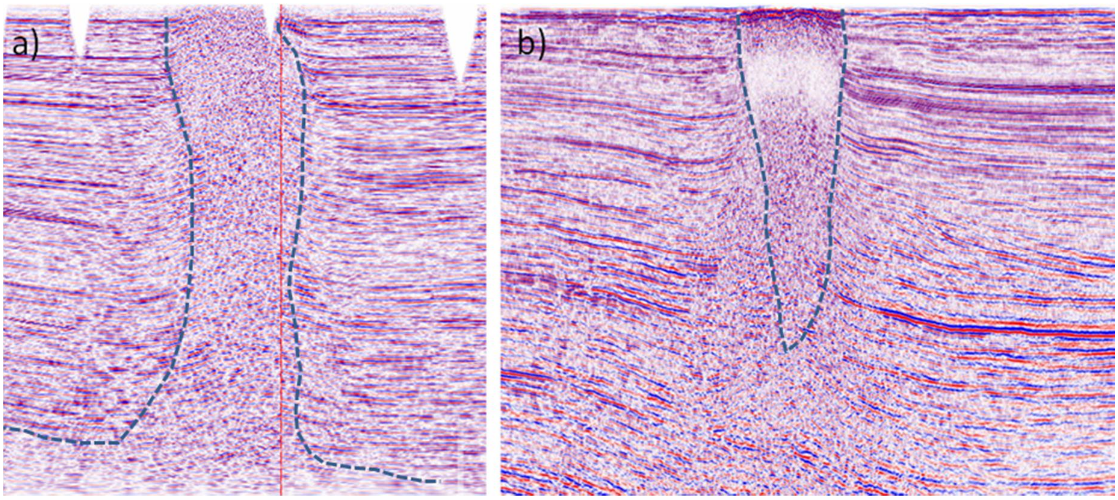

Fig. 4. Seismic sections across salt domes. a) Jebel Dhanna appears to be slightly down-tapering and still connected to the source beds; b) Sir Bu NôAir may be a diapir that became disassociated from its source.

At outcrop all the UAE salt domes have a central core of deeply dissected, rounded hills rising in altitude up to >140 m on Zirku. The rock-types making up the salt domes are grouped into a lithostratigraphic unit termed the *Hormuz Complex*. The complex is dominated by a dissolution breccia comprising clasts and matrix termed the *Hormuz breccia,* which forms the body of the salt domes. The Hormuz breccia is a halokinetic mélange that is heterogeneous in terms of grain size, clast content, alteration mineralogy, internal structure and fabric. It broadly comprises an altered evaporite matrix into which are set clasts of many different rock-types and which range in size from microscopic up to large rafts almost one kilometre across (megaclasts). The breccia varies from massive and structureless with a chaotic arrangement of clasts to well-layered, the latter style being common at dome margins, where the breccia is sheared. Fig. 5 shows a schematic cross-section across one of the salt domes (Jebel Dhanna).

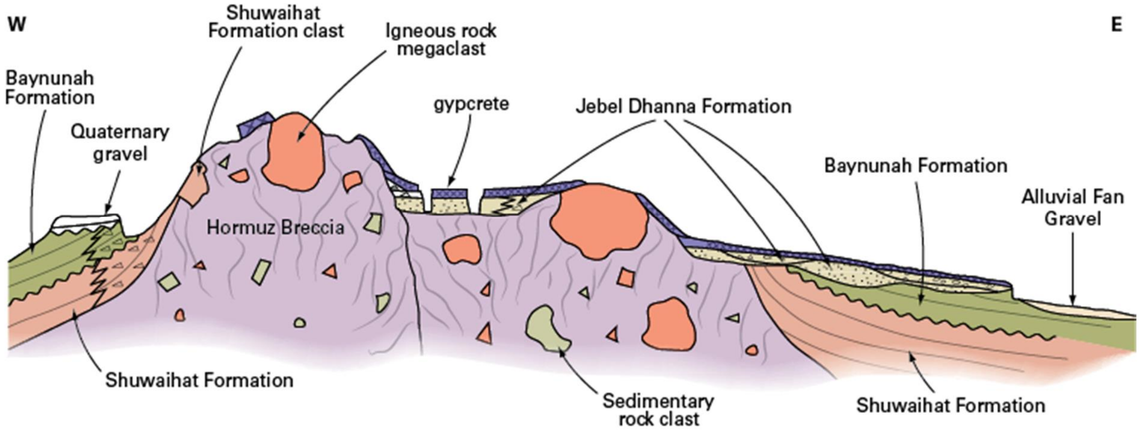

Fig. 5. Schematic cross section across a typical salt dome (Jebel Dhanna), showing relationships with the younger country and cover rocks. Shuwaihat and Baynunah Formations are Miocene; Jebel Dhanna Formation and gypcrete are Quaternary

The breccias contain a large variety of clast sizes, shapes and compositions. They range in size from megaclasts hundreds of metres across to sub-millimetric detritus in the rock flour matrix. Most outcrops show clasts up to at least one metre in size. The majority of the smaller clasts (less than10 cm in size) are so extremely altered they are often not readily identifiable in the field, while larger clasts tend to be fresher and their lithology can usually be determined.

Generally, the largest clasts occur in chaotically structured, massive breccia, whilst layered breccia tends to contain smaller clasts of up to a few tens of centimetres in size. Clasts are angular to sub-rounded, sometimes flattened and platy, their form dependent on their original lithology, structure and texture and on the local intensity of strain within the diapir. However, clast morphology is not only governed by lithology and internal fabric but also by the fabric of the breccia itself. Thus some incompetent clasts in layered breccia are flattened and oriented parallel to the layering. Table 1 lists the most common clast types, sedimentary, followed by igneous. Field photographs of typical breccia clasts from various salt domes are given in Fig. 6.

Clast Type	**Description**
Brown dolomite	Ubiquitous, up to 200 m across; massive, poorly- to well-bedded to platy-/papery-bedded (Fig. 6a). Some clasts are vuggy with pitted weathering patterns and heavily recrystallised with dolomite pseudomorphs. Many clasts show secondary growth of randomly-oriented plates of specular

	haematite.
Grey limestone, locally brown or purplish-brown	Very common, up to several hundreds of metres across. Often tabular with fine, planar fissile lamination. Often interbedded with dolomite, locally dark-grey, foetid. Bedding often deformed into meso-scale open monoclinal folds and kinks, suggesting regional deformation prior to inclusion in the breccia (Fig. 6b). Usually strongly recrystallised to coarse crystalline grey calcite and often secondarily haematised.
Sandstone, marl and siltstone:	Variable lithologies, probably not derived from same lithostratigraphic unit. Most common type is medium-grained, greyish-green, sugary impure sandstone. Sir Bu NôAir has large bleached white, highly altered, massive gypsiferous sandstone up to 200 m across. Other types include finely banded, pale, altered marly sandstone clasts with crenulated bedding and very fine-grained, greenish-grey, fine-bedded turbiditic siltstones. Includes Zirku Formation turbidites (Fig. 6c).
Sedimentary breccia	Quite common, up to a few metres in size. Typically comprise subangular brown dolomite clasts set in a dark ferruginous to manganiferous matrix, locally scoriaceous with black haematised or manganiferous fragments in a pale (gypsiferous?) matrix.
Meta-carbonate	Two clasts of low-grade metamorphic rocks, both finely-layered carbonates identified (Fig. 6f, h).
Mafic igneous rocks	Common in most domes, ranging up to almost 1 km across. Altered, with greyish-green/bluish-green secondary chlorite and epidote. Most clasts are basaltic, locally amygdaloidal and sometimes plagioclase- or clinopyroxene-phyric. Volcanic features such as flow-banding, pillows with inter-pillow hyaloclastite seen (Fig. 6d). Also medium-grained, locally porphyritic dolerite with epidote. Coarse-grained, bluish-green, sub-ophitic altered amphibole-bearing gabbros are rarer, but form large clasts up to several hundreds of metres in size.
Felsic igneous rocks	Present in most salt domes: grey, maroon, purple and pale brown quartz-feldspar porphyries. Medium- to coarse-grained types represent altered sub-volcanic porphyritic granite. Volcanic structures and textures in rhyolitic rocks such as brecciation, flow-banding are common, along with less common spherulitic, blebby and flaser textures. Secondary haematite

	and carbonate alteration are common.
Ignimbrite	Spectacular rhyolite-dacite ignimbrites seen in a number of salt domes. Locally net-veined by later mafic liquids to produce magmatic breccias (Fig. 6e). Northern ñhornò of Qarnain represents part of a dismembered volcanic caldera complex comprising basaltic vent agglomerate and felsic ignimbrite. Textures include vesicles, contorted flow banding and autobrecciation, locally accompanied by the injection of bluish-grey basalt magma forming complex stockworks.
Intermediate igneous rocks	Relatively uncommon, grey or purplish-maroon plagioclase-porphyritic andesite, locally amygdaloidal. Trachyte and dacite seen, locally pumice with open vesicles (Fig. 6g).
Tuff	The pyroclastic rocks locally contain lenses of greenish- to bluish-grey, poorly- to well-bedded, poorly sorted mafic crystal and lithic tuff, with local coarse surge deposits. Some possible explosion breccias composed of chaotic rhyolite clasts in a grey crystal tuff matrix.

Table 2. *Descriptions of the main clast types seen in the UAE salt domes.*

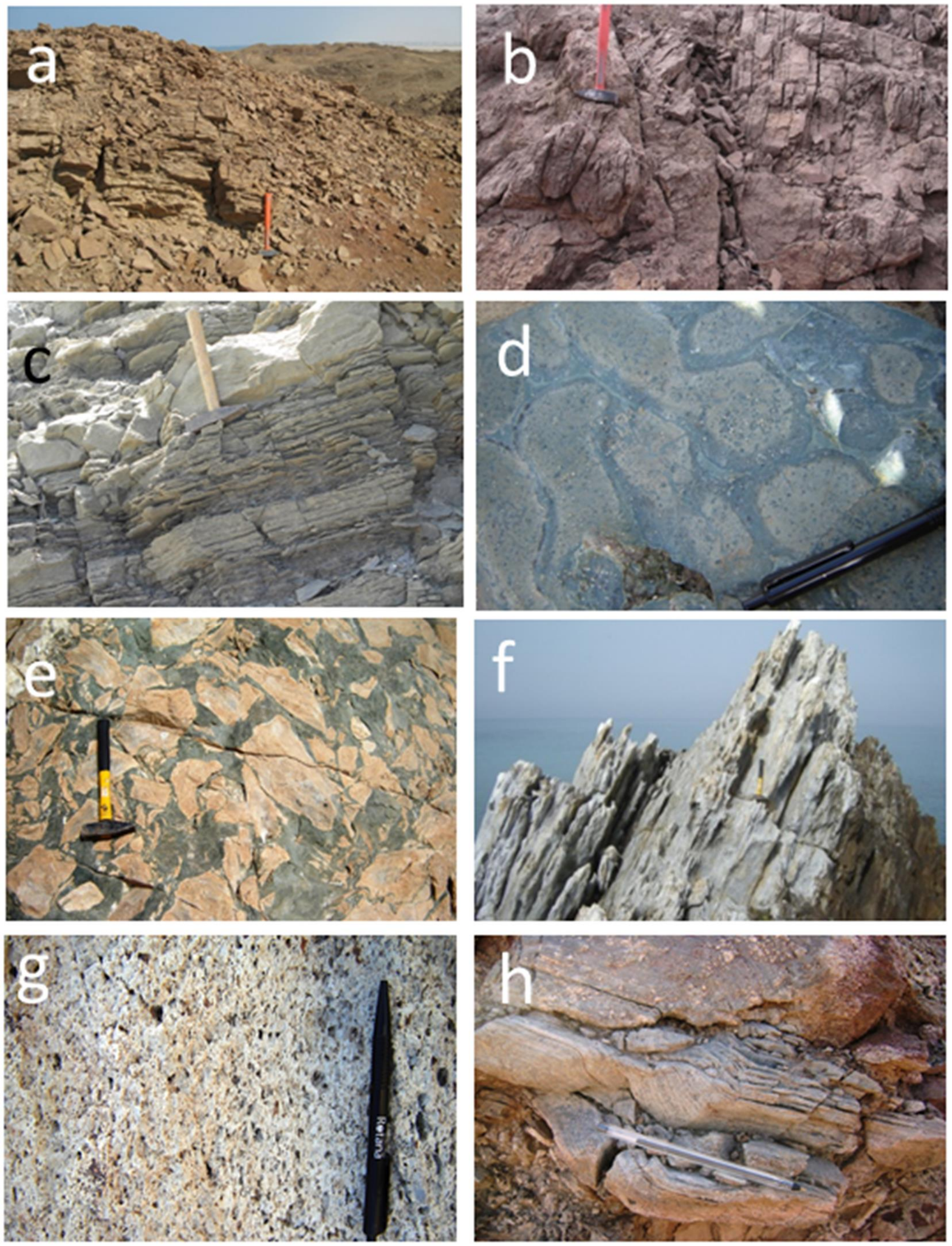

Fig. 6. Typical clast lithologies in the Hormuz Breccia. a) Bedded brown dolomite, Jebel Dhanna; b) Well-bedded grey limestone with kink-band folding, Arzana; c) Intercalated sandstone-siltstone, Zirku Formation, Zirku (detrital zircon sample UAE_7072).; d) Pillow-like structures in basalt with dark inter-pillow hyaloclastite, Sir Bu NôAir; e) Magmatic breccia with yellowish flow-banded ignimbrite blocks surrounded by later dark green basalt, Qarnain; f) Foliated recrystallised limestone/marble, Qarnain; g) Vesicular trachyte with unfilled vesicles, Sir Bu NÁir; h) recrystallized carbonate, Delma (detrital zircon sample UAE_7131).

The salt island of Zirku is significantly different from all other domes. It is dominated by rugged hills composed of a thick sequence of well-bedded, deformed sedimentary rocks termed the Zirku Formation. These rocks represent megaclasts, up to 1.5 km in length in the breccia, but are unique in that they appear to form the disrupted remnants of a near-continuous roof-zone carapace to the salt dome, preserved during emplacement (Fig. 7). The Zirku Formation is a succession of thinly bedded, greenish-grey, siliceous siltstones and purplish-red mudstones with interbedded, fine-grained, greyish to greyish-brown quartzose sandstone lenses and discontinuous layers forming about 5% of the rock mass (Fig. 6c). The succession is interpreted as a sequence of medial to distal turbidites. Sedimentary structures include low-angle cross-bedding, symmetrical ripple cross-lamination, soft-sediment convolute bedding and sole structures such as prod marks, along with small neptunian dykes filled with Quaternary carbonate grainstones. There is evidence of graded bedding and using the erosional bases of some sandstone beds to determine local younging direction, both normal and inverted beds were recorded. Surface trails of an unidentified organism were observed in one location and feeding burrows seen elsewhere. The Zirku Formation is folded on a regional scale, with fold wavelengths of several hundreds of metres. Small scale, often monoclinal folds and kink bands are seen on a metre- to sub-metre scale. The folding appears to be fairly unsystematic and probably relates to regional deformation prior to incorporation in the salt diapir, with subsequent further deformation and disruption during ascent and emplacement. Prior to this study, the Zirku Formation was presumed to be late Precambrian in age (M. Warrak, pers. comm.).

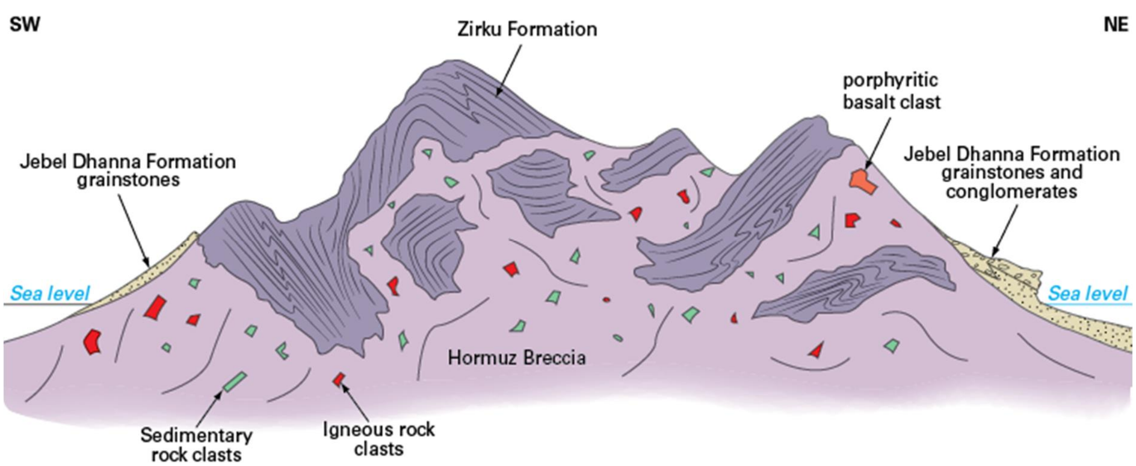

Fig. 7. Schematic cross section, showing relationship of the Zirku Formation as a disrupted roof carapace to the salt dome.

4. Salt domes of central Oman

The salt domes in Oman have been described in detail by Peters et al. (2003), who noted that all the domes contain numerous clasts up to several hundreds of metres in size of grey Cambrian Ara Group limestone. We visited all the domes and found, like Peters et al. (2003), that only the southernmost dome, Qarn Sahmah contained clasts of lithologies other than Ara Group limestone (Fig. 2). Qarn Sahmah has a large number of volcanic and sedimentary clasts concentrated in a small area at the centre; the margins appear to only have limestone. We collected a number of samples for comparative geochemical and dating purposes, the results of which are given below, but we did not study the domes in any other detail.

5. Sampling and analytical methods

The clasts of the UAE were sampled in great detail. Many are extremely altered, so thin sections were cut of all potential geochemistry and geochronological samples to ensure that the rocks chosen for analysis were the freshest possible, and accessory zircon was identified. Where possible, the salt domes were re-visited to collect larger amounts (5 to 10 kg) of the freshest samples identified in thin section. It was not possible to re-visit the Qarn Sahmah dome in Oman, with the result that only one of the three igneous samples contained sufficient zircons for dating.

5.1. Whole-rock Geochemistry

A total of 15 volcanic rocks were selected for whole-rock geochemical analysis, 12 from UAE domes and 3 from the Qarn Sahmah dome in Oman. Samples were crushed, sub-sampled and milled using an agate ball mill. Major element oxide concentrations were determined by X-ray fluorescence spectroscopy (XRF) and trace and rare earth elements by inductively coupled plasma mass spectrometry (ICP-MS) at the PANalytical laboratories at the British Geological Survey, Keyworth, Nottingham. Samples for ICP-MS underwent ótotalô dissolution using a sodium peroxide fusion, followed by a mixed acid dissolution. Samples for XRF were dried at 105°C and then heated to 1050°C for an hour before loss on ignition was determined. Fused beads were produced by fusion at 1200°C.

Uncertainty budgets (expanded uncertainty with a coverage factor of 2, representing the 95% confidence interval) have been calculated for XRF fused bead work during the method validation before UKAS accreditation of the laboratories. Estimates of the absolute uncertainty, at analyte concentrations at least an order of magnitude greater than the reporting limit, are from 0.1% to 1% for the major elements. Routine chemical quality control solutions demonstrate typical long term precision of analyses better than 10% relative standard deviation (RSD) for most elements by ICP-MS. Analyses of a wide variety of reference materials demonstrate typical long term precision of analyses better than 15% RSD for most elements; this assumes they are significantly higher than detection limits.

5.2. Geochronology

Eight samples were dated by LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry), the data are provided in the online supplementary files. The method is described in full in Spencer et al. (2014), and in brief, comprises measurement of Hg, Pb and U isotopes using a Nu Instruments Attom single collector ICP-MS, coupled to a New Wave Research 193nm Nd:YAG laser ablation system. A standard-sample bracketing routine is used to normalise Pb-Pb and U-Pb ratios, with reference material zircons 91500, GJ-1 and Pleġovice. Analyses were not corrected for common lead. The precision and accuracy of the method is within 3% for both $^{207}Pb/^{206}Pb$ and $^{206}Pb/^{238}U$ ages (see supplementary file). Laser parameters comprise a 25εm static spot, ablated for 30 seconds with a fluence of 2-3j/cm^2.

6. Petrography

The sedimentary rocks found as clasts within the salt domes include fine- to medium-grained limestone and dolomite, fine sandstone, siltstone and mudstone, and are commonly well-bedded. The most notable alteration due to their inclusion in the salt domes is the growth of secondary haematite.

The igneous rocks within the clasts show significant variability. Very felsic quartz and quartz-feldspar porphyries are common; euhedral, clear, unstrained quartz and sericitised feldspar crystals up to 2 mm in size are set in a fine-grained quartz-feldspar-muscovite matrix, with rare mafic minerals replaced by chlorite. Basaltic and andesitic samples are locally plagioclase-phyric, with tabular plagioclases up to 4 mm, and typically show alteration of all mafic minerals to chlorite; a few samples contain remnants of original clinopyroxene phenocrysts < 1mm in size, largely replaced by chlorite. Some samples have vesicles filled with quartz, calcite or zeolites. Dolerite and gabbro samples are also common, and although strongly altered they preserve their original sub-ophitic texture, with plagioclase laths and plates of colourless to pale green amphibole set in a groundmass of chlorite, sericitised plagioclase and haematite. A dolerite sample collected from the Sir Bu NôAir dome (sample UAE 6780) comprises altered plagioclase phenocrysts and original clinopyroxene phenocrysts that have been pseudomorphed by chlorite and opaque oxides, in a groundmass of chlorite, zoisite and haematite.

All the igneous rock samples are variably altered, with growth of secondary carbonate, chlorite and haematite. Alteration has not been accompanied by any deformation, such that samples retain their original igneous textures but locally with complete replacement of all the minerals by carbonate and haematite. The amount of alteration appears to vary significantly within each salt dome. Some pyroclastic igneous rocks have clear fiammé that are preserved by alteration to carbonate and haematite. The samples analysed for geochemistry were chosen from among the least altered examples.

7. U-Pb zircon Geochronology

7.1. Volcanic rock clasts

Four samples of acid to intermediate volcanic clasts from the UAE were analysed along with one from Oman (Table 2).

Sample	**Locality**	**x**	**y**	**Lithology**
UAE_6767	Sir Bani Yas	661337	2690411	Coarse feldspar porphyry (igneous)
UAE_7376	Sir Bani Yas	663308	2690852	Porphyritic rhyolite (igneous)
UAE_7391	Jebal Dhanna	662278	2671269	Banded rhyolite (igneous)
UAE_7399	Qarnain	686517	2758964	Flow-banded ignimbrite (igneous)
RTOM_9	Oman	457472	2278854	Porphyritic andesite (igneous)
UAE_7072	Zirku	709959	2753652	Turbiditic sandstone (sedimentary)
UAE_7131	Delma	633726	2708710	Meta-carbonate (meta-sedimentary)
RTOM_6	Oman	457392	2278558	Red sandstone (sedimentary)

Table 3. *Details of location and lithology of the geochronological samples.*

In all igneous samples analysed, the zircons are euhedral pyramidal crystals with length to width ratios of 2 to 5, unaltered with minor or no fracturing, and have well-developed crystal faces. The grains are typical of igneous zircons, featuring regular oscillatory zoning, occasionally with overgrowths of further zoned material. Where apparently different growth zones were dated, these were found to be part of the same age population within uncertainty. Some grains have small relict (inherited) cores exhibiting older ages. No significant metamorphic overgrowths were apparent from cathodoluminescene (CL) imaging. All samples exhibited a cluster of younger ages that are interpreted as representing crystallisation of the host rock, and a variable spread of older ages that are interpreted as inherited zircons. Concordant ages that are older than the main population of zircons are assumed to be inherited. Discordant (>10%) ages are not used for the age calculation, as these may reflect a mixture of any or all of the following: small amounts of common-lead, inheritance, or lead-loss. The ages and uncertainties given are weighted means or means with standard deviation (where stated), the latter is used for an age that has a high MSWD and is therefore not likely to represent a single population. Two uncertainties are provided, written as age ± x/y, where x and y are the 2ů uncertainties without and with systematic uncertainties (decay constant uncertainties, long term variance, reference material uncertainties) propagated.

Sample UAE_6767 is a coarse-grained felsic porphyry with altered K-feldspar phenocrysts up to 10 mm across, set in a highly felsic quartz-feldspar matrix with very minor quantities of chlorite and opaque minerals. The grain size, mineralogy and texture suggest that this rock may represent a sub-volcanic granitic body. It gave an age of 557 ± 3/12 Ma (MSWD = 1.7; 2ů), defined by a close grouping of concordant data. This sample contained a small number (n=3) of older, Neoproterozoic inherited zircon grains (ca. 650 and 850 Ma), and a discordant grain with an Archaean apparent age (ca. 2570 Ma).

Sample UAE_7376, a purple, highly altered quartz-feldspar porphyry gave a late Neoproterozoic (Ediacaran) age of 560 ± 2/12 Ma (MSWD = 1.8; 2ů). The sample contained mainly concordant zircons, with a few concordant inherited older grains (n=4) at ca 630, 800 and 1150 Ma, and older discordant grains (n=3) with apparent ages of ca. 2300 to 2700 Ma.

Sample UAE_7391 is a quartz porphyry/porphyritic rhyolite from Jebal Dhanna, consisting of clear euhedral quartz phenocrysts up to 3 mm across and sparse feldspar phenocrysts set in a microcrystalline quartz-feldspar groundmass which flows around the phenocryst phases. The only mafic minerals are a sparse opaque phase and some larger grains of secondary specular (micaceous) haematite. The sample gave an age of 546 ± 22/25 Ma (MSWD = 2.9; 2ů). One concordant inherited Archaean grain is dated at ca. 2520 Ma, other concordant inherited grains (n=3) have ages of ca. 850 and 1000 Ma.

Sample UAE_7399 is a flow-banded extrusive porphyritic rhyolitic to dacitic ignimbrite from the southern ñhornò volcanic mega-clast of Qarnain. The rock contains plagioclase phenocrysts up to about 2 mm across set in a very fine-grained, flow-banded quartz-feldspar matrix, with scattered skeletal opaque mineral grains. Some layers contain recrystallised glass fiammé which have been replaced by crystalline quartz. The sample gave an age of 560 ± 3/12 Ma (MSWD = 1.5; 2ů), with no inherited grains except for one concordant grain at ca. 595 Ma which was excluded from the age calculation.

Finally, sample RTOM_9 from a grey feldspar porphyritic andesite from the dome in Oman gave an age of 545 ± 4/12 Ma (MSWD = 1.1; 2ů), statistically identical to the UAE samples. Inherited ages (n=8) are recorded at ca. 700-750, 800-850, 2000 and 2500 Ma.

All the above quoted ages are considered to represent the crystallisation and/or extrusion/intrusion age of the samples; they show no evidence of any distinct later Pb-loss events, which is fitting with their subsequent (low temperature) entrainment and upward ascent within the salt domes.

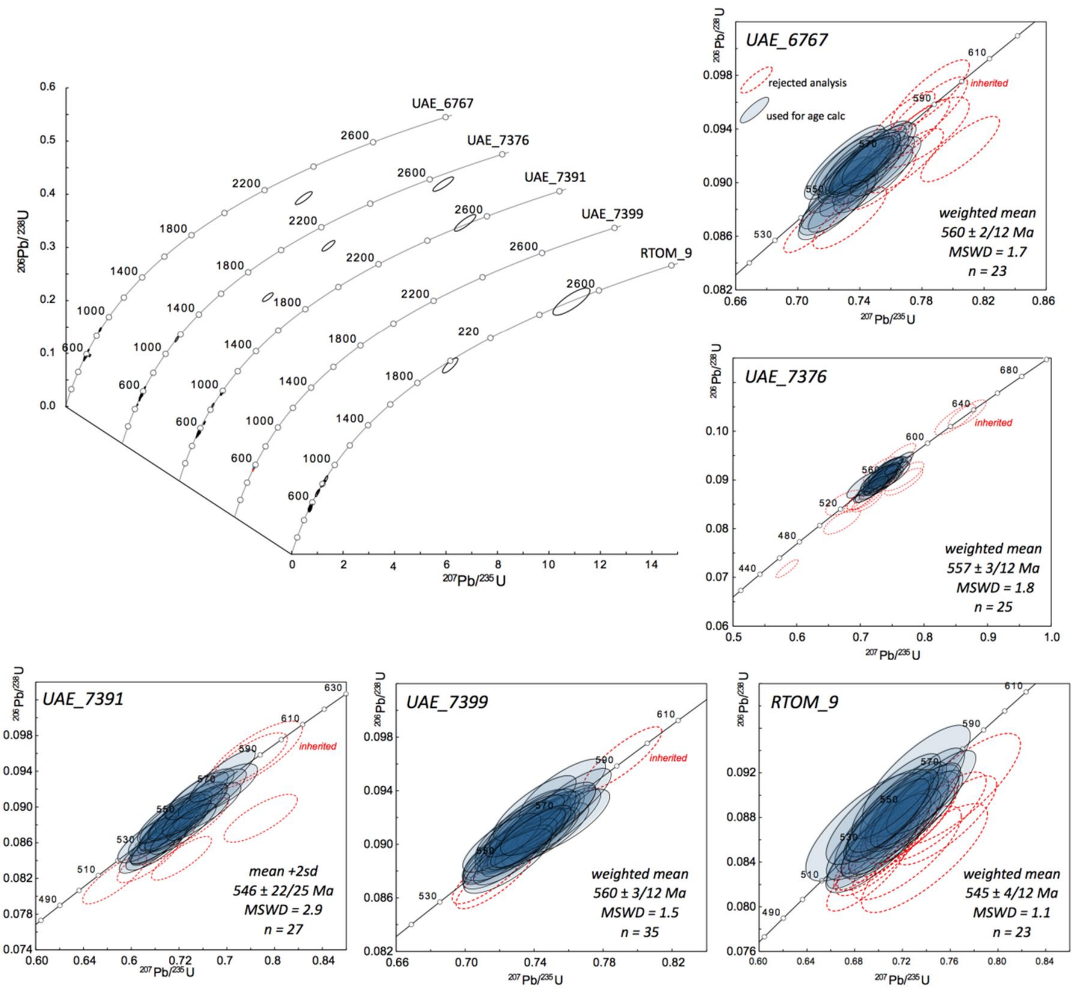

Fig. 8. Concordia plots of the five igneous clasts, all ellipses are shown at 2ů. Blue ellipses refer to those used for age calculation, dashed red ellipses are >10% discordant and assumed to be affected by lead-loss or common-lead, or are inferred to be inherited.

7.2. Sedimentary and low-grade metamorphic rock clasts

UAE_7072 is a sample of fine-grained, relatively equigranular sandstone of the Zirku Formation from Zirku. It contains sub-angular quartz grains with plagioclase and opaque minerals, set in a chloritic groundmass with flakes of muscovite and late secondary carbonate cement. Concordia and age-probability plots are given in Fig. 9. Seventy of the 85 analyses were concordant grains (out of a total of 92 grains analysed). The youngest set of 3 zircons whose uncertainties overlap at the 2ů level give a weighted mean $^{206}Pb/^{238}U$ age of **597 ± 20 Ma** (MSWD = 1.5). A younger concordant grain gave a Neoproterozoic age **558 ± 15** Ma (2ů). This analysis was slightly discordant (2.9%), and thus the older 597 Ma age provides a more robust indication of the maximum age of deposition of the sandstone. The age probability spectrum shows a trimodal distribution of Neoproterozoic to late Mesoproterozoic ages with maxima at ca. 622 Ma, 797 Ma and ca. 1017 Ma. The sample also has a few Palaeoproterozoic (ca. 1800 and 2050) and Neoarchaean (ca. 2500 to 2650 Ma) grains (see Fig. 9).

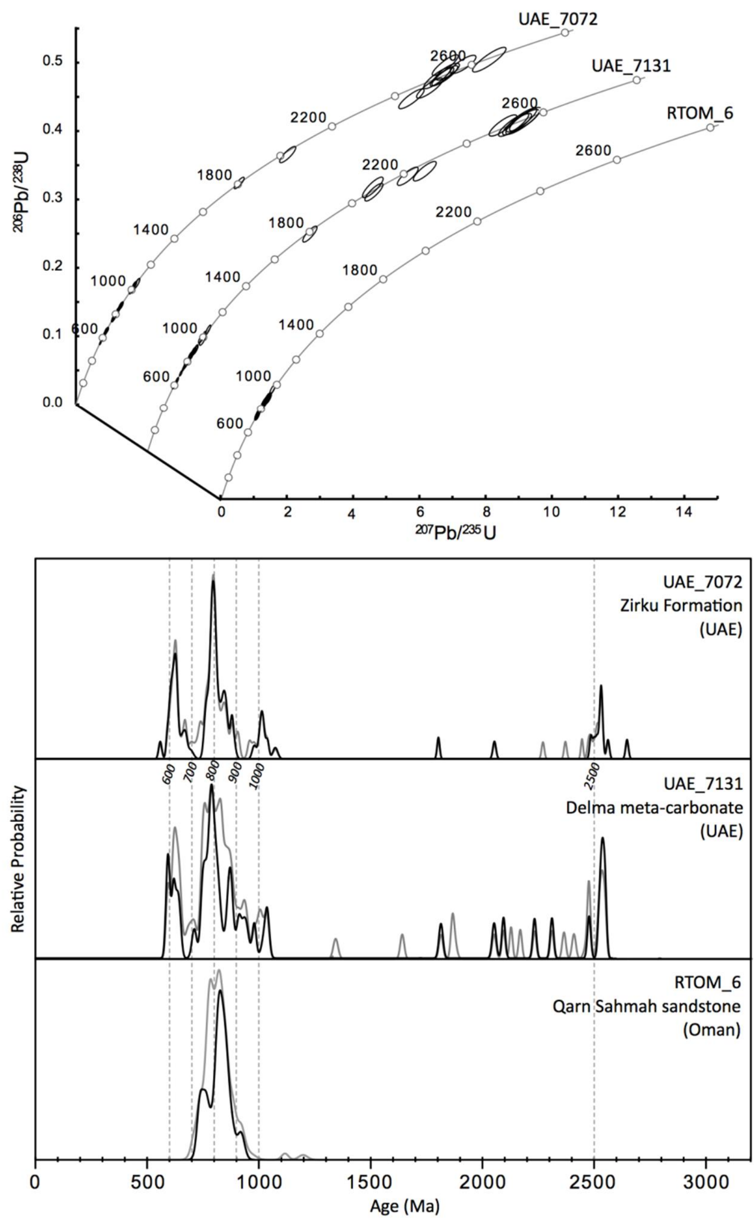

Fig. 9. Concordia and probability density plots of the three clasts with a sedimentary origin. All ellipses are shown at 2ů. Within the probability density plots, the black curves represent data that is >95% concordant, and the grey curves represent all data.

Only two metamorphosed sedimentary rock clasts were identified from all the salt domes. One of these is a layered marble on Qarnain, which was considered to be unsuitable for dating due to a potential lack of detrital zircons. A thinly-layered and folded quartz-bearing layered meta-carbonate from the Delma dome (UAE 7131) was analysed.

Sample UAE_7131 consists of 95% recrystallized carbonate in thin layer-parallel ribbons, with variable grain size. The rock contains scattered sub-rounded quartz grains and layer-parallel fine opaque minerals, zircon and apatite. Concordia and age-probability plots of the sample are given in (Fig 9). Forty-three of the ninety-two zircon grains analysed were concordant. The youngest zircon grains analysed (3 overlapping ages) gave a $^{206}Pb/^{238}U$ age of 593 ± 9 Ma (MSWD = 0.41), which constrains the maximum age of deposition of the sedimentary protolith. Most of the grains analysed were Neoproterozoic in age, with a markedly bimodal distribution exhibited by a narrow peak with a maxima at 610 Ma, and a broader peak with a maxima at 785 Ma. Some older grains have early Neoproterozoic to late Mesoproterozoic ages of 979 to 1038 Ma. The sample also contains a small number of Palaeoproterozoic (ca. 1823 to 2485 Ma) and Neoarchaean (ca. 2545) grains.

Sample RTOM_06 is a red, medium- to coarse-grained feldspathic sandstone from the Oman dome. This sample gave a zircon age-frequency spectrum with a much more restricted range of ages compared to the samples from the UAE, with one broad peak that has two maxima at ca. 740 and 820 Ma. The youngest three zircons have overlapping ages with a weighted mean of 734 ± 15 Ma (MSWD = 0.03), providing a maximum age of deposition of ca. 730 Ma (Fig. 9).

8. Geochemistry of the volcanic clasts

The samples analysed for whole-rock geochemistry were selected as the least altered examples of igneous rock found in the salt domes. Nonetheless, it is likely that later alteration associated with salt dome emplacement has had an effect on the whole-rock geochemistry. The samples show significant compositional variation, with SiO_2 contents varying from 45 to 75 wt%. Petrographic studies show that the main alteration effects in the clasts involve formation of haematite, but in the analysed samples SiO_2 correlates negatively with Fe_2O_3 as would be expected in a magmatic sequence (Fig. 10a), indicating that significant amounts of Fe_2O_3 have not been introduced by late fluids. Similarly, there is a reasonable negative correlation between SiO_2 and CaO (Fig. 10b); one sample (UAE 7397) has an unexpectedly high CaO value, and this very quartz-rich sample contains large (ca. 2 mm) secondary calcite rhombs, indicating late addition of $CaCO_3$. Na_2O and K_2O show greater variation and no clear correlation with SiO_2 (Fig. 10c and d), suggesting that these elements have been mobilised by fluid flow associated with salt dome emplacement. Thus, the samples are also widely scattered on a total alkali-silica diagram (Fig. 10e), and high total alkali contents may be due to late alteration rather than representing magmatic compositions. Similar introduction of fluid-mobile elements during clast alteration has been recognised in the Iranian salt domes (Taghipour et al. 2012).

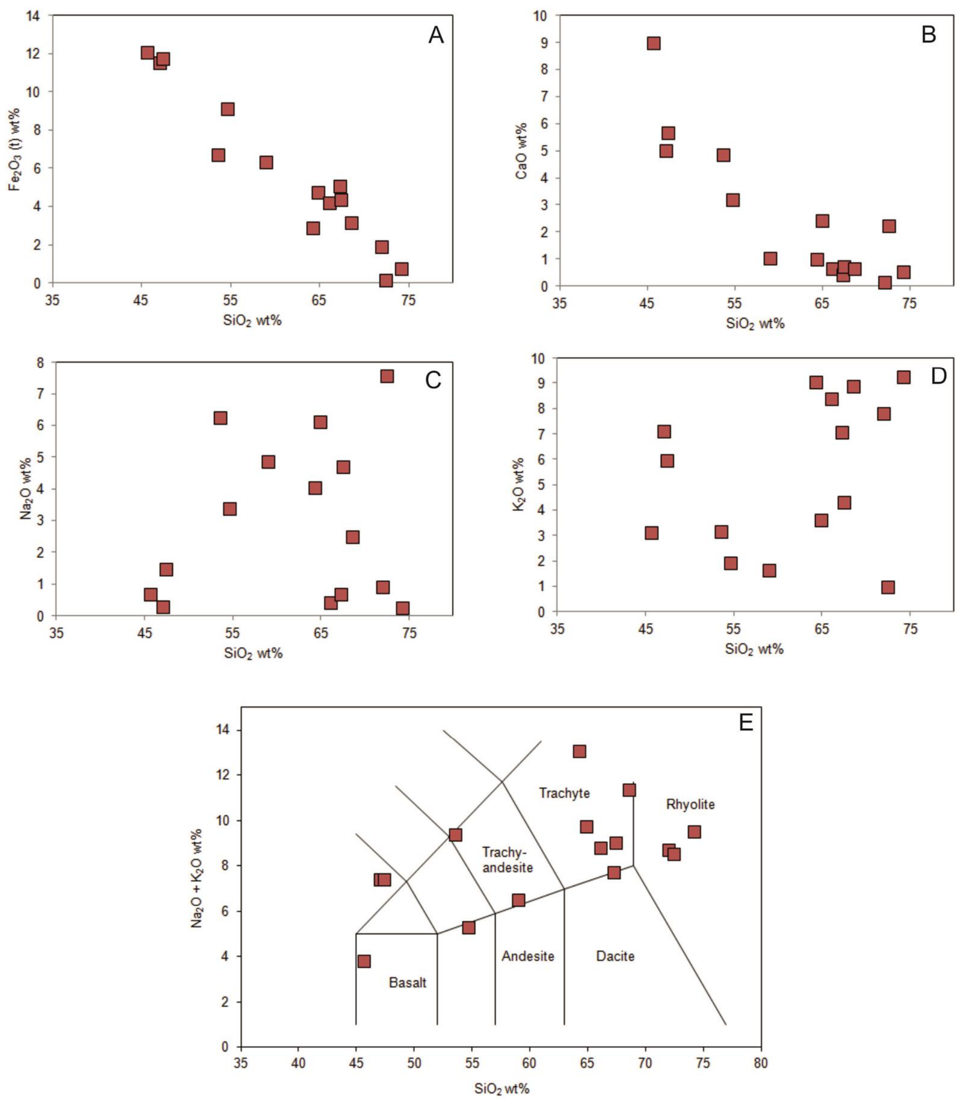

Fig. 10. Harker plots for all analysed igneous samples from the Oman and UAE salt domes. Fields in E, the total alkali-silica diagram, are from Gillespie and Styles (1999).

Primitive mantle-normalised trace element plots for selected samples are shown in Fig. 11. The mafic to intermediate samples (basaltic and andesitic, SiO_2 < 60 wt%) show significant scatter in the fluid-mobile elements, including elevated K and Rb contents, and variable Th and Sr, but are otherwise typified by relatively flat trace element patterns (Fig. 12a). They generally lack the strong negative Nb-Ta anomalies that might be expected of subduction-related basaltic rocks. Their chondrite-normalised rare earth element (REE) patterns are also flat to slightly LREE-enriched, with a trend towards greater LREE enrichment with increasing SiO_2 (Fig. 11b). The strong negative Sr anomaly in sample UAE 6780 is likely to be due to alteration, since there is no corresponding Eu anomaly that would indicate plagioclase fractionation.

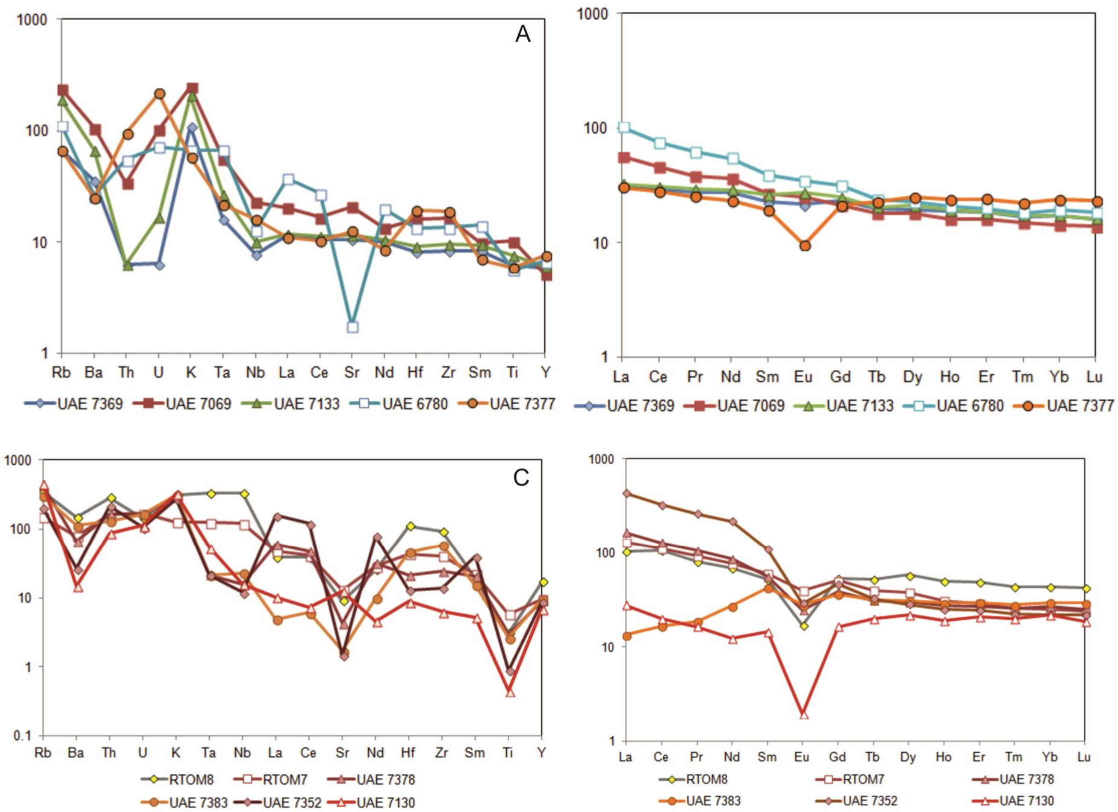

Fig. 11. A - primitive mantle normalised trace element plot for samples with <60 wt% SiO2; B - chondrite normalised rare earth element plot for samples with <60 wt% SiO2; C - primitive mantle normalised trace element plot for samples with >60 wt% SiO2; D - chondrite normalised rare earth element plot for samples with >60 wt% SiO2. Normalising factors from McDonough and Sun (1995).

The more evolved samples (SiO_2 > 60 wt%) show rather variable trace element patterns that are characterised by moderate enrichment in the alkali elements, particularly K and Rb, depletion in Eu, Sr and Ti, and significant variations in the elements that are generally considered as immobile (Figs. 11c, 11d). Samples from the UAE domes typically have negative Nb and Ta anomalies, whereas the samples from the Qarn Sahmah dome in Oman have positive Nb-Ta anomalies. The samples with SiO_2 <70 wt% all have similar REE patterns with mild enrichment in the LREE, but the more evolved (rhyolitic) samples show a significant amount of variability (Fig. 11d). The variability of the samples is most likely due to a combination of fractional crystallisation and crustal assimilation; evidence for the latter comes from the presence of inherited zircons in many of the dated samples. The general consistency of the REE patterns indicates that these have not been remobilised during fluid alteration in most of the samples.

There are many potential discrimination diagrams that can be used to understand the tectonic setting of volcanic rocks; these are usually interpreted in the context of field relationships, which in this case are not available. On the Nb/Yb vs Th/Yb diagram of Pearce (2008; Fig. 12), the three samples from the Qarn Sahmah dome in Oman all plot in the mantle array, and in the area typical of Ocean Island Basalts (OIB). Two dolerite samples from Sir Bani Yas and Delma also plot in this array by virtue of their low Th/Yb ratios, although this may be attributable to removal of Th by fluids associated with the salt domes. The remainder of the samples plot in the area indicating mantle-crust interaction. This could point to the magmatic source being influenced by a subduction zone, but could also be due to the magmas assimilating continental crustal material prior to eruption. Notably, the most SiO_2-rich magmas plot furthest away from the mantle array, indicating that the patterns on this diagram are largely influenced by crustal contamination.

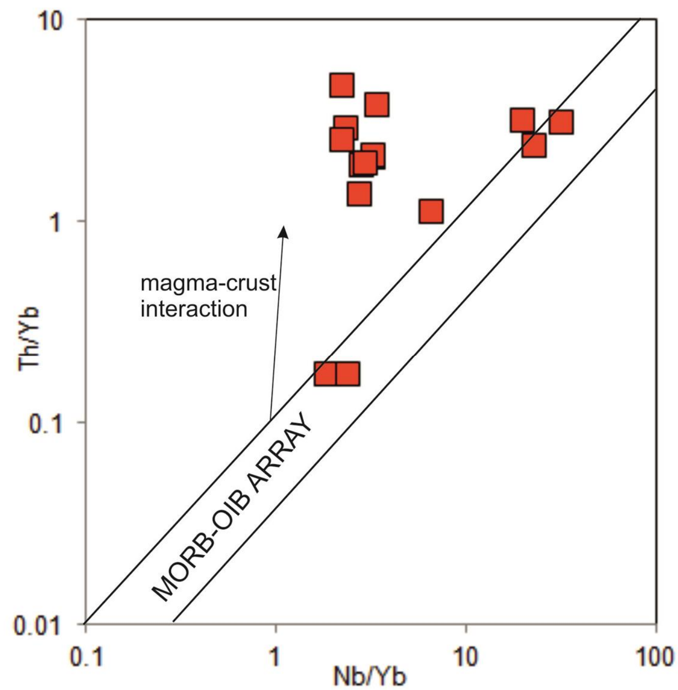

Fig. 12. Th/Yb vs Nb/Yb plot for all analysed igneous samples from the Oman and UAE salt domes. MORB-OIB array after Pearce (2008).

9. Discussion

The oldest maximum age of deposition of the samples analysed is the undeformed, unmetamorphosed sandstone from the Oman salt dome, with the youngest zircons dated at ca. 734 Ma. The actual depositional age of course, might be considerably younger than this, although the sandstone does not contain zircons of the same age as the volcanic rocks that also form part of the clast assemblage of the Qarn Sahmah dome.

The youngest three detrital zircon grains from sample UAE_7131, the meta-carbonate rock from Delma, gave a Neoproterozoic age of **593 ± 9 Ma**, thus constraining the maximum age of deposition of the original sediments. The rock subsequently underwent recrystallization under low-grade metamorphic (burial?) conditions and deformation to produce the observed kink-bands. The brittle-ductile style of deformation in the sample is part of a regional tectonic event and not as a result of entrainment in the salt diapir. Thus, the maximum depositional age also puts a maximum age constraint on this tectono-metamorphic event.

Except for an anomalously young, but slightly discordant grain ($^{207}Pb/^{206}Pb$ age = 575 ± 21 Ma, $^{206}Pb/^{238}U$ age = 558 ± 15 Ma) in the Zirku Formation, this unit has the same maximum depositional age as the Delma layered carbonate. The style of meso-scale deformation seen in the two rocks is similar, typified by small-scale kink-banding. This implies that both samples (and many of the large limestone clasts of most salt domes in the UAE) may have undergone the same deformation event.

The ages of the five felsic igneous clasts from three salt domes show that they all crystallised within error in the latest Ediacaran at around 560 to 545 Ma. The sedimentary samples do not reveal evidence of being sourced from this igneous event, and therefore were likely deposited after ca. 595 Ma and before ca. 560 Ma. The igneous rocks do not show the same deformation characteristics as the sedimentary samples. This may be due to their more massive, competent nature, if the deformation was later than their crystallisation. But more likely, is that the deformation event that affected the sedimentary samples occurred after their deposition at ca. 595 Ma, and before the igneous event at ca. 560 to 545 Ma. Igneous clasts similar to those sampled and dated were found in all five salt domes, suggesting that the extrusive event was spatially widespread from Oman to the UAE over at least 700 km.

The geochemistry of all the volcanic rocks within the salt domes is consistent with their having formed in an extensional setting along the margin of the Gondwana supercontinent. A combination of fractional crystallisation of mafic magmas with crustal assimilation led to the development of more evolved compositions with rather variable geochemistry. Superimposed upon this is significant alteration of the igneous rocks and remobilisation of the fluid-mobile elements which is likely associated with their entrainment in the salt domes. The alteration of igneous rocks with the introduction of Na_2O in particular, and also K_2O, Fe_2O_3 and CaO, has also been described in the Iranian salt domes (Taghipour et al. 2012).

10. Regional correlations, implications for the geological evolution of Eastern Arabia in Gondwana

A comprehensive review of the Neoproterozoic history in terms of basin development and plate tectonic setting of Arabia is given in Allen (2007). According to this work, the time period covered by the dated rocks in this study (ca. 600 to 545 Ma), was coeval with the deposition of the upper part of the regionally extensive Nafun Group of the Huqf Supergroup and equivalent sequences in other Oman outcrops, such as Jebel Akhdar. The deposition of the Nafun Group, which spans almost exactly the entire period of Ediacaran time (635 to 540

Ma) lies unconformably on the more restricted, fault-bounded Cryogenian basins and their crystalline basement in Eastern Arabia. The Nafun Group comprises an extensive blanket of siliciclastic and carbonate rocks, which was probably deposited on stretched crust in a continental rim basin inboard of a passive margin with Palaeotethys (Allen, 2007). The dated Delma meta-carbonate would fit into this type of model as would, quite probably, the majority of the deformed limestone/dolomite and siliciclastic clasts of the salt domes. The Nafun Group, which is characterised by an absence of volcanic rocks, was succeeded in the Huqf area by the Ara Group, deposited in a retro-arc setting inboard of a subduction zone along the line of the previous passive margin. Thus, to be more specific, the Delma metacarbonate has the age and lithology to possibly correlate with the Khufai Formation of the Nafun Group, while the Zirku Formation is likely correlated with the Shuram Formation (Fig. 13). However, the geochronological ages of the Khufai and Shuram Formations in Oman are unknown due to a lack of dateable materials. The youngest detrital zircons in the Shuram and Khufai Formation are 600-640 Ma. Le Guerroué et al. (2006) used decompacted thicknesses of Nafun Group stratigraphy and a best-fitting stretch factor to interpolate between 542 and 635 Ma; they obtained 609 ± 9 to 601 ± 8 Ma for the age of the Khufai and 601 ± 8 to 574 ± 7 Ma for the age of the Shuram. In contrast, Bowring et al. (2007) interpreted a major stratigraphic gap between the Khufai and the Shuram Formations, so that the Shuram Formation was dated from <580 to ca. 560 Ma. The Delma metacarbonate and Zirku Formation straddle the estimated age boundary between the Khufai and Shuram Formations.

The maximum age of deposition of the red continental arkosic sandstone clast from Qarn Sahmah (Oman) as given by the detrital zircon analyses is ca. 730 Ma. This would imply a time-correlation with the rocks of the Abu Mahara Group. However, this is essentially deep water marine sequence in the Jebal Akhdar region, making such a correlation unlikely. However, the Masirah Bay Formation, is dominated by yellow and red arkosic sandstone with mostly 820+ Ma zircons, derived from the Cryogenian Huqf region basement (Allen, 2007). The Shuram Formation also includes red sandstones, but is much finer-grained and better sorted than the Masirah Bay Formation. The Shuram Formation contains young detrital zircons in the 600-640 Ma age range in addition to Cryogenian zircons (Allen, 2007). On these grounds therefore, a correlation of the Qarn Shamhah sandstone clast with the Masirah Bay Formation is proposed (Fig. 13).

The geochemistry of the volcanic rocks suggests that these were most probably formed in a continental extensional, rifted margin, setting, with the range in compositions explainable by a combination of fractional crystallisation and assimilation of continental crust. That felsic and mafic volcanism was coeval can be demonstrated on Qarnain and in Jebel Dhanna, where the intimate association of felsic and mafic magmas is well exposed.

In view of the foregoing discussion of the age and geochemical constraints provided by the UAE and Oman salt dome clasts, Fig. 13 summarises the possible stratigraphic position of the UAE salt domes with respect to the rest of Arabia.

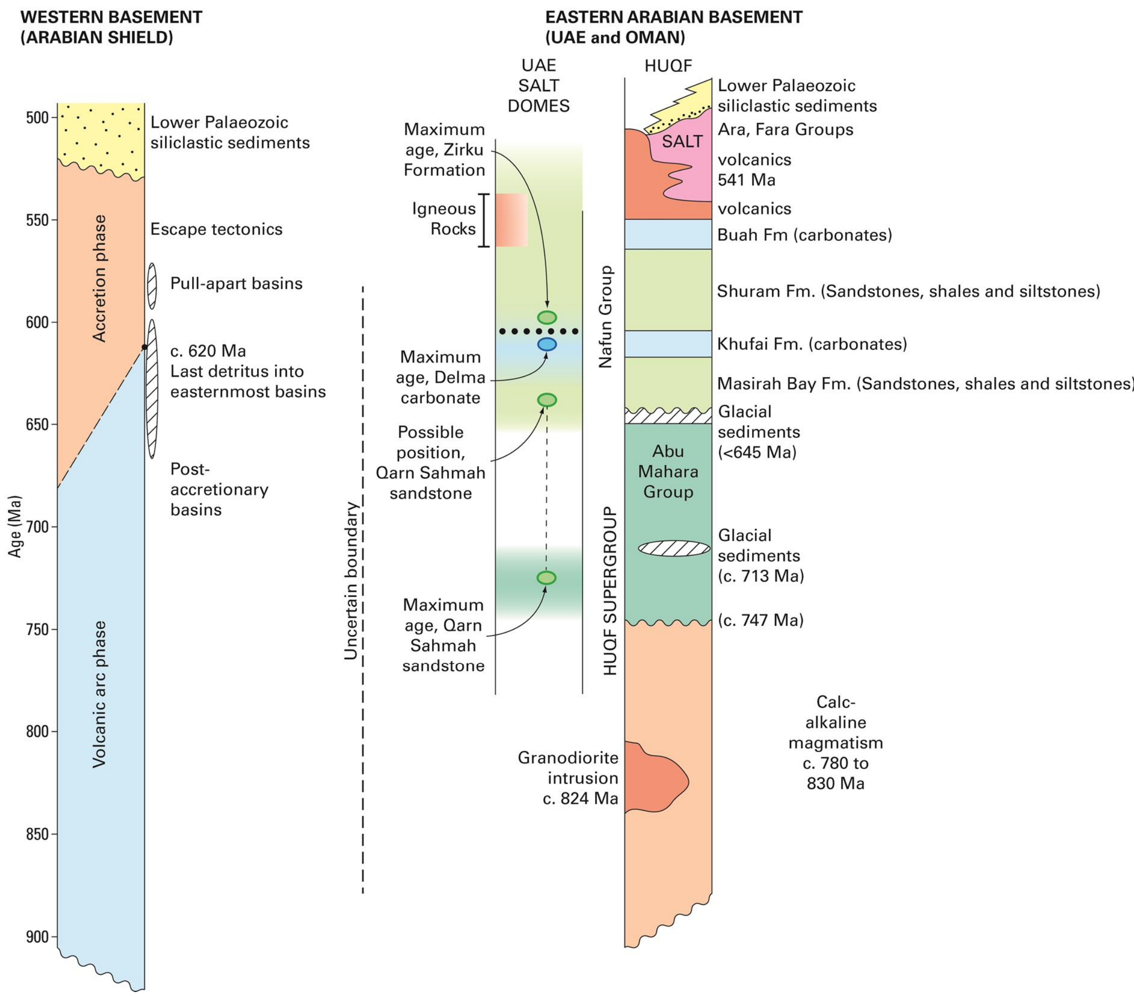

Fig. 13. Comparative stratigraphy of the UAE salt dome clasts with the Western Arabian basement (Arabian Shield) and the Huqf area of Oman as an example from the Eastern Arabian basement; possible correlations with the dated UAE rocks.

With regard to the provenance of the sedimentary rocks, the three analysed samples show an overwhelming influence from Neoproterozoic sources. The zircon ages from the

Oman sample show a simple pattern similar to that from the Huqf Supergroup (c.f. Rieu et al., 2007; Le Guerroué et al., 2006). The youngest grains are about 734 Ma, providing a maximum age of deposition, with a small peak at ca. 760 and a major peak at ca 830, and a few older grains at 900 to 950 Ma. All these zircons were probably derived from relatively local sources from the Cryogenian basement to the Huqf Supergroup.

The two samples from the UAE show comparable age-frequency spectra, with a strong bimodal nature typical of the ñPan-Africanò orogenic events between ca. 800 and 600 Ma, typical throughout the Arabian-Nubian Shield and the wider East African Orogen (e.g. Johnson and Kattan, 2007; Stern and Johnson, 2010). The dates record early juvenile island arc development, followed by collision orogeny, post-collision basin development and granitoid magmatism. The clarity of the Neoproterozoic age-bimodality, is clearly the major provenance influence on all clastic sedimentary rocks in the western UAE from the Late Neoproterozoic to the present day, seen in comparable detrital zircon spectra from Miocene and Quaternary rocks (Farrant et al., 2012). The minor amounts of c. 1 Ga zircons seen in all detrital zircon spectra are a reflection of the well-recorded remnants of late Mesoproterozoic earliest events in the initiation of the East African Orogen (Stern, 1994).

The two detrital spectra from UAE show minor input of detritus from older Palaeoproterozoic to Archaean sources, probably from rocks of the Arabian Shield as exposed in southeast Saudi Arabia and Yemen. It can be speculated that these were the source of the detritus, but other sources such as the basement terranes of various blocks presently residing between Iran and India that were quite close to Arabia in Ediacaran times, cannot be ruled out.

To further refine the provenance of the UAE samples, their age spectra can be compared to typical samples from the Eastern and Western Arabian basement. Stern and Johnson (2010 and references therein) provided representative zircon spectra from the Huqf Supergroup of Oman (eastern basement) and Lower Palaeozoic sandstones from Israel and Jordan (Western basement), where marked differences are apparent. These data are plotted in Fig. 14, along with the new data from the UAE and Oman salt dome sedimentary clasts. In the Neoproterozoic, the Eastern basement is characterised by strong age maxima at 850 ± 50 Ma, whereas the Western basement shows age maxima at 650 ± 50 Ma, with a prominent trough of few data at just over 700 Ma. The two UAE salt dome sandstones very strongly show both age peaks, with the same dearth of ages at just over 700 Ma. This is illustrated for one UAE sample (UAE_7072) of the Zirku Formation turbidite in Fig. 14, which is shown together with the Arabian basement ages of Johnson and Kattan (2007).

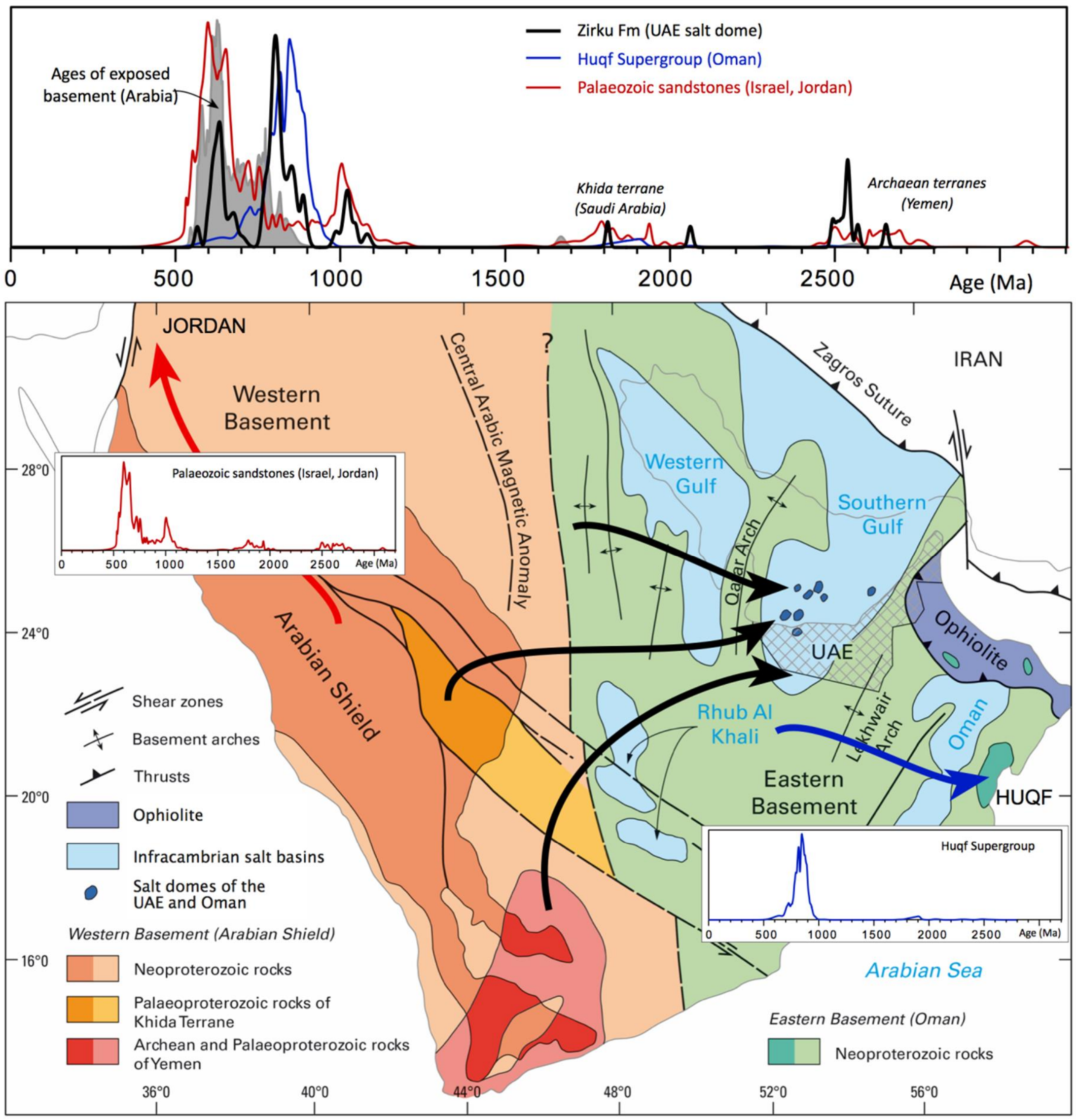

Fig. 14 Sketch geological map of Arabia (modified from Stern and Johnson, 2010). The Huqf Supergroup representative detrital zircon data (Rieu et al., 2007; Le Guerroué et al., 2006) are shown as a probability density plot in blue, along with inferred provenance trends. Representative detrital zircon data from the NW region is shown in red (from Avigad et al., 2003; Kolodner et al., 2006), along with inferred provenance trends. The top probability density plot compares with western and eastern detrital data with the Zirku Formation (this study; in black), and a compilation of Arabian basement ages (Johnson and Kattan, 2007; in grey).

From these comparative curves it thus seems likely that the UAE salt domes, which lie geographically between the sampled areas of basement in Johnson and Kattan (2007), show signals of derivation of detritus from both the Eastern and Western basement blocks. This has the implication that both blocks were probably juxtaposed by the time of deposition of the Zirku Formation and Delma metacarbonate, the maximum age of which is about ca. 597 Ma, thus giving an estimate of the timing of the final collision between the western and eastern basement blocks of Arabia. Since the eastern and western crustal blocks were sutured by ca. 597 Ma, and since the period just prior to this was one of tectonic quiescence, it is likely that the docking of the two terranes took place during the Cryogenian, prior to deposition of the Ediacaran-aged Nafun Group.

11. Conclusions

The main conclusions of this study can be summarised as follows:

- Clasts brought up in salt domes of the UAE and Oman provide insights into the basement architecture of eastern Arabia in a region otherwise covered by thick sedimentary deposits;
- A widespread igneous event occurring in a continental extensional setting, inferred to be along the Gondwana margin, occurred at ca. 560 to 545 Ma.
- Deformation recorded in <593 Ma sedimentary rocks, but not effecting 560 to 545 Ma igneous rocks implies the event causing this deformation occurred between these age brackets.
- Detrital zircon ages in sedimentary clasts suggest that collision and suturing of the western and eastern basement blocks of Arabia was accomplished by ca. 597 Ma.

Acknowledgements

This paper is published with the permission of the Director of BGS-NERC. We thank the help and support of Saleh Al Mahmoodi, Khalid Al Hosani and Abdullah Gahnoog of the Department of Mineral and Energy Resources, Ministry of Energy, Abu Dhabi, UAE over the more than a decade that BGS was involved in the geological mapping of the entire UAE, and for their hard work in arranging the very hard-to-obtain permits to visit the salt islands.

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