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ScienceDirect
Earth-Science Reviews 84 (2007) 139–185
EARTH-SCIENCE REVIEWS
www.elsevier.com/locate/earscirev

The Huqf Supergroup of Oman: Basin development and context for Neoproterozoic glaciation

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Received 21 August 2006; accepted 13 June 2007
Available online 6 August 2007

Abstract

The Huqf Supergroup of the Sultanate of Oman provides important information on the geological evolution of the Arabian–Persian Gulf region during a protracted period of continental dispersal and reassembly on the periphery of the Gondwanan supercontinent during the Neoproterozoic, and also provides important constraints on the nature of extreme climate swings during this critical period in the evolution of Earth's biosphere. The Huqf Supergroup spans the period *ca.* 725–540 Ma, and is composed of three groups. The Abu Mahara Group (*ca.* 725 to <645 Ma) hosts two glacial successions separated by an interval of non-glacial, deep to shallow marine sedimentary rocks. The base of the overlying Nafun Group (*ca.*<645–547 Ma) is marked by a transgressive post-glacial carbonate, which initiates an overstepping of basement-cored structural highs and the deposition of an extensive blanket of carbonate and siliciclastic stratigraphy. The Ara Group (*ca.* 547–540 Ma), which is known mostly from the subsurface, comprises carbonates, evaporites and organic-rich shales, with interbedded ashes, deposited in a large number of N–S trending troughs and platforms.

The three groups of the Huqf Supergroup correspond to three phases of basin development. The Abu Mahara Group was deposited on an eroded crystalline and metasedimentary basement. An early stage of basin formation preserved <1.5 km of marginal to deeper marine sedimentary rocks, including an older Cryogenian glacial succession infilling erosional palaeovalleys. Renewed tectonic subsidence associated with submarine volcanism allowed the preservation of a >1 km-thick, cyclical, rift basin-fill of glacial and non-glacial sedimentary rocks representing a younger Cryogenian icehouse epoch. Progressively older source areas were exhumed during the interval *ca.* 725 to <645 Ma, with unroofed 800+ Ma granitoid plutons providing the bulk of sediment, supplemented by syn-extension volcanics, and eventually by distant Meso- and Palaeoproterozoic sources.

The wide extent of the Nafun Group, basin-wide correlation of major lithostratigraphic units, and its modest thickness (~1 km) suggest a period of thermal contraction following Abu Mahara rifting. The Oman area was probably a region of slightly stretched continental lithosphere (which passed to the NE into a passive continental margin), occupied by a continental margin rim basin during deposition of the Nafun Group. The Nafun Group bears little resemblance to the coeval small basin-fills choked with calc-alkaline volcanic detritus in the Arabian Shield, but the correlation of the Nafun Group with the Jibalah Group indicates that the contiguous continental rim basin extended from Oman across the tectonically deformed eastern fringe of the Arabian–Nubian Shield. Inundation of the Arabian Shield area and incorporation within the Nafun basin was probably facilitated by extensional collapse and tectonic escape. Sources for 600–640 Ma zircons, found in the Nafun Group, can readily be identified in the Arabian–Nubian Shield.

Renewed volcanism, compartmentalization of the basin by N–S trending structural highs and troughs, and an increase in sediment accumulation rates, typifies the Ara Group. The Ara Group deposits formed part of an extensive, latitudinal evaporite belt, with a depocentre translated outwards relative to the Nafun basin, suggesting continuing tectonic progradation of the eastern margin of the Arabian–Nubian Shield. Subduction of ocean floor along the former passive continental margin along the periphery

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0012-8252/$ - see front matter
doi:10.1016/j.earscirev.2007.06.005

of eastern Gondwana is the most likely cause of Ara volcanism and tectonism, in which case the Oman area can be viewed as occupying a retro-arc setting at this stage, between a subducting margin and the East African orogen. Coeval calc-alkaline plutons and rhyolitic to andesitic volcanics are found in the Central Iranian Terrane.

Neoproterozoic glaciations are recorded in the rift and passive margin stratigraphy predating the final amalgamation of continental fragments into greater Gondwana. In Oman, glaciation was contemporaneous with the development of an Andean-type orogen in the Arabian–Nubian Shield while passive margin basins continued to subside in northern Iran, India and South China. The elevated topography associated with the Andean-type orogen together with passive margin mega-escarpments may have promoted nucleation of ice caps that sourced marine-terminating valley glaciers and ice streams. However, the triggering of Cryogenian glaciation must ultimately be related to the biogeochemical cycles operating on a planet with a nascent land biota, lack of calcifying plankton and reduced solar luminosity.

Keywords: Neoproterozoic; Huqf Supergroup; Oman; basin evolution; glaciations; detrital zircon geochronology

1. Introduction

The Sultanate of Oman contains relatively small but exquisite outcrops of Neoproterozoic rocks that provide critical information for the evaluation of palaeogeography and palaeoenvironments, and for the testing of ideas on the forcing mechanisms for extreme climate change in deep time. In addition, information from surface outcrop studies can be supplemented by an extensive database from well penetrations and geophysical surveys throughout the buried salt basins of the Oman interior. The combination of detailed sedimentological studies of outcrops and subsurface data generated by Petroleum Development Oman (PDO), backed up by an improving geochronological and chemostratigraphic database, makes the Oman Neoproterozoic an important piece in the global Neoproterozoic jigsaw. However, throughout the history of subsurface exploration and geological mapping in Oman, the basin evolution and controlling geodynamics for the Neoproterozoic to Early Cambrian interval has remained speculative. There are a number of possible reasons for this: (1) seismic quality beneath the salt of the latest Neoproterozoic to Early Cambrian Ara Group is poor; (2) deep well penetrations were disappointing, and core recovery was meagre; (3) the geochronological dating of the succession was until recently poorly constrained. The development of carbonate 'stringer' plays associated with Ara Group salt basins has renewed commercial interest in the Precambrian of Oman. A number of in-house PDO reports incorporating new seismic interpretations and core descriptions, University-led field studies and consideration of analogous deposits worldwide now provides a much-improved sedimentological, stratigraphic, geochronological and tectonic database allowing a re-evaluation of the Neoproterozoic evolution of Oman and surrounding area in terms of regional tectonics and basin development.

1.1. The assembly of Gondwana

The evolution of the Oman area needs to be placed in the wider context of the break-up of Rodinia, the opening and closing of the Mozambique Ocean, the accretionary events that led to the formation of the Gondwanan super-assembly, and the subsequent evolution of its collisional belts and forelands. Neoproterozoic rocks (Fig. 1) are found within and along the periphery of a number of megasutures that stitch together the supercontinent of Gondwana. The megasutures represent the deformed igneous, metamorphic and sedimentary products of orogenesis as successive continental fragments joined the core of western Gondwana in the *ca.* 100 Myr preceding the Cambrian. The reconstruction of Gondwana at the end of the Neoproterozoic shown in Fig. 1 illustrates two major megasutures: one marking the coalescence of South America and West Africa with the remainder of Africa (northern African, Congo and Kalahari cratons), and the other marking the coalescence of India, east Antarctica and Oman–Iran–Afghanistan with Africa. These two great megasutures are linked by the Damaran–Zambezi megasuture that wraps around the northern margin of the Kalahari craton. It is immediately clear that a great many Neoproterozoic basins are implicated in the rifting, drifting, oceanic closure and subduction/collision events associated with these major megasutures.

The plate tectonic reconstruction generally accepted for the end of Neoproterozoic time (543 Ma) (Fig. 1, based on de Wit et al., 1988; Powell et al., 1994; Unrug, 1997; Dalziel, 1997; Meert and van der Voo, 1997; PLATES Project, 1999; Kusky et al., 2003) shows Oman joined to the Arabian–Nubian Shield, India–Madagascar joined to the East African Orogen, and Australia–Antarctica joined to the southern extension of the Mozambique Belt, to form one large Gondwanan assembly, with its outer margin marked either by the subduction of oceanic lithosphere