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Ancient glaciations and hydrocarbon accumulations in North Africa and the Middle East

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ABSTRACT

At least six glaciations are purported to have affected North Africa and the Middle East region over the last one billion years, including two in the Cryogenian (Neoproterozoic), Hirnantian (Late Ordovician), Silurian, Carboniferous and Early Permian events. The sedimentary record associated with these glaciations, together with the intensity to which each has been investigated, is highly variable. As hydrocarbon exploration proceeds aggressively across the North Africa and Middle East regions, we review the relationship between glaciation and hydrocarbon accumulations.

With the exception of Oman, and locally Egypt, which were tectonically active both during the Neoproterozoic and Early Palaeozoic all glaciations took place along an essentially stable passive continental margin. During the Neoproterozoic, two glaciations are recognised, referred to as older and younger Cryogenian glaciations respectively. Both of these Cryogenian events are preserved in Oman; only the younger Cryogenian has been reported in North Africa in Mauritania and Mali at the flanks of the Taoudenni Basin. The process of initial deglaciation in younger Cryogenian glaciations resulted in incision, at least locally producing large-bedrock palaeovalleys in Oman, and the deposition of glacial diamictites, gravels, sandstones and mudstones. As deglaciation progressed "cap carbonates" were deposited, passing vertically into shale with evidence for deposition in an anoxic environment. Hence, younger Cryogenian deglaciation may be associated with hydrocarbon source rock deposits.

Hirnantian (Late Ordovician) glaciation was short lived (<0.5 Myr) and affected intracratonic basins of Mauritania, Morocco, Algeria, Libya, Egypt and Saudi Arabia. The organisation of the glacial sedimentary record is considered to be controlled at the basin-scale by the location of fast-flowing ice streams active during glacial maxima, and by the processes of meltwater release during glacial recession. In these latter phases, subglacial tunnel valley networks were cut at or near the ice margin. These tunnel valleys were filled in two main phases. The initial phase was characterised by debris flow release, whereas during later phases of ice retreat a range of glaciofluvial, shallow glaciomarine to shelf deposits were laid down, depending on the water depth at the ice front. Production of linear accumulations of sediment, parallel to the ice front, also occurred between tunnel valleys at the grounding line. In Arabia, the geometry of these features may have been influenced by local tectonic uplift. As glaciogenic reservoirs, Hirnantian deposits are already of great economic significance across central North Africa. Therefore, an appreciation of the processes of ice sheet growth and decay provides significant insights into the controls on large-scale heterogeneities within these sediments, and in analogue deposits produced by glaciations of different ages.

Deglacial, Early Silurian black shale represents the most important Palaeozoic source rock across the region. Existing models do not adequately explain the temporal and spatial development of anoxia, and hence of black shale/deglacial source rocks. The origins of a palaeotopography previously invoked as the primary driver for this anoxia is allied to a complex configuration of palaeo-ice stream pathways, "underfilled" tunnel valley incisions, glaciotectonic deformation structures and re-activation of older crustal structures during rebound. A putative link with the development of Silurian glaciation in northern Chad is suggested. Silurian glaciation appears to have been restricted to the southern Al Kufrah Basin in the eastern part of North Africa, and was associated with the deposition of boulder beds. Equivalent deposits are lacking in shallow marine deposits in neighbouring outcrop belts.

Evidence for Carboniferous–Permian glaciation is tentative in the eastern Sahara (SW Egypt) but well established on the Arabian Peninsula in Oman and more recently in Saudi Arabia. Pennsylvanian–Sakmarian times saw repeated glaciation–deglaciation cycles affecting the region, over a timeframe of about 20 Myr.

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Repeated phases of deglaciation produced a complex stratigraphy consisting, in part, of structureless sandstone intervals up to 50 m thick. Some of these sandstone intervals are major hydrocarbon intervals in the Omani salt basins. Whilst studies of the Hirnantian glaciation can provide lessons on the causes of large-scale variability within Carboniferous–Permian glaciogenic reservoirs, additional factors also influenced their geometry. These include the effects of topography produced during Hercynian orogenesis and the mobilisation and dissolution of the Precambrian Ara Salt. Deglacial or interglacial lacustrine shale, with abundant palynomorphs, is also important. Whilst both Cryogenian intervals and the Hirnantian–Rhuddanian deglaciation resulted in the deposition of glaciomarine deposits, Carboniferous–Permian deglaciation likely occurred within a lacustrine setting. Hence, compared to shales of other glacial epochs, the source rock potential of Carboniferous–Permian deglacial deposits is minimal.

Contents

1. Introduction

The aim of this paper is to deliver a comprehensive analysis of glacially-related deposits (Precambrian through Phanerozoic) of the North Africa and Middle East regions and their precise relationship to hydrocarbon exploration across this petroliferous region (Fig. 1). Here, we consider the strength of the sedimentological evidence for glaciation of each age in turn, the regional stratigraphy of their glacially-