Journal of African Earth Sciences 58 (2010) 354–364

Contents lists available at ScienceDirect

Journal of African Earth Sciences

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

Evidence for Late Ordovician glaciation of Al Kufrah Basin, Libya

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ARTICLE INFO

Article history:
Received 1 September 2009
Received in revised form 12 April 2010
Accepted 14 April 2010
Available online 24 April 2010

Keywords:
Glaciation
Ordovician
Ice sheet
Reservoir
North Africa
Al Kufrah Basin

ABSTRACT

Fieldwork at the flanks of Al Kufrah Basin, Libya, reveals that Late Ordovician ice sheets were present in the eastern Sahara and that they extended northeastward toward Egypt. Evidence for grounded ice sheets is preserved at the both the southeastern (Jabal Azbah) and northern (Jabal az-Zalmah) basin margins. Characteristic soft-sediment deformation structures, including soft-sediment folds, small-scale faults and striated pavements indicate subglacial shearing and the formation of glacial erosion surfaces. These findings support the presence of a Late Ordovician ice margin in the eastern Sahara and add vital new constraints to reconstructions of the morphology of North African grounded ice sheets. Prior to our study, there existed two plausible models on ice sheet geometry. The first was that separate ice sheets – namely a north and west African ice sheet and an Arabian ice sheet – extended over this part of western North Gondwana. The second was that ice cover was continuous. The presence of a suite of subglacially-generated deformation structures adds considerable credence to the latter interpretation.

1. Introduction

This paper is concerned with evidence for glaciation within a clastic succession of Late Ordovician age in Al Kufrah Basin, eastern Libya (Fig. 1). The case for Late Ordovician glaciations in the Tassili N'Ajjer on the Algerian–Libyan border is long since established (e.g. Beuf et al., 1971), but in recent years, systematic studies have been undertaken at the flanks of other Saharan basins that have spawned a considerable literature with more modern interpretations. For example, facies models and palaeogeographic summaries of Ghienne et al. (2007) emphasised that the northward advance of ice sheets peaked at a glacial maximum in the late Hirnantian (total duration ~3 Myr) and that up to five advance-retreat cycles of a large ice mass occurred in this short interval. More palaeo-glaciologically focussed research has attempted to carefully define palaeo-ice front positions across this area, positioning palaeo-ice streams at the glacial maximum and the location of major meltwater conduits during ice sheet retreat (Le Heron and Craig, 2008). The most recent studies based on both detailed outcrop and seismic reflection data (Le Heron, 2010) have given up-to-date palaeo-glaciological analyses of the Late Ordovician record in western Libya within the Murzuq Basin. Thus far, papers have been published specifically dealing with the evidence for and nature of the Late Ordovician glaciation in Al Kufrah Basin.

In recent years, concerted efforts have been made to unravel the Lower Palaeozoic stratigraphy of Al Kufrah Basin, and describing and interpreting putative Late Ordovician glaciogenic deposits within this succession has been a primary research objective. A number of international oil companies have exploration commitments in this basin, providing the impetus for new data to be gathered. No oil or gas discoveries have yet been made. By analogy to the stratigraphically and structurally comparable Murzuq Basin in SW Libya (Davidson et al., 2000), Early Silurian shale of the Tanezuft Formation is suggested to be the main source rock interval and underlying glaciogenic sandstones of the Mamuniyat Formation are the primary reservoir target (Lüning et al., 1999). The results of a 1999 field trip to the western Al Kufrah Basin, in Jabal Eghei, were released, albeit only in part, within Ghnia et al. (2008). These latter authors figured a soft-sediment striated pavement, interpreted to have been produced by subglacial erosion, but no sections or supporting data were published in that paper. Aside from this work, no evidence for glaciogenic processes has hitherto been presented from Al Kufrah Basin in the international literature. Extreme difficulty of access has led to imaginative but ultimately unsubstantiated papers that make stratigraphic predictions about the probable presence of Late Ordovician glacial deposits in Al Kufrah Basin based on what is known from the neighbouring Murzuq Basin, albeit without fieldwork (Clark-Lowes, 2008).

As prospective hydrocarbon reservoirs in Al Kufrah Basin, an understanding of the strength of evidence for glaciation, and its impact on stratigraphic architectures, should be deemed essential. By contrast to shallow marine successions deposited under non-glacial conditions which normally accumulate within orderly parasequence stacking patterns, glacially-related successions form complex and lithologically heterogeneous successions that are

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doi:10.1016/j.jafrearsci.2010.04.001

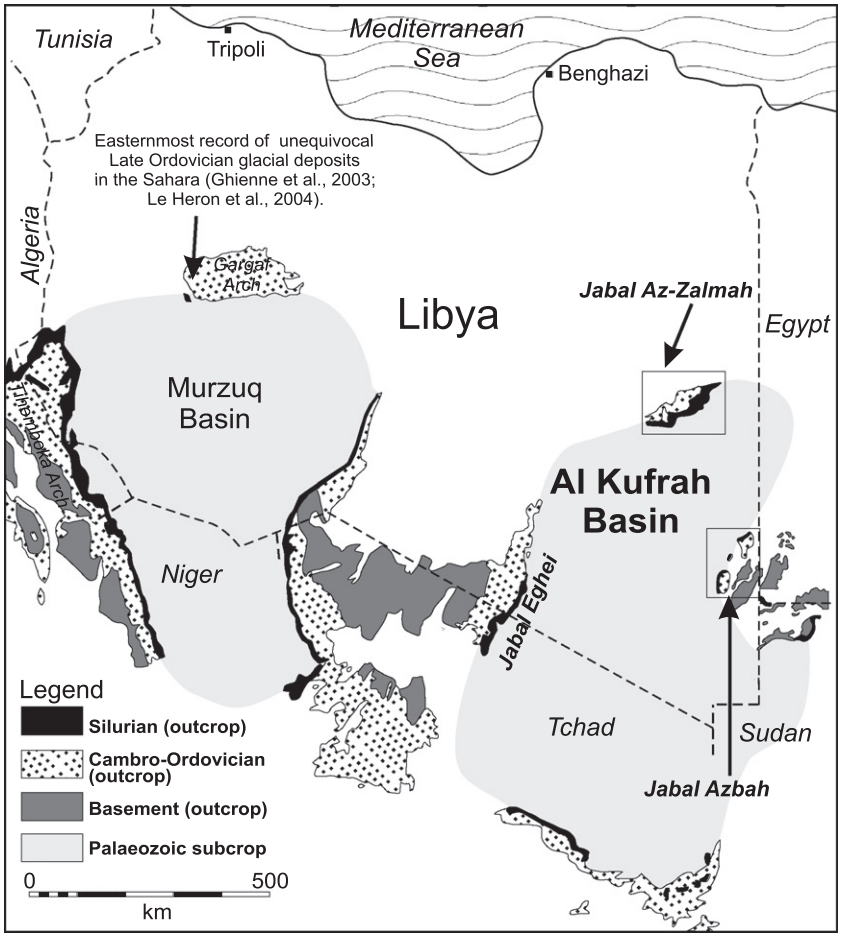

Fig. 1. Location of Al Kufrah Basin in southern Libya. Outcrops examined in the course of this fieldwork are located in the northern (Jabal Az-Zalmah) and south-eastern (Jabal Azbah) regions.

typified by dramatic lateral facies changes (e.g. Brodzikowski and Van Loon, 1991). In glaciogenic reservoir successions, such as the Late Ordovician examples of North Africa, the basin-scale arrangement of sedimentary successions is conditioned by such factors as the geometry of ice sheet grounding lines, together with internal flow heterogeneities within the ice sheets (e.g. ice streams) and the processes of reworking during meltwater release (Le Heron et al., 2009). At outcrop, the continuity of sandstone bodies, the style of subglacial bedforms which are preserved and, in particular, how glacially-related unconformities are manifested provide crucial data for the characterisation of glaciogenic reservoirs in the subsurface.

This paper aims to present new data on Late Ordovician deposits at both the south-eastern and northern flank of Al Kufrah Basin, and consider what evidence, if any, may be used to support or refute the hypothesis that ice sheets were present in the eastern Sahara at this time. It is not the purpose of the present study to deliver a comprehensive sedimentological analysis, but rather to highlight the implications of the presence or absence of Late Ordovician glacial deposits in this area for (1) palaeogeographic reconstructions and (2) hydrocarbon exploration.

2. Study area

Al Kufrah Basin is a large (400,000 km^2) intracontinental basin in the eastern Sahara, within which substantive evidence for ancient (Late Ordovician) glaciation has never before been found. Existing geological data is limited, as a result of an historical lack of interest by the oil industry prior to the present attempts to explore the basin. General papers have been published on basin scale structure and stratigraphy (Bellini et al., 1991), Palaeozoic sedimentology (Turner, 1991), and insights into the hydrocarbon potential of this basin are available (Lüning et al., 1999). A joint mapping project between Egyptian and Libyan authorities produced 1:200,000 geological maps for the southeastern part of the basin (Saïd et al., 2000), for which many formation names were correlated from their type sections in western Libya. Palaeozoic rocks of Neoproterozoic to Carboniferous age form the basin fill (Bellini et al., 1991) and these crop out at four basin-flanking uplifts.

During the course of this study, Lower Palaeozoic outcrops were visited in the Jabal Azbah region (SE basin flank) and in the Jabal az-Zalmah region to the north of the basin (Fig. 1). In this latter area, only regional-scale overview maps are currently available (Persits et al., 1997). However, a 1:200,000 scale geological map sheet is pending, a preview of which was recently published within Sherif and Shagroni (2008). Therefore, as type sections or even type areas have yet to be formally established, Cambrian through Ordovician strata remain undifferentiated. Other outcrops of Lower Palaeozoic rocks do occur at the other basin margin uplifts, namely at the western basin flanks in Jabal Eghei (Seilacher et al., 2002) and in the Ennedi-Bourkou Range, Chad (Fig. 1). These latter outcrops are out of bounds due to landmines and prevailing civil unrest. By contrast, outcrops in Jabal Eghei were revisited with CASP in 2008 and these will be the subject of a future paper.