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Architecture of a Late Ordovician ice-proximal multistorey palaeovalley in the Murzuq Basin (Libya): implication for sequence stratigraphy

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Sequence stratigraphy of Late Ordovician glacial strata at basin scale, and the architecture of depositional systems at field scale, remains a key challenge in reservoir prediction for several Palaeozoic Petroleum systems in North Africa. The aim of this paper is to present the architecture of a complex palaeovalley fill which is exposed in southwestern Libya. Sequences in the palaeovalley fill, which comprises a succession of seismic-scale, unconformity-bound, ice-related depositional units, are climatically controlled and may be used for correlations in the Late Ordovician sedimentary wedge at the platform scale.

During the latest Ordovician (Hirnantian), western Gondwana was covered by an extensive ice sheet, the front of which fluctuated throughout the present-day North and West Africa. In the study area, the Late Ordovician glacial record corresponds to the Melaz Shuqran and Mamuniyat Formations. At present, the nature of the lower bounding surface of the glacial wedge is still controversial, as no clear glacial features were recognized along the contact between Late Ordovician and Cambrian–Early Ordovician strata. Above, five ice-related depositional sequences are identified. They are separated by four erosional unconformities of subglacial origin.

Subglacial unconformities are inferred by the presence of highly deformed sandstones including intraformational striated surfaces and plurikilometre-scale streamlined bedforms visible on aerial or satellite images. These subglacial unconformities are gently dipping concave-up erosional surfaces, 5 to 15 km in width, up to 200 m in depth, which form up to 50 km long palaeovalleys. Geological mapping indicates that the four subglacial unconformities nest together, the older and widest palaeovalley including the subsequently narrower and younger valleys. As the long axis orientation of the successive palaeovalleys changes through time, a complex pattern of incision events results in a depositional architecture similar to Late Cenozoic multistorey alluvial terraces. Erosional remnants of former depositional sequence are adjacent to each other rather than vertically superimposed.

If totally developed and fully preserved, a glacial depositional sequence is made up of a 30–150 m thick, coarsening-upwards succession that can be subdivided in three units. The lower unit (20–75 m) comprises mica-rich, crudely laminated, shales to fine-grained sandstones, with intervening microconglomeratic horizons, slump balls and sparse gravel-size lonestones. These deposits are interpreted as relatively distal glaciomarine sediments. The middle unit (5–20 m), which has a sharp or rapid transitional contact with underlying fine-grained deposits, is made up of well sorted medium-grained to poorly sorted coarse-grained sandstones. They comprise a wide range of sedimentary structures such as climbing current ripples, occasional wave ripples, through or tabular cross-laminations, flat laminations with parting lineations. In places, lateral accretion surfaces reflecting meander belt systems are identified. These deposits are interpreted as shallow-marine to distal alluvial plain sediments. Above a deeply erosional bounding surface, the upper unit (few metres–up to 100 m) of a glacial depositional sequence consists of coarse- to very coarse-grained, massive to cross-laminated sandstones, including a number of internal erosional surfaces. These deposits are interpreted as amalgamated erosion-based fluvial channel fills in a high-energy, aggrading braidplain environment.

According to our provisional interpretation, subglacial unconformities are formed during major ice-sheet advances and maximum extents, whereas depositional sequences reflect ice-sheet retreat phases further south. The rapid retreat of the ice fronts results in marine flooding and subsequent progradation of a glacially influenced shelf–alluvial plain system (lower and middle units). Isostatic rebound could be responsible for severe fluvial incision whereas a continuously glacio-eustatic sea-level rise drives a major phase of fluvial aggradation (upper units that fills the residual accommodation space up to a level which depend of the magnitude of the glacial recession.

Throughout the northern Gondwana platform, a set of glacial depositional systems can be differentiated in preserved successions: (1) ice-distal systems, controlled by glacio-eustasy and never covered by ice; (2) ice-marginal systems, close to the maximum location of ice fronts; ice-covered systems, either (3) periodically deglaciated, with proglacial sedimentation during ice-retreat and subsequent stagnation phases, or (4) permanently covered by ice. The architecture of the studied palaeovalley fill that belongs to the ice-covered, but periodically deglaciated system, characterises low-accommodation systems, within which several “cannibalisation” events have occurred through repetitive glacial erosion events resulting in laterally juxtaposed depositional sequences. In contrast, in ice-marginal systems, with no or minor glacial erosion, glaciomarine depositional sequences comprising mainly glaciomarine sediments are vertically superimposed. Sequence stratigraphy concepts developed in alluvial terraces–delta lobes systems should be applied for investigation of the Late Ordovician glacial strata. As glacial depositional sequences reflect major, climatically controlled ice advances and retreats, they represent allostratigraphic units, which can be correlated from ice-distal to ice-covered systems as well as between adjoining or distant depositional profiles across the platform.