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Insights into the Regional Sedimentary Organisation of the Walloon Subgroup, Surat Basin

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Abstract

Despite more than a decade of intensive coal seam gas exploration and development in the Surat Basin, fundamental aspects surrounding the sedimentary organisation of the Middle Jurassic Walloon Subgroup remain unresolved. While generally agreed to have been deposited on a waterlogged alluvial plain (Exon 1976) contradictory models describe the Walloon Subgroup as an internally draining fluvio-lacustrine system (Exon 1976, Swarbrick 1974) or alternatively as a southerly prograding axial trunk drainage (Leblang 1981, Sliwa and Estrele 2008, Scott 2008, Hamilton 2011). The former, somewhat analogous to the Fort Union Formation in the Powder River Basin, invokes a radially organised fluvial system feeding a basin centre lake. Along the eastern Surat sediment dispersion and proximal-to-distal facies relationships are predicted to be oriented from east to west. In contrast, a prograding trunk drainage system assumes an axial system flowing southward towards a distant paleo-coastline. In this model (perhaps similar to the East African rift system), the prevailing sediment dispersal pattern and facies transitions are parallel to the basin axis, largely from north to south (with minor lateral inputs from east to west). Without a unifying conceptual model elucidating the controls on Middle Jurassic deposition, predictions about the spatial or temporal distribution of coal-mires or other sub-environments within the Walloon Subgroup are difficult.

This study tests previous hypotheses surrounding the Walloon Subgroup's sedimentary organisation by reconstructing regional sediment dispersal patterns and variations in alluvial plain architecture. The workflow builds on previous studies to integrate image log interpretation allowing for a regional exploration into the character of in-channel processes throughout the basin. Borehole image logs (BHI) are high-resolution wireline tools which record up to 192 oriented micro resistivity measurements within a wellbore. During processing individual traces are unwrapped, normalised, and interpolated to generate a pseudo 3D image of the wellbore annulus. Subsequent BHI interpretation involves modelling and classifying the features resolved in the unwrapped image, which may be interpreted to represent structural (fault / fracture) or sedimentological (lamination / textural) features. Via detailed interpretation multiple sedimentological structures were resolved, augmented by calibration with core descriptions and distributions of bedding plane dip, azimuth, and bedset thicknesses. These insights allowed for the delineation of three distinct in-channel sandstone facies, previously unrecognized in core or wireline logs.

Planar Cross-Bedded Sandstone

Simple bars composed of moderate to high angle cross-stratified sand laminations to form decimetre scale bedsets at or near the angle of repose. Key diagnostic criteria include uniform dip azimuth distributions and near horizontal non-erosive bedset boundaries. This facies often exhibits sharp, basal contacts in association with lower coal or organic or mudclast breccias; however the key diagnostic features are the uniformity of

foreset dip magnitude and azimuth as well as the planar horizontal bounding surfaces. This facies is interpreted as the product of straight crested two-dimensional dunes indicative of laminar or somewhat turbulent lower regime flow (Allen et al. 1996).

Trough Cross-Bedded Sandstone

Composed of 0.1 to 0.5 meters thick crossbedded sandstone bedsets, trough-cross bedding is formed under comparatively higher flow regimes, where due to flow separation in the dune lee a concave erosion surface forms ahead of the migrating bedform (Allen 1970). Trough cross deposits are characterized by cylindrical bounding surfaces as well as curvilinear sub-parallel foreset laminations. In outcrop, this facies is distinguishable from the previously described planar cross lamination by the erosive and convex upwards bounding surfaces, which in BHI result in a high degree of scatter observed in both foreset dip angle and orientation (Glover and Boreman 2006). The characteristically large azimuthal and dip magnitude scatter is an inherent function of the unit’s curved foresets. Unlike straight-crested dunes, which deposit sheet-like planar tabular forests of common dip direction and magnitude, the dip direction and magnitude of a convex foreset is a function of where on the forest the dip measurement is recorded. Only when the BHI intersects the exact axis of a linguiod dune will the resulting sinusoid measure the true dip direction. More commonly, the BHI will intersect a limb of the feature, recording an apparent dip direction that is a composite of the forest shape and the true dip direction. While this artifact will locally introduce high azimuthal scatter (a useful indicator of the facies); statistically these errors should cancel if sufficient measurements are considered, revealing the true bedform dip direction. The migration of three-dimensional linguoid dunes indicative of turbulent channelized flows is interpreted to form trough cross stratification (Miall 1977).

Epsilon Cross-Bedded Sandstone

Epsilon cross-bedded sandstones form 1-4 meter thick fining upward successions with low angle (10-15o) and unidirectional dipping foresets. Diagnostic criteria include a decrease in foreset dip magnitude upwards coupled with a subtle rotation in dip direction, which occurs due to downstream migration of the pointbar. Lateral accretion of pointbars occurs due to deposition on the outer side of a meander bend where water velocity and hence shear stress decrease due to helical channel flow (Allen 1970). Small-scale cross-stratified sandstones are deposited as dunes migrate across the lower point bar. When dunes are not present suspended load muds and silts accumulates, resulting in a heterolithic succession of fine-grained material rhythmically laminated with cross-stratified sandstones. Thick sequences of this facies were first recognized by Mossop (1980) along the bank of the Athabasca River, who termed the facies inclined heterolithic stratification (IHS). The slightly inclined (3-5o) nature of the fine-grained beds (due to preservation on a sloped pointbar) is a useful diagnostic feature.

Discrete in-channel sandstone facies are linked to the bedform responsible for their deposition and hence provide insights about the depositional energy (high vs. low flow regime) or processes (i.e. turbulence vs. traction or vertical vs. lateral accretion) operating within a channel. Ultimately, these observations were synthesised to unravel the fluvial style of the system in which they were deposited. The in-channel sandstones studied via borehole image-log (BHI) analysis are classified into vertically aggrading (straight crested transverse and three-dimensional linguoidal bars) or laterally accreting (pointbar) successions. Compound successions containing both types are also present.

Existing fluvial research (Miall 1977, Allen and Allen 1980, Rust 1987) has developed a fourfold classification of river type based on channel sinuosity and occurrence: low sinuosity single channel (straight), high sinuosity single channel (meandering), low sinuosity multiple channel (braided) and high sinuosity multiple channel (anastomosing). The Walloon depositional system is complex; however spatial and temporal fluctuations in fluvial process reflect changes in the overall alluvial system. Towards the central-north regions of the basin, the identification of channel successions dominated by epsilon cross bedding or IHS deposits indicates lateral migration of point bars and suggests the presence of a southerly oriented meandering river system. In the southeastern portions of the basin, successions dominated by vertically aggrading successions interpreted to represent sediments of a southerly oriented anastomosing fluvial system. Sediment dispersion in the northeastern portion of the basin appears to be towards the west, perhaps feeding the southerly oriented anastomosing or meandering system. Synthesis of observations supports the hypothesis of a southerly oriented system.