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A sedimentary model for early Palaeozoic fluvial fans, Alderney Sandstone Formation (Channel Islands, UK)

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ABSTRACT

Fluvial fans in the rock record are inferred based on critical criteria such as: downstream grain-size fining; evidence for drainage fractionation along bifurcating channels; increasing fluvial-aeolian interaction in the basinward direction; and radial palaeoflow dispersion. Since pre-vegetation fluvial rocks often lack heterolithic alluvium and channelisation at the outcrop scale, the recognition of pre-Silurian fluvial fans has, so far, not been straightforward. This research proposes a sedimentary model for the Alderney Sandstone Formation of Channel Islands (UK), so far considered as a fine record of early Palaeozoic axial-fluvial sedimentation. Here, outcrop-based and remote-sensing analysis of the formation's type-section reveal the interaction of fluvial and aeolian processes, expressed by the alternation of: compound fluvial bars enclosing macroform surfaces, related to phases of perennial discharge; fluvial sandsheets containing antidunal forms and soft-sediment deformations, related to seasonal (i.e. flashy) discharge; and aeolian bedforms overlying thin stream-flow deposits.

An up-section increase in aeolian deposits is accompanied by the shrinking of fluvial bars and minor-channel cuts, suggesting that drainage was fractioned along smaller channels terminating into marginal aeolian environments. Together with a propensity towards more dispersed values of fluvial cross-set thickness up-section (again due to discharge fractionation along intermittently active channels), these features depict an aeolian-influenced fluvial fan. This work discusses a set of criteria for the identification of fluvial fans in pre-vegetation environments. In doing so, it also explores possible parallels to modern environments, and underscores the potential of integrated outcrop and remotely sensed observations on ancient fluvial rocks and modern sedimentary realms.

1. Introduction

The prominence of fluvial systems with distributary planform (*e.g.*, alluvial and fluvial fans) in the rock record is the subject of heated debate (Nichols and Fisher, 2007; North and Warwick, 2007; Weissmann et al., 2010; Fielding et al., 2012), and recent reviews concurred that more field-based evidence is required, particularly to test the models for large fluvial fans (Latrubesse, 2015; Weissmann et al., 2015). It is accepted that down-fan discharge partitioning along bifurcating channels produces distinctive trends, such as grain-size fining, channel-body shrinking, reduced channel-body interconnectivity, apparent shift towards more seasonal discharge, and change in palaeosol draining (Friend, 1978; DeCelles and Cavazza, 1999; Horton and DeCelles, 2001; Cain and Mountney, 2009; Ralph and Hesse, 2010; Weissmann et al., 2013; Owen et al., 2015a). These trends are well perceived in vegetated (i.e., late Palaeozoic and younger) fluvial systems characterised by well-defined channelization, significant amounts of mud in their floodplains, and well-developed palaesols (Davies and Gibling, 2010). By comparison, the recognition of some of these trends in pre-Silurian fluvial rocks is challenged by the mud-free nature of many terrestrial deposits (Went, 2005; Marconato et al., 2014), by the scarcity of channel forms at the outcrop scale (Eriksson et al., 1998; Long, 1978, 2011), and by the almost complete lack of pedogenic features related to biotic processes (Álvaro et al., 2003). These features have been ascribed to dominant physical over chemical alteration (Went, 2005; Davies et al., 2011), and lack of sediment binding by plants alongside mobile fluvial channels (Long, 2006, 2011). For these reasons, it still has to be tested whether the sedimentary models developed for post-Silurian fluvial fans apply to pre-vegetation ones. A number of Precambrian and early Palaeozoic terrestrial deposits have been interpreted as proximal distributive systems (i.e. alluvial fans; Williams, 1966, 2001; Went, 2005; Chakraborty et al., 2009; Chakraborty and Paul, 2014; Santos et al., 2014), while the proper recognition of larger and more mature fluvial fans remains limited (Eriksson and Vos, 1979; Eriksson et al., 2006).

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The main goal of this research is to discuss a set of criteria for the detection of fluvial fans in pre-vegetation environments. These criteria are based on sedimentologic and depositional-architectural analysis, at both outcrop and remote-sensing scales, of the Cambrian Alderney Sandstone Formation of Channel Islands, UK (Fig. 1A). The Alderney Sandstone Formation is regarded as a fine example of early Palaeozoic fluvial sedimentation (Todd and Went, 1991; Davies et al., 2011). Deposited in proximity to basement highlands, and confined within a post-orogenic basin of ~200 × 100 km, the formation is currently believed to represent a set of axial fluvial trunks sided by basin-margin systems (Went and Andrews, 1990; Davies et al., 2011). This work provides a partial reappraisal of the Alderney Sandstone Formation, emphasizing the volumetric importance of fluvial-fan deposits and describing aeolian facies not documented to date. This study demonstrates that pre-vegetation fluvial fans, despite lacking heterolithic alluvium and well-developed channelization, can be differentiated from axial fluvial trunks based on the distinctive up-section trends in degree of fluvial-aeolian interaction, fluvial-bar shrinking due to drainage fractionation, and increased dispersion of cross-set thickness values. Given the nature of the studied exposure (a gently folded monocline; Fig. 1), this study is particularly intended to contribute to the recognition of fluvial fans based solely on lateral and vertical facies trends, i.e. in those situations where inferences on basin-scale planform cannot be directly drawn (cf. Trendell et al., 2013; Owen et al., 2015b). Finally, although any analogy to modern or extra-terrestrial fluvial systems is challenging, potential parallels with modern fluvial-aeolian landscapes are explored, providing two partial analogues located in the deserts of Mexico and Turkmenistan.

2. Geological setting

A suite of lower Palaeozoic clastic successions are exposed at several locations in the Channel Islands (UK), and Brittany and Normandy (Northern France), attaining a maximum thickness of 800 m (Sutton and Watson, 1970; Pudsey, 1977; Laffoley, 1986; Went and Andrews, 1990; Doré, 1994). Regionally, these strata record depositional environments that include proximal alluvial fans and mature fluvial systems passing basinward into nearshore-marine realms (Todd and Went, 1991; Went, 2005, 2013). The successions bear broad resemblance with each other, and are believed to have accumulated in post-orogenic basins related to uplift and extension affecting the late Precambrian to early Cambrian Cadomian Orogen (D'Lemos et al., 1990). According to accepted reconstructions, the Cambrian post-orogenic palaeogeography of the area was characterised by degrading uplands located to the west of the present-day Channel Islands. A set of eastward-draining alluvial basins occupied areas of up to ~200 × 100 km each, and drained eastward over an area corresponding to the present-day Channel Islands and Brittany. An articulated, NNW–SSE-striking marine shoreline shifted across present-day Normandy, controlling at least in part the regional facies distribution (Went and Andrews, 1990).

The Alderney Sandstone Formation, together with its stratigraphically related deposits found elsewhere in the Cambrian of Channel Islands and northern France, represents one of the main records of terrestrial deposition in the area (Doré, 1994). The Alderney Sandstone Formation has its type-section along a continuous coastal exposure on eastern Alderney Island, where it consists of 500-m-thick deposits sitting on late Proterozoic granitoid basement (Todd and Went, 1991; Fig. 1B). Locally, well-developed palaeosol profiles and colluvial deposits mark the nonconformity (Went, 1991). The Alderney Sandstone Formation comprises in its lower portion a thin slope-derived to alluvial conglomerate (Cotil Breccia) that passes over a thickness of less than 10 m into pebbly arkosic and litharenititic sandstone of fluvial origin (Becquets Sandstone; Fig. 1B). A nearshore-marine quartzarenite (Bluestone Bay Sandstone; Fig. 1B) is also exposed along southern Alderney Island, and has been interpreted as a palaeo-topographically lower deposit also part of the Alderney Sandstone Formation (Went, 2013). These three lower members transition upward into a thick fluvial arkose and

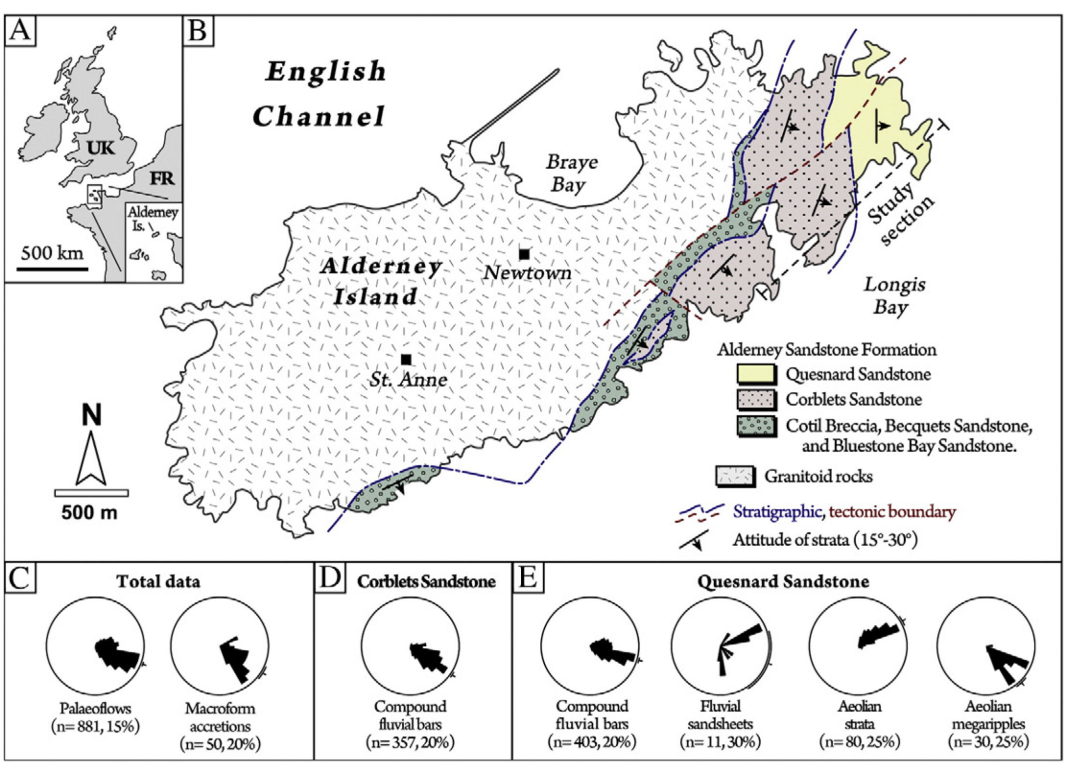

Fig. 1. Geographical and geological setting. A) Location of the study area. B) Geological sketch of Alderney Island, UK, modified from Went and Andrews (1990). C-E) Summary of palaeoflow and accretionary-surface data collected from the Corblets and Quesnard sandstones. Arcs indicate average vector and 95%-confidence intervals.