A Time-Slice of the Lake Eyre Basin: Towards Better Facies Models*

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Search and Discovery Article #10806 (2015)
Posted December 14, 2015

*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG/SEG International Conference & Exhibition, Melbourne, Australia, September 13-16, 2015, AAPG/SEG © 2015.

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Abstract

Understanding the processes governing sediment distribution is important for predicting reservoir, seal, and migration pathway properties. Cross-discipline collaborations across geomorphology and sedimentology can develop process-based facies models, which are adaptable to project-specific contexts (tectonic, climatic, provenance). Examples are given from Australia's Lake Eyre Basin, a presently underutilised modern analogue for fluvial processes in a dryland setting. The Lake Eyre Basin (LEB) catchment is arid to semi-arid, with extremely variable flow regimes. Drainage is centripetal towards Lake Eyre. The LEB is a continent-scale Australian intracratonic sag that overlies the Eromanga, Pedirka, Cooper, and Galilee Basins. Sediments have been accumulating since the Palaeocene; in the LEB's centre and inner north-west, where synsedimentary domal uplift and trough subsidence occurs, the Cainozoic attains thicknesses of 200->300 m. At the field and reservoir scale, the LEB hosts a variety of dissimilar river types, including anabranching and single-thread channels of low to high sinuosity, floodplains of sand or of mud, and bedloads of mud aggregates, sand or gravel. Within the rivers, there is a variety of landform suites related to flows moving from constricted to unconstricted settings. As geomorphic entities, they include 1) valleys with channel-floodplain suites, 2) floodouts (transition from channelized to unchannelised flow down-valley) and 3) distributary channel systems. As sedimentary packages, some will form valley- or basin-fill, and some will be low-angle alluvial fans. Few have been investigated from a sedimentologic viewpoint; others are better known from the geomorphic literature; many are undescribed. Their individual characteristics relate to differences in fluvial processes, sediment provenance, local base level, and post-pluvial history. Differences are expressed in different channel planform and bedload (sand body distribution and connectivity) and floodplain composition and creation (seal and migration barrier qualities). We will present examples from a range of these, in this initial collaboration between a basin-scale process geomorphologist and a reservoir-scale focused process sedimentologist, in the anticipation that this will enable the depositional systems within this large dryland basin to be explored in a new and useful light.

Introduction

Understanding the influences governing sediment distribution is important for predicting reservoir, seal, and migration pathway properties. Present-day geomorphology shows sediment content in, and spatial relationships between, landform elements. It also demonstrates the agents and processes that link landforms in causally-related systems, which operate across scales from macro to micro (basin and reservoir to outcrop and core). Process-based geomorphology can inform facies models, which are set within a process-based sequence stratigraphic hierarchy (e.g. Vakarelov and Ainsworth 2013). This paper presents key points of interest from an ongoing collaboration between a geomorphologist and a process sedimentologist in Australia's Lake Eyre Basin (LEB), a presently under-utilised modern analogue for fluvial and aeolian sedimentary deposits.

Chronostratigraphic Context

The Lake Eyre Basin is a continent-scale intracratonic sag that overlies the Eromanga, Pedirka, Cooper, and Galilee Basins. Located in the arid zone, the LEB’s catchments host drylands rivers with extremely variable flow regimes. The LEB’s surficial geology consists of sandy and/or muddy depositional lowlands (river valleys, lakes, and plains) fringed by and separated by erosional uplands (rocky uplands, alluvial fans, gibber plains, residual plains) (Figure 1).

As a time-slice (chronostratigraphic surface), the LEB is a regional-scale unconformity, exposed at surface in places, and elsewhere underlying up to ~300 m of sediments aged Palaeocene or younger (Figure 2). Crustal flexure lowering at the LEB depocentre (Lake Eyre-Kati Thanda) and ongoing domal uplift – synsedimentary subsidence in the Channel Country rivers are producing landforms whose sediments are in onlap, downlap, and basin-fill relationships with the underlying unconformity (Figure 2). Unfilled accommodation space exists at the basin depocentre, the wide river valleys, and parts of the sandplains.

The LEB is currently at lowstand, resulting from both late-Neogene depocentre shift and Holocene climate change. Rivers from the west and southwest (such as the Neales River and rivers draining into Belt Bay) (Amos et al. 2012) are incised-valley systems. The upstream Neales valley-floor grades to the Neales Delta surface and/or strata within it; the present Neales channel is incised into this surface, bypasses Neales Delta on its north side, and deposits its load at the Neales Terminal Splay Complex (Figure 3). River terminations around the Lake Eyre-Kati Thanda margin host terminal splay complexes whose geometries are analogous to deltaic and estuarine settings (Amos et al 2012), and whose sand geometries (Lang et al. 2004, Fisher et al. 2008) contribute to understanding sheet sandstones deposited in dryland fluvial environments. Sediments and bounding surfaces in the incised valleys and the in-embayment terminal splays are yet to be examined in the field.

Sand Deserts: Facies Change with Climate Change

The sandplains and dunefields of the Simpson, Tirari and Strzelecki Deserts are a complex patchwork of aeolian and fluvial sediment. The Channel Country rivers occupy interdune corridors, depositing mud-aggregates and quartzose fine sand and silt. The dune sand thicknesses vary but can be on the order of 10s of m, with greatest thicknesses along crests and in dune sets. Though dunes show some degree of previous northwards migration, generally, sediment transport has been only local and modern dunes are mostly stable. The sandplains arose during the Holocene’s increasing aridity: vast alluvial and post-lacustrine plains converted to aeolian landforms as surface sediments became mobile. Where sand cover is thinnest, the sandy palaeo-rivers’ scroll plains are visible beneath interdunes (Figure 4).

These areas pose interesting but presently unanswered questions. In the subsurface, there will be an upwards transition from fluvial to aeolian sediments, with potential migration paths between the underlying channel sands and the present day's dune sands. How meaningful is the erosion surface separating alluvium from aeolian sands if the sediment movement is only local, and/or if the disconformity is due to climate not base level change? How does this sit within the sequence stratigraphic theoretical framework? Would such a transition make a fuzzy or a patchy seismic reflector?

Cooper Creek and Diamantina River: Modern Analogues for Fluvial Massive Mudrocks

At the field and reservoir scale, the LEB hosts a variety of dissimilar river types, including anabranching and single-thread channels of low to high sinuosity, floodplains of sand or of mud, and bedloads of mud aggregates, sand or gravel. The landform elements of some of these fluvial styles are undescribed (e.g. the Georgina River channel, Figure 4), or documented in purely geomorphological literature in which facies relationships and sedimentological features are not explicitly addressed. The best-known LEB fluvial features are the mud-aggregate floodplains, which are prominent features of the Cooper and Diamantina Rivers. Observations and experimental work in the Cooper (e.g. Maroulis and Nanson 1996) have been used to interpret mudrock in the sedimentary record (e.g. Marriott and Wright 2004). The mud plains' physical properties indicate extremely low permeability, which together with their stratigraphic position (overlying a widespread quartz sand from the more high-energy palaeoriver) makes them an excellent reservoir-seal analogue.

However, whereas other modern analogues are documented in a large body of research, anabranching mud-aggregate rivers are relatively little known; they have great potential for providing further tools for mudrock interpretation and seal quality identification. Field observations include:

- though the floodplains present a braid-like appearance, depositional processes are unlikely to match braided-river qualities;
- as a sedimentary deposit, mud-aggregate deposits may be characterised by massive structure and semi-uniform lithology, in which depositional laminae are only patchily preserved
- nonetheless, channel and floodplain facies may be distinguishable by ichnofauna and palaeosols;
- grain-size trends do not relate to transport distance down the drainage network;
- as transport-limited systems, sand:mud ratios in channel bedload and floodplain sediment are more determined by a site's position with respect to valley margins and local base levels, and less determined by flow size or channel geometry.

Primary flow paths may (or may not) have substantial channels. The channels may (or may not) be flanked by levees or levee-like structures which are more sandy than the floodplain and can extend for 10s of km. The largest channel segments are the waterholes, which are incised through the floodplain muds and make intermittent permeable contact with the underlying sands. Controls on waterhole location are therefore key to understanding not only the present-day primary flow path, but also the places where permeable pathways exist between the layers.

An initial interpretation of such a system as it might present in the sedimentary record is as a largely massive mudrock, containing a sparse distribution of elongate sandy wings (Figure 5). Whether the mudrock is a seal, or alternatively contains windows for hydrocarbon migration (that is, if the sandy wings are hydraulically connected to the underlying sand layer) will depend on the channel fill, which will be governed by hinterland processes (amount and provenance of sediment supply). Quantitative spatial and textural studies are desirable to flesh out this picture.

LEB’s Distributary Rivers

The LEB’s rivers host a variety of landform suites related to flows moving from constricted to unconstricted settings. Few have been investigated from a sedimentological viewpoint; others are described in geomorphic literature; many are undescribed. Their individual characteristics relate to differences in fluvial processes, sediment provenance, local base level, and post-pluvial history. Differences are expressed in different channel planform and bedload (sand body distribution and connectivity) and floodplain composition and creation (seal and migration barrier qualities).

As geomorphic entities, the LEB’s distributary fluvial networks are either floodouts (down-valley transition from channelized to unchannelised flow) or distributary channel systems (drainage networks acting to disperse, rather than collect, flow) on low-angle alluvial fans. As sedimentary packages, some will form valley- or basin-fill, and some will be downlapping from a locally elevated base level onto a lower-elevation surface.

Of the several distributary systems present in the basin, this presentation presents results from geomorphological studies in the Finke River Floodout Complex and the Cooper Creek Fan (Wakelin-King 2013, 2015). Quantitative spatial and sedimentological investigations would be a desirable next step in this research.

The Finke River Floodout Complex is the terminus of the Finke River. Its headwaters in central Australia provide abundant bedload of quartz sand; its fluvial style is that of a sand-bed river, with limited sinuosity, sandy channels with a high width:depth ratios, and sandy and silty floodplains. The proximal floodout is a simple bifurcating channel dumping sand in unfilled accommodation space. The distal floodout has a more complex relationship with dunes and interdune corridors in the margins of the Simpson Desert.

The Cooper Creek Fan has its apex in the uplifting Innamincka Dome. The present-day channel supports offtake channels, and terminates in the split between the Cooper North West Branch and the Cooper Main Branch. Geomorphological and hydrological investigations demonstrate the long-term stability of the channel network, and the truly coexisting nature of the flow distribution. Sand body geometry is complex: the fluvial deposits include megaflood outwash, levees, and offtake deposits, while the channels and the palaeochannels have co-developed with the Strzelecki Plain’s compound dunes (Figure 6).

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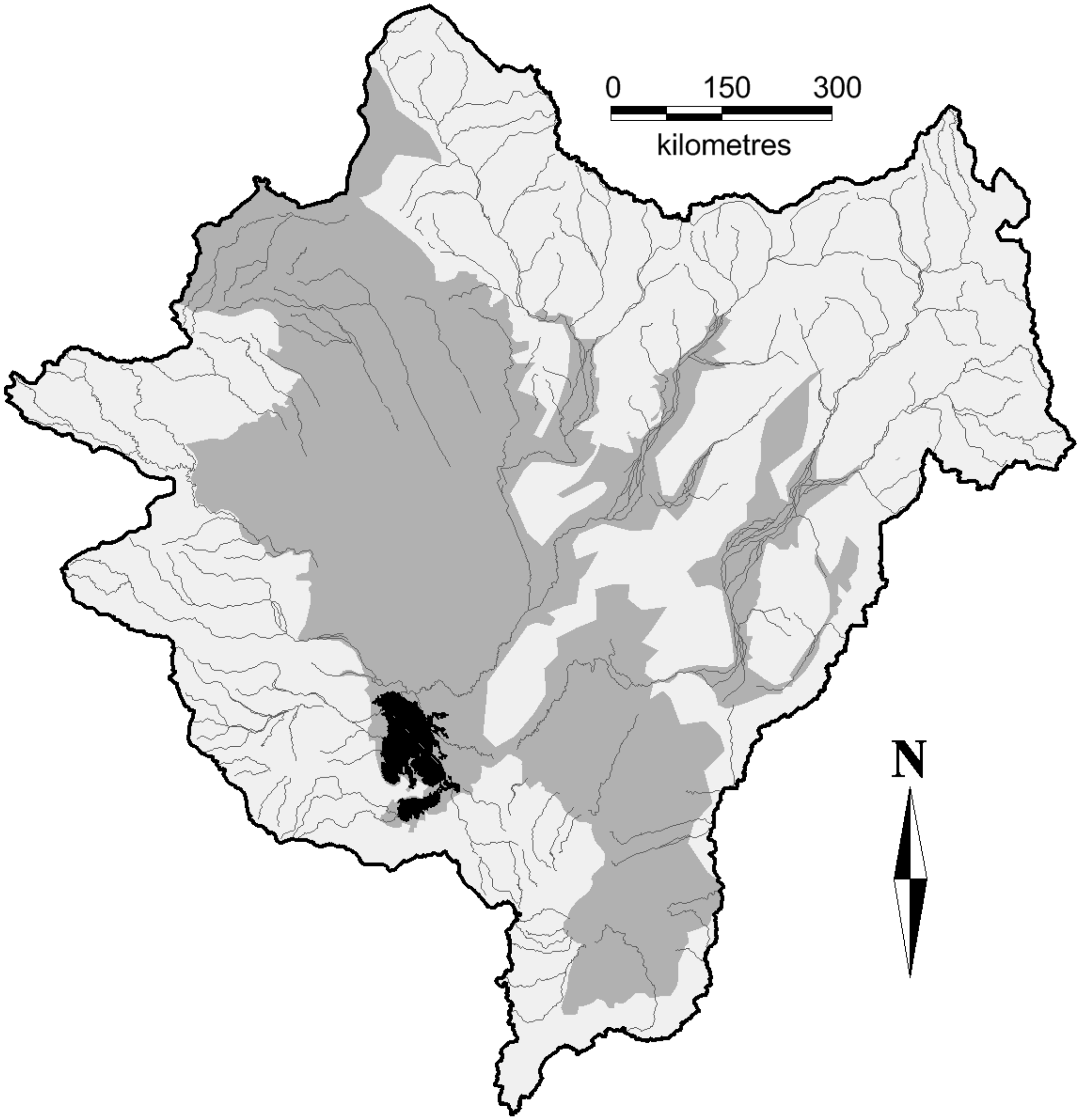

Figure 1. The Lake Eyre Basin. Black, Lake Eyre – Kati Thanda; pale grey, erosional or non-depositional surfaces; dark grey, depostional surfaces; grey lines, drainage. A-A’, see Figure 2.

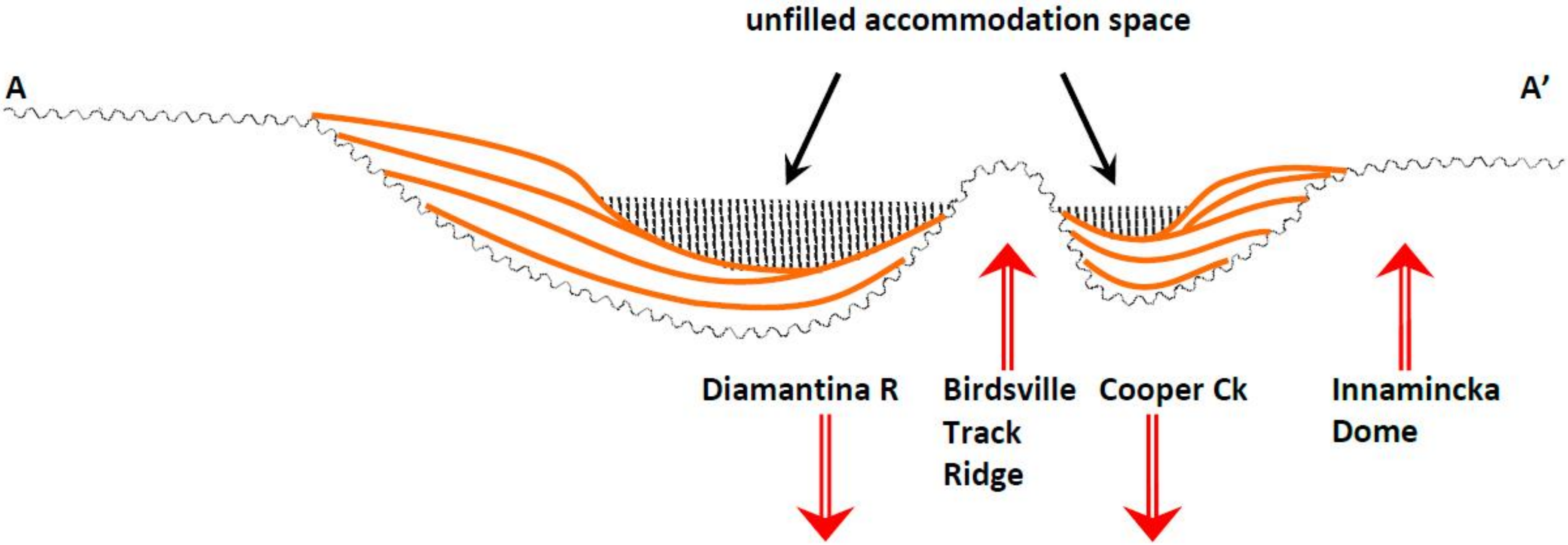

Figure 2. Schematic cross-section of the LEB (not to scale). See Figure 1. for location.

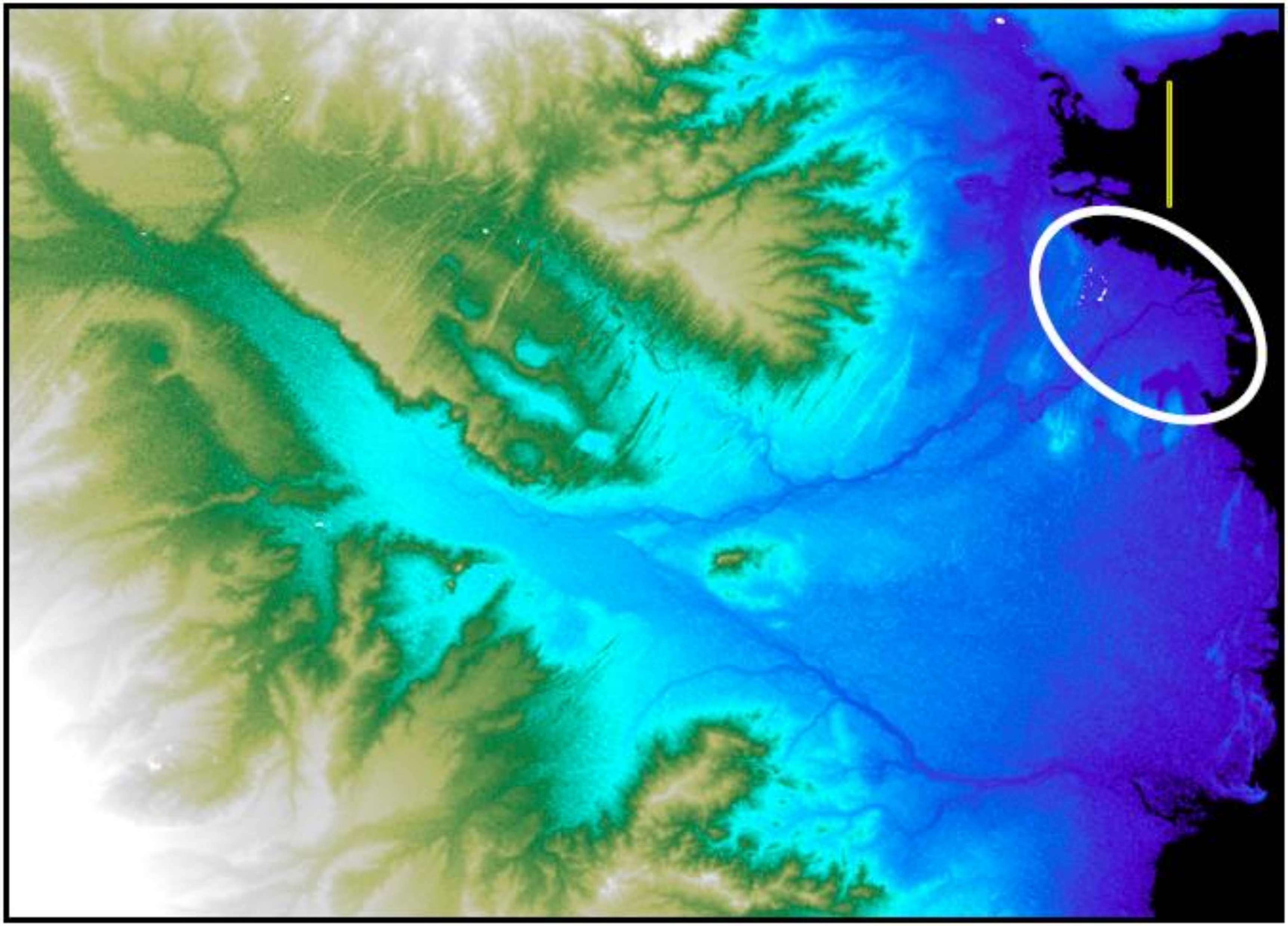

Figure 3. The incised Neales valley and its delta (3-sec SRTM DEM). The present-day channel bypasses the Neales Delta along its northern arm, depositing its sediments on the playa floor in the Terminal Splay Complex (circled in white). Yellow scale bar = 10 km.

Figure 4. The Georgina River. Between the orange longitudinal dunes, grey interdunes show underlying palaeochannels (white ribbons). Interdunes receiving present-day pale fluvial sands are the pale colour (top centre), main channel is on image right. Image is ~12km wide.

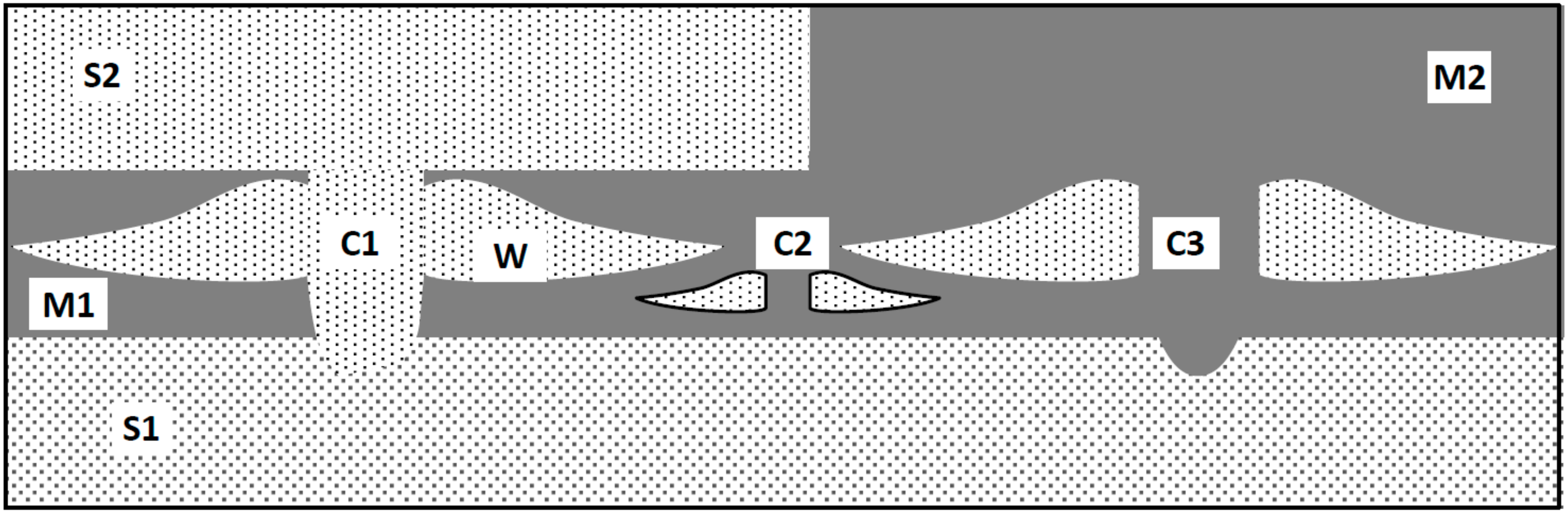

Figure 5. Valley cross-section of an hypothetical sedimentary deposit resulting from processes found in Cooper Creek and Diamantina River. Within massive mudrock (M) and flanked by wings (W) of sandy sediment, channels of large waterholes (C1, C3) incise into an underlying sand layer (S1). A smaller waterhole (C2) does not penetrate so deeply. Connectivity between the inderlying sand layer and the sandy wings within the mudstone depends on the eventual channel fill.

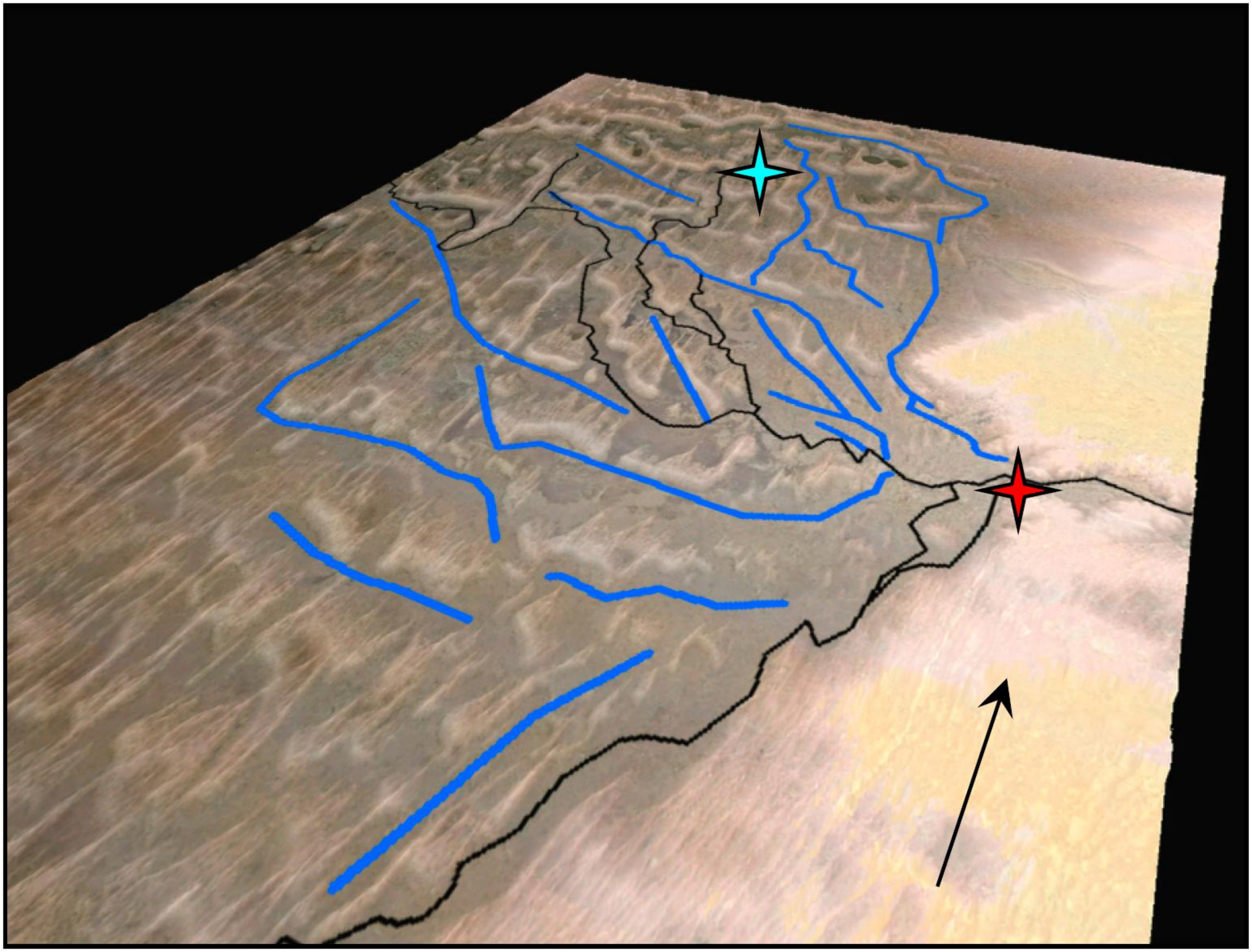

Figure 6. Oblique 3D view over the Cooper Creek Fan. Black lines: the largest of the present-day Cooper and Strzelecki Creek channels; blue lines: palaeodrainages. Scale arrow is 30 km long and points north; red star is Innamincka township, blue star is the Coongie Lakes. The image is a grey-to-white DEM overlain by a semi-transparent orthophoto.