Transcontinental Cainozoic paleovalleys of Western Australia

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SUMMARY

800-2400 km long transcontinental paleovalleys straddle the modern landscape of Western Australia (WA). These valleys formed following emergence of the Canning Basin at the end of the Lower Cretaceous, and reached their greatest development during Eocene time. They owe their preservation to limited erosion/burial and to an overall drying climate since the Upper Cretaceous. They represent the largest network of inactive valleys visible at the Earth's surface.

These valleys debouch at their downstream ends into well-dated depocentres and paleo-shorelines, which provide age constraints and firm milestones of their temporal and spatial evolution. Drainage network evolution and valley long profiles constrain the timing of long (~1000 km) to intermediate wavelength (~200 km) variations in uplift and subsidence rates over the continental interior. We use these data to decipher the respective contributions of regional tectonics and dynamic topography to the evolution of the Northwest Shelf. Upon emergence uplift determined the shape of the initial drainage that started to drain the emerging landmass. Later, a changing field of surface uplift triggered drainage rearrangements in the early Cenozoic. Rearrangement resulted in piecemeal rerouting of water and sediments towards the North West Shelf.

Increasing aridity during the Neogene contributed to the tectonic defeat of some of these rivers. We use the *Badlands* surface model developed by the Basin Genesis Hub to quantify sediment and water delivery to the North West Shelf during the lifespan of the drainage. Further, there is some debate regarding the chronology of aridification in the continental interior. We use the modelling to derive the first quantitative estimates of the water balance to see if numeric water balance assessments can reconcile discrepant sets of paleoclimatic proxies.

Key words: Tectonics, Drainage evolution, Western Australia, Sediment routing, Paleovalleys, Water Balance

MOTIVATION

A network of long paleovalleys (Figure 1) is preserved in the arid continental interior of Western Australia and conterminous states (van de Graaf, 1977). Before drying out this drainage delivered water, dissolved and particulate sediments to the North West Shelf (NSW) and the Great Australian Bight (GAB). Part of this drainage network predates the Cretaceous, especially on the Yilgarn Craton (de Broekert and Sandiford, 2005). Most of the drainage was laid out during the emergence of the Canning-Officer basin ~ 110 Ma ago (Frakes et al., 1987). Protracted slow uplift within a context of large amplitude eustatic sea level variations subsequently drove incision of this drainage within the underlying sediments and basement rocks. Spatial variations in surface uplift induced some limited drainage reorganization. Incision and reorganization determined the fluxes of terrigenous sediments delivered to the NWS and the GAB. Aridification of the continental interior initiated between the Late Eocene and the Late Miocene (Martin, 2006; McLaren et al., 2014) inducing a decrease in terrigenous sediment and freshwater delivery to the shelves, with sediment retention on land, before complete drying of the valleys in the Late Pliocene to Early Quaternary (Chen and Barton, 1991; Dodson and Macphail, 2004; English et al., 2001; Zheng et al., 1998). This evolution thereby influenced the formation of potential hydrocarbons traps and seals in the Cenozoic series on the shelves (Romine et al., 1997; Sit et al., 1994), the accumulation of heavy mineral placers along paleoshorelines and paleovalleys (Hou et al., 2003; Hou et al., 2008), and the retention of dissolved uranium in phreatic calcretes in drying valley floors (Jaireth et al., 2010). Besides, increased dominance of groundwater over surface routing in the context of an almost passively deforming surface has probably changed groundwater redistribution across the continental interior.

We use here numerical modelling of landscape evolution to inform poorly understood aspects of this evolution. First, although the drying out induced a decrease in terrigenous fluxes to the shelves, this overall trend has been punctuated by pulses of siliciclastic discharges along the NWS (for example Paleocene reservoir sandstones, Miocene Bare Fm. (Bourget et al., 2014; Sanchez et al., 2012)), tentatively ascribed to erosional reworking of upper shelf sediments during lowstands, or to changes in the natural land cover (Sanchez et al., 2012; Sit et al., 1994). Second, the chronology of aridification remains very loosely constrained (Martin, 2006; McLaren et al., 2014), due, 1) to inconsistencies in the age of the dated records (Clarke, 1994b; Zheng et al., 1998), 2) to the use of different proxies such as pollens, foraminifera (McGowran et al., 2004), lake water balance (English et al., 2001), water table lowering (Heim et al., 2006), 3) to the fact that aridification was far from synchronous across the interior (Martin, 2006), and 4) because the water balance and distribution of species was sensitive to topography and extent of feeding areas and therefore varied from (English et al., 2001). Some of these discrepancies maybe partly explained and reconciled using a model able to integrate these variables across space and time.

The Basin Genesis Hub at the University of Sydney has developed *Badlands*, a surface process model that simulates the evolution of topography and river drainages under the effects of uplift and precipitation, coupled to sediment deposition offshore. This open-source software is versatile and amenable to the incorporation of modules aimed at investigating the effects of specific processes of landscape evolution. Study of the paleovalleys of WA is part of an effort to adapt *Badlands* to semi-arid landscapes, where evapotranspiration and hyporheic exchanges with the water table significantly affect water and sediment routing. *Badlands* has previously been used to explore the potential effects of dynamic topography on the evolution of drainage in the Great Artesian Basin (Salles et al., 2017), and the routing of alluvial iron across the Pilbara Craton (Duclaux et al., 2013).

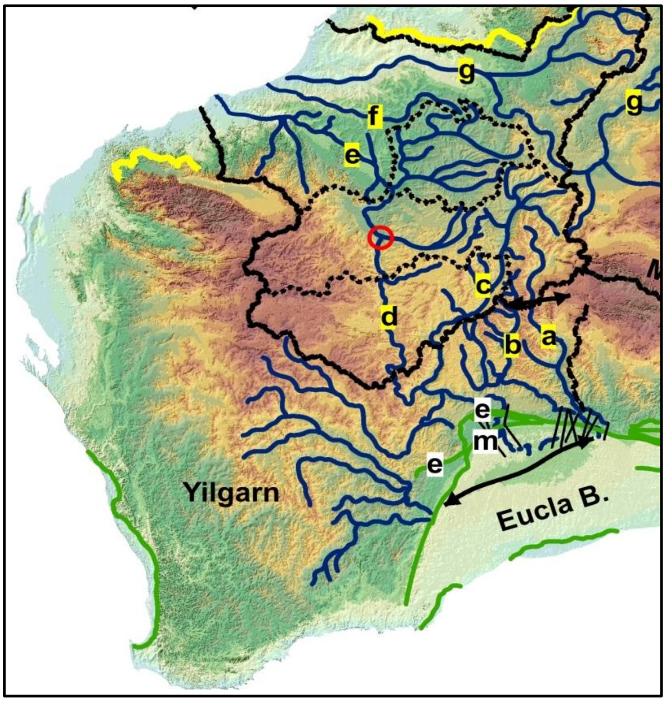

Figure 1: Map of the inactive network of drainage lines in Western Australia and conterminous states.

Blue: studied drainage lines. Green: Middle Eocene (e) and Middle Miocene (m) shorelines in the GAB. Yellow: front of a wave of landscape dissection affecting the coastal areas of the NWS. Black doted: successive position of the topographic divide between the NWS and the GAB, indicating a progressive expansion of the NWS drainage at the expenses of the GAB drainage. Red circle: river diversion.

Paleovalleys:
a: Kadgo
b: Baker
c: Throssel
d: Disappointment
e: Percival
f: Prescott
g:Mackay

IMPLEMENTATION

The recent age of endorheism development, limited sediment influxes over the period, and limited aeolian reworking altogether explain the preservation of paleovalleys in the topography of Western Australia (Alley et al., 2009; Beard, 2002; Beard, 1973; Bunting et al., 1973; de Broekert and Sandiford, 2005; Hou et al., 2008; Sandiford et al., 2009; van de Graaf, 1977). Analysis of the drainage pattern indicates that the network of flow lines has remained stable since its formation during the Albian emergence, with only sporadic changes in the connectivity of flow lines due to river diversions. This considerably reduces uncertainties in the landscape evolution modelling, which can focus on the exploration of the hydraulic parameters conducive to the observed chronology of incision and deposition in the paleovalleys, under testable climatic and tectonic boundary conditions.

Implementation of the model comprises two main steps. First, we simulate drainage incision during the period of highly positive water balance (110 – 43 Ma), under the effect of lowering fluctuating sea level and slow generalized surface uplift (average of 3.8 m/My). Total river incision during this phase is determined based on topographic and stratigraphic observations (see following section). This first phase of modelling is aimed at constraining basic parameters of the model, such as the erodibility of the sediment cover (Carboniferous, Permian, and Cretaceous sediments of the Canning and Officer basins) and that of the underlying basement rocks.

In a second step we implement algorithms to simulate water evaporation and hyporheic infiltration along the drainage network. The goal is to explore the consequences of a diminishing water balance (gains minus losses) on river incision, sediment deposition, and the size of lakes produced over time (Figure 2). This step is constrained 1) by various independent environmental proxies of precipitation and temperature (Gallagher et al., 2014; Martin, 2006; McGowran et al., 2004; McLaren et al., 2014), 2) by the erosional response of rivers to post Middle Miocene tectonic deformation (Bunting et al., 1973; Cope, 1974; McGowran et al., 2004; Müller et al., 2012; Sandiford and Quigley, 2009; Whitney et al., 2016) and erosional shoreline formation during the Middle

Miocene north of the GAB (Hou et al., 2003; Hou et al., 2008), inferred from the present-day topography (see following section), 3) by the amount of sediment stored within valleys (Alley et al., 2009; Beard, 2002; Clarke, 1994a; de Broekert and Sandiford, 2005; Jones, 1990), and 4) by the evolution of lake salinity (Clarke, 1994b; English et al., 2001; Zheng et al., 1998).

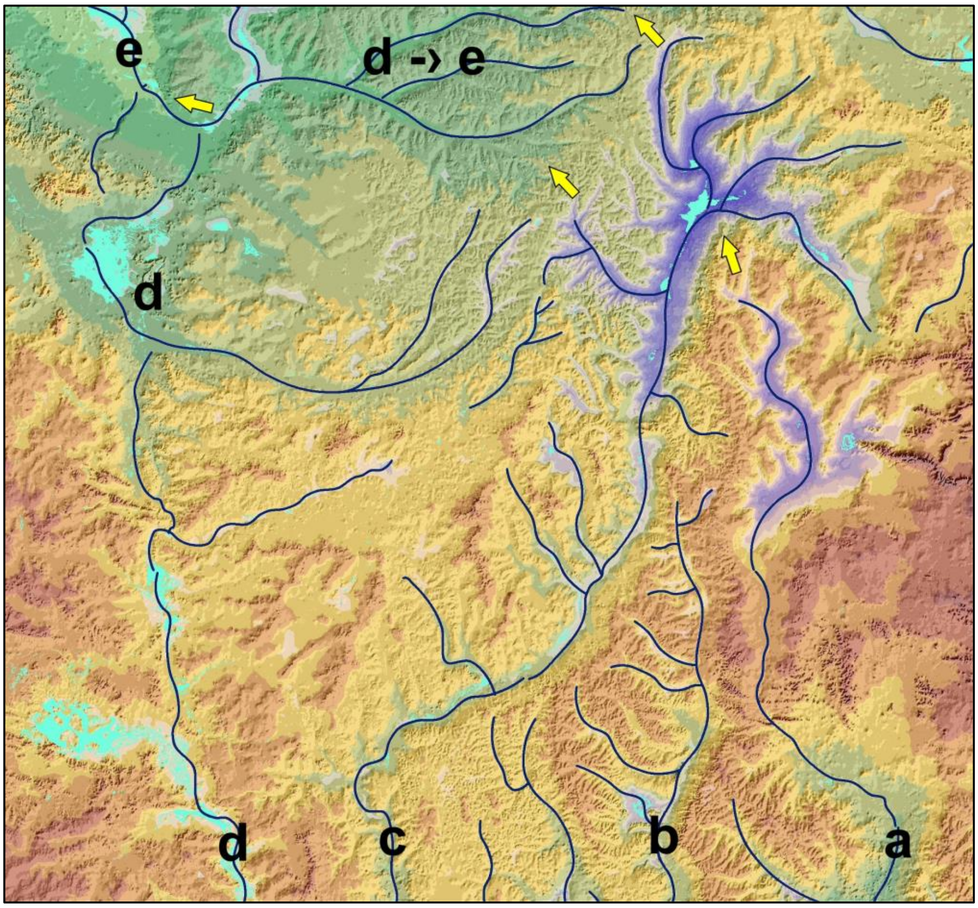

Figure 2: Topography of the upper reaches of paleovalleys a, b, c, d, showing ancient drainage lines (dark blue) and modern playa lakes (light blue). If water balance was positive, the upper catchments of a, b, and c would be filled by extensive lakes (intermediate shades of blue) due to tectonic backtilting of the valleys. The lakes would then eventually spill over their NW watersheds (yellow arrows), instead of resuming flow along the paleovalleys, due to the valley floors now standing higher than the interfluves upstream. Their overspilling would create a cascade of drainage reorganization, eventually integrating the drainage of the NWS. Since no breached interfluve nor high standing paleoshorelines are to be found in the area, it is likely that significant drying had occurred before the valley floors got back tilted. A possible exception to this is found in the continuous valley corridor that runs along the Yilgarn craton (d), which connects to the north to the Percival paleovalley (e). It seems that backtilting is responsible for the former headwaters of (d), being rerouted into (e).

GEOMORPHOLOGIC SIGNATURE OF ARIDIFICATION

In addition to published proxies of climate change (see above), we try to find a combination of parameters (climate and tectonic uplift) able to reproduce some of the consequences of climatic and tectonic forcing on the shaping of paleovalleys. During the period of highly positive water balance (110-45 Ma), erodibility is calibrated using a minimum estimate of the amount of total incision, which corresponds to the present depth local relief, from valley floors to nearest interfluves. Accordance of elevations along the interfluves indicates that little dissection has taken place on ridgelines, which have therefore experienced areal diffuse erosion which in the Australian interior typically occurs at rates of 2-5 m/My (Fujioka et al., 2014; Kohn et al., 2002; Nott and Roberts, 1996; Struck et al., 2015). The paleovalleys experienced systematic sediment filling in the Middle Eocene (Alley et al., 2009; de Broekert and Sandiford, 2005). Correcting for interfluve erosion and valley alluviation provides an upper estimate of total incision.

Inspection of paleovalleys long profiles provides additional constraints on river water balance and erosive power evolution (Fig. 3). Valleys debouching in the GAB are graded to the base of an Eocene erosional shoreline, and filled by estuarine deposits. It has been suspected that some paleovalleys continue below the former shore platform below the base of the erosional shorelines (de Broekert and Sandiford, 2005; Jones, 1990). Another erosional shoreline formed during a Middle Miocene highstand, set lower than the Eocene erosional shoreline due to 60 m of surface uplift occurring during the interval. By then however, the rivers had lost their erosive profiles and did not grade their profile to the retreating erosional shorelines. Farther upstream, the rivers had to overcome the rise of long wavelength (~ 1,000 km) and shorter wavelength (~200 km) deformation. Similar deformation of the interfluves and valley floors reveal that the rivers did not incise most of the structure rising across their course, nor alluviated significantly upstream. As a result the paleovalleys have developed upstream-facing slopes. Deformation of the Middle Miocene Nullarbor plain suggests that at least the short wavelength deformation postdates the Middle Miocene, like most of the intraplate contractional deformation in Australia (Jansen et al., 2013; McGowran et al., 2004; Whitney et al., 2016). The hanging character of the valleys over the Middle Miocene sea cliff, and absence of significant incision across rising structures indicate that the rivers had lost most of their erosive power. Assuming that aeolian deflation has remained limited over the Quaternary, it also seems that little alluviation, whether fluvial or/and lacustrine, has taken place upstream of the rising structures.

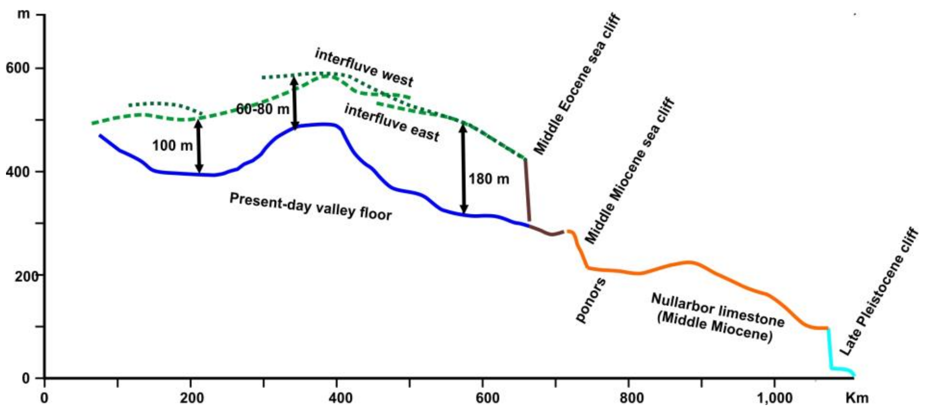

Figure3: Sketch north-south projection of the Kadgo paleovalley, showing the valley floor (blue), and surrounding interfluves (green). The valley is incised essentially in Cretaceous and Permo-Carboniferous sediments, with scattered outcrops of Cryogenian quartzite and other basement rocks within the central rise.

The absence of breached interfluves along the valley sides further indicates that no exoreic drainage existed from the moment the valley floor rose higher than the upstream interfluve, and probably before. The absence of any conspicuous paleoshorelines on the valley sides above the present-day elevation of the playa lakes further suggests that either shorelines have been eroded or buried, or that no large endoreic lakes ever occupied these valleys upstream of the rising structures, implying either a very early drying of the paleovalleys, or very recent, Quaternary tectonic deformation.

CONCLUSIONS

The dried continental valleys of Western Australia retain the hallmarks of their progressive aridification. Their evolution starts by wet conditions from 110 Ma until at least 45 Ma, allowing rivers to keep pace with uplift and subsidence by widespread incision and alluviation. Alluviation within the valleys starts in the Middle Eocene, to some extent in response to more limited transport capacity, and may explain the dominance of carbonates along the NWS during the Oligocene. Delivery of clastic sediments to the NWS during the Early Middle Miocene may be a consequence of changes in vegetation in the continental interior, or of drainage reorganizations due to long-wavelength deformation of the continent. Aridification was already quite advanced by the Middle-Late Miocene, as rivers became unable to keep pace with changes in sea level, or to incise rising tectonic structures. In the absence of significant alluviation upstream of the rising structures, it appears that sediment transport capacity has also diminished significantly. It also seems that the water balance was already generally low, as no large lakes seem to have ever flooded these valleys. These observations suggest that aridification was already well advanced, at least in some part of the continental interior, well before the Quaternary, and possibly as early as the Middle Miocene

The modelling will try to determine whether the different proxies of aridification can be reconciled through an exploration of the effects of environmental variables (climate and tectonics) on landscape evolution, sediment fluxes, and water routing.

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