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Submarine origin for the Neoproterozoic Wonoka canyons, South Australia

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ABSTRACT

An examination of the deeply incised Ediacaran Wonoka canyons in the Adelaide Geosyncline (most recently interpreted as subaerial valleys) demonstrates their submarine origin, and confirms them as some of the best examples of ancient outcropping submarine canyons in the world. The entire canyon-fill succession is interpreted to be of deep-water (below wave base) origin, consisting of calcareous shale and siltstone together with a variety of mass-flow deposits including turbidites, grain flows and debris flows. The canyon fill lacks definitive shallow-water structures (e.g. mud cracks, fenestral fabrics or wave ripples) at all stratigraphic levels. Canyon-lining carbonate crusts that have previously been interpreted as non-marine calcretes or tufas (and used to suggest a non-marine origin for the canyons) are argued to be of deep-water, marine, microbial origin. Extremely negative carbon isotope values from the canyon-fill and canyon-lining crusts have a primary marine origin. Previously interpreted deepening upward trends in the canyon fill (used as evidence of a subaerial erosion episode followed by drowning) are suggested to be fining upward trends, caused by the transition from canyon cutting to canyon filling, with the majority of the fill being of deep-water slope origin. The basal conglomeratic canyon-fill sediments represent the last vestiges of the high-energy, deep-water, canyon-erosion environment in which the incisions formed. A deep-water origin for the canyons is consistent with all previous stratigraphic observations of the Wonoka canyons, including the conspicuous lack of regional unconformities in the lower Wonoka Formation, and their emanation from the deep-water facies of the Wonoka Formation. A submarine canyon origin also removes the need for extreme (~1 km) relative sea level fluctuation and associated problems (i.e. an enclosed basin with Messinian-style evaporative drawdown or thermal uplift above a migrating mantle plume) required by the subaerial valley hypotheses.

1. Introduction

Recognition of ancient submarine canyons in outcrop is uncommon despite the abundance of submarine canyons found along continental margins today, thus begging the question: are submarine canyons less common in ancient settings than they are today; or is there a problem with the recognition of such features in outcrop? The fact that ancient submarine canyons are an almost ubiquitous feature seen in seismic data for Cenozoic successions strongly supports the latter interpretation. A related issue surrounding the interpretation of ancient canyon systems that are recognised in the sedimentary record has been their interpretation as either submarine or subaerial incisions. Debates over the subaerial vs submarine origin for canyons in general, are allied to sequence stratigraphic concepts and the interpretation of deep-water successions. Researchers have commonly interpreted submarine canyons as sequence boundaries, with the implication that submarine erosional events relate to low stands and may have had a component of subaerial incision (Posamentier and Vail, 1988; Feary and Loutit, 1998; Fulthorpe et al., 2000). However, there is much evidence to suggest that submarine canyons can form entirely within the deep-water realm and are not at all related to subaerial valley formation (Pratson and Coakley, 1996; Bertoni and Cartwright, 2005). If there is a genetic link at all between low stands and submarine canyons, it is likely to be indirect and related only to sediment supply on the slope (Bertoni and Cartwright, 2005).

Arguments about the origin of well-exposed, deep (>1 km) incisions present in the Ediacaran Wonoka Formation of the Adelaide Geosyncline in South Australia are typical of such debates. These canyons were first interpreted as being of marine origin (Coats, 1964; von der Borch et al., 1982; von der Borch and Grady, 1984; von der Borch et al., 1985) and later re-interpreted as subaerial, incised valley systems (Eickhoff et al., 1988; von der Borch et al., 1989; Christie-Blick et al., 1990). Since the Wonoka canyons are some of the best exposed ancient canyon systems in the world, determination of their submarine or subaerial origin is of great significance and may shed light on the greater problem of interpreting erosional features within deep-water successions.

To add to the significance of the Wonoka canyons, their associated carbonate deposits exhibit what is probably the largest negative

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carbon isotope excursion in earth history (Le Guerroué et al., 2006a,b). The unusually negative carbon isotopic values of the canyon-associated carbonates have played a large role in arguments concerning the origin of the canyons (e.g. that the carbonates are of non-marine origin, Eickhoff et al., 1988; von der Borch et al., 1989; Christie-Blick et al., 1990). However, recent research has led to the suggestion that the 'Wonoka isotope anomaly' may represent a global geochemical event, possibly related to the ~580 Ma Gaskiers Glaciation (Halverson et al., 2005). Clearly, it is important that the origin and setting of canyon formation be determined in order to better understand the negative carbon isotope values and their significance in relation to the global Neoproterozoic carbon cycle.

Deep incisions emanate from the lower Wonoka Formation and outcrop at several localities across the Adelaide Geosyncline (Fig. 1). Initial theories of canyon incision involved large-scale slumping and submarine erosion (Coats, 1964; von der Borch et al., 1982; von der Borch and Grady, 1984; von der Borch et al., 1985) or lithospheric extension (Jenkins, 1990). The submarine hypothesis was then refuted by two conflicting scenarios for subaerial erosion (Eickhoff et al., 1988; von der Borch et al., 1989; Christie-Blick et al., 1990; Williams and Gostin, 2000; Christie-Blick, 2001; Williams and Gostin, 2001).

In support of a submarine canyon origin, von der Borch et al. (1982) described features indicative of deep-water slope deposition. These included mass-flow deposits, turbidites with prominent climbing ripples and flute casts, channelised sands, and slumped sediments. In contrast, Eickhoff et al. (1988) and von der Borch et al. (1989) later suggested that the Wonoka canyons represented subaerially eroded valleys that were filled during coastal onlap. These authors argued that much of the canyon-fill was of shallow-water origin. Shallow-water indicators were suggested to include a lack of mass-flow deposits, and the presence of wave and tidally influenced features. A major and obvious problem for the subaerial valley hypothesis was the requirement for a kilometer-scale relative sea level change to allow the incision of kilometer-deep canyons. Two mechanisms suggested as potential causes of such large sea level change were regional uplift (Eickhoff et al., 1988; von der Borch et al., 1989; Christie-Blick et al., 1990; Williams and Gostin, 2000, 2001) and Messinian-style evaporative drawdown in an

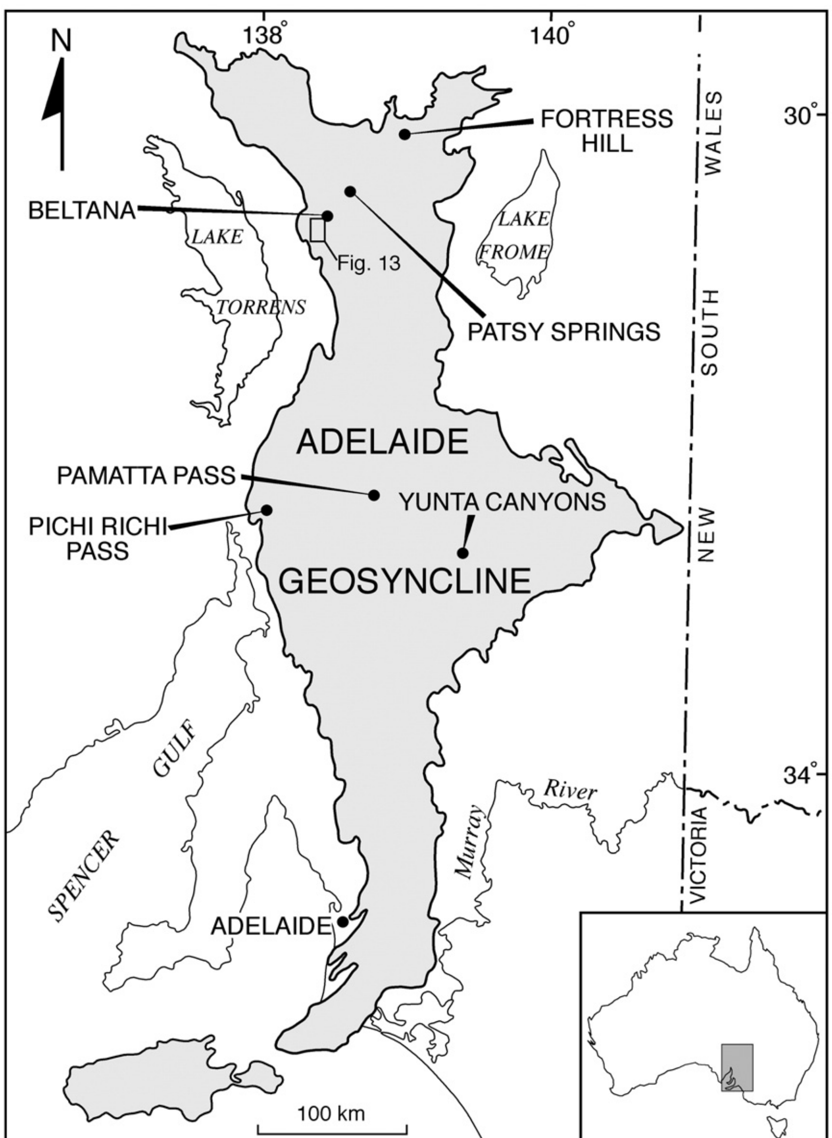

Fig. 1. Location map for the Adelaide Geosyncline. The locations of the five canyons examined in this study (Fortress Hill, Patsy Springs, Pamatta Pass, Pichi Richi Pass, Beltana) are also shown. There are also canyon exposures near Yunta (Yunta Canyon).