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Karst pocket valleys and their implications on Pliocene–Quaternary hydrology and climate: Examples from the Nullarbor Plain, southern Australia

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ABSTRACT

Karst on the Nullarbor Plain has been studied and described in detail in the past, but it lacked the determination of the karst discharge and palaeo-watertable levels that would explain the palaeohydrological regime in this area. This study explores the existence of previously unrecognised features in this area – karst pocket valleys – and gives a review on pocket valleys worldwide. Initial GIS analyses were followed up by detailed field work, sampling, mapping and measuring of morphological, geological, and hydrological characteristics of representative valleys on the Wylie and Hampton scarps of the Nullarbor Plain. Rock and sand samples were examined for mineralogy, texture and grain size, and a U–Pb dating of a speleothem from a cave within a pocket valley enabled the establishment of a time frame of the pocket valleys formation and its palaeoenvironmental implications. The pocket valleys document the hydrological evolution of the Nullarbor karst system and the Neogene–Pleistocene palaeoclimatic evolution of the southern hemisphere. A review of pocket valleys in different climatic and geological settings suggests that their basic characteristics remain the same, and their often overlooked utility as environmental indicators can be used for further palaeoenvironmental studies. The main period of intensive karstification and widening of hydrologically active underground conduits is placed into the wetter climates of the Pliocene epoch. Subsequent drier climates and lowering of the watertable that followed sea-level retreat in the Quaternary resulted in formation of the pocket valleys (gravitational undermining, slumping, exudation and collapse), which, combined with periodic heavy rainfall events and discharge due to impeded drainage, caused the retreat of the pocket valleys from the edge of escarpments.

Contents

1. Introduction

Solution of limestone and underground drainage, all strongly related to climate, are defining characteristics of karst landscapes; in addition,

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development of karst (karstification) influences topography and hydrology (Ford and Williams, 2007). Numerous detailed studies of karst features worldwide, especially cave deposits, have thus been used to provide an insight into landscape evolution, palaeohydrology and palaeoclimate (e.g., Wright, 1988; Ayliffe et al., 1998; Williams et al., 1999; Auler et al., 2009; Kenny, 2010; Lipar and Webb, 2015). Karst pocket valleys, however, have received relatively little attention in the scientific literature, and their utilities as tools for landscape and palaeoclimate interpretation are less well appreciated (Audra et al., 2004; Mocochain et al., 2011; Stepišnik et al., 2012).

Detailed descriptions of the karst features on the Nullarbor Plain and its aquifer have been published (Lowry, 1968; Hunt, 1970; Webb and James, 2006; Doerr et al., 2012; Miller et al., 2012; Burnett et al., 2013), but these have not accurately determined the karst discharge and related palaeo-watertable levels that would explain the palaeohydrological regime in this area. The key findings of this paper are the occurrences of previously unrecognised small steep-headed valleys with amphitheatre-like shapes along the stretch of the Wylie and Hampton scarps (Fig. 1), recognised herein as karst pocket valleys (Gunn, 2004; Ford and Williams, 2007). Their discovery, and a comparison to the worldwide occurrence of pocket valleys, contributes to the overall understanding of the karst of the Nullarbor Plain by explaining the locations of the outflow from this vast underground palaeo-discharge system in the past. Advances in U–Pb dating techniques allowed us to determine the time frame of the pocket valley formation. This information provided an additional valuable source of data that allowed the palaeoenvironment of the Nullarbor Plain to be reconstructed in aspects of palaeohydrological evolution of the Nullarbor karst system and the Neogene–Pleistocene palaeoclimate in the southern hemisphere.

2. Regional setting

The Nullarbor Plain (Fig. 1A) is one of the world's largest limestone outcrops and covers an area of more than 200,000 km^2, stretching from the Great Victoria Desert in the north towards the Great Australian Bight in the south where it ends abruptly with 40 to 90 m high cliffs. The two low-lying areas of the Israelite and Roe plains were formed during the cliff retreat as a result of coastal erosion in the Pliocene (James et al., 2006), rising from sea level to ~30 and ~40 m inland, respectively. The former coastal cliffs were abandoned when the sea withdrew, forming the Wylie and Hampton scarps (Fig. 1), which stretch for about 100 and 300 km, respectively, and have a general relief of about 50 to 100 m. The rest of the Nullarbor Plain represents a vast area with relief less than 10 m (Gillieson et al., 1994), divided into extensive clay-floored depressions and low rocky ridges (Gillieson et al., 1994; Webb and James, 2006).

At present the Nullarbor Plain has a semi-arid climate (Köppen BWk and BWh; Gillieson et al., 1994) with precipitation decreasing from the semi-arid coastal region (~400 mm per year) towards the very arid north with less than 150 mm rainfall per year. Potential evaporation increases from ~2000 mm near the coast to ~3000 mm inland (Bureau of Meteorology, 2014).

The Plain is underlain by a series of Cenozoic limestones, deposited in the Eucla Basin and composed predominantly of sand-sized fragments of calcareous bioclasts, with three distinctive formations:

- the white to grey, soft, poorly lithified, muddy to chalky bryozoan-rich middle to late Eocene Wilson Bluff Limestone, deposited in temperate water conditions on a drowned carbonate platform or ramp, and with

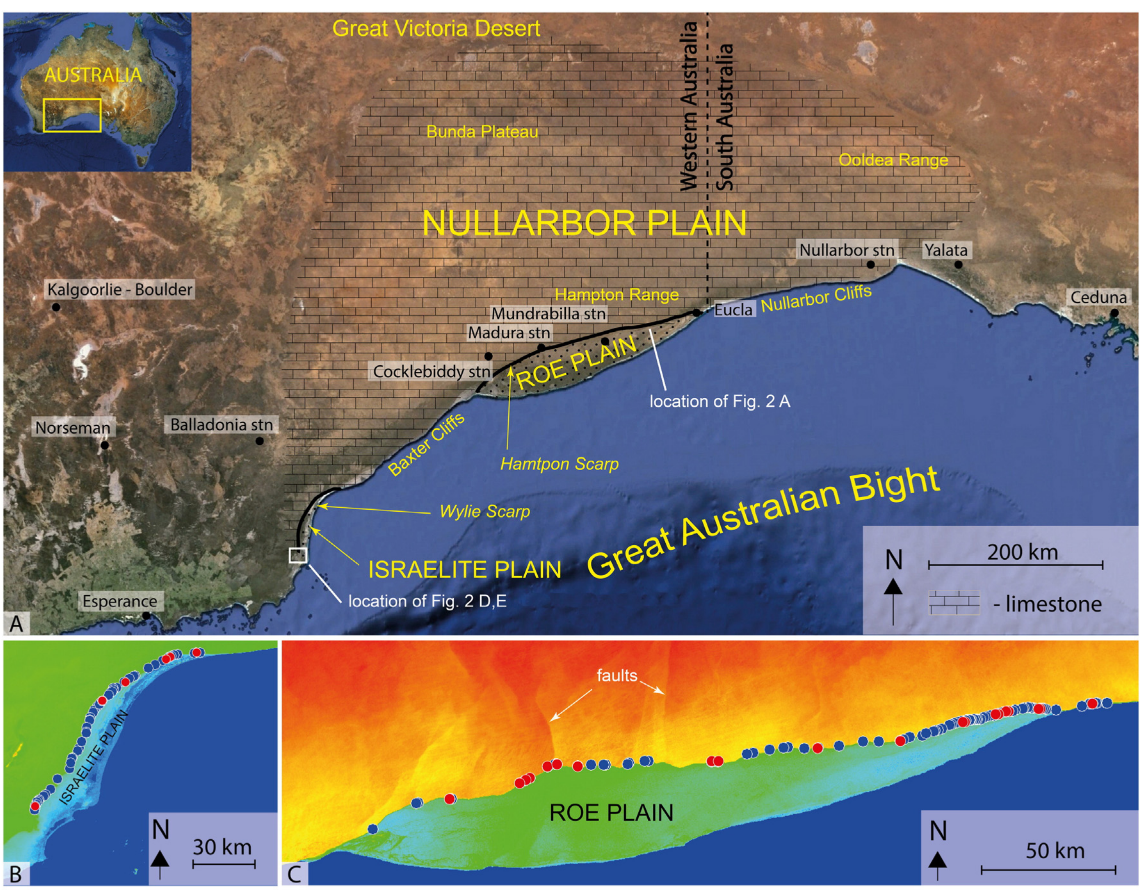

Fig. 1. Locality map of the Nullarbor Plain (A; satellite image downloaded from Google Earth) and digital elevation model images of Israelite (B) and Roe (C) plains showing locations of pocket valleys (examined in the field — red dots, observed only — blue dots). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
DEM downloaded from Shuttle Radar Topographic Mission website