Chemical Geology 440 (2016) 101–114

Contents lists available at ScienceDirect

Chemical Geology

journal homepage: www.elsevier.com/locate/chemgeo

Basin redox and primary productivity within the Mesoproterozoic Roper Seaway

Grant M. Cox [a,b,c,*], Amber Jarrett [a], Dianne Edwards [a], Peter W. Crockford [c], Galen P. Halverson [c], Alan S. Collins [d], André Poirier [e], Zheng-Xiang Li [b]

[a] Geoscience Australia, GPO Box 378, Canberra, A.C.T., 2601, Australia
[b] ARC Centre of Excellence for Core to Crust Fluid Systems and The Institute for Geoscience Research, Department of Applied Geology, Curtin University, WA, Australia
[c] Department of Earth and Planetary Sciences/Geotop, McGill University, Montréal, Québec, Canada
[d] Centre for Tectonics Resources and Exploration (TRaX), Dept. of Earth Sciences, The University of Adelaide, Adelaide, S.A. 5005, Australia
[e] Département des sciences de la terre et de l'atmosphère/Geotop, Université du Québec à Montréal, Montréal, Québec, Canada

ARTICLE INFO

Article history:
Received 4 December 2015
Received in revised form 20 June 2016
Accepted 25 June 2016
Available online 5 July 2016

Keywords:
Mesoproterozoic
McArthur Basin
Beetaloo sub-basin
Unconventional shale gas
High primary productivity
Basaltic weathering
Atmospheric oxygen

ABSTRACT

The ca. 1.4 Ga Roper Group of the greater McArthur Basin in northern Australia comprises the sedimentary fill of one of the most extensive Precambrian hydrocarbon-bearing basins preserved in the geological record. It is interpreted to have been deposited in a large epeiric sea known as the Roper Seaway. Trace element data suggest that the redox structure of the basin was a shallow oxic layer overlying deeper suboxic to anoxic waters along with a prominent episode of euxinia. These anoxic and sulfidic conditions, as inferred by Mo, V, and U concentrations (molybdenum, vanadium and uranium), developed due to high organic carbon loading consistent with models that suggest that euxinic conditions cannot develop until the flux of organic matter is significantly greater than the flux of bioavailable iron, which permits sulphate reduction to proceed. Considering the high reactive iron and molybdenum contents of these shales and the requirement for S/Fe ratios > 2 for euxinia to develop, suggests that sufficient atmospheric O_2 was available for oxidative scavenging of S and Mo from the continents. This is further supported by prominent negative cerium anomalies within these shales, indicative of active oxidative redox cycling of cerium. We propose that the high organic matter flux was the result of increased nutrient loading to the Roper Seaway from weathering of the continental hinterland. Data from both major and high-field strength elements (niobium, tantalum, zirconium and, hafnium) together with neodymium isotopes (143Nd/144Nd) indicate that a likely mechanism for this enhanced nutrient delivery was a shift in sedimentary provenance to a more primitive (i.e. mafic) precursor lithology. This switch in provenance would have increased phosphorus delivery to the Roper Seaway, contributing to high primary productivity and the onset of euxinia. This dataset and model serve as a basis for understanding the temporal evolution of the deepest sections of the Roper Seaway and finer scale changes in the environment at this time.

1. Introduction

The Mesoproterozoic Era (1.6–1.0 Ga) experienced low atmospheric pO_2 (Lyons et al., 2014; Planavsky et al., 2014; Zhang et al., 2016), generally anoxic deep oceans (Canfield, 1998; Lyons et al., 2009b; Reinhard et al., 2013; Sperling et al., 2015) although oxic deep water has been reported (Sperling et al., 2014), a low abundance of passive margins (Bradley, 2008), a period of reduced continental and oceanic arc volcanism (Cawood and Hawkesworth, 2014), and a relatively warm and stable climate (i.e. no evidence for glaciation; (Condie et al., 2001; Kasting and Ono, 2006). Consequently, the Mesoproterozoic has generally been considered a period of environmental stability within the Earth system, comprising the core of the unfortunately entitled "boring billion" years (1.8–0.8 Ga; (Brasier and Lindsay, 1998; Buick et al., 1995). However, against this backdrop of environmental stasis, this period includes the apparent breakup of the supercontinent Nuna (Ernst et al., 2008; Pisarevsky et al., 2014; Roberts, 2013; Rogers and Santosh, 2002; Zhang et al., 2012), formation of the Rodinian supercontinent (Li et al., 2008) and the first appearance of structurally complex microfossils of likely eukaryotic origin (Javaux et al., 2001, 2004; Zhu et al., 2016).

The ca. 1.4 Ga Velkerri Formation, a black-shale dominated unit within the greater McArthur Basin of northern Australia is a key environmental archive for the early–middle Mesoproterozoic due to its low metamorphic grade (sub-greenschist), exceptional thickness, well-constrained age (Kendall et al., 2009) and large variations in organic carbon content. Previous studies of the Velkerri Formation have been motivated by its hydrocarbon potential (Donnelly and Crick, 1988; Jackson and Raiswell, 1991; Volk et al., 2003; Warren et al.,

* Corresponding author at: Geoscience Australia, GPO Box 378, Canberra, A.C.T. 2601, Australia.
E-mail address: grant.cox@curtin.edu.au (G.M. Cox).

http://dx.doi.org/10.1016/j.chemgeo.2016.06.025
0009-2541/

1998), with a focus on source rock characterisation and hydrocarbon generating potential. Prior work has shown that the Velkerri Formation hosts some of the oldest known 'live' hydrocarbon occurrences (Jackson et al., 1986), and continues to generate substantial interest as an unconventional gas play (Munson, 2014). Despite these detailed studies on its source rock potential, the environmental conditions prevailing during the deposition of the Velkerri Formation have not been fully elucidated. A better understanding of the interplay between organic matter production, preservation and environment is essential to developing models for Precambrian petroleum systems.

High total organic carbon (TOC) content within sediments has been attributed to various factors including high primary productivity (Pedersen and Calvert, 1990), warm and wet climatic conditions resulting in high nutrient fluxes (Condie et al., 2001; Meyer and Kump, 2008), the combined effects of climate and palaeogeography creating nutrient traps (Meyer and Kump, 2008), basin redox conditions facilitating enhanced preservation potential (Hartnett et al., 1998), mineralogical controls on preservation potential (Hedges and Keil, 1995; Kennedy et al., 2002; Mayer, 1994) and the relative rate of clastic to biogenic sedimentation (Müller and Suess, 1979). In view of these competing processes, it is easy to envisage that the relative importance of these factors may vary in both time and space. Therefore, an understanding of the principal control on organic carbon burial serves to increase our understanding of both local and global environments and has implications for Mesoproterozoic atmospheric oxygen levels.

Here organic carbon data is coupled with major and trace element geochemistry, neodymium isotopic ratios and high-resolution quantitative mineralogy, in order to discriminate between competing processes that contributed to the formation of the exceptionally organic-rich sediments of the Velkerri Formation. This approach provides a basis for understanding key environmental controls on organic matter production and preservation that can be applied more broadly to assessing Precambrian petroleum systems.

2. Regional geology

2.1. The Roper Group

The Roper Group (Wilton Package of Rawlings, (1999)) of the Northern Territory is younger of the four unconformity-bound sedimentary packages (Fig. 1A) of the McArthur Basin (Jackson et al., 1987; Rawlings, 1999). Previous work has left the Roper Group with variable interpretations with it comprising of three (Warren et al., 1998), five (Powell et al., 1987) to possibly six (Abbott and Sweet, 2000; Jackson et al., 1987) shoaling (coarsening up) sequences forming a thick package (~1–5 km) of dominantly siliciclastic sedimentary rocks preserved

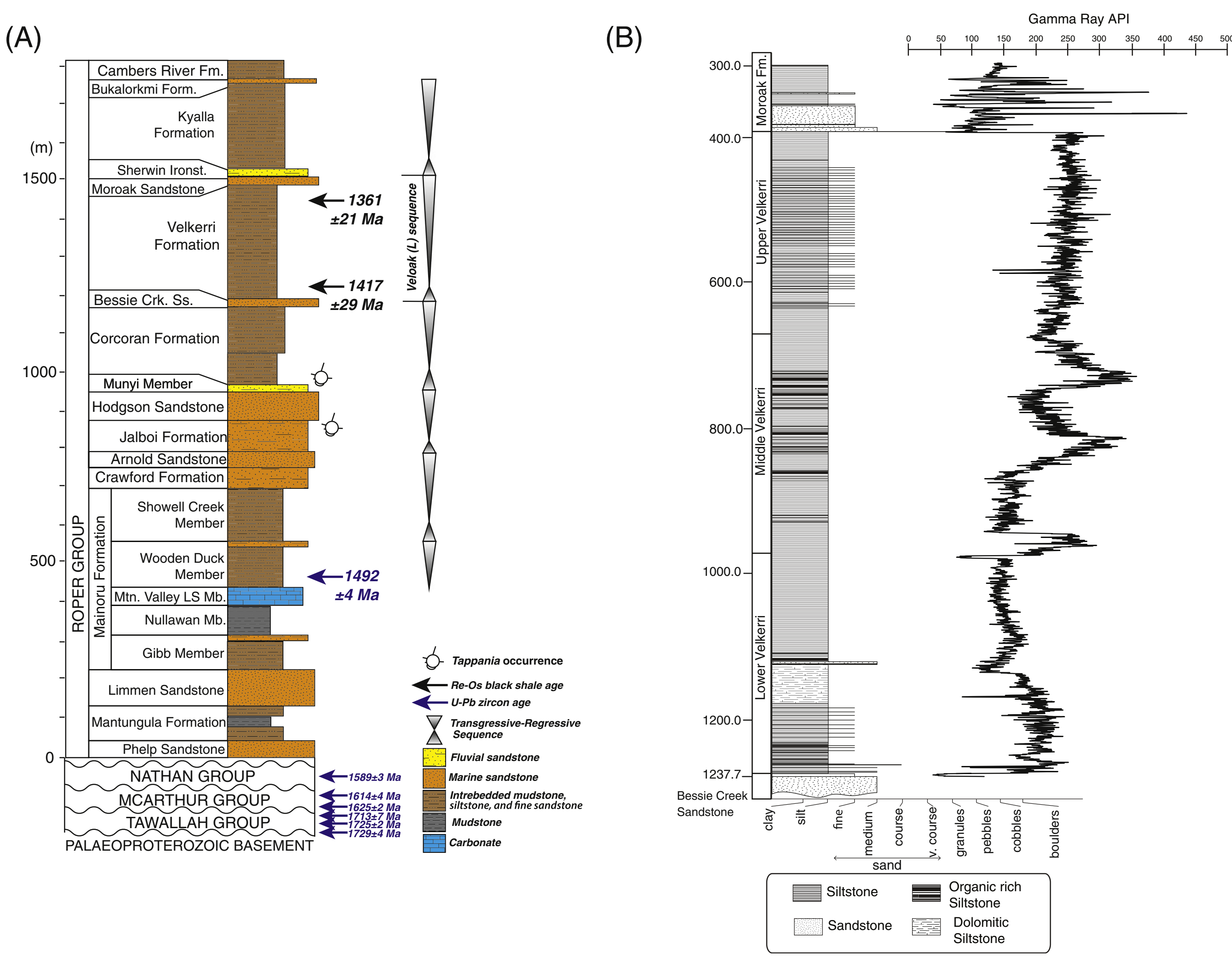

Fig. 1. (A) Simplified stratigraphy of the Roper Group, modified from Abbott et al. (2001), with transgressive–regressive sequences from Jackson et al. (1988) and Abbott and Sweet (2000). Re–Os ages for the Velkerri Formation are from Kendall et al. (2009) while the broader chronostratigraphy is adapted from Brasier and Lindsay (1998) and Southgate et al. (2000). Tappania occurrences are from Javaux et al. (2001). (B) Stratigraphic log of the Altree 2 core.