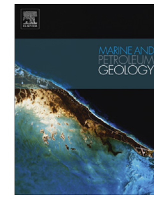
Marine and Petroleum Geology 69 (2016) 262–265

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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



Discussion

Response to comments by Nicholas et al. (2016) on “Evidence for the biotic origin of seabed pockmarks on the Australian continental shelf”

Robert Mueller

Curtin University, Australia

ARTICLE INFO

Article history:
Received 14 July 2015
Accepted 24 August 2015
Available online 1 September 2015

Keywords:
Pockmarks
North West Shelf
Fish pits

ABSTRACT

Nicholas et al. (2016) restate the results and conclusions of their own past work and that of colleagues on the North West Shelf. Although they accept that fish may be involved in ‘pockmark’ maintenance, they do not accept that fish can initiate such features. The fluid flow theory with which they have been working therefore remains intact. However, the restatement also provides no new information and no cause to revise the conclusions of Mueller (2015). More field data is required.

1. Introduction

Nicholas et al. (2016) are thanked for their detailed response to Mueller (2015). The significant body of work produced to date by Nicholas and his co-authors is acknowledged.

The aim of Mueller (2015) was to present the fine geomorphological detail missing from previous discussions by making use of commercial seabed survey data. A notable gap exists in the research data with respect to the acquisition and resolution of seabed topographic information: most research surveys have gridded their multibeam bathymetric and backscatter data at a relatively coarse 2–3 m pixel resolution, and not all surveys have acquired sidescan sonar data (*cf* Site 1 in Mueller, 2015; which utilised 0.1 m resolution bathymetric and sidescan sonar data).

The primary criticism of Nicholas et al. (2016) relates to the lack of geochemical analysis in Mueller (2015). Unfortunately, geochemical sampling is rare in the commercial sector and finite resources precluded the addition of any original work. On the other hand, geochemical analysis is one of the strengths of the research community and much of the work has already been done. It is agreed that an overview of the relevant geochemistry carried out by others would have been informative to the casual reader of Mueller (2015); the omission is rectified below.

2. Recent geochemical results from the North West Shelf

A summary of representative research surveys on the North West Shelf over the past decade begins with Geoscience Australia Survey 267 (2004), which investigated four sites on the north-–central North West Shelf with the aim of ground-truthing natural hydrocarbon seeps previously interpreted from remote sensing data (primarily SAR, ALF and geochemical sniffer). The primary target was a light hydrocarbon anomaly detected during a 1994 regional sniffer survey (Wilson, 2000). The 2004 survey successfully proved the existence of an active thermogenic hydrocarbon seep (the “Cornea Seep”; e.g. Jones et al., 2005; Rollet et al., 2006).

A follow-up survey in 2005 (SS06/2005A) recovered water column and seabed sediment samples for detailed geochemical analysis. Thermogenic gas was found during that survey to be issuing from a 500 m by 1400 m area which at low tide was “a mass of bubbles rising” (Brunskill et al., 2011); higher molecular weight hydrocarbons were also extracted from seabed carbonate debris and sampled from the water column (Burns et al., 2010).

Immediately prior to SS06/2005, research survey SS05/2005 visited the Arafura Sea (just outside the eastern limit of the North West Shelf) also with the objective of identifying natural hydrocarbon seeps. The geochemical analysis is described by Grosjean et al. (2007): elevated CH_4 levels were found within palaeochannels which retained a strong terrestrial signal from previous mangrove forests (pre-6000 years BP), but no evidence of thermogenic gas was found.

DOI of original article: http://dx.doi.org/10.1016/j.marpetgeo.2015.08.030.
E-mail address: r.mueller@fugro.com.

http://dx.doi.org/10.1016/j.marpetgeo.2015.08.031
0264-8172/

The results of the next survey on the central North West Shelf, with the express objective of identifying, characterising and sampling sites of natural hydrocarbon seepage (SS06/2006), were summarised in a Geoscience Australia pamphlet entitled, "No evidence of seepage on the central North West Shelf" (Kennard, 2007); the results are confirmed in Logan et al. (2010), "no evidence of active hydrocarbon seepage or shallow gas was detected [during SS06/2006]".

In 2010, a collation and re-evaluation of the results of all offshore hydrocarbon seepage surveys carried out over the last 30 years concluded that only one single hydrocarbon seep had been proven to date anywhere in Australian waters (the 2004-discovered Cornea Seep; Logan et al., 2010).

In 2012, the SOL5463/GA0335 survey investigated two sites on the northern North West Shelf, again with a primary objective of finding evidence of seepage at the seabed. According to Nicholas et al. (2014), head-space gases of seabed samples were dominated by CO_2 (no meaningful levels of hydrocarbons).

The most recently reported upon survey (2013 GA0339/SOL5650) also recovered seabed grab samples on the northern North West Shelf but did not test for hydrocarbons; CO_2 concentrations, however, appear to be high (Picard et al., 2014).

The earlier conclusion of Logan et al. (2010) therefore remains valid, that, "this region [the North West Shelf] should no longer be considered an area of significant, active hydrocarbon expulsion, migration and seepage".[1]

3. High CO_2 levels on the northern North West Shelf

In support of their proposition that pockmarks throughout the North West Shelf are nevertheless the product of gas escape, Nicholas et al. (2016) reference the high CO_2 concentrations found in surface sediments from the region of Site 12 of Mueller (2015) during the 2013 GA0339/SOL5650 research survey. According to Picard et al. (2014), CO_2 concentrations are "about twice as high", relative to porosity, as found in other sediments around Australia, which is proposed by Nicholas et al. (2016) to be indicative of a very high total organic content (TOC). Radke et al. (2015) are also referenced as having found high TOC within grab samples from pockmarked areas of the nearby eastern Timor Sea.[2] A high seabed TOC is not wholly unexpected as this region (the Bonaparte Depression) was pre-Holocene a brackish, shallow sea with a restricted connection to the open ocean (Yokoyama et al., 2001).

However, elevated CO_2 levels in surface grab samples are not evidence of deeper gas generation and migration. As was stated in Mueller (2015), no seismic indicators of gas accumulation or migration are present in the shallow seismic data (to 50 m sub-seabed) acquired during the Site 12 survey, nor is any visible on sample sections reproduced in Nichol et al. (2013) from the same area. Many examples illustrating the appearance of interstitial gas in shallow seismic profiles are available in the published literature (e.g. Szpak et al., 2015); the relatively soft and muddy sediments in this region of the North West Shelf are not special in this respect and if gas were present there is no reason that it would not be imaged (as it is, for example, in Figure 10 of Rollet et al., 2009 [3]).

Irrespective of seabed CO_2 levels, the main focus of Picard et al. (2014) was the elongation of pockmarks by seabed currents. Included in the elongated pockmarks are the trench-like features illustrated in Fig. 2a of Picard et al. (2014), which provide another good opportunity to demonstrate the value of improved resolution (Fig. 1B). Further close inspection of Fig. 2a of Picard et al. (2014) also reveals pockmark clusters on top of the oceanic shoals (Fig. 1C), which brings into question the relationship between pockmarks and the high CO_2/TOC sediments found around the base of the shoals.

4. Comment on Nicholas et al. (2014)

As it is referenced several times by Nicholas et al. (2016), it is worth briefly reviewing Nicholas et al. (2014), which discusses one of the sites investigated by the 2012 SOL5463/GA0335 survey. One aspect of the data is the "step-like asymmetry" of the observed pockmarks, for which several reasons are offered.[4] A close inspection of Figure 5a in Nicholas et al. (2014), however, reveals that the asymmetry in at least some cases is due to the twinning of a pockmark with an adjacent sediment mound (Fig. 2). This type of controlled, single point deposition was the primary line of evidence used by Mueller (2015) to argue for a biotic origin, which is further supported in this particular case by Coleman et al. (2010), who in their description of the redeposition of sediment by *Epinephelus morio* state that, "the direction of deposition … often occurred in the direction of the prevailing current".

Nicholas et al. (2014) concede that "most pockmarks in the study area are the result of recent processes, unrelated to hydrocarbon migration". The only remaining driver is therefore CO_2,[5] and the conclusion is thus reached that, "Pockmark development is … likely driven by fluid seepage … sourced from CO_2 produced in the shallow sub-surface (<2 m) sediment." Yet pockmarks within the study area are up to 1 m deep. It is not clear, therefore, where the "pressure build-up phase" of the "fundamental" pockmark formation process outlined in Nicholas et al. (2016) takes place.[6]

It may be noted that there is no reference to the work of Scanlon et al. (2005) or Coleman et al. (2010) in Nicholas et al. (2014), leading the reader to perhaps question whether the 2012 data was tested against any alternative to the standard fluid flow theory. For example, the final discussion paragraph of Nicholas et al. (2014)

[1] Albeit (Brunskill et al., 2011) may disagree, having concluded that there must be "tens of thousands" of seeps on the scale of the Cornea Seep to account for the consistently high CH_4 levels logged throughout their 2005 cruise (SS06/2005).

[2] Yet the presented correlation between high TOC and pockmarks is hardly definitive: using cluster analysis techniques the authors found that, "evidence for sub-surface seepage (including pockmarks) did not discriminate by cluster … [but] was especially prevalent in A5 and A6". Cluster A6 (in which ~42% of samples came from pockmarked seabed) did indeed have a median TOC (4.8) approximately twice the global median (2.8). However, Cluster A5 (in which ~55% of samples came from pockmarked seabed/areas with "acoustic water column flares") had a median TOC (2.5) less than the global median. The clusters with the second and third highest TOC (C: 4.2 and A7: 4.0) included only one sample between them which came from pockmarked seabed.

[3] Note that the corresponding SS05/2005 post-survey report (Logan et al., 2006) includes a lengthy discussion of the many putative shallow seismic gas indicators found and their correlation to the ubiquitous seabed pockmarks, yet Rollet et al. (2009) ultimately provide no more evidence of a link to pockmarks other than that pockmarks generally favour muddy sediments within palaeochannels and that those muddy sediments have an elevated TOC and gas (CO_2 and CH_4) content. The alternative hypothesis proposed in Mueller (2015) also fits the data, in that burrowing agents may favour the more cohesive palaeochannel sediments.

[4] Namely: the (postulated) seepage is tidally moderated – but Rollet et al. (2006) noted maximum seepage at the Cornea Seep at low ebb tide whereas the build-up of mounds here would require expulsion during flood tide; one side is scoured – but tidal currents are bidirectional and furthermore there is no elongation of the pockmarks (*cf* Picard et al., 2014); or one side has slumped – but the supporting reference paper (Hasiotis et al., 1996) describes the sidewall slumping of normal pockmarks up to 15 m deep; compare with the 0.5–1 m depth of the pockmarks here.

[5] Seabed cores from a pre-Holocene channel infill unit (maximum 6 m thickness) revealed high CO_2 values 1–2 m below seabed.

[6] Note that the expulsion of cobbles seen by Nicholas et al. (2016) in the "unsorted sediment mounds adjacent to pockmarks" would require a violent eruption of accumulated gas.