Comment on "A Global Probabilistic Prediction of Cold Seeps and Associated SEAfloor FLuid Expulsion Anomalies (SEAFLEAs)"

by Benjamin J. Phrampus, Taylor R. Lee, and Warren T. Wood.

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Abstract

The paper being commented on describes a useful project, but very shortcomings are identified, most significantly an apparent failure to be guided by the geological environment from which SEAfloor Fluid Expulsion Anomalies arise.

1 Introduction

Whilst the intentions and effort behind the SEAFLEAs project are to be applauded, sadly there are some shortcomings in the approach and the way in which it is presented.

The project concerns the compilation of a database of global occurrences of any feature that is "*indicative of past or present fluid expulsion*", and identifies the following relevant features: "*bubble plumes within the water column"*, "*seafloor mounds*" [presumably this means mud volcanoes and seep-related carbonate mounds], "*pockmarks"*, "*seafloor gas hydrate"* [only those exposed on the seabed?], "*shallow gas deposits"* [accumulations, not deposits!], *"authigenic carbonates (hardgrounds)"* [N.B. not all hard grounds are associated with seabed fluid flow; exposures of solid rock, gravel banks, and shell beds are other examples. Also, not all authigenic carbonates are associated with seabed fluid flow: it would be better to specify methane-derived authigenic carbonate - MDAC], and "*chemosynthetic communities*".

Potentially, such a database has enormous value, yet this paper offers no suggestions for how it might be applied; without an application it becomes an exercise in 'stamp collecting'. The authors missed the opportunity to introduce readers to the significance of seabed fluid flow. It impacts natural processes (geological, geomorphological, chemical, biological, and environmental) at the seabed, in the water column, and in the atmosphere, and affects numerous human activities, as discussed by Judd and Hovland (2007).

- the shallow gas accumulations associated with most seeps are hazards to any offshore structure, be it a petroleum facility, a wind farm or whatever.
- methane accumulations associated with seeps, either as shallow gas or gas hydrates, are potential commercial energy sources.
- seabed morphology is modified by the formation of pockmarks, mud volcanoes etc., which may be obstructions to the siting of offshore structures or the routing of pipelines, cables etc.
- methane rising to the seabed may be utilised by microbial communities undertaking anaerobic oxidation of methane (AOM)
- methane, and H_2S derived from AOM, are utilised by chemosynthetic macrofaunal benthic communities (particularly in deepwater). These communities are protected by environmental legislation in, for example, EU, UK and US waters.
- the formation of methane-derived authigenic carbonate (MDAC - a by-product of AOM) creates hard grounds that are attractive to many forms of benthic macrofauna, either as a hard substrate suitable for colonisation, or as shelter; such hard grounds also impact foundation conditions for seabed structures

such as pipelines. MDAC 'reefs' are protected by environmental legislation in, for example, EU and UK waters.

- the microbially-mediated oxidation of methane passing into the water column contributes, directly and indirectly, to marine biomass.
- a proportion of methane from seabed seeps enters the atmosphere, either via rising bubbles, or by sea:air exchange of methane dissolved in the seawater. As a 'Greenhouse Gas' far more potent than CO_2, this is potentially significant to global climate change.

The database is useful. Why not advertise this fact?

2 Database compilation

The authors state that the database was compiled from "*33 unique data sources that quantitatively identify at least one of the anomalies of interest*", a dataset comprising "*over 10,000 unique anomalies*". Whereas Section 3.1 states that "*many known anomalies exist but are difficult to digitize*" it should be noted that the database resolution, 5 x 5 arc minutes (i.e. 5 x 5 nautical miles) is sufficient for many more reported occurrences to be included without detailed digitisation, and that neither Fleischer *et al*. (2001), nor Mazurenko and Soloviev (2003) provide positional data to this precision. Perhaps, for the purposes of the analyses they attempted, they could have recorded presence/absence data in each of the grid cells. This would have avoided the laborious digitisation process, making it possible quickly to increase geographical coverage. Accounts of the global distribution of individual types of feature also may have provided useful guidance. Using mud volcanoes as an example, Milkov (2000) and Dimitrov (2002) both cited numerous original reports of submarine mud volcanoes distributed around the world. Various publications provided maps of mud volcanoes in the Gulf of Cadiz (e.g. Magalhães et al., 2012), and some (e.g. Pinheiro *et al.*, 2003) tabulated precise locations of samples collected from mud volcanoes. Judd and Hovland (2007) described the global distribution of relevant features, and cited references which (generally) provided adequate positional data; there is also a link to a collection of maps showing the location of the features described in their text.

Of course, it would be unrealistic to expect the SEAFLEA database to be comprehensive. Inevitably, any attempt to map the global distribution is bound to be an underestimate for two reasons: 1) by the time a publication is prepared and published it is out of date as the rate of relevant publications increases; 2) the most detailed knowledge of seeps and associated features has been acquired over many decades by the petroleum industry, but the vast majority of these data have not entered the public domain.

3 Data-driven prediction methodology

Surely, if you are wishing to predict the distribution of features associated with fluids escaping through the seabed, one must first identify these fluids (mainly methane and groundwater), and secondly, understand the sources of these fluids. Both are primarily geological fluids, so why not attempt to determine the distribution of geological environments that produce them, and/or allow them to migrate to the seabed? As the petroleum industry developed, seeps were used to site oil wells and to identify petroleum-bearing sedimentary basins. Now that there is good understanding of sedimentary basins, thanks to geological mapping on land, at sea and from space, this logic can be reversed: seeps occur in sedimentary basins, so identify them as areas with a high potential for hosting seeps. There is no need for sophisticated algorithms and their application to datasets including such parameters as elevation, chlorophyll density, sea conductivity, etc. They may be correlated with sites of seabed fluid flow, as a bird's egg is to a nest or a tree; better to identify the source of the fluid (the chicken, not the egg!). I submit that this project needs a strong geological drive assisted by solid mathematical modelling. Instead it appears that it has been driven by the modelling, an understanding of the geology being secondary.

This approach was, for example, in predicting the global distribution of gas hydrates (Kvenvolden *et al.*, 2003, for example). Gas hydrates occur in strictly limited temperature / pressure conditions, and only where there is a source of a suitable clathrate-forming gas (e.g. methane). Locations with suitable physical conditions can be determined by a combination of water depth and geothermal temperature gradient; within these locations, methane is most likely to occur where there are thick sediment sequences. It is therefore possible to identify sedimentary basins where the physical conditions are suitable as possible locations of gas hydrates; validation of this prediction may be made by reference to reported locations of evidence of, or actual samples of gas hydrates.

Notwithstanding the shortcomings alluded to above, the implications of correlations between SEAFLEAs and various parameters shown in their **Figure 5** raise some interesting questions. On the one hand, the apparent value of water depth as a predictor seems untenable considering that active methane seeps have been reported at depths ranging from inter-tidal (Iglesias and García-Gil, 2007) to >4,000 m in the Aleutian Trench (Suess *et al.*, 1998); again, an understanding of the geological sources of methane would explain why. On the other hand, the apparently strong correlation of various biological parameters (chlorophyll and biomass) strengthens the argument that methane seeps are a positive benefit to biological productivity, and appears to provide a 'pathfinder' to seeps areas.

Other 'anomalous' regions can be explained if their geological context is considered. In section **3.2 Prediction** three areas are described as "*parametrically distinct from regions of observed SEAFLEAs*": the Baltic Sea, the mouth of the Amazon river, and the Kuril Islands.

- The Baltic Sea is largely characterised by ancient rocks of the Fennoscandian Shield which are inherently unsuited to the formation of thermogenic methane as the rocks are mainly metamorphic. However, microbial methane does escape from the seabed in some locations, for example in Eckenförde Bucht, where groundwater discharge has resulted in the formation of pockmarks and the inhibition of AOM by the presence of sulphate-free freshwater (Bussman and Suess, 1998). In Stockholm Archipelago microbial methane is generated from organic matter trapped in fractures and fissures in the crystalline basement of the Fennoscandian Shield (Söderberg and Flodén, 1992).
- In contrast, the Amazon river mouth is characterised by huge accumulations of sediment in a deep sea fan. This provides an ideal environment for methane formation, and evidence of seabed fluid flow features (seeps, gas hydrates etc.) have been reported in the literature (Ketzer *et al.*, 2018), but these have not been included in the database.
- The Kurils are a chain of volcanic islands located where the Pacific Plate subducts beneath the Okhotsk Plate. Fluids escaping through the seabed in this area are likely of volcanic origin (steam, CO_2, etc.) and are not comparable to the hydrocarbon fluids (particularly methane) characteristic of sedimentary environments, although features such as pockmarks could be present if the seabed sediments are conducive to their formation and preservation.

Some areas appear to be of no significance to the study for lack of data. In the North Sea, for example, Phrampus *et al.* estimate the probability of relevant features being present at 20 - 40% (Figure 2a), despite the extensive literature about pockmarks and seeps in the area (dating back to 1973; van Weering *et al.*, 1973, Judd and Hovland, 2007 - and many subsequent papers), and the fact that it is a major petroleum province. The lack of geological guidance is self evident.

4 Implications

This section defines Earth's [continental] 'margins' as active and passive, presumably with reference to the plate tectonics context. It goes on to note that seabed fluid flow is (more or less) evenly distributed between these two geological environments. However, it fails to investigate the various geological environments present within each type of margin. The presence/absence of thick sedimentary sequences, deltas, hydrocarbon resources, etc, is surely more significant than this very broad brush contrast.

5 Quantification of absence data

In Part 1 of this section it is suggested that all surveys should use the same equipment and interpretation techniques. Thanks primarily to the petroleum industry, there have been enormous strides in the development of offshore geophysics in recent years. Are the authors suggesting that all such developments (multi-beam echo sounders [MBES], high resolution [hi-res] seismic, remotely operated vehicles [ROVs] autonomous underwater vehicles [AUVs], underwater video and photography, video-guided sampling etc.) should be frozen, or that all data that pre-dates these developments should be discarded? Part 2 recommends "*only mapping an area for one particular* [type of] *anomaly*". Subsequent parts of this Section discuss future surveys aimed at identifying SEAFLEA-prone areas. Seep surveys are normally preceded by a desk-study of geological contexts. Once a suitable area has been identified, it would be less time- and funding-consuming to first concentrate on acquiring as many relevant data types as possible. Surveys commonly deploy various geophysical tools (echo sounder, MBES, hi-res seismic etc.) simultaneously, and maximise ship-time (the single most expensive resource) by also deploying equipment to visualise and sample the seabed, and sensors to identify hydrocarbon anomalies in the water and near-surface air.

6 Conclusions

The authors state that their methodology "*represents a potential future for 'seep hunting'*". However, better protocols have been employed, most notably (but by no means exclusively) by the petroleum industry, for several decades, using a combination of satellite, air-borne, ship-borne and underwater techniques.

In summary, this paper describes a valiant, but ill-considered effort to determine the global distribution of seabed fluid flow features. It is a project that would be of great value, particularly if applied to the various geological, oceanographic and environmental processes and issues affected by seabed seeps. Sadly, it fails to recognise the fundamental importance of the geological contexts in which seabed fluid flow occurs.

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