Foraminifera of ancient methane cold-seeps as paleodepth indicators in the Pierre Shale, South Dakota

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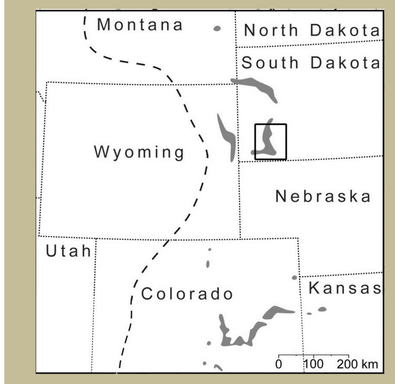
Abstract

Recently, an abundance of paleo-methane cold-seeps have been recognized within the Late Cretaceous Pierre Shale of the Western Interior Basin, U.S.A.. In an effort to understand the depth at which these methane seeps formed, we examined foraminiferal assemblages from three American Museum of Natural History localities (AMNH) of the upper Campanian (~74 Ma) from the *Baculites compressus* Zone (AMNH loc. 3528), *Baculites cuneatus* Zone (AMNH loc. 3545), and the *Didymoceras cheyennense* Zone (AMNH loc. 3546) in Custer County, South Dakota. The ratio of planktonic to benthic foraminifera (P/B) can be used to estimate water depth of deposition, assuming similarity to present-day conditions, thus the depth of methane seep formation. Foraminiferal species distribution patterns have long been used to determine paleodepth (Van der Zwaan et al., 1990), and it has long been known that the ratio of planktonic relative to benthic foraminifera increases systematically towards deeper waters . The specific values vary geographically, however, because they are influenced by such factors as regional food availability and bottom and pore water oxygenation. Foraminifera from these localities were analyzed to calculate planktonic versus benthic values. We used the P/B formula, Depth = $e^{(3.58718 = (0.03534\%P))}$(Van der Zwaan et al., 1990), and arrived at an estimate of the approximate depth of formation of the methane cold-seeps as ranging from 100 – 125 m.



Map of the general area of investigation east of the Black Hills, South Dakota.

Materials and Methods

Samples of shale were collected from AMNH South Dakota methane seep localities and surrounding areas in July 2013. Equal volumes, 100 cm^3, of each sample were digested using hot water and a deflocculant. Samples were sieved and the sediment from the 125 micrometer sieve was examined for tests using a microscope

Results

Specimens found were small and rare:

- ~80 tests found in total, at all three seeps localities
- 53 were preserved sufficiently for identification
- 40 benthic and 13 planktonic species were recognized

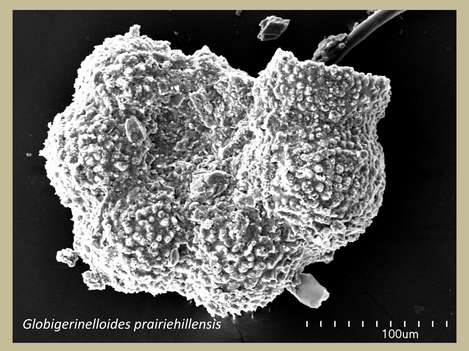
In implementing the Van der Zwaan et al. (1990) equation for P/B Depth = $e^{(3.58718+(0.03534\%P))}$ we determined that the approximate depth of formation of the seeps in the Western Interior Seaway of Custer County, South Dakota, during the late Campanian was in the range off 100 – 125 m.

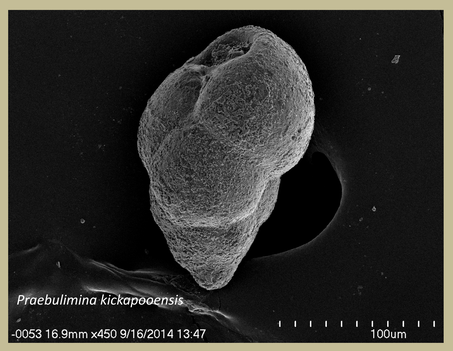
Discussion

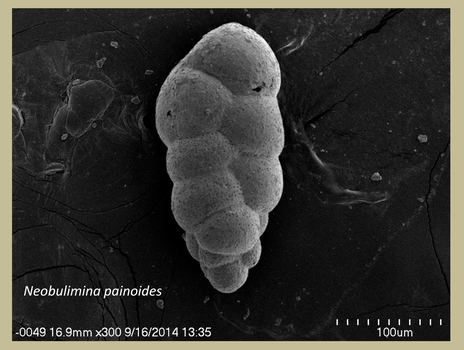
This depth of deposition of the Pierre Shale has long been debated, Kaufman and Caldwell (1993) argued, based upon stratigraphic investigations, that the paleo-depth at our localities was closer to 200 m. However, Landman et al. (2012) argued that the depth cannot have been greater than ~80 m, based on ammonite morphology. The paleodepth of seep formation as estimated from the planktonic to benthic foraminifera ratio of AMNH locs. 3528, 3545, and 3546 is between 100 – 125 m. between 100-125 m. This depth is somewhat larger than estimated by Landman et al. (2012) based upon ammonite morphology (~80 m), but in fairly close agreement, and shallower than argued by Kaufman and Caldwell (1993), ~200 m.

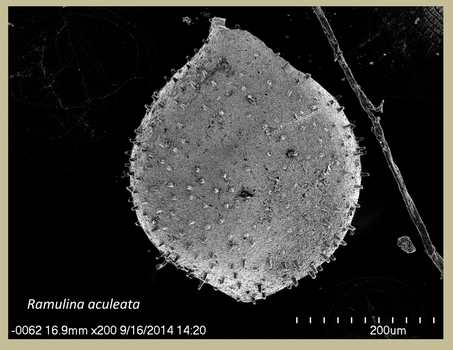
Conclusion

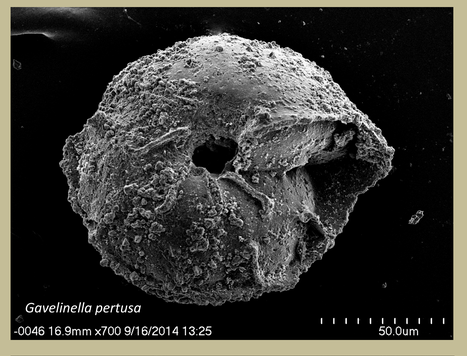
The paleodepth of seep formation based on planktonic to benthic foraminifera ratio of AMNH locs. 3528, 3545, and 3546 is between 100 – 125 m. This range is close to that (~80 m) estimated by Landman et al. (2012) based on ammonite morphology. Further research is necessary to determine the potential effects of dysoxic bottom waters on benthic populations around methane cold-seeps, and to determine whether foraminiferal populations around seeps contain opportunistic or stress-tolerant or high-food requiring species different from background populations distant from the seeps

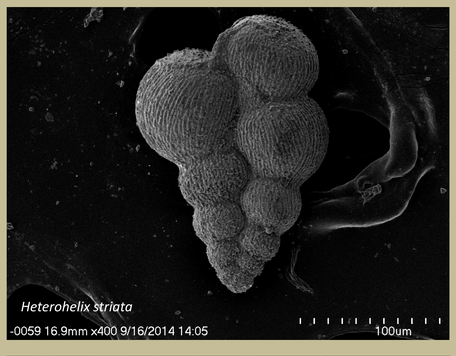


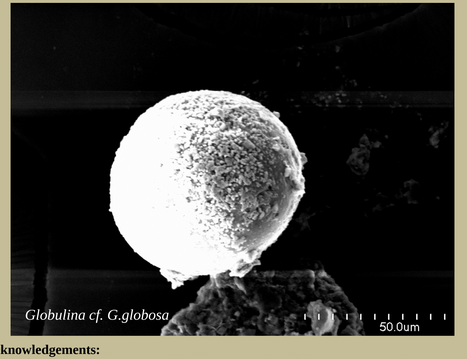


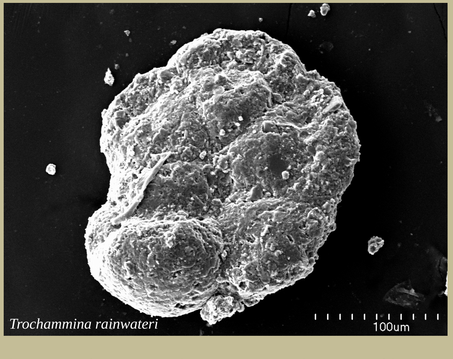












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