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Analogue Modelling of Diapir Generation

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Abstract*:Surface tension supporting deposited sediments is one of the unusual properties of deep hypersaline anoxic basins (DHAB). It has also been proven that the following properties are also true for the water of a DHAB: high viscosity, extremely high salinity concentration. Accordingly, this water behaves similar to starch; as a non-Newtonian fluid.*
The question is just common sense: the amount of a sediment sequence that such a non-Newtonian fluid can support. Our research group performed several analogue experiments in order to test the assumption whether the DHAB can be buried by basin filling sediments.
These DHABs contain methane generated by euryhaline bacteria. In our view, above a critical pressure, this gas content can generate diapirs breaching up the covering sediments. This premise was modelled by analogue experiments creating diapirs at a minor, laboratory scale.
Keywords:*analogue modelling, starch, sodium bicarbonate, vinegar, diapir formation*

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I. Introduction

Starting from the extreme properties of the deep hypersaline anoxic basin (DHAB) discovered in the East Mediterranean Range by MEDRIFF (Mediterranean Ridge Fluid Flow) Project (MEDRIFF Consortium, 1995), we formulated an assumption for the amount of the buried sequence of the DHAB. An important feature of the DHAB is its high viscosity, that is having non-Newtonian fluid properties: the fluid surface can and does support deposited fine grain sediments (Corselli et al.,1995).

On one hand, at laboratory scale we worked to reproduce the burial sequence sediment weight and lithostatic pressure to analyse the deformation patterns.On the other hand, we reproduced the gas saturated DHAB, which formed diapir over a critical internal pressure, breaching up and penetrating the covering deposits.Based on these analogue models, we attempted to prove that the DHAB supports the buried sediment sequences and that the gas saturation is the engine for diapir formation.

II. Methods and Experiments

Supporting the basin sediments

In the early eighties the Mediterranean Ridge Fluid Flow Project described in details the properties of a DHAB. Salty brines of high viscosityand high saturation“meet” abruptly marine water of normal salinity; a surface blocks diffusion between brine and normal saline water. In the Discovery Basin researchers found abruptly increasing conductivity at the brine surface (Corselli et al.,1995) from 40 to 125 mS/cm. In the same basin, the salinity abruptly increases at the same depth from 40 ppt to 125 ppt. MEDRIFF also found anomalous superficial tension between the sea water and salt brine layers. An important feature of any DHAB is its high viscosity and its surface characteristic: it can and does support deposited fine grain sediments, which testifiesthe non-Newtonian fluid property (Corselli et al.,1995).

This non-Newtonian fluid behaves as starch by showing mechanical properties between those of a liquid and a solid material. We deposited in a vessel a repeated sequence of starch and medium grained sand. The starch powder was mixed with saturated salty water, until it formed a ball in our hands. (On leaving alone the ball, it became fluid again, flowing out between our fingers. This is how we check reaching the non-Newtonian fluid property.)
Finally, we covered the layers with a ring and we used two carpenter clamps to assure the lithostatic pressure.(Fig. 1.)

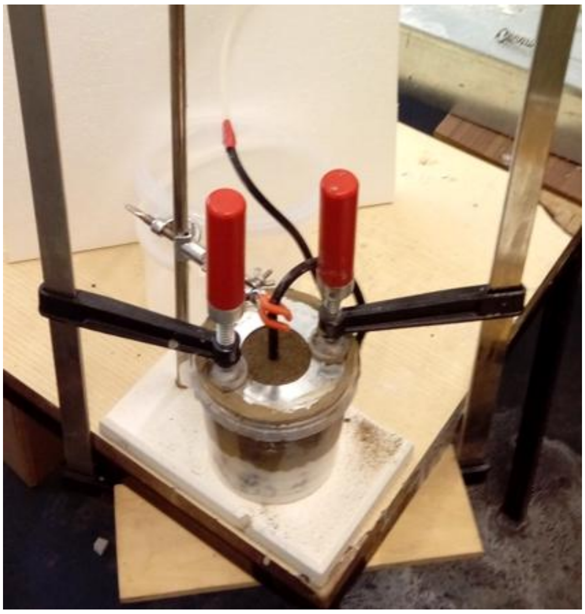

Fig. 1. Vessel prepared with starch and sand under “artificial lithostatic pressure”

According to the manufacturing description, these carpenter clamps can grant 10 000 N compression, which corresponds to ~1 000m water weight or ~500m sediment coverage. After 24 hoursof leaving the vessel under pressure, during which we tried to tighten the handle until it snapped, we checked the deformation of the deposited layers.

Eventually, turning over the vessel and cutting the filling into slices, we could follow the deformation of the starch and sand under the described pressure (Fig. 2.).

Thus we could prove the statement by Corselli et al (1995), that this non-Newtonian fluid supports the sediments and its weight, i.e. there is no important deformation between the layers. We repeated several times the experiment, gaining the same results.

As a conclusion, this weight, i.e. lithostatic pressure generated by the force of theclamps (max 10 000N) didn’t produceany deformation in the deposited strata. The conclusion is thatit can support the deposited sediments.

Fig. 2. The sand and starch sequence supports the weight with no relevant deformation

Diapir formation

Based on the MedRIFF Project (MEDRIFF Consortium, 1995.), we learned that the DHAB brines contain methane generated by bacteria (~70mg/L).Due to the burial processes, when pressure increasesabove a critical pressure, the brine breaches up, forming a diapir(Unger & LeClair 2018).

At laboratory scale we strove to simulate circumstances similar to the natural ones. Thesalt powder was mixed with baking soda ($NaHCO_2$) which we deposited at the bottom of the vessel. This was coveredby an argillaceous layer (Fig.3.) in order to reach a more closed system for the gas to be generated.

Fig.3. An argillaceous layer follows after the salt with baking soda powderin order to assure a better system

Between the lower layers we spread active carbon powder, thin films in order to draw the possibledeformation. Over the argillaceous layer the vessel was filled by medium to fine grain sand. From time to time, and step by step, during the filling process we did compaction to reach a massive, compacted sediment package.

During this process we installeda plastic pipe in the middle of the sediment layers through which to introduce the vinegar into the salt and baking soda layers. The aim of the reaction between the vinegar and baking soda is gas generation (CO_2), which increases the internal pressure in the lower strata.

Fig. 4. The installation for diapir generation

1 vinegar tank;2 pipe for the vinegar; 3 vessel holding salty baking soda, covered by sediments; 4 clamps assuring the exterior pressure similar to the lithostatic pressure.

Introducing the vinegar into the lower level of the vessel, where we set the salt and baking soda powder (3), CO_2 is formed as long as all the vinegar is consumed from the tank (1). This reaction yields internal pressure. Clamping stands for the external pressure. Above a critical pressure point, the lower, gas saturated layer will breach up, penetrating the covering sediments, releasing the CO_2. This ascending movementlifts the salty layer from the bottom into the sediments. The blackcarbon films will outline the internal structure of the diapir.

The solid content of the vesselis cut into several slices (Fig 5.).The 5^{th} slice (Fig. 6.) shows the formed diapir and its internal structure (placed into the original position).

Fig. 5. After the gas releases, we cut into slicesthe content of the vessel

Fig. 6. Internal structure of the 5^{th} slicerevealing the internal structure of the diapir(original position)

III. Discussions

Unger and LeClair (2018) set up a hypothesis about the deep marine salt and methane parallel generation. In the article based on the MedRIFF description of the DHAB, Unger and LeClair deduce that these brines could have been buried over the geological time scale. They are saturated in salt and biogenic methane, of high viscosity, as non-Newtonian fluid, and they will support the covering deposits. This layer will be over-pressured, on the one hand internally, owing to the gas content, on the other hand, externally, which is due to the lithostatic pressure. If the pressure reaches a critical point, the overpressure can only be released if the lower, salty layer breaches up, penetrating the covering deposits and forming a diapir.

Therole of this article is to reproduce (at lab scale) similar environmentto that of DHAB. This is why,as a first step, we tried to build up a model to test whether the non-Newtonian fluid is really able tohold theweight of the covering sediment. The first analogue experiment proved that the layered build-up of the vessel can resist ~10 000 N, i.e. ~1 000 m water column or ~ 500m sediment (sand) weight.

The second step in the process was to evaluate the possibility of diapir formation attributed to the gas-saturated layer. The idea on diapir formation by Posepny (1871) seems to be valid.

Similarly, using a vessel as the one in the previous experiments, in the second experiment we produced gas under an isolated sedimentary sequence build-up. The reacting vinegar and baking soda produced CO_2 which,above a critical pressure, “blew up” while releasing the CO_2. The over-pressured layer with salt breached up and penetrated the covering, compacted and clamped sediments. The pressure, in our view, is of the same range,max. 10 000 N,as the one described in the carpenter clamp factory case.

IV. Conclusions

The authors performed two analogue experiments on laboratory scale. The set purpose was to validatetwo crucial premisesof the hypothesis on deep marine salt generation parallel with methane generation (Unger&LeClair 2018).

The first trial-and-error test results of both analogue experiments confirmed the initial premise even after repeating the tests several times. The premise holds thatthe sediments supported by the non-Newtonian fluid and gas-saturated strata can be the engine for diapir generation. In order to prove every step of the mentioned hypothesis (Unger & LeClair 2018), further laboratory-scale analogue experiments will be performed in the near future.

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