Workshops on Marine Research Drilling (Magellan Workshop Series)
'Capturing a Salt Giant'
Scientific Report

C. Hübscher, J. Cartwright, H. Cypionka, G. De Lange, J. Urai

SCIENTIFIC CONTENT AND CONSENSUS OF RESULTS

Remark: Our proposal writing workshop had the clear aim to compile the scientific challenges related to a future drilling of a salt giant in a written form. This text represents the core text of the future pre-proposal. Therefore we can not distinguish between 'scientific content' and 'assessment of results'.

Expert group forming and networking

The workshop participants and the working groups represented by them agreed to cooperate in order to finalize an IODP-pre-proposal before the next deadline on April 15. The following persons will act as proposal proponents and are responsible to advantage the particular ISP topics by further networking:

Basin formation

Joe Cartwright, School of Earth, Ocean and Planetary Sciences, Cardiff University, UK
Christian Hübscher, Institute of Geophysics, Hamburg, Germany
Alastair Robertson, School of GeoSciences, University of Edinburgh, UK
Janos Urai, Geologie-Endogene Dynamik, RWTH Aachen, Germany

Extreme paleo-environmental changes and subseafloor ocean

Gert J. De Lange, Department of Earth Sciences – Geochemistry, Utrecht University, Netherlands.
Wout Krijgsman, Department of Earth Sciences, Utrecht University, The Netherlands
Jean-Pierre Suc, Laboratoire PaléoEnvironnements et PaléobioSphère, Université C. Bernard - Lyon, France

Deep biosphere

Heribert Cypionka, Institut für Chemie und Biologie des Meeres, Universität Oldenburg, Germany.

General importance of salt giants

The compilation of recent scientific work by the workshop participants suggests that basins with vast thicknesses of preserved evaporites or 'salt giants' are potential frontiers for a diverse range of challenging research, encompassing their structural and biogenic evolution as well as fluid dynamics. Salt giants are a global phenomenon because of their impact on the world ocean during the deposition of the salt deposits, and are both indicators and generators for significant environmental changes. Salt layers up to several kilometres thickness strongly affect the structural, chemical and biological evolution of sedimentary basins. Fluid inclusions within the salt represent ice-core-like microbial habitats of so far unknown importance. The world's most significant hydrocarbon traps are related to salt structures. Quantitative understanding of salt dynamics and associated fluid flow is further necessary in order to assess associated geo hazards and exploration or production risks.

However, in spite of their global occurrence and general importance within the earth system, there is a significant lack in our knowledge about the early evolution of juvenile salt giants and its controlling factors. The petroleum industry regularly drills through thick evaporite successions always in positions where the evaporites have been massively remobilized by protracted phases of salt tectonics. It is correct to state that there is no complete stratigraphic record of any major evaporite basin in a relatively undeformed state.

Drilling through the complete Messinian succession represents perhaps the only opportunity to understand the stratigraphy, biosphere and fluid dynamics of a global salt giant in a state close to its original depositional configuration. This is a novel concept for scientific drilling in sedimentary basins beyond the IOPD Initial Science Plan and one of the last scientific frontier challenges in sedimentary basin research.

It was consensus among the participants that a future Salt Giant drilling proposal is multi-thematic rather than fitting within only one of the presently specified IODP themes (and may even go beyond the ISP). All aspects and themes are integrated, equally important, and interrelated.

Salt giants and sedimentary basin formation

In a global context, drilling a relatively youthful salt giant is a unique chance to advance our understanding of gravity tectonics on basin evolution in the presence of a mobile layer. The semi-enclosed Levantine Basin in the easternmost Mediterranean represents a natural laboratory for the investigation of salt tectonics and associated fluid dynamics for several reasons:

1. The less than 6 Ma old Messinian evaporites are very young compared to the Permian Zechstein salt or the Mesozoic evaporites in the North Atlantic.
2. The salt structures are almost free of any overprinting by plate tectonic processes and thus reflect almost pure salt tectonics caused by differential load and basin subsidence.
3. On the basin margins the thickness of the Pliocene-Quaternary sediment cover varies between 1000 m (northern Israel) and 3000 m (Nile-Cone). In the central basin, the thickness is reduced to less than 500 m. The impact of differential sediment load on salt dynamics in terms of lateral salt flow can be therefore studied under laterally variable, but well constrained conditions.
4. The abundant academic and industrial seismic data available show the distribution of six seismic sequences within the basin. Each of the intra-evaporitic sequences is independently deformed by folds and faults. In many regions, the lower Pliocene deposits overly M concordantly, even if the intra-evaporite sequences are deformed. The time of deformation obviously predates the erosional truncation of the uppermost evaporites. The thin-skinned shortening occurred during the depositional phase during the Messinian Salinity Crisis. This behaviour of young salt giants has been observed for the first time.

5. There is a clear line of evidence that a 2nd phase of thin-skinned extension started in the later Pliocene. Extensional faults in the overburden include listric and antithetic growth faults, turtle back structures and crestal graben. Some faults pierce the seafloor proving that this phase is still active. Salt rollers emerged in the extensional domain. A pre- and syn-tectonic unit can be clearly identified. The pre-tectonic unit is about 250-400 m thick and it is characterized by parallel horizons. The syn-tectonic unit includes the sediment prism off the western shelf and reveals divergent horizons above the salt rollers. The pre- and syn-tectonic sequences are separated by a huge late-Pliocene slump complex off the southern Levantine slope. A time correlated sequence of low seismic reflectivity can be traced all over the basin separating pre- and syn-tectonic also in the compressional domain. The slump complex has been mapped by means of 3D-seismic data and the volume was estimated to ca. 1000 km^3. Several trigger mechanisms are possible, e.g., oversteepening, seismicity, gas migration and initial salt tectonic.

A single and preferable continuous core from the seafloor down to beneath the evaporitic layers will calibrate the extensive 2D-and 3D-reflection seismic data sets from the geometrically well defined Levantine Basin. Since the geometry of the evaporite succession and the overburden is known in detail, the knowledge of the petrophysical parameters of all sequences will enable thermo-mechanical modeling of the structural evolution of multi-layered salt giants.

Extreme and fast environmental changes in the Messinian

The Messinian salinity crisis started when the gateway between the African and Eurasian plate was closed due to the Afro-Eurasian convergence. The resulting sea-level drop of more than 1 km represented the most significant environmental change of the pan-Mediterranean realm. The salinity of the present-day ocean has still not recovered from this major salinity crisis, and is still below that of the pre-Messinian period.

The discovery that the Mediterranean experienced a catastrophic desiccation phase in the Messinian has since proven to be one of the major achievements of the DSDP program. However, safety concerns with the non-riser drilling of the Joides Resolution meant that the full Messinian succession could not be drilled at that time, only the upper few meters have been sampled. In the 35 years since that leg was completed, over 1000 papers have been published on the Messinian Salinity Crisis. However, the temporal and stratigraphical relation between marginal and basinal evaporites is still a matter of debate. Some research groups assume diachronic deposition. Others suggested a progressive but fast deposition of evaporites from the margin to the deep central basin. The same age for the onset of evaporite deposition on the margin and the deep basin is considered by a third group. It is noteworthy that the reconstruction of the Messinian paleo-environment has up till now been based almost entirely on the descriptive and analytical work on the succession preserved in the marginal basins and its relationship with subaerial erosion.

Similar to marginal basins, deep evaporites are likely to contain astronomically determined cycles of deposition. High-quality deep seismic lines do indeed suggest that at least 6 of such cycles occur in the Levantine Basin. A complete core through the basinal Messinian evaporites would open an outstanding archive of environmental changes since the Messinian, since 95% of the Messinian evaporites (> 100 km^3) are therein enclosed.

Salt giant control on deep biosphere and subseafloor ocean

Recent studies gave compelling evidences for fluid flow through and out of more than 1000 m thick evaporites. Fluid escape structures have been reported from the southern and eastern basin margin. Possible fluid resources are located beneath and within the ME. Several controlling parameters interacting in fluid release locations. E.g., the ME were considered as a sealing sequence and syn-tectonic faults as conduits. However, a mud volcano is located at the lower NDSF and above almost undisturbed and 1.5 km thick ME without any evidence for lateral fluid flow. A cone like feature at the top of the ME directly beneath the mud volcano was interpreted as salt that precipitated from fluids escaping out of the ME. This fluids remobilized sediments within the overburden that feed the mud volcano.

Buried circular collapse structures above the tabular ME are recorded by 3D-seismic data on the eastern basin margin. The structures formed during the Pliocene as the buried ME underwent extensive dissolution in a submarine, deep-water setting. The authors proposed that focused vertical fluid flow at the base of the evaporitic series dissoluted the more soluble evaporites within the entire ME succession. Fluid through and outflow from the ME has been also reported. Near vertical faults represent the conduit from the top of the ME to the seafloor, where muddy fluids escape. Possible fluid reservoirs within the ME are intercalated sediments or water that was released from gypsum-anhydrite conversion.

The fluid escape structures at the eastern basin margin are located at the lower slope. It can be concluded that the prograding slope caused differential sediment load on the basin margin and differential subsidence, respectively. The fluids trapped within the ME and beneath were overpressurized and started to migrate upwards.

The accompanying flux of salinity, nutrients, dissolved organic matter, sulphate and sulphides strongly influence the biological habitat above and beneath the salt. The reported different seismic characteristics of the six evaporitic sequences indicate different densities/compositions and thus different evaporite stages and environmental conditions. All of these are likely to be expressed in the microbial communities compositions accommodated to each of such environments. Consecutive cycles of deposition and within-evaporite preservation (inclusions) of microbial life will produce an ice-core-like archive of microbial life enclosed/captured during cycles of paleo-environmental change. Besides the microbial archives, active interfaces will stimulate active microbial life. Such interfaces can not only be found within and between evaporite cycles but also at the lower and upper evaporite boundaries. The high salt content leads to improved preservation of reactive organic matter not only between evaporite cycles, which themselves contain sulphate (e.g. gypsum/anhydrite), but also immediately above them where sulphate-depleted pore water within organic matter containing sediment occurs.

At the interface between anhydrite and reactive OM, intense microbial activity is anticipated very much the same as has recently been discovered for some on-land gypsum deposits. Although no major methane accumulations are expected below the evaporites, some presence of methane is likely. This presents an attractive food source together with the anhydrate-sulphate, thus an active microbial interface.

A continuous core of the complete sequence of the Messinian sequence will give insight into the extreme habitat of a salt giant for the very first time. Everything will be new by definition.

Hypothesis to be tested by scientific drilling

We hypothesize that emerging salt giants are features of a high intrinsic dynamics:

- Layered and different evaporitic facies and intercalated clastics with trapped fluids cause a layered rheology and detachment layers, with cause creeping of individual layers during the precipitation phase even without external forcing. The layering strongly influences the structural evolution of salt giants.
- Embedded fluids have a significant impact on the early deformation history of salt giants.
- Salt giants are not necessary seals. Fluids may flow through or out of them.
- Inclusions in evaporites contain ice-core-like microbial and environmental archives recording paleo-environmental cycles.
- The salinar fluids and the accompanying nutrient flux strongly influence the biological habitat above and beneath the salt.
- Enhanced microbial activity occurs at active evaporite interfaces.

Conclusion

The workshop is considered as very successful. Since the number of participants was relatively small the group working was highly effective. All information needed for the scientific justification of future IODP drilling has been compiled, thoroughly discussed and was stipulated in written form. The proposal strategy has been also discussed and defined.

OUTLOOK AND FUTURE ACTIVITIES

Submission of workshop report to EOS:
Hübscher, C., Cartwright, J., Cypionka, H., DeLange, G., Robertson, A., Suc, J.P., Urai, J., Scientific Drilling of a Salt Giant within IODP. Submitted on Dec. 7

Promotion of proposal during a scientific delegation journey to Japan (e.g., Tokyo University and JAMSTEC) December 9-16 (*done*)
Discussion of a future multi-lateral research project aiming on further investigation of fluid outflow from Messinian Evaporites with Prof. Tokuyama, Ocean Research Institute (ORI), Tokyo University.
Japanese colleagues from Nagoya University are interested to investigate salt giants as an extreme habitat in the frame of the IODP-project.
The president of JAMSTEC, Prof. Yasuhiro Kato, ensured his personal support.

Preliminary selection of potential drill sites in 3D-seismic data.

Pre-proposal to be submitted April 15.

Workshop Schedule

October 10

Meeting of workshop proponents, discussion of working program

October 11

Plenary Session (all day)

10:15h
Dr. Christian Hübscher, Dr. Gesa Netzeband, University of Hamburg
'Capturing a salt giant – IODP drilling perspectives for the eastern Mediterranean'

10.45h
Prof. Dr. Alastair Robertson, University of Edinburgh
'Tectonic Evolution of the easternmost Mediterranean: a short overview'

11.45h
Prof. Dr. Joe Cartwright, Cardiff University
'Insights into gravity tectonics and Messinian stratigraphy from 3D seismic interpretation in the Levant Basin'

12.30h
Prof. Dr. Gert De Lange, Utrecht University
'Composition/origin of fluids and gas and diagenetic features for pre/post & Messinian deposits'

Lunch

14.30h
Prof. Dr. Janos Urai, RWTH Aachen
'Rheology and fluid transport in evaporites'

15.15h
Prof. Dr. Heribert Cypionka, University of Oldenburg
'Bacteria of the deep biosphere below the seafloor'

16:15
Prof. Dr. Jean-Pierre Suc, Université C. Bernard - Lyon
'Information on land both in the West and East Mediterranean (including Paratethys) for an ultra-long coring through the Central basin Messinian evaporites'

17:00
Dr. Tanja Kouwenhoven, Utrecht University
'Deep marine record of the Messinian salinity crisis (MSC)'

October 12

Morning plenary Session (open to public)

09:00
Dr. Warner Brückmann, IfM-GEOMAR
‘IODP and the Initial Science Plan’

09:45
Dr. Henrikk Sass, Cardiff University
‘Microorganisms in the subsurface of the Mediterranean Sea - what we know and we want to find out’

Workshop participants only:

11:00
Dr. Christian Hübscher, Hamburg University
Review of workshop goals, appointment of working group (WG) leaders (Christian Hübscher)

Lunch

Working groups

Working group 1: Salt tectonic and basin evolution
Working group 2: Deep biosphere and subseafloor ocean
Working group 3: Extreme environmental changes – the Messinian Salinity Crisis

17:30
Presentation and discussion of working group results

October 13

Morning working groups

09:00
Continue of group working

12:00
Discussion of working group results

Lunch

13:00
Continue of group working

16:00
Workshop summary (working group leaders)

Workshops on Marine Research Drilling (Magellan Workshop Series)
'Capturing a Salt Giant'
Workshop Participants

Manuel Beitz
Institut für Geophysik, Universität Hamburg, Bundesstrasse 55, 20146 Hamburg, Germany
Manuel.Beitz@zmaw.de

Warner Brückmann
Leibniz-Institute of Marine Sciences, IFM-GEOMAR, Wischhofstr. 1-3, 24148 Kiel
wbrueckmann@ifm-geomar.de

Torsten Dahm
Institut für Geophysik, Universität Hamburg, Bundesstrasse 55, 20146 Hamburg, Germany
Torsten.Dahm@zmaw.de

Stefan Dümmong
Institut für Geophysik, Universität Hamburg, Bundesstrasse 55, 20146 Hamburg, Germany
Stefan.Duemmong@zmaw.de

Henrik Echtler
GeoForschungszentrumPotsdam (GFZ), Telegrafenberg, 14473 Potsdam, Germany
helle@gfz-potsdam.de

Alexander Gerst
Institut für Geophysik, Universität Hamburg, Bundesstrasse 55, 20146 Hamburg, Germany
Alexander.Gerst@zmaw.de

Lutz Lüdenbach
Institut für Geophysik, Universität Hamburg, Bundesstrasse 55, 20146 Hamburg, Germany
Lutz.Luedenbach@zmaw.de

Christian Hübscher
Institut für Geophysik, Universität Hamburg, Bundesstrasse 55, 20146 Hamburg, Germany.
Christian.Huebscher@zmaw.de

Anja Reitz
Leibniz-Institute of Marine Sciences, IFM-GEOMAR, Wischhofstr. 1-3, 24148 Kiel
areitz@ifm-geomar.de

Gerhard Schmiedel
Institut für Geologie und Paleontologie, Universität Hamburg, Bundesstrasse 55, 20146 Hamburg, Germany
gerhard.schmiedl@uni-hamburg.de

Thomas Spies
Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Stilleweg 2, 30655 Hannover, Germany
Thomas.Spies@bgr.de

Joe Cartwright
School of Earth, Ocean and Planetary Sciences, Cardiff University, Park Place, Cardiff CF10 3YE, UK.
joe@ocean.cf.ac.uk

Hendrik Sass
School of Earth, Ocean and Planetary Sciences, Cardiff University, Park Place, Cardiff CF10 3YE, UK.
sassh@ocean.cf.ac.uk

Heribert Cypionka

Institut für Chemie und Biologie des Meeres, Carl-von-Ossietzky-Str. 9-11, 26129 Oldenburg, Germany.
Cypionka@icbm.de

Gert J. De Lange
Department of Earth Sciences – Geochemistry, Utrecht University, P.O. Box 80.021, 3508 TA Utrecht, Netherlands.
gdelange@geo.uu.nl

Tanja Kouwenhoven
Department of Earth Sciences – Geochemistry, Utrecht University, P.O. Box 80.021, 3508 TA Utrecht, Netherlands.
tkouwenh@geo.uu.nl

Alastair Robertson
School of GeoSciences, University of Edinburgh, Edinburgh EH9 3JW, UK
Alastair.Robertson@ed.ac.uk

Jean-Pierre Suc
Laboratoire PaléoEnvironnements et PaléobioSphère (UMR 5125), Université C. Bernard - Lyon 1
27-43 boulevard du 11 Novembre, 69622 Villeurbanne Cedex, France
suc.jean-pierre@wanadoo.fr

Janos Urai
Geologie-Endogene Dynamik, Lochnerstrasse 4-20, 52056 Aachen, Germany
j.urai@ged.rwth-aachen.de