Marine Impacts and Environmental Consequences – Drilling of the Mjølnir Structure, the Barents Sea

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Introduction

In September 2007, thirty-three scientists attended an international workshop in Longyearbyen (Svalbard, Norway) to discuss impacts of extraterrestrial bodies into marine environment and to prepare for the drilling of the 142-Ma-old Mjølnir impact structure in the Barents Sea (Fig. 1; Gudlaugsson, 1993; Dypvik et al., 1996, Tsikalas et al., 1998). A field trip visited the ejecta layer in the Janusjellet Mountain in Isfjorden, just outside Longyearbyen (Fig. 2).

The workshop focused on two topics: 1) mechanisms of marine impact cratering including ejecta formation and distribution, geothermal reactions, and the formation of tsunami, and 2) environmental effects of marine impacts. Both topics are highly relevant to the Mjølnir event and the geological evolution of the Arctic, as well as to the biological changes at the Jurassic-Cretaceous boundary. Against this background were a) concrete drilling targets formulated, b) plans outlined for compiling data from existing geological and geophysical surveys as the basis for Integrated Ocean Drilling Program (IODP) and International Continental Scientific Drilling Program (ICDP) drilling proposals, and c) a steering group and science teams established for compiling old and new material as a foundation for the development of drilling proposal.

Scientific Background

Asteroid and comet impacts are now recognized as an important and regular geological process releasing vast amounts of energy and resulting in near instantaneous increase in temperature and pressure, structural deformation, and redistribution of target materials. It is presently accepted that impacts, especially those in a marine environment, have very important influences on the development of Earth. However, detailed knowledge of the geological and physical aspects of the impact process itself, as well as its environmental and biological consequences, is still limited. This is mainly due to the fact that a large majority of the ~170 currently known impact craters on the Earth and their ejecta deposits are rather poorly preserved. Only twenty-five of these craters represent marine impacts, and very few of those have remained submerged with a potential for preservation of the original structure (Dypvik and Jansa, 2003). No completely retained marine crater has been investigated in detail yet, while in the last years ICDP land coring projects in the Chicxulub, Bosumtwi, and Chesapeake Bay impact structures were of great scientific gain.

One of the best preserved known impact craters on Earth is the Mjølnir impact structure. It was discovered by seismic data during petroleum exploration in the Barents Sea but never sampled by coring. An extensive geophysical database has been collected over the Barents Sea, and more than sixty wells have been drilled, particularly along basin margins and on structural highs. In addition, many shallow drill holes on sub-cropping sedimentary sequences have been drilled in the more central and remote areas of the Barents Sea. See also the Norwegian Petroleum Directorate (NPD; http://www.npd.no).

The Mjølnir Structure is 40 km in diameter and is located at the Bjarmeland Platform in the central Barents Sea (Fig. 1), beneath 350 m of water. Its elevated central high (Fig. 3)
is covered by ~50 m of younger sediments. Geophysical, geo-
logical, and mineralogical data unequivocally substantiate
the origin of the structure by an impact event into a sedi-
mentary platform with 300–500 m paleo-water depth (e.g.,
Dypvik et al., 1996; Smelror et al., 2001; Sandbakken et al.,
2005). The impact has been dated at about 142 Ma (Dypvik
et al. (1996), very close to the Jurassic-Cretaceous boundary.
At this time, the platform is comprised of upper Paleozoic
strata, mainly carbonates and evaporates, overlain by 4–5
km of thick Mesozoic siliciclastic marine sediments
(Dallmann, 1999).

The Workshop Program

The workshop included the following topics:

(1) Review the science behind marine impacts and the
Mjølnir project. The state of knowledge, and ongoing
geological and geophysical investigations in the Arctic
realm, the Barents Sea, and Mjølnir were outlined by
specialists of Arctic geology and members of the Mjølnir
research group.

(2) Review of petroleum exploration drilling in the Barents
Sea was presented by one representative from the NPD
and representatives from Norsk Hydro and Statoil (now
StatoilHydro). Drilling experts from ICDP, Drilling,
Observation and Sampling of the Earths Continental
Crust (DOSECC) and IODP presented different drilling
options.

(3) Scientific goals and drilling strategies for the Mjølnir. A
plenary session was followed by discussions in two
break-out groups, whose recommendations are summa-
ized below.

(4) An excursion was organized to the site of possible
Mjølnir ejecta at the mountain Janusfjellet in Isfjorden
(Fig. 2).

The Workshop Outcome

Deep wells in the Mjølnir impact structure would be of
great interest to the international scientific community, in
order to study the shock propagation, collapse, and re-sedi-
mentation of the ~6-km-thick sedimentary succession.
Coring through this succession will make structural analy-
sis and detailed understanding of crater generation and
deformation possible and help constrain numerical model-
ing. However, the costs for deep coring in the harsh environ-
ments of the Barents Sea makes it unrealistic to raise fund-
ing for such operations in the foreseeable future.

One of the great scientific advantages with the Mjølnir
impact crater is the clear correlation between the crater and
its very well preserved ejecta found in shallow drillings in
the Barents Sea and on land (Svalbard and possibly Siberia);
Dypvik et al., 2004, 2006). During a large part of late Jurassic
and early Cretaceous, the Barents Sea region formed an epi-
continental sea dominated by anoxic sedimentation of black,
organic-rich clays. The Mjølnir bolide impacted into these
sediments, and the crater and portions of the ejecta localities
were buried and have remained buried under sediments and
water since its formation. Those ejecta localities are well-pre-
served and accessible by shallow drilling (e.g., Bugge et al.,
2002). It is one of the few places on the Earth where such
important relations can be studied in detail. This is clearly of
great importance for understanding the crater and ejecta for-
mation, including the study the environmental consequences
of marine impacts (Dypvik et al., 2006; Smelror et al., 2002).
We will use Mjølnir as a type locality to study ejecta genera-
tion and distribution and possible relationships between the
impact and biotic evolution. Mjølnir ejecta may even serve as
a Boreal-Tethyan stratigraphic marker and could be useful in
correlation of these two distinct provinces near the poorly
understood Jurassic-Cretaceous boundary (Smelror et al.,
2001, 2002). Further research could greatly expand our ini-
tial knowledge on tsunami generation and formation, impact
ignitions of hydrocarbons in the target area, fires and subse-
quent soot precipitation. Calculations show that organic mat-
ter equivalent to a year’s oil production of one Norwegian
Shelf giant field (about thirty million std. m3 oil in place) was
burned during the first twenty minutes of the Mjølnir event
(Dypvik et al., 2008).

The development of the Mjølnir research program should
be carried out in full cooperation with the NPD and in close
contact with the oil industry active in the region (e.g.,
StauilHydro, ENI), making use of their extensive geophysical
database and deep wells. A two-step drilling project was
recommended:
Step 1. Drilling of five to six, up to 300-m-deep core holes in 350–400 m water depth around the Mjølnir structure to map and understand ejecta formation and distribution, coupled with in situ disturbance of sediments due to seismic and shock waves, or erosion by displaced water near the crater. Analysis of the cored material will be accompanied by sophisticated simulation models (Shuvalov and Dypvik, 2004) of the formation and deposition of ejecta in a marine environment.

Step 2. Drilling of one or two deep holes within the central moat to understand the inner structure of a large crater. At this point, however, the cost of such a project possibly requiring riser drilling is difficult to assess.

**Future Plans**

An international steering group (the authors of this paper) was established and charged with drafting a project proposal by the end of spring 2008. The steering group will also be responsible for compiling the final drilling proposals to IODP, ICDP, and the Norwegian Research Council (NFR) by spring 2009. For further information on the Mjølnir drilling project, please contact the authors or visit http://mjoelnir.icdp-online.org/.

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**References**

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Fig. 3: Filippos Tsikalas, University of Oslo and ENI, Norway.