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Operational Report about Phase 1 of the Collisional Orogeny in the Scandinavian Caledonides scientific drilling project (COSC-1)

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Abstract

The Collisional Orogeny in the Scandinavian Caledonides (COSC) scientific drilling project focuses on mountain building processes in a major mid-Paleozoic orogen in western Scandinavia and its comparison with modern analogues. The project investigates a subduction-generated complex (Seve Nappes) and how these in part under ultra-high pressure conditions metamorphosed outer continental margin and continent-ocean transition zones (COT) assemblages were emplaced onto the Baltoscandian platform and there influenced the underlying allochthons and the basement in a section provided by two fully cored 2.5 km deep drill holes. This operational report concerns the first drill hole, COSC-1 (ICDP 5054-1-A), drilled from early May to late August 2014.

COSC-1 is located in the vicinity of the abandoned Fröå mine, close to the town of Åre in Jämtland, Sweden and was planned to sample a thick section of the Seve Nappe and to penetrate its basal thrust zone into the underlying lower grade metamorphosed allochthon. Despite substantial technical problems, the drill hole reached 2495.8 m driller's depth and nearly 100 % core recovery was achieved. Although planning was based on existing geological mapping and new high-resolution seismic surveys, the drilling resulted in some surprises: the Lower Seve Nappe proved to be composed of rather homogenous gneisses, with only subordinate mafic bodies and its basal thrust zone was unexpectedly thick (> 800 m). The drill hole did not penetrate the bottom of the thrust zone. However, lower grade metasedimentary rocks were encountered in the lowermost part of the drill hole together with tens of metres thick mylonites that are, unexpectedly, rich in large garnets. The tectonostratigraphic position is still unclear and geological and geophysical interpretations are under revision. The compact gneisses host only 8 fluid conducting zones of limited transmissivity between 300 m and total depth. Downhole measurements suggest an uncorrected average geothermal gradient of ~20°C/km.

The drill core has been documented on-site and XRF scanned off site. During various stages of the drilling, the borehole has been logged by comprehensive downhole measurements. This operational report provides an overview over the COSC-1 operations from drilling preparations to the sampling party and describes the available data sets and sample material.

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Coordinates of main spot: 63.4063, 13.203057

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2. The Caledonides – the world's major mid Paleozoic mountain belt

The Caledonides of western Scandinavia and eastern Greenland (Fig. 1) have long been recognised to have been part of a collisional orogen of Alpine-Himalayan dimensions, essentially the result of the closure of the Iapetus Ocean during the Ordovician and subsequent underthrusting of continent Laurentia by Baltica in the Silurian and Early Devonian during Scandian collisional orogeny. Several hundreds of kilometres of thrust emplacement of allochthons have been demonstrated, E-directed in the Scandes and W-directed in Greenland. In both the Scandinavian and Greenland Caledonides, the allochthons that originated from the outer parts of the continental margins were subjected to high-grade metamorphism and emplaced apparently hot, onto the adjacent platforms (c.f. Gee et al., 2008). Baltica, as the smaller of the two paleo-continents involved in the collision (referred to as Scandian Orogeny in the North Atlantic region), played a similar role to that of India in the present-day Himalaya-Tibet context.

2.1. The Scandinavian Caledonides

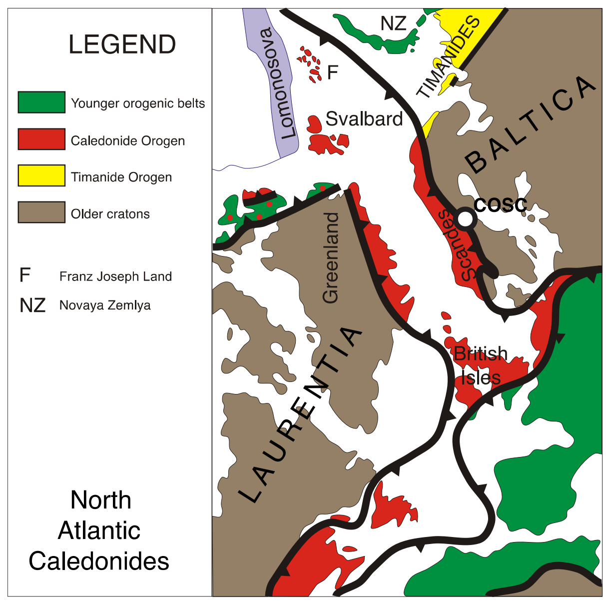

Figure 1: The Caledonides prior to opening of the North Atlantic Ocean. The project area is marked. Map modified from Lorenz et al. (2012).

The Scandinavian Caledonides comprise thrust sheets transported onto the Paleozoic platform successions of the Baltoscandian margin of Baltica (Fig. 2). The Caledonian front is marked by a sole thrust that dips 1-2° westwards beneath the orogen, underlain by a thin veneer of Cambrian (locally Ediacaran) sedimentary rocks that unconformably overlie Proterozoic crystalline basement. The thrust sheets are subdivided into the Lower, Middle and Upper and Uppermost allochthons (Gee et al., 1985). The Lower Allochthon (Jämtlandian Nappes) is dominated by a sedimentary succession of Neoproterozoic and Cambro-Silurian strata, featuring westerly-derived turbidites in the Ordovician and Silurian. Only minor basement-derived units are incorporated in eastern parts of this allochthon (Greiling et al., 1998), but towards the west, seismic profiling suggests that the basal décollement passes beneath the crystalline basement exposed in windows (Palm et al., 1991; Juhojuntti et al., 2001). The Middle Allochthon is of higher metamorphic grade than the underlying units (Andréasson and Gorbatschev, 1980). In most areas it contains a basal basement-derived thrust sheet (e.g. the Tännes Augen Gneiss Nappe), overlain by greenschist facies Offerdal Nappe metasandstones, composing the footwall for the remarkable Särv Nappe (Strömberg, 1961) with its abundant c. 600 Ma dolerite dyke-swarms. The sedimentary host-rocks are composed of neoproterozoic sandstones with subordinate carbonates and tillites (Kumpulainen, 1980). The uppermost tectonic unit in the Middle Allochthon (Andréasson and Gee, 2008; Gee et al., 2008) previously included in the Upper Allochthon, is the Seve Nappe Complex, composed in most areas of three units (Sjöström, 1983; van Roermund, 1985; Bergman and Sjöström, 1997): a lower part of similar protolith to the Särv Nappe, but ductilely deformed in amphibolite (locally eclogite) facies; a central part (e.g. Åreskutan Nappe) of migmatites and paragneisses (Arnbom, 1980) with a previous ultra-high pressure metamorphic history (Klonowska et al., 2015); and an upper, amphibolite-dominated unit with mica-schists and psammites. The high-grade metamorphism and leucogranite intrusions of the Seve Nappes have yielded early Silurian ages (Gromet et al., 1996; Williams and Claesson, 1987; Ladenberger et al., 2014). The entire Middle Allochthon was derived from west of the Norwegian coast and the upper units transported at least 400km eastwards during Scandian orogeny (Gee, 1978). The tectonostratigraphically highest rocks in Jämtland are the Köli Nappes in the Upper Allochthon. This low to high greenschist facies unit contains basal slices of ophiolite (e.g. at Handöl) and is dominated by sedimentary rocks of Early Paleozoic age (Kulling, 1933). The Uppermost Allochton, metasedimentary and carbonate rocks inferred to be derived from the Laurentian margin, are only exposed farther to the northwest in the mountain belt.

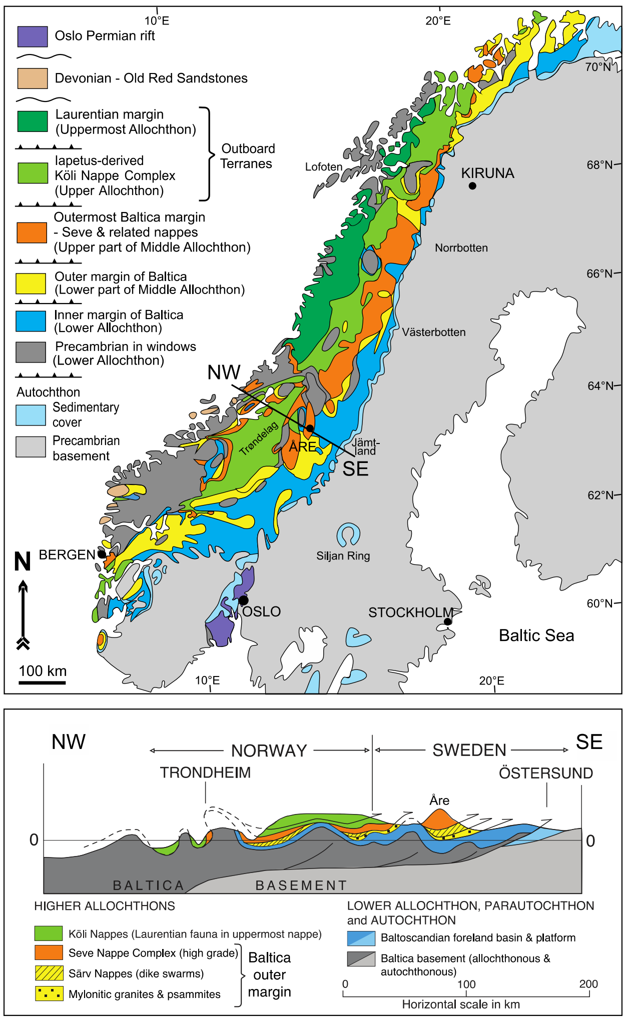

Figure 2: Tectonostratigraphic map of the Scandinavian Caledonides and sketch section along the geotraverse from Östersund to the Norwegian coast. Modified from Gee et al. (2010).

3. Scientific objectives

The COSC project aims to study mountain building processes at mid-crustal levels in a major orogen, in particular the transport and emplacement of subduction-related high-grade allochthons with focus on the Seve Nappe Complex. During the last four years of preparation for the drilling, following the initial COSC workshop in 2010 (Lorenz et al., 2011), investigations of the Seve Nappe Complex in the Jämtland area have improved our understanding of the subduction systems that existed along the Baltoscandian margin during Ordovician closure of the Iapetus Ocean. UHP metamorphism was recognized in both the lower and middle parts of the Seve Nappe Complex in northern Jämtland (Janák et al., 2013) and the mid Ordovician age confirmed (Root and Corfu, 2012). In central Jämtland, both in the Åreskutan Nappe and fifty kilometres farther west in the correlative Snashögarna Nappe (Majka et al., 2014; Klonowska et al., 2015), microdiamonds were discovered in garnets of the “granulite facies” migmatitic gneisses. These discoveries have profound implications for our understanding of Caledonian Orogeny in Scandinavia and for the interpretation of high grade rocks in the orogen particularly those in the deeper structural levels of the hinterland (e.g. in the Western Gneiss Region of southern Norway) where basement and allochthonous cover were subducted a second time in the early Devonian, during the final phases of Scandian collision.

Topical working groups developed the scientific objectives of the COSC scientific drilling project. Major targets are:

- to establish a coherent model of mid Paleozoic (Scandian) mountain building and to apply these new insights to the interpretation of modern analogues, in particular the Himalaya-Tibet mountain belt
- to determine the origin of observed seismic reflections and constrain geophysical interpretations in order to use this information to further our understanding of the geological structure of the mountain belt and the Fennoscandian basement
- to refine knowledge on climate change at high latitudes (i.e. Scandinavia), including historical global changes, recent paleo-climate development (since last ice age)
- to understand the hydrological characteristics of the geological units and research present groundwater circulation patterns of the mountain belt
- to analyse the extent, functions and diversity of microorganisms in the drill hole as a function of the different penetrated geological strata and their depth

4. Strategy

Two wireline fully cored drill holes, each to c. 2.5 km depth, can penetrate through the tectonic stack from the high-grade Lower Seve Nappe and well into the Baltican basement. COSC-1, near Åre, was finished during 2014 (this report) and has a focus on the Middle Allochthon with its inverted metamorphic gradient, thick ductile shear zones and mylonites (Fig. 3). At the top of the mountain Åreskutan, granulite facies gneisses of the Åreskutan Nappe are exposed. These rocks can be followed downwards, along the slopes of Åreskutan into the underlying, amphibolite facies gneisses of the Lower Seve Nappe. There, the COSC-1 drill site is located, which provides a nearly complete section through the Lower Seve Nappe and into the underlying thrust zone. COSC-2 will begin drilling in units of similar tectonostratigraphic position as those in the deepest parts of COSC-1. Thus, its geographical location will be farther east towards the thrust

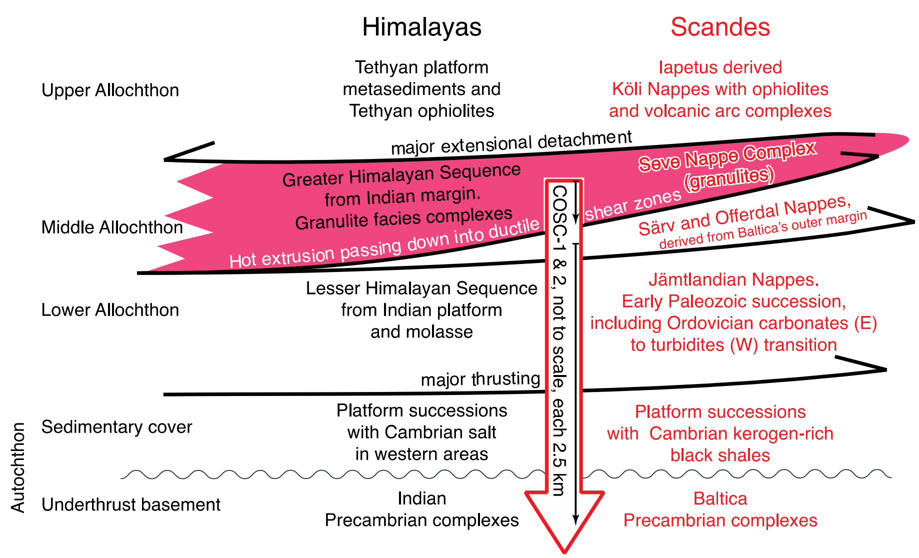

Figure 3: Schematic comparison of tectonostratigraphic units between Himalayas and Scandes with COSC-1 and COSC-2 indicated.

front. COSC-2 will investigate the composition, metamorphism and structure of the Lower Allochthon, the basal décollement, footwall alum shale and underlying Precambrian basement (Fig. 3).

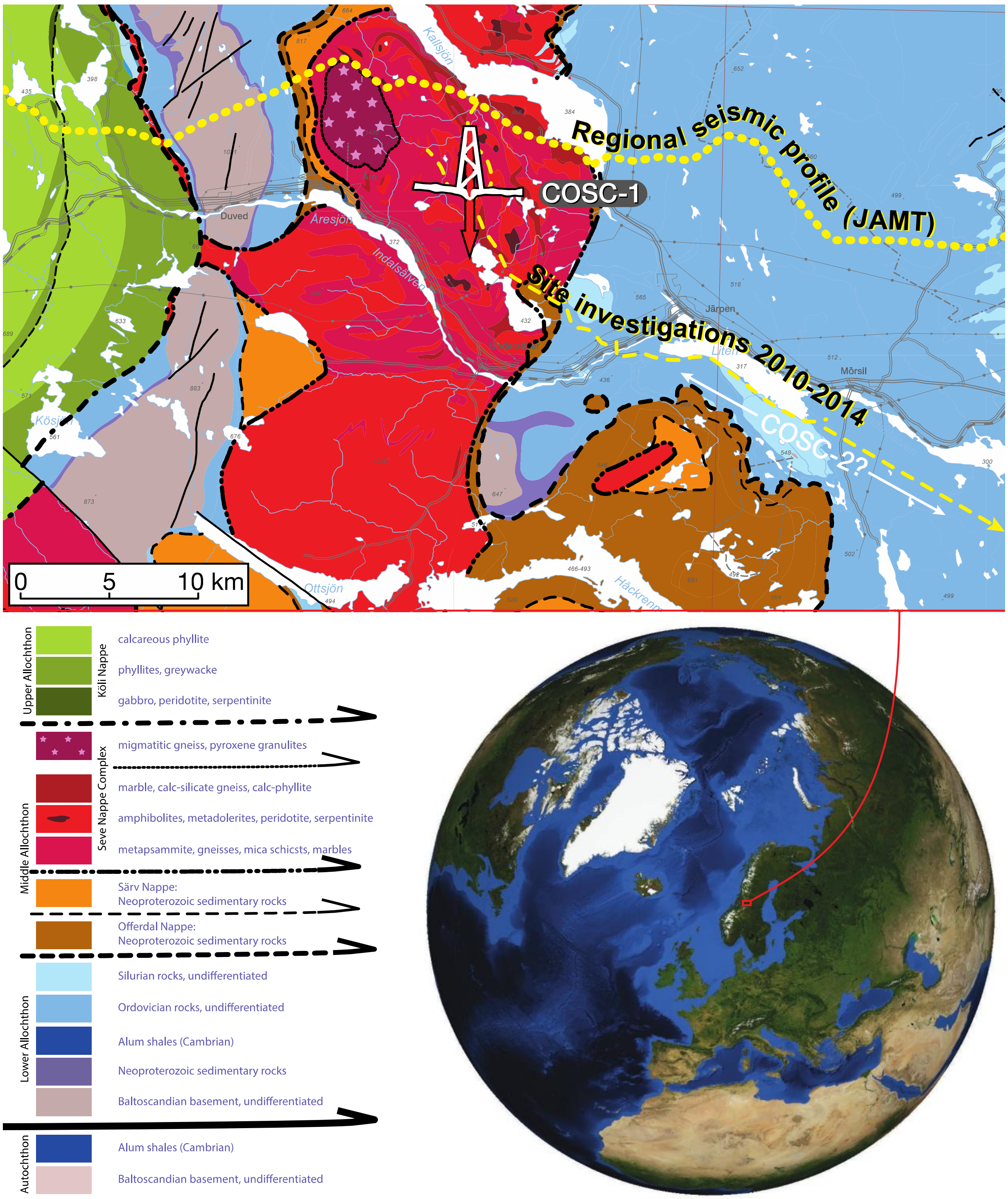

Figure 4: Tectonostratigraphic map of the Åre-Järpen area (based on the 1:200.000 scale geological map by the Geological Survey of Sweden). The map shows the COSC-1 drill site and relevant geophysical surveys in relationship to the tectonic units of the Scandinavian Caledonides.

4.1. COSC-1 site selection

To determine the optimal location for the COSC-1 drill site (Fig. 4), a high-resolution reflection seismic survey was carried out in 2010 and extended in 2011. Details on the 2010 survey can be found in (Hedin et al., 2012). The scientific criterion for the selection of the drill site was to sample an as thick-as-possible section of the Lower Seve Nappe before penetrating through the thrust zone and into the underlying nappes. Technical criteria were accessibility (the drill site is located just besides a minor road), access to the electrical power grid at the Fröå mining museum and that the landowner, Åre municipality, was very positive to the scientific drilling project.

4.2. COSC-1 drilling strategy

Continuous core drilling with triple-tube core assemblies was planned to a target depth of 2500 m, which according to the available site surveys and their interpretations is in the rocks underlying the Seve Nappe. Triple-tube core assemblies include an inner aluminium liner that protects the drill core from mechanical actions of the drill string and inner tube (Fig. 5), making it particularly suitable for drilling in fractured rock. For COSC-1, triple tube was chosen because of the unknown rock quality in the fault- and thrust-zones that were expected within and below the Lower Seve Nappe. H-size drilling (61 mm core/96 mm hole diameter) was chosen for the upper part of the drill hole, beginning at the lower end of the conductor casing (103 m). At 1600 m, or earlier if required by technical circumstances, drilling was planned to continue with the smaller N-size (45 mm core/75.7 mm hole diameter) to target depth, with the H-size drill rods left in the hole as a temporary casing. This strategy was designed to provide the COSC science team with an (below 103 m) uncased drill hole, i.e. allow access to the formation at any depth. Downhole surveys were planned for depth of c. 700 m, 1600 m (change of drilling dimension) and total depth (TD).

Figure 5: The first drill core (bedrock in the lower part, cement in the upper part) was pushed out of the inner tube of a triple tube core barrel assembly. Clearly visible is the split aluminium liner that protects the drill core from external forces. The second tube is also called core barrel, and the third tube is the drill string, hence "triple tube".

5. Preparations

The timing of the COSC operations is summarised in Table 1. The drill site was constructed by a local entrepreneur Brattlands Åkeri AB adjacent to a public road. Thus, no access road was built. A surface area of approximately 1050 m^2 (30 m x 35 m) was cleared of trees and bushes. The original topsoil was removed and stockpiled on the sides of the drill site. The site was constructed from local compacted soil materials and covered with gravel and angular crushed rock from a local quarry size 0-80 mm and levelled with gravel and angular rock size 0-40 mm. A geotextile was placed on the compacted soil material. The ground below the drill rig was reinforced with gravel and angular rocks, 0-200 mm, from the top of the bedrock up to the designed ground level. A circular cellar construction was built by placing

Table 1: COSC-1 operations by time

Date	Task
12th to 21st August 2013	Construction of the drill site
2nd to 5th September 2013	Installation of conductor casing to 103 m
March & April 2014	Mobilization
28th April 2014	Start of drilling operations
1st May 2014	First core on deck
1st to 28th May 2014	HQ3 drilling to 767 m
28th to 30th May 2014	Downhole logging
30th May to 8th July 2014	HQ3 drilling to 1616 m
8th to 14th July 2014	Downhole logging and installation of HQ3 temporary casing
14th to 18th July 2014	NQ3 drilling to 1709 m
18th to 19th July 2014	NRQ V-wall drill string replaced by NRQ standard drill string
19th July to 26th August 2014	NQ drilling to TD (2496.8 m)
3rd September to 16th October 2014	Downhole logging and major VSP and surface seismic survey
September to December 2014	XRF scanning by Minalyze AB
2nd to 6th February 2015	Sampling party at BGR core repository, Berlin, Germany

two concrete rings, inner-diameter 1.2 m, around the position for the planned COSC-1 borehole (5054-1-A).

Electricity for the drill site, mainly used for cabins, illumination, smaller pumps, etc. was supplied by the power grid. A temporary 300 m long electric cable was laid out between the closest transformer and the drill site (63 A at 400 V). A small creek located around 50 m away from the drill site supplied water. Wastewater was disposed of by truck.

5.1. Installation of conductor casing

The conductor casing was installed by a local drilling company Jämtborr AB. Initially a 3 m long surface casing with an outer diameter (OD) of 193.8 mm and an inner diameter (ID) of 183.8 mm was installed. Thereafter a hole with 165 mm diameter was drilled down to 103 m using a 5-inch down-the-hole (DTH) hammer. No problems with borehole stability or water production zones were observed during the drilling. The conductor casing (OD 139.7 mm/ID 129.7 mm) was later installed using a casing advancement method called ODEX115 and cemented from the bottom to the surface. Since no return of cement was observed in the casing annulus, cement was added into the annulus from the surface.

Table 2: Location of the boreholes on the COSC-1 drill site obtained by differential GPS, geodetic datum WGS84 (EPSG:4326).

Name	Designation	Driller's depth [m]	Latitude	Longitude	Elevation [m a.s.l.]
COSC-1	5054-1-A	2495.8	N63.401629°	E013.202926°	522.8
Observation 1	5054-1-B	100	N63.401788°	E013.202924°	522.5
Observation 2	5054-1-C	50	N63.401762°	E013.202819°	522.5

Two additional drill holes to 100 m (5054-1-B) and 50 m (5054-1-C), respectively were drilled, equipped with seismometers and cemented for passive monitoring of the drilling operations. The exact locations of all drill holes are given in Table 2.

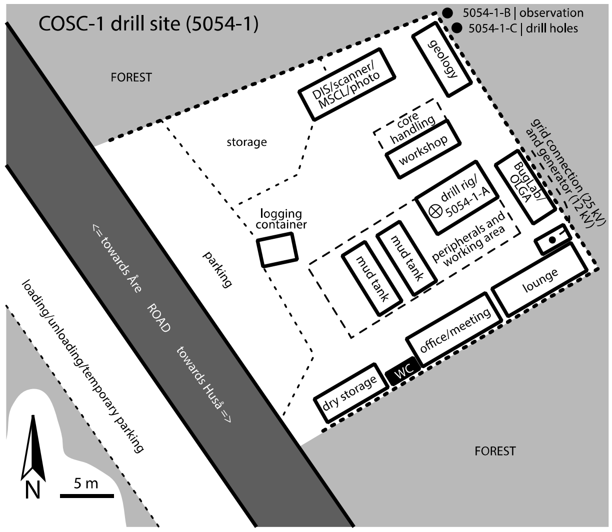

Figure 6: Sketch of the COSC-1 drill site.

5.2. Mobilization

In late March, the snow was cleared from the drill site and all heavy equipment mobilized during the first half of April, i.e. before the frost left the ground and the local road became impassable for heavy traffic. Technical and scientific site installations were established during the second half of April. Altogether, eight truckloads were needed for the drill rig, drilling and scientific equipment and containers.

5.3. Site Overview

The working area of the drill site is nearly quadratic with an area of about 1050 m^2 (Fig. 6). The drill rig, the combined mud tanks and manual pipe handling system and some peripherals such as workshop and mud mixer formed the central part of the drill site. In immediate proximity to the northwest, the BugLab container (Mangelsdorf and Kallmeyer, 2010) was located. It hosted OLGA, the on-line gas monitoring system (Erzinger et al., 2006; Wiersberg and Erzinger, 2011) and provided space for microbiological work and mud sampling. The southeastern part of the drill site was occupied by common facilities and office space. In the northern quarter of the drill site, the on-site science was located. The remaining space was used as storage space for drill rods, logging equipment, and drill core and for parking.


Figure 7: The "Riksriggen" drill rig with the manual pipe handling system on top of the mud tanks and c. 1400 m of HRQ drill pipe.

6. Technical operations

The technical operations were coordinated by Lund University, Sweden.

6.1. Drilling equipment

The Swedish national research infrastructure for scientific drilling, the so-called "Riksriggen", is operated by Lund University and financed by the Swedish Research Council (Vetenskapsrådet). The drill rig is a crawler mounted Atlas Copco CT20C. It can handle the three common sizes P, H and N (123/85 mm, 96/63 mm and 76/48 mm hole/core diameter) with depth capacities of around 1050 m, 1600 m and 2500 m, respectively. These capacities assume a vertical water-filled hole and are based on the rig's lifting capacity of 178 kN. Maximum torque is 6245 Nm and maximum spindle speed is 1300 rpm. The rig's mud pump is a Trido140 with a maximum capacity of 140 l/min and a pump pressure of 70 bar. The drilling fluid was recirculated. The volume of the two mud tanks was around 20 m^3. The "Riksriggen" is specially equipped with a data acquisition system (see below) and a torque limiter, but not yet with an automatic rod handling system. A manual rod handling system was constructed at the drill site and welded on top of the mud tanks (Fig. 7). The drill rods were stored in 9 m lengths. A 5'' annular BOP (Fig. 8) was used during the COSC-1 drilling operations.

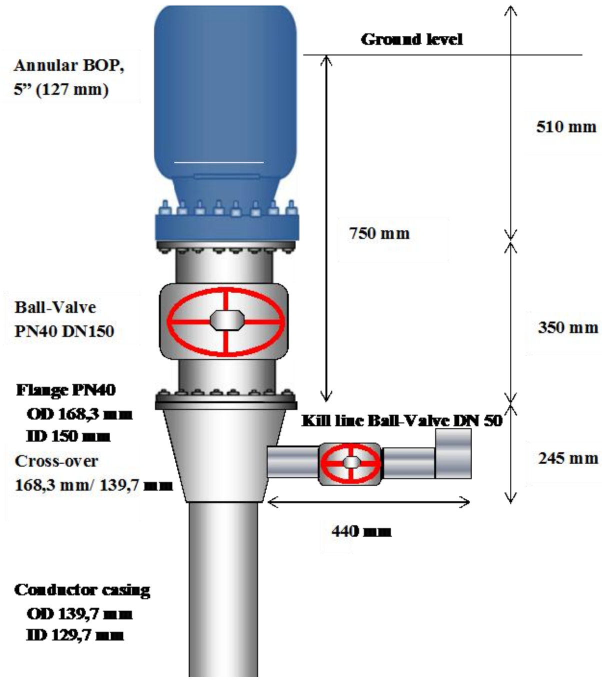

Figure 8: Sketch of the COSC-1 wellhead. A 5'' annular Blow Out Preventer (BOP) was attached on top of the main valve, a DN150 ball valve. A DN50 ball-valve was used for the kill line.

6.2. Drilling

Drilling operations started on 1st of May 2014 and were completed on 26th of August 2014. Driller's depth of COSC-1 is 2495.8 m.

6.2.1. Drilling crew

A Swedish drilling company, Prospekteringsteknik i Norr AB (Protek Norr), was the drilling contractor. Drilling operations were conducted 24h/day with initially two drillers per 12 h shift and three drillers below 545 m driller's depth (after two weeks of drilling). Initially each shift worked six days, beginning on Monday evening. The non-drilling day was used for maintenance and borehole testing. From the 4th of August, the drilling crew worked 7 days a week. Personnel from Lund University and Larsson Drilling Consulting AB supervised the drilling operations on a daily basis.

6.2.2. Start-up

The triple-tube H-size core barrel assembly was used to drill through the cement plug in the lowermost part of the conductor casing and into bedrock (gneiss) down to 109.7 m. To reduce the annulus between the HRQ-drill string and the conductor casing, a HWT-casing (OD 114.3 mm/ID 101.6 mm) with an over-sized casing shoe was installed down to the conductor casing shoe and cemented from bottom to the surface. The small annulus between H-size drill rods and the HWT casing reduces the risk of damage to the drill rods and guarantees an efficient transport of the cuttings to the surface. The wellhead passed the pressure test after some minor adjustments to the seals.

6.2.3. Description of core drilling

Wireline core drilling with the following core assemblies was used (inner tube sample length, core diameter, hole diameter):

- H-size triple-tube core barrel assembly (3 m/61 mm/96 mm)
- N-size triple-tube core barrel assembly (3m/45 mm/75.7 mm)
- N-size double-tube core barrel assembly (6 m/47.6 mm/75.7 mm)

A double-tube assembly consists of an outer tube (drill string) with an inner tube (core barrel) that captures the core sample. The triple-tube has an additional split tube ("core liner") placed inside of the inner tube (Fig. 5). The inner tube is equipped with a spearhead and release mechanism at the top for retrieval and with a core lifter at the bottom. The drill bit and reamers are attached to the outer tube.

Core drilling progresses until the inner tube is full. The driller terminates the drilling and lifts the drill string to break the core at the bottom of the drill hole. An overshot is then lowered into the drill pipe on a wireline cable and the inner tube retrieved. Afterwards, a new inner tube is pumped down the drill string. At surface the retrieved inner tube is emptied and the core handling starts.

6.2.4. HQ3 core drilling (103 - 1616 m)

The progress of HQ3 core drilling was in the order of 30-60 m/day when neglecting interruptions by other activities such as bit change, servicing or testing (Appendix A). Lightweight drill rods with reinforced threads (HRQ V-wall, OD 88.9 mm, ID 77.8 mm, weight 27.4 kg/3 m), diamond impregnated drill bits and surface set reamers on top of the drill bit were employed. Below 770 m, a so-called rod reamer was attached between the core barrel assembly and the drill rods. In addition, full-hole locking couplings and fluted/broached core lifters were used. The drilling fluid down to 500 m was fresh water. From 500 m to 1616 m a biodegradable polymer (Atlas Copco Supermix) was added to reduce the friction between the drill string and the borehole walls and to improve the removal of cuttings.

Drilling parameters were recorded manually for each core run: rotations per minute, rate of penetration, weight on bit, pumping rate and pump pressure (Appendix A). From 1100 m to TD, the data acquisition system was continuously recording the same drilling parameters as above, except for the pumping rate because of sensor problems.

6.2.5. Problems with HQ3

The brand-new drill rods were bent beyond tolerance already before the first use. This resulted in high friction between the drill string and the borehole wall and a much higher torque than expected under normal conditions. Thus, the drill rig was not able to perform according to the drill bit specifications, performing at only 400 rpm instead of the recommended 750 to 950 rpm. As a consequence, the rate of penetration had to be limited and the drill bits wore out faster than normal, which delayed the drilling operations.

6.2.6. HQ3 casing

After HQ3 drilling was completed, the drill string was pulled out of the hole and the core barrel assembly removed and replaced with a rod shoe. Thereafter the HRQ-drill string was installed as temporary casing from surface down to 1616 m, i.e. the casing/drill string was not cemented to allow for removal after drilling was finished. The annulus between the HRQ-drill string and the already installed HWT-casing was sealed off inside the wellhead to avoid sedimentation of cuttings into the annulus.

6.2.7. Drill bits

21 drill bits were used during HQ3 drilling (Appendix B). This high consumption was mainly due to the low rotational speed, as explained above. The maximum drilled interval by one drill bit was around 173 m and the minimum around 13 m. The bit that lasted only 13 m was damaged during the retrieval of a core drop (loose core pieces smash the drill bit). The average drilled interval was approx. 72 m/drill bit.

6.2.8. NQ3 core drilling (1616 - 1709 m)

After installation of the HQ3 drill string as temporary casing, drilling continued with N-size triple-tube core barrel assembly. Low rotational speed caused by bent drill rods was the major problem. The coring progress with NQ3 was in the range of 24-33 m/day, excluding drilling breaks. Lightweight drill rods with reinforced threads (NRQ V-wall, OD 69.9 mm, ID 62 mm/60.3 mm, weight 20.7 kg/3 m), diamond impregnated drill bits (Atlas Copco Excore) and surface set reamers were employed. A standard reamer was placed above the drill bit and a surface set adapter coupling replaced the standard adapter coupling above the core barrel assembly. In addition, standard locking couplings with ground carbide pads and fluted/broached core lifters were employed. The drilling fluid was the same polymer based mud as in the lower part of the HQ3 drilling. Drilling parameters were also recorded in the same way.

6.2.9. NQ drilling (1709 - 2495.8 m/TD)

At 1709 m, it was decided to use a double-tube core barrel assembly that could sample 6 m of core in order to save time compared to using one that samples only 3 m (30-40 % faster). Given the excellent rock quality it was expected that good core quality would be obtained even with double-tube drilling. NRQ V-wall drill rods were used down to 1965 m. At this depth, the drill string was replaced with standard NRQ drill rods (OD 69.9 mm, ID 60.3 mm, weight 23.4 kg/3 m). The types of drill bits and reamers were similar to those used with NQ3. Below 2000 m a second polymer, Atlas Copco Superdrill, was added to the mud to reduce friction. Drilling parameter acquisition continued without changes. The coring progress using NQ was in the order of 36 m/day, excluding drilling breaks.

6.2.10. Problems during the NQ3 and NQ drilling

New NRQ V-wall drill rods were used for the drilling. To avoid a repetition of the problems that occurred during HQ drilling, each rod was checked for deformation before it was attached to the drill string. Despite this effort, also these rods became deformed with problematic low rotational speed as a result (300 to 400 rpm instead of recommended 900 to 1200 rpm). The manufacturer was contacted about this issue and replacement rods were dispatched to the drill site. These rods were standard type, not lightweight V-wall rods.

The complete drill string was replaced with the new rods at 1965 m. Initially the rotational speed was around 900 rpm, but decreased rapidly to 300-400 rpm. During the next drill bit change it became clear that those drill rods that were inside of the temporary casing while drilling were deformed, but not those in the open hole below. A possible explanation is that the new drill rods were deformed due to the design of the HRQ V-wall drill rods, where the inner diameter is smaller at the rod-joints compared with the mid-body. However, this has to be investigated further before a final conclusion can be drawn.

Another problem occurred at 2196 m when the rotation unit broke down. A replacement unit was immediately sent to the site and the repairs were finished within 2 days.

6.2.11. Drill bits

Nine drill bits were used during N-size drilling, two NQ3 and seven NQ drill bits (Appendix B). The high consumption of drill bits was mainly due to the low rotational speed. An attempt to compensate with a higher pump rate may also have contributed to the high wear rate between 1935 m and 2035 m. The mud system needs to be improved since fine rock fragments may have been recirculated with increased wear on the equipment, including the drill bit, as a result. The maximum drilled interval of a drill bit was around 288 m (to TD) and the minimum around 12 m - also here due to damage caused during the retrieval of a core drop. The average drilled interval for the drill bits was around 46.5 m/NQ3 drill bit and 112 m/NQ drill bit. The time for changing the drill bit at 2000 m was around 24 hours.

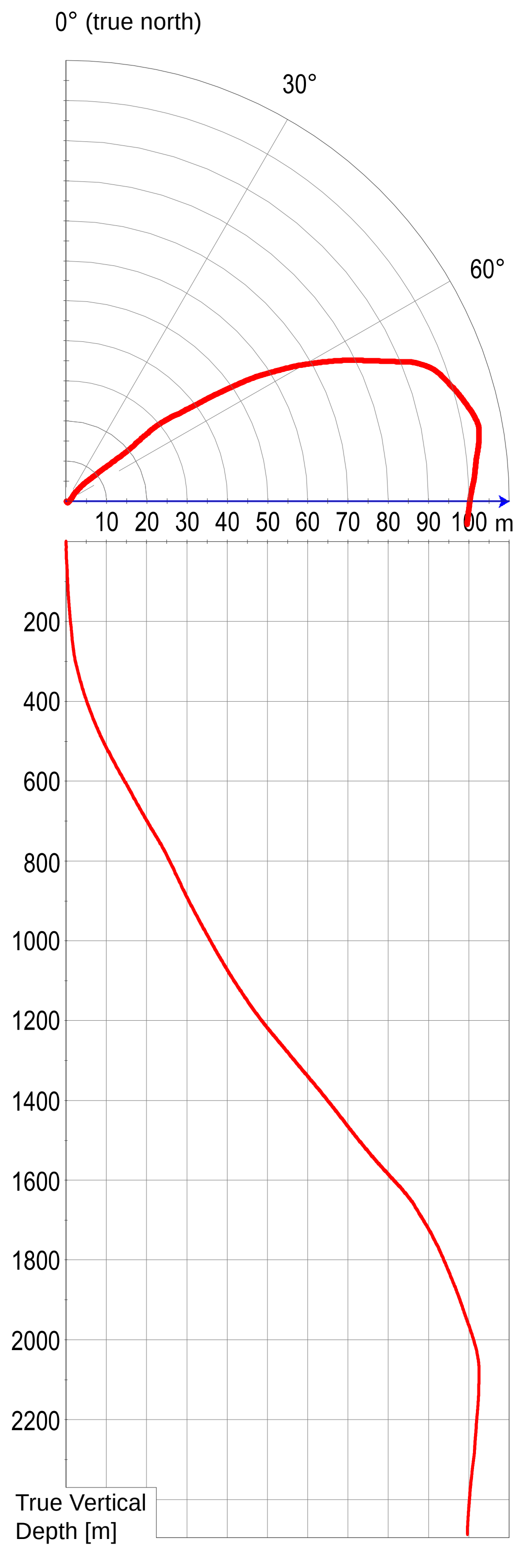

Figure 9: The COSC-1 drill hole deviation, seen from above (with azimuth) and plotted vs. depth. 10 x horizontal exaggeration.

6.2.12. Drilling activities after TD

After reaching TD the NRQ-drill string was placed on the bottom of the hole and disconnected at the surface. Thereafter the HRQ-drill string (the temporary casing) was successfully retrieved and the mud-column replaced with freshwater through the NRQ-drill string. An end of hole deviation survey was conducted while the NRQ-drill string was pulled out of the hole. The drill hole has very small deviation (Fig. 9).

6.2.13. General comments about the drilling

To drill almost 2400 m with full core recovery while retrieving top quality cores is exceptional. In addition, no cementation was carried out during the entire core drilling operation and no drilling crew accidents were reported.

Despite the major problem with deformed drill rods the target depth was reached. However, with a considerable delay because of slower penetration rates and more frequent round trips to replace the drill bit. Unfortunately, dedicated triple-tube drilling for microbial samples had to be omitted because of the unavoidable switch to faster double tube drilling.

The COSC-borehole is the deepest drilled hole in Sweden using H- and N-size and the deepest hole drilled by this type of drill rig, an Atlas Copco CT20C. The borehole is cased down only to 103 m, the rest, around 2400 m, is left as an open-hole completion.

6.3. Wireline packer testing

Hydraulic testing using wireline packers was attempted but failed. Initially, a leaking packer delayed the test, but also a second attempt with the aim to test an inflow zone around 1250 m (identified by FFEC-logging) failed. The experiment was terminated when the stock of spare parts was depleted.

7. Scientific operations

The scientific operations were coordinated by Uppsala University, Sweden. The on-site scientific work was performed in two 12 h shifts per day. Normally, three scientists were on-site at any time during the operational phase. Two groups were rotating on a 10-day schedule, partly with changing personnel. The first group began its work on the 26th of April 2014, two days before planned spud in, and the last scientists left the drill site on the 29th of August 2014. The complete on-site scientific work from mobilization to demobilization is estimated to about 4.75 man-years. The personnel are listed in chapter 1.

7.1. Workflow drill core handling

The on-site science team received the drill core from the drilling team at the drill rig, noting top

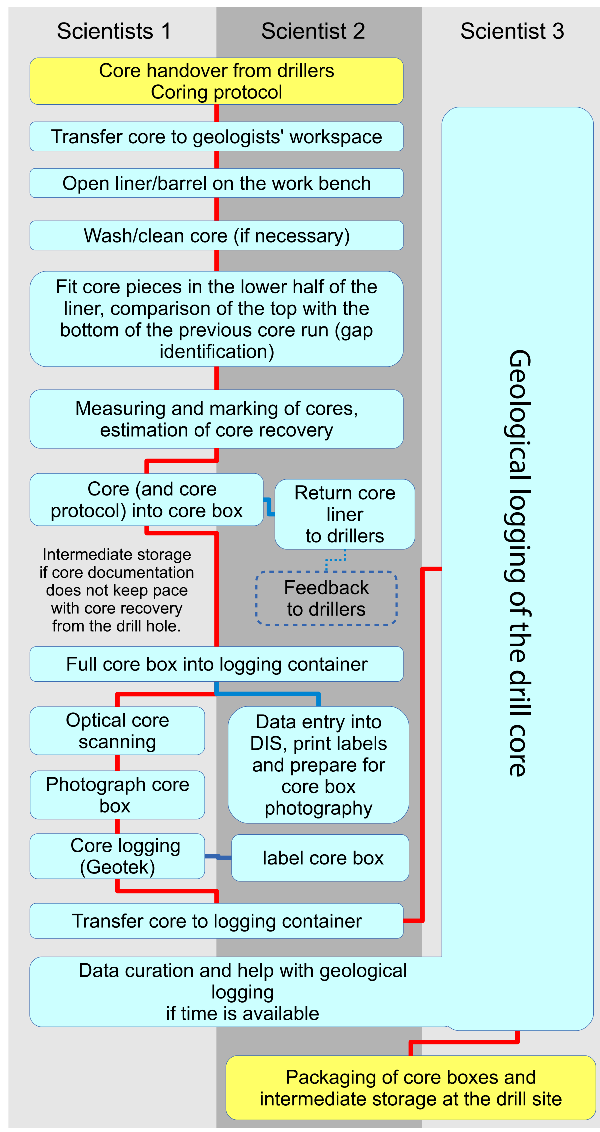

Figure 10: Flowchart over the COSC-1 drill core handling workflow.

and bottom depths and possible comments on the core run protocol. For cores drilled with 3 m triple tube core assemblies, this was done on the pipe handling rack, where the drill core in its aluminium split-liner was hydraulically extracted from the inner tube (Fig. 5). The closed liner was then transferred to the geologist's core handling table for further processing (Fig. 10). The 6 m core barrel assembly had to be split in two halves. To guarantee that core extraction without an inner liner was done in the most careful way, the drilling team removed the core from each half of the inner tube piece by piece, handing them immediately over to the science team who placed them in empty core liners (from the triple tube system), always under rigorous control of top and bottom. In this way, the drill cores from the double and triple tube systems could be processed in the same way.

At the geologist's working table, the core pieces were restored to their original position (with few exceptions where this was not possible) and marked with two coloured lines for orientation (red line on the left when looking downwards, and blue). Not until this was finished were the other tasks performed. These were (1) measuring the total length of the drill core along the red line, (2) washing with a sponge and clear water and subsequent drying with a paper towel (usually enough since the only additive in the drilling fluid were biodegradable polymers) and (3) placing the drill core into core boxes.

From the geologist's working table, full core boxes were transferred to the first science container. Here the core run protocol was scanned and archived, and its data together with information about the core's position in the respective core boxes was registered in the Drilling Information System (DIS). Unrolled core scans were acquired for each section after drying with a hair dryer and the images were added to the DIS. Afterwards, each core box was photographed on a repro-stand and the photos added to the DIS. Colour profiles were calculated along each core section with the help of a GNU Octave script. Subsequently, geophysical parameters of the core sections were logged on a Geotek MSCL-S core logger (provided by ICDP).

For the last step of core documentation, the core boxes were transferred to the second science container where a working place for geological drill core logging was installed. The geologists entered this description directly into the DIS. Finally, the core boxes were packed for transport and temporarily stored at the drill site.

7.2. Sampling

All samples in the COSC scientific drilling project are marked with an International GeoSample Number (IGSN), a hierarchical unique identifier that is used to track samples and relationships between samples (see also http://www.geosamples.org/igsnabout).

On-site sampling of the drill core was very restricted and only permitted for the following purposes: study of changes in thermal conductivity in relation to time after drilling (sample to be returned), matrix gas extraction and analysis (samples have been returned), microbiology (destructive). In addition, the on-site science team took DNA and ATP swab-samples on fracture surfaces. The tracer used for microbiology was fluorescein dye. More advanced setups to employ tracers together with NQ triple tube drilling were ready for employment, but not used due to the strategic decisions to only use the faster double tube drilling in the lower part of the drill hole.

7.3. Mud logging

Due to the relative simplicity of the mud composition, mud logging was restricted to pH, temperature and conductivity measurements every four hours. A sample was taken every eight hours. The mud samples are archived together with the drill core.

7.4. OLGA

The on-line gas monitoring system, OLGA (Erzinger et al., 2006), for a qualitative analysis of gas extracted from the drilling mud by mass-spectroscopy was for the first time deployed in a slim hole and diamond core drilling project. This was an experiment because the parameters are substantially different from oil-field type drilling, in which the system had successfully been deployed before (Wiersberg and Erzinger, 2011). The degasser was installed in a 10 l vessel in the cellar and directly fed with the returning drilling fluid (Fig. 11), c. 30-80 l/min depending on drilling conditions and the proportion that actually was led to the vessel. The gas flow from the degasser was controlled and adjusted to the available volume, usually between 0.5 to 1 l/min. In the laboratory, the mass-spectrometer and a sampling line were fed with the extracted gas.

Figure 11: The OLGA degasser. The test setup to the right. A drainage pipe leads the drilling fluid into a bucket with an active volume of 10 l. The fluid is degassed by a propeller in an airtight aluminium cylinder below the electric motor and the gasses are pumped from there into the laboratory container. Under deployment to the left: the drilling fluid is caught by the drainage pipe below the wellhead and returned from the bucket via the outlet into the cellar, from where it is pumped to the settling tanks.

7.5. Downhole investigations

Lund University performed several logging campaigns during drilling breaks to secure data in case of a hole loss while drilling and a comprehensive downhole logging programme to TD was planned in collaboration with the ICDP Operational Support Group (OSG). Unfortunately, OSG instruments were returned late from a previous campaign due to custom problems and, thus, several probes could not be repaired in time for COSC logging. Other probes broke down during the logging operations. The COSC-1 downhole logs are listed in table 3.

Pumping while logging temperature and electrical conductivity was done on several occasions to identify the few hydraulically conductive features in this otherwise massive rock. Fluid samples were taken at 339 m, 699 m and 1244 m.

A major post-drilling seismic survey was carried out in and around the COSC-1 drill hole, including vertical seismic profiling (VSP) in the drill hole, a sparse 3D survey centred on the drill hole and three long-offset profiles centred on the drill hole equipped with fifteen 3C geophones. The data from this survey are not part of the COSC-1 base data and will be published elsewhere.

Table 3: Summary of COSC-1 downhole logging operations

28th – 30th May at 767 m driller's depth (Lund University campaign 1)

- Calliper with natural gamma
- Electric rock resistivity short, long normal, SP, temperature, single point resistance, natural gamma
- Sidewall sonic
- Sidewall density, natural gamma, temperature
- Temperature, conductivity, natural gamma
- Temperature and conductivity while slowly pumping water out of the borehole

8th June at 1090 m driller's depth (Lund University campaign 2)

- Focussed Electric rock resistivity, to 670 m
- Acoustic borehole televiewer (because of technical problems during campaign 1)

28th – 29th June at 1465 m driller's depth (Lund University campaign 3)

- Calliper with total natural gamma
- Electric rock resistivity short, long normal, SP, temperature, single point resistance, total natural gamma
- Acoustic borehole televiewer
- Temperature, conductivity, total natural gamma

8th to 10th July at 1616 m driller's depth (Lund University campaign 4)

- Calliper with total natural gamma
- Electric rock resistivity short, long normal, SP, temperature, single point resistance, total natural gamma
- Sidewall sonic
- Sidewall density, total natural gamma, temperature
- Temperature, conductivity, total natural gamma
- Acoustic borehole televiewer

3rd to 6th September at TD (Lund University campaign 5)

- Calliper with total natural gamma, 1600-2000 m
- Electric rock resistivity short, long normal, SP, temperature, single point resistance, total natural gamma, 1600-2498 m
- Temperature, conductivity, total natural gamma, 0-2000 m

10th to 12th September at TD (ICDP-OSG Logging I)

- Temperature, pressure, mud resistivity, total natural gamma, 5-130 m (resistivity sensor broke down at 130 m)
- Oriented borehole geometry (4-arm caliper), total natural gamma, 1600-2492 m
- Acoustic borehole televiewer, 1675-2002 m (probe did not work above 1675 m, orientation data corrupt)
- Electric rock resistivity, total natural gamma, 2-2492 m

9th to 11th October at TD (ICDP-OSG Logging II)

- Spectral gamma, total natural gamma, 5-2493 m
- Temperature, pressure, mud resistivity, total natural gamma, 5-2493 m

15th to 16th October at TD (Lund University campaign 6)

- Temperature, conductivity and natural gamma were repeatedly logged with and without pumping, 0 – c. 2000 m

8. The COSC-1 drill core and geology

The main outcome from the COSC-1 drilling project is the rock sample, the COSC-1 drill core. Core drilling in bedrock commenced at 102.7 m and was completed at 2495.8 m driller's depth. According to the scientific documentation, 2396.0 m core were recovered, resulting in a core recovery of 100.12 %. Moreover, the content of two inner tubes was lost in the drill hole because of malfunctioning core catchers and had to be “over-drilled” in order to retrieve it. In total, approx. 2.5 m drill core were unaccounted for, i.e. are documented core loss. Down to about 1800 m, the COSC-1 drill hole penetrated a succession that is dominated by gneisses of varying compositions (felsic, amphibole, calc-silicate, other), often garnet and diopside bearing. Meta-gabbros and amphibolites are common and apparently correlate with seismic reflections between 500 and 1000 m depth. Also, marbles, pegmatite dykes and minor mylonites occur. These rocks are highly strained. Small-scale structures (e.g. isoclinal folding) are occasionally discernible in the narrow section provided by the drill cores. (Young) Fractures are sparse. One obviously fluid conducting set of very steep fractures is resulting in dissolution of calcite-rich bands in the gneisses to form “micro-karst” (at about 175 m and several levels between 1200 and 1320 m).

First signs of the thrust zone below the Seve Nappe appear shortly below 1700 m in form of narrow deformation bands and thin mylonites. The mylonites increase in thickness to around 1 m between 1900 and 2000 m. Below c. 2100 m, mylonites are dominating and garnets become common (but are not present in all mylonites). The deepest rock of mafic origin (possible amphibolite in the Seve Nappe) was identified at 2314 m. A transition from gneiss into lower grade metasedimentary rocks occurs between 2345 and 2360 m. The lower part of the drill core to TD is dominated by quartzite and meta-sandstone of unclear tectonostratigraphic position that are mylonitised to varying degree. The rocks sampled in the lowermost part of the drill core are the thickest mylonites encountered, tens of metres thick and (again) rich in garnet, i.e. the drill hole does not penetrate the bottom of the thrust zone.

9. COSC-1 basic data sets

The following paragraphs describe the data sets included in the COSC-1 basic data. These data sets are listed in tables 4 and 5 and available from the COSC-1 data repository (Lorenz et al. 2015) at DOI 10.1594/GFZ.SDDB.ICDP.5054.2015. Explanatory remarks are available at the data repository.

9.1. Data sets originating from the drilling operations

A PLC (programmable logic controller) based data acquisition system is installed on “Riksriggen”. In the configuration used during COSC-1 it measured hydraulic pressure signals (feed, holdback), rotational speed, chuck position, mud flow rate (inbound), pump pressure and wireline winch position. The PLC software is coded in ST (a standard language for PLC programming), whereas the software for system control, data display, database, etc. is written in C# and run on a Windows 7 computer. While operating, the system broadcasts an XML data stream with real-time values that can be received and displayed by all computers in the local network or off-site using appropriate software. During COSC-1 operations, one string per second was transmitted and archived for later analysis in a SQL database that is physically separated from the rig computer/PLC.

9.2. Data sets based on the drill core

9.2.1. Originating from the DIS

The DIS contains descriptive information about the drilling project, primary data and links to primary data (e.g. imagery). Available data sets are:

1) Drill core metadata. Number of core run, depth, length of core run, sections, length of sections, core recovery, the location of sections in core boxes. Some 20 core runs in the lowermost part of the drill hole were oriented by a Devico Devidrill BBT device (R&D collaboration). The orientation values (based on the gravity field) are available in the comments field. The lower end of each oriented core run is marked on the upper side of the drill core. This mark is in relation to the inclination of the (deviating) drill hole.
2) The Geological description of the drill core was done continuously while drilling according to a standard form plus comments.
3) Unrolled core scans, i.e. the drill core was rolled below a line-scan camera on a DMT CoreScan3 scanner (provided by ICDP), which resulted in images of the whole drill core surface (360° around core axis) at a spatial resolution of 10 pixels/mm and a spectral resolution of 8 bit/channel. The images are available in TIFF and JPEG formats.
4) Core box images. The core boxes were photographed with a Nikon D800 camera and Zeiss Distagon T 1:2/35 mm lens. The images were developed with Rawtherapee 4 software with colour-calibration and correction for optical distortions. Core box images have an effective spatial resolution of 6.5 pixels/mm and spectral resolution of 14 bit/channel.
5) MSCL geophysical core logging was performed with the following sensors: gamma attenuation, core diameter deviation, P-wave travel time and magnetic susceptibility, resulting in processed data for: density (calculated from gamma attenuation and core diameter), P-wave velocity (calculated from an automatically picked P-wave travel time and core diameter) and magnetic susceptibility. The sensors of the MSCL were calibrated every day. All data were processed under the assumption that the drill core has the nominal inner diameter of the diamond core bit it was drilled with because of consistent problems with drift in the thickness deviation sensor. According to on-site observations, the drill core diameter deviates only under unfavourable conditions during the last few metres of bit life (up to 2 mm). Due to age and wear on the instrument and limitations by the design (a feeding mechanism that is adopted for perpendicular section boundaries), an error of several centimetres along core axis (usually 2-3 cm, but up to 7 or 8 cm in exceptional cases) might occur for each individual section. The MSCL dataset provides valuable data on rock density and magnetic susceptibility despite these problems. However, p-wave velocity values seem to be constantly very low, possibly due to the automatic picking algorithm.
6) XRF geochemical data. In a R&D collaboration, the Swedish company Minalyze AB scanned the whole drill core in their new Minalyze CS XRF scanner at their facility in Sävedalen, Sweden between September and December 2014. The dataset contains weight percent for Al_2O_3, SiO_2, P_2O_5, S, Cl, K_2O, CaO, TiO_2, Fe_2O_3 and ppm for Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb and Pb. For details refer to Sjöqvist et al. (this volume).
7) Mud parameters, manually measured with handheld instruments every four hours while drilling: temperature, pH, conductivity.

9.2.2. OLGA

Only the mass-spectroscopy line of the OLGA was deployed in the COSC-1 project. Gas was continuously extracted from the returning drilling mud and analysed with a quadrupole mass-spectrometer (Pfeiffer OmniStar) every minute for ^{36}Ar, ^{38}Ar, ^{40}Ar, CH_4, CO_2, H_2, He, Kr, N_2, O_2. Gas samples were taken from the gas line for laboratory studies on e.g. noble gas isotopes and stable isotopes. Each single core run created one specific so-called "tripgas" peak analyzed 20-30 min after core arrival on deck. With known core depth and arrival time on deck, all measured tripgas peaks could be attributed to a depth and nearly complete depth profiles were obtained from 662 m to 2490 m depth.

9.3. Data sets based on downhole surveys

The depth reference for the COSC-1 drill hole is a composite log of total natural gamma measurements from the oriented borehole geometry and electric rock resistivity logging in the ICDP-OSG logging I campaign. These reference data are located in the column "GR_DLL_Master" of the data file "5054_1_A_COSC-1_OSG_GR_RES_FTOT_CAL_ORI.txt" which is part of the data set "Composite Borehole Log Plots".

Individual, quality controlled data files are available for each downhole log acquired by Lund University. Data are provided in Log ASCII Standard (LAS) format, except for the acoustic televiewer where Robertson Geologging LGX is used. ICDP OSG logging data were compiled into several composite logs and are available in ASCII (txt) format.

The logging data were evaluated, depth-matched and compiled into a reference document for the COSC-1 drill hole, to give scientists easy access to the content. The individual depth matched logs are also available as ASCII files, the composite document in WellCAD format and as a pdf file for convenience.

Table 4: Available archive files with data sets from COSC-1

DATA	FORMATS	
All Data	XLSX	
Sites	TXT	A
Holes	TXT	A
Core Runs	TXT	A
Core Sections	TXT	A
Core Boxes	TXT	A
Core Overviews	PDF	
Lithological Descriptions	TXT	A
Sample Requests	TXT	A
Core Samples taken	TXT	A
Mud Samples taken	TXT	A
Multi Sensor Core Logging	TXT	A
XRF logging	TXT	A
Borehole Measurement Campaigns	TXT	A
Borehole Measurement Runs	TXT	A
Borehole Measurement Files*	TXT	A
Composite Borehole Log Plots	ZIP	
Drilling Time Breakdown per Day	TXT	A
Drilling Time Breakdown of Tasks	TXT	A
Drilling Technical Parameter	TXT	A
Used Drill Bits	TXT	A

* = the individual Borehole Measurement Files are downloadable from the archive system
A = is part of the 'All Data' file

Table 5: Available archive files (zip) with imagery from COSC-1

IMAGES	Low Resolution	High Resolution
Core Overviews	Hole 1-A	---
Cores	Hole 1-A, unrolled, cores 1-529 Hole 1-A, unrolled, cores 530-696	Hole 1-A, unrolled, cores 1-10 Hole 1-A, unrolled, and so on for each package of ten cores Hole 1-A, unrolled, cores 691-696
Core Boxes	Hole 1-A, core boxes 1-719	---

10. Core repository and 1st sampling party

The COSC-1 drill core is archived at the Core Repository for Scientific Drilling at the Federal Institute for Geosciences and Natural Resources (BGR), Wilhelmstr. 25-30, D-13593 Berlin (Spandau), Germany. The first sampling party was held from 2nd to 6th February 2015 at the core repository, where samples that amount to c. 110 m total length were taken for laboratory investigations.

11. Preliminary Scientific Assessment

11.1. Geology

The quality of the COSC-1 drill core is beyond all expectations. With only very minor losses caused by technical failure, it provides a complete and unique geological section through the lower part of the Lower Seve Nappe and its basal thrust zone. Regarding on-site science and core description, we conclude that it is very difficult to establish a proper geological description while drilling. Experience and knowledge from the field is not readily applicable to the drill core as geology looks different in drill core and outcrop, and the core does not necessarily contain what is expected due to its limited diameter. Thus, the geological description and interpretation needs to be complemented and modified during the coming years. The geological scientific targets of the COSC project require detailed studies. These have been initiated during the sampling party in early February 2015. In the meantime, a couple of direct observations concerning the geology can be made:

The gneisses of the Lower Seve Nappe are more homogenous than expected, in principle similar from the surface to >2000 m, but with the different lithologies (amphibolite gneisses, felsic gneisses, calc-silicate gneisses) dominating at different levels. Detailed studies will show whether this first impression of homogeneity is correct.

A major surprise is the nature of the thrust zone below the Seve Nappe. Firstly, it is much thicker than expected. After more than 800 m of drilling in it, the lower boundary was not encountered. Such a thickness has not been reported before, possibly because of poor exposure. Secondly, the mylonites contain a large proportion of garnet of considerable size (occasionally up to 1 cm). This suggests metamorphic conditions that support garnet growth late during thrusting, while the adjacent rocks are bare of garnet.

11.2. Geophysics

Two dimensional crooked line processing of the pre-drilling seismic survey over the COSC-1 site (Hedin et al., 2012) showed a highly reflective unit to be present from the near surface down to about 2.2 km (Fig. 12). Correlation of this reflective unit, and the less reflective rock below it, to the boundary between the Seve Nappe Complex and the Ordovician turbidites about 9 km to the east of the COSC-1 site suggested that the high reflectivity was characteristic of the Seve Nappe Complex itself. Later sparse 3D processing of the crooked line data indicated significant lateral variability in the reflectivity. At the location of the COSC-1 borehole it appeared that the rock was most reflective in the uppermost 1 km with a rather distinct reflection originating at about 900 m depth (Fig. 13). A gently east dipping reflection coming from about 2.1 km depth was thought to represent the base of the Seve Nappe Complex. The uppermost 500 m was poorly imaged due to the acquisition geometry. Potential field modelling (Hedin et al., 2014) also indicated the base of the Seve Nappe Complex to be at about 2 km depth at the COSC-1 site, consistent with the seismic data.

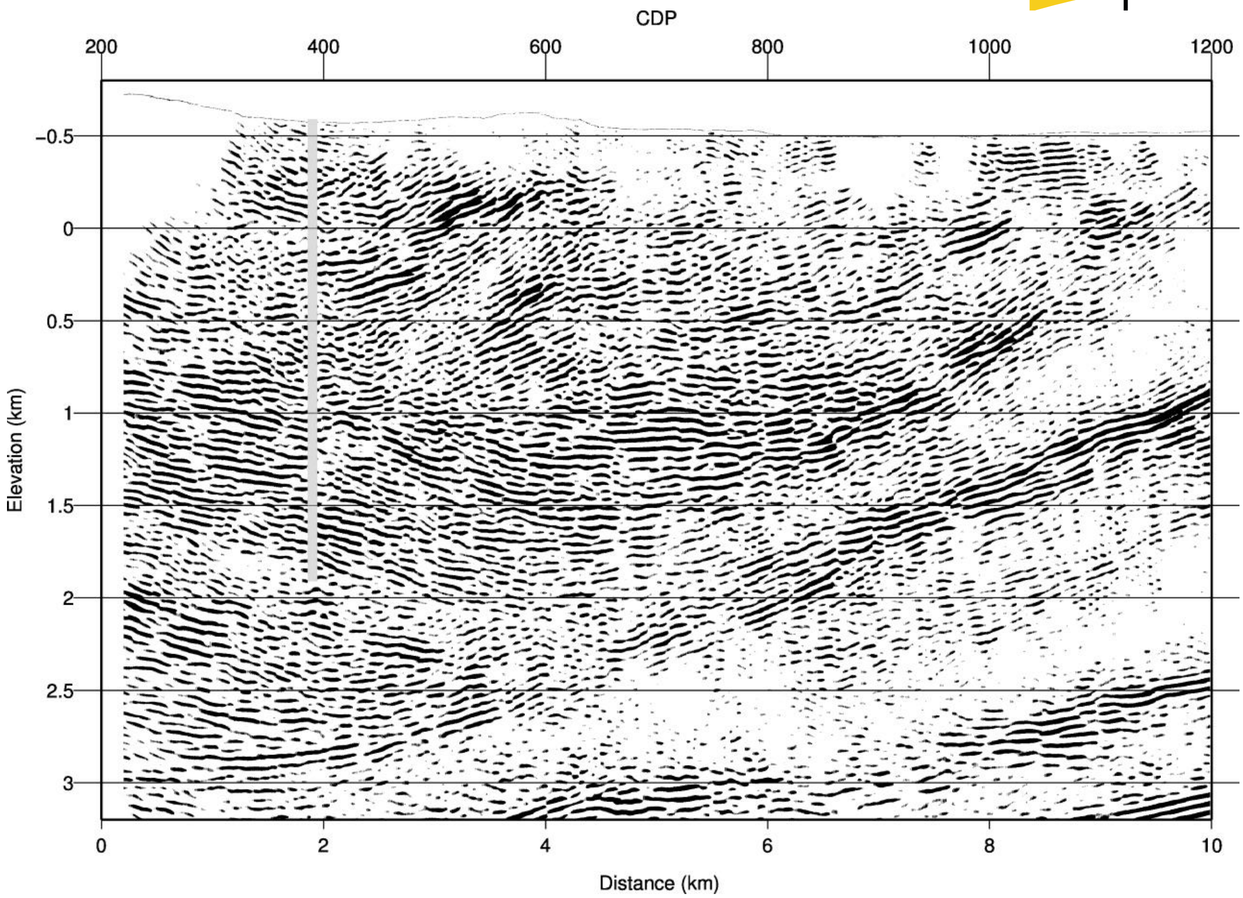

Figure 12: Seismic section from the pre-drilling seismic survey (Hedin et al., 2012)

Preliminary analyses of the geophysical logging data and the MSCL data show that the upper 1000 m contain the largest proportion of thicker units (> 15 m) of amphibolites. The interval 1000 m to 1800 m also contains a significant proportion of amphibolite, but the units are generally much thinner than above 1000 m. Below 1800 m, amphibolites are much less common. It is likely, that it is the contrast in velocity and density between amphibolite and gneiss that is generating much of the reflectivity within the Seve Nappe Complex. Given that the average velocity of the complex is 6000 m/s and that the dominant frequency in the surface seismic data is 70-80 Hz, the layers which are on the order of 20 m thick will generate the strongest reflections due to tuning. This is consistent with observations on the 3D sparse processed data, which indicate the upper 1000 m to have higher amplitude reflections in the COSC-1 area (Fig. 13). The extensive four week long post-drilling seismic survey

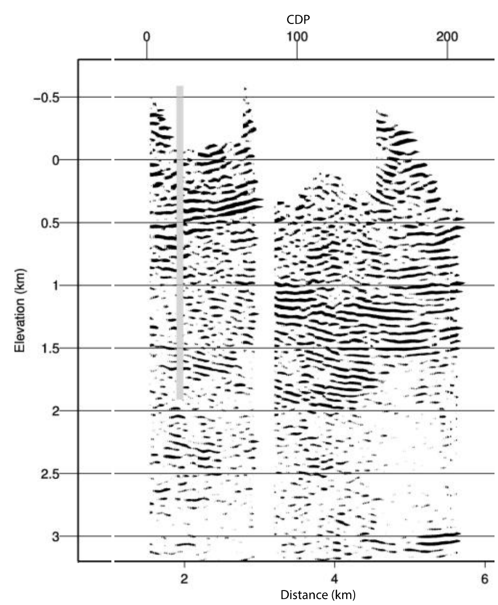

Figure 13: Data from the pre-drilling seismic survey reprocessed with a 3D geometry over the crooked acquisition line.

should help to better define the geometry of the base of the Seve Nappe Complex in the vicinity of the COSC-1 borehole. The combined use of surface and borehole seismics will provide true 3D coverage around the borehole and allow better resolution imaging at depth.

11.3. Geothermics

Eighteen abandoned mining boreholes were logged down to 100-200 m in 2012. This pre-drilling study resulted in expectedly low temperature gradients but constrained average ground temperatures to c. 4°C at elevations corresponding to the COSC-1 drill site (i.e. c. 500 m a.s.l.). Six temperature logs and one spectral gamma log were acquired since drilling was finished. However, three of the temperature logs were measured on the 15th and 16th of October 2014, only four days after a pumping test and other post-drilling operations were conducted in the hole. These logs show signs of temperature disturbances (Fig. 14). A fourth temperature log acquired by Lund University between 1600 m and TD, using the E-log probe, shows a surprising offset with respect to all other measured temperature profiles. Only two temperature logs recorded respectively six and thirteen days after final cleaning of the drill hole (28th August 2014) can give some insights on the expected steady state (Fig. 14). The relatively slow temperature recovery observed between 1600 m and 2000 m depth (Fig. 15) suggests negligible deviations from true formation temperatures along this specific depth interval and an uncorrected average gradient of c. ~20°C/km. A preliminary estimation of heat generation rates based on the spectral gamma log indicates moderate heat production in the penetrated rocks (Fig. 16). The sharp spikes in the heat generation profile are mostly related to highly radioactive pegmatite dykes. Future temperature measurements in the COSC-1 drill hole will include the installation of a 2.5 km distributed temperature sensing optical fibre early in 2015. Thermal property measurements at the Geological Survey of Sweden (SGU) were conducted up to four times on 24 core samples coming from 5 different depth ranges using a thermal conductivity scanning device. Thermal and hydraulic properties will be measured on 100 core samples at Ruhr University Bochum and 10 representative ones will be shared by the members of the geothermal team and used for laboratory comparisons.

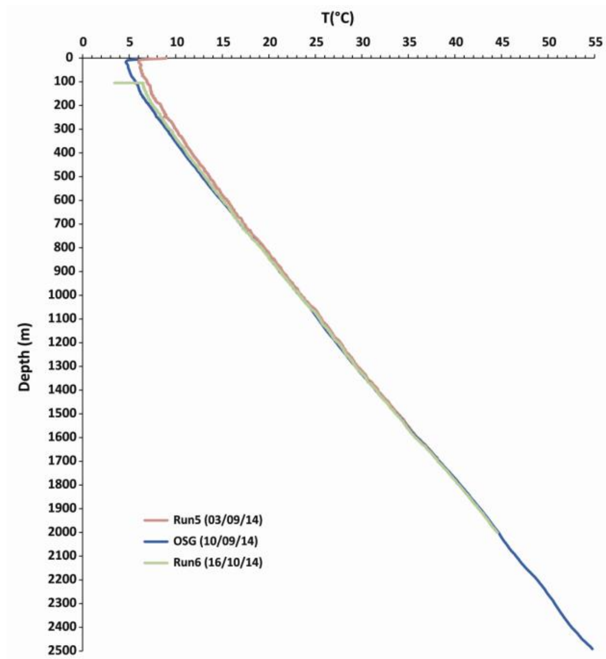

Figure 14: Post-drilling temperature logs. Note gradual cooling (i.e. thermal re-equilibration) of the uppermost section of the borehole early in September 2014. The log measured in October is affected by post-drilling operations. Campaigns 5 and 6 were acquired down to 2 km depth by the logging team of Lund University (LU); the Operational Support Group (OSG) of ICDP measured temperatures down to 2.5 km depth.

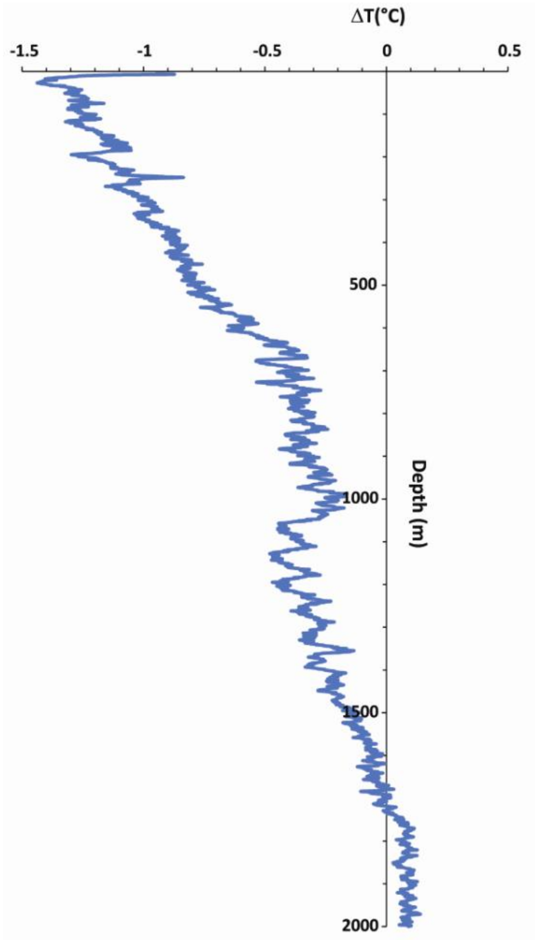

Figure 15: Temperature variations (ΔT) in the COSC-1 drill hole from 3rd (LU campaign 5) until 10th September 2014 (OSG logging).

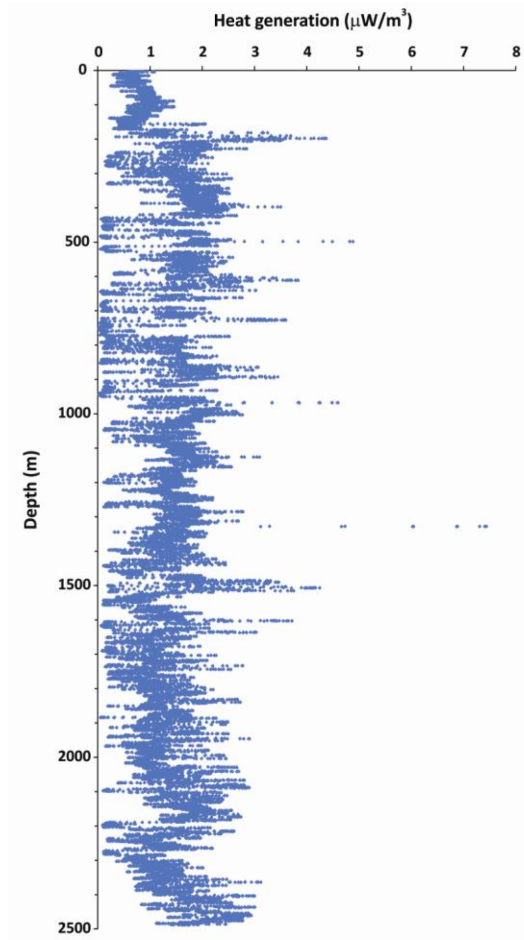

Figure 16: Heat generation rates as derived from the spectral gamma log measured in the COSC-1 drill hole.

11.4. Hydrogeology

Hydrogeologic tests were conducted during a drilling break at 1616 m and at TD. Drilling of a deep borehole does not normally allow for hydrogeologic testing during the drilling period, except when a large loss (or high return) of drilling fluid indicates the presence of a large transmissivity zone. Then, either the zone is cemented for drilling to continue or drilling is stopped for conducting, e.g., a drill-stem test (DST, packer installation with pressure or flow transient test). Cementing the conductive zone means a loss of critical information on in-situ hydraulic transmissivities and DSTs provide only information about a single high-transmissivity zone with a significant delay in the drilling schedule. However, COSC-1 provided the opportunity to introduce a hydraulic test with negligible impact on the drilling schedule and the potential to provide important and accurate information on in-situ hydraulic conductivities on both high- and low-transmissivity zones already during the drilling period. This information can be used to guide downhole fluid sampling programs and future detailed borehole testing. The particular testing method used is the Flowing Fluid Electric Conductivity (FFEC) logging method, which is capable of identifying large and small hydraulically active zones and provides data that can be used to estimate their transmissivity values and local formation water salinity (Tsang et al., 1990; Tsang and Doughty, 2003; Doughty et al., 2013). Based on FFEC logging in July and September 2014, eight hydraulic active zones between 300 m and TD were identified. Transmissivity values are very low and range over one order of magnitude.

11.5. Microbiology

Deep biosphere research suffered some bad luck during the COSC-1 drilling operations. A successful setup of the sampling equipment, including tracer pumps and special liners for core drilling, could not be deployed since the microbiologists' presence at the drill site was always accompanied by unplanned drilling breaks (switch of drilling dimension, gear box breakdown, etc.). Finally, quicker drilling with the double-tube core barrel assembly had to be employed in order to reach target depth. This prevented dedicated coring for microbial sampling which requires a triple-tube core barrel assembly. Consequently, the microbiology group did not get the planned samples.

However, some drill core samples, taken by the on-site geologists directly after opening of the inner tube, and gas data were analysed. ATP and DNA swab samples were taken where the on-site science team encountered open fractures in the drill core. ATP samples are being processed, DNA samples including drilling mud being analysed successively by pyrosequencing. The data will be ready during Spring 2015. If nothing else, we have learned how difficult deep drilling microbiology can be when the rock is solid without aquifers.

12. Conclusion

The drilling of COSC-1 was very successful and provided the scientific community with nearly complete and unique sample material from a high-grade metamorphic nappe and its basal thrust zone, and with access to a largely uncased drill hole. Questions that originate from the COSC-1 drilling are the nature and tectonostratigraphic position of the seemingly lower-grade metamorphic rocks close to the bottom of the drill hole, and how they relate to the intercalated garnetiferous mylonites. Did the garnet grow before and/or during deformation? What is the protolith of the mylonites?

COSC-1 research will continue during the coming years. In the meantime, the planning for COSC-2 has already begun: to drill through the basal Caledonian detachment into the basement of the Fennoscandian Shield.

13. Acknowledgements

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The Geological Survey of Sweden (SGU) supported the project with data acquisition over the target area during the planning phase and with in-kind contributions during the operational phase. In R & D collaborations, Devico AS supplied a core orientation tool for NQ drilling and borehole orientation data, and Minalyze AB scanned the whole drill core with their new XRF scanner (c.f. Sjöqvist et al., this volume). The ICDP Operational Support Group (OSG) provided training and practical help.

This project would never have been possible without the help of all the volunteers who did a great job. Many thanks to the drilling team for a superb drill hole and core to almost 2500 m, despite technical problems and the sometimes seemingly endless succession of nights and days with pipe handling. A full list of personnel is available in this operational report in chapter 1.

We thank Reinhard Greiling, Ulrich Harms and Aivo Lepland for their reviews and improvements to the manuscript.

14. Glossary

ASCII	American Standard Code for Information Interchange
ATP	adenosine triphosphate
BOP	blow out preventer
COSC	Collisional Orogeny in the Scandinavian Caledonides
COT	continent-ocean transition
C#	C sharp programming
DIS	Drilling Information System
DMT	company name (Deutsche Montan Technologie)
DNA	deoxyribonucleic acid
DST	drill-stem test
FFEC	flowing fluid electric conductivity
GFZ	German Rearch Centre for Geosciences (Deutsches GeoForschungsZentrum)
GNU	a unix-like operating system
HRQ	wireline drill rods in H-size (HQ) with reinforced thread
HWT	flushing joint casing in H-size
ICDP	International Continental Scientific Drilling Program
ID	inner diameter
IGSN	International GeoSample Number
I/O	input/output
LAS	Log ASCII Standard
LU	Lund University
Ma	million years (mega anni)
MSCL	multi-sensor core logger
MWD	measurement-while-drilling
OD	outer diameter
OLGA	on-line gas monitoring
OSG	the operational support group of ICDP
P-T-t	pressure-temperature-time
PDF	Portable Document Format
PLC	programmable logic controller
RPM	revolutions per minute
ROP	rate of penetration
R&D	research and development
SQL	Structured Query Language
ST	structured text programming
TD	total depth
VSP	vertical seismic profiling
WOB	weight on bit
XML	Extensible Markup Language
XRF	x-ray fluorescence
ZIP	'zipped', archive file format

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Appendix A – Drilling parameters and drillers' notes (data set: Drilling Technical Parameter)

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
										(Core barrel 4,1 m - distance to ground elevation)
103.1										
106.2										
109.3										Excore 6-8
110.0										
113.0	900	900	3.0	3.0	15	29	40	60	5	
116.0	900	900	2.0	3.0	17	30	50	60	7	
119.0	900	900	2.0	3.0	20	20	48	48	5	
122.0	900	900	2.0	3.0	24	24	48	48	4	
125.0	900	900	2.0	3.5	17	22	45	55	4	
128.0	900	900	3.5	5.5	12	18	0	50	4	
131.0	940	940	4.0	5.0	13	15	30	30	4	
134.0	980	980	3.7	4.5	16	22	40	40	5	
135.4	1030	1030	5.0	6.0	4	8	25	25	5	
138.5	1000	1000	3.8	4.5	17	21	40	60	5	
140.8	1000	1000	4.0	4.0	20	22	60	65	7	
143.0	1000	1000	4.0	5.0	17	19	50	60	6	
146.0	1000	1000	4.0	4.0	18	20	60	70	7	
149.0	1000	1000	3.6	4.0	18	22	50	60	7	
152.0	850	850	4.5	4.5	9	15	45	45	5	
155.0	950	950	4.9	4.9	5	14	48	48	6	
158.0	1000	1000	4.5	4.5	7	14	54	54	7	
161.0	1000	1000	2.0	3.2	15	42	56	56	7	
164.0	1010	1010	1.6	2.7	16	32	61	61	9	
167.0	920	920	2.0	3.8	18	25	62	62	10	
170.0	1030	1030	2.0	3.4	20	33	62	62	10	
173.0	990	990	2.0	2.2	15	22	55	55	8	
176.0	980	980	2.0	2.4	20	25	60	60	9	
179.0	1040	1040	1.6	2.0	21	24	62	62	10	
182.0	920	920	1.2	3.2	15	18	56	64	10	
185.0	920	920	2.0	4.3	6	17	43	55	10	
188.0	870	870	2.2	3.9	12	17	50	56	10	
191.0	890	890	3.4	3.7	20	27	57	64	12	
194.0	950	950	2.0	2.9	19	28	60	61	10	
197.0	950	950	2.2	2.5	18	25	55	63	10	
200.0	940	940	2.3	3.2	18	30	65	66	12	
203.0	920	920	2.4	3.7	14	16	62	62	11	
206.0	920	920	3.0	3.8	14	17	64	64	11	
209.0	970	970	3.5	4.0	12	15	58	58	11	
212.0	930	930	3.0	4.2	12	18	38	65	10	
215.0	900	900	3.0	4.0	15	18	50	60	10	
218.0	920	920	4.0	5.5	6	18	35	60	9	Pump pressure 8-10 bar
221.0	960	960	3.8	4.2	16	26	46	58	11	
224.0	960	960	2.5	3.0	17	25	65	65	13	Pump pressure 12-14 bar
227.0	930	930	2.5	3.2	14	18	54	65	14	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
230.0	940	940	2.8	3.0	16	20	60	62	13	
233.0	950	950	2.8	3.0	15	21	63	63	13	
236.0	920	920	3.5	4.0	14	17	55	60	12	
239.0	930	930	3.6	3.8	15	18	55	65	12	
242.0	930	930	3.0	3.2	17	27	60	63	14	
245.0	1000	1000	2.4	2.8	15	21	65	65	15	
248.0	950	950	2.7	3.1	12	20	67	67	17	
251.0	930	930	3.2	4.0	15	20	57	68	15	Pump pressure 14-16 bar
254.0	940	940	2.2	2.4	24	27	62	62	15	
257.0	930	930	2.2	2.4	16	20	56	64	15	
260.0	920	920	2.5	2.5	20	22	62	62	15	
263.0	940	940	2.6	3.8	16	21	60	72	18	Pump pressure 16-20 bar
266.0	960	960	2.8	3.6	14	18	60	60	14	
269.0	960	960	2.8	3.1	16	20	62	62	16	
272.0	950	950	2.2	2.8	16	22	60	68	17	Pump pressure 16-18 bar
275.0	960	960	2.2	3.0	12	22	58	63	16	Pump pressure 15-16 bar
278.0	930	930	2.2	2.8	18	22	63	63	17	Pump pressure 16-18 bar
281.0	920	920	1.8	4.0	10	22	54	62	16	Pump pressure 15-17 bar
282.7	900	900	3.0	5.0	6	15	54	60	18	Pump pressure 18-30 bar
284.0	930	930	2.2	2.4	16	20	74	74	18	Excore 8-9
287.0	900	900	2.2	2.6	16	18	72	72	18	
287.6	900	900	2.2	2.4	15	18	72	72	18	Core catcher unscrewed, water blockage
290.0	890	890	2.2	2.6	13	19	72	72	19	
293.0	900	900	1.8	5.0	10	18	55	72	19	
296.0	890	890	2.2	4.0	9	20	60	75	18	
299.0	900	900	2.0	3.0	9	20	61	75	20	
302.0	890	890	1.6	2.0	10	20	70	81	21	
305.0	890	890	1.6	2.4	10	20	70	80	21	
308.0	900	900	2.0	2.4	9	20	80	80	21	
311.0	890	890	2.0	2.3	14	17	78	78	22	
314.0	840	840	2.3	3.2	13	17	73	73	20	
317.0	630	630	2.3	5.5	6	17	37	75	19	
320.0	633	633	2.5	2.8	15	17	73	73	15	
323.0	630	630	2.0	3.8	8	17	70	75	19	
326.0	630	630	2.5	3.0	8	20	68	68	16	
329.0	630	630	2.5	3.0	8	20	75	75	21	
332.0	650	650	2.8	3.0	5	17	72	72	20	
335.0	680	680	3.0	4.4	5	18	73	73	21	
338.0	870	870	3.0	4.0	5	18	74	74	24	
341.0	860	860	3.0	4.0	5	18	68	74	24	
344.0	800	800	4.0	5.0	5	18	60	70	20	
347.0	830	830	3.6	4.5	5	18	65	68	20	
350.0	800	800	3.2	5.0	5	20	60	73	21	
353.0	830	830	3.4	4.0	5	20	60	73	24	
356.0	850	850	2.6	2.8	10	19	73	73	30	
359.0	850	850	2.8	3.8	10	17	65	79	25	
362.0	800	800	2.8	3.2	12	17	64	73	25	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
365.0	800	800	2.2	3.6	10	17	70	79	25	
368.0	780	780	3.0	3.6	12	17	71	71	30	
371.0	780	780	2.4	3.4	12	17	68	71	25	
374.0	840	840	2.4	4.6	7	16	63	75	23	
377.0	780	780	2.5	4.8	5	16	62	68	20	
380.0	740	740	3.5	4.6	5	16	53	72	19	
383.0	790	790	2.5	3.0	5	16	69	69	24	
386.0	730	730	3.3	4.4	5	17	60	70	21	
389.0	790	790	2.5	3.1	5	20	66	66	24	
392.0	830	830	3.2	4.4	5	20	68	68	23	
395.0	760	760	2.5	3.0	5	20	65	65	23	
398.0	810	810	2.8	4.6	5	18	50	68	21	
401.0	800	800	3.8	4.8	5	20	60	62	23	
404.0	800	800	3.8	4.0	5	15	60	60	23	
407.0	700	700	4.0	6.0	1	21	44	55	18	
410.0	640	640	4.0	4.0	17	18	62	65	20	
413.0	680	680	4.4	4.4	18	19	60	60	19	
416.0	610	610	4.0	4.0	17	18	60	60	21	
419.0	740	740	4.2	4.2	18	20	60	60	21	
422.0	700	700	4.2	4.2	17	18	62	62	21	
425.0	750	750	3.8	3.8	18	21	61	61	24	
428.0	660	660	4.2	4.2	19	20	60	60	21	
431.0	690	690	4.3	4.3	19	21	60	60	23	
434.0	700	700	3.0	3.5	18	20	60	60	20	
437.0	700	700	3.0	3.5	17	21	60	65	25	
440.0	600	600	4.0	4.5	8	18	60	60	25	
440.5	600	600	4.0	4.5	10	10	60	60	25	
443.0	720	720	1.8	2.0	15	15	68	68	30	
446.0	710	710	1.5	2.0	10	16	66	66	27	
449.0	700	700	1.8	2.0	12	15	62	62	25	
452.0	680	700	1.7	2.0	11	15	65	65	25	
455.0	700	700	1.8	1.8	11	15	67	67	26	
458.0	720	720	1.0	1.3	15	17	62	62	25	
461.0	740	740	1.0	1.3	14	15			28	no flow meter
464.0	730	730	2.1	2.1	17	17	60	60	25	
467.0	720	720	2.0	2.0	17	17	68	68	26	
470.0	550	550	3.0	3.0	10	10	61	61	21	
473.0	550	550	4.8	4.8	12	12	60	60	26	
476.0	560	560	4.2	4.2	12	12	70	70	28	
477.3	500	500	4.4	4.4	13	13	55	55	23	
477.4	550	550	5.0	5.0	1	1	70	70	28	
479.0	690	690	2.7	2.7	15	15	75	75	27	New Excore 8-9 new reaming shell
482.0	670	670	4.0	4.0	15	15	90	90	40	
485.0	670	670	3.5	3.5	15	15	78	78	30	
488.0	650	1000	2.0	4.0	8	13	65	65	27	
491.0	650	1000	3.0	3.0	5	5	70	70	33	Start mud
494.0	650	650	3.0	5.0	6	6	70	70	30	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
497.0	750	750	3.0	4.0	8	9	65	65	28	
500.0	700	800	3.0	4.0	9	9	68	68	30	
503.0	740	740	3.0	4.0	9	9	65	65	28	
506.0	730	730	3.0	4.0	9	9	66	66	28	
509.0	730	730	3.0	4.0	9	9	66	66	28	
512.0	720	720	4.0	4.0	9	10	70	70	29	
515.0	730	730	3.8	3.8	10	10	70	70	30	
518.0	710	710	3.0	4.0	9	10	73	73	29	
521.0	700	700	3.2	3.2	10	10	74	74	29	
524.0	650	650	2.7	2.7	9	10	74	74	31	
527.0	680	680	3.0	3.0	9	10	76	76	30	
530.0	610	610	4.5	4.5	5	9	50	75	30	New tube, pump pressure 30-50 bar
533.0	650	650	3.8	3.8	7	9	75	75	32	
536.0	690	690	2.9	2.9	9	10	76	76	33	Dropped 50 cm
538.7	630	630	3.2	3.2	9	10	80	80	33	
541.7	650	650	3.0	3.0	9	10	75	75	32	
544.8	710	710	3.0	3.0	9	10	74	74	32	Quartz veins
547.9	630	740	3.0	4.7	7	9	70	80	35	Quartz veins
551.0	600	730	2.0	4.5	5	9	70	80	30	Quartz veins
554.0	590	720	2.0	4.0	5	9	70	80	30	
557.0	610	720	2.5	3.4	1	21	74	74	33	Pump in 114l/min around 5 min
560.0	630	680	2.8	3.2	1	23	72	74	32	Pump pressure 30-34 bar
563.0	670	670	2.0	3.2	3	18	76	76	32	
566.0	640	670	2.0	3.2	3	20	76	76	32	Pump pressure 30-34 bar
569.0	620	670	2.0	4.0	3	20	70	70	32	Pump pressure 30-34 bar
572.0	560	650	2.6	3.9	2	20	74	78	33	Pump pressure 32-35 bar
575.0	620	650	2.6	2.9	2	21	72	74	31	Pump pressure 30-32 bar
578.0	620	660	2.6	3.9	2	21	72	74	31	Pump pressure 30-32 bar
581.0	580	600	3.0	3.9	4	21	72	74	31	Pump pressure 30-32 bar
584.0	590	590	3.0	3.4	5	19	74	74	35	
587.0	600	600	2.0	2.5	12	14	72	72	30	
590.0	600	600	2.0	2.0	12	16	70	70	30	
593.0	620	620	1.4	1.4	12	18	70	72	35	
596.0	610	610	1.0	2.0	15	15	70	70	30	
599.0	590	590	1.8	2.2	12	15	72	72	35	New Excore 8-9 new reaming shell
600.2	590	590	2.0	2.8	12	17	72	72	34	
602.0	610	610	2.0	2.8	3	17	76	76	32	
605.0	600	600	2.0	2.8	7	17	72	72	32	
608.0	600	600	2.5	2.5	16	16	70	70	32	
611.0	580	580	1.8	2.1	11	14	74	74	35	
614.0	590	590	1.6	2.0	11	15	76	76	34	
617.0	580	580	1.6	2.0	12	12	70	70	32	
620.0	520	520	1.6	2.0	1	12	70	70	32	
623.0	620	620	1.8	2.4	11	15	72	74	35	
626.0	560	600	1.8	2.1	9	12	76	78	35	
629.0	550	580	1.8	2.6	9	15	72	76	34	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
632.0	540	580	1.6	1.8	9	12	74	74	35	
635.0	500	570	0.8	2.0	7	20	76	78	35	
638.0	600	620	2.0	2.7	3	19	72	72	32	
641.0	570	630	1.0	2.0	3	19	74	74	35	
644.0	570	630	1.0	1.7	8	17	76	76	36	
647.0	600	630	1.8	2.2	7	19	72	72	36	
650.0	600	600	1.8	2.2	8	17	74	74	36	
653.0	570	620	2.2	2.2	7	19	76	78	38	Pump pressure 36-39 bar
655.5	580	600	2.5	3.0	7	20	74	77	38	Pump pressure 36-39 bar, New Excore 6-8 Jet16
658.6	620	650	1.8	2.2	11	14	68	68	35	
661.7	550	610	2.0	4.3	7	16	76	76	37	Pump pressure 35-39 bar
664.7	490	550	3.0	4.4	4	16	66	66	34	Pump pressure 32-35 bar
667.9	520	550	3.0	4.0	4	20	66	66	32	
670.9	520	550	1.8	3.6	7	14	70	70	33	
674.0	520	550	2.0	4.0	7	14	68	68	33	
677.0	550	560	2.8	3.0	7	20	72	72	36	
680.0	450	520	2.0	3.4	7	16	66	78	35	Pump pressure 34-36 bar
680.4	510	510	2.0	2.0	3	17	72	74	34	
683.0	480	530	2.4	2.4	10	16	72	74	34	
686.0	490	580	2.2	2.2	10	14	52	70	34	
689.0	490	540	2.6	2.6	10	14	72	72	34	
692.0	460	530	1.6	2.1	8	11	66	72	34	
695.0	530	530	2.0	2.0	9	15	50	70	30	
698.0	530	560	1.4	2.0	11	16	72	74	32	
701.0	530	530	2.0	2.0	14	14	65	65	30	
704.0	470	540	1.8	2.2	8	14	62	70	30	
707.0	490	540	1.8	2.4	8	15	62	72	30	
709.0	560	560	2.2	2.2	14	14	60	60	30	
710.0										
713.0	450	560	2.5	2.8	10	20	75	75	40	
714.3	420	540	2.3	2.3	7	18	74	74	37	
716.0	550	550	2.2	2.2	12	14	60	60	30	New Excore 6-8 FD13 10 WW/new reaming shell
719.0	520	550	1.2	1.6	11	14	68	68	34	
722.0	480	520	1.6	3.0	10	14	68	70	30	
725.0	550	550	2.1	2.1	12	15	60	60	30	
728.0	550	550	1.6	1.8	11	14	70	70	34	
731.0	470	610	2.0	2.6	8	16	74	74	35	Pump pressure 33-37 bar
734.0	520	550	1.5	1.8	10	17	75	75	35	Pump pressure 33-37 bar
737.0	450	550	2.0	2.2	12	20	70	70	32	
740.0	530	560	1.8	1.8	10	17	76	76	36	
743.0	520	550	1.5	2.2	10	17	72	72	35	
746.0	500	550	2.0	3.0	10	20	70	70	32	
749.0	460	520	2.0	3.2	10	17	74	74	33	
752.0	480	510	1.5	3.0	10	17	72	72	33	
755.0	420	480	2.0	4.0	10	18	68	72	31	Pump pressure 30-32 bar
758.0	430	480	2.8	3.2	10	13	74	74	32	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
761.0	380	420	2.2	2.2	8	12	60	60	30	
764.0	380	420	2.6	2.6	8	12	68	68	30	
767.0	390	450	1.8	2.2	9	13	68	74	33	30 minutes to pump down the inner tube, 1370l
770.0	450	500	3.0	4.0	10	11	70	70	35	Excore 6-8, new reaming shell + additional upper shell
773.0	470	470	4.0	4.0	10	10	70	70	35	
776.0	280	500	2.0	4.0	10	10	70	70	35	
779.0	470	470	3.0	3.0	10	10	70	70	33	
782.0	430	480	2.5	3.0	10	10	74	74	35	
785.0	530	530	3.0	3.0	11	11	70	70	35	
788.0	510	510	3.0	3.0	11	11	72	72	35	
791.0	530	530	1.8	1.8	10	10	60	60	25	
794.0	560	560	1.0	1.0	10	10	68	68	35	
797.0	550	550	1.5	1.5	10	10	68	68	35	Core drop 0,8 m
797.6	480	480	1.5	1.5	10	10	60	60	30	
800.0	550	550	2.0	2.0	10	10	68	68	35	
803.0	480	560	1.5	2.0	11	11	68	68	35	
803.3	550	550	1.5	1.5	10	10	60	60	50	
806.0	540	540	1.5	1.5	11	11	60	60	30	
809.0	560	560	2.0	2.0	11	11	68	68	35	
812.0	560	560	2.0	2.0	10	10	70	70	35	
815.0	540	540	2.0	3.0	11	11	74	74	37	
818.0	540	540	3.0	3.0	11	11	70	70	35	
821.0	550	550	3.0	3.0	11	11	70	70	35	
824.0	190	600	2.0	5.0	11	11	75	75	40	Gear 3
827.0	200	600	2.0	4.0	11	11	75	75	40	
830.0	500	500	3.0	3.0	11	11	72	72	40	
833.0	480	530	2.0	4.0	11	11	76	76	41	
836.0	500	500	3.0	3.0	11	11	70	70	40	
839.0	510	510	3.0	3.0	10	10	74	74	38	
839.1	550	550	2.0	2.0	11	11	72	72	40	Problems with head assembly (water stop)
842.0	550	550	2.0	4.0	10	10	70	70	38	
845.0	530	530	2.0	4.0	8	10	70	70	38	
847.8	450	570	2.0	4.0	10	10	60	60	35	
848.8	530	530	3.0	3.0	11	11	72	72	38	Problems with head assembly
851.0	530	530	2.0	3.5	11	11	74	74	40	
854.0	480	500	2.5	2.5	10	10	65	65	35	
857.0	480	530	2.0	3.0	10	10	72	72	38	
860.0	450	550	1.0	2.0	8	11	72	72	38	
863.0	390	550	1.0	2.0	9	11	60	60	35	
866.0	470	470	3.0	3.0	8	8	72	72	35	
869.0	210	530	2.5	5.0	7	11	74	74	40	
872.0	500	500	2.1	2.1	11	11	70	70	35	
875.0	500	500	2.0	3.0	11	11	75	75	38	
878.0	500	500	3.0	3.0	11	11	70	70	38	
881.0	390	500	2.0	3.0	11	11	75	75	38	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
882.5	310	430	2.0	5.0	11	11	78	78	40	Excore 8-9 JET16, used reaming shell (67 m)
884.0	480	550	2.0	3.0	11	11	65	65	35	
887.0	390	510	2.0	4.5	5	10	65	70	36	
890.0	390	400	3.0	4.0	5	9	70	70	36	
893.0	400	400	5.0	6.0	2	3	60	60	30	2nd gear
896.0	400	400	2.0	5.0	8	11	66	66	32	
899.0	400	400	3.0	3.0	10	10	68	68	32	
902.0	400	400	2.0	3.0	11	11	74	74	38	
905.0	400	400	2.0	3.0	11	11	70	70	35	
908.0	510	510	0.5	1.0	11	11	76	76	42	3rd gear
911.0	500	500	1.0	1.0	10	10	66	66	38	
914.0	360	510	1.6	3.0	11	11	60	70	38	
917.0	400	400	1.6	3.0	11	11	68	68	35	
920.0	400	400	2.0	2.0	11	11	66	66	35	
923.0	340	400	1.0	1.4	10	10	66	66	35	
926.0	390	400	1.2	1.8	11	11	66	66	35	
929.0	400	400	1.0	1.0	11	11	66	66	35	
932.0	400	400	1.0	2.0	11	11	66	66	35	
935.0	400	400	1.0	1.8	11	11	66	66	35	
938.0	400	400	1.0	1.0	11	11	66	66	35	
941.0	390	390	1.8	2.2	9	10	66	66	35	
944.0	340	410	1.8	1.8	9	11	66	66	34	
944.3	380	380	1.8	3.8	5	10	66	66	34	
947.0	380	380	1.8	2.7	10	10	66	66	34	
950.0	390	390	1.8	2.5	10	10	66	66	35	
952.0	350	350	1.8	2.8	10	10	66	66	35	
953.0	390	390	1.8	2.9	9	10	66	66	35	
956.0	390	390	1.8	3.5	10	10	66	70	35	Change of valve in rotation unit
959.0	460	460	2.0	2.0	11	11	66	66	35	
962.0	440	440	2.0	2.0	11	11	68	68	35	
965.0	370	410	1.6	2.4	11	11	66	66	35	
968.0	400	400	2.0	2.0	11	11	68	68	35	Excore 6-8, new reaming shell + additional upper shell
971.0	350	500	3.7	4.5	3	7	38	60	20	
974.0	300	400	3.5	4.3	8	10	48	68	22	
977.0	390	390	4.0	4.0	10	10	72	72	35	
980.0	340	410	1.8	3.4	7	10	64	72	35	
983.0	310	310	1.8	3.2	7	10	62	66	30	
986.0	390	390	2.5	2.5	10	10	76	76	35	
988.4	350	390	2.4	4.0	6	10	62	76	30	
991.5	380	400	2.0	4.0	9	11	68	70	35	Excore 8-9 Jet16
994.6	400	400	3.5	4.0	9	10	66	66	35	
997.1	480	530	3.2	4.0	7	10	60	60	32	
1000.2	470	500	3.0	4.5	5	11	48	52	32	
1003.3	480	480	2.0	2.0	11	11	62	62	32	Both head assemblies 55 mm
1006.4	480	490	1.2	1.8	11	11	66	66	33	
1009.6	460	480	1.4	2.6	5	11	66	66	33	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
1012.7	480	480	2.0	2.0	11	11	68	68	33	
1015.8	480	520	1.8	2.2	11	11	70	70	34	
1018.9	510	520	1.4	2.2	11	11	68	70	35	New water swivel pipe
1022.0	390	500	1.5	1.5	10	10	68	68	35	
1025.0	500	500	1.0	1.8	11	11	70	70	40	Core barrel travel time 14-17 minutes
1028.0	500	500	1.0	2.6	11	11	70	70	38	
1030.0	500	560	3.0	4.0	8	10	67	67	39	
1031.0	500	500	3.0	3.8	8	10	68	68	37	
1034.0	500	500	2.5	3.4	10	11	68	70	40	
1037.0	350	500	2.0	3.2	10	11	70	70	37	
1040.0	510	530	2.2	3.8	10	10	68	68	40	
1043.0	510	540	2.2	3.3	10	11	68	68	35	
1046.0	500	540	2.0	4.0	9	10	68	70	35	
1049.0	460	500	2.0	4.4	8	10	52	70	38	
1052.0	520	550	2.0	3.5	10	10	70	70	38	
1055.0	380	380	3.0	4.0	9	9	70	70	39	
1058.0	440	500	2.4	3.8	7	11	68	74	40	
1061.0	460	500	2.4	4.2	9	11	68	70	40	
1064.0	480	480	2.8	2.8	10	10	68	68	40	
1067.0	450	500	2.8	4.0	9	11	70	70	40	
1070.0	480	500	2.8	4.0	9	11	69	70	40	
1073.0	380	500	3.0	4.0	10	10	68	68	40	
1076.0	470	510	2.0	3.6	9	11	70	70	40	
1079.0	460	510	2.2	4.0	9	11	68	70	40	
1082.0	410	540	2.5	4.0	4	10	52	70		
1085.0	350	450	3.0	4.2	3	8	38	60	29	Pump pressure 25-33 bar
1088.0	320	390	3.0	4.0	4	8	50	60	30	Pump pressure 28-33 bar, 2nd gear
1091.0	350	480	3.0	3.8	6	10	66	66	35	
1094.0	500	540	2.0	4.2	6	10	64	64	34	
1095.5	380	380	3.0	4.0	10	10	66	66	36	
1097.0	520	520	2.0	3.0	10	10	72	72	40	Excore 9 JET16 New lower reaming shell
1100.0	350	400	3.0	4.5	5	10	70	70	38	
1103.0	340	340	3.0	4.0	9	9	62	62	38	
1106.0	320	350	3.0	4.2	7	9	68	68	38	
1109.0	320	350	3.0	4.5	7	9	70	70	38	Excore 10 JET16
1112.0	370	370	3.0	4.0	8	8	76	76	38	
1115.0	350	400	3.5	4.5	5	10	75	75	35	
1118.0	400	400	3.5	4.0	6	7	70	70	35	
1121.0	400	400	1.0	5.0	0	8	75	75	45	
1124.0	400	400	5.5	5.5	0	5	50	50	28	
1121.7	400	400	6.0	6.0	0	5	60	60	30	
1127.0	400	400	5.0	5.0	7	8	70	72	40	
1130.0	400	400	3.0	5.0	6	8	68	72	38	
1133.0	400	400	4.0	5.0	6	8	72	72	40	
1136.0	400	400	4.0	5.0	5	8	70	70	40	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
1139.0	380	380	4.0	5.0	6	9	70	70	40	
1142.0	360	400	3.0	4.0	6	8	75	75	40	
1145.0	350	380	3.0	4.0	5	7	76	76	40	
1147.7	330	330	3.0	4.0	5	7	72	72	44	39 m of reaming
1150.8	400	400	3.0	4.5	8	8	82	82	40	Excore 8-9 JET16, new lower and upper reaming shell
1153.9	370	370	3.0	4.0	7	7	82	82	40	
1157.0	340	340	3.0	4.5	5	8	80	80	40	
1160.0	340	500	4.0	5.0	4	8	82	82	42	
1163.0	400	400	4.0	5.0	10	10	82	82	42	
1166.0	410	410	3.0	5.0	8	9	80	80	40	Pump time inner tube around 20 min
1169.0	410	410	3.0	5.0	5	7	76	76	35	
1172.0	270	400	4.0	6.0	0	8	60	80	38	2 hours drilling? Pump pressure 30-45 bar
1175.0	410	410	4.0	6.0	0	5	60	80	30	
1178.0	410	410	4.0	6.0	3	9	60	70	35	Pump pressure 30-40 bar
1181.0	400	400	3.0	4.0	8	8	78	78	45	visual inspection of wire
1184.0	400	400	3.0	4.5	8	8	80	80	45	
1187.0	400	400	3.0	4.0	9	9	80	80	45	
1190.0	400	400	3.0	4.0	8	8	76	76	43	
1193.0	400	400	3.0	4.0	8	8	80	80	45	
1196.0	400	400	3.0	4.0	10	10	80	80	45	New water swivel
1199.0	400	400	3.0	4.5	9	9	78	78	45	
1202.0	400	400	3.0	4.2	8	12	70	72	45	
1205.0	510	540	2.5	2.8	11	12	72	74	48	
1208.0	490	520	2.5	3.9	9	12	66	70	39	
1211.0	350	480	2.8	4.3	3	12	60	75	42	Pump pressure 39-44 bar
1214.0	460	480	2.0	3.0	11	12	68	68	41	
1217.0	330	410	2.0	3.0	9	12	72	72	41	
1220.0	320	380	2.0	3.0	6	11	70	75	40	
1223.0	450	470	3.0	4.0	10	12	72	74	45	Around 400 m removed from the drum
1226.0	400	400	3.0	4.0	10	11	74	74	45	
1229.0	370	410	2.4	3.6	6	9	74	74	40	
1232.0	380	410	2.4	3.9	8	10	74	74	40	
1234.7	400	400	2.0	4.0	10	10	74	74	45	New Excore 8-9, new reaming shell and landing ring
1237.8	400	400	2.0	4.0	11	11	74	74	40	
1240.9	390	410	3.0	3.6	9	10	74	74	42	
1244.0	390	410	2.0	3.4	9	11	74	74	40	
1247.0	480	480	2.0	4.0	11	11	74	74	45	
1250.0	480	510	2.8	3.8	9	10	76	76	45	
1253.0	400	410	2.0	3.7	9	10	74	74	40	
1256.0	480	480	2.0	4.0	11	11	74	74	45	
1259.0	480	500	2.6	3.4	9	9	76	76	45	
1262.0	320	480	2.0	4.0	5	10	60	76	38	
1265.0	330	410	3.0	3.8	7	11	74	74	38	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
1268.0	330	400	3.0	4.2	8	10	60	60	30	
1271.0	330	410	2.0	3.2	7	11	60	60	30	
1274.0	330	360	2.0	3.0	5	11	72	72	37	
1277.0	288	360	3.0	4.0	7	11	72	72	37	
1280.0	300	390	3.0	4.0	10	10	72	76	37	Pump pressure 32-45 bar
1283.0	390	490	2.6	4.8	4	9	66	74	39	
1286.0	300	380	3.6	3.8	5	9	74	74	35	
1289.0	330	380	3.0	4.0	9	9	74	74	35	
1292.0	380	410	2.6	3.6	6	9	76	88	39	Pump pressure 35-43 bar
1295.0	360	410	2.1	3.3	9	10	84	86	45	
1298.0	390	410	2.0	3.8	8	10	74	82	40	New Excore 8-9
1301.0	390	490	2.0	4.0	10	10	82	82	48	
1304.0	470	410	2.6	3.8	7	9	84	84	45	Dropped 3 m of core, but the core was catched
1307.0	370	410	2.6	4.0	7	7	86	86	40	
1307.6	370	410	2.6	4.0	0	7	86	86	45	
1310.0	370	410	2.6	3.8	6	8	80	80	45	New Excore 8-9
1313.0	400	400	3.0	4.2	9	9	84	84	45	
1316.0	480	480	2.0	3.0	10	10	86	86	45	
1319.0	400	400	3.0	4.3	8	9	84	84	45	
1322.0	370	400	3.2	4.4	7	9	84	84	45	
1325.0	390	490	2.0	4.0	10	10	84	84	45	
1328.0	370	400	2.0	4.0	6	9	84	84	45	
1331.0	350	400	3.0	4.6	4	9	70	84	36	Pump pressure 27-45 bar
1334.0	330	370	4.0	5.2	4	9	70	76	34	
1337.0	390	390	4.0	4.4	10	10	80	80	34	
1340.0	390	390	3.0	4.4	9	11	80	80	45	
1343.0	360	400	4.3	4.3	7	11	78	82	37	
1346.0	390	400	3.0	4.0	8	11	80	82	42	
1349.0	390	400	2.0	4.0	10	10	82	82	45	
1352.0	390	410	2.8	3.8	9	9	84	84	45	
1355.0	400	410	2.0	3.2	9	9	84	84	44	
1358.0	400	490	2.0	4.0	10	10	84	84	45	
1361.0	390	470	2.2	3.8	8	9	84	84	45	
1364.0	390	400	2.0	4.0	7	9	82	82	40	Pumping time inner tube 22-24 min
1367.0	400	400	2.0	5.0	7	10	80	80	50	
1368.0	290	400	3.0	5.0	4	10	80	80	55	
1369.7	270	300	4.0	5.0	1	5	75	75	50	
1372.7	280	310	3.0	5.0	4	5	65	65	40	New Excore 8-9 new reaming shell
1375.9	280	310	3.0	5.0	3	5	70	70	45	
1378.4	280	300	3.0	5.0	0	5	70	70	45	
1381.3	300	400	3.0	5.0	8	9	72	72	50	
1384.4	300	400	3.0	5.0	8	9	74	74	50	
1387.5	360	410	3.0	4.0	9	10	74	74	48	
1390.5	250	310	2.0	3.0	3	10	75	75	50	
1393.6	290	310	2.0	3.5	5	6	77	77	50	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
1396.7	290	340	1.5	3.0	6	6	78	78	50	
1399.8	290	310	2.0	3.0	6	6	78	78	50	
1402.9	290	320	2.0	3.0	6	6	82	82	50	
1406.0	290	320	2.0	3.0	6	6	78	78	50	
1409.0	290	320	2.0	3.0	6	6	80	80	50	
1412.0	290	320	2.0	3.0	6	6	82	82	50	
1415.0	290	320	2.0	3.0	6	6	80	80	50	
1418.0	290	320	2.0	3.0	6	6	82	82	55	
1421.0	290	310	2.0	3.0	6	6	74	74	50	
1424.0	290	310	2.0	3.0	6	6	80	80	52	
1427.0	290	310	2.0	4.0	6	6	76	76	50	
1430.0	290	310	2.0	4.0	5	6	80	80	45	
1433.0	290	310	2.0	4.0	6	6	80	80	48	
1436.0	300	300	3.0	3.0	6	6	80	80	60	
1439.0	300	300	2.0	4.0	6	6	80	80	55	
1442.0	300	300	2.0	4.0	4	6	78	78	55	
1445.0	370	370	2.0	4.0	6	6	82	82	58	
1448.0	370	370	2.0	4.0	7	7	78	78	55	
1451.0	370	370	2.0	4.0	7	7	80	80	56	
1454.0	370	370	2.0	4.0	6	8	74	74	53	
1457.0	370	370	2.0	4.0	6	8	80	80	58	
1460.0	350	350	2.0	4.0	6	6	80	80	56	Pumping time inner tube 30 min (98 l/min)
1463.0	300	300	4.0	5.0	6	6	80	80	60	
1466.0	300	300	4.0	5.0	6	6	80	80	60	
1469.0	300	400	4.0	5.0	2	6	80	80	60	
1470.0	300	400	4.0	5.0	0	3	80	80	60	New Excore 8-9
1472.0	400	400	4.0	4.0	6	6	80	80	58	
1475.0	400	410	3.4	4.0	6	6	82	82	58	
1478.0	400	400	3.0	4.0	6	6	80	80	55	
1481.0	400	410	2.0	4.0	6	8	78	80	55	
1484.0	390	410	2.3	3.7	6	8	78	82	53	
1487.0	390	400	3.0	4.0	5	7	78	80	53	
1490.0	390	400	3.0	4.0	5	7	78	80	53	
1493.0	400	410	3.6	4.4	6	7	80	80	52	
1496.0	400	400	2.0	4.0	6	7	80	80	53	
1499.0	400	410	3.2	3.8	6	7	82	82	53	
1502.0	400	400	2.0	4.0	6	7	80	80	53	
1505.0	400	410	3.0	3.8	6	7	82	82	53	
1508.0	400	400	2.0	4.0	6	7	80	80	55	
1511.0	400	410	3.0	4.0	6	7	82	82	54	
1514.0	400	410	3.0	4.6	6	8	75	82	52	
1517.0	400	400	3.0	4.0	6	7	76	78	53	
1520.0	400	400	2.5	3.4	6	8	76	78	53	
1523.0	400	410	2.5	3.6	5	7	80	80	52	
1526.0	390	400	3.0	4.0	5	7	78	80	53	
1529.0	360	390	3.0	4.0	5	7	78	80	53	
1532.0	400	400	3.0	5.0	6	7	80	80	55	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
1535.0	380	400	3.5	4.8	5	7	82	86	55	
1538.0	400	400	2.0	4.0	6	7	82	82	55	
1540.7	350	400	3.0	5.0	4	7	76	84	54	
1540.8	350	400	3.0	5.0	3	5	80	80	55	New Excore 8-9
1543.8	400	400	3.0	5.0	7	7	80	80	60	
1546.9	390	410	3.8	5.0	7	7	80	80	60	
1550.0	390	390	3.0	5.0	7	7	80	80	57	
1553.0	380	410	3.6	3.8	6	8	78	82	52	
1556.0	400	400	3.8	3.8	6	7	80	82	52	
1559.0	390	390	3.0	4.0	6	7	80	82	55	
1562.0	390	400	3.6	4.1	6	8	78	82	53	
1565.0	400	400	3.3	3.5	6	8	80	80	53	
1568.0	400	400	3.3	4.0	6	8	80	82	53	
1571.0	400	400	3.0	4.0	7	7	80	80	53	
1574.0	390	410	2.8	4.2	6	7	80	80	53	
1577.0	350	410	3.0	5.0	5	7	80	80	53	
1580.0	400	410	2.8	3.6	7	7	80	80	53	
1583.0	400	400	3.0	4.0	7	7	80	80	53	
1586.0	400	410	2.4	3.2	7	7	80	80	53	
1589.0	400	400	3.0	4.0	7	7	80	80	54	
1592.0	400	410	2.8	4.0	7	7	80	80	54	
1595.0	400	410	2.8	3.8	6	8	80	84	55	
1598.0	400	400	2.6	3.0	6	8	80	82	54	
1601.0	350	400	2.5	3.8	6	8	78	82	55	
1604.0	300	370	2.5	4.0	3	8	80	84	55	
1607.0	380	380	2.7	3.5	5	8	82	82	55	
1610.0	400	400	2.0	4.0	7	7	80	80	57	
1613.0	380	400	2.8	4.2	6	7	82	82	57	
1614.6	400	400	2.0	4.5	7	7	80	80	57	
1615.4	330	370	2.2	3.8	2	6	76	86	57	
1616.0	400	450	2.0	2.0	2	5	80	80	57	
1619.0	670	680	3.0	3.0	16	16	60	60	30	Dimension change from H to N
1622.0	600	680	2.0	3.0	10	16	64	64	32	
1625.0	490	590	2.0	3.5	10	16	60	70	32	
1628.0	440	500	2.5	3.0	10	17	64	64	32	
1631.0	420	520	2.0	3.3	10	16	64	64	30	
1634.0	450	500	2.0	3.4	8	12	64	64	30	
1637.0	450	470	2.2	3.0	7	9	68	68	35	
1640.0	450	450	3.0	3.5	7	9	68	68	33	
1643.0	430	440	2.2	3.6	7	9	68	68	33	
1646.0	390	430	2.2	3.4	6	8	64	64	31	
1649.0	360	410	2.2	3.6	6	8	64	64	33	
1652.0	380	400	3.0	3.8	6	8	70	70	34	
1655.0	360	400	2.5	3.8	7	9	68	71	31	Head assembly damaged
1658.0	280	320	3.0	4.3	10	13	72	72	30	New Excore 8-9 new reaming shell
1661.0	350	390	2.0	3.0	8	11	76	76	35	
1664.0	350	370	2.0	3.1	7	9	76	76	35	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
1667.0	310	330	2.0	2.0	9	10	76	76	35	
1670.0	340	380	2.0	3.0	7	10	76	76	37	
1673.0	380	410	1.5	1.8	9	9	78	78	40	
1676.0	350	390	1.6	3.0	8	8	76	76	38	
1679.0	340	380	1.6	3.0	8	8	76	76	37	
1682.0	340	380	1.5	3.0	7	8	76	76	38	
1685.0	330	370	1.6	3.4	8	8	76	76	38	
1688.0	350	380	1.5	2.6	8	8	76	76	38	
1691.0	340	380	1.8	3.2	7	9	76	78	40	
1694.0	320	340	2.0	4.0	8	10	70	75	38	Pump pressure 35-40 bar
1697.0	340	360	2.0	3.2	7	10	72	74	38	Pump pressure 35-40 bar
1700.0	340	380	2.0	3.6	6	9	78	80	43	Pump pressure 42-44 bar
1703.0	280	300	3.0	4.0	7	10	70	70	38	
1706.0	290	370	2.0	4.0	6	10	72	74	45	Pump pressure 40-50 bar
1709.0	250	310	2.0	4.0	7	8	72	80	50	New Excore 8-9 new reaming shell and 6 m core barrel, core assembly 0.4 m longer
1715.4	300	360	2.0	4.0	7	9	78	80	40	
1718.4	300	380	2.0	3.2	7	7	78	78	50	Pump pressure 48-52 bar
1721.4	310	350	2.2	3.2	7	8	76	78	50	Pump pressure 45-55 bar
1724.4	300	350	1.8	3.2	7	8	76	78	45	Pump pressure 45-55 bar
1727.4	300	350	1.8	3.2	7	8	76	78	45	
1730.4	300	370	2.0	3.0	8	8	80	80	47	
1733.4	300	370	2.0	3.0	8	8	80	80	47	
1736.4	280	330	2.0	3.8	8	8	74	76	47	
1739.4	260	340	2.2	4.0	6	9	78	80	48	
1745.4	230	300	3.0	3.0	6	12	78	82	51	Pump pressure 48-53 bar
1751.4	300	320	2.0	2.0	6	12	78	82	45	Pump pressure 40-50 bar
1757.4	290	340	2.4	3.3	7	10	78	82	54	Pump pressure 50-58 bar
1757.6	300	300	3.2	3.2	6	6	82	82	60	Pump pressure 50-70 bar
1763.4	350	370	2.0	4.0	6	7	68	68	40	New Excore 6-8 JET new adapter coupling
1769.4	320	320	2.0	4.0	5	7	62	62	25	
1775.4	280	280	4.0	4.0	7	7	62	62	25	
1781.4	320	320	2.0	4.0	6	7	60	60	28	
1787.4	340	340	3.0	4.0	7	7	60	60	28	
1790.4	300	400	2.0	4.0	6	7	60	60	30	
1796.4	380	400	2.0	4.0	6	7	60	60	37	
1802.4	370	370	4.0	4.0	7	7	60	60	40	
1808.4	370	370	4.0	4.0	7	7	60	60	45	
1814.4	370	370	2.0	4.0	7	7	60	60	50	
1820.4	380	380	2.0	4.0	7	7	60	60	55	
1826.4	360	360	2.0	4.0	7	7	60	60	55	
1832.4	360	360	2.0	4.0	6	6	60	60	55	
1838.4	350	350	2.0	4.0	6	7	60	60	52	
1841.4	340	380	2.2	3.8	6	7	62	62	52	
1844.4	340	380	2.2	3.8	6	7	62	62	52	
1850.4	330	400	2.0	4.0	6	7	60	60	52	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
1856.4	340	340	2.6	4.4	5	7	62	62	50	
1862.4	140	360	2.4	4.4	5	9	62	72	50	Pump pressure 45-55 bar
1868.4	280	350	2.2	3.5	5	8	68	72	60	Pump pressure 55-65 bar
1874.4	320	350	1.8	2.8	5	8	72	76	59	Pump pressure 58-60 bar
1880.4	330	370	1.8	2.8	6	7	60	60	52	
1886.4	290	340	2.2	3.8	6	7	62	62	50	
1892.4	290	360	1.8	4.4	6	7	60	60	52	
1898.4	280	350	1.8	3.8	6	7	62	62	50	
1904.4	320	360	2.1	3.2	5	9	72	74	55	
1910.4	280	330	2.0	4.0	5	8	70	72	55	
1916.4	220	300	2.7	4.0	5	8	64	72	53	Pump pressure 50-56 bar
1922.4	280	380	2.0	4.0	6	7	64	64	53	
1928.4	290	350	2.2	4.2	6	7	64	64	53	
1934.4	350	380	2.0	3.0	6	7	62	62	49	
1936.7	280	310	1.8	3.0	6	7	66	70	55	New Excore 6-8 JET new adapter coupling, add core orientation tool, core barrel extended 0,4 m
1940.8	320	360	2.2	3.0	5	8	76	76	45	
1946.8	350	350	2.0	3.0	5	7	74	74	45	
1952.8	340	370	1.8	3.2	6	7	74	74	45	
1958.8	320	400	2.0	3.0	6	7	64	64	40	
1964.8	300	370	1.8	4.0	6	7	74	74	45	
1970.8	800	900	3.0	4.8	15	18	80	80	60	Pump pressure 50-70 bar
1976.8	550	800	3.0	5.0	12	16	80	80	60	Pump pressure 50-70 bar
1982.8	520	600	3.0	4.0	9	9	78	78	70	
1988.8	460	500	3.0	4.0	12	15	82	82	75	
1994.8	430	500	3.0	4.0	9	12	80	80	65	
2000.8	450	450	4.0	4.0	10	11	80	80	70	
2006.0	420	460	3.5	4.8	9	11	80	80	68	
2012.3	450	450	3.0	4.0	9	11	90	90	70	
2018.7	450	450	3.0	4.0	9	10	85	85	68	New Excore 6-8 new reaming shell and adapter coupling
2021.8										170 m of reaming
2024.8	450	450	3.5	3.5	9	10	80	85	65	
2030.8	420	420	3.5	3.5	8	10	80	80	70	
2034.9										New Excore 8-9 new reaming shell
2039.8	400	400	2.0	2.0	5	5	60	60	50	
2042.8	400	400	2.0	2.0	5	5	60	60	50	
2045.8	400	400	2.0	2.0	5	5	60	60	50	
2051.8	400	400	2.0	2.0	5	5	60	60	50	
2057.8	450	450	2.0	2.0	6	6	60	60	50	Pumping time inner tube 23.5 min
2063.8	450	470	1.5	2.2	5	6	55	55	45	
2069.8	450	470	1.0	2.2	5	6	55	55	45	
2075.8	450	480	1.0	3.0	5	6	53	53	43	
2081.8	450	450	2.0	3.0	5	6	54	54	45	
2087.8	450	450	2.0	3.0	5	6	54	54	45	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
2093.8	450	450	2.0	3.0	5	6	54	54	45	
2099.8	450	450	2.0	3.0	5	6	54	54	45	
2105.8	450	450	2.0	3.0	5	6	54	54	45	
2111.8	430	450	2.0	3.0	5	6	54	54	45	
2117.8	430	450	2.0	3.0	5	6	54	54	45	
2123.8	430	450	2.0	3.0	5	6	54	54	45	
2129.8	420	420	2.0	3.0	5	6	54	54	45	
2135.8	420	420	2.0	3.0	5	6	54	54	45	
2141.8	430	430	1.0	2.0	5	6	54	54	45	
2147.8	430	430	1.0	2.0	5	6	54	54	45	
2153.8	430	430	1.0	2.0	5	6	54	54	45	
2159.8	430	430	1.0	2.0	5	6	54	54	45	
2165.8	420	460	1.0	2.2	5	8	54	56	47	
2171.8	410	420	1.8	3.0	4	9	54	54	49	Pump pressure 47-50 bar
2177.8	410	450	1.8	2.6	4	8	54	56	49	Pump pressure 47-50 bar
2183.8	400	450	1.6	2.7	4	8	54	58	52	
2189.8	400	450	1.0	4.0	5	6	54	54	52	Dropped 6 m of core
2195.8	400	450	1.0	2.8	5	6	54	54	52	New Excore 6-8 new reaming shell and adapter coupling
2198.8	380	450	1.5	3.5	5	8	62	62	48	Pump pressure 45-50 bar
2201.8	380	450	1.5	3.5	5	8	62	62	48	Pump pressure 45-50 bar
2207.8	390	450	1.5	2.6	5	8	56	58	43	Pump pressure 42-44 bar
2207.9	410	450	1.5	1.5	5	8	56	58	44	Pump pressure 42-45 bar New Excore 6-8 new reaming shell
2210.8	410	480	1.6	2.8	5	8	56	58	45	Pump pressure 42-48 bar
2213.8	410	460	1.0	4.0	5	8	54	54	45	
2219.8	450	450	1.0	3.0	5	8	54	54	45	
2225.8	460	460	1.0	3.0	5	8	54	54	48	
2231.8	450	450	1.0	3.0	5	8	54	54	45	
2237.8	480	480	2.0	2.8	6	6	55	55	54	
2243.8	420	470	1.0	3.0	6	6	54	54	45	
2249.8	420	470	1.0	3.0	6	6	54	54	45	
2255.8	420	470	1.0	3.0	6	6	54	54	45	
2261.8	420	470	1.0	3.0	6	6	54	54	45	
2267.8	420	470	1.0	3.0	6	6	54	54	45	
2273.8	400	450	1.0	3.0	5	6	54	54	45	
2279.8	400	400	2.0	2.0	5	5	50	50	45	Pumping time inner tube 24.5 minutes (around 110 l/min)
2285.8	400	450	1.0	2.5	5	6	54	54	50	
2291.8	390	440	1.0	3.0	5	6	54	54	50	
2297.8	310	400	1.0	4.0	0	7	45	60	45	Pumping pressure 40-50 bar
2303.8	380	410	1.0	4.0	2	7	50	50	48	
2309.8	300	400	1.0	4.0	1	7	52	52	48	
2315.8	320	400	1.0	4.0	5	5	50	50	45	
2321.8	320	400	1.0	4.0	3	5	48	52	45	
2327.8	350	400	1.0	4.0	4	5	50	50	45	
2333.8	350	390	1.0	4.0	2	6	52	52	48	
2339.8	350	390	1.0	4.0	2	6	50	50	45	

Driller's depth (m)	RPM (min)	RPM (max)	WOB (min) (ton)	WOB (max) (ton)	ROP (min) (cm/min)	ROP (max) (cm/min)	Pumping rate (l/min)	Pumping rate (l/min)	Pump pressure (bar)	Remarks
2345.8	350	390	1.0	4.0	2	6	50	50	45	
2351.8	350	390	1.0	4.0	2	6	50	50	45	
2357.8	320	400	1.0	4.0	3	5	50	50	45	
2363.8	320	370	2.0	4.0	2	6	52	52	50	
2369.8	320	370	2.0	4.0	2	6	52	52	50	
2375.8	320	370	2.0	4.0	2	6	52	52	50	
2381.8	270	350	2.0	4.0	2	5	50	50	48	
2387.8	270	350	2.0	4.0	2	5	50	50	48	
2393.8	270	350	2.0	4.0	2	5	50	50	48	
2399.8	270	350	2.0	4.0	2	5	50	50	48	
2405.8	320	350	1.0	4.0	2	6	52	52	52	
2411.8	320	350	1.0	4.0	2	6	52	52	52	
2417.8	310	350	1.0	4.0	5	6	54	54	55	
2423.8	310	350	1.0	4.0	5	6	50	50	45	
2429.8	310	350	1.0	4.0	5	6	50	50	45	
2435.8	310	350	1.0	4.0	5	6	50	50	48	
2441.8	290	350	1.0	4.0	2	5	54	54	53	
2447.8	290	350	1.0	4.0	2	5	50	50	50	
2453.8	320	360	2.0	3.0	2	5	52	52	55	
2459.8	300	350	2.0	3.0	2	5	50	50	55	
2465.8	280	370	1.5	3.8	2	5	50	50	55	
2471.8	280	370	1.5	3.8	2	5	50	50	55	
2477.8	280	370	1.5	3.8	2	5	50	50	55	
2483.8	280	370	1.5	3.8	2	5	50	50	55	
2489.8	250	350	2.5	4.0	2	5	52	52	55	
2495.8	250	320	2.5	4.0	6	6	52	54	55	EOH

Appendix B – Drill bits (data set: Used drill bits)

Drill bit description HQ3	Depth (m) from	Depth (m) to	Total (m)
Excore 6-8 FD13 10WW *)	103	110	7
Excore 8-9 JET16 10WW	110	282.7	172.7
Excore 8-9 JET16 10WW	282.7	440.5	157.8
Excore 9 JET16 10WW	440.5	477.35	36.85
Excore 8-9 JET16 10WW	477.35	600.15	122.8
Excore 8-9 JET16 10WW	600.15	655.45	55.3
Excore 8-9 JET16 10WW	655.45	714.25	58.8
Excore 6-8 FD13 10WW	714.25	767	52.75
Excore 6-8 JET16 10WW	767	882.5	115.5
Excore 8-9 JET16 10WW	882.5	968	85.5
Excore 6-8 JET16 10WW	968	991.45	23.45
Excore 8-9 JET16 10WW	991.45	1095.5	104.05
Excore 9 JET16 10WW	1095.5	1109	13.5
Excore 10 JET16 10WW	1109	1147.7	38.7
Excore 8-9 JET16 10WW	1147.7	1234.65	86.95
Excore 8-9 JET16 10WW	1234.65	1295	60.35
Excore 8-9 JET16 10WW	1295	1307.6	12.6
Excore 8-9 JET16 10WW	1307.6	1369.65	62.05
Excore 8-9 JET16 10WW	1369.65	1470	100.35
Excore 8-9 JET16 10WW	1470	1540.8	70.8
Excore 8-9 JET16 10WW	1540.8	1616	75.2

*) used for drilling cement, not worn out

Drill bit description NQ3	Depth (m) from	Depth (m) to	Total (m)
Excore 8-9 JET16 8WW	1616	1649	33
Excore 8-9 JET16 8WW	1649	1709	60

Drill bit description NQ	Depth (m) from	Depth (m) to	Total (m)
Excore 6-8 JET16 8WW	1709	1936.65	227.65
Excore 6-8 JET16 8WW	1936.65	1964.8	28.15
Excore 6-8 JET16 8WW	1964.8	2005.95	41.15
Excore 8-9 JET16 8WW	2005.95	2034.95	29
Excore 6-8 JET16 8WW	2034.95	2195.8	160.85
Excore 6-8 JET16 8WW	2195.8	2207.8	12
Excore 6-8 JET16 8WW	2207.8	2495.8	288

Excore is the name of the bit, the number designates the rock group (6-8 and 8-9 is medium hard to hard rocks and abrasive to slightly abrasive formations), JET16 is the flow profile with 16 mm crown height and 8WW is the number of water ways.