SCIENTIFIC DRILLING IN NEW ZEALAND: EXPERIENCE FROM THE DEEP FAULT DRILLING PROJECT

VĚDECKÉ VRTÁNÍ NA NOVÉM ZÉLANDĚ – ZKUŠENOSTI Z PROJEKTU HLUBOKÉHO VRTÁNÍ NA SLEDOVÁNÍ ALPINSKÉ DISLOKACE

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Abstract

The Deep Fault Drilling Project (DFDP) is an international scientific drilling project co-financed by ICDP. Its aim is to study a major plate-boundary fault at depth. After the success of the first phase (DFDP-1) in 2011, the project continued in 2014. The second phase of the Deep Fault Drilling Project (DFDP-2) took place from October to December 2014 in Whataroa, South Westland, New Zealand. It drilled to the depth of 893 m, and experienced temperatures exceeding 80°C at depths smaller than 500 m. The target depth of 1300 m and the Alpine Fault was not reached due to equipment failure. However, the large number of wireline logs, hydraulic measurements and cuttings and fluid samples provided valuable information on heat and fluid transfer, rheology and structures in the hanging wall of the Alpine Fault. This paper summarizes DFDP-2 as seen by one of the postgraduate students participating on site.

Abstrakt

Projekt hlubokého vrtání na sledování alpinské dislokace je mezinárodní vědecký vrtný projekt, který financuje organizace ICDP. Cílem je sledování hlavní rovinné hraniční dislokace s hloubkou. Po úspěchu prvé fáze v roce 2011, (DFDP-1), projekt pokračoval v roce 2014. Druhá fáze projektu (DFDP-2) proběhla od října do prosince roku 2014 v lokalitě Whataroa, South Westland na Novém Zélandě. Vrtalo se do hloubky 893m a zjištěné teploty byly vyšší než 80°C už v hloubkách do 500m. Plánované hloubky 1300 m k zastižení alpinské dislokace nebylo dosaženo, protože došlo ke zkolabování pažnice. Avšak velký počet záznamů kabelové karotáže, hydraulických měření, vyplavených vrtných úlomků a odebraných vzorků kapalin poskytly cennou informaci o zdroji tepla a pohybu kapalin, reologii a nadloží alpinské dislokace. Práce hodnotí projekt DFDP-2 tak, jak jej viděl jeden ze studentů, kteří přímo na něm se spolupodíleli.

Keywords

Alpine Fault, scientific drilling, New Zealand

Klíčová slova

alpínská dislokace, vědecké vrtání, Nový Zéland

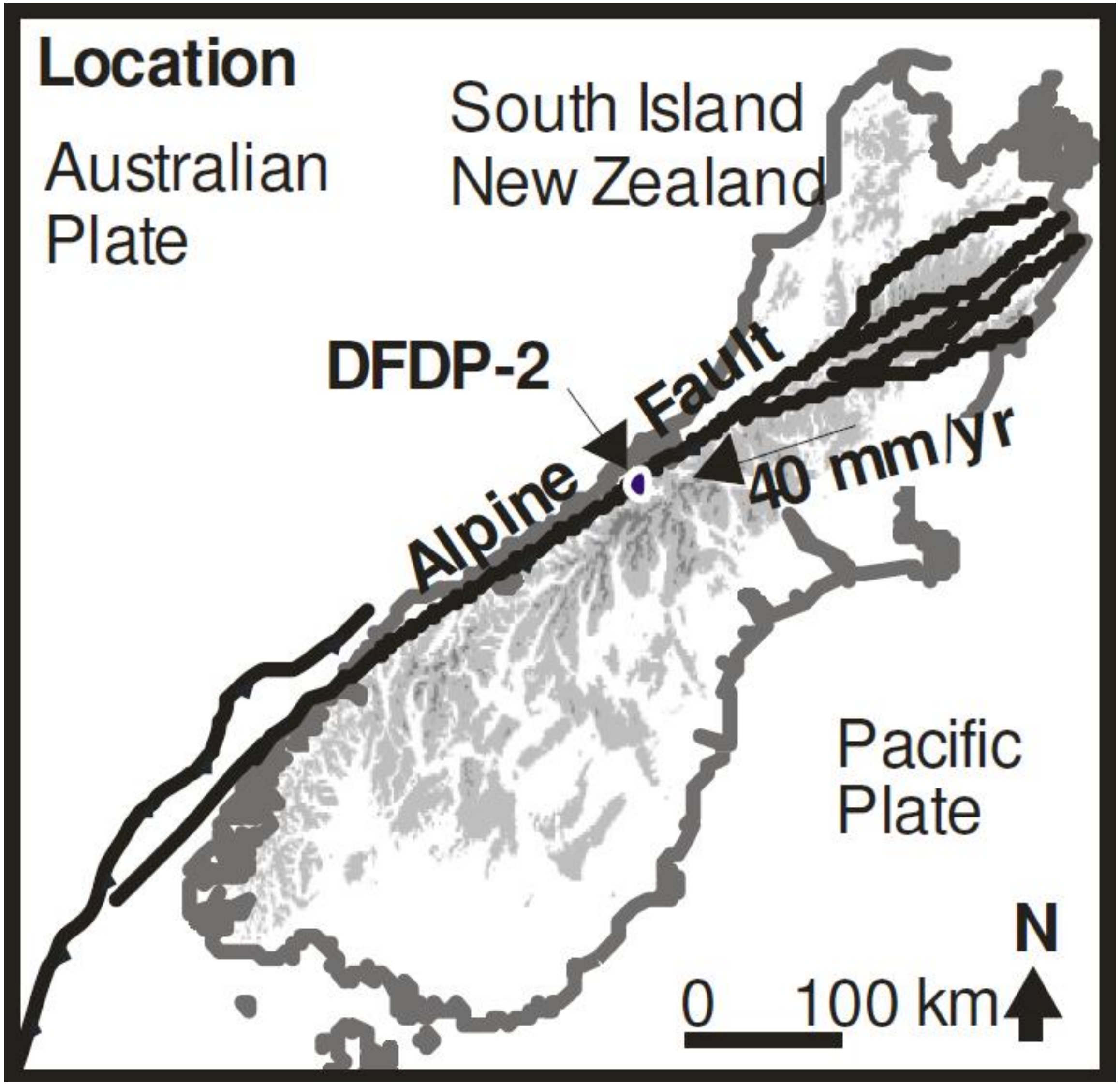

Fig.1 Plate boundary on the South Island of New Zealand and the location of DFDP-2. After Sutherland, R., Townend, J., Toy, V. (2014) Deep Fault Drilling Project, Alpine Fault Borehole DFDP-2: the Technical Outline. Internal project material (unpublished)

1 Introduction

Deep Fault Drilling Project (DFDP) is the first scientific drilling project ever aiming to study a major active fault on a plate boundary that is late in its earthquake cycle. The first phase of this project, DFDP-1, took place in 2011 in Gaunt Creek, South Westland, New Zealand, and revealed a crucial role of the Alpine Fault in fluid and heat transport in the Southern Alps. After the success of these two shallow (100 and 150 m) boreholes, the second phase of the project was launched in the Whataroa Valley (Fig.1) in 2014 with the goal to intersect the Alpine Fault at 1000 m depth.

First, it is necessary to point out that this is not an official drilling report. The Operational Report of DFDP-2 is to be published in the near future. This paper summarizes the subjective experience of one of the Science Team members and does not aim to present any results acquired during the research.

1.1 New Zealand Geology

New Zealand, or the microcontinent of Zealandia, lies on the convergent boundary between the Australian and Pacific plates. East of the North Island, the Pacific plate is subducting beneath the Australian plate along the Hikurangi trench, whereas the Puysegur trench south of the South Island exhibits the opposite direction of subduction, as shown in Fig. 2. A large portion of the motion on the plate boundary is accommodated on the transform fault system in between, of which the most significant is the Alpine Fault. These faults pose a great earthquake hazard to the South Island; the Alpine Fault alone is known to produce M8 earthquakes every 200 – 400 years

(Berryman et al., 2012; Sutherland et al., 2007).The Alpine Fault is an oblique reverse strike-slip fault, with approximately 27mm/yr

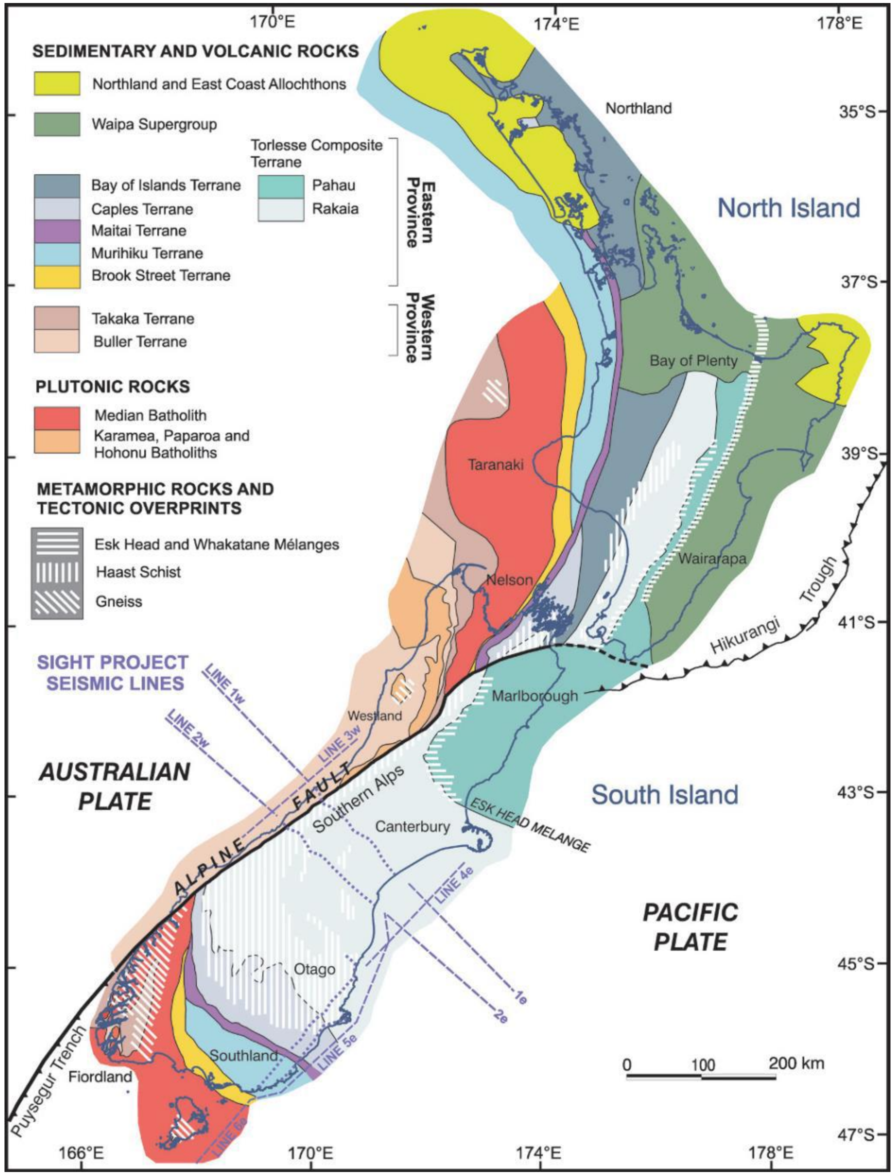

Fig.2 Simplified Geological map of New Zealand after Cox & Sutherland (2007)

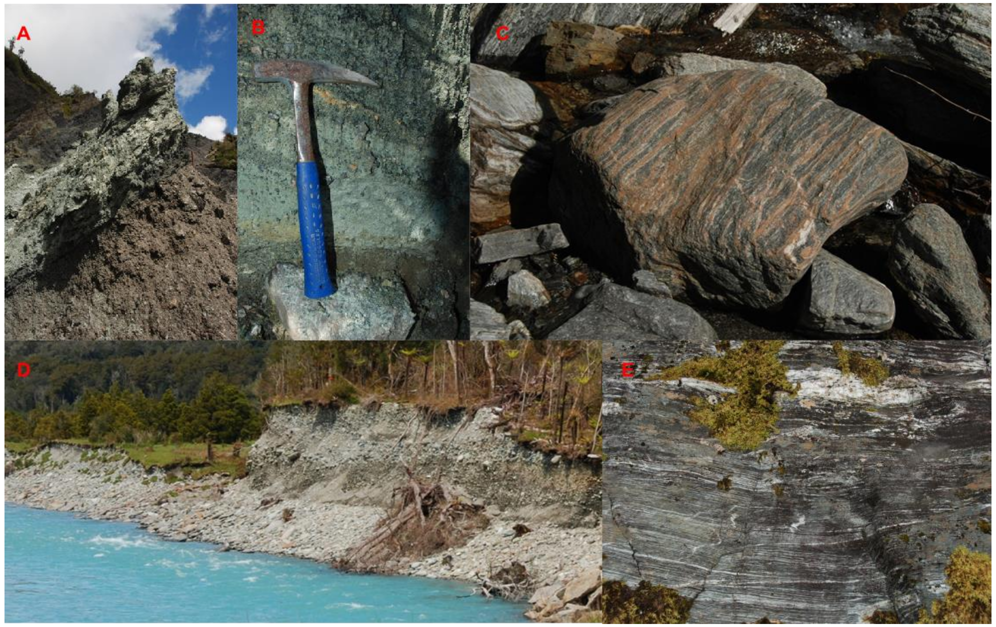

Fig. 3 Geological features of the West side of Southern Alps
A: outcrop of the Alpine Fault at Gaunt Creek
B: Alpine Fault Gauge and ultramylonite
C: boulder of Alpine Schist
D: profile through Quaternary sediments
E: Alpine Schist with glacial striations

of dextral motion and up to 10 mm/yr of uplift (Cox & Sutherland, 2007; Norris & Cooper, 2007). Due to such a high uplift rate, the Southern Alps, the orogen formed by this uplift, is not in thermal and hydrological equilibrium, which is demonstrated by high geothermal gradients and presence of hot springs.

On the inbound side of the orogen, deformation is driving meteoric fluids through fractures to greater depths (Wannamaker et al., 2002), which may explain the high formation pressure experienced in DFDP-2B.

Tab. 1

Hole	2A	2B
Casing	12” to 29 m, 10” to 125 m	16” to 47 m, 12” to 237 m, 10” to 264 m, 8.5”& 5.5”& 2.25” to 893 m
Bits	Roller-cone, stratopack	Roller-cone, Poly-crystalline diamond, (Coring diamond bit – planned for fault rocks)
Technique	Dual-rotary air, Dual-rotary mud	Dual-rotary mud, Rotary mud

In the Whataroa Valley, the basement consists of the Alpine Schist, a highly anisotropic metamorphic rock intersected by numerous quartz veins. Foliation dips at 60°, parallel with the anticipated Alpine Fault plane. The valley is filled with heterogeneous, mostly glacigenic Quaternary sediments. Their thickness in DFDP-2B reached 240 m. The overview of typical rocks of the western side of Southern Alps is shown in Fig. 3.

2 Drilling equipment and techniques during DFDP-2

The overview of techniques, drillbits and steel casing diameters used during DFDP-2 is given above (Tab. 1). In detail, it has been described in Sutherland, Townend and Toy (in press).

3 Timeline of drilling operations

- Aug –Sep 2014: Site preparation, drilling in DFDP-2A, Quaternary drilling in DFDP-2B (Fig. 4).
- 1st Oct: Official start of drilling. Majority of Science Team participating in the ICDP workshop in Franz Josef until 6th October. Quaternary drilling continues.

Fig. 4 A: Quaternary drill rig abandoning its position
B: Collection of cuttings and gas monitoring, mud pit, Quaternary drill rig
C: Basement drill rig
D: View down the DFDP-2B, drillstring in hole
E: Steel casing and polycrystalline drillbit.

- 10th October at 236.6 m intersecting artesian hydrothermal horizon.
- 14th Oct: Hit the basement in the morning. Drilling to 260 m then stopped. Removing rig. Running wireline logs and monitoring mud level in the hole ("slug test").
- 15th Oct: new rig in place, start of drilling in the basement.
- 23rd Oct: Calamity No.1 – BHA fell down the hole at 396 m. More logging and slug tests.
- 9th Nov: drilling recommenced.
- 12th Nov: Calamity No. 2 – lost drillbit due to previous damage to the BHA. Depth 489.5 m.
- 16th Nov: drilling resumed and 17th Nov: slow progress, equipment worn down. Drilling stopped and equipment sent to Christchurch for servicing.
- 24th Nov" drilling resumed.
- 11th Dec: Calamity No.3 – Based on cuttings, geologists report that the mylonite has been reached. The hole is being cased with the 8.5" casing followed by a 5.5" pipe for coring and a 2.25" pipe with a fibre optic cable. During cementation, cement arrives at surface earlier than anticipated. Operations stop, investigation of the problem.
- 13th Dec: Coring through the cement. Rock retrieved at 471 m.
- 16th Dec: Investigation at end - casing is misaligned, irreversible damage to the borehole. It is impossible to continue drilling in DFDP-2B. Majority of Science Team leave site. Volunteers hold security shifts over Christmas break.
- Jan 2015: installation of the downhole geophysical observatory (seismometers at 400 m depth and fibre-optic cable for temperature monitoring along the full length of the borehole).

At the moment, data acquired during drilling are being processed and distributed among the Science Team and first results are to be published in near future. A special DFDP workshop is to be held at the AGU Meeting in December 2015. Once the results are published, efforts will be made to acquire sufficient funding and resume drilling in order to reach the target depth and intersect the Alpine Fault.

4 Monitoring during DFDP

The Operations Team, which I was a member of, was responsible for ensuring the stability of the borehole; smooth drilling operations, security on site and hydraulic research.

4.1 Measuring mud properties

Mud parameters were essential for smooth drilling. Both outflowing mud and injected mud was monitored 24 hours a day, usually on an hourly basis. Viscosity of the mud was measured by the Fann calibrated marsh funnel. Mud density was measured using the Fann balancing tool. Due to high fluid pressure in the deeper parts of the hole, the mud density was maintained at 1.08 g/cm^3. Temperature of the mud was measured by temperature sensors, one installed in the outflow pipe and another one in the suction mud pit. Conductivity and pH of the outflowing mud was measured daily.

4.2 Monitoring mud level in mud pits

Measuring posts were installed in the suction and returns pit for monitoring potential mud losses or gains.

4.3 Monitoring rig parameters and pump rate

These parameters were recorded automatically by the rig and were downloaded on a daily basis. During late November and December, pump rate needed to be taken manually due to malfunction.

4.4 Monitoring mud level in borehole when not drilling

During interruptions in drilling, mud level in the borehole was monitored using a water level dip meter. This procedure was done for two reasons. Firstly, it was necessary to prevent overflow in order to maintain borehole stability (from 260 m onwards, the drilling was in open hole). Secondly, monitoring the mud level changes served as improvised slug test to estimate the hydraulic conductivity of the intersected formations and the hydraulic head.

4.5 Monitoring gas chemistry

Gas chromatograph, mass spectrometer and radon detector were installed on site to monitor gas chemistry of the outflowing mud. This ensured safety of on-site staff (in case poisonous or explosive gases were encountered during drilling), monitored equipment failures (oil spills and corrosion of drill rods) and served as important source of scientific data for the geochemists.

4.6 Monitoring seismicity

To mitigate induced or triggered seismicity, an array of seismometers had been deployed around the drillsite and existing seismic networks were used as well. Seismologists were on shift 24 hours a day to promptly locate and assess all seismic events in the region and inform the scientists and drillers immediately if they suspected induced or triggered seismicity. Fortunately, no seismic events were related to the drilling. In addition to operational monitoring by the Operations Team, monitoring of geology was carried out by the Geology Team. The geologists were responsible for the following tasks:

- **Collection of cuttings**

Sieves were installed at the outflow pipe and cuttings were collected at regular depth intervals.

- **Making thin-sections**

Thin-section making facility was installed on site and thin sections were produced from cuttings every 6 meters. Additional thin sections of quartz grains only were produced, too. They were used for monitoring of the degree of deformation, so that the distance from the fault could be estimated.

- **Cuttings analysis and identification of geological units**

The on-site laboratory was equipped with microscopes. Cuttings, as well as thin sections, were analysed continuously 24 hours a day and the results were entered in the Drilling Information System (DIS) run by the ICDP.

- **Monitoring penetration rate**

To match the cuttings samples with correct depth, the lag depth and penetration rate were monitored continuously. A complete summary of the operations with descriptions of all used methods is to be published in the Operational Report.

5 Wireline logging during DFDP

The Wireline Team, of which I was a member as well, closely cooperated with the Operations Team to secure the borehole conditions as well as help better understanding of the geological, hydraulic and technological state of the borehole. The following methods were used:

- Numerous repeated **temperature logs** (+ fluid properties: conductivity, pH, pressure)
- Natural **gamma** & gamma spectrometry
- Flowmeter & Spontaneous Potential (only shallow)
- **Laterolog**
- Full-waveform **sonic**
- **Acoustic borehole televiewer (BHTV),** Magnetic susceptibility, Caliper

No active-source radioactive methods were used and the spontaneous potential was only used in the shallowest portions of the borehole, because the tool was not designed for temperatures exceeding 60°C. In spite of the temperature limitations of most tools, high-quality data have been acquired.

6 How is DFDP special from different perspectives

6.1 New Zealand geology

The environment of the Southern Alps is challenging for drilling for several reasons. Probably the greatest challenge is the seismic risk. Drilling in the proximity of a major fault that is likely to slip in the next few decades raises concern both among the public and scientists. Therefore, the location was chosen in the portion of the orogen with the lowest seismicity and non-stop seismic monitoring was taking place before, during and after the drilling operations. In addition to seismic risk, the thick heterogeneous Quaternary fill of the Whataroa Valley required changes in the technology of drilling and resulted in unpredictable penetration rate. Hard anisotropic basement schist dipping at ~60° caused the borehole to increasingly deviate from vertical. High fluid pressure required using heavy mud, which complicated wireline logging as the tools tilted and occasionally got clogged with mud. The temperature exceeding 80°C did not allow the use of some logging tools and limited other tools to very fast runs, resulting in low resolution of measurement (particularly with BHTV and spectral gamma tools).

Fig. 5 Whataroa River and Southern Alps

6.2 New Zealand climate

The Southern Alps form a barrier to westerly winds, causing precipitation shadow over the Canterbury Plains on one hand, and on the other hand extreme rainfall on West Coast of the South Island. The mean precipitation rate along the West Coast ranges from 2154 mm per year in Westport to 6715 mm per year in Milford Sound (NIWA). Austral spring 2014 was particularly rich in rainfall. Together with strong winds and occasional hail and thunder storms, this created a considerably unpleasant environment for on-site staff and equipment.

6.3 Other aspects of the drillsite location

New Zealand as a country is one of the most remote places on Earth, so that transport of persons and equipment is costly and time-consuming. Moreover, the West Coast of the South Island is one of the most remote places in the country. The nearest town with basic facilities such as a supermarket, hospital etc. (Hokitika) was located 100 km away from the drillsite, i.e. approximately 90 minute drive away. However, at the same time, this location is near several tourist highlights such as the Okarito white heron sanctuary and Franz Josef Glacier. Even Whataroa Valley itself presents scenery highly appreciated by all on-site participants (Fig.5). The local communities were very supportive, providing shelter and resources for 60 – 100 scientists and drillers for three months and showing interest in the science behind drilling. Several excursions to the drillsite were organized for local school children and public talks were given by the Principal Investigators in Franz Josef and Hari Hari.

Fig.6 Female majority of the wireline logging team (Jehanne Paris, Cécile Massiot, Lucie Čápová, Tamara Jeppson). Photo by Bernard Celerier.

6.4 Scientific non-commercial drilling

DFDP is a purely scientific project with no commercial interest. As such, it is operating on a very limited budget. It is funded from diverse sources, with the largest contribution from ICDP. However, with no commercial target, the main value is in data collected during drilling. This fact provides certain freedom to the researchers and encourages international cooperation. The Science Team (which includes the Operations, Wireline and Geology teams) has 122 members from organizations in 12 countries, of whom a large portion consists of postgraduate students. Thus, the project provided a unique opportunity for the future generation of scientists to participate in high-level international research.

6.5 Atmosphere

DFDP-2 featured unique, unforgettable atmosphere (see Fig. 6). By spending three months together in physically and mentally challenging conditions in a remote place, the Science Team members developed genuine friendships, went to great lengths for the general good of the project and supported each other in the hardest moments.

7 Publicity

DFDP appeared in the media, including Radio NZ, TV3 and TVNZ (New Zealand national stations) and was on display at the exhibition on scientific drilling in the Czech Academy of Sciences in April 2015. For more information and photographs, follow the blog http://www.rupertsnztectonics.blogspot.co.nz and Facebook page Deep Fault Drilling Project-2 https://www.facebook.com/pages/Deep-Fault-Drilling-Project-2/1474306806176703?ref=aymt_homepage_panel.

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