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Hydrothermal Eruptions During Excavation of a Seawater Pump Sump at Bouillante

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ORKUSTOFNUN
GeoScience Division

Short Report
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1. INTRODUCTION

At the request of CFG Mr. Sverrir Thorhallsson Head of Engineering Dept. at Orkustofnun GeoScience Division traveled to Bouillante in Guadeloupe March 12-15 2003 to inspect steam eruptions that had recently occurred there while excavating a 4 m deep pump-sump. The pit being excavated is on an active geothermal site with steaming ground. The sump is close to the beach and will provide seawater to a turbine condenser. The condenser is a part of a new 11 MW power plant now under construction at Bouillante (B2) by the existing 4 MW power plant (B1).

The terms of reference (TOR) were, as outlined in an E-mail message from Mr. Hervé Traineau of CGF to Orkustofnun dated 4. March 2003:

a) To provide an expertise about the phenomena experienced two times at the pumping station, its origin and mechanism, its potential hazards regarding safety of workers on the site (on basis of data provided by CFG and site survey).
b) To recommend equipment to be installed during implementation of the pit and later in order to monitor the shallow aquifer.
c) To provide recommendations on the design of the pit and other adjacent structures and about usual practices in such a geothermal environment.

2. ACTIVITY REPORT

March 13. Traveled to Paris March 11. After taking part in a one-day IEA geothermal meeting on March 12 I joined Mr. Herlander Correia of CFG and Mr. Pascal Pitois (El. Eng) at Orly West airport for the 12:00 flight to Guadeloupe. Landed at Pointe à Pitre airport at 16:00. Went directly to the power plant in Bouillante to pick up keys to the apartment. A short walk was made along the waterfront where the new 900 mm seawater pipeline had been excavated and taken out of the ditch due to damage incurred in a storm after it was laid in January. A few photos were taken of the ditch and peninsula where the seawater pumping station is located. There is some hot ground in places along the pipe route and the floor is hot in two nearby houses where people live. Worked into the night preparing figures.

March 14. Went with Mr. P. Pitois to the power plant at 7:30 to meet Mr. H. Correia. It was decided to go to the field with Mr. Mayer the CFG engineer in charge of the expansion to observe and make measurements. Measurements were made with the handheld digital thermometer and IR thermometer I brought with me. I did not carry with me 1,8 m long temperature probe used in Iceland for soil temperature measurements to map areas with abnormally high heat, both for exploration and also for siting of buildings. I received information from CFG that a similar device would be available in Bouillante and thus not necessary for me to bring it along. The local thermocouple was not watertight and the insulation not designed for the high temperature. Several measurements were made in the seawater pit after it showed erratic readings. It was subsequently discovered that the instrument was not in order. Then a mercury thermometer from the plant graduated to 150°C was lowered into the wells to make readings. When it showed so high temperatures that they could not be believed, inspection revealed that the mercury column of the thermometer had separations (air pockets) in it leading to high readings. A decision to lower the water level in the pit had to be postponed as the pump did not start. This completed the day's effort.

March 15. A new thermocouple wire encased in a SS pipe was obtained from a bagasse power plant and sugar refinery in Moule. Mr. Pascal made the arrangements and drove early in the morning for 2,5 hr to pick it up. It was strapped to a pipe and was used to repeat the measurements in the well and pit from the day before that turned out to be faulty. A gasoline powered pump on floating platform started emptying the pit at 7:30 AM and in 6,5 hr managed to draw the level down by 1,3 m. Temperature measurements were made in the flow from the pump and water level. Location and relative amount of gas bubbles breaking the surface was noted. No changes of significance were noted. Late in the afternoon we paid a short visited the new wells site and separator. I discussed with Mr. H. Correia the main observations and recommendations that I would make. Then work started on preparation of the report in the CFG office by the power plant gates.

March 16. Work continued in preparing the report in time for my departure for the flight back to Paris at 14:30. I handed in this draft to Mr. Herlander Correia before my departure and spoke by phone to Mr. H. Traineau in Orleans about the findings.

3. Main Observations

- The site of the seawater pump station is clearly in a geothermal field with surface manifestations such as steam vents and thermal spring in the ocean. The thermal manifestations also appear on several locations along the beachfront to the power station. These sites had been identified by CFG and should have received more scrutiny before deciding to site the pit on such a spot.
- The temperature profile with depth approaches the well known Boiling Point with Depth curve (BPD curve) as is to be expected with boiling springs and the pressure near surface controlled by the sea level.
- The high-temperature geothermal reservoir of 260°C has a positive hydrostatic pressure, but no signs are that it is the leading cause for the boiling breaks that occurred.
- The fluid withdrawal from the reservoir has been small as only the 4,5 MW station has be connected, in the past to BO.2, now to BO.5. An increase in enthalpy had been noted in BO. 2 but not the formation of a large "steam cap". Such boiling zones are known to increase the steam flow to surface and affecting surface manifestations.
- There is some escape of geothermal gases (CO_2) and that is to be expected as there are the "non-condensable gases" in all geothermal steam. This is seen as gas bubbles breaking the surface of the water in the pit and are a good indicator of where there is hot inflow of steam or hot water into the pit. These gases undoubtedly play a role in how a "blow-out" occurs from shallow depths as in this case. No samples were collected and the bubble flow was small in any case. The non-condensable gas concentration is 0,4% in the steam to the turbine, what one would expect from a liquid dominated resource. Should a steam cap develop the concentration of the gas in the steam can be expected to be an order of magnitude greater (x 10).
- The pump station site where the excavations for the channel and pit have taken place are on a 1-2 m thick landfill into the ocean from the time well BO.3 was drilled.
- The excavations now go a lot deeper (6 m) than for the old pump station. This may explain why hydrothermal eruptions did not interfere with the construction of the old station.
- Land on the beach is at a premium and puts constraints on the search for an alternative site for the pump station.
- Photographs taken during and just after the hydrothermal eruptions show that a thick fluid, almost like thick drilling mud, issued out by the steel pile sheet (driven to 9 m depth) and when the hydrothermal eruptions occurred. This implies that the "source rock" of the eruptions are altered clays that can easily become unstable and cause such a "blow-out" if the pressure drops below the saturation pressure. That causes a part of the water in the clay to be quickly converted into steam (flashing). Thus the quick steam and mud blasts - that only last a short time. These give no or short advanced warnings. How big and dangerous these blasts can be, depends on how deep they reach and the volume of soil (mainly clays) that spontaneously can flash and degas.

4. Recommendations

1. The pit is in a very active thermal area and the hydrothermal eruptions have every sign of what in drilling is referred to as a "BLOW-OUT". The countermeasures should be much the same as in drilling, that is to say:

- Maintain the pit FULL of water until the bottom can be secured by cementing.
- The temperature at 6 m depth, the intended excavation depth is about 110°C and the saturation pressure is about 1,4 bar-a. This means that a water level of 4 m H_2O has to exerted at -6 m depth to avoid flashing. As the water level in the full pit is at about - 1 m there is a small overpressure of about 1 m H_2O as a margin of safety.
- The well can first be excavated a further 1,5 m (with the pit full of water) but the bottom will be with soft clay and not have much bearing capacity.
- Cement the bottom to secure the pit and allow it to be drained of water. Then the reinforced cement bottom can be poured and the final cemented structure built.
- It is felt that installing breather tubes or drain pipes below the first cemented layer to relieve the pressure that may build up, can increase the danger of a secondary "blow-out" as a small hydrothermal eruption through such pipes could "trigger" a larger one.
- This period will be a time of experimentation as to how best to carry out the work. It is thus important that a qualified inspector follow the progress and be able to give guidance on the spot. He should also act as a safety inspector and insure that only the required personnel be allowed near the pit until it has been secured.
- Early signs of changes that should give alarm are:
  - Increased flow of gas bubbles breaking the surface in the pit and new locations of bubble flow.
  - Elevation of temperature in the pit (record every hour).
  - Increased activity in the flow from the three observation holes (make regular photographs of the pit and site for reference purposes).
  - Increased activity in the area outside the pit.
  - Hydrothermal eruptions.

2. The area outside the pit has had the appr. 1 m thick landfill removed and is now at the level of the old shoreline. There is considerable thermal activity in this very soft clay ground. In spite of me taking precautions where I walked, one of my legs sank deep into the 83°C clay below. I was saved from burns by my knee-high rubber boots. This area needs to be secured by removing some more clay and then filling in with small rocks (separating the clay with geotextile?) and then filling up with compacted soil.

3. There are numerous safety related issues that need to be addressed. The worker-safety related issues are:

- Inform the workers on the potential blow-out situation and how it is being tackled. Stress that this is very much the same as faced by geothermal drillers daily. Explain the countermeasures being taken.
- Hot sticky mud makes deep skin burns and is in many ways more dangerous than a direct flame. Protective clothing is advised for anyone working close to a potential blow-out site. This includes: ankle high rubber boots, tough rainwear and pants, hard hats with a face shield. Rubber gloves. Flushing any burn sites with cold water immediately is essential first aid and the workers should know where and how to apply it.
- The non-condensable geothermal gases (mainly CO_2) may accumulate in cellars and the deep pit, even after the cement has been poured in place. A lone worker should thus not be there and precautions taken at the start of the working day by checking that the pit is gas free.

- Should hydrothermal eruptions recur, inside or outside the pit, people should move away at least 30 m and take note of what is happening, rather than go close to inspect. Only properly clothed persons should go close do so. Photographic evidence is very valuable in evaluating each incident.

3. In order to get a clear picture of the extent of hot ground it is recommended that a surface temperature survey be made. The lines should be laid out perpendicular to the suspected fault or controlling structure. In Iceland, where such surveys are used for the same purpose, the lines are 20 m apart and the measuring points spaced at 5 m. Where straight lines are not possible due to obstructions randomly selected sites are used to give good coverage. First a survey hole is made by a 20 mm pin is inserted to a fixed depth in the range 60-80 cm, sometimes aided by a hammer, and then shortly thereafter the 15 mm dia. temperature measurement probe is inserted for the reading. Such ground temperature surveys may be supplemented by aerial infrared surveys or by remote sensing from satellite. This is furthermore an inexpensive way to monitor any long term changes in the environment. Had such surveys been available, they could have influenced the siting of the pump station and would now allow evaluation of alternate sites, should the present site have to be abandoned.

Bouillante, Guadeloupe
15.03.2003
Minor revisions:
19.03.2003

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Sverrir Thorhallsson

Att.
Appendix I – Figures
Appendix II – Photographs

Appendix I

Figures

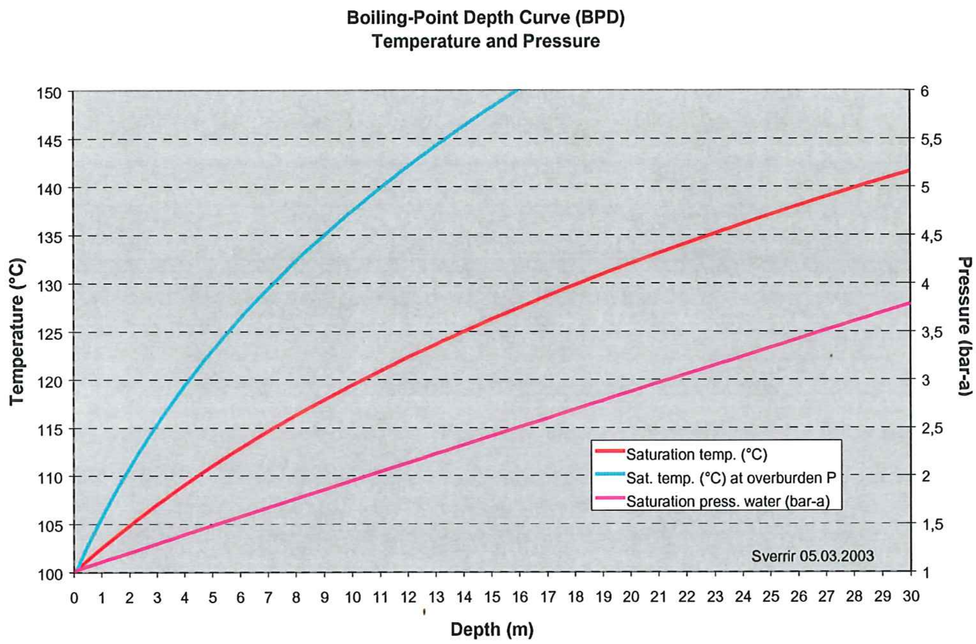


Figure 1. Diagram sent to CFG prior to the trip to act as a guide to assess the danger of a blow-out. Wells with temperatures below the boiling point (BPD curve) are stable. The red line BPD curve can be considered as the "maximum" temperature vs. depth and is often found in natural high-temperature geothermal systems.

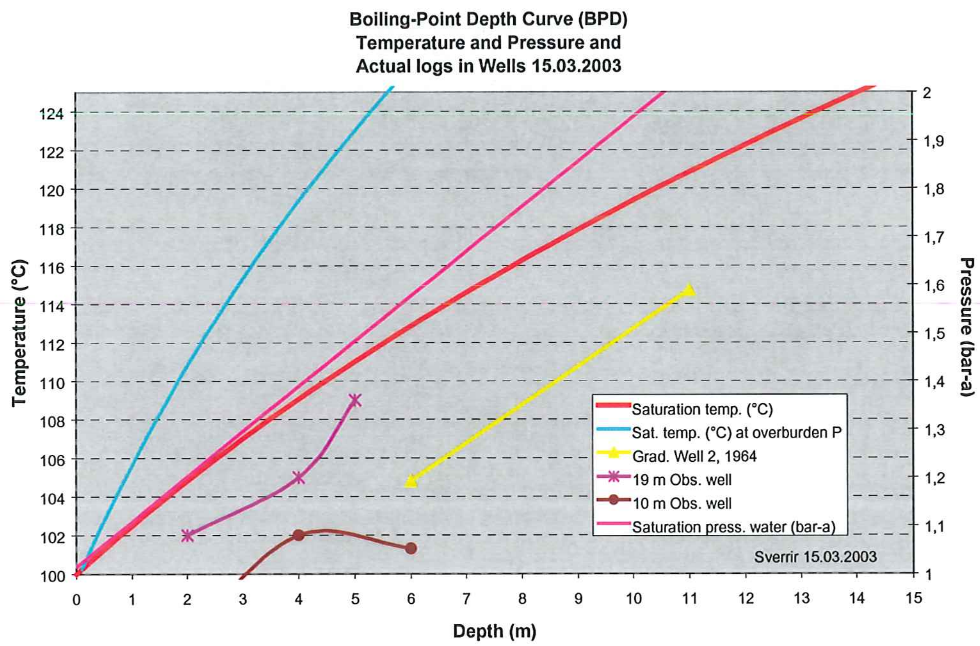


Figure 2. This diagram includes the same guidelines as fig. 1 but shows the temperatures logged in observations wells by the sea water pit 15.03.2003. All of the wells have temperatures below the BPD curve when the pit is full of water but do become unstable once the water level drops much below 2 m from the present.

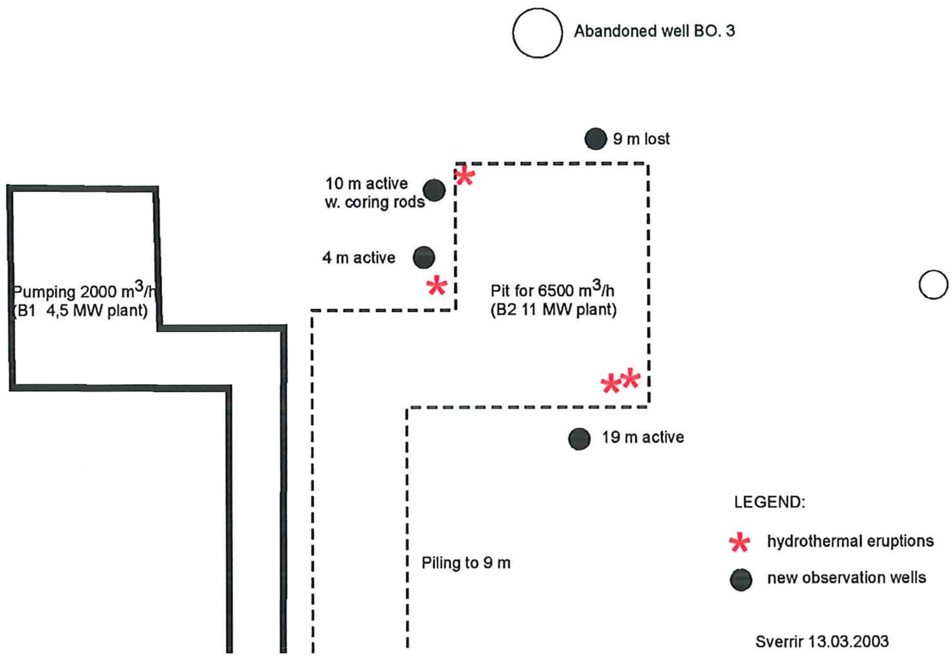
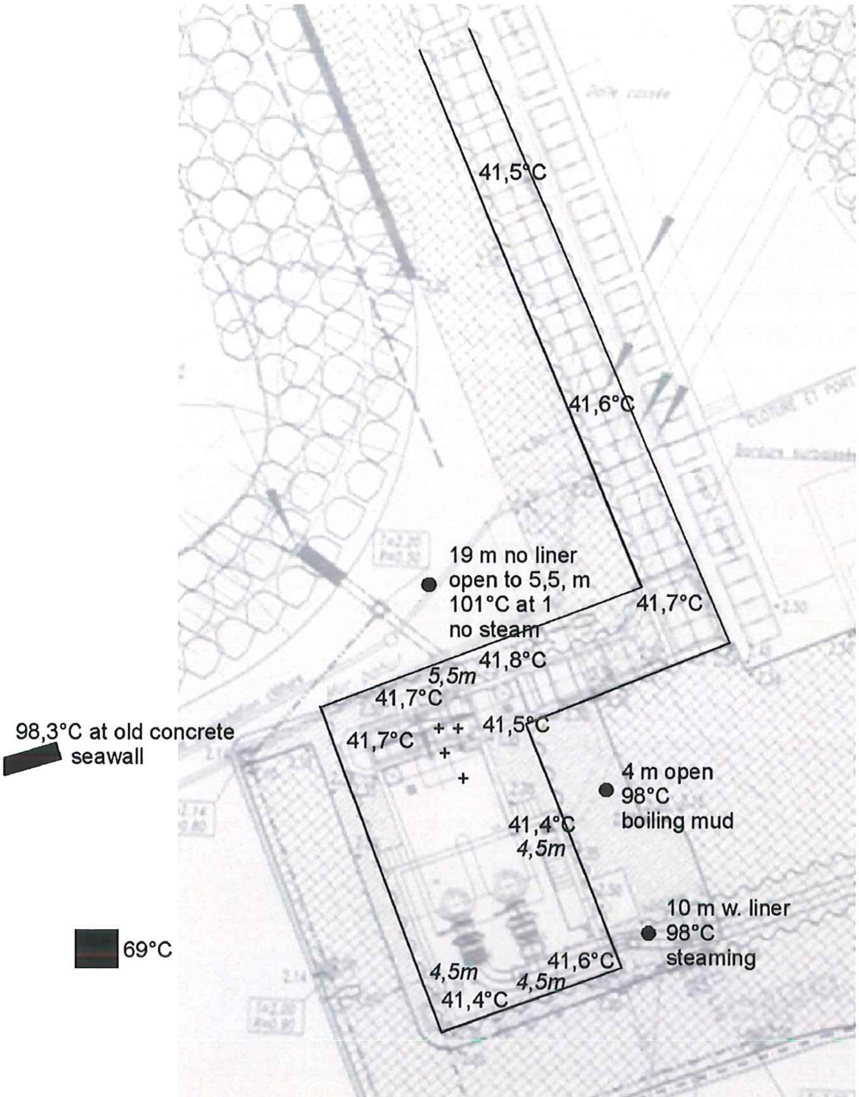


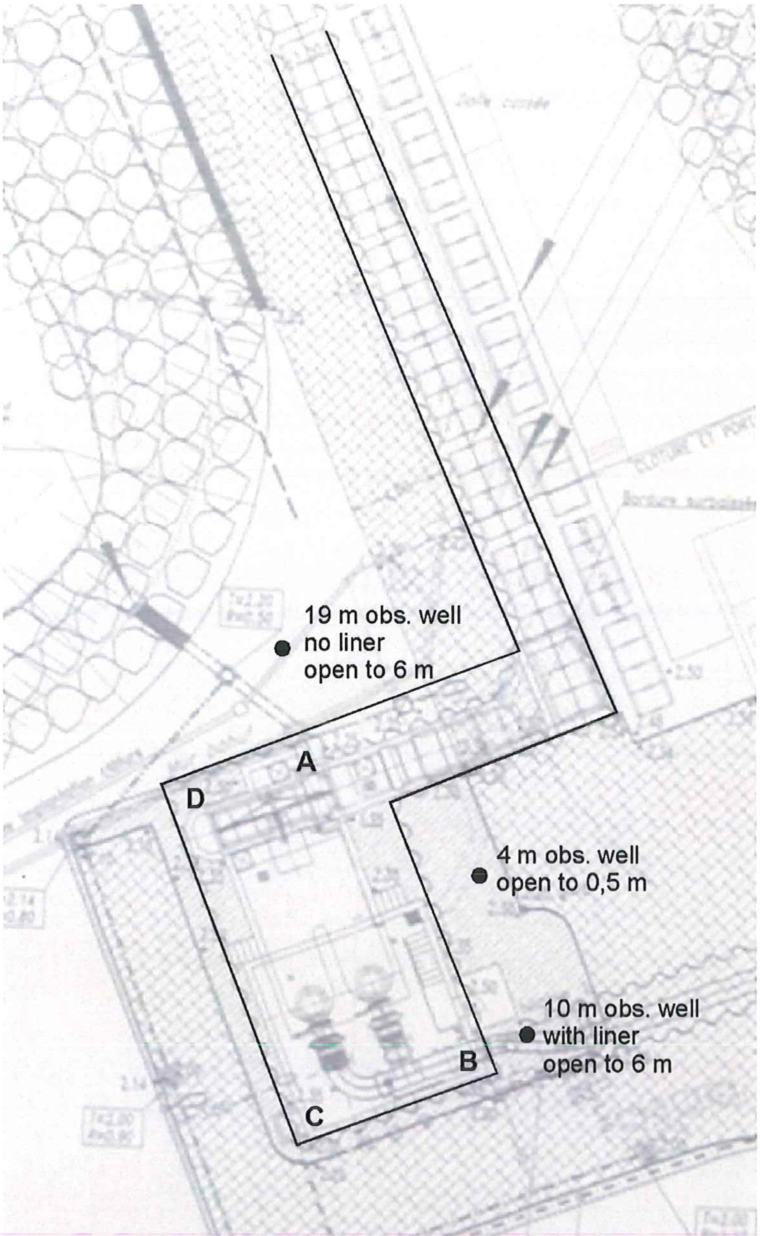
Figure 3. Figure showing where the hydrothermal eruptions occurred. Sketch made after a verbal description of Mr. Herlander Correia. Photographs showed the erupted material to be thick clay having the consistency of thick drilling mud. With this mud there was the release of steam. The eruptions started on February 20th and lasted as short time - a sort blast.



Measurements in the B2 sea water pit made 14.03.2003, 9:30-10:00
Temperature probe at 10 cm under the water surface.
Water has been stagnant in the pit one week. Temperature thus not very high.
Small flow of gas bubbles in one place only - thus small inflow of virgin steam.
Uniform temperature distribution - inflow not focused or very active.
Slow heating - from walls mainly (convection currents noted by walls - no gas)

Sverrir 14.03.2003

Figure 4. Temperature measurements made at the surface of the sea-water pit 14.03.2003. The pit had stood full for one week. Measurements were also made at the mouth of the observation wells. Finally the water depth was measured at several locations as shown in the figure.



Measurements in the B2 sea water pit made 15.03.2003, mornig.
The capital letters refer to the positions where the temperature measurements were made. Highest temperatures were logged in the mud at postions B and D.
The three observation wells were also logged, but only to the depth shown on the figure as the wells had filled in or collapsed.

Sverrir 15.03.2003

Figure 5. Measurements were made in the sea-water pit at several depths and the final measurements were at each location were made by thrusting the probe 10-20 cm into the soft bottom clay. The pit is relatively cold but the bottom gave high readings (see next fig.).

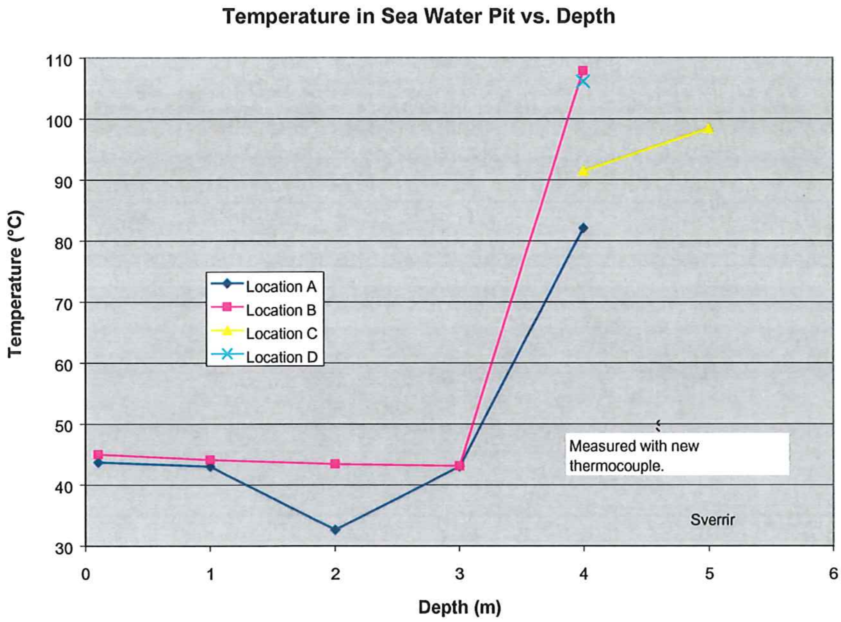


Figure 6. Temperature measurements made in the sea-water pit 15.03.2003. The water in the pit is relatively cold suggesting small inflow with the pit full of water. The bottom readings were made by thrusting the temperature probe some 20 cm into the soft bottom layer. The temperature there approaches 108°C m at 4 m depth. For location of measurement sites in the pit and approximate location of the wells see fig. 5.

Pit logged

Depth (m)	A (°C)	B (°C)	C (°C)	D (°C)
0,1	43,7	45		
1	43	44,1		
2	32,6	43,4		
3	43	43,1		
4	82	108	91,4	106
5			98,4	

Wells logged

Depth (m)	Well 10m cased	Well 19 m uncased	Gradient well 2 Drilled by river 1964
2	97	102	
4	102	105	
5		109	
6			104,8
11			114,7

Figure 7. Temperature readings made 15.03.2003. See also graphs of this data, fig. 6 for the pit logs and fig. 2 for the observation wells logs.

Appendix II
Photographs

Photo 1. Sverrir Thorhallson (report author) in front of the Bouillante power plant. Recently removed sea water pipeline in background.

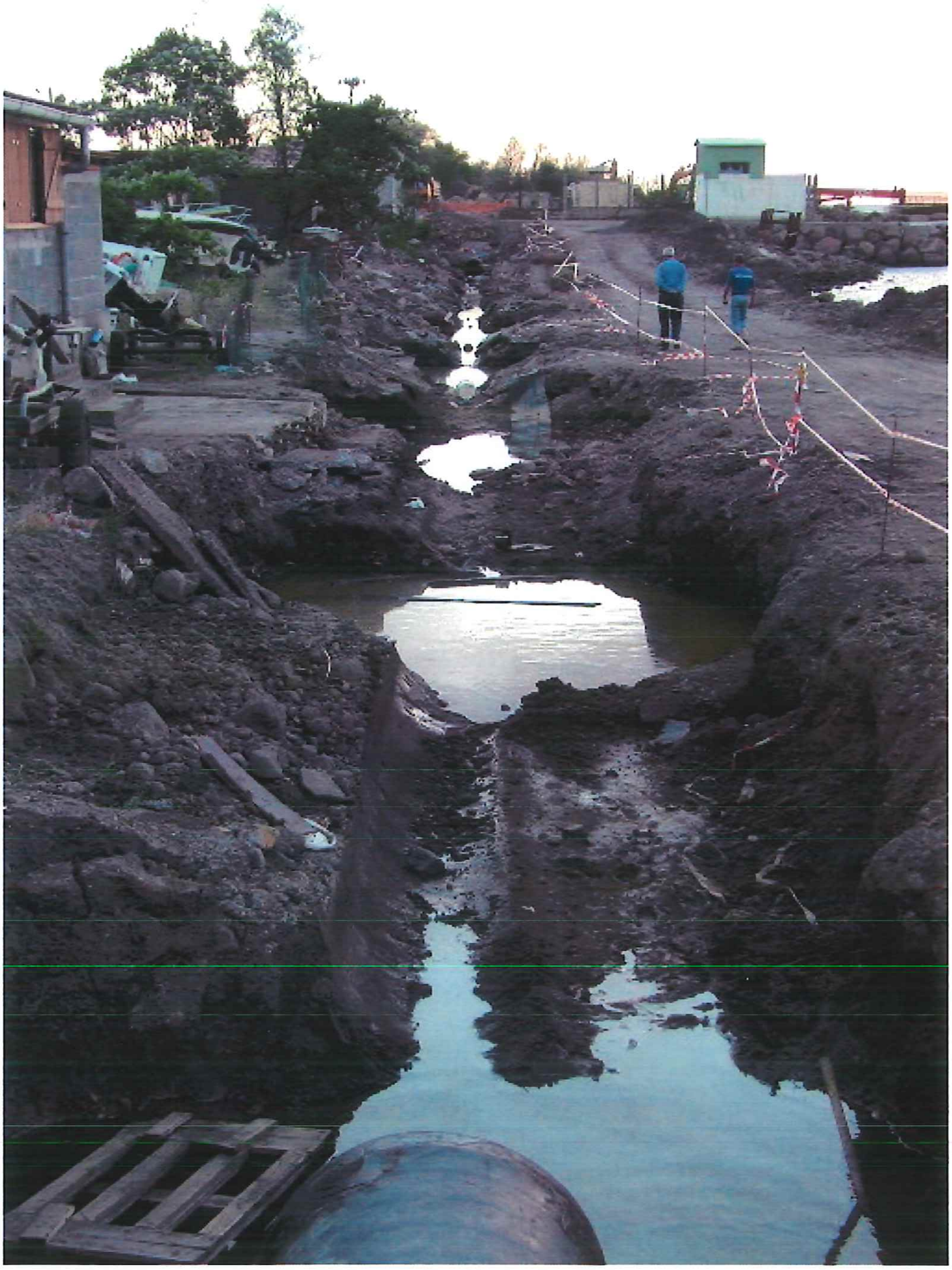


Photo 2. Ditch after removal of the new 900 mm sea water pipeline. Pump station far in background.

Photo 3. A house near the pipeline where the floor is hot and depostis on the outside of the foundations. The stone stairs to the main door under the window issue steam at 98,9°C.

Photo 4. Another house next to photo 3 with a warm floor. The living room floor in the top left corner of the house measured 46°C. Other parts of the floor were warm as well.

Photo 5. Site of well BO-3 where the construction of the seawater pump station is under way. The photograph is taken March 14th. The test pit in the lower left corner had a temperature of 70°C.

Photo 6. Shallow temperature reading in 19 m test well showing 101°C at 1 m depth.

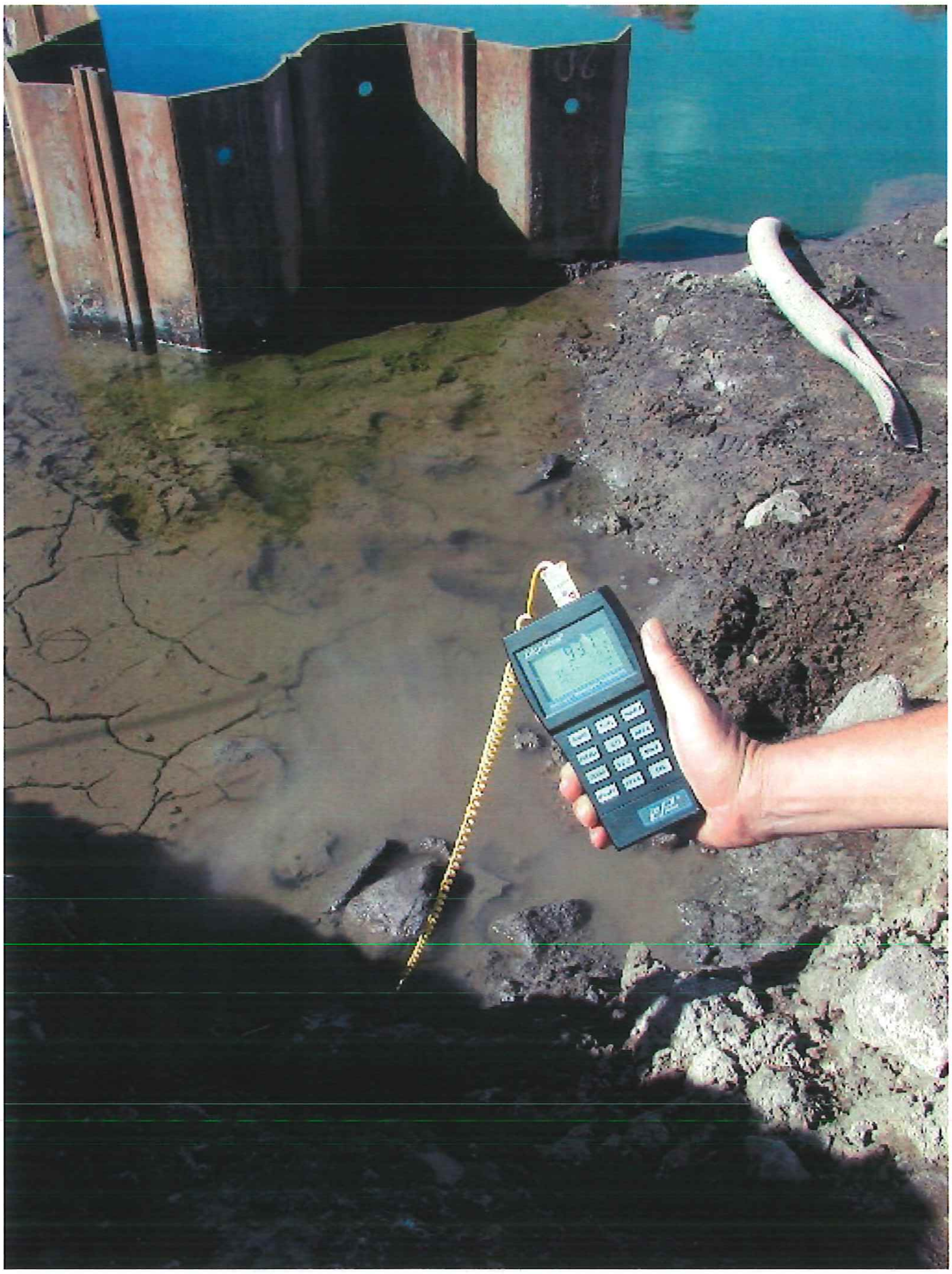


Photo 7. Hot mud (93,1°C) on surface just outside the steel piles. The mud is very soft and did not support the authors weight.

Photo 8. Photograph of pit showing position of hot spots and three observation holes.

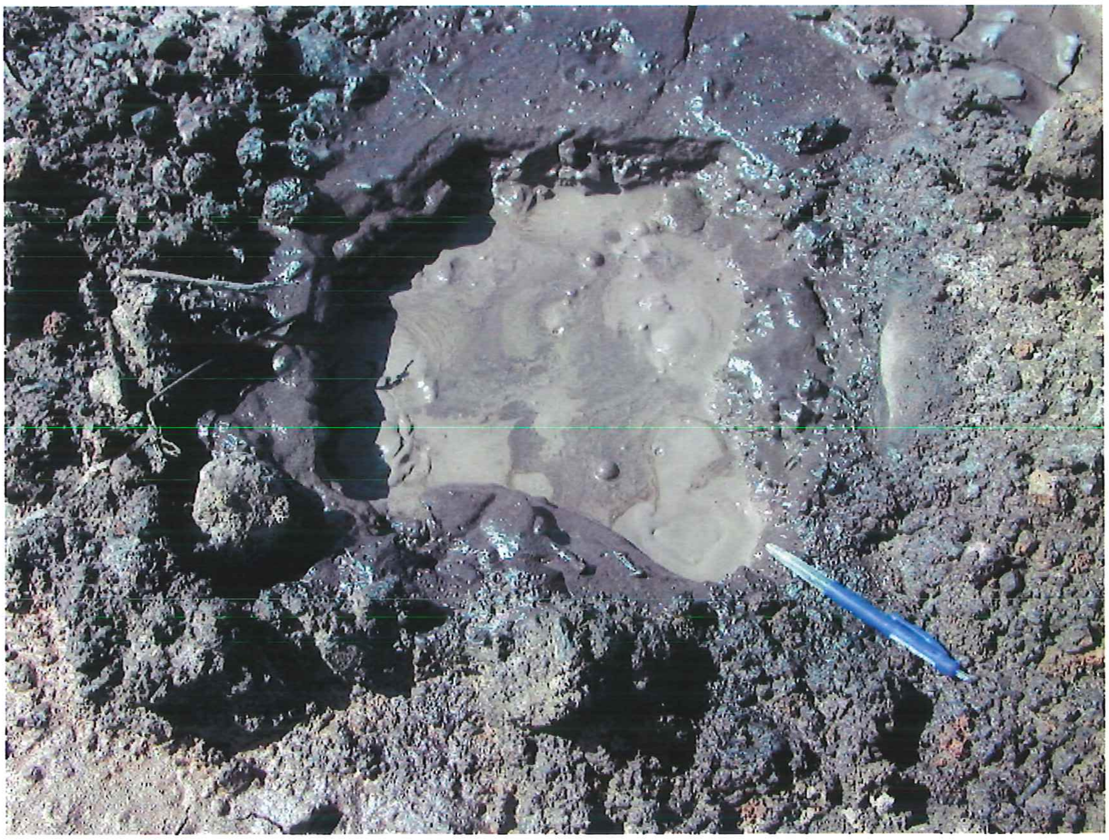


Photo 9. This is the boiling mud where the 4 m deep observation hole was drilled. Temperature measured 100°C so the bubbles are steam bubbles and not gas.

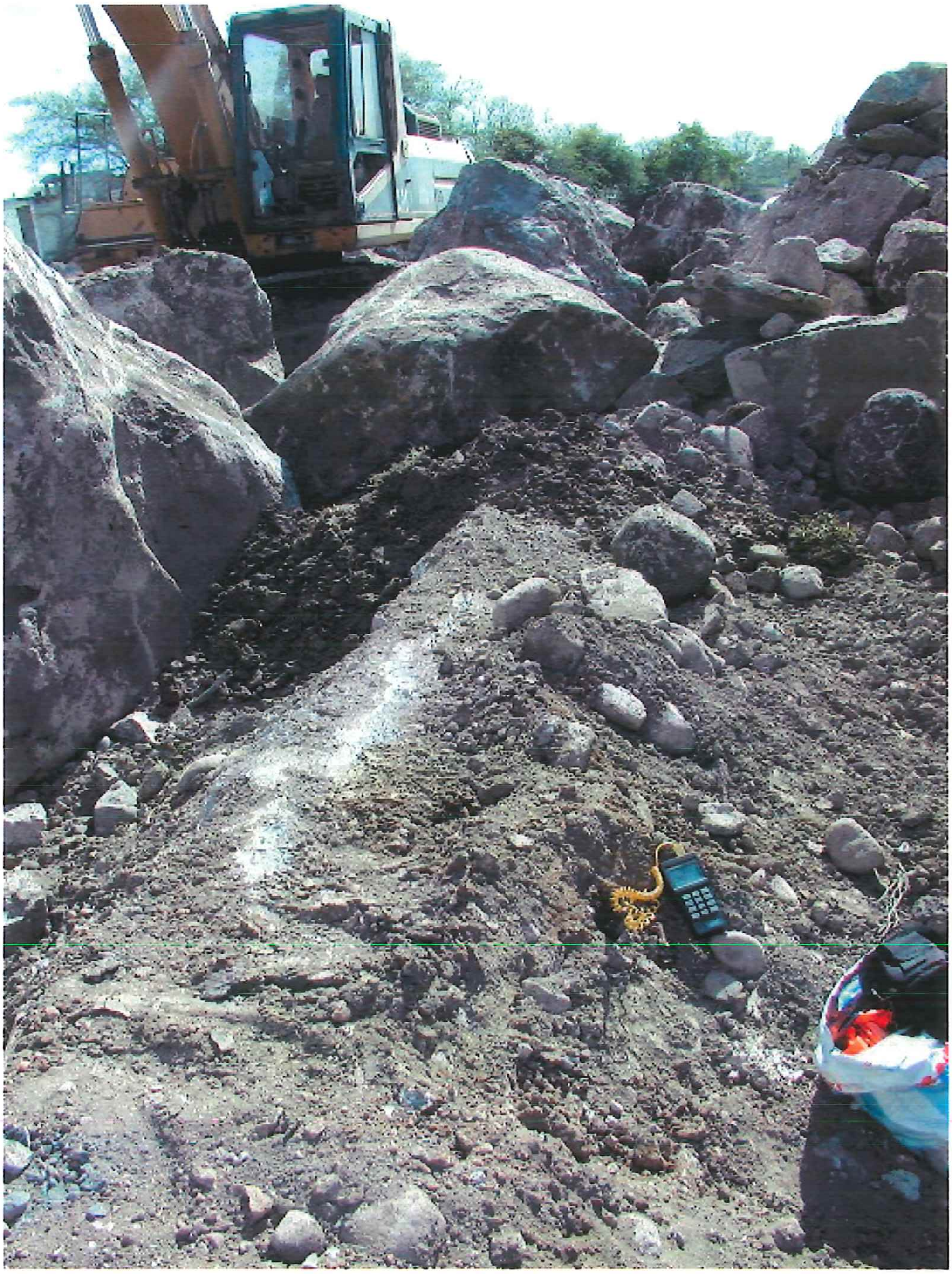


Photo 10. Steam escaping on the outside of the old concrete sea-wall. Measured temp 98,3°C.

Photo 11. Logging of the observation hole with a thermocouple. The wire insulation failed due to poor temperature resistance of the plastic isolation tape.

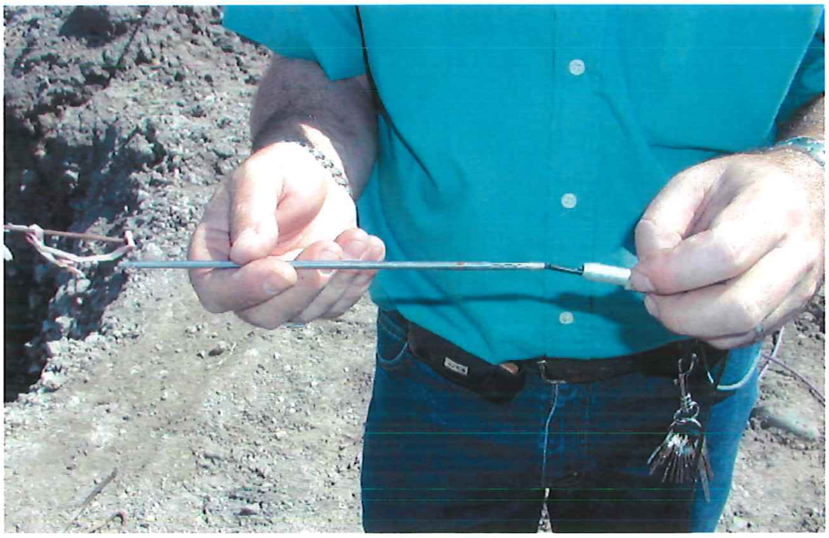


Photo 12. Close-up of failure of thermocouple wire.

Photo 13. A mercury thermometer gave wrong readings also, due to separation in the mercury column!

Photo 14. An encapsulated thermocouple wire strapped to a pipe finally worked.

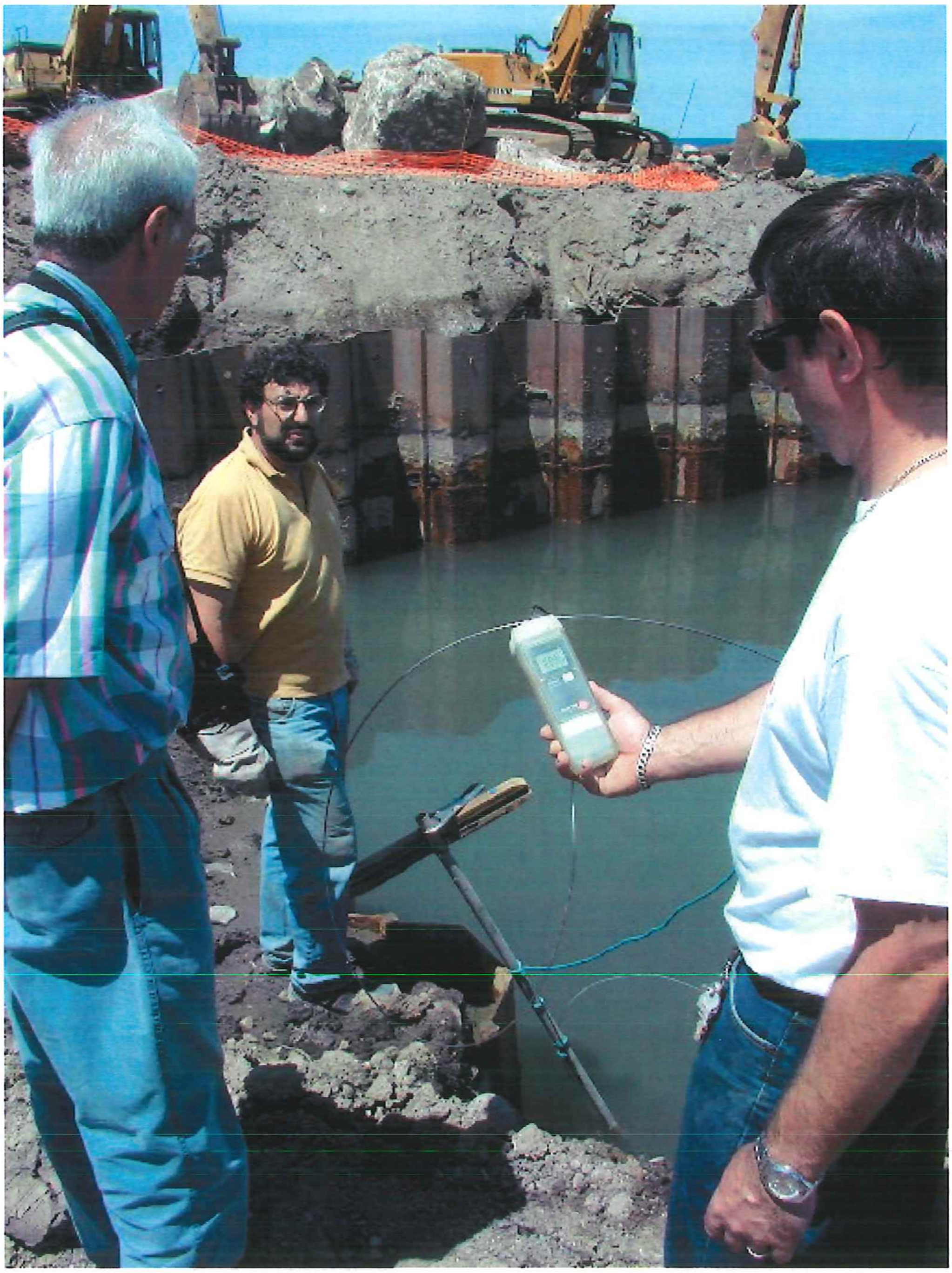


Photo 15. Temperature reading at location B in the bottom of the pit where the highest readings were obtained, 109°C at 5 m depth. When the picture is taken the reading is 104.5°C. Note the total length of the pipe that the thermocouple wire is strapped to is 6 m long.

Photo 16. Photograph of the pit Saturday 15.03.2003 after being drained by pumping. There was no increase in thermal activity during this period. Only a few gas bubbles were surfacing near the pump barge.

Photographs to explain how soil temperatures and measured in Iceland

Photo 17. Hydrothermal eruption at Krýsuvik Iceland. Hot mud was thrown into the air and carried for 200 m. This photograph is taken from an airplane shortly thereafter.

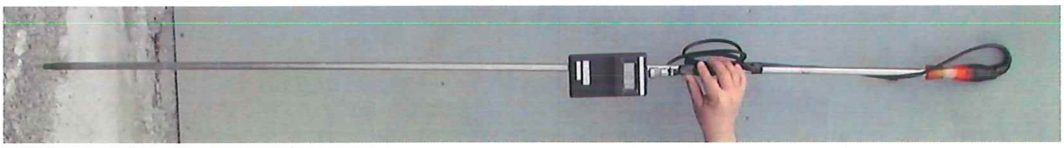


Photo 18. Temperature probe of the type used for surveying ground temperatures in Iceland. Measurement are taken about every 5 m and laid out in parallel lines spaced about 20 m apart running perpendicular to the expected thermal anomaly.

Photo 19. A steel chisel is first driven into the ground with a big sledgehammer to make a pilot hole for the temperature probe. The chisel is removed and the hole stays open. After temperature equilibration the temperature probe is lowered into the hole for the reading. Depth of reading in firm soil is usually 60 cm.

Photo 20. The temperature reading is made.