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Final disposal of spent nuclear fuel – equipment for site characterization

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FINAL DISPOSAL OF SPENT NUCLEAR FUEL - EQUIPMENT FOR SITE CHARACTERIZATION

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A list of other reports published in this series during 1983 is attached at the end of this report. Information on KBS technical reports from 1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26), 1981 (TR 81-17) and 1982 (TR 82-28) is available through SKBF/KBS.

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Sweden May 1983

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ABSTRACT

The suitability of a certain geological formation as a repository for the final disposal of spent nuclear fuel can be determined only after detailed investigation and analysis. The purpose of the investigations is to provide information on the geology and the hydrology and chemistry of the site concerned. The value of these data largely depends on the way in which they have been collected. The report of the findings should enable the investigating party to evaluate the function and the accuracy of the equipment with which field data have been collected for KBS 3.

This report describes the geophysical equipment, the hydraulic testing equipment, the water chemistry sample extracting equipment and the core-logging equipment used. The objectives of the instrument development have been

- to obtain a high data quality

- to collect data automatically in logs and tape recorders for direct transfer to a central processing unit

- to provide back-up in order to counteract loss of data

- to make instrument more efficient

1 INTRODUCTION

1.1 GENERAL BACKGROUND

Development work is carried on within Swedish Nuclear Fuel Supply Co, division KBS (SKBF/KBS) on a current basis for the purpose of improving methods and instruments in order thereby to raise the quality of collected field data.

During the period 1979-82 these efforts were concentrated on developing hydrological measurement equipment. Improvements were achieved also of geophysical and chemical sampling equipment.

The objectives were

- a high data quality
- automatic data collection in logs or tape recorders for direct transfer to central processing unit
- data back-up in order to counteract data losses
- efficient instrument handling
- a robust design adapted to varying climates
- a good working environment for extended periods in the field.

All equipment has been designed to be used within the SKBF/KBS study site program, i.e. the harsh conditions encountered during field work. For many years, geophysical equipment has been developed into light-weight and durable units, whereas at the same time the hydraulic equipments have become considerably larger and more sensitive.

The technical characteristics of the instruments used are described in this report.

Measurement and evaluation methods are reported on in /1:1/. A summary of the investigation program is given in Chapter 1:4 of the Standard Program.

1.2 TECHNICAL BACKGROUND

Geophysics

Geophysical measurements are undertaken on the ground surface and in drill holes. The geophysical measurements which are comparatively fast provide indications of the geological and hydrogeological properties of the bedrock within a study site.

Ground geophysics in combination with geological mapping provide the basic data for the location of drill holes.

The following techniques are used for ground surface measurements: Magnetometer, Resistivity, Induced polarization, Slingram (Horisontal Loop EM) VLF and Seismics.

The measurements provide information on the position and extention of fracture zones and of the physical characteristics of the rock enabling i.a. the localization of rock interfaces and mineralisations. The penetration depth of the ground geophysical methods is in the range of 25 - 100 m.

Magnetometric measurements: Indicate the existance of fracture zones and the extention of rocks of varying magnetic properties.

Resistivity measurements: Indicate the existence of water bearing fracture zones as well as black schist and certain ore deposits.

Induced polarization: Indicates the existence of electrically conductive minerals also in low concentrations. Is used in this context in order to differ between fracture zones and mineralizations.

Slingram (Horizontal Loop EM): Indicates the existence of water bearing fracture zones as well as graphitic schists and certain ore deposits. Is used in order to determine the location, strike and dip of fracture zones.

VLF: See Slingram.

Seismic: Indicates the existence of fracture zones. Thickness of overburden is also obtained.

Drill hole geophysical methods provide information on the fractures and porosity of the rock, chemical properties of the drill hole fluid and the existence of certain minerals. The deviation of the drill hole is also measured.

The standard program includes the following methods:

IP: Existence of sulphide minerals.

Deviation measurement: The depth, inclination and azimuth of the drill hole.

Salinity: Salinity of drill hole fluid.

Gammalog: Natural radio activity.

Single point resistance: Small fractures.

Resistivity: Zones of high water-content.

Self-potential: Sulphide minerals, water flow.

Temperature: Temperature differences in the drill hole liquid.

The results of the different measurements are used in characterizing various bedrock sequences, fracture zones and individual fractures observed in the drill hole.

An interpretation is then made based on data from ground- and drillhole geophysics together with geological and hydrological data in order to obtain a three-dimensional model of the bedrock stratigraphy and fracture zones.

Hydrogeology

Determining the hydraulic characteristics of the bedrock to begin with requires a knowledge of the hydraulic conductivity and porosity of the bedrock, and the pressure gradients of the groundwater at different depths, and the hydraulic interconnection between low fractured rock and existing fracture zones.

The measurements of hydraulic conductivity were performed by sectioning of drill holes. These examinations were made using a method for transient conductivity measurement under constant pressure and with a subsequent fall-off period. This method was chosen after inventorying available methods and field tests. During the tests different methods have been compare in the same measurement sections, and the findings will be presented in KBS' technical report series during autumn 1983.

From the fall-off phase in the hydraulic single-hole tests referred to above an overview is also obtained of the natural piezometric pressures in a drill hole.

For the purpose of checking these pressures, piezometric measurements are additionally made using a multi-packer sysem. The results of these checks subsequently constitute a verification of the flow estimates.

In certain important fracture zones test pumpings have been executed for the purpose of measuring the zone's hydraulic properties. The effects of the pumping were then measured in sections of surrounding drill holes. The porosity has not been measured in the individual study sites, seeing that it is found to vary in a relatively limited degree as compared with the other parameters. The porosity values have been drawn from literature and from our own R&D programs.

Hydrochemistry

The chemical characteristics of the ground water influence the possible spreading of radio-nuclides, the stability of bentonite buffer and to a certain extent corrosion of the capsules. Information on the chemical properties, differences in density and C^{14}-age contributes a knowledge of the movements of the ground water. Water samples have been taken for analysis in certain sections. Field analyses have been made of Eh • pH • pS,O_2 and of conductivity. The chemical sample extraction is described in Chapter 4.

Geology: A deshtop computer system is used as a data collection unit for core loggins. The equipment does not perform any measurement operations of its own but has still contributed to a more efficient mapping and rapidly available results. The system is briefly described in Chapter 5.

1.3 SITE CONDITIONS

The investigation of a study site is carried on by stages, the results of the next preceding being basic to the next stage, etc. See 1.4 of the Standard Program. The field work goes on for approx. 2 years per site. During this time, the activities vary between individual field observations to hydraulic measurements and chemical sampling for the purpose of which as much as 10 measurement stations may be in operation simultaneously. Seeing that no direct supply of electricity and water is in most cases available, the equipments must largely be self-sufficient.

A study site area is 4-6 km^2. Within the area, 10-50 hammer drill holes, Ø 110 mm, are sunk as well as 5-15 inclined core drill holes Ø 56 mm, down to a maximum depth of 1 000 metres.

The requirements of high measurement accuracy and repeatability is fundamental in designing measurement equipment. Apart from this, stringent requirements are made on the practical solutions in order to enable measurements to be made in and by-passing crushed zones without wasting equipment or having it stuck.

1.4 STANDARD PROGRAM

For the purpose of obtaining a pilot planning and work schedule a standard program has been drawn up /1:2/.

The standard program provides basic information on the different stages of the investigation. The program is flexible throughout. Experiences in actual practise will always entail modifications and supplementations.

A detailed overview of different stages of the standard program is provided in Annex 1.

2 EQUIPMENT FOR GEOPHYSICAL MEASUREMENTS

The geophysical equipment used for ground and drill hole measurements have been developed and designed by SGU/SGAB. Supplementary equipment have been purchased from other manufacturers. The following chapters contain a brief description of the instruments used in the project.

2.1 EQUIPMENT FOR GROUND MEASUREMENTS

The instruments used for ground geophysical measurements on the study sites are the following:

Method	Instrument	Manufacturer
Magnetometer	MP-2 Proton GSM-8 Proton	Scintrex, Canada GEM-Systems, Canada
Resistivity	RIPT-400 RIPS-2	SGU/SGAB, Sweden " "
IP	RIPT-400 RIPS-2	" " " "
Slingram	18 kHz, 60 m	" "
VLF	EM 16	GEONICS, Canada
Seismic	TRIO SX-24	Atlas Copco/ABEM, Sweden
Field computer	Geomac	SGU/SGAB, Sweden

The magnetometer is used for measuring local variations in the magnetic field intensity. Variations in the field reflect the composition of the bedrock across which the measurement is performed. The instrument used is a proton precession magnetometer. The measurement values are expressed in the unit nanoTesla. The measurement accuracy of the instrument is 1 nT in the interval 20,000 - 100,000 nT. Maximum permissible gradient of the magnetic field with retained measurement accuracy is 5,000 nT per metre. Power supply is via 8 demagnetized 1.5 V standard type batteries. The mesurement sensor is mounted on a backpack frame, Figure 2-1. Measurement height above the ground is aprox. 1.5 m. Total weight including backpack and sensor is approx. 5 kg.

Measurements are performed in grid system with 20 m station spacing and 40 m line spacing or along compass-oriented profiles for regional surveys with a station spacing of 20 m. The measurement stations can be determined with approx. 5 m accuracy within the grid system and with 10-20 m accuracy along the regional profiles.

Figure 2-1. Magnetometer measurement

Within each study site a fixed base station is used for checking of the daily variations in the earth-magnetic field. A measurement value is recorded automatically every five minute and stored on tape. The base station includes measurement unit, sensor, field computer, and tape station. The measurement unit is a Geometrics 823, proton precession magnetometer with a measurement accuracy of 1 nT. The base station is powered from the AC mains network or by a motor generator.

The data obtained from the magnetometer and the base station are stored digitally directly in the field computer system Geomac (Figure 2-2). In addition to measured data other necessary information is stored in the computer, such as survey area, survey crew, date, time of measurement, and the coordinate of the measured station in the grid system.

Geomac is an interactive, micro processor-based field computer system adapted to both BCD and analoge signals. Ten different instructions are preprogrammed including storage search and optional alphanumeric comments to individual measurements. Data can be transferred from the field computer to printer, tape recorder or analog chart recorder by a field office unit (Figure 2-3). The tapes are sent to the main office for further processing.

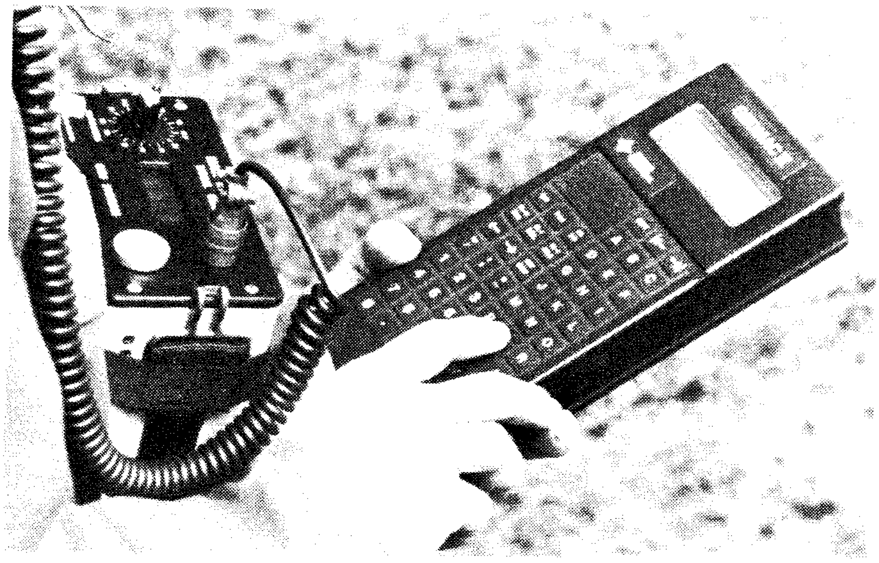


Figure 2-2. Field computer Geomac connected to magnetometer

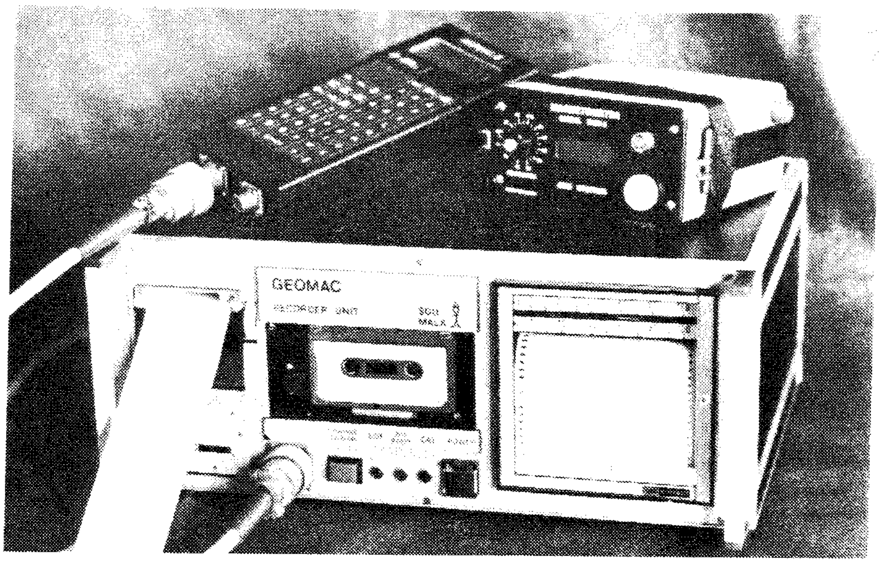


Figure 2-3. Transfer of field data to printer, tape recorder and analog printer

The <u>resistivity</u> and <u>IP</u> (induced polarization) measurements are performed simultaneously in a 20 x 40 m grid system (Figure 2-4). The equipment consists of a transmitter with 400 W output power, receiver, two current electrodes, two non-polarisable potential electrodes (Cu-$CuSO_4$) and cables. The current electrodes are generally placed at 1.5 km distance from each other and are stationary during measurements. The potential electrodes are mobile and the gradient of the potential field is measured. The distance between the potential electrodes is 20 m. The measurements are displayed on an analog meter on the receiver.

The measurement system is a DC-time domain system. The transmitter is equipped with a radio transmitter for synchronization of the receiver. The current is emitted in the form of a continuous square wave. The influence of natural currents in the ground

Figure 2-4. Combined Resistivity and Induced Polarization measurements

(self-potential effect) are automatically corrected by the receiver. Relative accuracy of the measurement is 1-2 % depending on the magnitude of the measured value.

The power supply of the transmitter is a motor generator of 220 V, 50 Hz AC. The transmitter weighs 15.5 kg. The receiver is operated using a re-chargeable NiCd battery with a continuous operating time of 10 hours.

Two different types of electromagnetic methods are employed, viz. Slingram (Horizontal Loop EM) and VLF (Very Low Frequency). The measurements are performed both in grid systems and along regional profiles.

The Slingram System consists of a transmitter and a receiver, interconnected with a 60 m long reference cable (Figure 2-5). The transmitter emits an electromagnetic field with a frequency of 18 kHz. This field induces secondary fields in the ground. The resulting field measured by the receiver will deviate from the primary field in intensity, phase and direction. Deviations indicate the presence of electric conductors in the ground, such as fracture zones.

Figure 2-5. Slingram (Horizontal Loop EM), frequency 18 kHz, coil separation 60 m

Transmitter operating voltage is 15 V supplied by 10 rechargeable NiCd batteries. Operating time is aprox. 10 hours at continuous operation. The transmitter weighs 7.5 kg.

The receiver measures the real and the imaginary component of the anomalous field in percent of the primary field. The result is read directly on an analog meter. The measurement accuracy is 0.1 percent of the primary field in regard to values between ± 10 % and 1 % between ± 100 %. The receiver is operated by an ±18 V re-chargeable NiCd battery with a continuous operating time of 12 hours. The weight is 6 kg.

The VLF method measures the magnetic field strength of distant military radio transmitters operating in the frequency range 15-25 kHz. The instrument consists of a radio receiver with two coils perpendicular to each other (Figure 2-6). The coils are oriented in a certain position in relation to the VLF transmitter and the quotient between the field strength of the coils is measured. This is, in principle, a measurement of the vertical component of the magnetic field, induced in subsurface conductors, relative to the primary field. The measurement accuracy is approx. one percentage unit. The power source of the instrument consists of 6 x 1.5 V alkaline batteries with an operating time of approx. 200 hours. The weight is 1.6 kg.

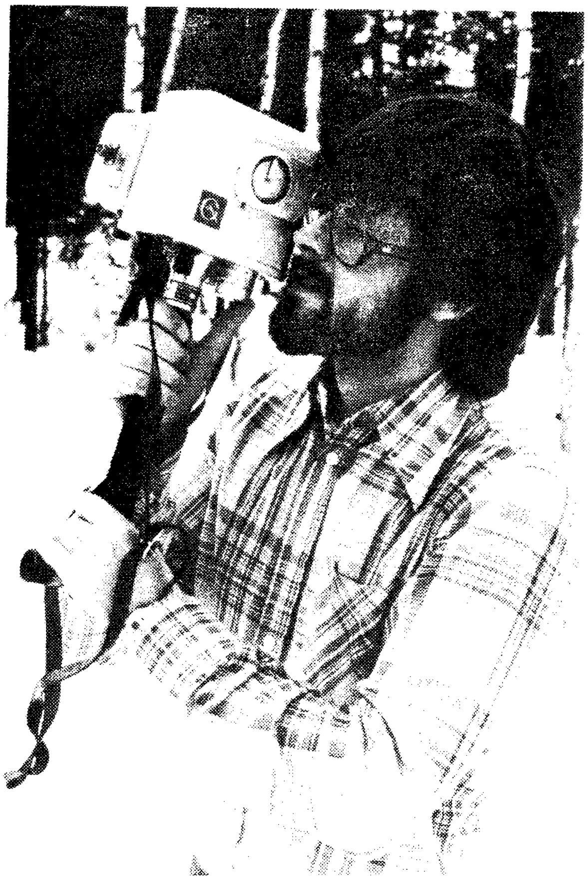


Figure 2-6. VLF measurement with Geonics EM 16

The results of the Slingram measurements are processed in the same manner as the VLF data. The finally processed data are presented in the form of colour maps and profiles. The evaluation of the results is by means of identifying anomalous structures and their geological causes. The profiles are compared with type curves and estimations of the width, dip, conductance, and depth to the zone are done.

Seismic measurements are employed in order to verify the existence of fracture zones in the bedrock and in order to determine composition and thickness of overlying soil layers. The instrument used is a portable 24-channel seismic equipment. The measurements are generally done along individual profiles within the grid system. The distance between the geophones are normally 5 m and 24 geophones are used simultaneously.

The seismic wave is generated using explosives. A separate high voltage shotbox (Nitro Nobel, C115 VA) in used fore firing. The travel times of the seismic wave between the shotpoint and the geophones are registered on an optical recorder. The travel times can be read with an accuracy of 1 m sec.

Soil depth and seismic velocity in soil layers and bedrock are calculated from the seismic travel times recorded.

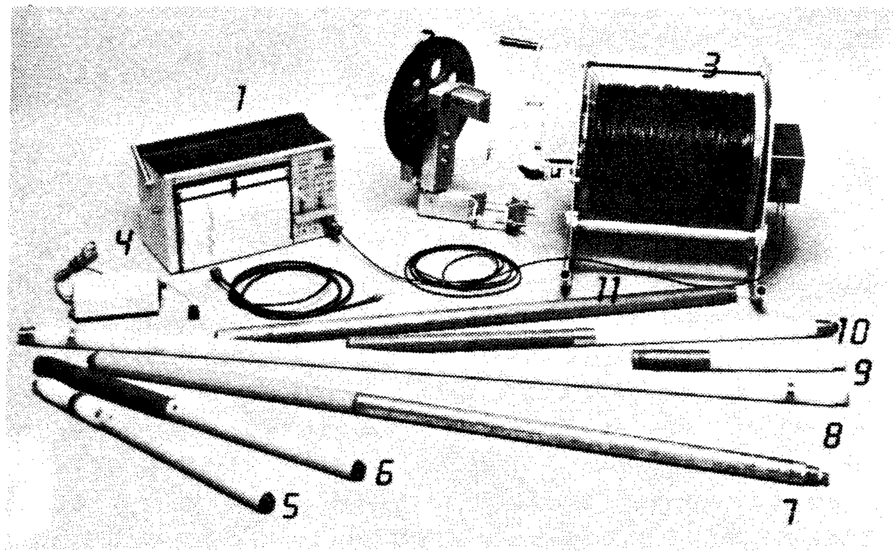


Figure 2-7. Drill hole logging systems. 1) Analog recorder. 2) Depth indicator wheel with digital counter. 3) Cable reel. 4) Charging unit. 5) SP lead electrode. 6) SP electrolyte electrode. 7) Magnetic susceptibility. 8) Lateral resistivity. 9) Differential resistivity. 10) Single point resistance. 11) Natural gamma radiation

2.2 EQUIPMENT FOR DRILL HOLE MEASUREMENTS

In the standard program for site investigations the following measurements have been undertaken:

1 Drill hole deviation
2 Natural gamma radiation
3 Single point resistance
4 Resistivity
5 Self-potential
6 Temperature
7 Resistivity of drill hole fluid
8 Induced polarization

The equipment has been developed and manufactured by SGU/SGAB. In Figure 2-7 a number of the drill hole logs referred to in the text are displayed.

Drill hole deviation measurement is performed in order to determine the orientation in 3-dimensions of the entire drill hole. The probe contains a wheel for determining the inclination of the drill hole. The orientation of the drill hole in the horizontal plane is determined by a magnetic compass. The accuracy of the inclination is 0,1 degree and in the horizontal plane 1 degree. The accuracy determining the location of the drill hole is in practice estimated to 1 m per 100 m drill hole length.

The natural gamma radiation is registered using a scintillometer and registered continually on an analog shart recorder. The detector unit is a NaI-crystal with the dimension 1 x 1.5 inch (25 x 37.5 mm). The lower cut-off limit in gamma ray energy is 300 KeV which is obtained by means of a natural filter consisting of aluminium, brass and lead.

The point resistance method is, in principle, constituted of a two electrode system with one of the electrodes in the drill hole, with a length of 5 cm. This electrode is surrounded by two insulated plastic tubes which causes the contact resistance to be sensed very locally. The frequency of the current emitted can reselected between 100 Hz and 3 Hz. Recording of the contact resistance is continous using the same shart recorder as used for recording natural gamma radiation.

The resistivity of the bedrock is determined by means of a 4-electrode system. Two different configurations are used, viz. normal configuration and a lateral configuration. In the normal configuration one current electrode and one potential electrode is in the hole, the distance between these two is 1.6 m. In the lateral configuration one current and two potential electrodes are in the hole. The distance between the current electrode and the nearest potential electrode is 1.6 m and the distance between the potential electrodes is 0.1 m. The same probe is used for both configurations, the diameter of the probe is 53 mm. The distance between measurements is normally 1 m. The surface unit is the same as used for ground geophysical IP and Resistivity measurements. The relative accuracy of the measurement is better than 2 %.

The induced polarization is measured with the same surface unit as used for the resistivity measurement, although the probe and the cable are different. The probe has one current and two potential electrodes, each with a separation of 5 m. The potential electrodes are of the non-polarizing type (Cu-$CuSO_4$). A special twocable system is used where the one cable supplies the current electrode whereas the other cable is connected to the potential electrodes.

The self-potential is continously registered on a chart recorder. The voltage between two non-polarizable electrodes, one in the hole and one on the ground surface is registered. The chart recorder is the same as the one used for registration of natural gamma radiation and point resistance.

The temperature and conductivity of the drill hole fluid is measured simultaneously using the same probe. The temperature is measured by a thermistor in the hole with an accuracy of 0.01 ^{o}C. The thermistor is calibrated against a quarts-thermometer.

The resistivity of the drill hole fluid is measured with a 5-electrode system; three current and two potential electrodes. This electrode configuration assures that the measurement results are not influenced by the presence of electrically conductive minerals in the rock.

Storing and evaluation of data

All data are stored in a database system on a main frame computer. The results registered on a chart recorder are digitized, and the manually recorded results are typed into the computer before processing. All data except the drill hole deviation data are displayed in the form of curves in scales 1:500, 1:2,000 and 1:5,000, and in addition statistical calculations are made of mean value, standard deviation, and the frequences distribution of data is plotted for each drill hole.

The results are calibrated. The drill hole geometry is calculated from this measured horizontal and vertical angles, and plotted in different projections. The geometry data are used for determination of the positions of other information registered the drill hole concerned.

The measured values of natural gamma radiation are calibrated against calibration curves for the probe used, and are expressed in μR/h. The natural gamma radiation primarily provides information on the rock composition in the immediate vicinity of the drill hole.

The point resistance results are calibrated and expressed in ohms. The point resistance provides high resolution of details of fracture zones and in many cases even individual fractures can be detected. The results of the resistivity measurements with normal and lateral configuration are expressed in ohm m. The normal configuration indicates an average value of the resistivity within a volume extending approx. 1 m from the drill hole. The results may be used for computing the porosity. The lateral configuration is used for the purpose of obtaining more detailed information on the location of fracture zones in comparison to the normal configuration.

The induced polarization is expressed in % of the voltage transmitted. The induced polarization indicates the existance of electrically conductive mineralizations and can also be used to find aquiferous zones.

The temperature measurement results are expressed in ^{o}C and a calculation is made of the temperature gradient in the hole, expressed in $^{o}C/km$. From these parameters information is obtained on water flow in the hole.

The resistivity of the drill hole fluid is expressed in ohms and can after correction for the temperature of the drill hole fluid be used to determine the salinity.

3 EQUIPMENT FOR HYDRAULIC TESTING

The hydrological measurement program carried out on the study sites consisted of hydraulic injection tests, pumpings test and piezometric measurements. All these tests were performed in sections of the drill holes sealed-off with packers. The difference in procedure of the tests entails that a special equipment for each testing method had to be used. With regard to hydraulic injection tests, which was the dominating measurement type, two different measurement equipments were used, viz. pipe string equipment and multi-equipment, respectively. These equipments have been developed and manufactured by SGU/SGAB and IPA-Konsult, respectively, on SKBF/KBS' order. In the following, the different equipments are described each separately.

3.1 INJECTION TESTS EQUIPMENT - PIPE SYSTEM, GENERAL LAYOUT AND FUNCTION

The equipment used in hydraulic injection tests, type pipe string system, (Figure 3-1) consists of the following component parts with regard to the location of the different units:

- measurement probe
- surface unit
- equipment for communication between these units

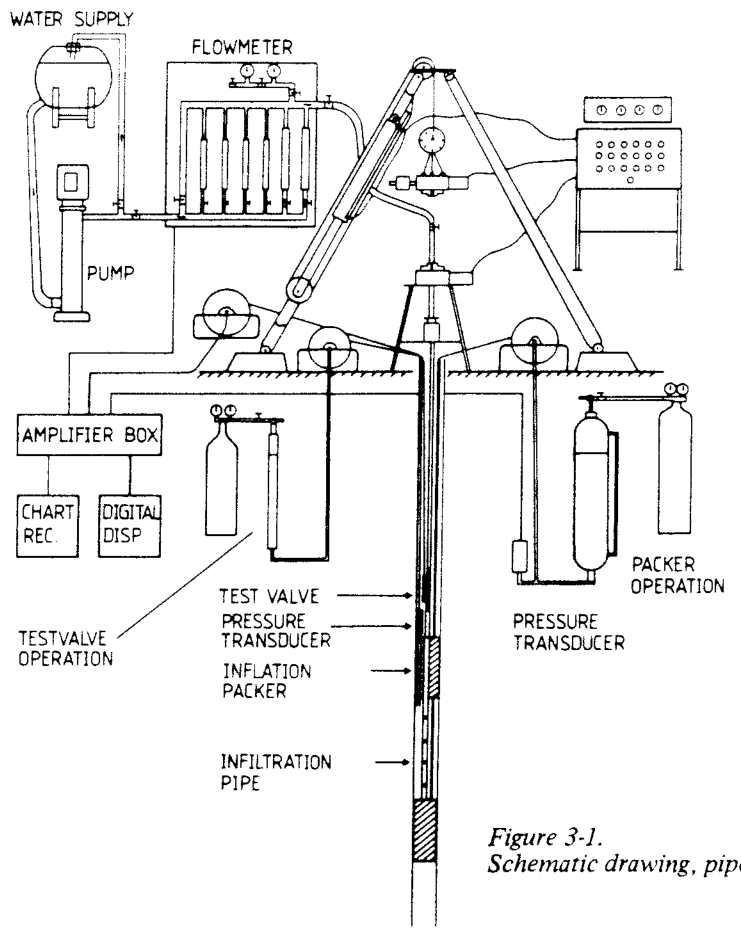


Figure 3-1.
Schematic drawing, pipe equipment

The measurement probe consists of packers (connected with infiltration pipe), pressure transducer and test valve.

Ground surface unit consists of regulating equipment for packers and pulse valve, water tank, pump, flow meter, amplifier unit, data collection unit and hoisting equipment.

The communication equipment consists of pipe strings for the injection water, simultaneously the measurement probe carrier, hydraulic tubes as well as operating pressure lines to packers and test valves, as well as signal cable for transmitting of pressure values.

The component parts of the equipment, however, will in the below be treated with regard to function in the following order:

o Injection equipment
  - packers
  - test valve
  - pipe string
  - hydraulic tubes
  - pump unit for water injection

o Measurement instruments
  - pressure transducer
  - flow meter

o Data collection
  - data logs
  - printer
  - data processing

o Hoisting equipment

<u>Injection equipment</u>

Packers

The measurement section is sealed-off by two packers joined with infiltration pipes. The design of the packers is shown in Figure 3-2. The packer rubber, reinforced with crosswise positioned canvas cord is attached by means of hydraulic pressing to a stainless steel frame with two through-pipes, a larger one for water supplied to the test section, and a smaller one to function as a pressure line between the test section and the pressure transducer. By pressurizing the packers the rubber is made to expand against the drill hole wall and the test section to be sealed-off from the other parts of the drill hole.

The packers are connected to pressure vessel, gas regulator and gas bottle via hydraulic tubes. The system is filled with water

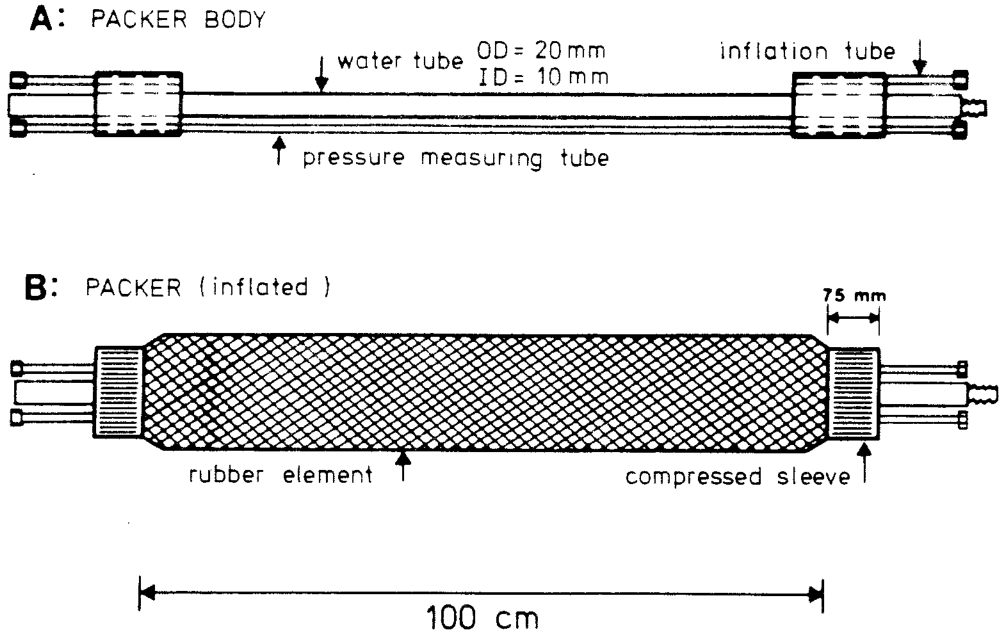


Figure 3-2. Schematic drawing, packer

or antifreeze liquid in addition to the gas used for creating the sealing overpressure.

The packers seal at an overpressure of 0.4 MPa, but in order to achieve as rigid section boundries as possible an overpressure of 1.5 MPa is used. The pressure is controlled throughout by means of a pressure transducer connected to the pressure vessel.

The packers have been tested together with other types of packers, both own constructed and standard types.

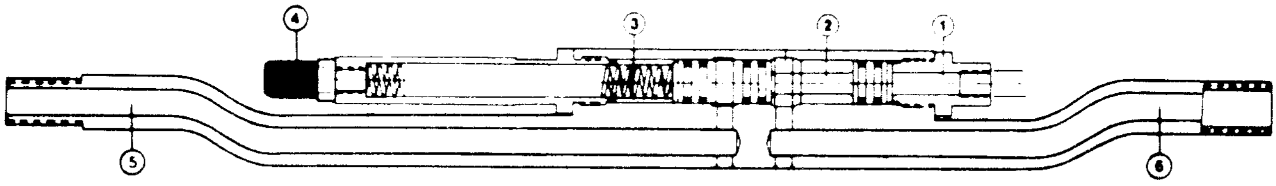
Test valve

In order to close off the test section in a way to permit a piezometric pressure to be measured, to evacuate the air in the pipe string without influencing the section, and to momentarily start injection tests and interrupt such tests for the subsequent pressure fall off test, a pressure-controlled test valve is used (Figure 3-3). The valve is located between the pipe string and the test section, connecting on to the packers.

The valve functions in a way to cause the spring-loaded valve slide to close, in a pressureless state the connection between the tube duct and test section. The slide is displaced under pressure to open the connection. Like the packers the test valve is regulated with gas overpressure in an otherwise water-filled unit consisting of pressure vessel and hydraulic tube.

Pipe string

The pipe string is composed of 2 m (± 1 mm) long steel pipes of an external and internal diameter of 20 and 10 mm respectively. By



SPECIFICATION

1 Connection, hydraulic tube

2 Valve piston

3 Return spring

4 Filter

5 Connection test section

6 Connection pipe

Figure 3-3. Test valve

both ends of the pipe being threaded with M 16 interior respectively exterior thread with O-ring groove a completely tight pipe joint is achieved without change of interior or exterior dimensions.

The injection water is led via the pipe string down to the measurement section. The pipe string is also carrier of the measurement probe and can take a load of approx. 4 tons.

Hydraulic tubes

The hydraulic tubes for the packer and the test valve systems are Alencoflex HRI, a steel-reinforced high-pressure tube (operating pressure 29 MPa) of 1/4" dimension. The tubes which can be jointed are 450-650 m long and wound on tube reels with a rotating snap-coupling in the centre. In the measurement probe the line between the packers and the pressure line to the pressure transducer are polymide tube (Tecalan TR 6/4) with an operating pressure of 4.5 MPa. All tube couplings are of the locktite-type according to DIN 2353 with an O-ring seal where possible.

Water injection pump unit

The water for the hydraulic injection tests is drawn from special water catchments and is pumped through a filter where particles 0.5 μm are separated. The water is stored at the measurement locations in 1,000 l tanks and kept warmed to C. 15°C using an electric heater.

The water is pumped through tubes and a shunt-coupling to a combined flow meter and regulator unit. From there the water is led via a copper pipe to the pipe string. The pump used for the purpose is a Grundfos centrifugal pump Type CP 2-200 or CP 2-120. The pump capacity is in both cases 20 respectively 45 l/min at 1.0 MPa pressure increase.

Measurement instruments

Pressure transducer

The pressure is measured using a Kistler piezoresistive transducer Type 4043, 10 MPa. The pressure transducer causes the pressure being measured to be transferred via a thin steel membrane and an oil-filled chamber to a silicon measurement cell where four bridge-connected resistors are affixed to a pressure-sensitive silicon membrane. The values of the resistors is influenced in such a way that the output voltage is proportional to the pressure applied.

The pressure transducer is placed over the packers but connected via coupling adapters and cannular tubes connected to the test section. The pressure transducer's current supply and output signal are obtained by connecting it via a specially devised contact adapter to a c. 800 m shielded signal cable with under-water contacts. The cable is of 7-wire type and is polyurethane isolated. The cables and contacts are sealed for water pressure up to 35 MPa and designed to permit jointing when necessary.

The output signal from the pressure transducer is received at ground level by an amplifier unit amplifying the signal from the pressure transducer, 0.05 mV/kPa, to 0.1 and 1.0 mV/kPa, respectively, for different purposes. A digital multimeter, Type Keithley 191, with 5.5 digit resolution, is used for reading of the pressure value.

The pressure sensors have, according to information from the manufacturer, an accuracy (including linearity, hysterisis and repeatability) of < 0.5 %. In order to improve this value, a special pressure transducer with an extra-high accuracy has been selected. It has been calibrated by the FFA (The Research Institute of the Swedish National Defence), the national measurement

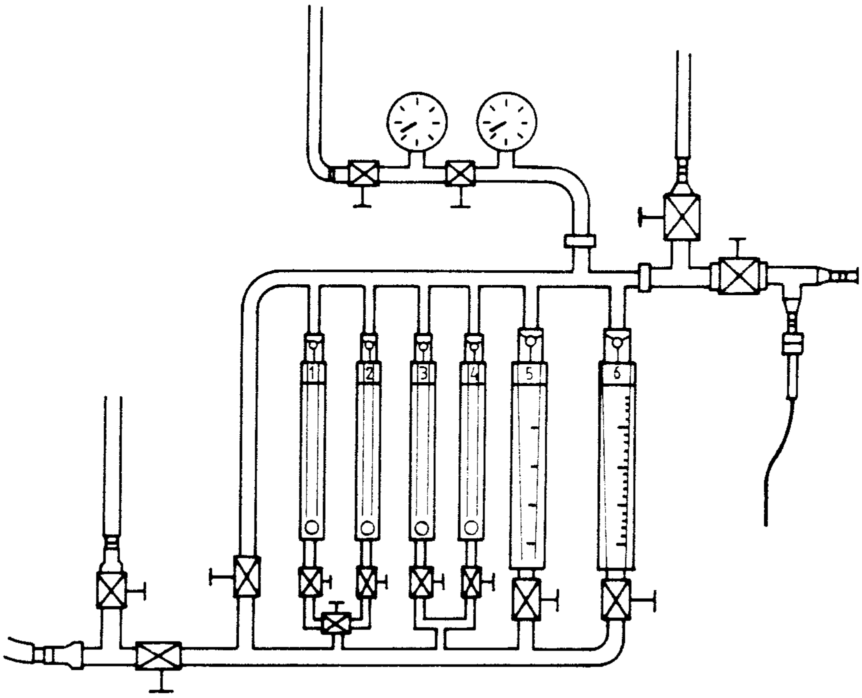


Figure 3-4. Flow meter unit

centre for pressures. For this calibration transducer a minimum square adaption is then been made. The third degree polynomial obtained thereby offsets most of the non-linearity of the transducer. The calibration transducer is then used for trimming and calibrating of all measurement pressure transducers.

Flow meter with flow regulation

The flow meter unit (Figure 3-4) consists of five flow meters connected in parallell, type Brook's rotameters with mutually overlapping measurement sectors within the range 1.5 x 10^{-9} - 2.5 x 10^{-4} m^3/s. A rotameter is a graded, slightly conical erect glass tube with an interior float. By the water flow being conducted upwards in the tube, the float is raised to a height which is contingent on the flow capacity.

For each meter a cut-off valve, a regulator cock, and a non-return valve are connected. By means of them, the flow is directed to the correct meter and regulated in a way to achieve a specific overpressure in the test section (to be read on the multimeter) which is kept constant during the entire testing period. The measurement values are read and recorded manually at stepwise increasing intervals.

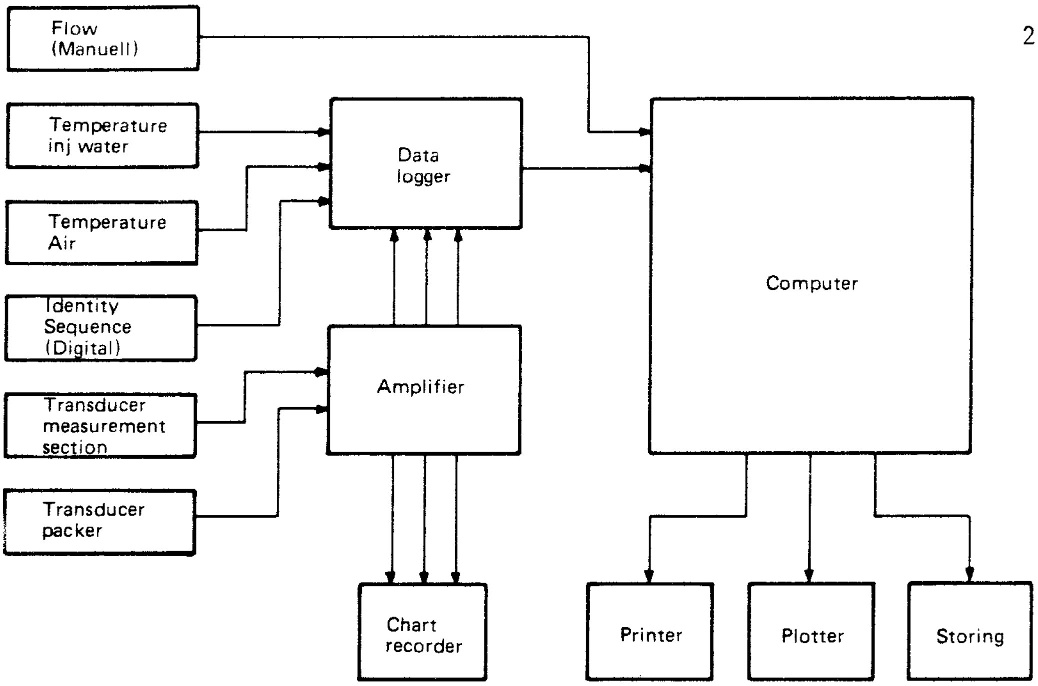


Figure 3-5.
Data flow and handling scheme

The resolution of the flow meters is 0.7 % of full deflection (1 % for meter No. 5) the flow reading error being 5 %. Calibration of the meters is effected at regular intervals at the measurement locations. The unit is devised in a way to permit complete deaeration before each measurement.

Temperature gauge

Two temperature transducers are connected in the measurement system, the one to measure the air temperature in the measurement housing, and the other to measure the temperature of the injection water when it has just passed the flow meter. Water temperature changes may influence the measurements in very low-conductive measurement zones. Type J thermo elements of 0.1 ^{o}C resolution have been used for this purpose.

3.1.1 Data collection

Data collection and processing are schematically presented in the block diagram Figure 3-5.

Datalogger

The central unit of the data collection system is a datalogger, minilogger ML 10-A, with the following specifications:

10 analog inputs, input signal 0.02 - 20 V, automatically selected (4 areas), 32-bit digital input, 3.5-digit resolution, realtime clock, scan-interval of 10 secs - 1 hour (7 sectors), data to be stored on cassette tapes.

Pressure and temperature values were assembled in the datalogger, scanning being effected at step-wise increasing time intervals.

By aid of the suppression facility of the amplifier unit, 0.1 kPa resolution is obtained at an injection pressure of max. 200 kPa. The section´s absolute pressure before injection is fed in manually as digital data (multimeter value) as well as all section identification and the indications of the different stages of the injection test. For checking purposes, the section´s absolute pressure (lower resolution) as well as the pressure of the individual packers, are also fed in into a separate channel for each.

The chart recorder

Parallell with the datalogger the measurement values are also registered on a chart recorder W + W 314. This is done primarily in order for the measurement operator to be in control of the progress of the test. The registration can also be used for evaluation in case of datalogger breakdown. The printer has 4 channels with 10 measurement sectors each (1 mV - 1 V) as well as automatic zero-point suppression up to 700 %. This option entails registration of the injection pressure with a resolution of 0.5 kPa per scale division (2.5 mm), whereas the absolute pressure and the packer pressure are written with 10 kPa respectively 5 kPa resolution per scale division. The paper feed varies between 1 cm/h and 60 cm/h (16 divisions).

Data processing

Cassette tapes with measurement data recorded are sent to the central computer for playback. Together with punched flow data, the measurement values are processed for printing of 13 diagrams and are thereupon stored. In addition to the injection pressure and flow sequence used for evaluation, also packer pressure and temperature are plotted. Variations in these parameters may sometimes influence the measurements (applies to low-conductivity formations).

Hoisting equipment

The hoisting equipment consists of a 3-leg rig and a hydraulic hoisting unit. The rig is adjustable for use at drill holes of different inclination.

A hydraulically operated chuck with jaws adapted to the pipe string grips the same and is lifted and lowered, respectively, by being connected via a wire with a hydraulic ram. The hoisting height is c. 2 m and at gripping and pipe-jointing the pipe

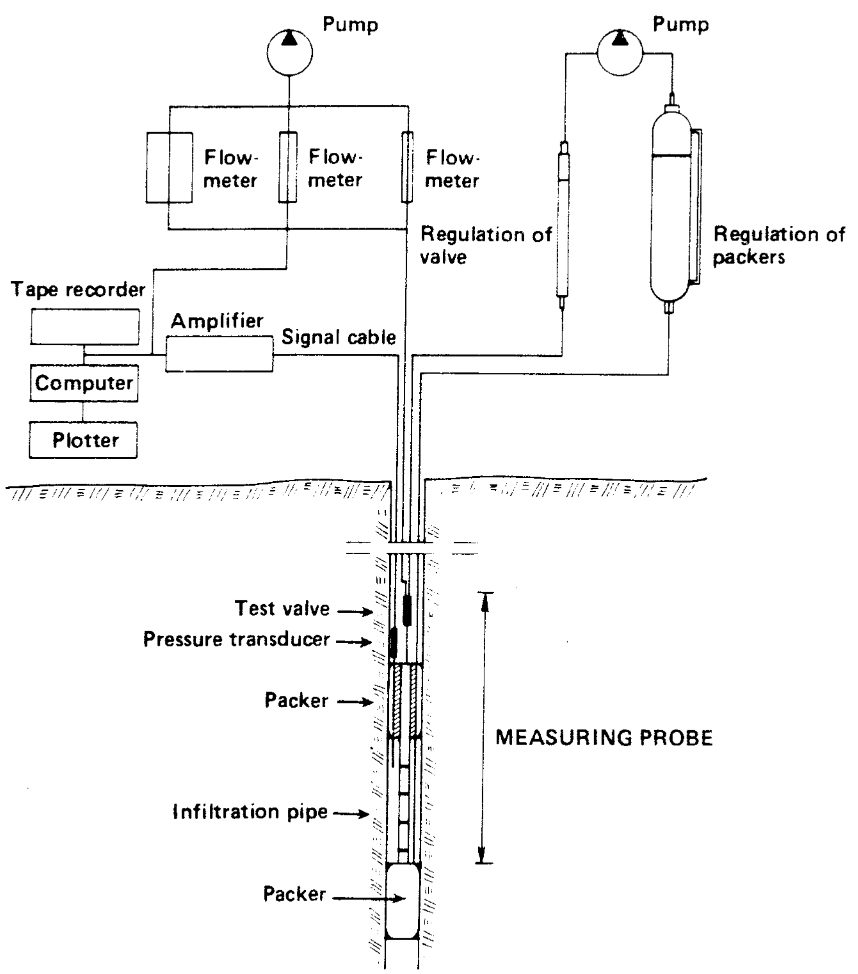


Figure 3-6. General umbilical hose system

string is locked by means of an additional chuck. A built-in safety system prevents more than one chuck at a time to be opened. The hoisting equipment has a lifting capacity of 3.5 tons. The hoisting speed is c. 60 m/h including pipe-jointing and taping in position of hoses and cable at the pipe string.

3.2 INJECTION TEST EQUIPMENT - UMBILICAL HOSE SYSTEM, GENERAL LAYOUT AND FUNCTION

The equipment consists of three separate units: a portable electric power unit, a recording trailer and an instrument trailer.

The functions of the system is to enable water injection tests based on one or more investigation methods, and thereby to measure and register water volume by time unit, pressure, and temperature (Figure 3-6). Additional tasks are to pressurize one or more packers and then to measure and register packer pressure, to operate separately the relief valve and the test valve, and to measure and register the groundwater hed of the drill hole by means of a pressurized bubble tube.

The electric power unit is built around a Slanzi diesel engine with electric equipment such as control cabinet and automatic equipment of Swedish manufacture. Max. output is 12 KVa. A 5 KVa

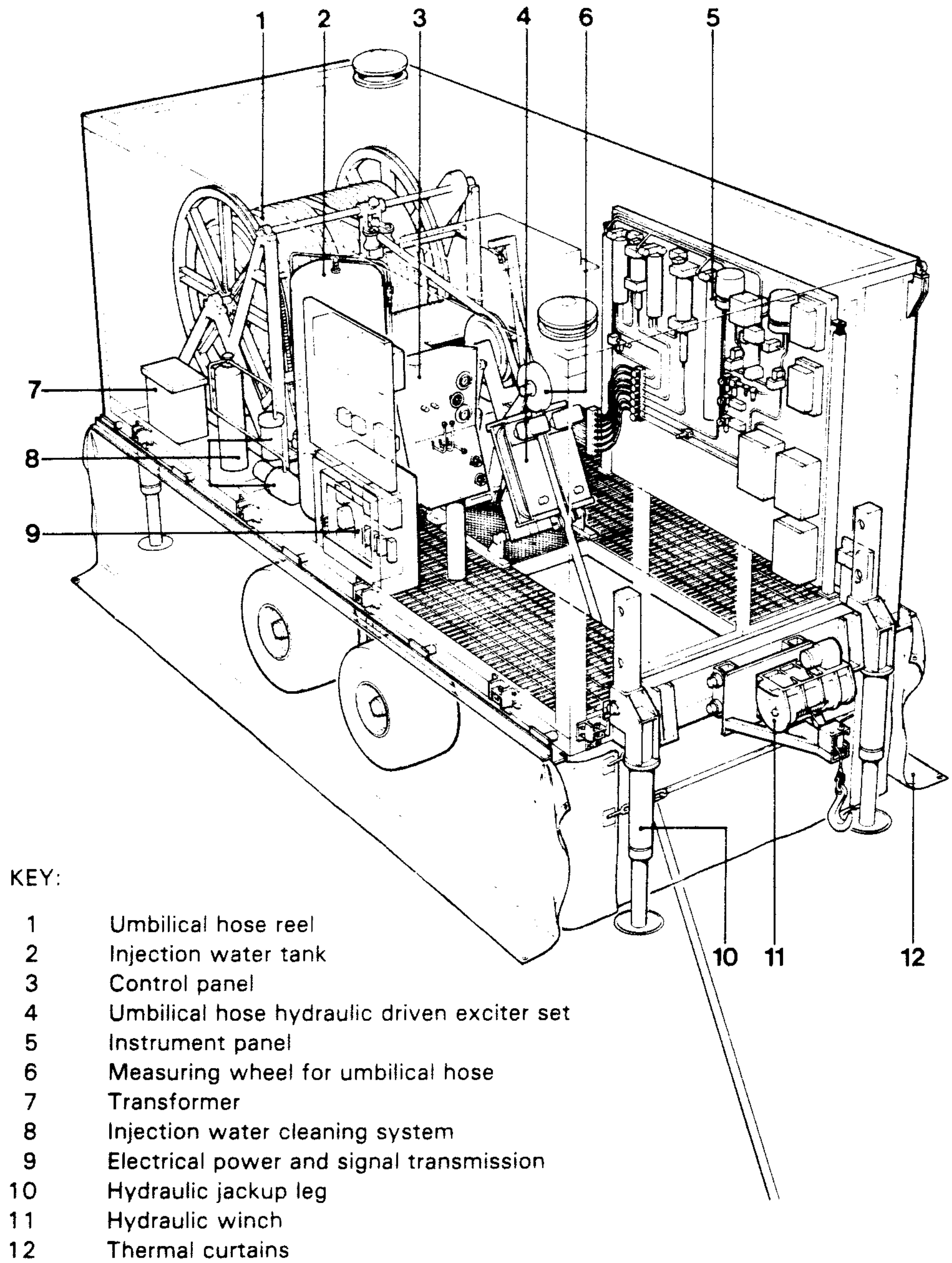


Figure 3-7. Instrument trailer

transformer is part of the equipment, and the transformer is fitted on to the recording trailer.

<u>The instrument trailer</u> is built on a special-type chassis with detachable superstructure, the following equipment being installed:

One down-feed device enabling the reeling down and up of a multihose. Transportation speed is > 360 m/h.

Instruments, grouped in principle around three main functions. These are: pressure registration, temperature registration, and volume registration. The different functions in these three sections are interconnected and are influenced on various occasions during the measurement period.

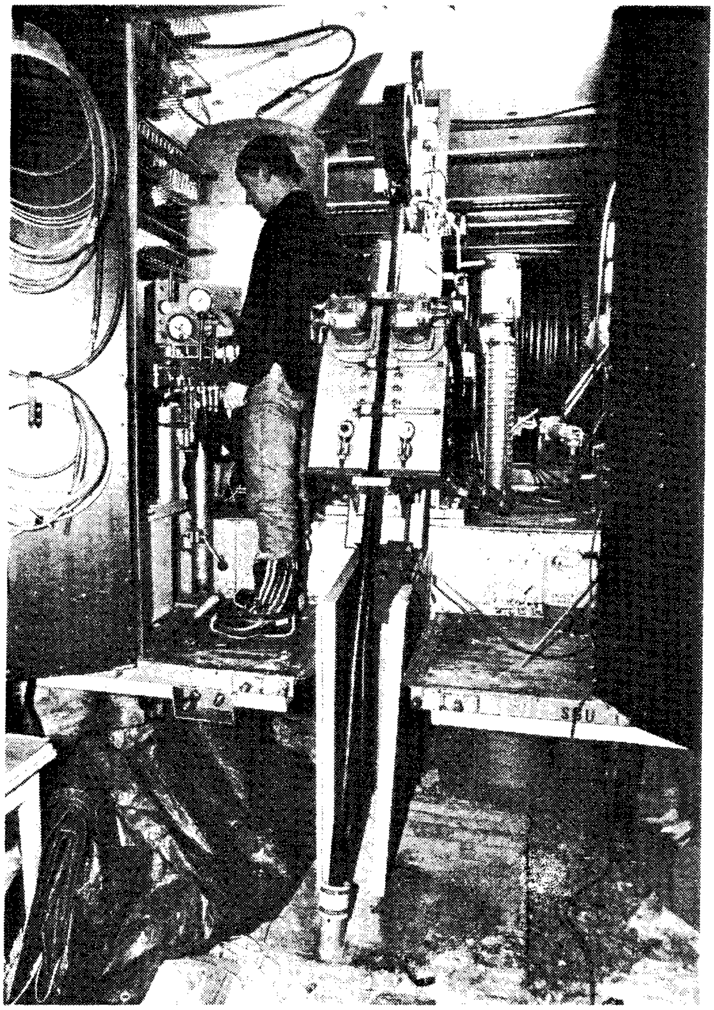


Figure 3-8. Interior of instrument trailer

The instrument trailer furthermore accomodates a pressure tank for water which is pressurized for the purpose of the investigation. There is also a compressor unit and a hydraulic unit. The hydraulic unit is used for the operation of the down-feed device and reel. The recording trailer may moreover be placed on hydraulic supporting legs which contributes to a stable and correctly level-adjusted assembly.

When setting up the equipment at the measurement location a hydraulic winch is used to pull the measurement carriage in position.

The compressor unit supplies primary-side air at c. 14 bar. This primary pressure is used for the pressurizing of three tanks, of which one is connected to the relief valve, one to the test valve, and one to the packer fitting device. The remaining air demand of the trailer is reduced from the 14 bar of the primary air to, in the first place, 9.0 bar, i.e. the operating pressure for the pressure tank water, and also for cleaning air. There are additionally two reductions in the system, viz. one reduction for control of the pressure booster which operates via the test valve, and a reduction for the measuring of bubbles; furthermore, one pressure measurement of the position of the groundwater head in relation to the casing tube edge.

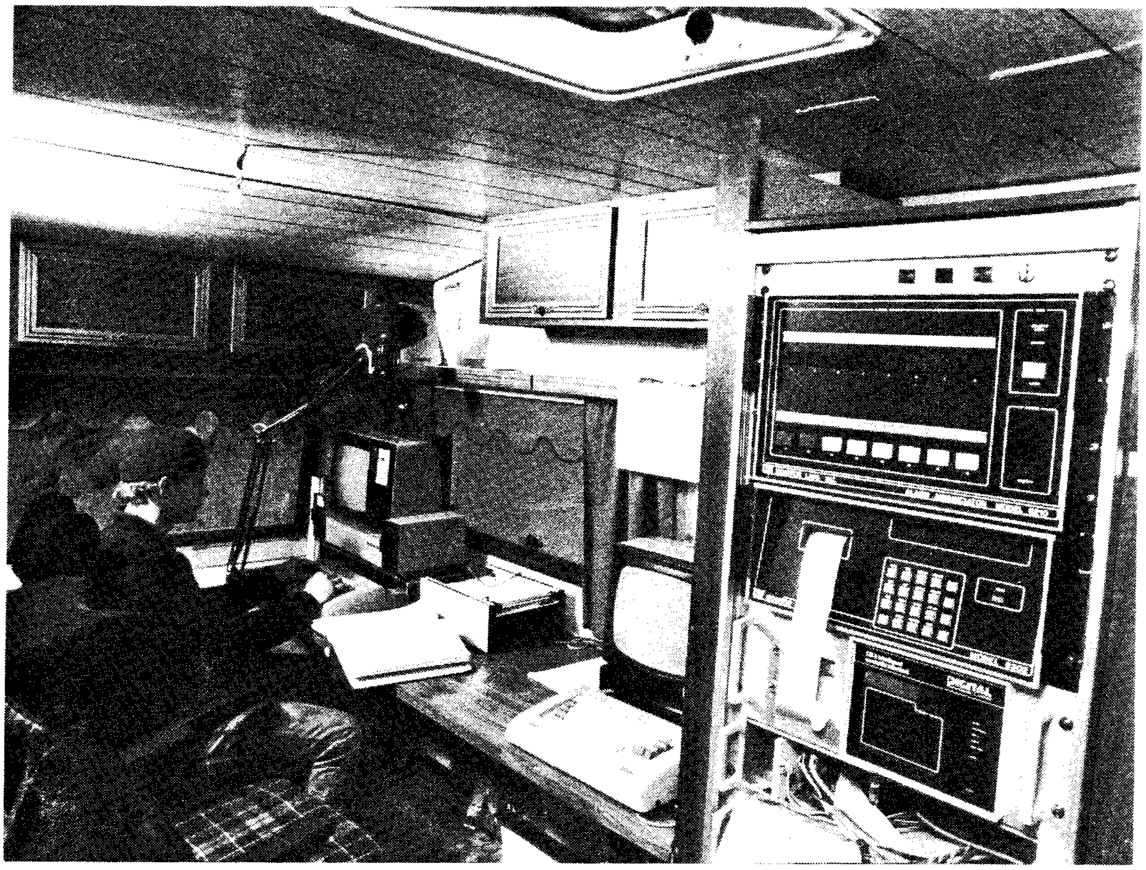


Figure 3-9. Interior of trailer for data handling and storage

The instrument trailer has two separate heating systems, the one being electrically controlled, using thermostat-controlled electric radiators, the other being an emergency-type thermostat-controlled reserve system for heat-maintenance should the power supply break down.

This latter system is LP-gas operated.

On the <u>recording trailer</u> the registration equipment is built around a computer, Type ABC 80, which is connected via an expansion box with a datalogger and a tape recorder (Figure 3-9). ABC 80 is also directly on-line with a plotter. This system enables control of investigation method, and the registration and storing of information while the measurement is in progress. Upon completed measurement, the data tape can again be read into the ABC 80 for plotting. In order to make possible fast evaluations in the field, there is additionally one ABC 80 which enables the evaluation via diskette of measurement data at the same time as collection of new measurement data is carried on via the other system. The trailer is electrically heated by means of an LP-operated reserve system.

Description of the systems

The system is divided into four partial systems with a joint compressed air service system. The individual systems are: volume measurement of water, packer regulation, control of relief valve and test valve, and measurement of groundwater level. All these activities are well defined and are described in the below, each separately.

Flow measurement

In a pre-programmed water injection test sequence is determined what operating pressure is to apply during the continuance of the measurement process. Pressurizing is effected by applying the pertinent operating pressure across tank TA 1. This pressurizes the entire system from TA 1 to the test valve on the other side of the 1 000 m long multi-hose. Before the measuring starts, a reference measurement is made by opening a cannular tube in the system. The through-flow in the tube is then registered as are simultaneously also pressure and temperature. There are 3 flow meters in the system (all manufactured by Fischer and Porter). They represent three strictly delimited measurement ranges.

Q1 =	7,000	-	70	ml/min
Q2 =	100	-	5	"
Q3 =	6	-	0.3	"

The measurement accuracy in each range has been specified by the manufacturer at min. 1 % of the max. deflection in each measurement range. Q1 is always connected, when flow measurement is going on. Measuring via this flow meter is by registering a change in the induction voltage applied across a measurement hole. This flow meter has no mobile parts and can consequently not be damaged by an excessive flow passing through. When the lower limit value approaches for this flow meter, the next smaller stage in the measurement range 100 - 5 ml/min is automatically switched in. When the flow approaches the lower value in this flow meter, the next flow meter in the sequence is switched in. The measurement range of the equipment will consequently be 0.3 ml - 7,000 ml/min with continuous overlapping of measurement results between the different flow measurement ranges. The driving pressure is set in the sequence and computer-controlled. Driving pressures can be set, varying between an overpressure of a few cm water column up to 10 MPa max. pressure which is the upper limit pressure of the components.

The system is normally maximized to 9 MPa. Available water volume in TA 1 is c. 450 l. All computer-operated valve functions in the system can also be manually operated in the recording trailer via an electrical relay box.

Packer regulation

The setting pressure of the packers is regulated by means of water and air, the air functioning as pressure setting medium and the water as pressure transmitting medium. The tank TA 2 is the regulating point when the packers clamp or unclamp. The volume of the TA 2 is c. 15 l and when starting up it is filled with c. 12 l of water. The packers are connected to TA 2 with a Ø 4 hose in the multi-hose. Air of a working pressure of c. 14 bar is used in setting up the packers. When the TA 2 is pressurized water is forced down into the multi-hose, expanding the packers. When level and pressure are stable in TA 2 the packers are set. The valve between TA 2 and the multi-hose then closes and continous pressure measurement and registration of packer pressure goes on during the whole measurement. To relieve the pressure in the packers TA 2 is opened. If, during the duration of the measurement sequence, the packer pressure should come down under c. 0,2 MPa as compared with the preset value, the computer alarm is released and the water injection test sequence is as a result discontinued. This means that the packer pressure is a prerequisite during the duration of the test.

Relief valve regulation

A relief valve is located in the packer space. The task of this valve is to relieve the packer space in a way to prevent an overpressure from forming due to the expansion of the packers in the space. The valve functions in such a way that a plunger opens up the passage between the packer space and the space above and under the packers. This takes place while the packers are being expanded to. The regulating plunger is operated via a pressurizing tank, the plunger returning to its original position when the pressure in the tank is let out. The valve is connected to tank TA 3 by means of a Ø 4 mm hose in the multi-hose. The regulating plunger in the valve starts to open at c. 0,8 MPa and is fully open at c. 1,1 MPa. Pressurizing of the tank is effected via the compressor system using primarily air of c. 1,4 MPa.

Test valve regulation

A test valve is located in the packer space. The task of this valve is to distinctly open and close the water supply to the test section during the test. A regulating valve connects the Ø 10 mm hose with the packer space. This is effected by means of hydraulic water pressure, compressor air at c. 14 bar first pressurizing tank TA 4, causing the pressure booster, fitted between TA 4 and the test valve, to open a few seconds later. The pressure booster increases the pressure in the regulator hose to the ram to c. 2,5 MPa. This gives the ram a very distinct opening sequence. The switching in of the pressure booster is via a time delay relay.

Level measurement of groundwater head

In order to obtain a correct depth measurement via pressure transducers between and immediately above the packers, an indication of the level of the groundwater head is also required but during the same measurement period. The measurement of the level of the groundwater head is undertaken by means of a Ø 6 mm steel pipe of known length, air being made to pass through the pipe by means of a back pressure valve. The air drive pressure corresponds to the water column height in the pipe, the existing pressure being measured and registered. Also the barometer pressure is registered in conjunction with measuring the level of the groundwater head.

The compressor system

The system is built around a compressor unit, BIABino, Type 2093, of 40 l air volume and a highest permissible working pressure of 1,5 MPa. The system is minimized to 1,4 MPa, and this primary air is used as drive pressure for controlling the relief and test valves. There are in addition three different reduction steps in the system, giving 0,9, 0,45 and 0,01 MPa respectively. These reduction steps can be activated to suit different operating requirements of different investigation methods. The compressor system feeds the pressure regulation of injection water.

Pressure regulation

The purpose of the pressure regulation is to achieve an accurately controllable pressure in the water. Air is used as driving medium and the pressure is consequently changed by air being admitted or let out. A high degree of regulation accuracy can be achieved, and the pressure is independent of water or regulated pressure being used up or fed in.

The function is as follows (Figure 3-10):

A pressure transducer P measures the pressure to be regulated. The electrical signal from the transducer is compared with a set-point value in an electronics unit. The electronics unit controls a number of solenoids which admit and let out air in a way to keep the real value equally large as the set-point value. Each valve has a choking regulator. The choking stages are differently large, the smallest one being used for precision regulation, and the large ones if the pressure needs to be adjusted quickly or if the water flow is excessive. This is necessary, since the air flow is all the time to compensate for water added or removed.

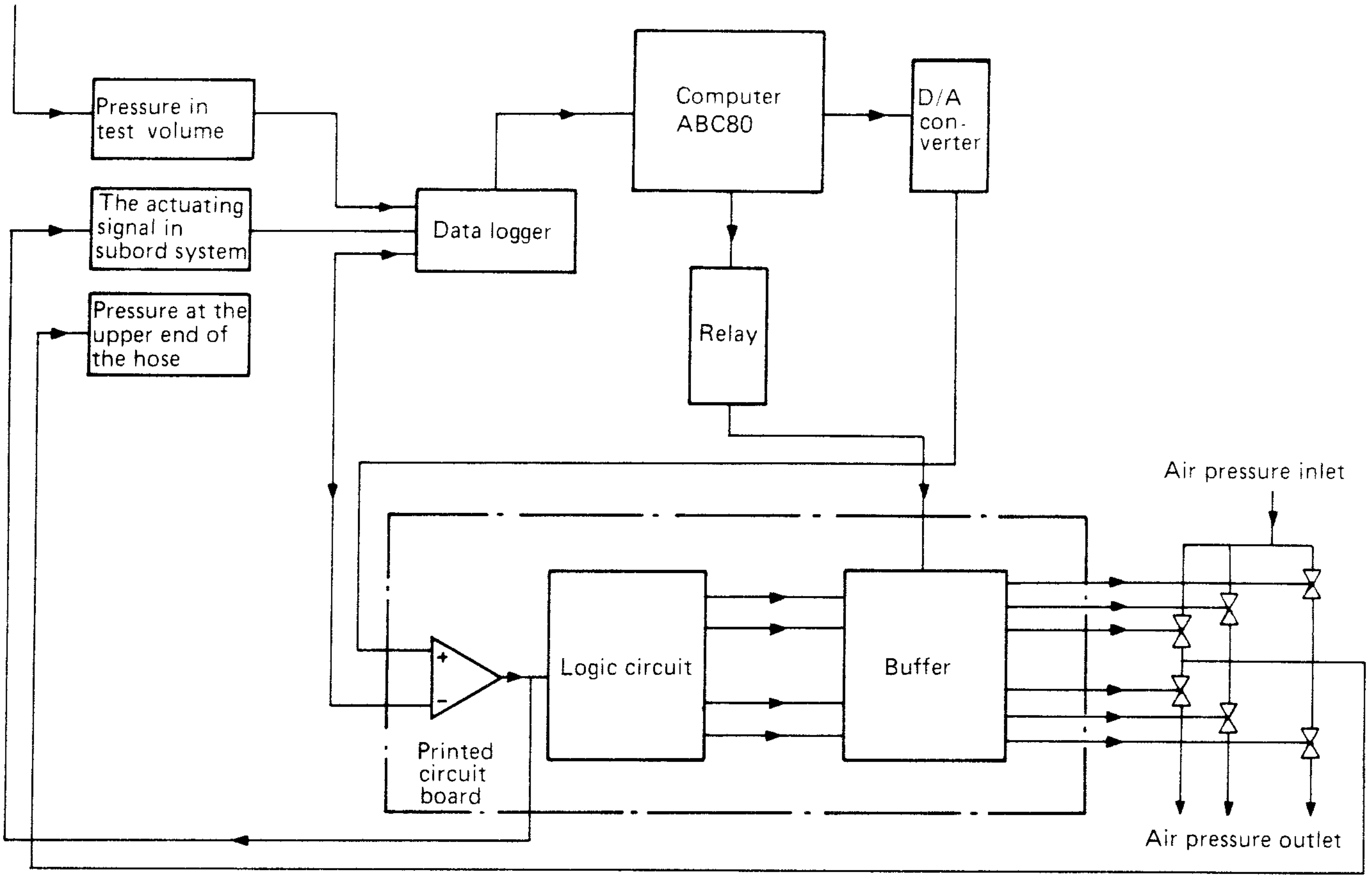


Figure 3-10. Pressure holding system

The electronics circuitry consists of a circuit card deviced especially for the purpose. Additionally required are a current generator and an amplifier for the pressure transducer, and something to generate the set-point value, e.g. a potentiometer. This and the power supply is contained in one single unit. The accuracy of the system is ± 0,5 kPa.

3.2.1 Data storage and evaluation

The task of the system is to collect and register measurement values when exploring a drill hole, and to enable the operator to supervise and check the measurement values during the duration of the data collection process. Specific tasks are as follows:

- Collect c. 20 measurement quantities from a datalogger (Monitor lab).

- Correct certain measurement values according to a calibration curve and to process certain values in accordance with predetermined formulas.

- Display current measurement values on the display screen of the ABC 80.

- To display on request measurement quantities graphically on the display screen as a function of time.

- Register the measurement on a connected data taperecorder (Type CS 3) in accordance with instructions given in advance.

- Apply control voltage in accordance with a predetermined mathematical formula on a D/A channel.

- Operate relays in conjunction with flow measurement.

- Operate via relays all valves needed in order to carry out a complete measurement sequence.

- Keep tabs on how much hose has been fed down into the drill hole.

- Regulate a feed pressure sufficient to keep a constant overpressure down in the measurement section during the measurement process.

- To plot the measurement results after completed measurement.

- Emit an alarm in case of abnormal measurement values. The alarm may be constituted of a relay closing or of an acoustic signal.

In devising the system, the following overriding principles have also been applied:

- The system is to be as simple to handle as to permit a person not accustomed to computers to perform data collection without special training.

- The system is to be flexible enough to permit the operator in the field to modify the function according to actual circumstances.

- The system is to permit simple extension with new functions which prove necessary.

System structure

The heart of the system is an ABC 80 unit. It receives measurement values from the datalogger. After processing, the measurement values can be stored in the data taperecoder or be displayed on the screen as curves. All the time, the operator can control the data flow on the display and intervene when necessary with corrections of measurement values or calculation routines. It is consequently not necessary to stop the measurement work in order to adjust the data flow to the taperecorder or to change the processing of the measurement quantities in the ABC 80.

The ABC 80 also contains a sequence table in storage. The table holds information on the times at which valves are to open and close, when the taperecorder is to be started, how the pressure in the measurement section is to be regulated, etc. For normal measurement purposes the operator thus needs only to initiate the measurement. An acoustic signal warns if something is wrong or when the measurement sequence ends. The operator is capable, however, all the time to intervene in the sequence and can simply cut-out the automatic function.

Upon completed measurement, the data tape can be reread to the ABC 80 for plotting. The operator can plot any of the measurement quantities as a function of whatever other measurement quantity there is. Each quantity can be obtained with linear, logarithmic and inverted scale. In addition, special scales can be achieved, such as the square root of the quantity. The computer then automatically proposes a scale for maximum utilization of the paper, displaying the result on the screen. After possible adjusting of the scale using an adjust instruction, the curve can be drawn on a plotter.

Hardware

The data acquisition, storage and evaluation system consists of the following units connected to the ABC 80 computer via an expansion box (Fig 3-11).

- Plotter for A4. This is connected directly to the V:24 gate in the keyboard of the ABC 80.

- Datalogger, connected to an SIO card (series interface according to V:24). The card holds two channels of which the datalogger uses the one referred to as the A channel.

- Data taperecorder connected to the B channel of the same card.

The expansion box also contains a D/A card for two analog signals and a relay card with 16 closing and/or breaking contacts. For the length measurement of the hose, a special circuit card with a microprocessor has been designed. This processor keeps tabs on the hose length either the ABC 80 is switched in or not. A 16 kbyte extra storage is also part of the system, since the program products used required more storage capacity than available in the ABC 80 keyboard. In order to keep up a constant pressure a special pressure regulator has been devised, which is also connected to the expansion box. To facilitate simple and rapid program loading a drive routine for the CS3 taperecorder has been added in a pROM placed on the SIO card. Also an automatic starting routine has been included in this pROM, the program consequently being loaded automatically when the ABC 80 is switched on or reset.

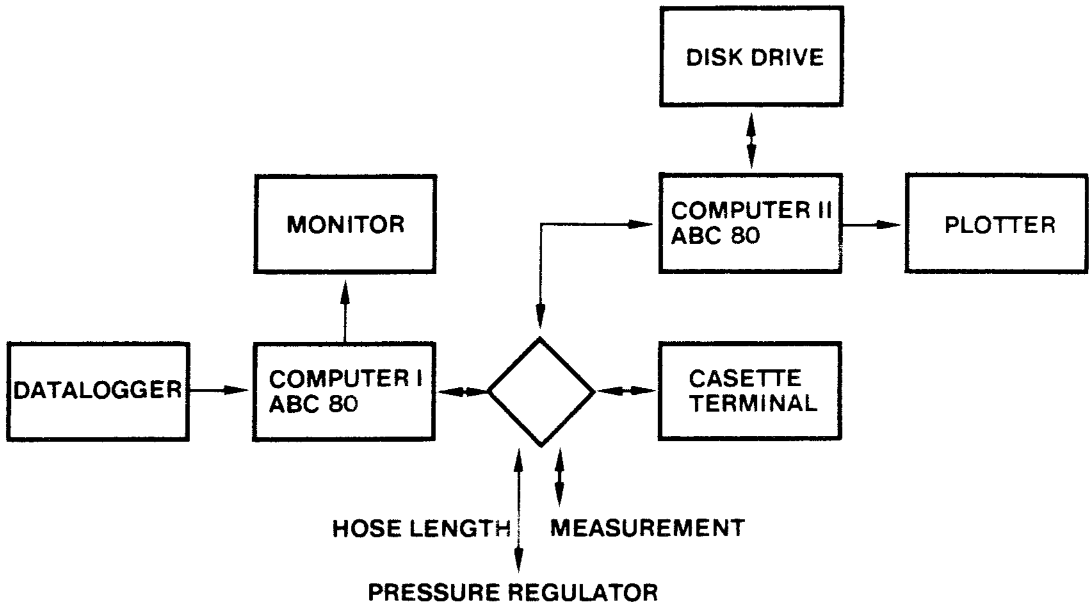


Figure 3-11. Configuration of the data aquisition equipment

Software

The software is devided into two main programs, "WATER" and "PLOTOUT". "WATER" is used in collecting of data whereas "PLOTOUT" is used in plotting over data from the data tape. Independent drive routines are used for the plotter, for the CS3 taperecorder and for handling of data received from the datalogger. These drive programs are written in Assembler (machine language) and cannot be revised without special equipment. Other drive routines are enclosed in the main programs in the form of sub-routines and consequently written in BASIC. The Assembler routines are loaded by means of special BASIC pograms named "MON" and "PLOTDRIVE", respectively. These programs must consequently be run before running the main programs.

Data collection program

The "WATER" program simultaneously performs three different main functions:

- controlling the measurement process
- showing the operator what is going on
- saving measurement data for subsequent evaluation

The control function has been included in the form of a sequence table where a complete measurement cycle is automatically run through after it has been once initiated. A measurement cycle consists of an injection test and a pressure equalization test immediately afterwards. Below is a description of the activities stored in the sequence table. "T" signifies minutes after start of measurement.

T = 0 Certain output data, such as date, name of drill hole, length of measurement section, are stored in the taperecorder.

T = 1 The relief valve opens. Measurement data begin to be stored on tape.

T = 2 Pressurizing of the packers. Adaption of the feed water tank pressure to the groundwater level. Initiating of rapid measurement value storage (every other second). The biggest flow meter is switched in to pressurise the hose.

T = 3 Stopping of rapid measurement value storing.

T = 22 Checking that flow = 0 (no leaks). The cannular test valve is opened. Automatic exchange of flow meters initiated.

T = 25 Saving of cannular flow for subsequent check. Closing of cannular test valve.

T = 29 Repeat check that flow = 0. Closing of relief valve. Switching in of the biggest flow meter.

T = 30 The now pressurized packers are cut-off from their pressure tank. Supervision of packer pressure initiated. Rapid measurement value collection started. Test valve opened.

This is the starting point for the injection test.

T = 31 Rapid measurement value collection stopped. Automatic exchange of flow meters initiate. Regulation of overpressure in measurement section to 200 kPa initiated.

T = 150 Regulation of a pressure in measurement section discontinued. Rapid measurement value started. Test valve closes. This is end of injection test and initiation of the pressure equalization test.

T = 151 Rapid measurement value collection stopped. Checking that flow is = 0.

T = 170 Cannular test valve to be opened.

T = 174 Checking that cannular flow = previous cannular flow. Flow meters disconnected. Test of change in pressure in measurement section initiated. Should the pressure decrease slow enough the test can be discontinued, i.e. the computer jump to T = 290.

T = 290 Packer pressure released. This is end of pressure equalization test.

T = 320 One measurement cycle completed. The data storing is discontinued. Comments may be entered on the data tape.

The evaluation program

There are two plotting programs: one for the automatic and one manual. The automatic is ordinarily to be used for productional diagrams as soon as possible on preprinted forms. The manual program makes it possible to plot random measurement values in order e.g. to check a transducer or a regulation device.

3.3 PIEZOMETRIC MEASUREMENT EQUIPMENT

For measuring at the natural piezometric pressure the distribution in a drill hole a special equipment is utilized. This enables the measuring of the pressure in five different sections by scanning using one pressure transducer. The equipment consists of the following main units (see also Figure 3-12):

- multipacker system
- pressure measurement probe
- data collection and control unit
- data transfer unit (via radio/tele)
- power supply
- hoisting device

Multipacker system

Delimiting of the different sections is effected by means of packers specially built for the purpose. The packers are equipped with 4 pressure tubes and are otherwise devised as injection test packers (a solid tension rod in centre position instead of a pipe). The packers are connected onto a pipe string (the same as for injection tests) and sunk into the drill hole for the sealing-off of selected measurement sections.

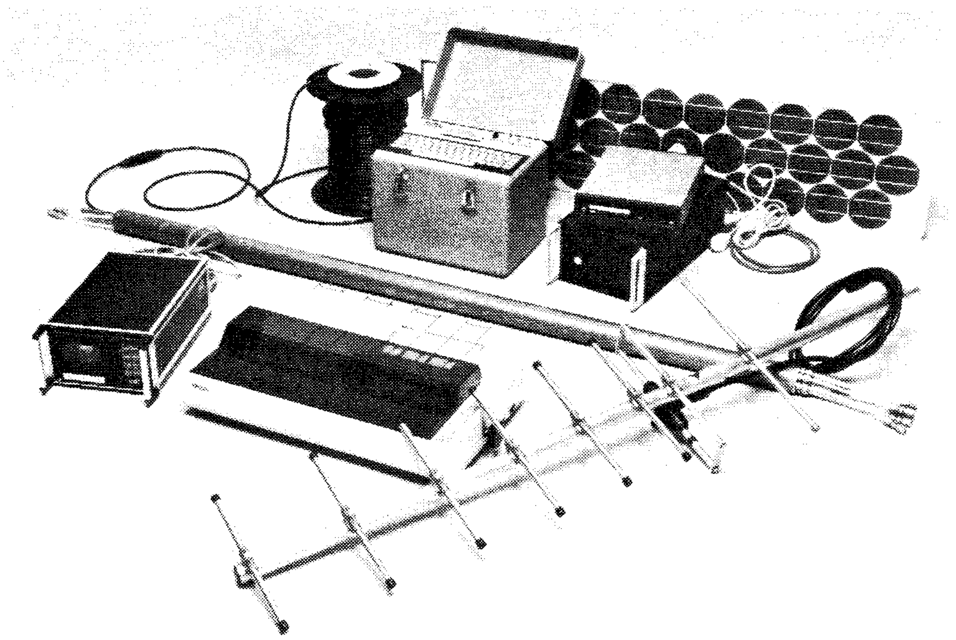


Figure 3-12. Complete measurement equipment including piezomac, probe, radio, solar cells, tape recorder and printer

Pressure measurement probe

Pressure tube connects all measurement sections with a pressure measurement probe (see Figure 3-13). The probe consists of a number of solenoid valves, a pressure transducer, a pressure amplifier and a unit for analog-to-digital conversion of measurement signals to serial form. The pressure measurement probe is placed c. 20 m below the groundwater level and is filled with nitrogen gas. The pressure transducer, Kistler 4043, 500 kPa, is of the type used in injection tests. The measurement range 500 kPa in most cases allows sufficiently large measurement range, ± 200 kPa at 20 m depth, 100 kPa air pressure), for the pressure levels of the sections to be registered at the moment the resolution is adequate. The serial measurement values are obtained at a resolution of 0.03 kPa which corresponds to 0.3 cm water column. At the solenoid valves the pressure transducer is connected to the pressure tubes from the individual measurement sections, one at a time. There is also a line from the probe to the ground surface through which water is fed down under pressure before start of measurement in order to deaerate the pressure tubes to all sections. The pressure tubes used are Tecalan TR 6/4 h. The probe is connected to the data collection control unit on the ground surface through a cable, which can be extended up to 1,000 m.

Hoisting device

For the piezometric measurements a low weight, hydraulic hoisting unit is used, built on a two-wheel trailer to permit simple towing with a car. When operating it is stationary on three supporting legs. The pipe string is kept in place using hydraulic chucks, the vertical movement of which is regulated by a hydraulic plunger.

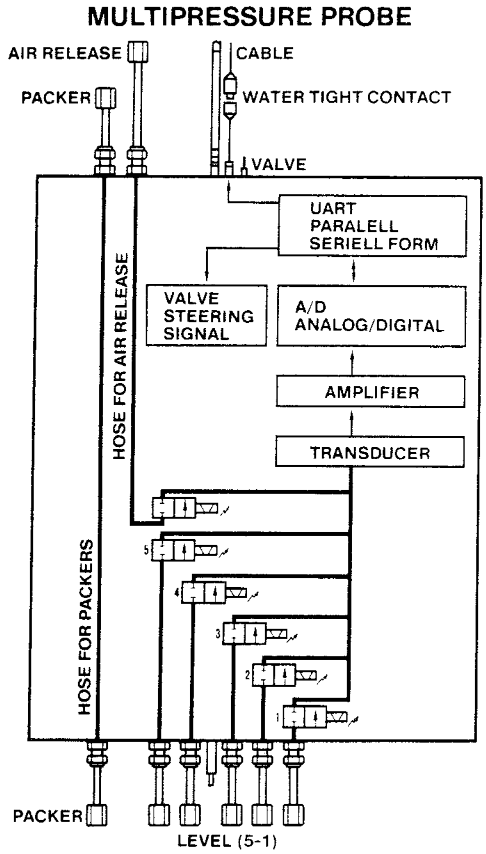


Figure 3-13. Schematic drawing multipressure probe

The hoisting capacity is c. 4 tons. The equipment can also be used for delivering pressure with the same capacity, provided that it is firmly anchored in the ground. The hoisting speed is c. 100 m/h, including pipe-jointing and taping of hoses in position at the pipe string.

3.3.1 Data collection control unit

For control of the pressure measurement probe and for storing of pressure data, SGAB has developed the data collection and control unit Piezomac (Figure 3-14).

Piezomac is a battery-operated climate-resistant (-30°C to +50°C) unit for the purpose of simultaniously controlling measurements in 1 - 5 pressure measurement probes, to receive and store data from these probes together with time data, and to transfer the results to other units. Piezomac consists of:

- Microcomputer
- Semi-conductor storage (up to 64 k byte)
- Keyboard
- Display (16 characters)
- Serial inputs/outputs (9 pcs, 300 baud)

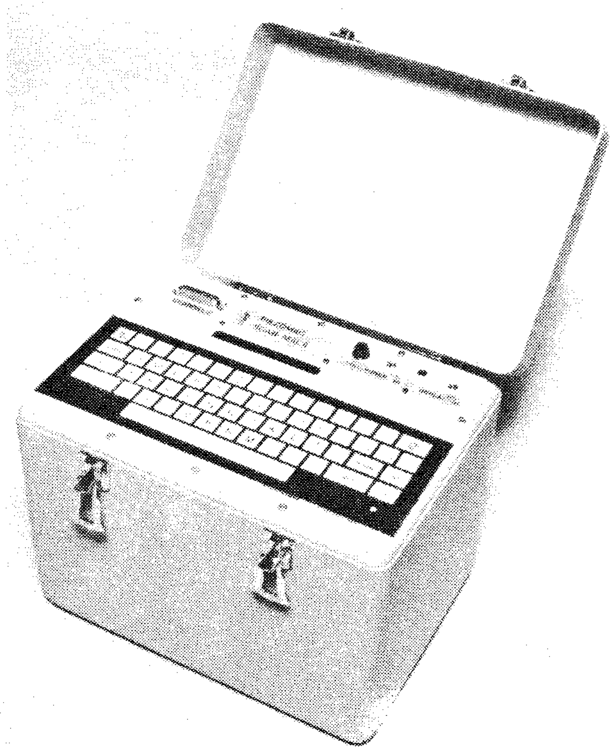


Figure 3-14. Piezomac data collection and control unit

The Piezomac has low power-consumption during measurement sequence, 15 mA from 24 V and consequently capable of measuring for a couple of months on two car batteries. The Piezomac can be equipped with a solar cell module (up to 33 W) for charging of the batteries.

Measurement sequence

When measurement is to start, the power is switched on to the probe and a solenoid valve opens. After a few seconds, two measurement values are sent to the microcomputer. These values are compared, and should they differ more than 0.06 kPa from each other two new measurement values are extracted for comparison purposes (4 trial or "error"). The first valve closes and the other opens etc. When measurement values have been obtained from all measurement sections, the feed voltage to the probe is switched off and the measured values are stored in a semi-conducter memory. The microcomputer now waits until time is in for the next measurement. The interval between measurements (scan time) is optional, between 1 minute and 17 hours.

Data transfer and data processing

Terminals, printers or taperecorders can be connected to Piezomac, although data transfer is generally via radio to telephone modem and from there to a main computer terminal. Data are checked and identified, in order subsequently to be processed, and successively plotted on a monitor or on paper. In this way the measurement sequence can be continuously supervised from the office. From terminals, the instrument in the field can be reprogrammed via the same radio/tele-communication during the continuance of the measurement process. This handling procedure, and the possiblity of supplying the low current unit with power from

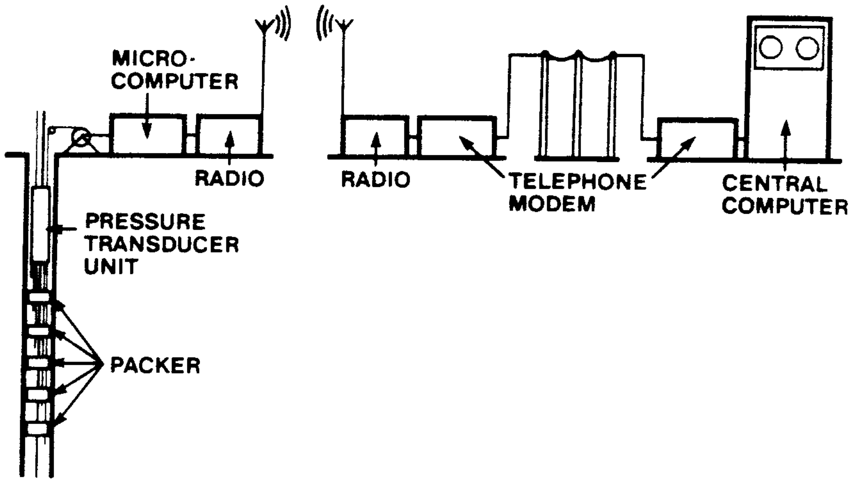


Figure 3-15. Flow diagram for piezometric data

a solar cell module, permits the measurements to be made with minimum staffing (Figure 3-15).

3.4 TEST PUMPING EQUIPMENT

By means of test pumpings studies are made as to how a major hydraulic disturbance of long duration in a fracture zone influences a major volume of the surrounding rockformation. The pumping is effected in a number of percussion drilled 4" observation holes, sealed off in sections by the following main units (Figure 3-16).

- pump
- flow meter and regulator unit
- multipacker system
- pressure measurement probe
- data collection and control unit
- data transfer equipment
- hoisting unit

Pump

For the test pumping a submersible pump is used, placed in the open pump hole at a depth permitting sufficient drawdown lowering of the waterlevel. The pump preferably used is the Grundfos CP 10-25 with a capacity of 180 l/min at 60 m lifting height. The power consumption of the pump is 40 A (380 V) at the start and the power supply is a 15 kVa diesel-operated power plant. The water is led from the pump via the regulator unit and the flow meter as far away from the pumping area that it is prevented from influencing the measurement by reinfiltration.

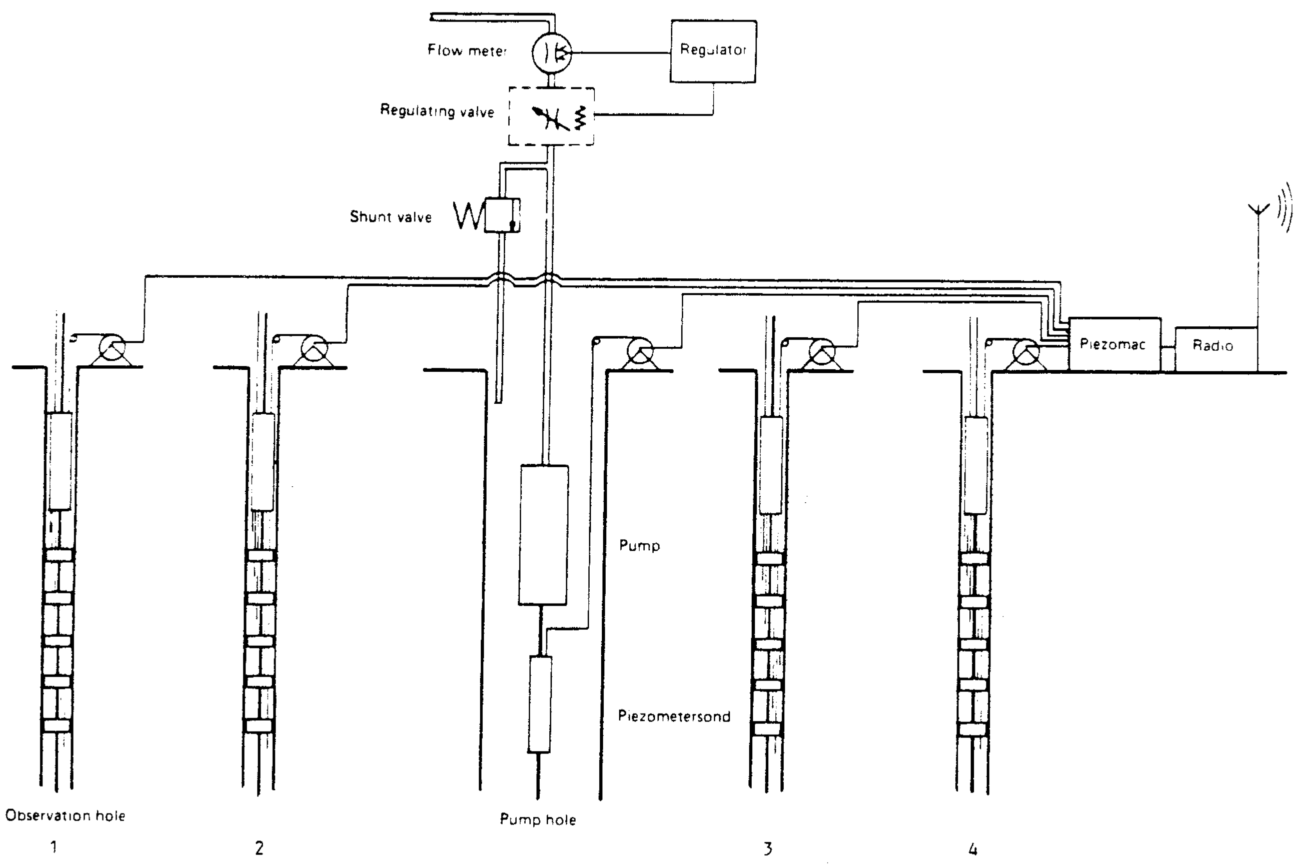


Figure 3-16. General layout, test pumpequipment

Flow meter and regulator unit

The test pumpings are performed at constant flow capacity maintained by means of an automatic regulator unit.

The flow meter is of the type described in the Section 3.1, but in this case a larger model permitting flows up to 100 l/min to be measured. The flow meter has been supplemented with an automatic registration unit. The unit consists of 100 phototransistors arranged in a line on one side of the meter, where they sense the position of the float. The signal is transmitted to an electronic Philips Witromat regulator connected to a control valve, type Ramén Ball Sector Valve. This device automatically sets the flow at a predetermined capacity and keeps it constant throughout the pumping sequence.

The resolution of the flow meter is 1 % and the indication error < 5 %. The automatic regulator keeps the flow constant within 1 %.

Multipacker system

During the test pumpings the response in each observation hole has been registered at 3 levels, viz. at 2 sealed-off sections between and under packers, and one open above the packers.

The packers manufactured for the purpose are of the same principle design as the injection packers (Section 3.1) but equipped with 2 pressure tubes and adapted for larger hole dimensions. The packers are connected onto a pipe string or an aluminium bar and lowered into the drill hole to seal off selected sections.

Pressure measurement probe

The pressure measurement in the observation holes is effected using the same technique and equipment as the Piezometric measurement (see Section 3.3). Also in the pump hole a pressure measurement probe is installed under the pump. This probe lacks solenoid valves, however, since there is only one measurement section.

Hoisting unit

For lowering/lifting of packer system and pump, a manual winch is used, mounted on a bracket clamped to the casing of the drill hole.

3.4.1 Data storage and evaluation

For the collection of pressure values and the controlling of the pressure measurement probes, the same equipment is used as for the piezometry, viz. the Piezomac (see Section 3.3.1). The difference is that in this case up to 5 probes are connected.

Measurement sequence

The measurement sequence at "normal measurement" is the same as discribed in Section 3.3.1. Since several probes are connected, the order sequence chosen is such that on each scanning occasion the uppermost level is measured first in all probes, the second level being measured next, etc. The pump hole is consequently measured for each level at the observation holes. In addition to "normal scanning", "continuous measurement" and "pump measurement" is effected in conjunction with the test pumpings. The purpose of these both latter variants is to condense the scanning interval in the initial stage of the test pumping. "Continuous measurement" implies in principle "normal scanning" without any waiting time (with 5 probes connected, the measurement interval will be c. 2 min.). "Pump measurement" means measuring directly after valve opening and without checking of measurement values received. In the case of the two latter measurement types, the measurement interval in the pump hole will be c. 30 and 18 secs., respectively. The duration of "pump" and "continuous measurement" respectively, as well as of the scanning interval for normal measurement purposes, is preprogrammed before starting of the pump.

Data transfer and data processing

Data transfer is identical with the Piezometric equipment. The results of the test pumpings are presented in an extensive back-up report for evaluation.

4 EQUIPMENT FOR HYDROCHEMICAL INVESTIGATION, GENERAL LAYOUT AND FUNCTION

Ground water collector

Investigation procedure

Ground water from deep drill holes has been collected from distinct water bearing levels where previous hydraulic investigations indicate a relatively high conductivity.

A 2.7 m section around a single fissure is sealed off by rubber packers and water is continuously pumped out of the section for two weeks, with a flow tare of 100-200 ml/minute. More details about the working procedures are given in /4:1, 4:2, 4:3/.

Down-hole equipment

The set up for the ground water characterization is schematically shown in Figure 4-1. A hydraulically operated piston pump is positioned immediately above the sealed off zone. In the pump both the piston and the cylinder are made of stainless steel.

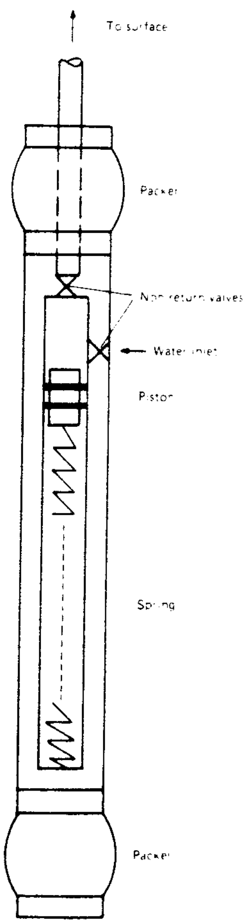


Figure 4-1. The borehole pump

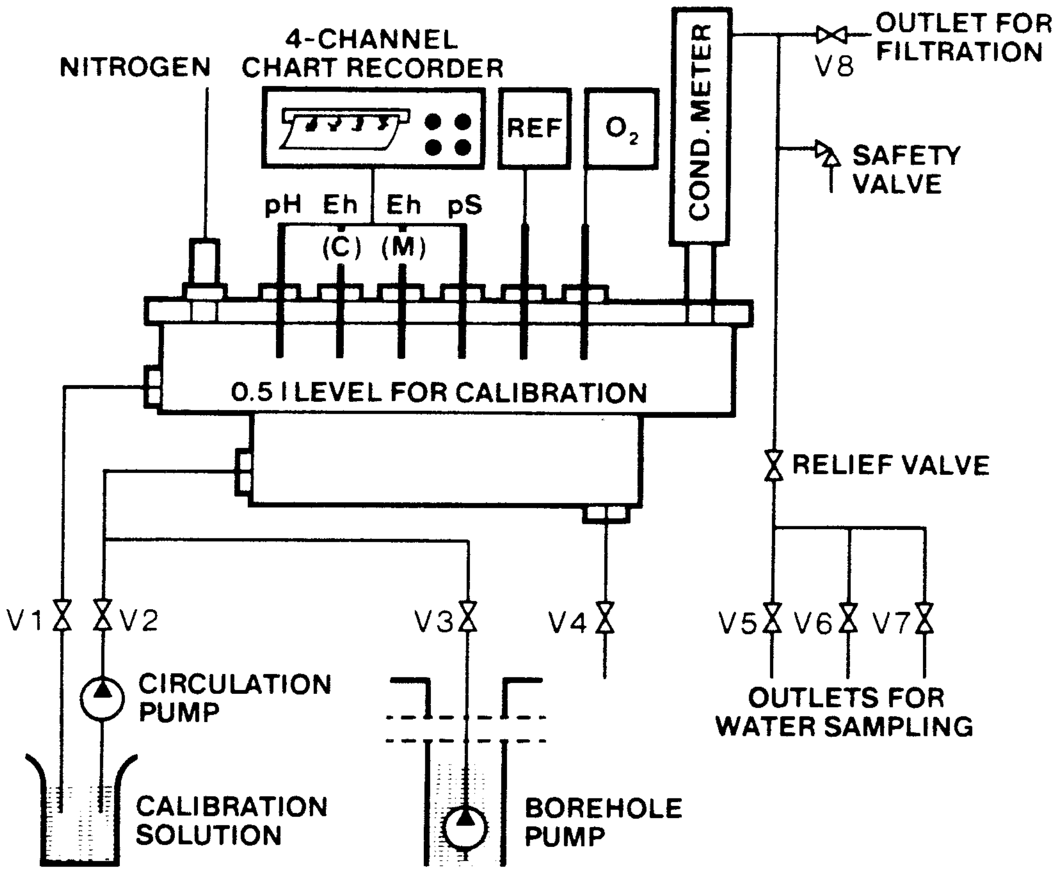


Figure 4-2. Schematic drawing of method used for water sampling in deep boreholes

All parts of the pump that come in contact with the water are made of stainless steel, except for two one way valves that are made of brass. These valves control the inlet and outlet from the pump.

From the pump the water is transported to the ground surface through a line consisting of 2 m sections of steel pipes that are screwed together. Inside each of these steel pipes there is a plastic tube of the same length as the pipe section when screwed in place.

At the ground surface the water is led over to a tecalan tube (polyamid) leading to the flow through cell where the field parameters are monitored.

The flow through cell

The flow through cell where all the field measured quantities are monitored is made of stainless steel. A drawing of the cell is presented in Figure 4-2. The cell consists of two cylindrical parts, where the one with a smaller diameter is placed below the one with a larger diameter. This configuration resulted from the need of minimizing the volume of the calibration solutions.

The water coming up from the packer section enters through valve V1 and flows into the cell, filling it up with a volume of approximately 1.5 litre, and flows out through the conductivity cell.

The electrodes for measuring pH, E_h and pS reach down into the smaller cylinder of the cell. Consequently, calibrations can be made by circulating the solutions in through valve V2 and out through valve V4. In this way, 1 litre of solution is sufficient. The circulation pump is marked by a P in Figure 4-2.

The valves V5, V6 and V7 are the normal outlets for the water. They are supposed for different types of water sampling. Before these valves there is a relief valve that keeps a small overpressure in the flow through cell. The outlet valve V8 lies in front of the relief valve, and consequently the water that comes out is pressurized. This valve is used for filtration.

In case all the valves are closed there is a safety valve that will open to let the water out.

All the parts used in this system are made of stainless steel. The tubings between the parts are polyamid plastic Tecalan 6/4.

Instrumentation for field measurements

The field measurements can depending on their measuring principle be classified as EMF measurements or other types of measurements.

EMF measurements

pH, Eh and pS^{2-} are parameters that are monitored by EMF methodes in the field. The Eh value is recorded by two different inert materials. Both a platinum and a glassy carbon electrode are used.

All the EMF:s are recorded in mV with a resolution of 0.1 mV against a gel filled silver/silverchloride reference electrode. The pH, Eh and pS^{2-} values are recalculated using the measured and the calibration potential readings.

The measuring instrument is a multimeter type Fluke 8062A with an input impedance > 1 000 MOhms. Besides of the reading the electrodes are also connected to a chart recorder for continuous monitoring of the potentials.

A listing of the electrodes used is presented in table 4-1.

Table 4-1. Electrodes used for the field EMF measurements.

Sensor	Manufacturer	Model	Type
pH	Electrofact	SM 21/AG4	industrial glass electrode
Eh_C	Metrohm	EA 276	"glassy carbon" graphite electrode
Eh_{Pt}	Metrohm	EA 281	massive platinum electrode
pS^{2-}	own construction	Ag/Ag_2S	electrode
Ref	Electrofact	SR 20/AP4	gel filled Ag/AgCl

Other field measurements

Besides of the EMF measurements the amount of dissolved oxygen (DO), the temperature and the electrical conductivity of the water are monitored directly as the water passes through the flow through cell. These parameters are monitored with commercially available compact systems as listed in table 4-2.

Table 4-2. Field measurements performed by commercial compact measuring devices.

Sensor	Manufacturer	Model	Type
DO	YSI	57	dissolved oxygen meter
Temp			meter
Conductivity	Kemotron	802-81	four electrode system

Calibration of field sensors

The flow through cell is equipped with a number of inlet and outlet valves in order to make the calibrations as convenient as possible c.f. Figure 4-2.

The calibration solutions are prepared from concentrates that are diluted with destilled water. The solution is circulated through the cell by the circulation pump. The different calibration solutions are listed in table 4-3.

Table 4-3. Calibration solutions and the corresponding parameter values, valid at 10°C.

Solutions	pH	Eh mV	pS	cond mS/m
pH-buffer + quinhydrone	4.0	487		
pH-buffer + quinhydrone	7.0	316		
pH-buffer	10.0			
0.01 mol/l Na_2S in HCO_3/CO_3 buffer	(10.5)		5.5	
0.05 mol/l Na_2S in 0.1 mol/l NaOH	(13.3)		2.0	
0.01 mol/l KCl				142
0.1 mol/l KCl				1 298
air saturated water: DO = f(temp, pressure)				

From the calibrations that have been made the accuracy of the pH measurements can be estimated to be within ± 0.1 pH unit and the accuracy of the pS measurements to be within ± 0.5 pS units. The accuracy of the Eh measurements is solely depending on the buffer capacity of the ground water.

Ground water sampling procedure

After flowing through the cell where the field measurements are made the water passes out through a relief valve and on to selectable sampling locations.

Sampling for analysis of main constituents

One outlet valve is used for ordinary sampling of water. Whenever a sample is taken a new piece of acid washed plastic tubing is mounted in order not to contaminate the water with dust gathered on the old tube. Normally a whole set of different samples are taken subsequently.

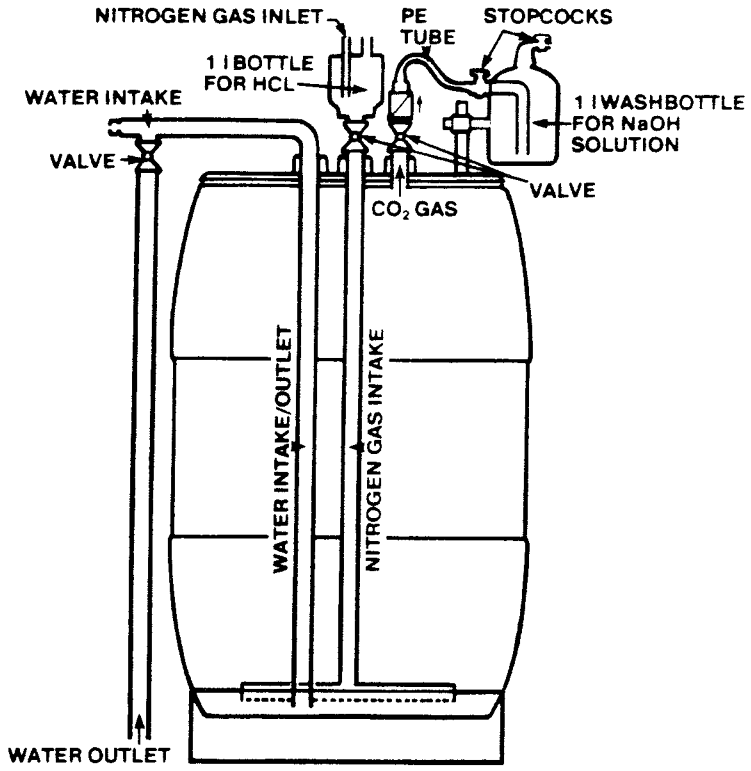


Figure 4-3. Equipment for sampling of C^{14}

Sampling for ^{14}C analysis

The amount of carbon needed for a ^{14}C analysis corresponds to the total carbonate content of ca 100 l of natural ground water. In order to obtain a convenient sample volume the carbon dioxide is expelled from 130 l of acidified ground water and collected in a one washbottle containing a NaOH solution. A schematic drawing of the equipment is presented in Figure 4-3.

The barrel is filled up with water through the water inlet tube. After that the 1 litre bottle for the hydrochloric acid is filled. The acid is pressed into the water by nitrogen which also serves the purpose to mix the acid and the water and to expell the carbondioxide from the water. The CO_2 is then trapped in the wash bottle whereas the nitrogen passes right through it.

The barrel is emptied afterwards by applying an over pressure with nitrogen when all the valves exept for the water outlet valve are closed.

5 EQUIPMENT FOR GEOLOGICAL CORELOGGING

A microcomputer-based drill core logging system has been developed. The system is used for registration, storage and presentation of information from fracture and rocktype mapping of drill cores.

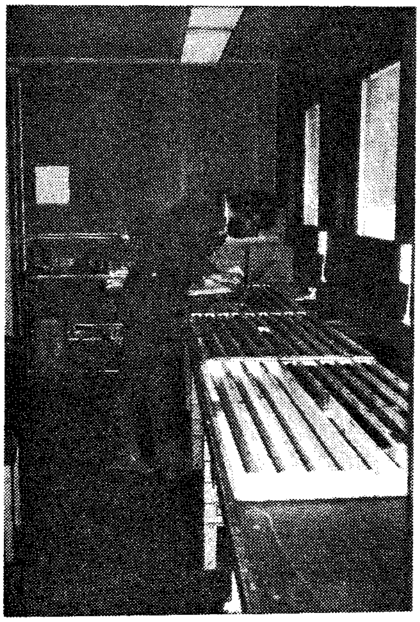
Equipment

The system is based on the Swedish microcomputer ABC 800 M and consists of keyboard, display, diskette unit (ABC 832) and an Epson MX 100 matrix printer (Figure 5-1). The computer has a 32 kbyte RAM-memory and data is stored on a 5 1/4" diskette. The diskettes are doublesided and have a storage capacity of 0.6 Mbyte each. Figure 5-1.

Software

The software of the system is based on a general database system named Basregister 800. The database is made by PDTA.

The software is built up according to the menu technique. This means that handling and user training is comparatively simple. The operator is guided by text menues and different functions in the system can be selected by chosing among the various alternatives.



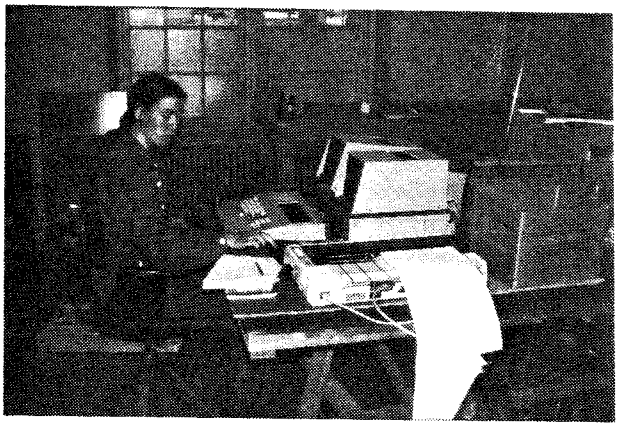


Figure 5-1. Equipment for core logging

The information is stored in five registers:

Register	Name	Max. no. of items	Comments
1	Format	10	Contains print-out formats
2	Rocktype mineral codes	100	To be modified/ extended by the operator as necessary
3	Drill hole information	1	Storage of general data on drill holes
4	Core log 4500	4,500	Storage of all observations in connection with fracture and rocktype mapping
5	Comments	1,000	Storage of comments in connection with mapping

Since the system is connected to a matrix printer, the operator is free to plot, on selected occasions, the stored fracture and rocktype information.

The print out is divided into one rocktype profile and one fracture mapping profile. These profiles are plotted side by side. The charting resolution is 5 cm, i.e. the observations are rounded off to 5 cm intervals. Each page of the print-out will display 7 m of the drill hole. The average printing time is approx. 100 m/h. A diskette has the capacity to store information from approx. 1,000 m drill core.

Up to February 1983 the system has been tested on c. 6,000 m drill core. Even to staff not accustomed to computers the system can be easily learned and after c. 2-3 days, they can handle the functions required in order to achieve the same mapping speed as in manual mapping. The equipment has endured the mapping environment satisfactorily, although frequent cleaning of the diskette unit is necessary. This can be handled by the mapping staff. It is reasonable to assume that the equipment must be adapted to more strenous environmental conditions when mapping is to be undertaken in field offices.

As in the case of the manual procedure, computer mapping is handled by two persons, one of them measuring and making observations, while the other person handles the registration. Earlier, a form had to be filled in, but today the observation is registered directly in the computer.

Upon completed mapping, all information on the drill hole is transferred to the central computer for storing in the data base. Data are then available for search in the data base and for more sophisticated processing, e.g. for statistical summaries of fracture frequencies, of fracture frequencies in different rocktypes etc. Within a near future, plottings will also be available in the form of large-scale drill hole information summaries.

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