Nationale Genossenschaft für die Lagerung radioaktiver Abfälle
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NAGRA

TECHNISCHER BERICHT 81-11

Stripa Project

Equipment for hydraulic testing

Lars Jacobsson
Henrik Norlander

Ställbergs Grufve AB, Stripa, Sweden

July 1981

Geschäftsstelle Parkstrasse 23 CH–5401 Baden Telephon 056/22 01 82

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Das Stripa-Projekt ist ein Projekt der Nuklearagentur der OECD. Unter internationaler Beteiligung werden von 1980-84 Forschungsarbeiten in einem unterirdischen Felslabor in Schweden durchgeführt. Diese sollen die Kenntnisse auf folgenden Gebieten erweitern:

- hydrogeologische und geochemische Messungen in Bohrlöchern
- Ausbreitung des Grundwassers und Transport von Radionukliden durch Klüfte im Gestein
- Chemische Zusammensetzung des Grundwassers in grosser Tiefe
- Verhalten von Materialien, welche zur Abdichtung von Endlagern eingesetzt werden sollen

Seitens der Schweiz beteiligt sich die Nagra an diesen Untersuchungen.

The Stripa Project is organized as an autonomous project of the Nuclear Energy Agency of the OECD. In the period from 1980-84 an international cooperative programme of investigations is being carried out in an underground rock laboratory in Sweden. The aim of the work is to improve our knowledge in the following areas:

- hydrogeological and geochemical measurement methods in boreholes
- flow of groundwater and transport of radionuclides in fissured rock
- geochemistry of groundwater at great depths
- behaviour of backfill material in a real geological environment

Switzerland is represented in the Stripa Project by Nagra.

Le projet Stripa est un projet autonome de l'Agence pour l'Energie Nucléaire de l'OCDE. Il s'agit d'un programme de recherche avec participation internationale qui sera effectué entre 1980 et 1984 dans un laboratoire souterrain en Suède. Le but de ces travaux est d'améliorer et d'étendre les connaissances dans les domaines suivants:

- mesures hydrogéologiques et géochimiques dans les trous de forage
- écoulement des eaux souterraines et transport des radionucléides dans les roches fracturées
- chimie des eaux souterraines à grande profondeur
- comportement dans un environnement réel des matériaux de bourrage pour dépôts de déchets radioactifs

La Suisse est représentée dans le projet Stripa par la Cédra.

STRIPA PROJECT 81-04

Equipment for hydraulic testing

Lars Jacobsson
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July 1981

INTERNAL REPORT

An OECD/NEA International project managed by:
SWEDISH NUCLEAR FUEL SUPPLY CO/DIVISION KBS

STRIPA PROJECT

SKBF KBS

Mailing address: **SKBF/KBS**
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EQUIPMENT FOR HYDRAULIC TESTING

Lars Jacobsson
Henrik Norlander

Ställbergs Grufve AB, Stripa, Sweden

July 1981

This report concerns a study which was conducted for the Stripa Project. The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the client.

A list of other reports published in this series is attached at the end of this report. Information on previous reports is available through SKBF/KBS.

CONTENTS

ABSTRACT

Hydraulic testing in boreholes is one major task of the hydrogeological program in the Stripa Project. A new testing equipment for this purpose was constructed. It consists of a downhole part and a surface part. The downhole part consists of two packers enclosing two testsections when inflated; one between the packers and one between the bottom packer and the bottom of the borehole. A probe for downhole electronics is also included in the downhole equipment together with electrical cable and nylon tubing. In order to perform shut-in and pulse tests with high accuracy a surface controlled downhole valve was constructed.

The surface equipment consists of the data acquisition system, transducer amplifier and surface gauges. In the report detailed descriptions of each component in the whole testing equipment are given.

1. INTRODUCTION

1.1 General background

The hydrogeological program included in the Stripa Project includes the designing and testing of methods and instruments for the geological, hydraulical, hydrogeochemical and geophysical fields.

In the first phase in investigations for future repository sites, deep vertical boreholes from the surface will be an important tool. Later on, during the construction of the repository, the rock has to be tested from the excavated shafts and drifts in order to obtain the best directions to extend the repository. In this phase, investigations in horizontal boreholes will be a key instrument.

To fulfill these purposes of the program it is a need to develop a new testing equipment for the hydraulical tests. This report will give a brief description of the equipment developed and used in the hydrogeological program of the Stripa Project. The program for the investigations are given in more detail in the first Technical Report of Stripa Project (1).

1.2 Technical background

Techniques of borehole hydraulic investigations need further development and testing for better knowledge about groundwater in rock. Also the validity of the results has to be demonstrated. Therefore a complete testprogram was decided upon at the TSG-meeting in May - 1980. The hydraulic testprogram includes:

- o Determination of hydraulic conductivity within different sections of the boreholes.
- o Measurements of hydraulic pressure within different sections of the boreholes and if possible record the natural fluctuations of this pressure.
- o Construction of a new downhole probe to be used for measurements of the hydraulic properties, temperature of the water and also when collecting watersamples.

The program for the investigations is given in more detail in the first Technical Report of Stripa Project (1).

1.3 Test site

The test site for the hydrogeological investigations included in the Stripa Project, is situated in the eastern fringe area at the 360 m level in the mine, as

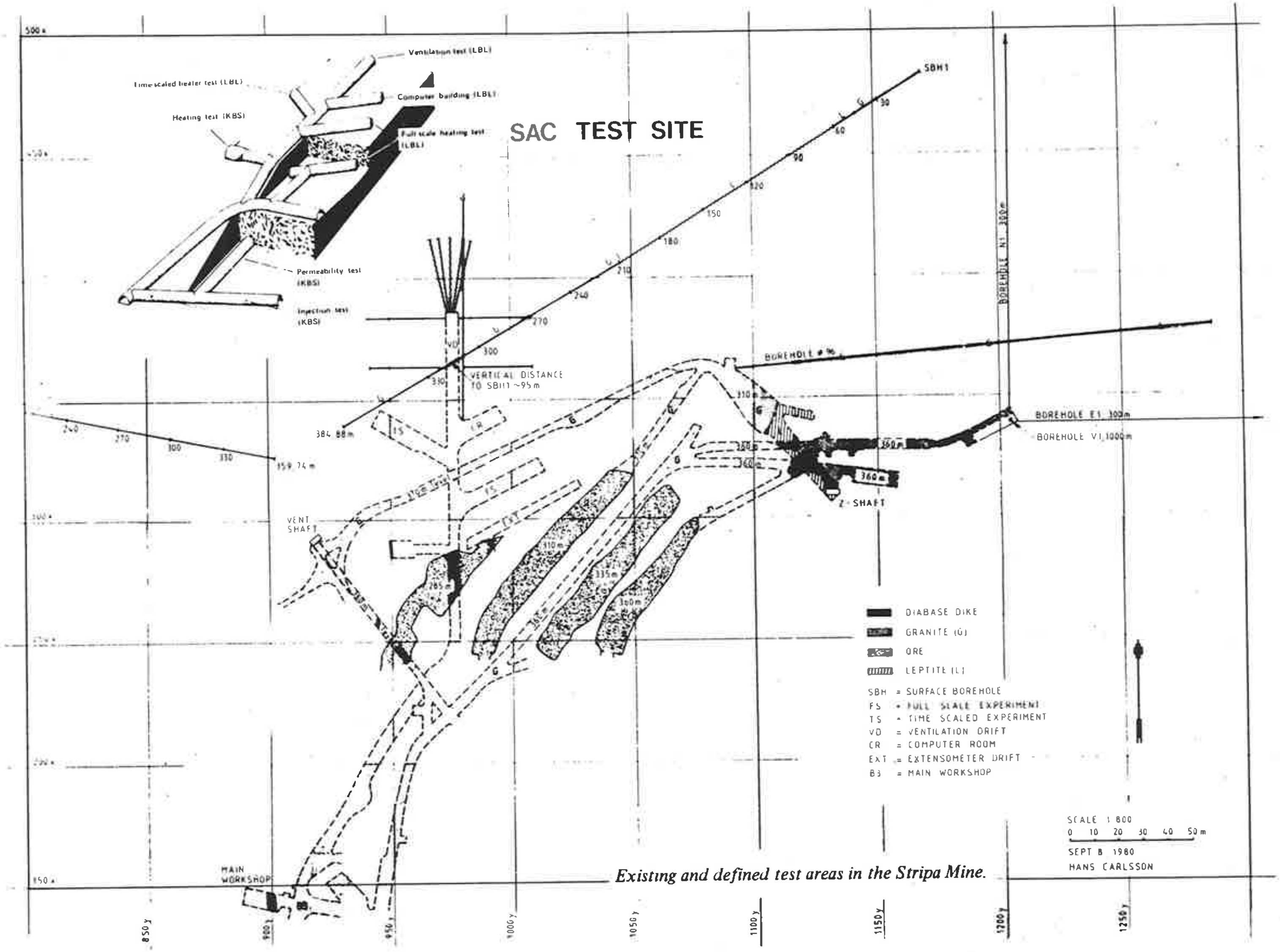

Figure 1 Map of the drifts at the 360 m level in the Stripa mine, with the extension of the ore body at different depths. The test sites used for former hydrogeological investigations are also shown. SAC = Swedish-American Cooperative program.

shown in Fig. 1. This location of the site is chosen in order to maintain a large distance to other sites and thus minimizing the hydraulic disturbances.

In order to prepare the site for the planned drilling program, one vertical ϕ 76 mm and two near horizontal ϕ 76 mm bore-holes, the excisting drift had to be enlarged. The axis of the new site heads in a east-north-east direction and has a length of about 15 m and a crossectional area of 20 m^2.

In the drift a housing for the equipment is built. Fig. 2 gives an internal view of the drift during the drilling stage. The location of the different boreholes are marked in the figure.

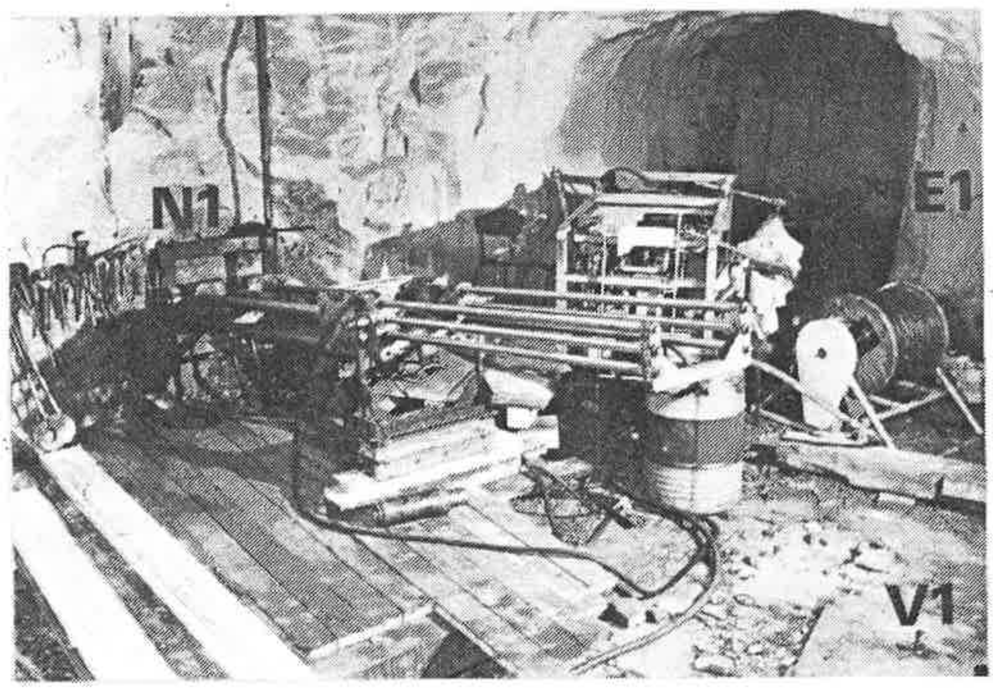

Figure 2 — *The site for the hydrogeological investigations during drilling of bore-hole N1. This borehole is inclined 8.5° from the horizontal. Holes V1 (vertical) and the starting point for E1 (5.5° from the horizontal) are indicated in the figure.*

2. DESCRIPTION OF THE EQUIPMENT

The equipment in total consists of a downhole probe containing two pressure transducers and one temperature detector. The probe is downwards connected to a two-packer system and upwards to a surface controlled valve used for shut-in and pulse tests. In Fig.3 a schematical view of the equipment during testing is given.

The packers are operated from the surface with gas through a nylon tubing. When inflated the packers enclose two testsections; one between the packers and one between the bottom packer and the bottom of the hole. These two sections are connected via 1/8" steel tubings to the pressure transducers in the probe.

The section between the packers is also connected to a temperature measuring system so that the water temperature can be determined.

From each stripped section watersamples can be collected through 1/4" nylon tubings going to the surface.

The downhole electronics are connected through a 12- conductor cable to the surface equipment. The signals coming to the surface are first treated in a signal amplifier and are from there send to a datalogger. From the datalogger, which act as the test control unit, the data will be send over to a ABC-80 deskcomputer for preliminary processing and recording. To get a transcription of the different steps and the processed data during the tests a printer is continuously used during the test. For control of the downhole equipment a flatbed multiple pen chartrecorder is used together with a Houston digital plotter.

3. DOWNHOLE EQUIPMENT

3.1 Probe for downhole electronics.

The probe for pressure transducers and temperature detector-transmitter consists mainly of four parts as illustrated in Fig. 4.

1. On top of the probe there is a fastening device for the ϕ 20 mm steelrods leading to the surface and which control the position of the probe in the borehole.

2. Below this connection is the next part, acting as a lead-in for the cable to the electronics in the housing by using a 12-pin bulkhead connector.

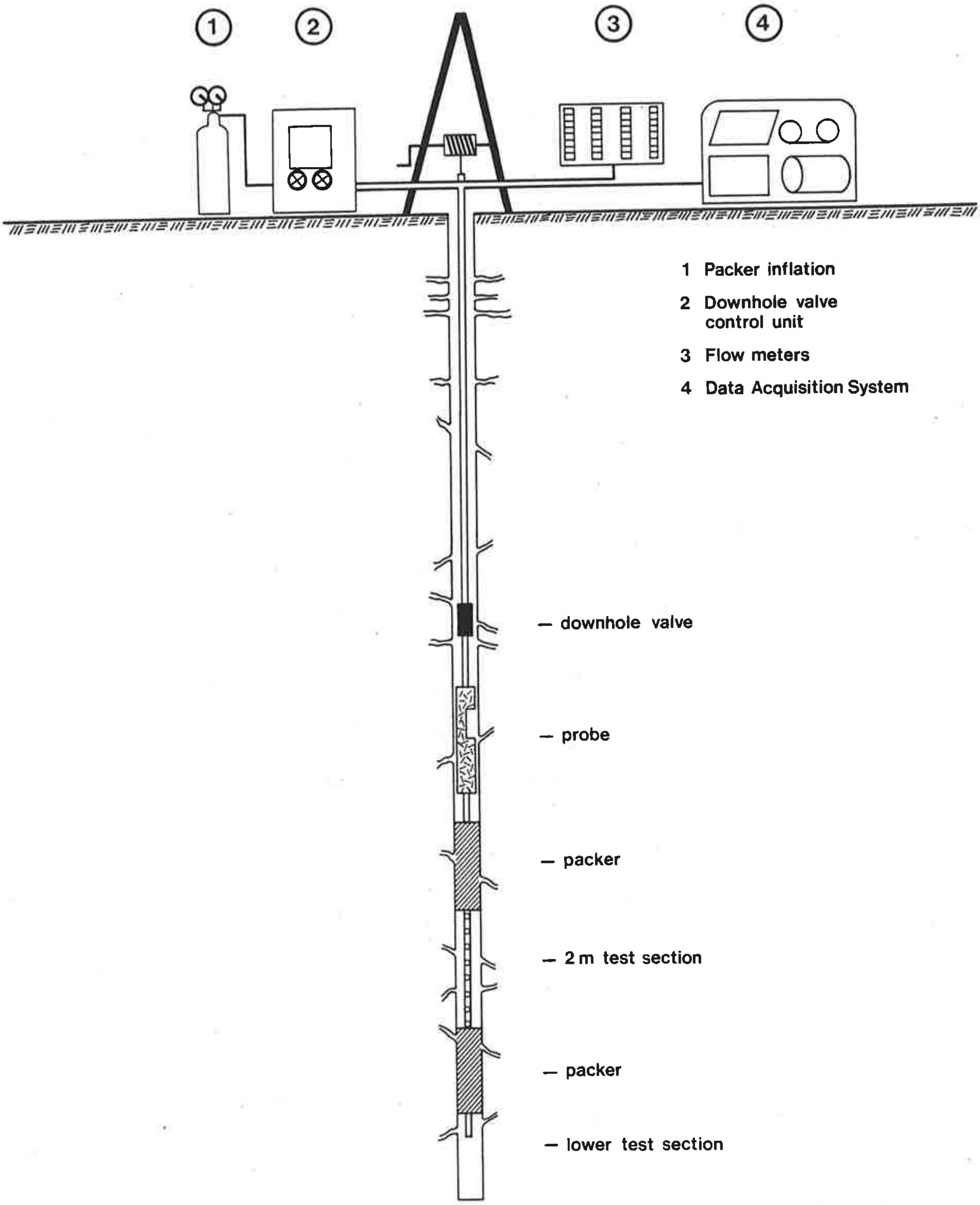

Figure 3 Schematic view of the equipment during testing.

3. Inside the watertight housing, equipment are mounted for pressure and temperature measurements. The housing is designed as a ϕ 69 OD tube with a 6 mm wall.

4. Part four functions as a seat for transducers and temp. detector and as a lead-in for two 1/8" stainless steel tubings, one from each stripped interval, to the pressure transducers. The probe is from here connected to the packers via a ϕ 20 mm steelpipe which also acts as a lead-in for water from the interval between packers, to the temperature detector.

The probe housing is threaded in both ends and screwed on to the both lead-in pieces with a right and a left hand thread. The tight seal is obtained by using O-rings in rotary cut seats.

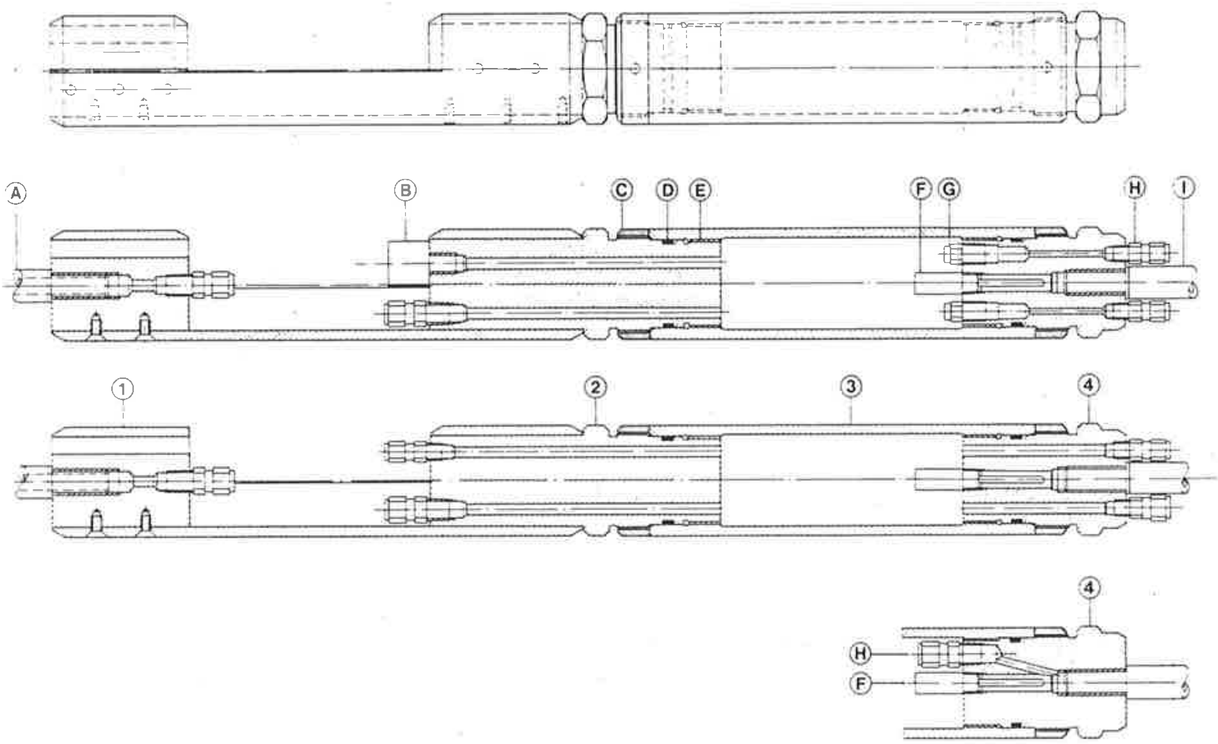

Figure 4 *Down-hole probe for pressure and temperature measurements. 1. Top-piece - fastening device, 2. Feed-through for electrical cable and water. 3. Watertight housing for electronics. 4. Feed-through for water.*

A. 20-mm steelrods. B. 12-pin bulkhead connector. C. Locking nut. D. O-ring seat. E. left and right hand thread. F. Temperature detector. G. Pressure transducers. H. Swagelok couplings. I. 20-mm steelrod.

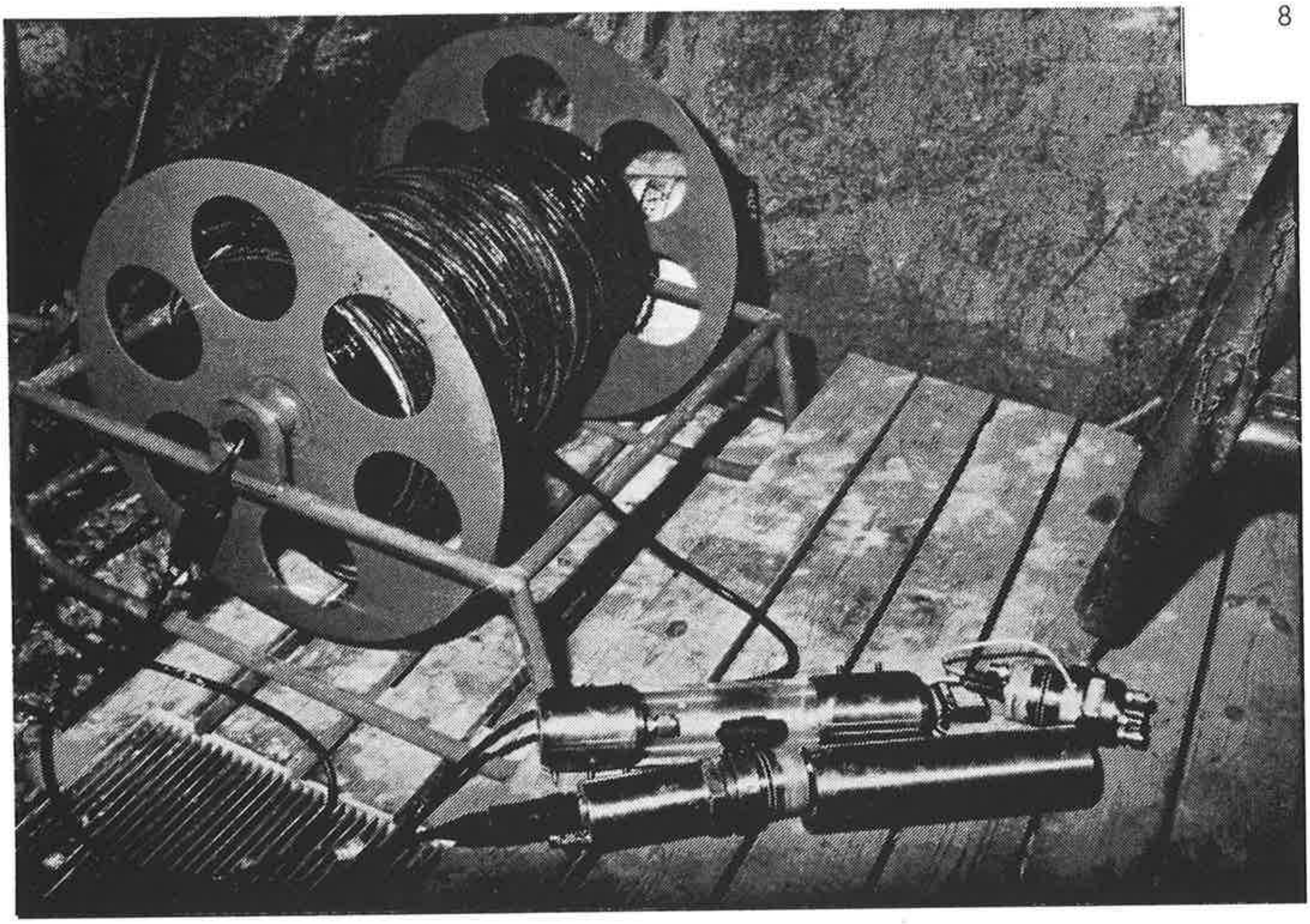

Figure 5 *Down-hole probe with 12-conductor cable.*

Through all the probe runs two 1/4" SS and one 1/8" SS tubing. They are used for watertransport and gas for packerinflation. The tubings are sealed between the different part in the probe with Swagelok and Lenz couplings. All parts of the probe are made out of 2343 stainless steel (Sw. standard) except the couplings who are made out of 316 stainless steel (Am. standard). The probe has a maximum diam of 63 mm, a length of 0.66 m and an approx. weight of 15 kg. The probe connected to the electrical conducter is shown in Fig. 5.

3.1.1 Pressure transducers

Kistler 50 and 100 bar FSO (full scale output) piezoresistive transducers measuring absolute pressure are used. They are mounted into the bottom part of the probe with straight M 12 threads and copperbushings for a tight seal. A total accuracy including linearity, hysteresis and repeatability less than 0.5 % FSO is presented in the data-sheets. With a very accurate calibration it is possible to obtain an accuracy of 0.1 % FSO or better.

The pressure acts through a thin steel diaphram, welded to form a tight seal with the transducer housing, on to a silicon measuring cell. The measuring cell contains diffused piezoresistive resistors connected to a Wheatstone bridge. Through the effect of pressure the bridge is unbalanced and an output signal is the result. Electrical connection is made with a 4-pole plug which has an O-ring for sealing.

3.1.2 Temperature detecting system

The detector is placed in the center of the bottom part of the probe as shown in Fig. 4. It is a standard serie 21 platinum resistance detector with a 100 ohm resistance and with a tolerance of better than 1 %. The sheath is of 316 stainless steel and the diameter is 1/4".

Due to the long distance between the detector and the datalogger at the surface and that only two wires are available for the system, a signal transmitter has to be used. It is a Templan two-wire transmitter which is placed inside the watertight housing. The transmitter has a linearity better than 0.08 % of span which is 4 - 20 mA. Factory calibration is better than 1 % and operating temperature is 0 - 50 ^{o}C. It is supplied from the surface with a variable voltage-current regulator.

3.2 Electrical cable and nylon tubing

The cable used for signal and power from and to the probe is a 12-conductor colour coded cable with a polyurethan sheath, and male-female couplings at the ends. The couplings are rubbercasted to the cable and designed to withstand pressures up to 200 bar. The crossectional area of each conductor is 0.35 mm^2.

Nylon tubings of high-pressure typ are used for both sampling water from the stripped intervals and for the inflation of the packers. The two sampling tubings running from the probe to the surface has a diameter of 1/4" and a ability to withstand a differential pressure of 70 bar. The 3/16" inflation tubing has a bursting pressure of 172 bar.

3.3 Packers

In order to enclose two test sections of the borehole a twopacker system have to be used. The packers chosen for the Stripa Project hydraulical testing are Lynes surface controlled injection packer (SCI PIP) with an element diameter of 2.75" and an element length of 48". Maximum working differential pressure is 5 500 PSI (379 kg/cm^2).

This packertype was selected because it does not have any movable parts that will elongate the test section during the inflation-phase, and also that this type has been found reliable. The system is inflated with nitrogen gas from a gasbottle at the surface. To protect the packers from damage due to overpressure the bottle is equiped with a security valve. The packers are connected to each other through a 1" perforated steelpipe.

3.4 Downhole valve

To perform shut-in and pulse tests with high accuracy it was essential to construct a downhole valve, that would cut off the watercolumn in the watersample tubing from the test section.

The valve shown in Fig. 6 is operated with a waterfilled 1/4" nylon tubing connected to a pressuretank at the surface. Through the effect of pressure a springloaded piston opens or closes a passage between the testsection and the nylon tubing.

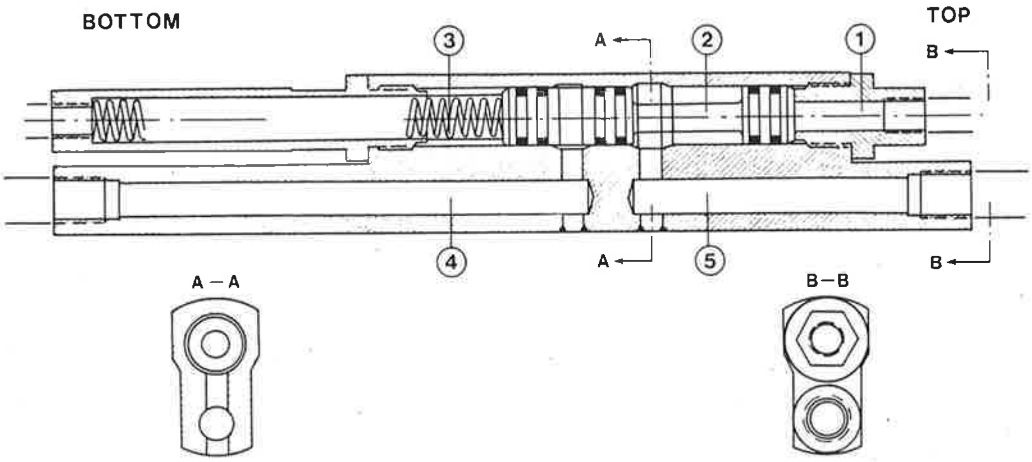

Figure 6 *Water operated down-hole valve. 1. Connection to surface control unit. 2. Spring loaded piston. 3. Spring. 4 and 5. Connections to test section and surface respectively.*

4. SURFACE EQUIPMENT

4.1 Data acquisition system

The DAS was designed and constructed to provide a small, easily handled system with good usefulness in the field. Raw data log prints, processed data log prints and processed data log tapes minimize data loss. Nevertheless will a short power failure in the mine electrical system cause a loss of the computer program but it does not affect on raw data logging. Fig. 7 shows a block diagram of the DAS and figure 8 the set up of the equipment in the mine house.

4.1.1 Datalogger

A Fluke 2 240 B datalogger provides the basis of the DAS. Fluke was selected primarily because of its flexibility and reliability. Fluke dataloggers have been in use for several years in the mine. The datalogger is a processor and recorder which is expandable. It measures voltages from 40 mV full scale to 40 V full scale (4 ranges) with an accuracy of μV. It is equiped with a low level scanner, high performance A-D converter and a remote programming interface. Once a test is started, data from transducers and temperature probe are automatically sampled at optional intervals from 1 sec. upto 24 hours. Analog data is digitized in the A-D converter. Acquired data are logged on a raw data print out. Present channel capacity is 20 but could easily be extended up to 60. Simple front panel push button selections cause the micropro-

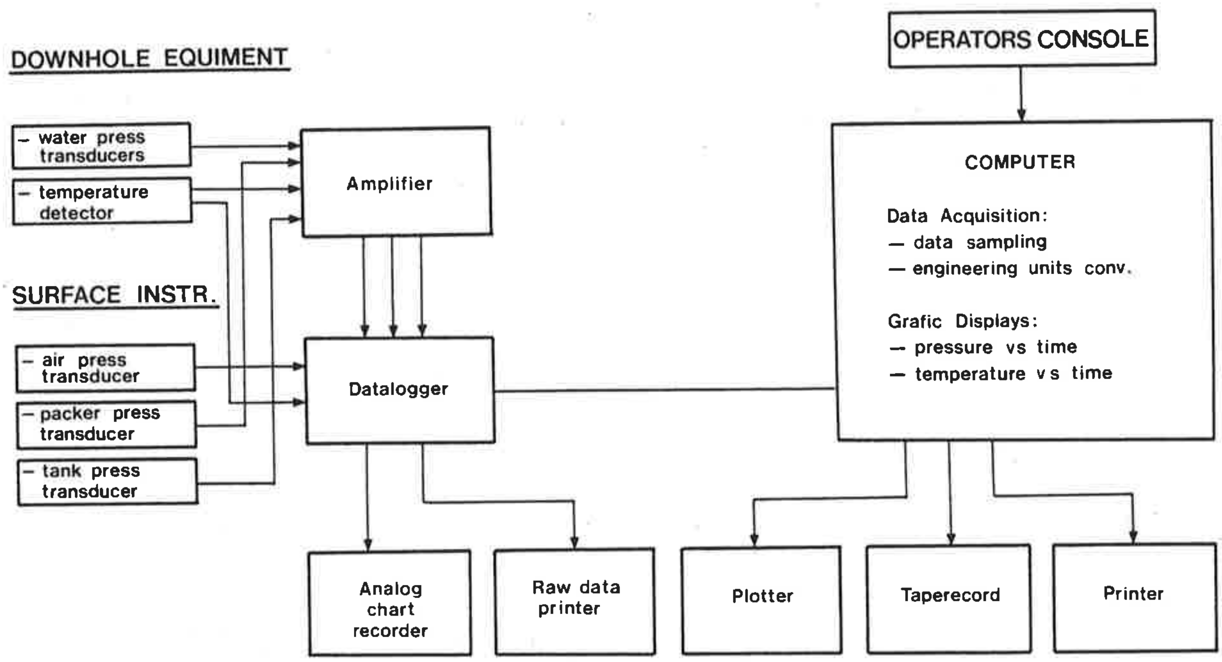

Figure 7 Block diagram of the data acquisition system.

cessor to store and execute the measurement routins.

4.1.2 Deskcomputer

The computer, Luxor ABC 80, is a Swedish made system in three units; monitor, keyboard and tapedrive. It operates in BASIC language which is permanently stored in the ABC 80. The central processor is a 8 bit Z80 A and the capacity of the standard read/write memory is 16K bytes, here extended to 24K bytes. Acquired data are time-tagged and converted to engineering units, using calibration data.

4.1.3 Peripheral devices

For monitoring packer pressure and pressure in the packed off zone an analog chart recorder is connected parallel to the datalogger. This recorder, a Yokogawa 3 channel Flatbed Pen Recorder is using a servo pen drive system and each channel has 13 calibrated voltage ranges from 5 mV/cm to 5V/cm. Maximum sensitivity is 5 μV/cm. To the computer three devices are connected:

1. To get a transcription of the different steps and processed data during a test a Centronic 779-2 is used. The Centronic is a matrix printer and especially adapted to the ABC 80. The device prints upto 100 (5 x 7 dot) characters per sec.

2. Processed data is also recorded on tape with a CDS tape recorder. The CDS system records or reads digital data with high speed using a Phillips cassette as data store. The CDS is interchangeable with the main computer system at SGU, where the tapes are send to. The CDS writes data in 256 byte/block and the buffer has a capacity of two times one data block.

3. A Houston Instrument Plotter is also connected with the computer. This digital plotter is generating graphics from the computer.

4.2 Transducer amplifier

Kistler piezoresistive amplifier build on Euro-Card is used. The various amplifier elements are designed as modules, simplifying assembly and servicing alike. The current source excites the transducer with a constant current, independent of the cable length. A differntial voltage amplifier amplifies the transducer signal by 8 (1 to 400-times is possible) to give the transducer a signal FSO of 4 V and gives an asymmetrick output voltage of 10 V. With the electrical zero displacement, the electrical zero may be shifted up to ± 1 FS. Special feature is the standardizing plug which adapts the amplifier to a given transducer by setting the current

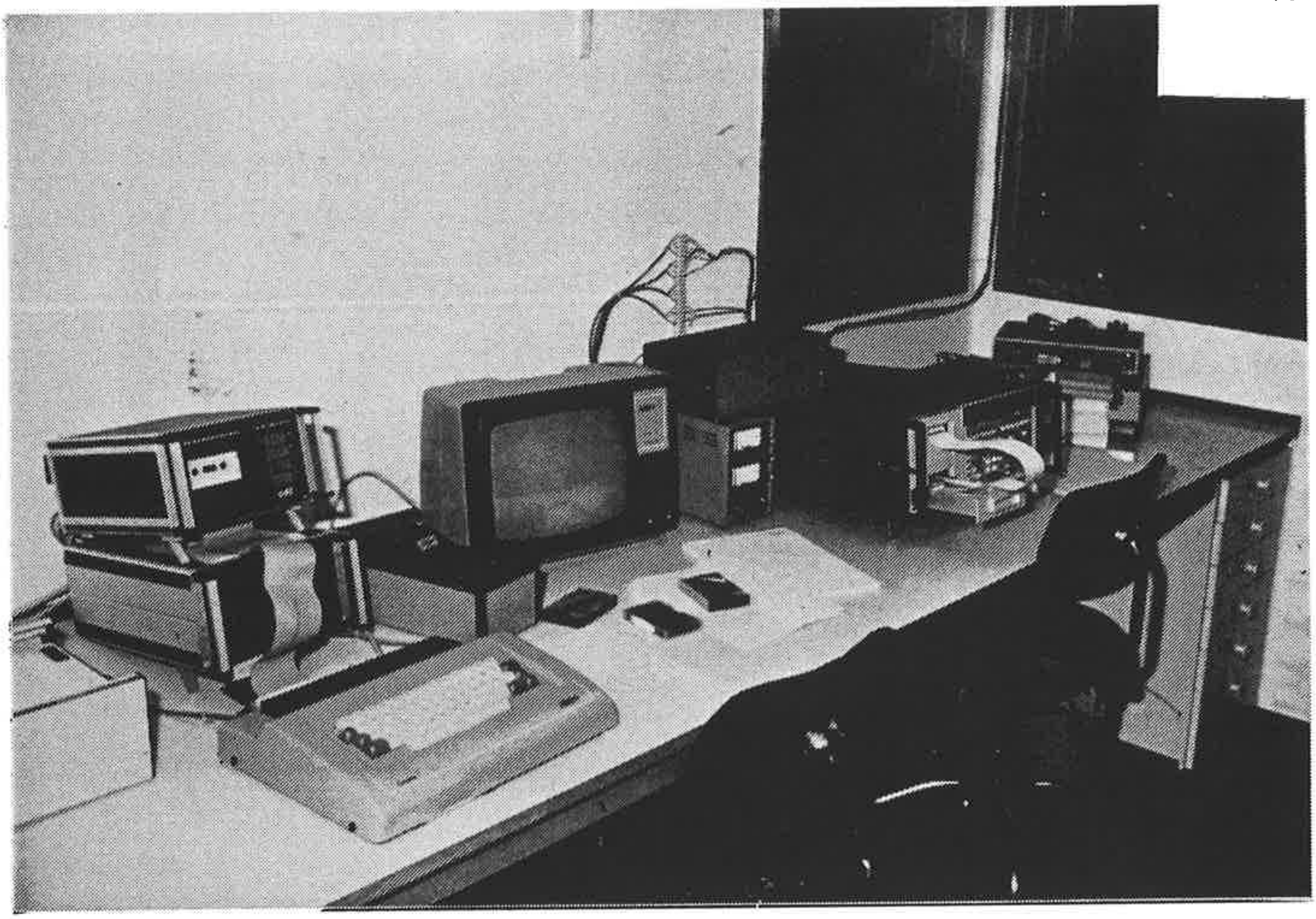

Figure 8 The main parts of DAS.

source to the calibration current of the transducer and by correcting the transducer zero.

4.3 Surface gauges

The downhole transducers are measuring absolute pressure, i. e. the pressure referred to vacuum and not to the prevailing atmospheric pressure. The barometer pressure are therefore measured as well with a Kistler transducer and this must be taken into account, especially in the ranges up to 10 Bar. With a sensitivity of 10 mV/mBar, changes in hydrostatic pressure in the borehole can be separated from changes in air pressure. For calibrating the transducers a Heiss Pressure Indicator is used. This digital gauge has a microprocessor which converts analog output of the pressure sensors to a digital format. The range is between 0 - 100 Bar, and the FS error is 0.04 %.

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