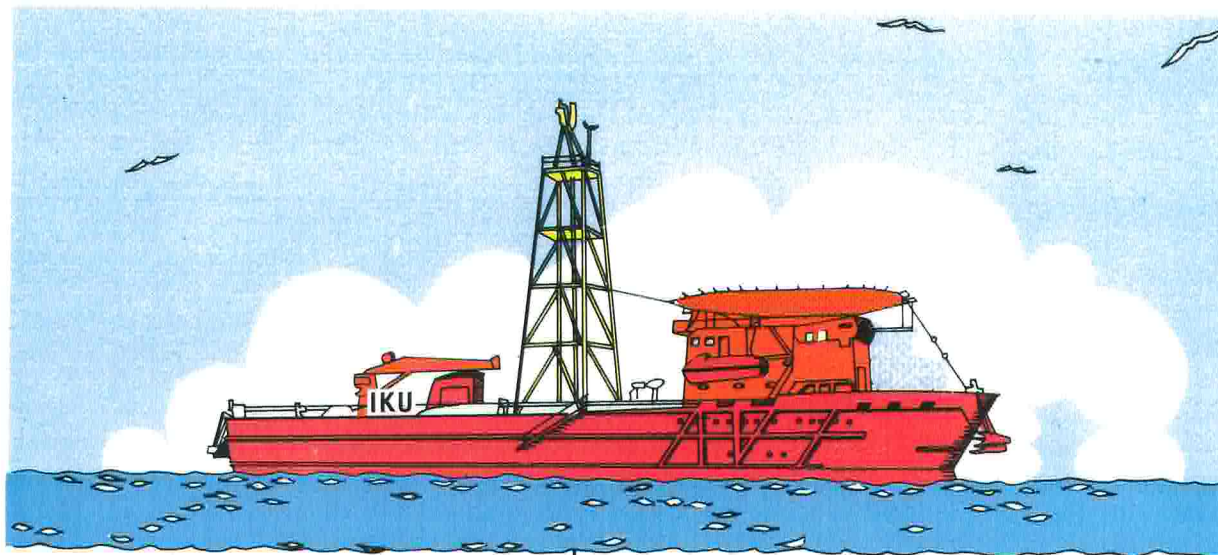
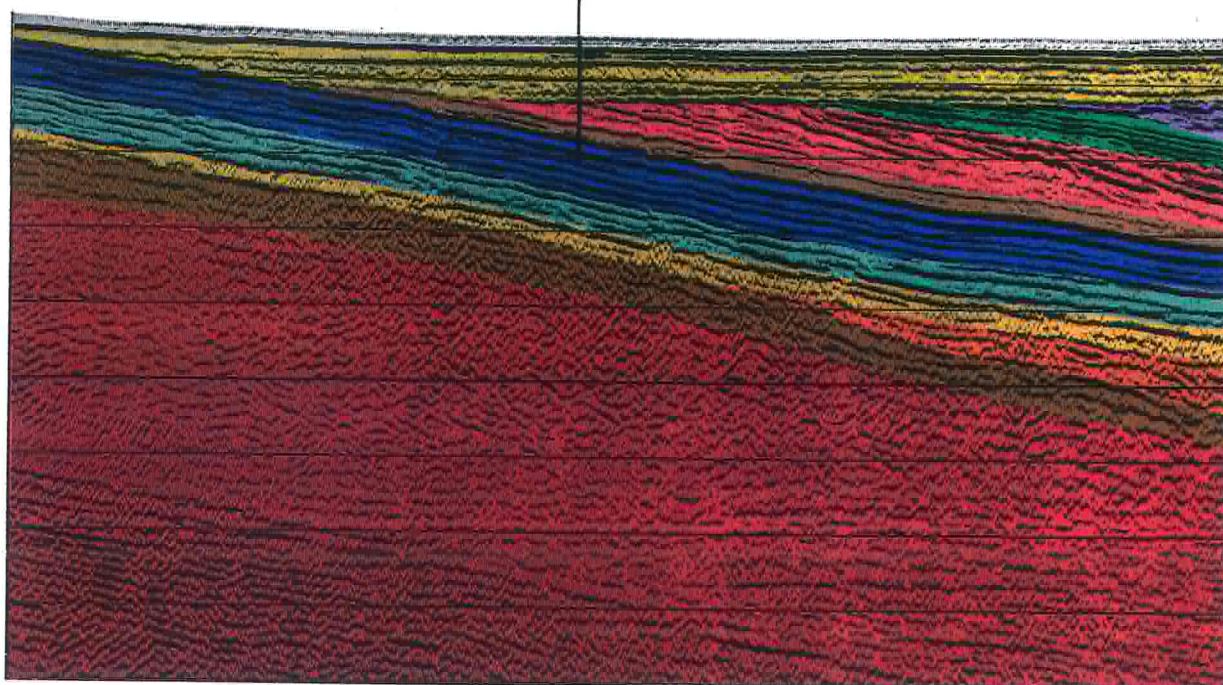




Shallow Drilling Barents Sea 1988

Appendix volume 1

Field work
Analyses etc.
Core logs (1:100)





Institutt for kontinentalsokkelundersøkelser og petroleumsteknologi A/S
Continental Shelf and Petroleum Technology Research Institute A/S

Håkon Magnussønsøgt. 1B • P.O.Box 1883, Jarlesletta • N-7002 Trondheim, Norway
Tel.: + 47 7 920611 • Telex: 55 434 iku n • Telefax: + 47 7 92 09 24 (aut)

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APPENDIX VOLUME 1

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AUTHORS:

Tom Bugge, Stig Bakke, Stein Christensen,
Geir Elvebakk, Nilmar Janbu

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SUMMARY:

This is Appendix volume 1 to the main report "Shallow drilling Barents Sea 1988" and has the following content:

- A.1 Field work - seismic survey and drilling operation
- A.2 Navigation
- A.3 Analytical methods
- A.4 Oedometer tests
- A.5 Discussion of petrophysical core measurements and wireline logs
- A.6 Core logs in scale 1:100.

KEY WORDS:	
Shallow drilling	Mesozoic
Barents Sea	Logging
Paleozoic	Oedmeter test

CONTENTS

- A.1 FIELD WORK
- A.2 NAVIGATION
- A.3 ANALYTICAL METHODS
- A.4 OEDOMETER TESTS
- A.5 DISCUSSION OF PETROPHYSICAL CORE MEASUREMENTS AND WIRELINE LOGS
- A.6 CORE LOGS IN SCALE 1:100

Appendix A.7 Summary sheets of each core, A.8 Organic geochemical summary of all cores and A.9 Correlation diagram of the Paleozoic in the Finnmark East area are enclosed in the main volume. All organic geochemical analysis data are found in Appendix volume 2.

APPENDIX A.1
FIELD WORK - SEISMIC SURVEY AND DRILLING OPERATION

A.1 FIELD WORK - SEISMIC SURVEY AND DRILLING OPERATION

A.1.1 Seismic survey

The collection and processing of seismic data was subcontracted to A/S Geoteam in Oslo.

The vessel M/S "Southern Surveyor" was used for the field work, and mobilization started 30 April in Hammerfest. After testing and acceptance test the survey started 2 May and lasted until 18 May with demobilization in Honningsvåg.

The survey area was split into two, with one part along the coast of Finnmark and one part from the Nordkapp Basin and north to 74°30' N (Figure A.1.1). On the transit between the two areas a continuous line tying the lines IKU-01-88 and IKU-3015-88 together was shot as part of another IKU project. About 18 hours were also spent on a re-survey at a drill site where some equipment was lost last year. The cost of these two jobs was paid for separately.

The navigation chains in the Barents Sea were operated by Bentech Navigation A/S in Tromsø, but the Geoteam personnel took care of the navigation on board. More details about navigation are given below in Appendix A.2.

As in previous years multichannel digital data and analog single channel data were collected, in addition to side-scan sonar and deep towed boomer data, but for the first time all this was recorded simultaneously. This means that both analog and digital data were in collected in one pass. Exceptions were a few lines that had been run in 1987 and some lines when bad weather did not allow use of the digital equipment. More details are given in Geoteams field report (see Appendix A.2).

Running all this equipment together was meant as a test, but the result was so good that this has become more or less a standard for later surveys. The analog airgun was fired 3 - 4 times between each "digital" shot. As expected the noise caused by the larger airgun influenced on the general noise level, but only to a degree that should be accepted for this use of analog data.

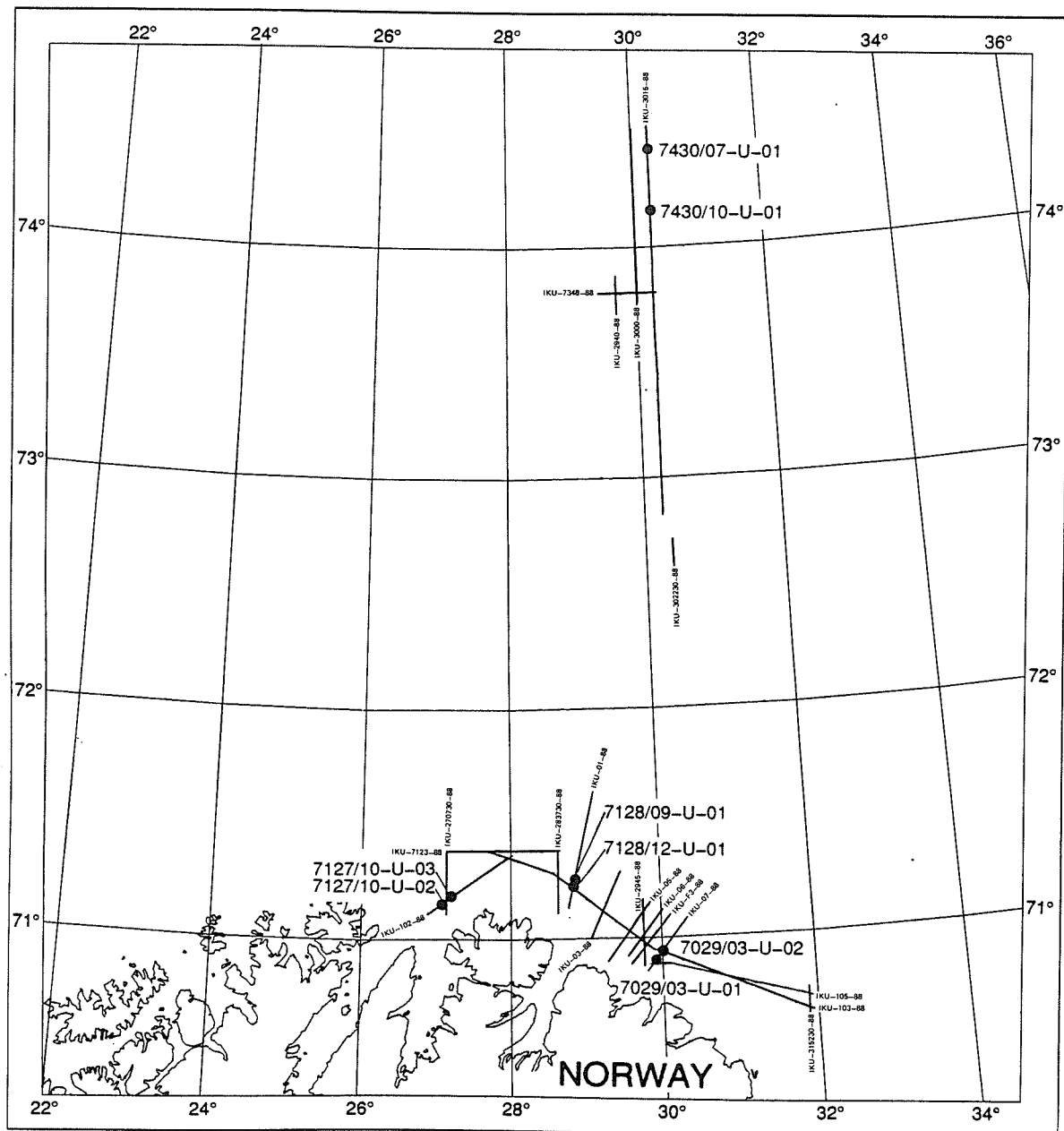


Figure A.1.1 Seismic lines shot in 1988. The lines along the coast partly overlap and partly fill in the lines shot in 1987. Consequently most of the lines have both digital multichannel data and analog single channel data. The eight 1988 drill sites are also shown.

The weather conditions were partly far worse than the average for this time of the year and as seen in Figure A.1.2 the weather downtime was 4.7 days or 33.5%. The program had therefore to be reduced, and this was done mainly in the eastern area.

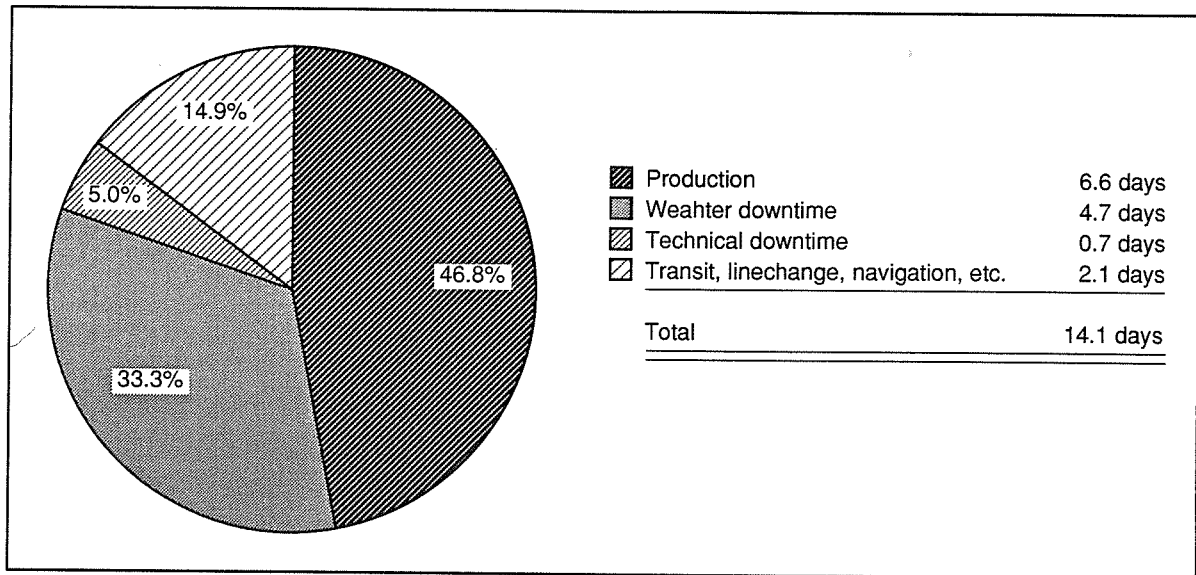


Figure A.1.2 Duration of field work activities for the seismic survey (totally 14.1 days).

In total the following amount of data was collected:

- Digital seismic	857.9 km
- Analog seismic	1009.1 km
- Side-scan sonar	915.5 km
- Deep towed boomer	671.6 km
- Echo sounder	1016.4 km

Main technical specifications

Analog data

Mini air-gun:

- Single air-gun, Bolt 600 B, 10 cu inch
- Shot interval 1 sec
- Recording time 1 sec
- Streamer length 15 m
- Filtering 70-700 Hz

Deep towed sparker:

- Hunttec, multielectrode
- 375 joule output energy
- Shot interval 0.5 sec
- Recording time 0.25 sec
- Filtering internal hydrophone 1200-8000 Hz
- Filtering external hydrophone 400-2000 Hz

Side-scan sonar:

- EG&G 990 SMS
- Shot interval 0.75 sec
- Frequency 59 kHz
- Scale corrected, range 500 m

Digital data

- Bolt air-gun Model 1500 C
- Single air-gun 350 cu inch, Geoteam design
- 12.5 m shot point interval
- Teledyne T2, 1500 m streamer
- 120 channels
- Towing depth streamer 2-4 m
- Towing depth air-gun 3 m
- 12.5 m group interval
- 11.25 m group length
- 2.5 sec recording time
- 2 msec sampling rate
- Filter 8-180 Hz

A.1.2 Drilling

General

Main contractor for the drilling operation was A/S K/S Farmand Survey II in Oslo, using the Norwegian built drill ship M/S "Bucentaur" (Figure A.1.3). The bedrock coring was based on the piggyback coring concept as described below. Farmand Survey had subcontracted Dia-Team in Trondheim for diamond coring staff and Fugro-McClelland BV in Holland to operate the seabed template with the pipe clam. IKU had subcontracted A/S Geoteam in Oslo for the positioning (see Appendix A.2 below) and British Plaster Board (BPB) Ltd in U.K. to carry out downhole logging.



Figure A.1.3 The drilling vessel M/S "Bucentaur".

Technical data

M/S Bucentaur

Length over all	78.07 m
Breadth moulded	16.00 m
Draft fully loaded	5.55 m
Displacement	4.470 tons
Gross register tonnage, international	2.768 tons

Main engine: Four Wärtsilä diesels, type Vasa 8R22HE, each driving a van Kaick generator of 1200 kW at 1200 RPM, 600V/60 periods AC.

Propulsion units: Two azimuthing thrusters with CP propeller in nozzle, make Liaaen.

Bow thrusters: Two tunnel thrusters with CP propeller, make KaMeWa.

Dynamic positioning system: One GEC simplex system with GEC-Elliott 2050 computer, video display and joystick. Positioning reference by deep water tautwire system and by Simrad HPR T209 hydro-acoustic system.

Derrick: 26 m high from deck to water table, base 7.40 x 11.55 m, water table 4.50 x 4.50 m, max. 40 tons dynamic hookload, 80 tons static hookload.

Drillstring Heave Motion Compensator: One Fugro/Hydraudyne type CSC 90.23, max. 40 tons dynamic load, 80 tons load in locked position, accomodates for max. heave of 7 m.

With piggyback platform frame installed the max. heave is about 4.5 m.

Drillbits: Rollerbits, stratapaxbits, dragbits etc. Bit OD 8½" - 10", bit ID 100 mm.

Drilling winch: One hydraulic winch, make SAS, max. linepull 12 tons max. linespeed 136 m/minute, 4 speed ranges. This gives a max. pull of 48 tonnes on the travelling block hook.

Mud system: Complete dry mud system, mud mixing equipment, mud storage and mud pumps (three X: WIRTH TPK 5½" x 5½", 84 HP hydraulic motor, capacity 1600 l/min at 20 bar). No mud resirculation.

Main drilling system

Rotation unit: Wirth type B3 max. torque 3000 Kpm, max. speed 194 rpm. 3 speed gear box. Max. dynamic load 40 tonn.

Elevator: Wirth, type special pipe pick-up chuck, suitable for 5½" F.H. joints.

Deck drillstring retaining device: Wirth power slips type B12, with inserts for 5" pipe.

Main drill string

Drill pipe: 2000 m of API-5" Grade E, range II, 32 kg/m in air, 28 kg/m in water with 5½" tool joints, 4" ID.

Drill collars: 5 m long, 7" OD and 4" ID with 5½" tool joints. Weight 0.1 tons/m.

Coring and sampling devices: Christensen rotary coring: (Core diameter 3" (76 mm) or push/hammersampling (Max. sample diameter 3")).

Hard-tie winch: One Ingersoll Rand, max. pull 5 tons, with auto. failsafe brake. This system forces the drill string to compensate similarly as the seabed reference frame.

Piggyback coring system (diamond core drill system)

Drilling machine: DBH 1500S electro/hydraulic drill.

Spindle opening: 127 mm.

Rotating speed: max. 900 rpm.

Drill string: Wireline HR heavy duty rods OD 88.9 mm, ID 77.8 mm, 70.8 mm at internal joint upset, length 10 ft, weight 12.5 kg/m in air, 10.9 kg/m in water. Back-up NR heavy duty wire line drill rods, OD 69.9 mm, ID 60.3 mm, 54.8 mm at internal joint upset.

Core barrels: Triple tube, 10 ft with steel split tube liner or double tube 10 ft without liner.

Core diameters: HR triple tube 54.5 mm, NR triple tube 38.1 mm.
HR double tube 57.6 mm, NR double tube 41.6 mm.

Seabed reference frame

Heavy lift winch: One winch make Pusnes, capacity on single drum 2 lengths each 1200 m wire 36 mm dia. Braking force 90 tons.

Secondary heave motion compensator: One Hydraudyne guideline-tensioner type, max. 60 tons dynamic load, accomodates for max. heave of 7.0 m.

Seabed template: Fugro SEACLAM with hydraulic pipe clamping system, inclinometers and underwater TV camera.

Brief description of the piggyback coring operation

The bedrock coring is carried out by an approx. 9 cm OD drillstring with a 3.05 m long retrievable wireline operated corebarrel. Normally a surface set or impregnated diamond bit is used, and the diameter of the core is about 5.5 cm.

The drilling method is often referred to as Piggyback drilling. This is because the diamond coring drillstring is operated by a coring machine resting on top of the powerswivel of the main drilling system (Figure A.1.4), and is run inside the 5"OD, 4"ID string. The benefits of the Piggyback method and the use of a diamond drilling machine are several:

- high core recovery
- fast production
- good core quality
- ability to core fractured and poorly consolidated sediments (even in clays of shear strength down to 100 kPa)

The piggyback concept was used for the first time by Encore (UK) in 1975 and later by the same company in 1981 (Braithwaite 1985).

Since then much experience has been gained and with the equipment presently available the concept offers an efficient method for high recovery core drilling in offshore conditions.

The piggyback drilling operation is carried out as follows (Figure A.1.4).

- (a) M/S Bucentaur moves onto position and sets the dynamic positioning system (D.P.) in operation.
- (b) Seabed re-entry template is lowered to the seabed, and constant tension is applied to the template wires via the template heave compensation system.

- (c) The 5" drill pipe with open centre bit is lowered and guided by a template cable rider through the re-entry frame at the seabed.
- (d) The Quaternary overburden is penetrated until the drillbit is drilled into rockhead. Hammer samples of main Quaternary units are recovered during drilling.
- (e) The powerswivel heave compensator is then set to give the chosen main bit weight (often slightly in excess of the maximum weight that may be required by the diamond core bit used for the coring, but still ensuring that there is tensional stress in all parts of the drillstring that is above seabed), and the 5" drill string is clamped to the seabed template.
- (f) The coring string and wireline core barrel is then lowered inside the 5" drill string.
- (g) Core drilling commences, with length of each run being determined by the length of the inner tube (3.05 m), or by the drilling conditions. Coring continues for 1-2 days. Typical production rates are 2.5 - 4.5 m/h.
- (h) The coring string and subsequently the 5" drill string are pulled and stored on the deck. The seabed template is hoisted into the moonpool, D.P. is disengaged and the vessel proceeds to the next location.

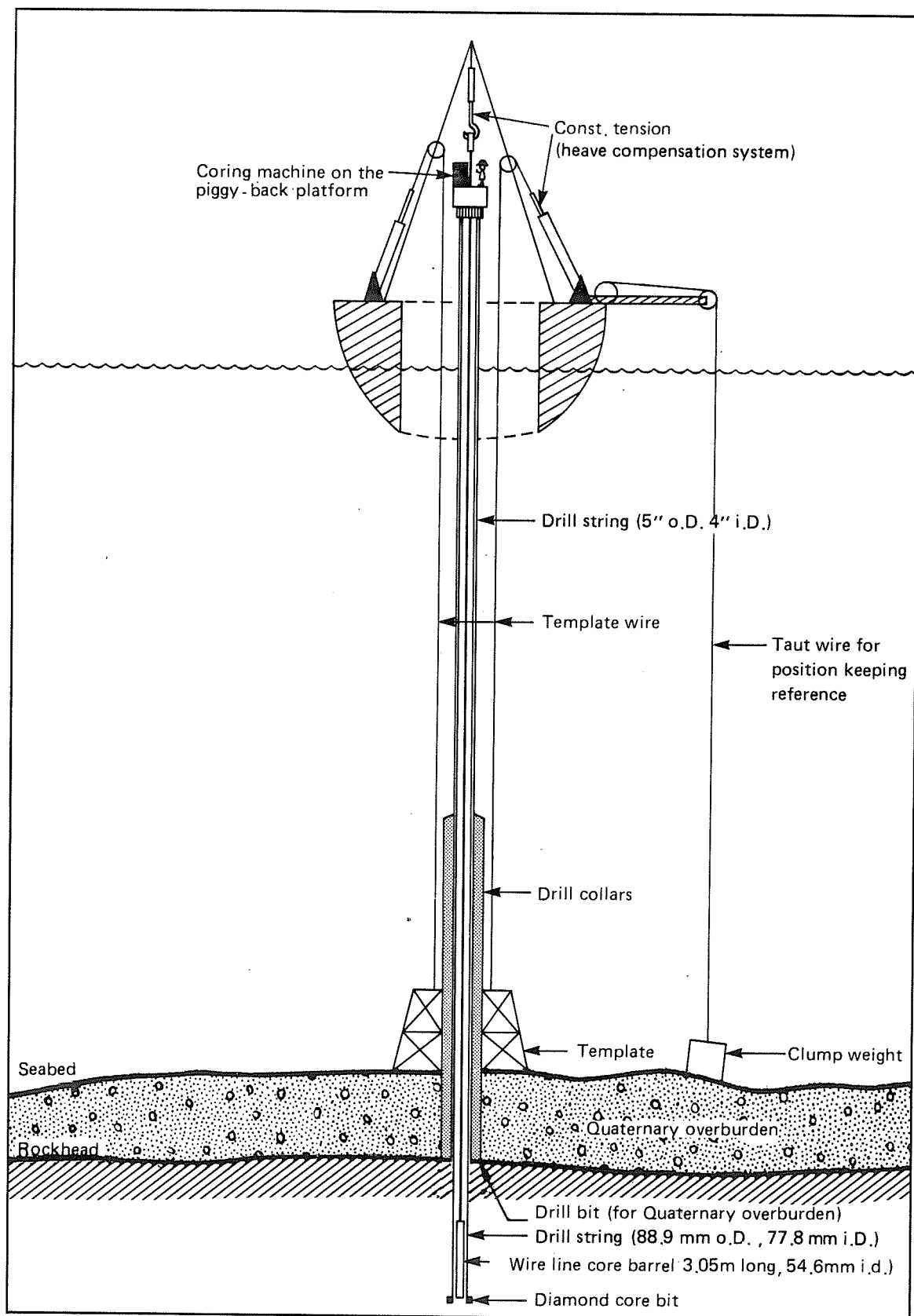


Figure A.1.4 Sketch showing the piggyback coring operation on board M/S "Bucentaur".

The coring operation

The field operations started with mobilization at the Coast Center Base outside Bergen 15 July 1988. Here all the equipment was mobilized before the vessel sailed to Honningsvåg where all the IKU personnel and personnel subcontracted by IKU came on board 20 July.

Because some extra equipment were needed for positioning of the two northernmost localities, they were drilled first. On the transit some soil samples were taken in another IKU project. After having cored 57 m into bedrock at the first site (7430/10-U-01) the pipe clam function on Fugros seabed template stopped working. The clam prevents the 5" outer pipe from rotating during coring. Despite several attempts to continue coring, it was impossible to go on, which meant that the lower half of the late Jurassic shale was not cored. The second core (7430/07-U-01) was drilled 110 m into bedrock without any problems.

After this the two western cores in the Finnmark East area were drilled very efficiently to 200 m and 153 m below seabed. Core 7128/12-U-01 in the late Permian was then drilled in a lateral position and to about the same depth as core 7129/10-U-01 from 1987. When drilling the next core (7128/09-U-01) similar problems as experienced with the pipe clam function once again occurred. Direct coupling of a hydraulic host to the clam was successful, but during the time spent for this some of the coring equipment was damaged downhole and prevented continued coring.

The next core (7029/03-U-01) was drilled 93 m into bedrock and entered basement as planned, and the last core (7029/03-U-02) was drilled to the maximum allowed depth of 200 m below seabed. With 189 m of bedrock coring this is the longest core ever drilled in a shallow coring project.

The operation was completed 28 August with demobilization in Hammerfest. The below statistical data (Figure A.1.5) show that the total breakdown time was higher than usual because of the pipe clam problems (5.5 days 14.3%). This was, however compensated in that the shipowner sponsored some extra days of operation and by the fact that we did not have any weather downtime. The operation was also more efficient than earlier because it was possible to use helicopter for most of the crew changes.

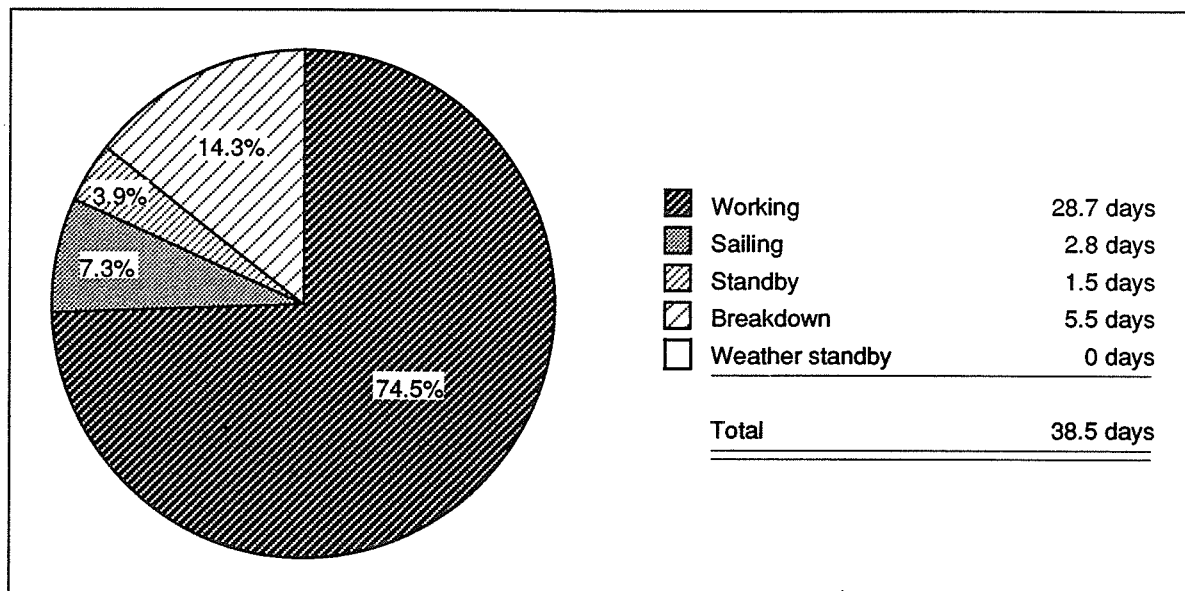


Figure A.1.5 Statistical field data of the drilling operation.

The final result was therefore nearly uninfluenced by the seaclam problems. Drilling depths, core recovery etc are shown in Table A.1.1. Here it is seen that 693 m of core were obtained with an average core recovery of 89.1%. Average coring length in bedrock was nearly 100 m per hole compared to the planned 80 m, and average total penetration below seabed was 144 m.

Table A.1.1 Key data of the core holes.

Core no	Seismic line	Shotp.	Water depth	Quat. overburden	Penetr. in bedrock	Tot. penetr. below seabed	Core length	Core recover
7430/10-U-01	IKU-3015-88 (dig)	15488.5	335 m	10.5 m	57.10 m	67.60 m	55.35 m	96.9%
	IKU-3015-88 (an)	15485.5						
7430/07-U-01	IKU-3015-88 (dig)	17550.8	343 m	7.3 m	109.88 m	117.18 m	103.50 m	94.1%
	IKU-3015-88 (an)	17547.8						
7127/10-U-02	IKU-102-88 (dig)	ca 3245.0	279 m	69.00 m	131.2 m	200.20 m	126.46 m	96.4%
	IKU-102-88 (an)	ca 3242.0						
7127/10-U-03	IKU-102-88 (dig)	2919.9	264 m	74.85 m	78.15 m	153.00 m	56.77 m	72.6%
	IKU-102-88 (an)	2916.9						
7128/12-U-01	IKU-01-88 (dig)	998.8	409 m	62.5 m	97.68 m	160.18 m	73.84 m	75.6%
	IKU-01-87 (an)	256.9						
7128/09-U-01	IKU-01-88 (dig)	1164.7	408 m	66.20 m	21.55 m	87.75 m	12.75 m	59.2%
	IKU-01-87 (an)	211.3						
7029/03-U-01	IKU-07-88 (dig)	2060.4	366 m	71.16 m	93.45 m	164.61 m	83.64 m	89.5%
	IKU-07-87 (an)	560.1						
7029/03-U-02	IKU-07-88 (dig)	ca 1692.8	308 m	11.85 m	189.10 m	200.95 m	180.91 m	95.7%
	IKU-07-87 (an)	461.0						
				373.36 m	778.11 m	1151.47 m	693.18 m	89.1%

Logging

For the first time this year downhole logging was carried out routinely. BPB provided the equipment and personnel. Except for two holes (7430/10-U-01 and 7128/09-U-01) the following logs were run in all holes: gamma, density, porosity, sonic and caliper. In addition dip meter log was run in three holes (see also Table A.5.1). The logging was carried out by BPB in a professional manner and with no technical problems.

References

BRAITHWAITE, R.W., 1985: Coredrilling over water - one contractor's experience. Geodrilling August 1985, 12-17.

APPENDIX A.2 NAVIGATION

A.2 NAVIGATION

A.2.1 General

The navigation services during the seismic survey and the drilling were undertaken by A/S Geoteam, Oslo. Two field reports have been compiled:

- "Field report regional shallow seismic syrvey in the Barents Sea for IKU", Geoteam Report No. 31604.4.

and

- "Navigation and positioning of M/V Bucentaur Barents Sea. Shallow drilling for IKU A/S", Geoteam Report No. 31744.8.

Both reports have been submitted to the participants, and below we present some key data from the reports.

A.2.2 Seismic survey

The following navigation equipment was used for the seismic survey:

- Hyperfix in range-range mode
- Syledis
- Navstar GPS, partly with differential corrections
- HPR for positioning of towed instrument fishes

The Hyperfix and Syledis chains were operated by Bentech Navigation A/S, Tromsø, and the following base stations were used:

Syledis

- Nordkapp
- Sværholt (extra station)
- Kinnarodden (extra station)
- Berlevåg
- Makkaur

Hyperfix

- Fruholmen
- Knivskjellodden
- Slettnes
- Makkaur (extra station)
- Vardø
- Bjørnøya

The two extra Syledis stations were set up in order to have good navigation in the western area close to the coast (cores 7127/10-U-02 and -03) and an extra Hyperfix station in order to improve navigation in the eastern area close to 32°E. Because no cores were drilled in the eastern area, the extra Hyperfix station was demobilized before the drilling started, while the two extra Syledis stations were reactivated for the drilling.

In the extreme northern area the Hyperfix was partly heavily influenced by sky wave effects. This is quite normal, but reduced the accuracy for parts of the northernmost seismic lines. The GPS helped us to keep lane control, so accuracy should be within +/- 50 - 60 m for these parts and generally within +/- 15 - 25 m for the remaining part of the northern area. In the coastal area Syledis was used for parts of the survey, providing accuracies within appr. +/- 10 m, and Hyperfix for the rest, giving accuracies of +/- 10-20 m.

The station combinations used are listed in the seismic survey field report.

A.2.3 Drilling operation

In general the same station combinations were used for the drilling as for the seismic survey. Exceptions were the two 7127/10 drillings because the Syledis stations at Sværholt and Kinnarodden did not work when the "Bucentaur" went into position at these two sites.

As a back-up and partly to gain experience a Geoloc navigation system was on board in addition to what had been used on the seismic survey. This was of great help for the first drill site because neither the Hyperfix nor the GPS systems were working at the beginning of the survey. Geoloc was therefore used for positioning at site 7430/10-U-01 and partly as a primary system at site 7430/07-U-01.

The experience of using Geoloc in areas where the ranges for Hyperfix are marginal (>350 km) was positive and should be evaluated for future surveys. A more detailed discussion and evaluation is given in the drilling navigation report by A/S Geoteam.

The coordinates of some of the drill sites (7128/12-U-01, 7128/09-U-01 and 7029/03-U-02 and -03) were pre-selected on analog seismic lines shot in 1987. The same navigation stations and mainly the same station combinations were used at that survey as for the seismic and drilling surveys in 1988. The accuracy should therefore be maintained. Below is a list of final positions of the drill sites (Table A.2.1). The locations relative to the shotpoints on the digital as well as the analog seismic data are given in Table 2.1 in the Summary chapter.

Table A.2.1 Final positions of drill sites (ED50 and UTM Zone 35 with central meridian 27°E).

Core no.	Latitude	Longitude	Northing	Easting	UTM
7430/10-U-01	74°12'47.79"N	30°14'44.22"E	8238748.0	598521.3	27°CM
7430/07-U-01	74°26'34.69"N	30°14'56.17"E	8264345.9	597223.2	27°CM
7127/10-U-02	71°09'39.42"N	27°05'26.46"E	7895563.0	503268.4	27°CM
7127/10-U-03	71°10'55.04"N	27°11'02.34"E	7897913.6	506624.0	27°CM
7128/12-U-01	71°14'25.61"N	28°50'28.93"E	7905433.2	566087.8	27°CM
7128/09-U-01	71°15'30.20"N	28°51'16.03"E	7907447.8	566495.9	27°CM
7029/03-U-01	70°54'10.13"N	29°54'14.94"E	7869308.9	606015.7	27°CM
7029/03-U-02	70°56'07.02"N	29°58'53.59"E	7873063.6	608661.3	27°CM

APPENDIX A.3 ANALYTICAL METHODS

A.3 ANALYTICAL METHODS

A.3.1 Core description and sampling

Detailed core description was undertaken on board the ship (as time permitted) as well as all subsampling for the screening analyses. Both core description and sampling were completed at IKU laboratories in Trondheim. The legend of the sedimentological columns is given below in Figure A.3.1.

A.3.2 X-ray diffraction analysis

1. Samples for X-ray diffraction analysis were ground in ethanol to a fine powder dried and pressed in sample holders for whole rock analyses.

Radiation: monochromatic $\text{CuK}\alpha$
Voltage: 40 kV
Current: 30 mA
Speed: $2^\circ/\text{minute}$, $2\theta = 2^\circ\text{--}35^\circ$

The quantification is based on the peak height multiplied by the width of the peak at half maximum and by a weighted factor relative to quartz of the following reflections

Smectite	(Smec):	$(14\text{\AA} - 4.7\text{\AA}) \times 0.35$
Mixed layer minerals	(Mix):	$10 \text{ to } 14\text{\AA} \times 0.55$
Muscovite/Illite	(Mic/Ill):	$10\text{\AA} \times 1.0$ or $10\text{\AA} \times 1.4$ (illite)
Chlorite	(Chl):	$4.74\text{\AA} \times 3 \times 0.7$
Kaolinite	(Kaol):	$7\text{\AA} \times 0.7 - \text{Chl}$
Quartz	(Qtz):	$4.26\text{\AA} \times 1$
Opal C-T	(Op C-T):	$4.05\text{\AA} \times 1$
Goethite	(Goet):	$4.18\text{\AA} \times 1$
K-feldspar	(KFsp):	$3.24\text{\AA} \times 0.5$
Plagioclase	(Plag):	$3.19\text{\AA} \times 0.5$
Calcite	(Calc):	$3.04\text{\AA} \times 0.25$
Dolomite/Ankerite	(Dol/Ank):	$2.89\text{\AA} \times 0.20$
Siderite	(Sidr):	$2.79\text{\AA} \times 0.25$
Gypsum	(Gyps):	$7.56\text{\AA} \times 1$
Pyrite	(Pyr):	$2.71\text{\AA} \times 0.7$
Zeolite	(Zeol):	$9.00\text{\AA} \times 0.5$
Marcasite	(Marc):	$2.71\text{\AA} \times 0.7$
Melankrite	(Mela):	$4.90\text{\AA} \times 1$
Bassanite	(Bass):	$3.00\text{\AA} \times 1$

LITHOLOGY, SEDIMENTARY STRUCTURES & FOSSILS	
	Claystone / shale
	Siltstone
	Sandstone
	Limestone
	Dolomitic limestone
	Dolomite
	Calcareous dolomite
	Siderite
	Sandy carbonate
	Anhydrite
	Calcite cement
	Dolomite cement
	Siderite cement
	Phosphorite
	Chert, chert nodule
	Concretion
	Clasts
	Clasts
	Erosion
	Horizontal lamination
	Ripple lamination
	Wave ripples
	Trough cross stratification
	Coal
	Loading
	Styolites
	Meta sandstones
	Increasing bioturbation
	Fecal pellets
	Sparse
	Abundant
	Mudstone clast
	Pyrite
	Glauconite
	Palaeoaplysina
	Bryozoa
	Corals
	Fossils in general
	Unspecif. fossil fragments
	Bivalve
	Inoceramus
	Buchia
	Brachiopods
	Coquina
	Gastropod
	Ammonite
	Belemnite
	Echinoderms
	Foraminifera
	Fusulinides
	Ostracoda
	Trilobite
	Fish remains
	Cephalopod hook
	Cephalopod fragment
	Spicule
	Plant fragments
	Algae
	Borings
	Wood debris
	Roots
	Ooide
	Oncoide
	Fossil fragment

Figure A.3.1 Legend to the sedimentological logs.

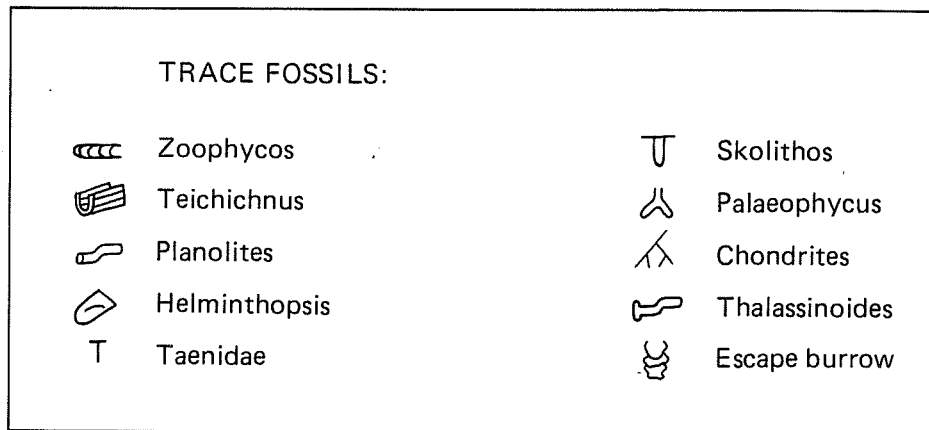


Figure A.3.1 Continued

A.3.3 Thin section microscopy

The studies were undertaken on a Leitz ortholux polarizing microscope. Due to the friable nature of some samples and to avoid destruction of pore filling minerals, most samples had to be impregnated by epoxy resin prior to preparation. Scanning electron microscope studies and analyses were carried out on an Jeol 733 Superprobe with a Tracor Northern EDS System on polished carbon coated thin sections.

A.3.4 Sound velocity measurements

Sound velocity measurements, mainly horizontal and a few vertical, were carried out on board on wet, consolidated core pieces, using a portable ultrasonic (100 kHz) non destructive digital indicating tester (PUNDIT).

The pulse velocity (v) was calculated using $v = \frac{L}{T}$

where L is the path length and T is the transit time. Sound velocity measurements are discussed in Appendix A.5.

A.3.5 Natural gamma-radiation

The measurements were carried out on board using a 5" x 5" NaI-detector connected to a 4048 channel analyser of the Canberra 40 series. The core was placed below the detector with its long axis parallel to the detector window. In that position a spectrum was accumulated for 600 sec (10 minutes). To reduce the background radiation, the detector and the samples were shielded by lead. The method requires a minimum sample length which is equal to the detector diameter if the collimation is 100% effective. To avoid this problem, only core pieces longer than twice the detector diameter (= 26 cm) were analysed.

The measured peaks are:

- 1) K-40: 1.460 MeV
- 2) U-238 via Bi-214: 1.764 MeV
- 3) Th-232 via Tl-208: 2.615 MeV

The results are presented as counts per 10 minutes. The logs show the relative amount of radiation and not the absolute abundance of K, Th and U. The lab measurements are discussed further and compared with the downhole gamma logs in Appendix A.5.

A.3.6 Thermal conductivity

Thermal conductivity has been measured on core samples from all the eight cores except for core 7128/09-U-01. A total of 44 samples has been measured. The measurements are carried out at the University of Aarhus under supervision of Niels Balling. A complete report by Balling is included in Appendix A.5.

The conductivity is measured by the needle probe method. The measurements are undertaken with the probe vertically in the cores (yielding horizontal thermal conductivity, k_h) and with the probe horizontally in the cores (yielding a weighted mean of vertical and horizontal thermal conductivity, k_m). Thermal conductivity measurements are discussed in Appendix A.5.

A.3.7 Palynology

The standard processing for palynology included hot hydrochloric and hydrofluoric acids with continuous stirring. In most cases the organic residues were oxidized by the use of nitric acid (app. 3 minutes) followed by KOH. If necessary this process was repeated.

Samples from the cores were prepared at 1 - 10 m intervals mainly dependent on lithology, leaving reference material at all levels.

Slides were prepared of: the total residues, unoxidized sieved residues, and oxidized residues at various stages.

A.3.8 Microfauna

Samples were prepared at approximately 3 m intervals, adjusted for lithological units. The samples were soaked in water for some days after being dried. Problematic samples were treated by diluted H_2O_2 , and pH conditions were checked during oxidation. The fraction $>125 \mu m$ was analysed with respect to foraminifera, ostracods and macrofossil debris. The fraction $63 - 125 \mu m$ was examined for siliceous microfossils.

The microfaunas were counted, and the legend in the range charts show the figures corresponding to approximately 10 g of sediment.

A.3.9 Other analyses

The technical part of the oedometer (compressional) tests are presented in Appendix A.4 and the organic geochemical analytical methods are presented in Appendix volume 2.

APPENDIX A.4 OEDOMETER TESTS

(including laboratory report by
S. Christensen and N. Janbu,
Sintef Division of Geotechnical Engineering)

A.4 OEDOMETER TESTS

A.4.1 Introduction

It is well known that some time during the Late Tertiary the Barents Sea was uplifted and a significant erosion took place. The implication for maturation, migration and preservation of hydrocarbons are also well known, in theory. The magnitude of the erosion is, however, less known and great efforts have been made to quantify the erosion and its variations throughout the Barents Sea.

As a new contribution to this, we have initiated the testing of a new type of analysis. Geotechnical engineers have for 20-30 years applied compressional tests, so-called oedometer tests, to measure the maximum load of previous overburden on non-lithified soil samples. The Sintef Division of Geotechnical Engineering has been one of leading institutes on this research, and in co-operation with IKU they have built a special oedometer test rig for bedrock samples. The objective of this has been to investigate whether the well established theory and procedures on soil samples analysis could be transferred to bedrock samples.

Nine core samples were subjected to analysis in the new test rig, six from the two cores north of the Nordkapp Basin and three from the coastal area. Cores with slightly different lithologies and from different stratigraphic intervals were selected. The technical part of the analyses was very successful with unambiguous and slightly different results for the two areas. The technique, the laboratory analyses and the results are presented by the Division of Geotechnical Engineers in the report below.

A.4.2 Thin section studies

In order to study the diagenesis of the analysed cores, thin sections were prepared of six of the samples. These are from 7430/07-U-01 (47.93 m, 58.08 m, 103.30 m, 113.41 m), 7430/10-U-01 (48.02 m) and 7128/09-U-01 (75.26 m).

Core 7430/07-U-01

47.93 m and 58.08 m: Both samples are grain supported siltstones with grain size 20-30 μm . Pyrite and siderite cement occur as patchy distributed clusters. The siderite is microcrystalline and seems in most cases to replace detrital biotite. Quartz cementation is commonly observed (recognized as tight, long grain contacts). The abundance of quartz cements is, however, difficult to estimate due to the small size and lack of dust rims on the host grains.

103.30 m: This is a slightly porous (estimated to <5% under the optical microscope), grain supported, siltstone to very fine-grained sandstone (40-100 μm). The main cementing phases seem to be a few percent of patchy distributed calcite cement and a mixture of illite and kaolinite in the matrix.

113.41 m: This sample consists of a thinly laminated shale with alternating laminae of grain supported medium to coarse-grained siltstone (grainsize 30 μm) and fine to very fine-grained siltstone laminae. The laminae contain small amounts of pyrite and carbonate cement, recrystallized clay minerals (matrix) and some silica cement. The latter seems to be confined to the coarser grained laminae.

Core 7430/07-U-01

48.02 m: The sample is a thinly laminated organic rich claystone/slightly silty shale. Due to grain size, diagenetic effects other than the results of compaction are not observed.

Core 7128/09-U-01

75.26 m: This sample is a coarse-grained siltstone with abundant very fine-grained silt and matrix. Abundant neoformed kaolinite and illite from alteration/leaching of feldspar and mica are the main cementing phases in this sample.

A.4.3 Discussion

In the laboratory report the results of the analyses are given in Table 4.3.1 and discussed in Chapter 5, and we advise the reader to study this. In short it was measured a "preconsolidation" stress of ~40 MPa in the northern area and 30-35 MPa in the coastal area. If these values are directly considered to reflect the load of previous overburden, they correspond to sediment thicknesses in the order of 3-3.5 km in the northern areas and 2.5-3 km in the southern area.

As is concluded in the laboratory report, there is no doubt that this conclusion is incorrect, because the sedimentary bedrock samples have experienced diagenetic processes with cementing between grains, compared to soil samples where this has not occurred and a more or less simple compression has taken place. In most of the samples described above, several neoformed minerals are observed (clay minerals, quartz, carbonate and pyrite). The effect of the diagenesis must therefore be estimated before the measured values can be compared with previous sediment load. But if this can be quantified, we strongly believe that oedometer tests will provide reliable values of the overburden. The difference in measured value between the two areas and similar and very confident results in another IKU project support this. Unfortunately time did not allow further petrographic analyses of the samples, but quantitative SEM and XRD analyses will probably help us further on.

In conclusion we would tend to believe that the oedometer analysis reflects difference in erosion between the two areas, but that the effect of diagenesis will reduce the overburden estimates to a certain and at present unknown degree.

**SHALLOW DRILLING
BARENTS SEA 1988**

**- OEDOMETER TESTS ON
SEDIMENTARY ROCKS**

Division of Geotechnical Engineering

N-7034 Trondheim-NTH Norway

Telephone: (+ 47 7) 59 30 00
Telex: 55 620 SINTEF N
Telefax: (+ 47 7) 59 24 80

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Author(s) S. Christensen, N. Janbu	Divisional responsibility (sign.) <i>G.J. Westerlund</i> G.J. Westerlund
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Abstract

SINTEF - Division of Geotechnical Engineering has upon request from IKU performed a number of oedometer tests on sedimentary rocks cored from the Finnmark East Area and north of the Nordkapp Basin at about 74°20'N, 30°E.

The main findings are:

- All tests from about 74°20'N, 30°E revealed a preconsolidation stress of 40 MPa
- All tests from the Finnmark East Area revealed a preconsolidation stress of 30-35 MPa
- This indicates that the sedimentary rocks in question cored from present depths 50-125 m with present effective vertical stresses of 0.5-1.5 MPa, could previously have been overlain by either 3.0-4.5 km ice thickness or roughly 2.5-4 km of sediments which now have been eroded.

	Indexing terms: English	Norwegian
Group 1	Geotechnics	Geoteknikk
Group 2	Testing	Prøving
Key terms selected by author(s)	Sedimentary rocks	Sedimentære bergarter

SUMMARY

During the summer of 1988 IKU cored samples of sedimentary rock in the Barents Sea. SINTEF, Division of Geotechnical Engineering obtained samples from depths 48 to 125 m below the seabed at latitudes 70°54' to 74°26'N, and longitudes 27°05' to 30°14'E. Several different lithological units were tested.

The testing was carried out in a new oedometer rig, designed for testing sedimentary rocks up to a vertical stress level of 90 to 120 MPa. The results have been interpreted in the same manner as in geotechnical engineering, using the NTH-models of soil behaviour /1/. It was found that in all tests the stress-strain-time behaviour was in principle identical to well-established soil behaviour, the only difference being that the absolute values of the resistances of the rock samples were of course much larger than similar soils, say of Quaternary age.

The main findings can briefly be summarized as follows:

- The test material from site 7430/07-U-01, taken from depths 48 to 125 m below the seabed, showed a preconsolidation stress level around 40 MPa, as compared to the present overburden of 0.5 to 1.5 MPa. The compression modulus around σ_c' was found to be in the range 2.0 to 2.5 GPa.
- The test materials from site 7430/10-U-01 taken from depths 48 to 66 m below the seabed, showed the same preconsolidation stress level as at site 7430/07-U-01. The modulus in the OC-range were around 1 GPa.

- The test material from sites 7127/10-U-02, 7128/09-U-01 and 7029/03-U-01, from depths 125, 75 and 125 m respectively, showed a preconsolidation stress of 30-35 MPa. The modulus in the OC-range were around 0.6 GPa.

The preconsolidation stresses obtained for the clay-type materials are approximately the same whether interpreted from the stress-strain-, the modulus-stress-, or the creep-stress-curves, or even semi-empirical rules.

Typical for all curves are the breakdown of rigidity of the grain structure around the preconsolidation stress. This effect is most evident in the change of creep behaviour, exactly as previously observed for Quaternary soils of much lesser density, rigidity and strength.

The preconsolidation stress for some silt/sand-type materials are often difficult to interpret from strain-stress or modulus-stress curves. In such cases the change in creep behaviour may be the best way to reveal σ_c' . This creep procedure has therefore been applied to all samples reported herein.

TABLE OF CONTENTS

	Page
SUMMARY	2
TABLE OF CONTENTS	4
1 INTRODUCTION	5
2 GEOTECHNICAL TESTS TO AID GEOLOGY	6
3 TEST FACILITIES	7
4 LABORATORY TESTS	8
4.1 Methods of interpretation	8
4.2 Test material	9
4.3 Test results	9
5 EVALUATION OF TEST RESULTS	15
5.1 General	15
5.2 Evaluation	15
5.3 Comments	16
6 REFERENCES	17
FIGURES	
APPENDIX	

1 INTRODUCTION

At the request of IKU, (The Continental Shelf and Petroleum Technology Research Institute A/S) the SINTEF - Division of Geotechnical Engineering has carried out a number of oedometer tests on samples of sedimentary rocks during the late autumn of 1988. The material was cored from M/S Bucentaurer during the summer of 1988 in the Finnmark East Area and north of the Norkapp Basin at about 74°20'N, 30°E. These tests will be included in IKU's multiclient project called "Shallow Drilling Barents Sea 1988".

2 GEOTECHNICAL TESTS TO AID GEOLOGY

During several decades geotechnical engineers have used oedometer tests to determine the preconsolidation pressure of various sediments, primarily clay and clayey silts. Information about the preconsolidation pressure, σ_c' , as compared to present overburden, p_o' , has been of considerable help in clarifying the past geological history of these sediments.

For instance, when $\sigma_c' \gg p_o'$ it indicates that the sediment has previously been subjected to effective (granular) stresses much larger than today's stress level, leading to the following question to geology: Have the soil been loaded by ice, or with soil now eroded, or subjected to other actions? Another example; when $\sigma_c' \ll p_o'$ the question can be whether or not artesian pressure with upwards gradients has caused the state of underconsolidation.

Over the last 2 to 3 years our Division has used these same principles to interpret compression tests on sedimentary rocks, and it has been verified that these rocks in principle behave in exactly the same way as samples from Quaternary soil layers. This analogy applies whether the interpretation is based on stress-strain, modulus-strain, or creep-stress relationship. Even semi-empirical rules established in soil mechanics appear to be helpful in interpreting sedimentary rock behaviour. The absolute resistance values of sedimentary rocks are of course much larger than for soils in general.

Oedometer tests on sedimentary rocks, carried out and interpreted in the same way as in geotechnics, will no doubt become a tool of utmost importance in aiding the geologists in their identification of the geological history.

3 TEST FACILITIES

The rig for performing oedometer tests on sedimentary rocks consists of three main units

- An hydraulic jack, providing up to 600 kN (60 tons) force, with oil pressure of 30 MPa.
- Measuring device, consisting of three excentrically positioned LVDT's (Linear Variable Differential Transducers) for axial strain measurements, a load cell with a capacity of 200 kN, and a recorder for axial strain, force and time.
- An oedometer cell, made of high-quality, acid-resistant steel.

A new oedometer ring has been made for each test to fit the diameter of the cored sample, and each sample has been machine-levelled prepared to a height of approximately 20 mm. The net sample area was varied, by precision drilling, between 20 and 23 cm². The oedometer ring with the sample, was placed in the rig in a fresh water bath for saturation over night. An initial stress of 200-400 kN/m² was applied. Then the sample was loaded stepwise up to a stress level of 90 to 120 MPa, depending on the material. The axial strain, the load and the time were recorded automatically with connection to our HP1000 data machine. A key sketch of the oedometer rig is shown in Fig. 1.

4 LABORATORY TESTS

4.1 Methods of interpretation

The modulus concept was first introduced by Janbu /1/ in 1963. The definitions of the modulus and the time resistance are shown in Fig. 2. The axial strain (ϵ) at the end of each loadstep is plotted versus effective stress (σ'), and the tangent modulus to this curve (M) can be plotted versus average effective stress ($\bar{\sigma}'$). For a low stress on the loading branch the resistance (M) against deformation is large. While the stress increases this high resistance eventually decreases appreciably, owing to partial collapse of the grain skeleton. This breakdown of the resistance occurs around the preconsolidation stress level σ_c' . When the effective stress is increased beyond σ_c' the resistance increases with increasing effective stress. The behaviour in the normally consolidated stress range can be approximated by a linear oedometer modulus as shown in Fig. 2.

The tangent to the strain-time curve of each load step is defined as the time resistance (R). Irrespective of whether $\sigma' \gtrless \sigma_c'$ a linear dependency of the time resistance is found after some elapsed time for each load level. The time resistance number (r_s) can be found as a straight line fit to the R - t -curve. When plotting the time resistance number versus effective stress the preconsolidation stress (σ_c') can be interpreted from the lowest point of the r_s - σ' -curve. This method of interpreting the preconsolidation stress can often be more precise than interpretation of σ_c' from either the ϵ - σ' or the M - $\bar{\sigma}'$ -curves.

A linear time resistance indicates a creep behaviour. Therefore, the term creep resistance is also used more frequently. As a consequence r_s is also called the creep number.

4.2 Test material

A total number of 9 oedometer samples of sedimentary rocks from the western part of the Barents Sea have been tested. The rock samples have been cored from depths 48 to 125 m below the seabed at latitudes 70°54' to 74°26'N, and longitudes 27°05' to 30°14'E. For geological description of the material reference is made to the main report.

4.3 Test results

The measured ϵ - σ' curves and the computed M- σ' curves for each oedometer test are shown in the Appendix, together with the R- σ' -curves from each test. The obtained deformation characteristics are shown in Tables 4.3.1 and 4.3.2.

The load levels used in the tests were basically
1.0 - 2.5 - 5.0 - 10.0 - 20.0 - 30.0 - 50.0 70.0 - 100 (MPa).

Test 7430/07-U-01, D = 47.93 m

The material was a very fine to fine sandstone. The sample was machine prepared to an area of 20 cm² and loaded in steps to a vertical stress of $\sigma_v' \sim 100$ MPa. From the modulus-stress curve a square-root fit gave a modulus number of $m = 900$ which indicates a very low porosity. The preconsolidation stress level $\sigma_c' \approx 40$ MPa according to the interpreted time resistance numbers r_s which were found to be $r_s \sim 1000$ at σ_c' . No signs of swelling properties were detected.

Test 7430/07-U-01, D = 58.08 m

The material was a sandstone/siltstone. A steel ring was made to fit the diameter of the sample with an area of 22.9 cm². The maximum load level applied was $\sigma_v \approx 90$ MPa. From the

modulus-stress curve a square-root fit gave a modulus number of $m = 1200$ which indicates a very low porosity. Interpretation of the time resistance numbers for each load revealed a preconsolidation stress level $\sigma_c' \approx 35$ MPa. The time resistance number was found to be $r_s \sim 2100$ at σ_c' . No signs of swelling properties were detected.

Test 7430/07-U-01, D = 103.03 m

The material was a siltstone/silty claystone. The sample was machine prepared into a steel ring with net area of 22.9 cm^2 and loaded in steps to a vertical stress of $\sigma_v' \sim 90$ MPa. A square-root fit of the modulus-stress curve resulted in a modulus number of $m = 1200$. Interpretation of the time resistance numbers for each load level revealed a preconsolidation stress level $\sigma_c' \sim 40$ MPa. The value of the time resistance number at σ_c' was around $r_s \approx 500$. No signs of swelling properties were detected.

Test 7430/07-U-01, D = 113.41 m

The material was a siltstone. The sample was machine prepared to an area of 20 cm^2 and loaded in steps to a vertical stress of $\sigma_v' \approx 100$ MPa. A square-root fit to the modulus-stress curve resulted in a modulus number of $m = 850$. Interpretation of the time resistance numbers for each load level revealed a preconsolidation stress level $\sigma_c' \sim 40$ MPa with a corresponding value of $r_s \approx 1800$. No signs of swelling properties were detected.

Test 7430/10-U-01, D = 48.02 m

The material was a black shale. The sample was machine prepared into a steel ring with net area of 22.9 cm^2 and loaded in steps to a vertical effective stress of $\sigma_v' \sim 90$ MPa.

The shale had a clay-type deformation behaviour with a constrained modulus $M = 1$ GPa in the OC-range and a modulus number of $m \approx 25$ in the NC-range. Interpretation of the preconsolidation stress from both the ϵ - σ' , M - σ' and the r_s - σ' curves pointed at a value $\sigma_c' \approx 40$ MPa. The time resistance number was $r_s \approx 400$ at the preconsolidation stress level. No signs of swelling properties were detected.

Test 7430/10-U-01, D = 66.20 m

The material was a black shale. The sample was machine prepared into a steel ring with net area of 22.9 cm^2 and loaded in steps to a vertical effective stress of $\sigma_v' \sim 90$ MPa. The shale had a clay-type deformation behaviour with a constructed modulus $M = 1.1$ GPa in the OC-range and a modulus number $m = 21$ in the NC-range. Indications from the M - σ' -curve and the r_s - σ' -curve point to a preconsolidation stress level around 40 MPa. No signs of swelling properties were detected.

Test 7127/10-U-02, D = 125.52 m

The material was a dark grey siltstone, and the sample quality indicated some sample disturbance. The material was first tested in our conventional incremental loading (IL) oedometer up to an axial stress of 5 MPa. In this oedometer the pore pressure response due to an additional load is measured at the bottom. The pore pressure response for this material was extremely low indicating a very low degree of water saturation. The sample was then unloaded and pushed into an oedometer ring for further loading in the hydraulic high-pressure rig. The sample was loaded to a maximum vertical stress of $\sigma_v' \sim 100$ MPa revealing a preconsolidation stress $\sigma_c' \sim 30$ MPa with a modulus in the OC-range $M \sim 0.5$ GPa and a modulus number in the NC-range of $m = 14$. The resistance numbers are in the range of $r_s \sim 1500$ at σ_c' . The sample showed signs of swelling properties during the test.

Test 7128/09-U-01, D = 75.26_m

The material was a silty sandstone. The sample was machine prepared into a steel ring with net area of 20 cm² and loaded in steps to a vertical effective stress of $\sigma_v' \sim 120$ MPa. The sample had a clay-type deformation behaviour with a constrained modulus $M \sim 0.65$ GPa in the OC-range and a modulus number $m \sim 10$ in the NC-range. Indications from the ϵ - σ' -curve, the M - σ' -curve and the r_s - σ' curve all point to a preconsolidation stress level $\sigma_c' \sim 35$ MPa. The time resistance number at σ_c' was found to $r_s \sim 400$. No signs of swelling properties were detected.

Test 7029/03-U-01, D = 125.53_m

The material was a dark grey claystone, and the sample quality indicated some sample disturbance. The material was first tested in our conventional IL-oedometer and then further tested in the high-pressure hydraulic rig. The pore pressure response at the low load levels indicated a low degree of water saturation. The material showed a silt-type behaviour described by a modulus number $m \sim 160$ and a stress exponent $a \sim 0.4$. From interpretation of the time resistance number at each load level a preconsolidation stress $\sigma_c \sim 35$ MPa was found. The corresponding value of r_s were around 800. No signs of swelling properties were detected during the test.

TABLE 4.3.1 Stress- and time resistance interpreted oedometer tests (for curves, see Appendix A)

Experiment	Stress-strain				Time-strain											
	M_{oc}	σ_c'	m	a	σ_a'	r_s	σ_a'	r_s	σ_a'	r_s	σ_a'	r_s	σ_a'	r_s	σ_a'	r_s
	MN/m ²	MN/m ²			MN/m ²		MN/m ²		MN/m ²		MN/m ²		MN/m ²		MN/m ²	
7430/07-U-01 F141 D = 47.93 m	2000	~ 40	900	0.5	-	-	-	-	25.0	5000	50.0	1085	75.7	1065	99.7	1040
7430/07-U-01 F152 D = 58.08 m	2500	~ 35	1200	0.5	10.2	5555	21.7	3333	33.7	2142	49.4	3125	70.1	3280	89.4	3450
7430/07-U-01 F188 D = 103.03 m	2500	~ 40	1200	0.5	-	-	19.7	8480	29.7	5600	53.0	2680	70.5	3075	88.5	3225
7430/07-U-01 F198 D = 113.41 m	2000	~ 40	850	0.5	11.1	10870	19.5	8300	30.1	3125	53.0	1850	69.3	2100	100.0	2210

STRESS-DEPENDENCY:

Modulus: $M = m \cdot p_a \left(\frac{p'}{p_a} \right)^{1-a}$

Strain: $\epsilon = \frac{1}{m \cdot a} \left[\left(\frac{p'}{p_a} \right)^a - \left(\frac{p_0'}{p_a} \right)^a \right]$

TIME-DEPENDENCY:

Time resistance: $R = r_s \cdot t$

Strain rate: $\dot{\epsilon} = \frac{1}{r_s \cdot t}$

NOTATIONS:

σ_a and σ_a' = applied stresses in oedometers

TABLE 4.3.2 Stress- and time resistance interpreted oedometer tests (for curves, see Appendix A)

Experiment	Stress-strain				Time-strain											
	M_{oc}	σ_c'	m	a	σ_a'	r_s	σ_a'	r_s	σ_a'	r_s	σ_a'	r_s	σ_a'	r_s	σ_a'	r_s
	MN/m ²	MN/m ²			MN/m ²		MN/m ²		MN/m ²		MN/m ²		MN/m ²		MN/m ²	
7430/10-U-01 F 48 D = 48.02 m	1000	~ 40	25	0	11.1	2540	20.3	1270	32.1	850	49.3	385	69.3	500	89.4	600
7430/10-U-01 F 73 D = 66.20 m	1100	~ 40	21	0	9.9	15000	20.5	5330	33.1	1900	50.4	725	70.7	760	88.6	800
7127/10-U-02 * F376 D = 125.52 m	500	~ 30	14	0	9.6	8570	19.7	5260	32.9	1540	49.3	2220	69.3	2270	98.7	-
7128/09-U-01 F806 D = 75.26 m	650	~ 35	10	0	11.5	2885	19.7	2350	31.5	748	49.0	420	71.6	400	90.3	440
7029/03-U-01 * F874 D = 125.53 m	600	~35	160	0.4	10.6	3075	19.6	2875	29.6	1330	53.8	750	71.4	780	98.6	780

STRESS-DEPENDENCY:

Modulus: $M = m \cdot p_a \left(\frac{p'}{p_a}\right)^{1-a}$

Strain: $\epsilon = \frac{1}{m \cdot a} \left[\left(\frac{p'}{p_a}\right)^a - \left(\frac{p_0'}{p_a}\right)^a \right]$

TIME-DEPENDENCY:

Time resistance: $R = r_s \cdot t$

Strain rate: $\dot{\epsilon} = \frac{1}{r_s \cdot t}$

NOTATIONS:

σ_a and σ_a' = applied stresses in oedometers

5 EVALUATION OF TEST RESULTS

5.1 General

All oedometer test results show clearly an appreciable pre-consolidation stress level as compared to the present effective stress which is, in the range of $\sigma_v' = 0.5-1.5$ MPa for depth intervals $z = 50-125$ m. The interpretation of the pre-consolidation stress was based on the curves of $e-\sigma'$, $M-\sigma'$ and $r_s-\sigma'$. However, the most accurate interpretation of σ_c' was made from the evaluation of the time resistance numbers (r_s) for each load level. For some materials the only method to obtain σ_c' is to use the $r_s-\sigma'$ curve.

5.2 Evaluation

The measured deformation behaviour of the test material lead to the following over-all evaluation.

- The test material from site 7430/07 showed a deformation behaviour similar to Quaternary silt/sand, apart from the higher stress levels.

Both the modulus (M) and the modulus number (m) lead to roughly the same value of the preconsolidation stress σ_c' . This finding may indicate that large masses of sediment have been eroded, or that the material has previously been overlain by more than 4 km thick ice sheets. Most probably combinations of these effects have been present at some time after deposition.

- The shales from site 7430/10 disclosed a deformation behaviour equal to Quaternary clay, as expected. A preconsolidation stress $\sigma_c' \sim 40$ MPa was found for these shales, which is the same as was found for the

test material from site 7430/07. The shale samples from 7430/10 are found to be twice as compressible as the sand/siltstones from 7430/07.

- The test materials tested from the sites 7127/10 and 7128/09 showed a clay type deformation behaviour. These materials are found to be four times as compressible as the materials from 7430/07. A preconsolidation stress of $\sigma_c' \sim 30-35$ MPa was found. Hence, approximately 2.5-3 km of overlying sediments, or 3 to 3.5 km thick ice-sheets, could have caused this σ_c' -value.
- The samples tested from 7029/03 gave a σ_c' similar to that found for the material from 7127/10 and 7128/09. The values mentioned above for previous depth of burial or ice-sheet thickness may be the cause.

5.3 Comments

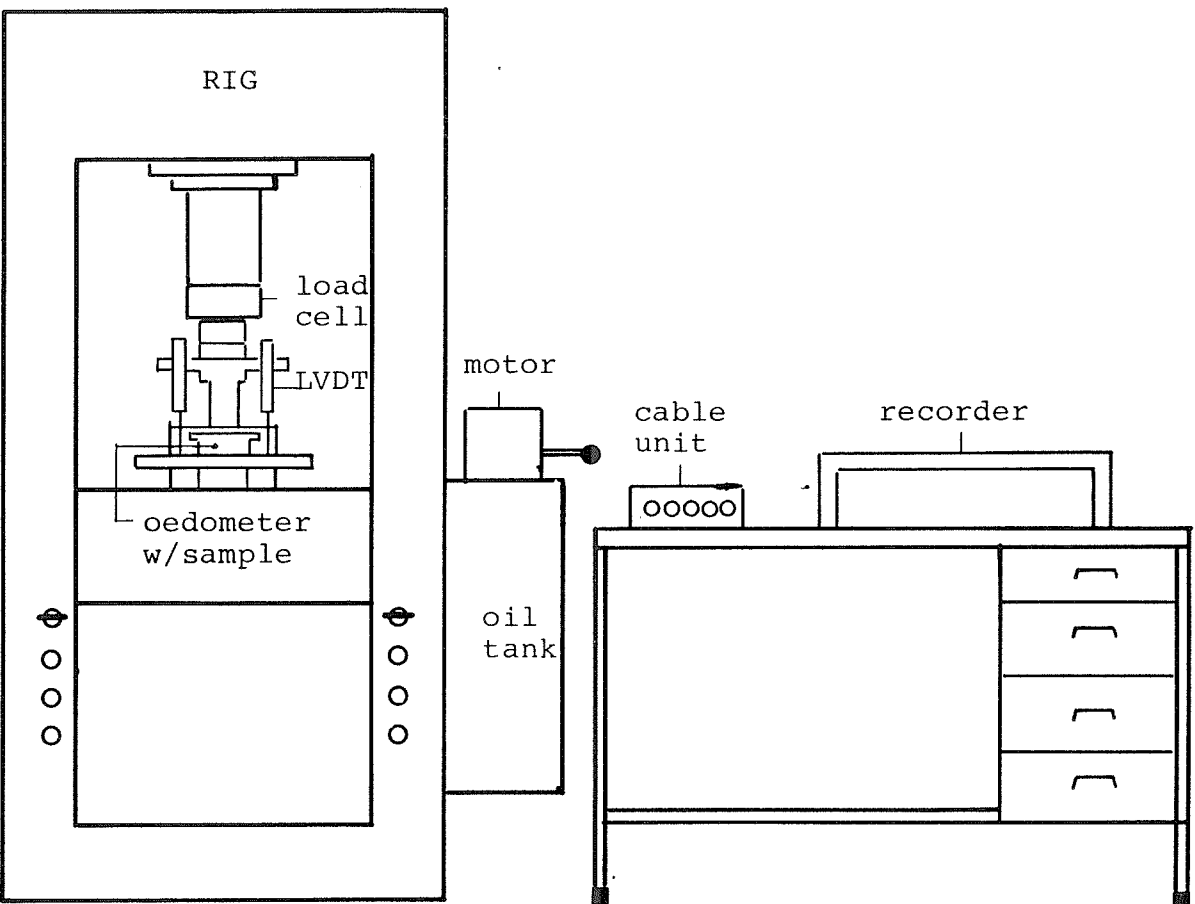
It must be emphasized that these interpretations are entirely based on findings from the oedometer tests only, and that no effects of grain bonding or cementation have been considered. Scanning electron microscope (SEM) applied to prepared samples may give information of degree of cementation or secondary porosity which may have affected the oedometer test results. However, apart from the above mentioned effects, the laboratory methods and interpretation techniques applied on the tested materials herein have resulted in reliable values of the preconsolidation stress. The possible effect of diagenesis on σ_c' has not been discussed, because it is considered to be beyond the scope of this report.

6 REFERENCES

- /1/ JANBU, N. (1963): "Soil compressibility as determined by oedometer and triaxial tests". Proc. 3rd Eur. Conf Soil Mech. Wiesbaden 1, 19-25.
- /2/ JANBU, N. (1985): "Soil models in offshore engineering". 25-Rankine Lecture, Geotechnique 35, No. 3, pp 241-281.
- /3/ JONES, M. (1986): "The mechanical behaviour of reservoir chawks and overburden shales". NIF-course: "Application of rock mechanics to petroleum reservoir problems".

F I G U R E S

(2)



Principal sketch of hydraulic rig with oedometer and equipment.

PROJECT

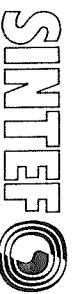
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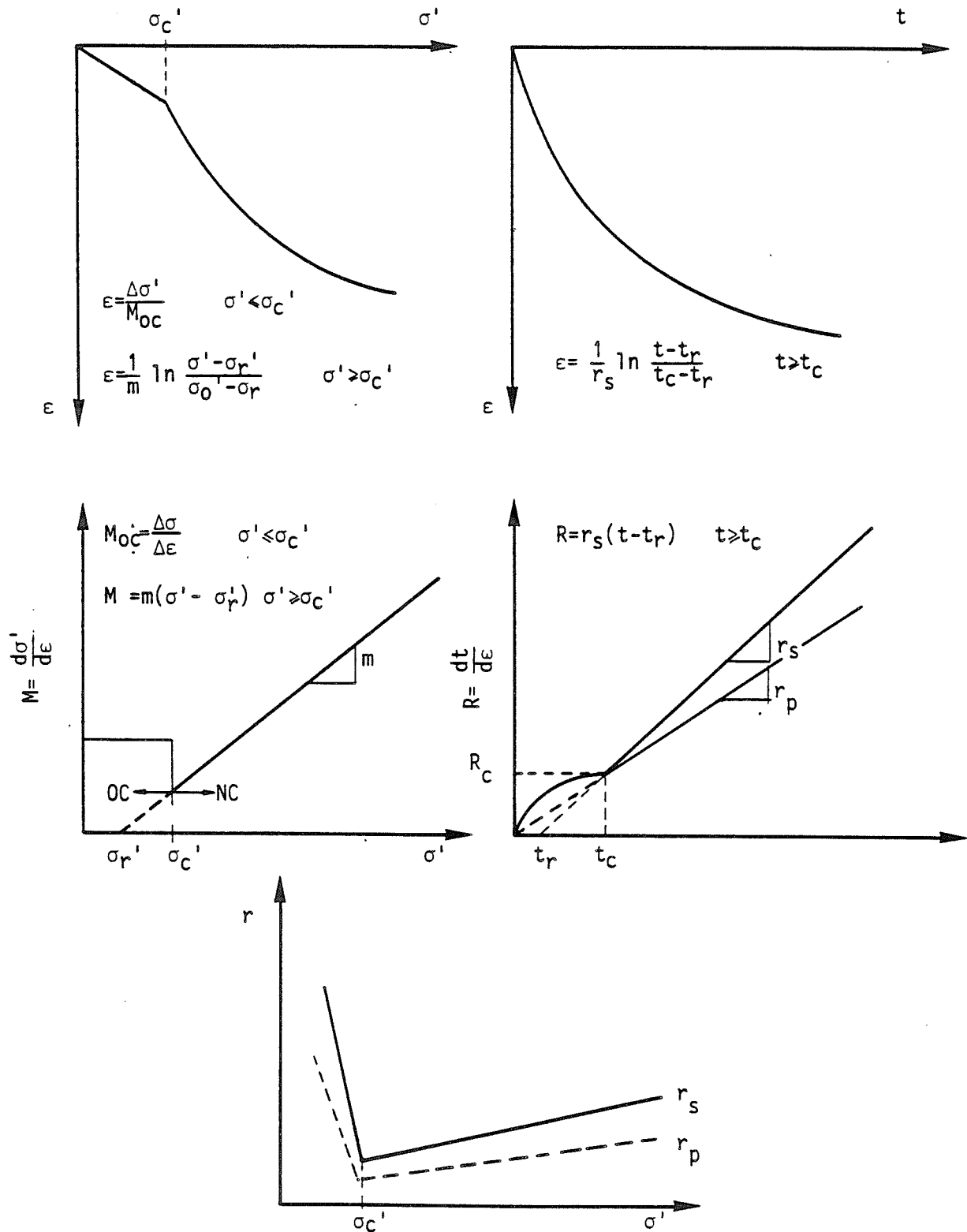
FIG.

1



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Note : All axis in arithmetic scale



Definition of modulus and time resistance.
Principal sketches.

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FIG.

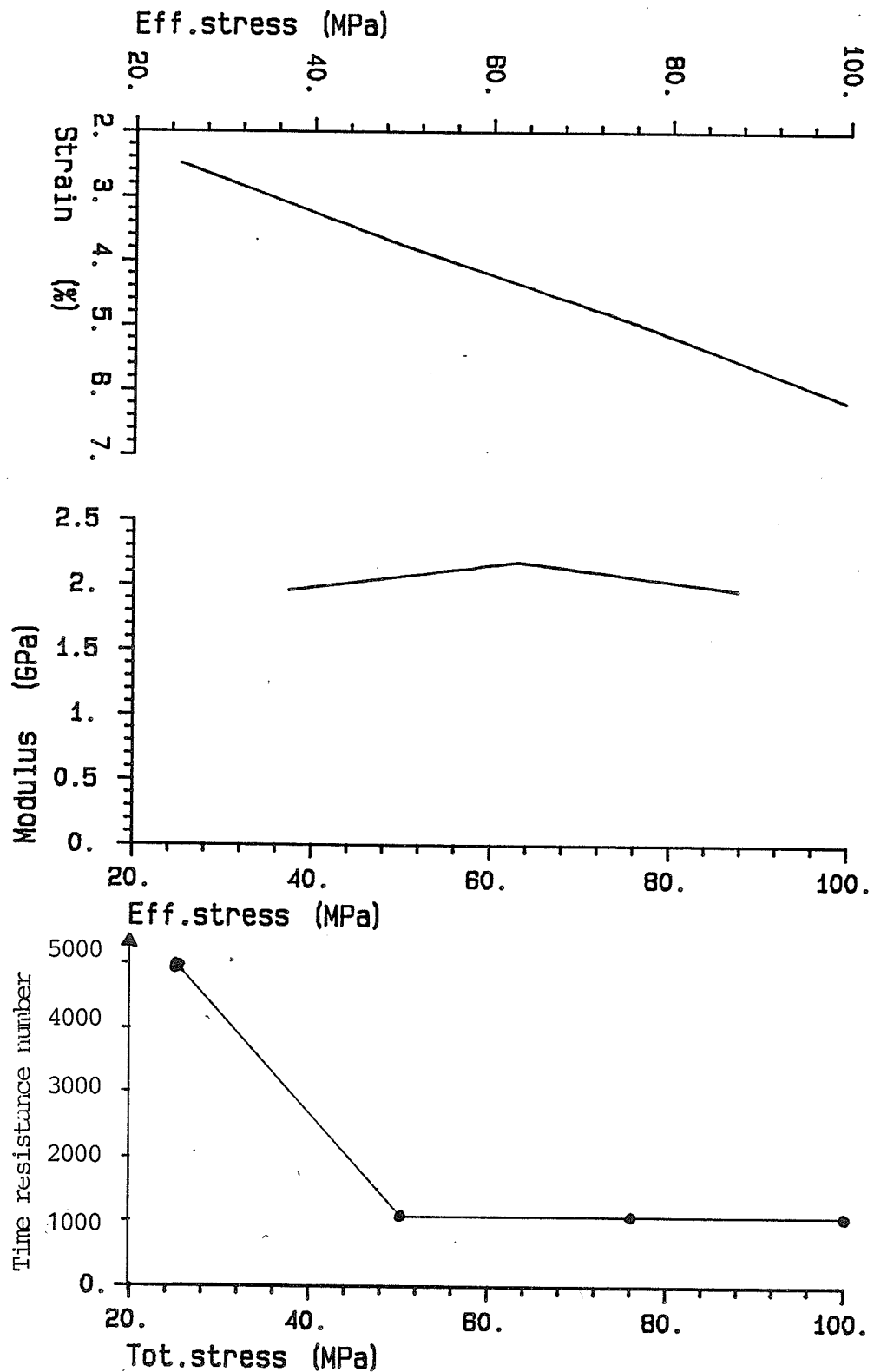
2



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A P P E N D I X

(1 - 11)



IL - oedometer.

**IKU, 7430/07-U1, F141, D=47.93m



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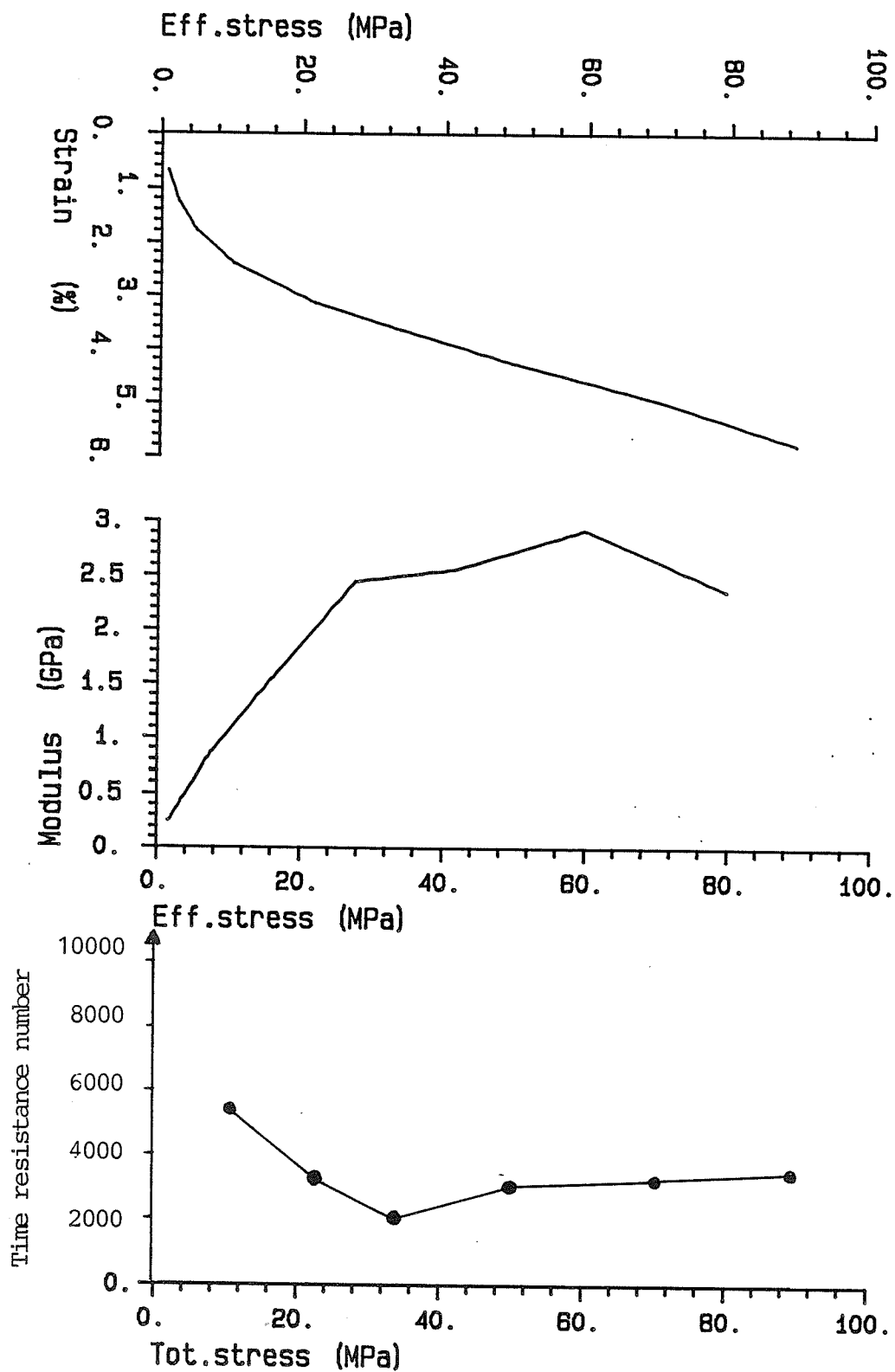
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FIG.

A-1



IL - oedometer.

**IKU, 7430/07-U-1, F152, D=58.08m



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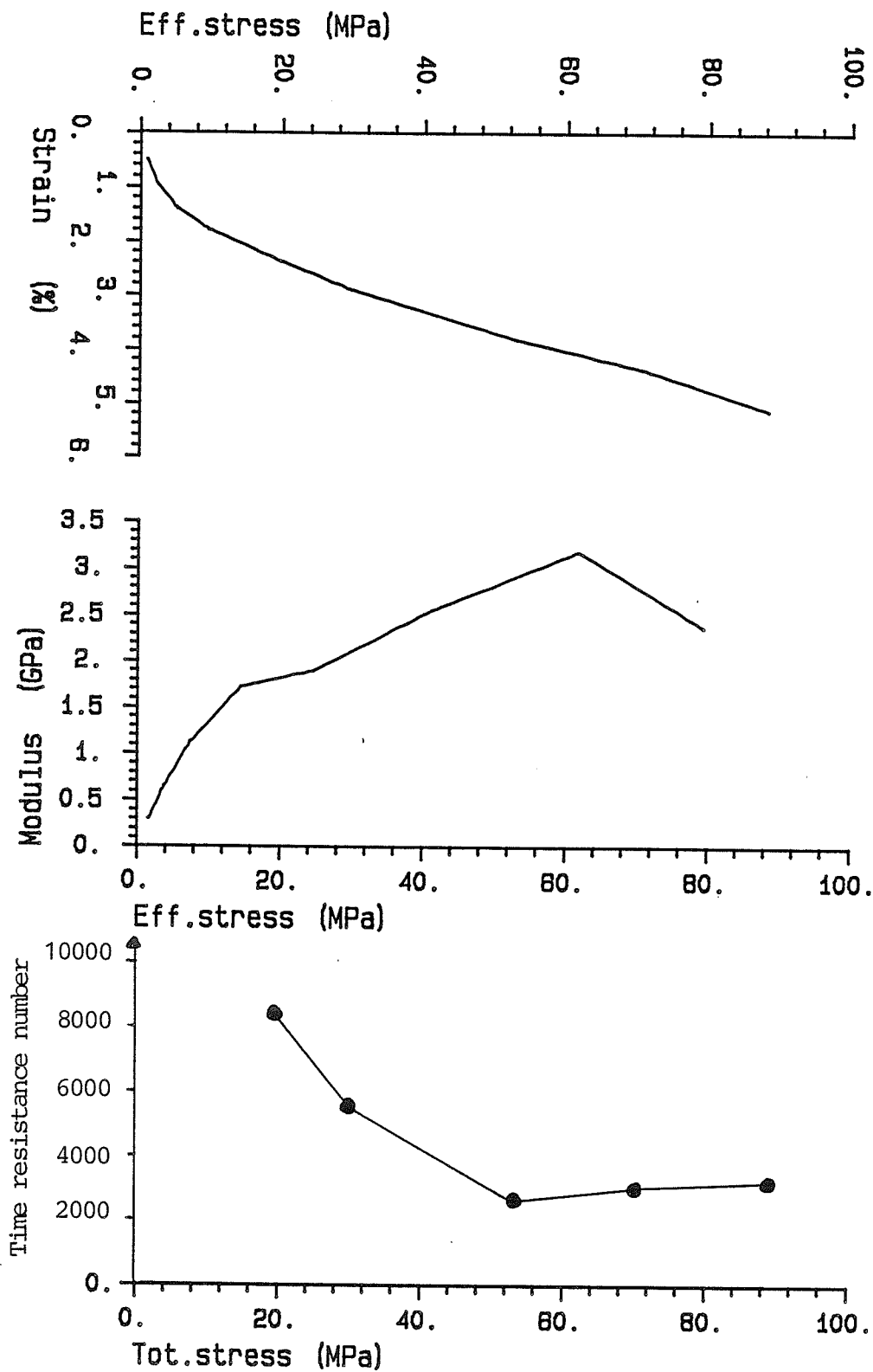
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FIG.

A-2



IL - oedometer.

**IKU, 7430/07-U-1, F188, D=103.03m



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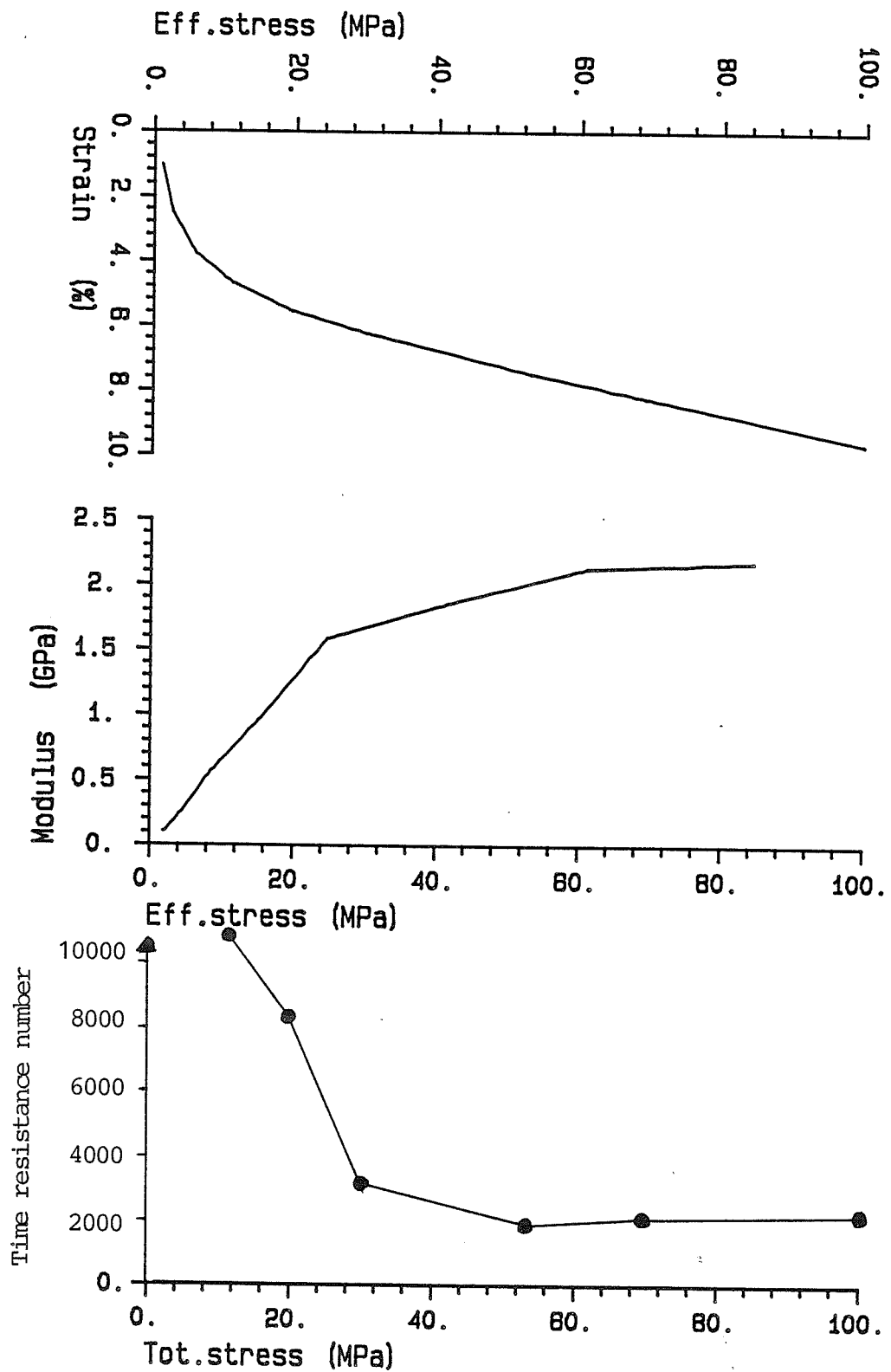
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DATE

6 JAN., 1989

FIG.

A-3



IL - oedometer.

**IKU, 7430/07-U-1, F198, D=113.41m

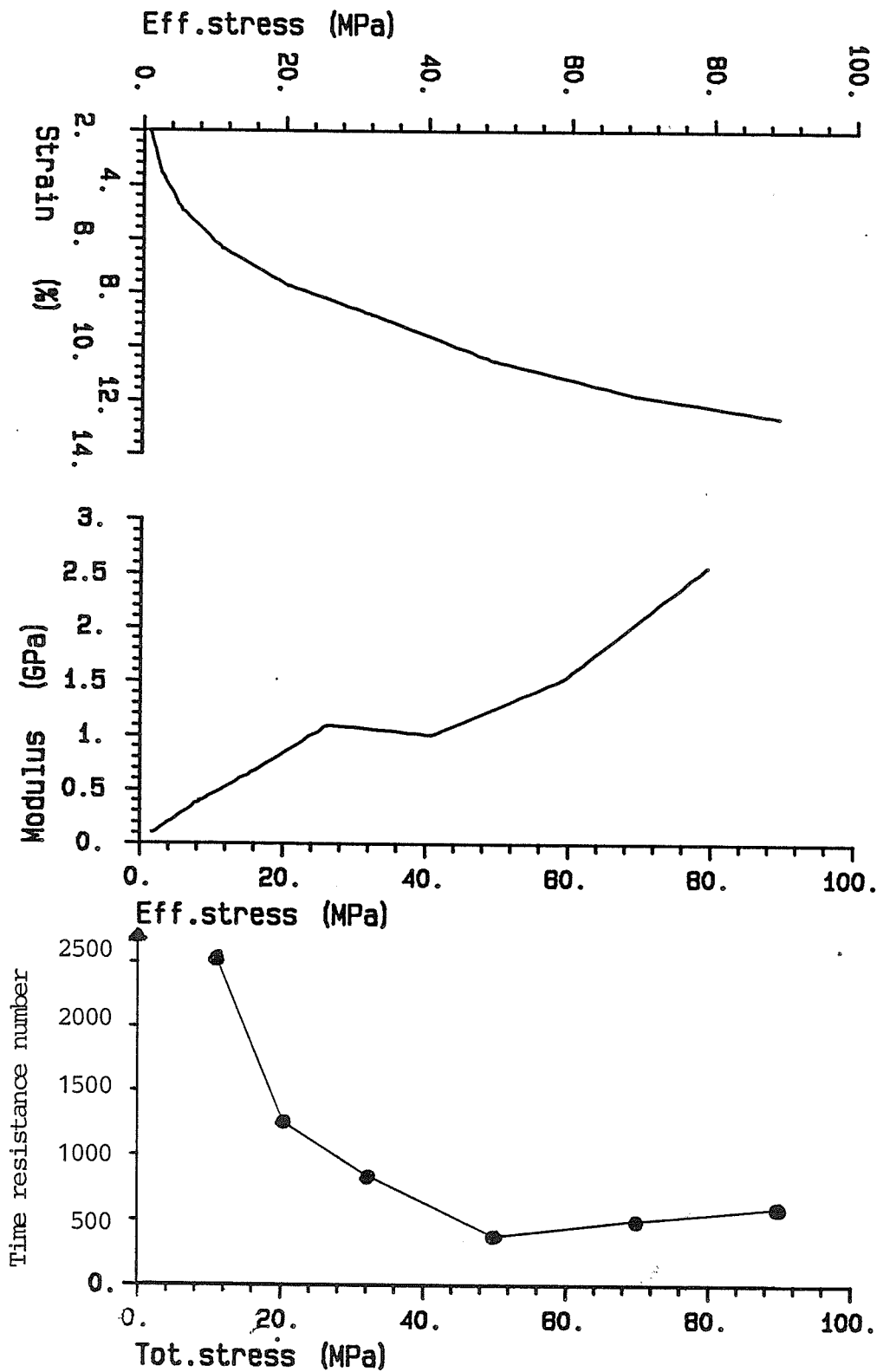


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DATE
3 JAN., 1989

FIG.
A-4



IL - oedometer.

**IKU, 7430/10-U-1, F4B, D=4B.02m



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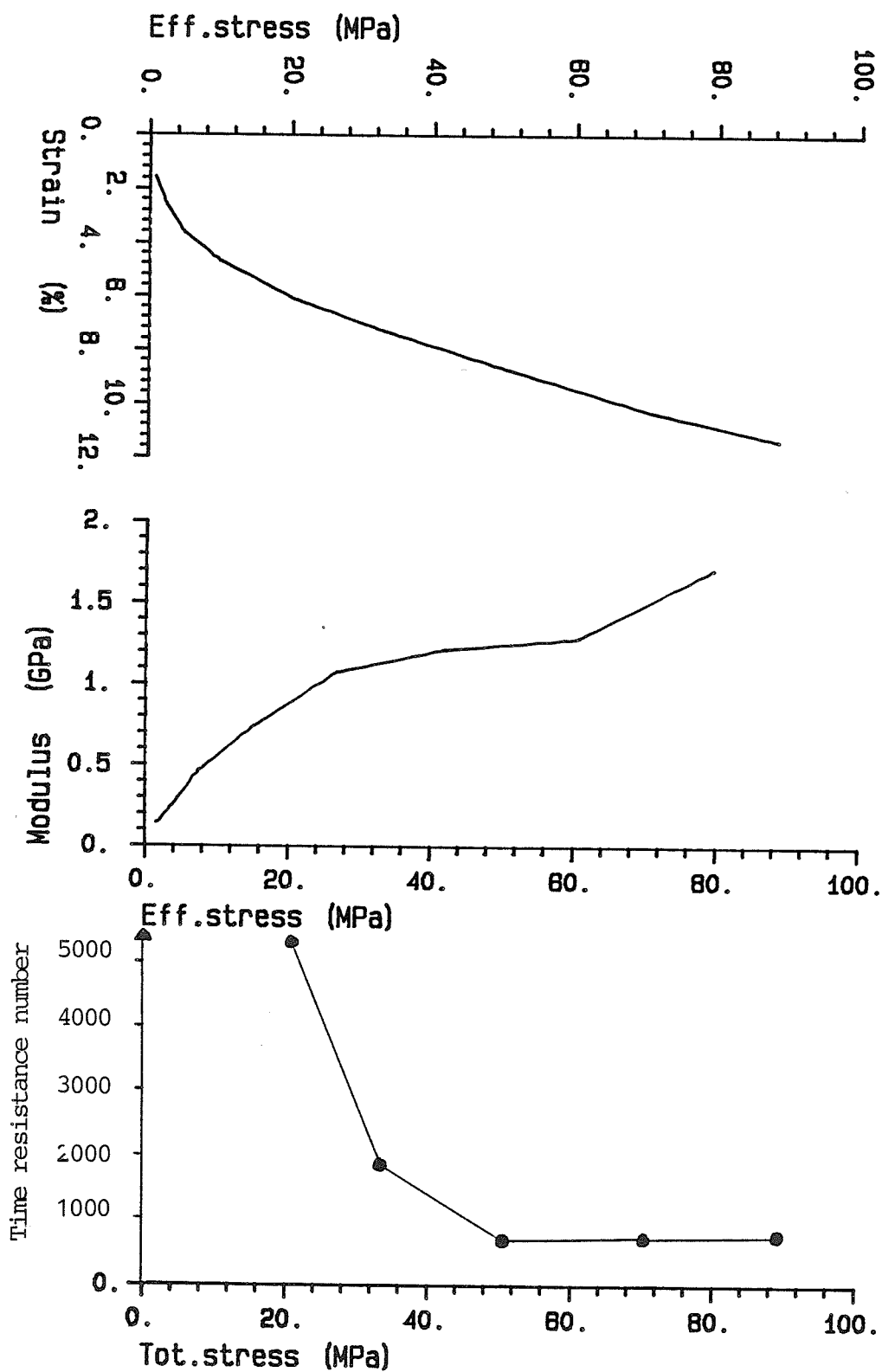
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FIG.

A-5



IL - oedometer.

**IKU, 7430/10-U-1, F73, D=66.20m



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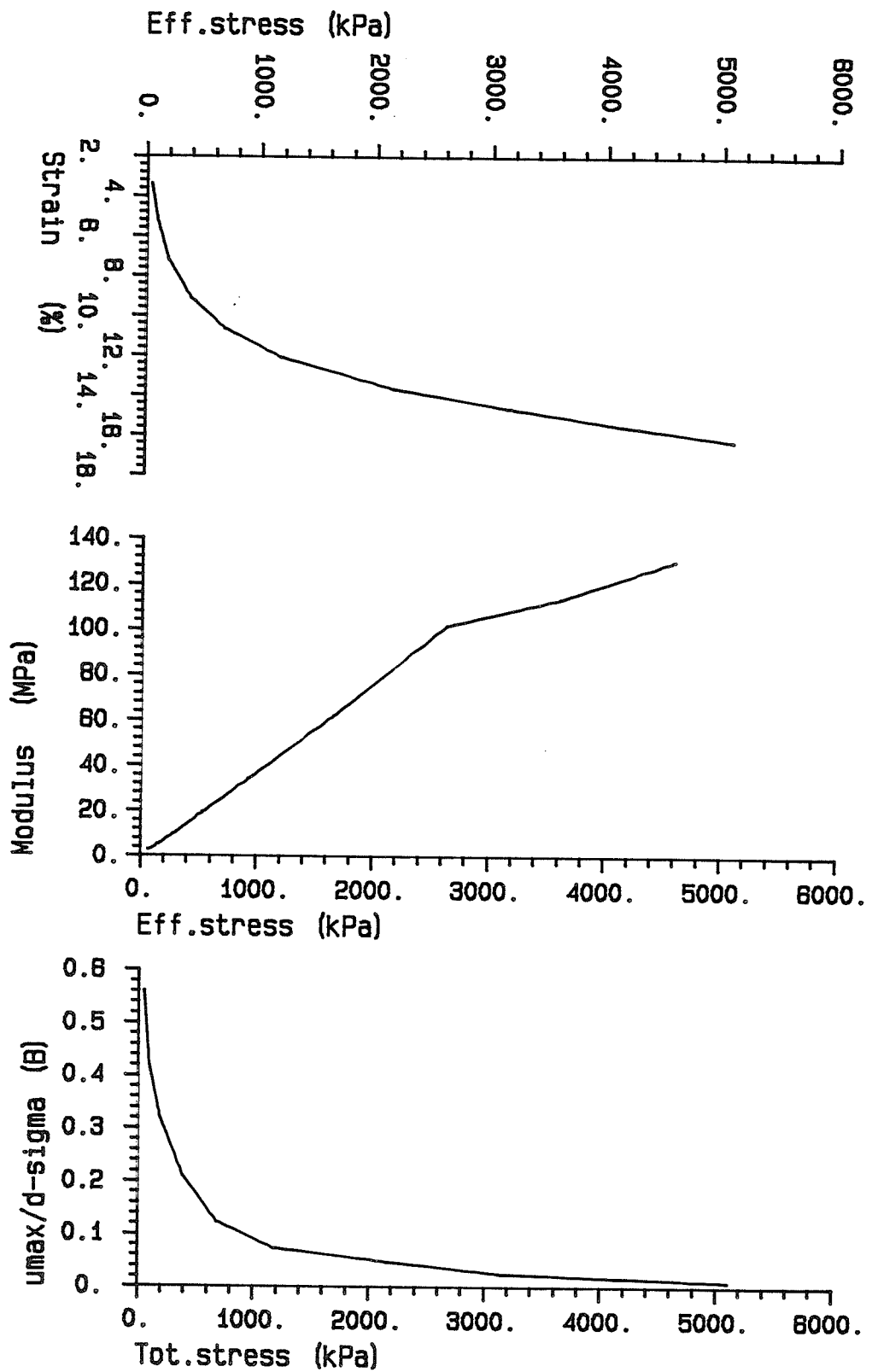
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12 JAN., 1989

FIG.

A-6



IL - oedometer.

**IKU, 7127/10-U-02, F376, D=125.52m

PROJECT

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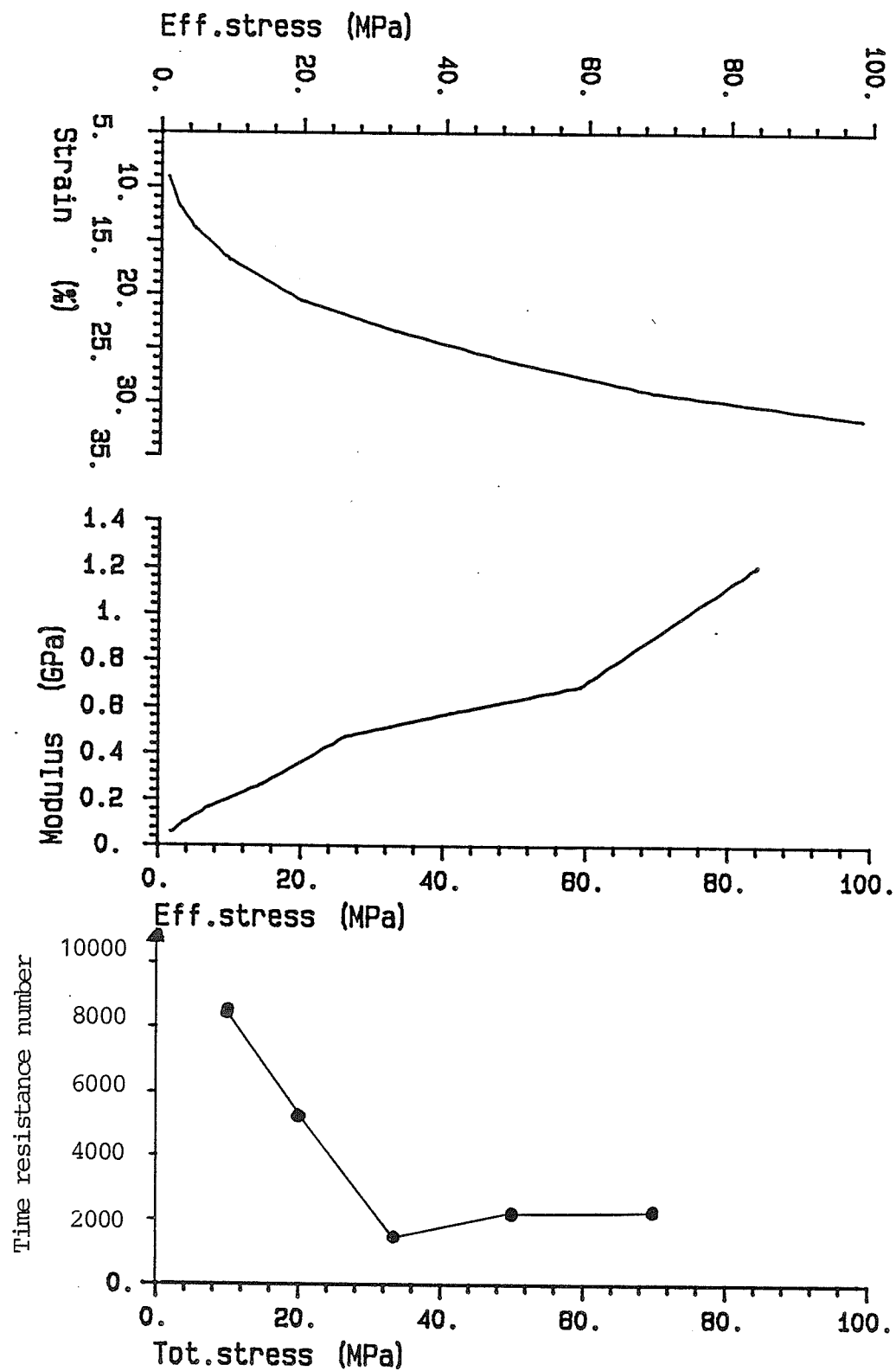
22 DEC., 1988



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FIG.

A-7



IL - oedometer.

**IKU, 7127/10-U-02, F376, D=125.52m



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PROJECT

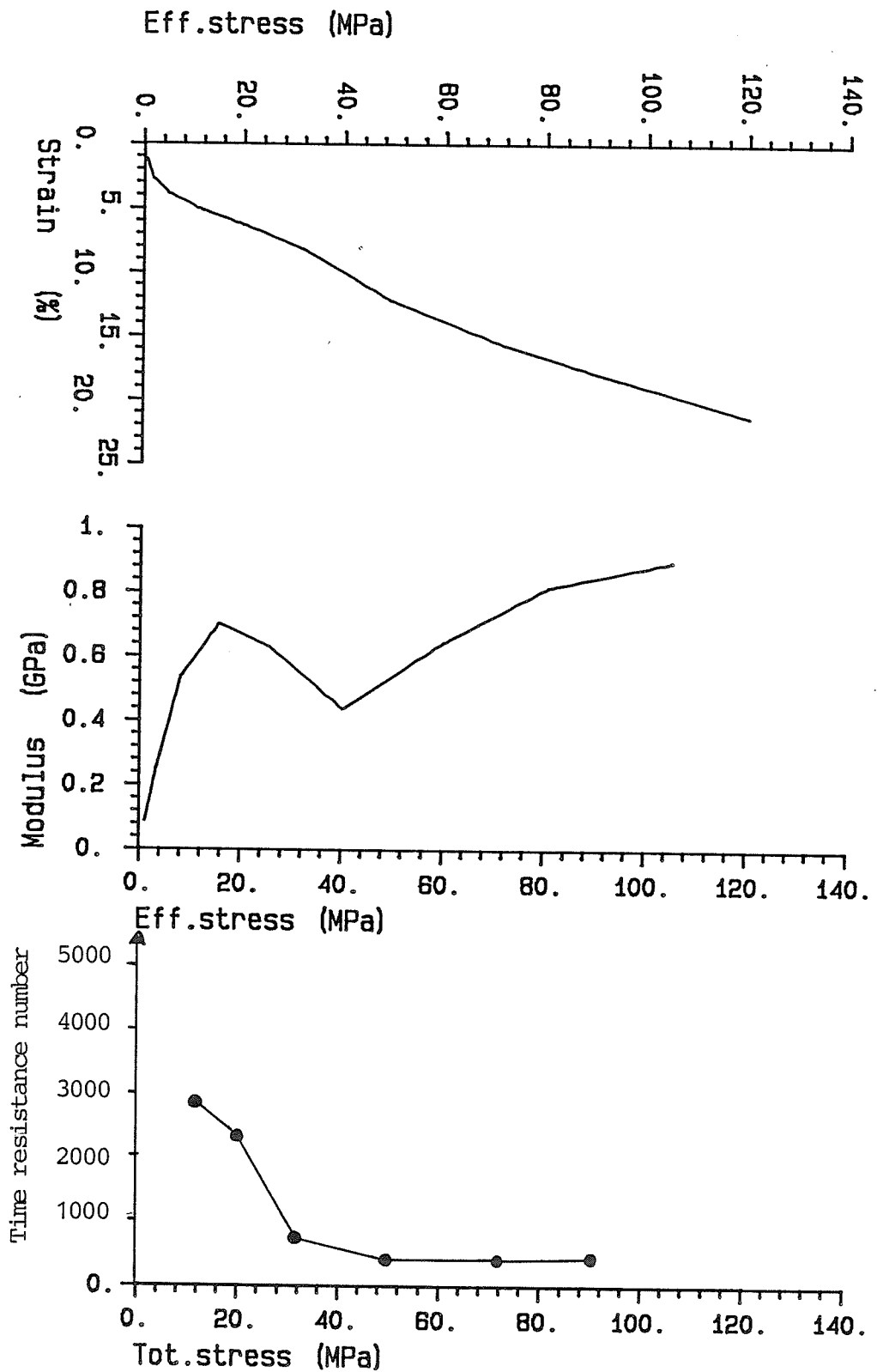
690151

DATE

27 DEC., 1988

FIG.

A-8



IL - oedometer.

**IKU, 7128/09-U01, F806, D=75.26m

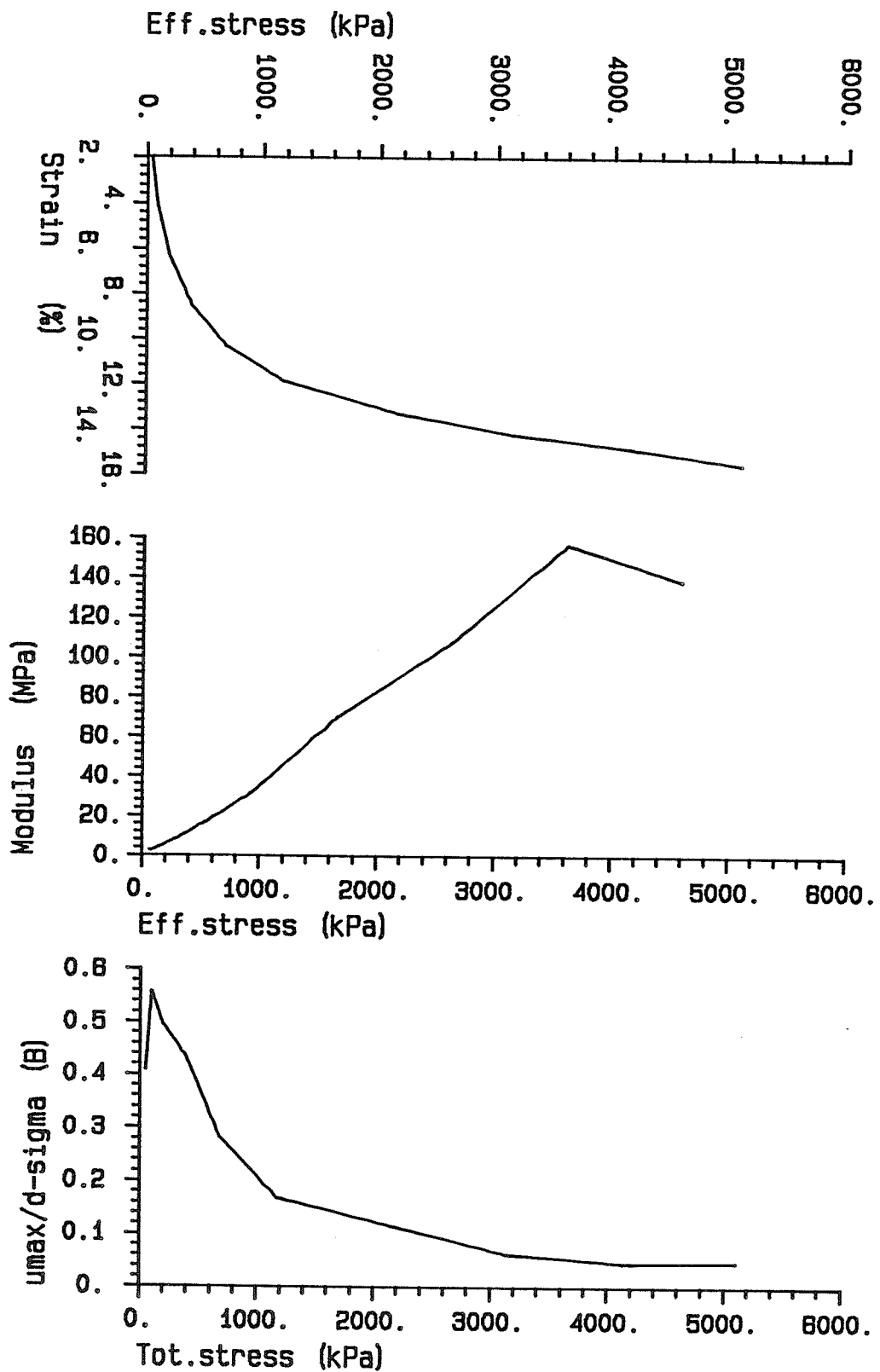


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DATE
21 DEC., 1988

FIG.
A-9



IL - oedometer.

**IKU, RUN20, 7029/03-U-01, D=125.53 M



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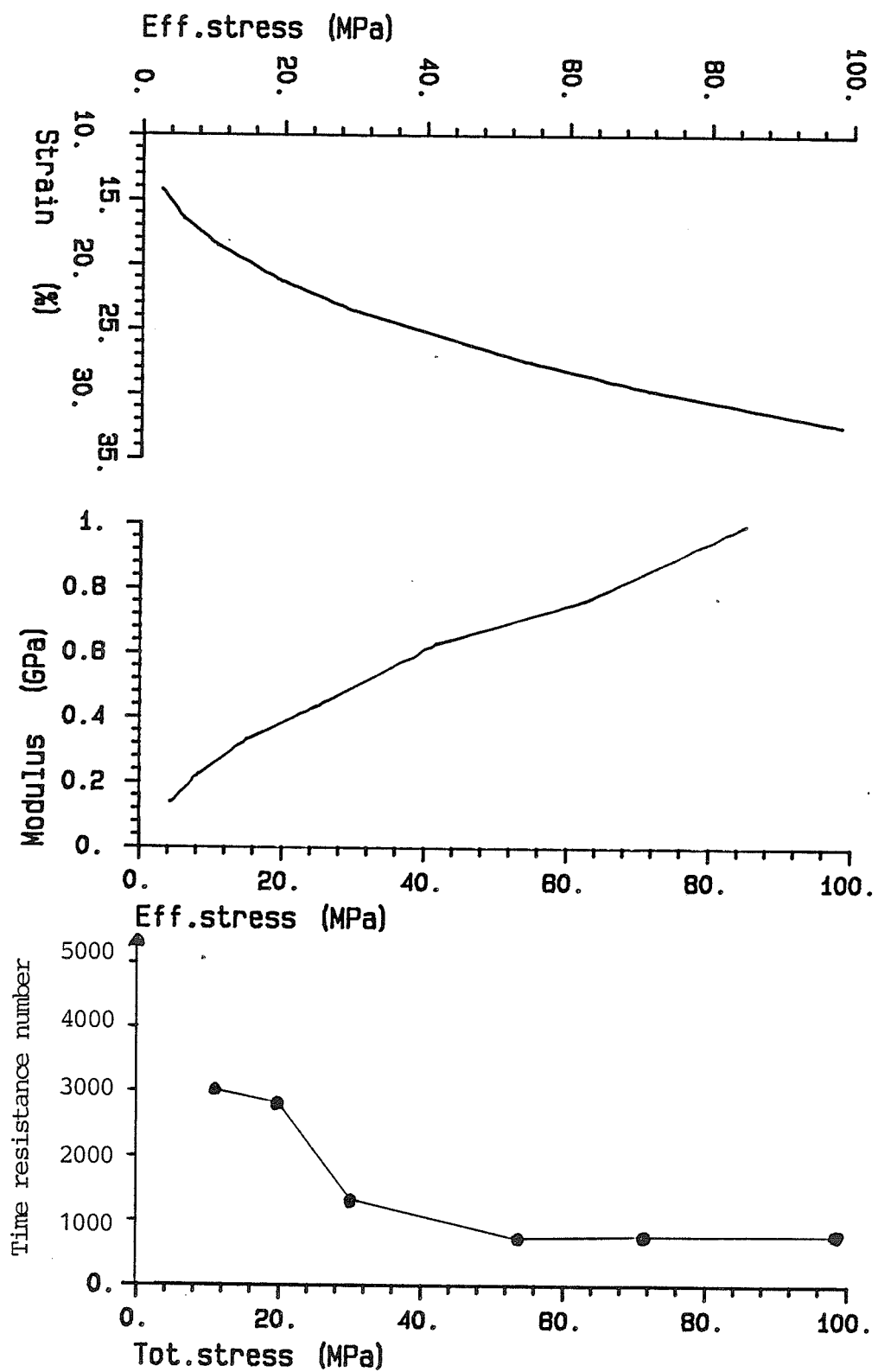
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DATE

11 JAN., 1989

FIG.

A-10



IL - oedometer.

**IKU, 7029/03-U-01, FB74, D=125.53m



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690151

DATE

14 JAN., 1989

FIG.

A-11

APPENDIX A.5
DISCUSSION OF PETROPHYSICAL CORE
MEASUREMENTS AND WIRELINE LOGS

A.5 DISCUSSION OF PETROPHYSICAL CORE MEASUREMENTS AND WIRELINE LOGS

A.5.1 The logging operations

With aims to gain a maximum of information from the cores and the drillholes, an extensive program for core measurements and downhole logging was carried out. No major technical problems occurred during the logging operations.

The logging operations was done by the logging section of BPB (British Plaster Board Instruments Ltd.) who perform API calibrated slim line logging. A full log suite for each well contained gamma, long spaced and short spaced sonic, bed resolution and long spaced density, neutron porosity, caliper, dipmeter and full waveform sonic. Full waveform sonic was not run at all mainly due to low sound velocity (below 3000 m/s). To ensure that some log data were collected, some of the wells were logged in two runs, one inside the HR drill string and one in open hole after pulling the drill string. Table A.5.1 summarizes the operational data for the logging operations and Table A.5.2 the technical data of the sondes and logs.

The logging values were recorded both on analog and digital form. The logs are sent to the participants plotted on paper and as LIS format tapes. Please note that the logs are not finally depth shifted and that the sonic logs on the tapes are recorded in $\mu\text{s}/\text{ft}$.

The dipmeter data were used to define the dip direction of the formations and further used to interpret the depositional environment of the sediments.

Horizontal sound velocity measurements and spectral gamma measurements on cores were done contemporaneously with the drilling operations in the laboratory on board, see Appendix A.3. These data were recorded on the survey data base. Lab and log sonic and gamma measurements are plotted side-by-side for each core and matched visually, see figures in sections "Petrophysical logs and core measurements" of each core description chapter.

Porosity and permeability have been measured by GECO on samples from the sandstone formations. In addition, porosity has been measured by image

Table A.5.1 Sondes run and operational comments.

Hole no.	Sondes run	Depths	Remarks
7430/10-U-01 Water depth 335 m	I) DD3, NN1 II) MS1	67-0 m -	I) Run through HR drill string. II) HR withdrawn, but hole had collapsed below API.
7430/07-U-01 Water depth 343 m	I) DD3, NN1 II) MS1, DV1 DD3, NN1	66-0 m 118-18 m 118-0 m	I) Run through HR string. II) Hole drilled on to 118 m. HR pulled back to 18 m. Formation too slow for SS1.
7127/10-U-02 Water depth 279 m	I) DD3 II) MS1, DV1 DD3, NN1	198-0 m 198-75 m 198-0 m	I) Run through HR string. II) HR string pulled back to 75 m Formation too slow for SS1.
7127/10-U-03 Water depth 264 m	I) DD3 II) MS1 DD3 NN1	154-0 m 151-100 m 150-90 m 150-0 m	I) Run through HR string. II) HR string pulled back to 100 m. DD3 logged to 90 m and joined to run I.
7128/12-U-01 Water depth 409 m	MS1, DV1 DD3, NN1	159-62 m 158-0 m	HR drill string pulled back to 65 m.
7128/09-U-01 Water depth 408 m	DD3γray only	67-0 m	Core barrel lost downhole. Hole in bad condition so only γ attempted. Blocked off 3 m below API.
7029/03-U-01 Water depth 366 m	DD3 NN1	154-0 m 151-0 m 156-70 m	HR string pulled back to 73 m Hole filling in during logging.
7029/03-U-02 Water depth 308 m	I) DD3 II) MS1 DD3, MS1	198-0 m 192-12 m 192-0 m	I) Run through HR string. II) HR string pulled back to 11 m.

DD3 = Dual density, gamma ray, caliper

NN1 = Dual neutron (porosity), gamma ray

MS1 = Multichannel sonic

SS1 = Full waveform sonic

DV1 = Dipmeter

analysis on digitised BSE (backscattered electrons) images on samples from the two unconsolidated 7127/10 cores. Measured porosity values are plotted together with the neutron porosity log and total and effective porosity

Table A.5.2 Technical data for BPB sondes and logs.

Log type	LIS tape name	Sonde name	Source/receiver spacing	Unit
Gamma ray	GRNP	NN1		API
Gamma ray	GRDE	DD3		API
Long spaced density	LSDE	DD3	48 cm	g/ccm
L.s. dens., uncompensated	LSDU	DD3	48 cm	SDU
Bed resolution density	BRDE	DD3	15 cm	g/ccm
Neutron porosity	NPRS	NN1	45 cm	%
Caliper	CADE	DD3		inch
Long spaced sonic	SONL	MS1	60 cm	µs/ft
Short spaced sonic	SONS	MS1	20 cm	µs/ft
Dipmeter		DV2		

calculated with Elphick's (1987) algorithms in figures in each core description chapter and on the summary sheets in Appendix A.7.

Thermal conductivity has been measured on several samples and also calculated from the log values with algorithms developed by Griffiths (1987). This is discussed in Section A.5.3 below.

A.5.2 Depth shift of logs

There were some deviations between drillers depth and loggers depth on the survey. A manual correction of log depth was done on board and all depths were referred to depth in core (drillers depth). Optimal depth shift was later obtained by finding the maximum correlation coefficient for laboratory measurements of gamma and the gamma log for depth shifts between -2.0 and 2.0 m in 10 cm steps, shown as the maxima in Figures A.5.1 a-g. The resulting optimal depth shifts are listed in Table A.5.3. and have been added to the logging depths on the LIS tapes. These depth shifts were not added on the LIS format logging tapes forwarded to the oil companies.

Table A.5.3 Final depth shifts of the petrophysical logs.

Well	Depth shift (m)
7029/03-U-01	0.50
7029/03-U-02	0.20
7127/10-U-02	0.30
7127/10-U-03	0.10
7128/12-U-01	0.00
7430/07-U-01	0.00
7430/10-U-01	-0.70

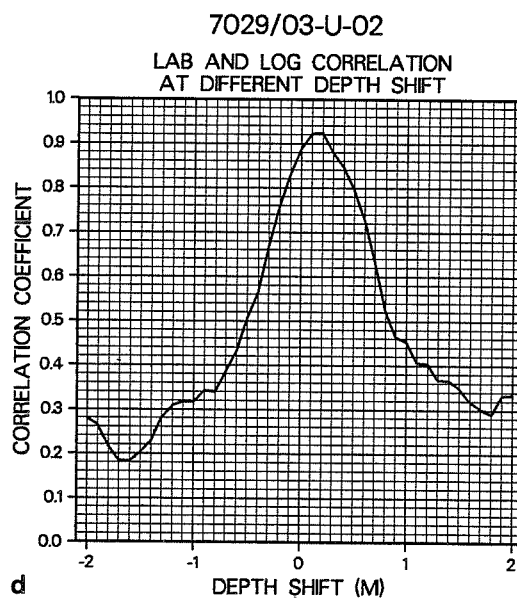
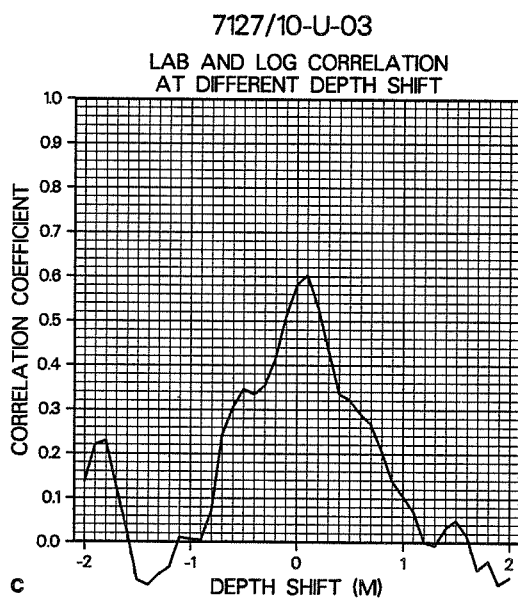
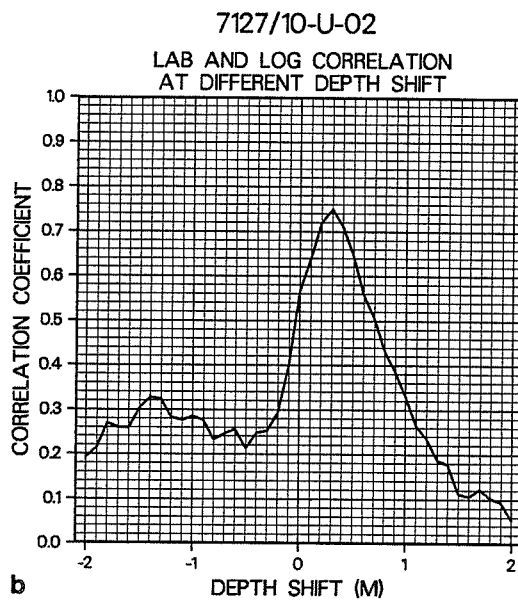
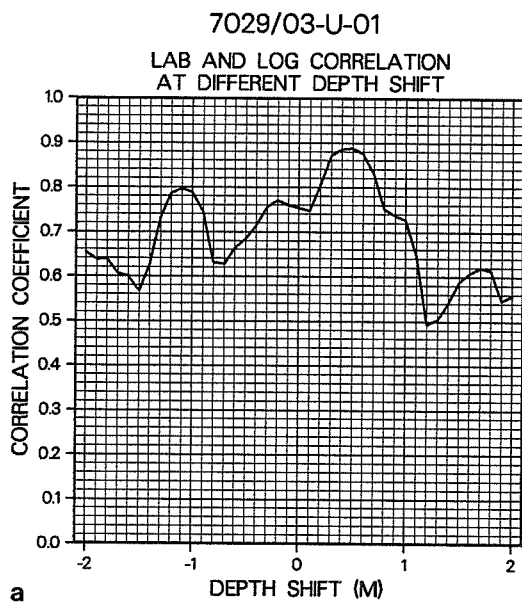


Figure A.5.1.a-d. Optimal depth shift calculation for wells 7029/03-U-01, 7127/10-U-02, 7127/10-U-03 and 7029/03-U-02.

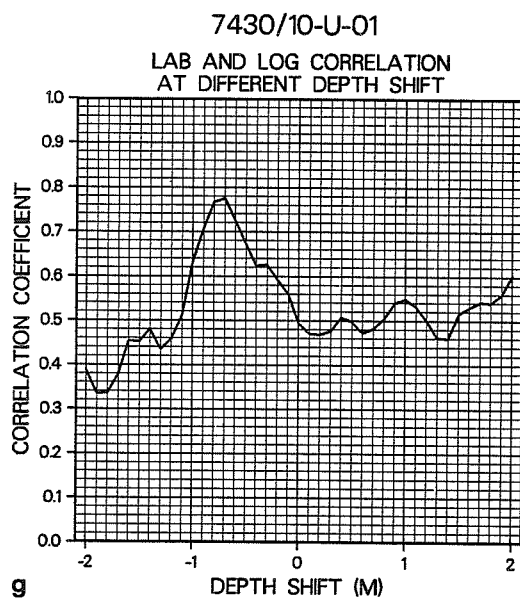
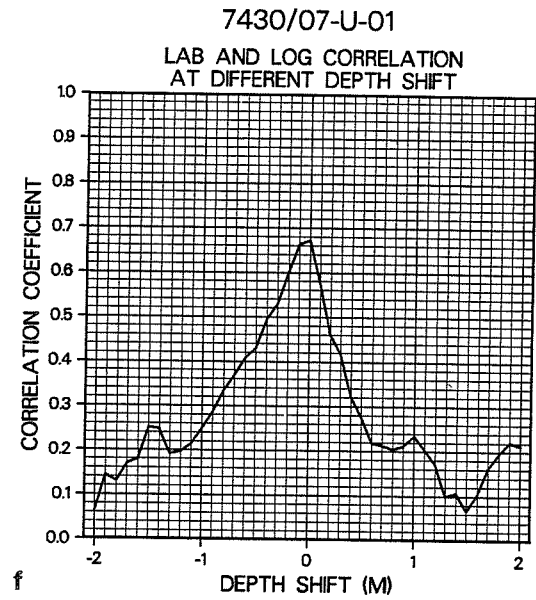
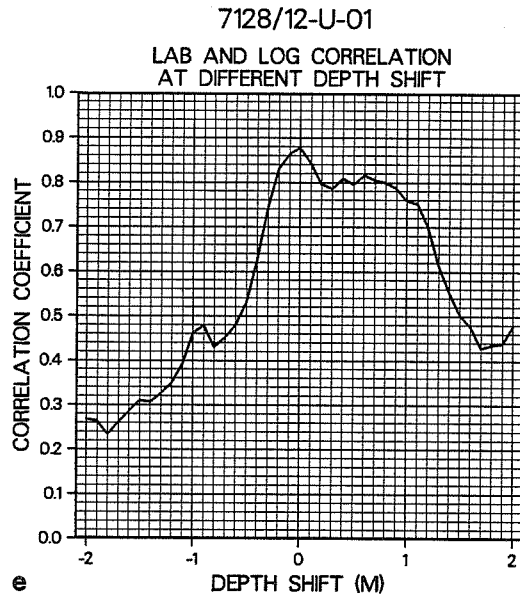


Figure A.5.1.e-g. Optimal depth shift calculation for wells 7128/12-U-01, 7430/07-U-01 and 7430/10-U-01.

The general level of the correlation coefficients in Figures A.5.1 may be regarded as a measure of how well the core losses have been correlated to the logs. Especially wells 7127/10-U-02, 7127/10-U-03 and 7430/07-U-01 show generally low levels of correlation coefficients. The unconsolidated sediments in the 7127/10 cores made it very difficult to correlate the small core losses to the logs.

For the wells with the highest correlation coefficient peaks, the depth shift and the distribution of core losses have been most successful (i.e. 7029/03-U-02, Figure A.5.1.d). The three maxima for well 7029/03-U-01 in Figure A.5.1.a are difficult to explain. One reason might be that there has been a kind of cyclicity in the sedimentary processes during deposition of the rocks.

A.5.3 Log and laboratory measurements of porosity

Measured porosity values are plotted together with the neutron porosity log and total and effective porosity calculated with Elphick's (1987) algorithms in figures in the core description chapters and on the summary sheets in Appendix A.7.

Elphick's (1987) algorithm needs some mineral densities as input parameters, and 2.5 g/cm^3 is used as density of dry clay and 2.65 g/cm^3 as density of heavy minerals. Other density values may have changed the results. The algorithms are developed for shaly sands and do not compensate for high gamma values caused by K-feldspar in arkosic sandstones. Where K-feldspar is present, the algorithms interpret this as high clay contents and the result is too high V_{clay} and too low effective porosity. These algorithms are also used in carbonatic rocks, and the results of this must be interpreted with care.

The plots of the different porosity values show varying correlations between measured values and total or effective porosity. The porosity values measured on SEM on samples from the 7127/10 cores, show the best correlation with calculated total porosity.

The poor correlation for some of the other wells (i.e. 7128/12-U-01 and 7430/07-U-01) may be due to wrong input of mineral density parameters, to

high K contents in other minerals than clay (i.e. K-feldspar) or to carbonate rocks.

A.5.4 Gamma log inside drill string and in open hole

Gamma logs from wells 7029/03-U-02, 7127/10-U-03 and 7430/07-U-01 were run both inside the HR drill string and in open hole. This provides a means for establishing a relationship between API gamma values measured inside the HR drill string and values from open hole logging. As Figure A.5.2 shows the relationship is:

$$\text{OPEN(API)} = 1.313749 * \text{HR(API)} - 2.0$$

The correlation coefficient is 0.97. OPEN is the API value measured in open hole and HR is the API value measured inside the HR drill string. This equation is used to calculate open hole API values from parts of wells logged through the HR string (e.g. 7430/10-U-01).

A.5.5 Log and laboratory measurements of natural gamma radiation

The gamma log values are depth shifted and displayed together with the lab measured gamma values for each core in figures in the core description chapters for visual and qualitative correlation. Both the trends and discrete values seem to correlate well.

Linear regression analyses of the lab measurements of total gamma radiation in counts/10 min vs. the values from the gamma log in API units has been performed for all the wells except for 7128/09-U-01, and the data are plotted in Figures A.5.3.a-g. All the lab/log gamma data are plotted together in Figure A.5.4. Deviations of sampling depth between the two measurement methods are maximum 5.0 cm. The result of this analysis is that the empirical linear formula for converting IKU lab measurements of total gamma radiation in counts/10 min (CM) to API units is:

$$\text{API} = 0.012805 * \text{CM} - 202.3$$

with correlation coefficient 0.78, based on 413 measurements from the Barents Sea project (Figure A.5.4). This equation is very much like the result of an analog regression analysis performed on similar data from another shallow drilling survey by IKU.

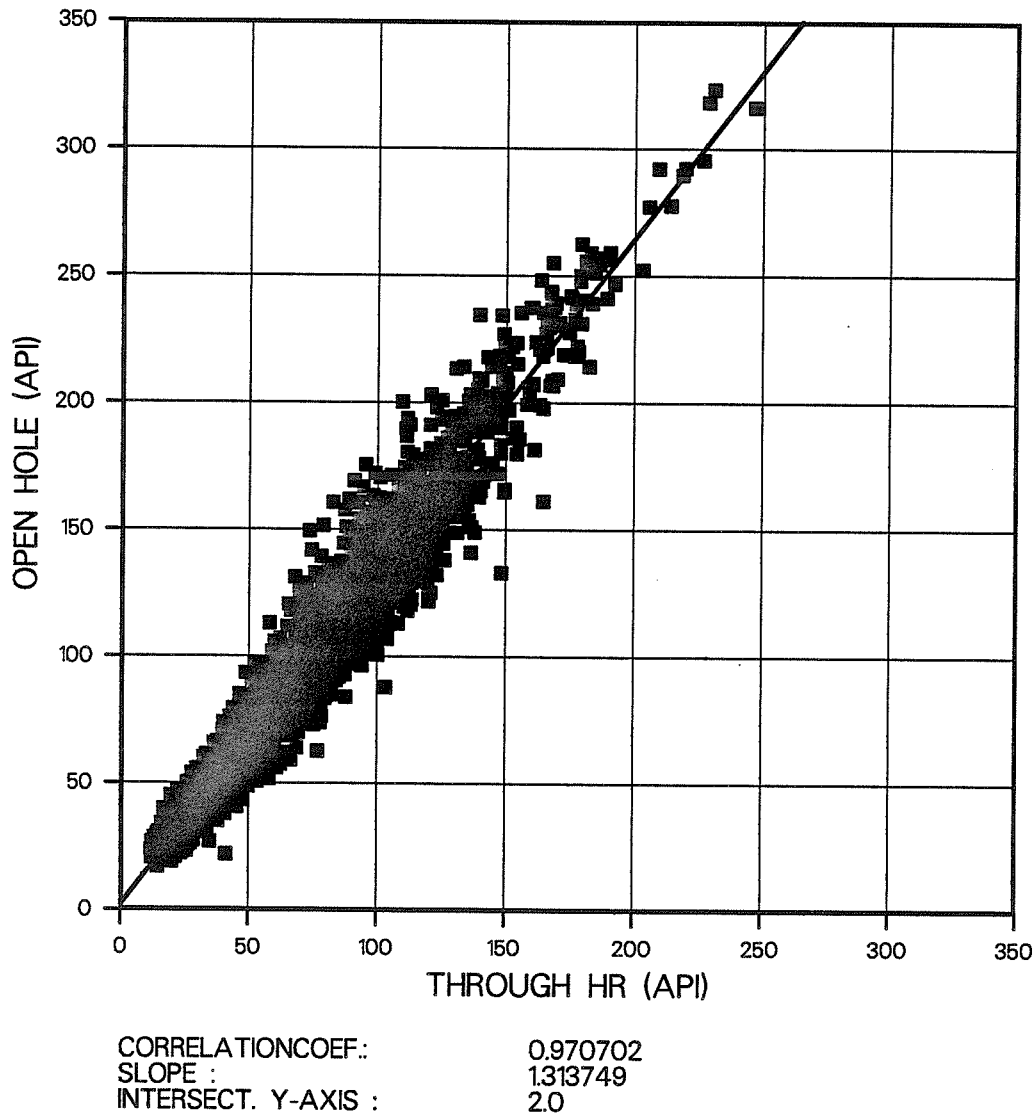


Figure A.5.2 Correlation between gamma logged inside the HR drill string and in open hole.

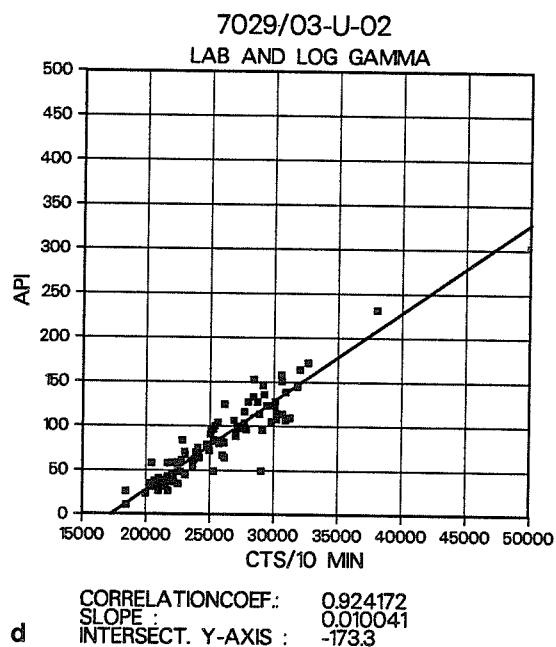
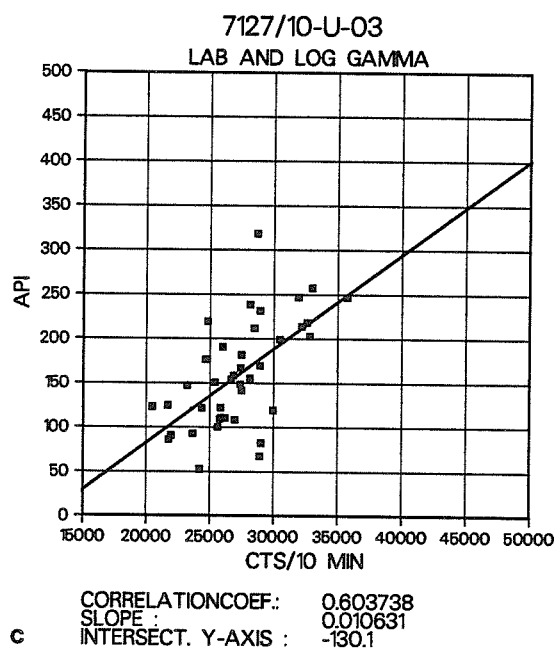
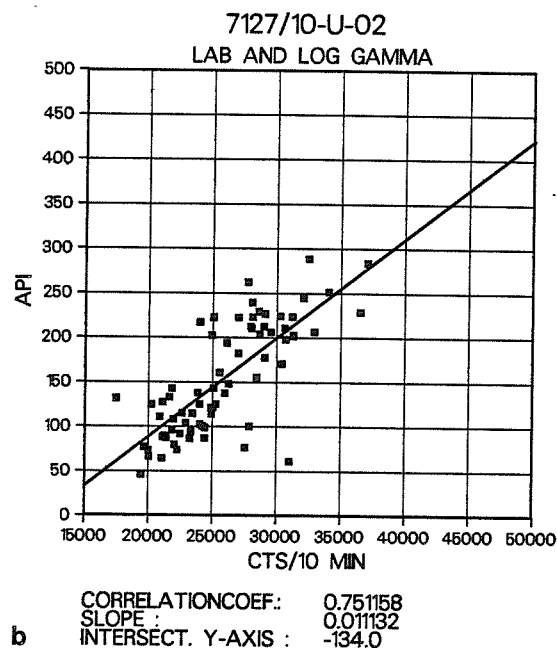
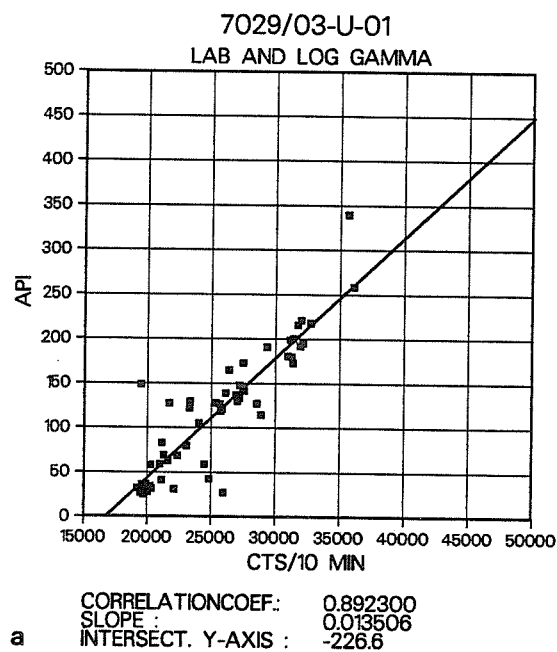


Figure A.5.3.a-d. Crossplot of lab measurements of total gamma radiation (counts per. 10 minutes) and log values (API) for wells 7029/03-U-01, 7127/10-U-02, 7127/10-U-03 and 7029/03-U-02.

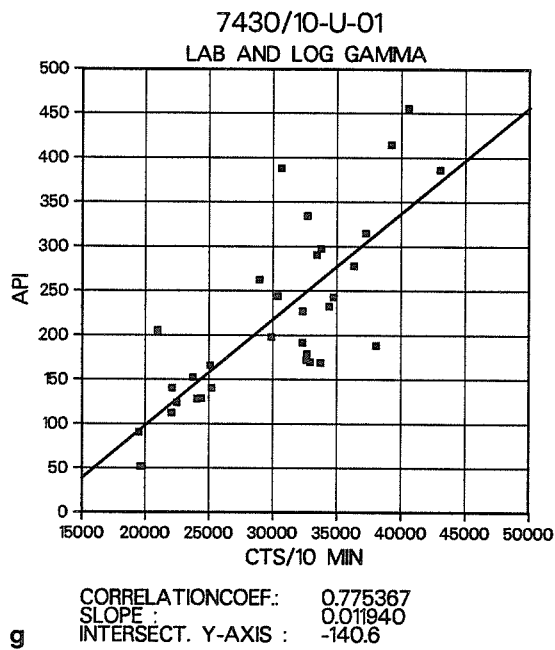
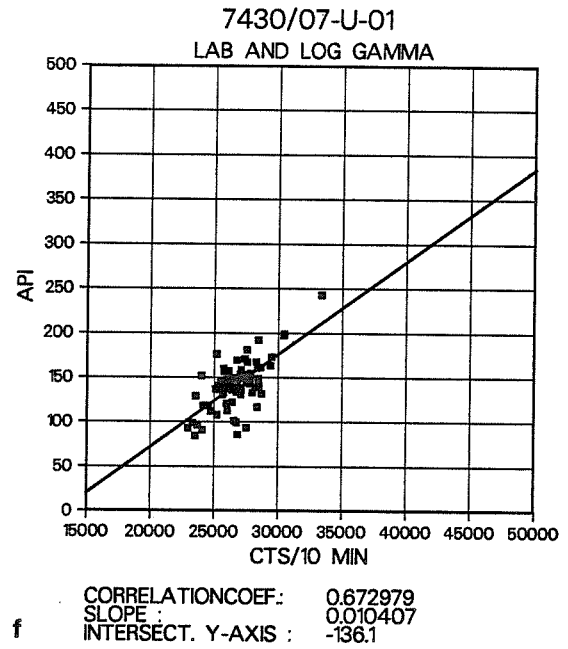
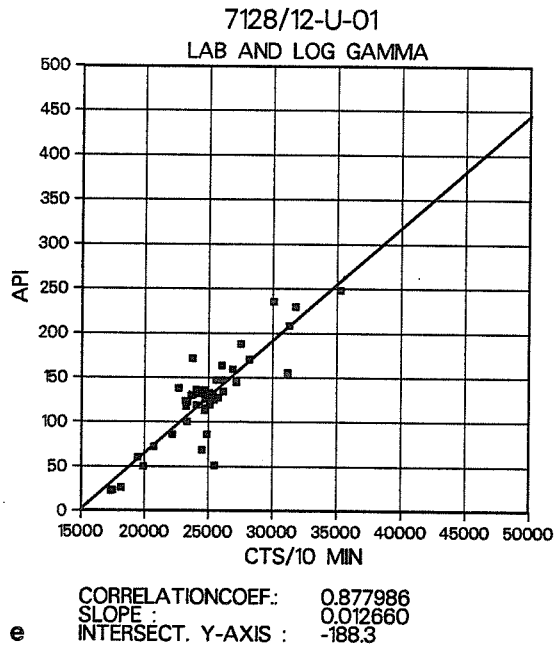


Figure A.5.3.e-g. Crossplot of lab measurements of total gamma radiation (counts per. 10 minutes) and log values (API) for wells 7128/12-U-01 and 7430/07-U-01.

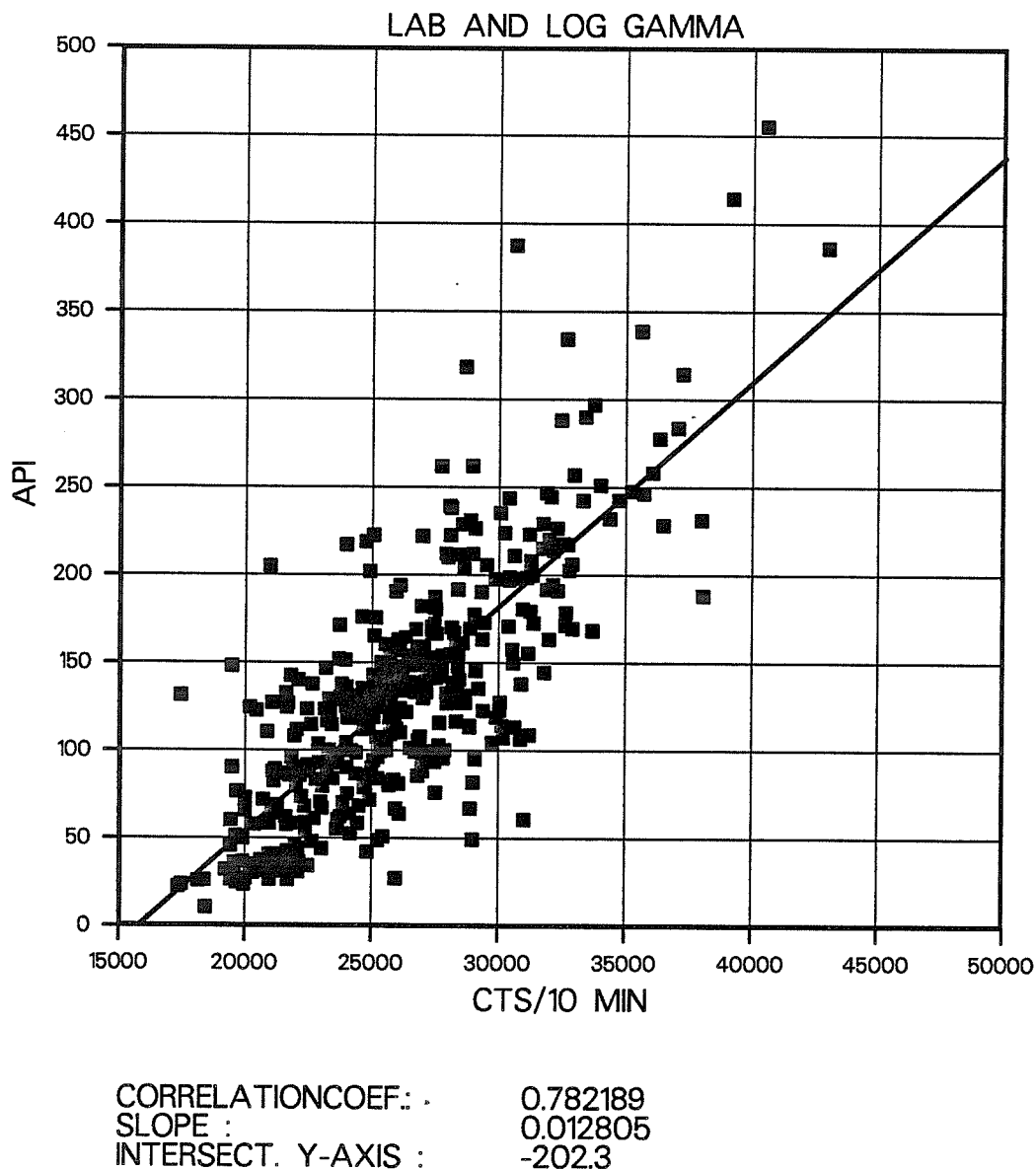


Figure A.5.4. Crossplot of lab measurements of total gamma radiation (counts per. 10 minutes) and log values (API) for all wells.

The correlation coefficients of the linear regression analyses of each well in Figure A.5.4 may, in the same way as Figure A.5.1, be regarded as a measure of how successful the depth shifts and the distribution of the core losses have been. This has been most successful for well 7029/03-U-02, with its correlation coefficient of 0.92, and least successful for well 7127/10-U-01 which has a correlation coefficient of 0.60.

A.5.6 Log and laboratory measurements of sound velocity

The log measured sonic velocity values are displayed together with the sound velocity values calculated from the long spaced sonic log for each core in the core description chapters for visual and qualitative correlation. The trends and discrete values seem to correlate reasonably well.

Figures A.5.5 a-f and Figure A.5.6. show crossplots of the values from the lab measurements of horizontal sound velocity vs. sound velocity calculated from the short spaced sonic log. The short spaced sonic log is used because even the source/reciever spacing for this log (20 cm, see Table A.5.2) is large compared to the diameter of the transducers of the Pundit (Appendix A.3). Deviations of sampling depth between the two measurement methods are maximum 5.0 cm. Figure A.5.6 shows a good correlation between the lab and log values with a correlation coefficient equal to 0.79 based on 1055 measurements.

The crossplot of all the data shows a significantly higher correlation coefficient than the average of the coefficients for each well. Only well 7029/03-U-01 shows higher correlation coefficient than the crossplot of all the data. Only three of the wells show any kind of correlation between log and lab measurements. As for the gamma lab and log correlation, wells 7127/10-U-02, 7127/10-U-03 and 7430/07-U-01 show the lowest degree of correlation, in fact, the data for these wells cluster around single points and do not correlate at all. The crossplot of all the data shows, however, that these three clusters together make a good correlation.

Thermal conductivity

Thermal conductivity has been measured on 44 samples from seven of the eight cores. Based on the wireline logs, thermal conductivity has also been calculated from all the wells except for 7128/09-U-01 and 7430/10-U-01 which were not logged in open hole. The laboratory measurements were performed by N. Balling at the University of Aarhus, Denmark. His report is as follows behind Figure A.5.6 below.

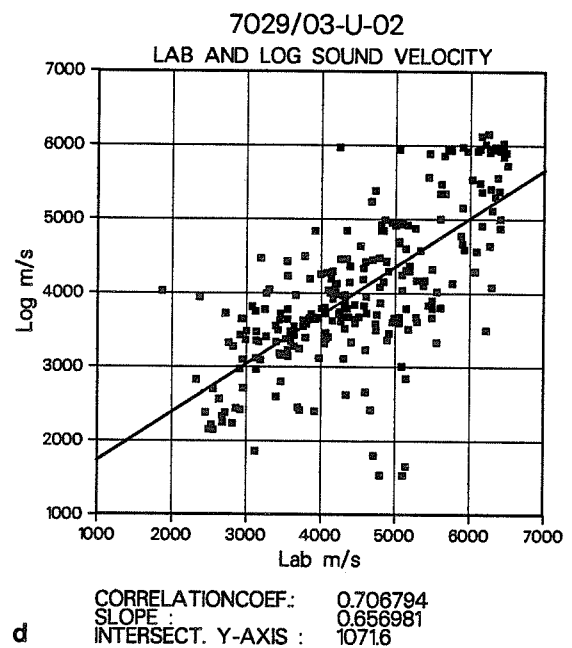
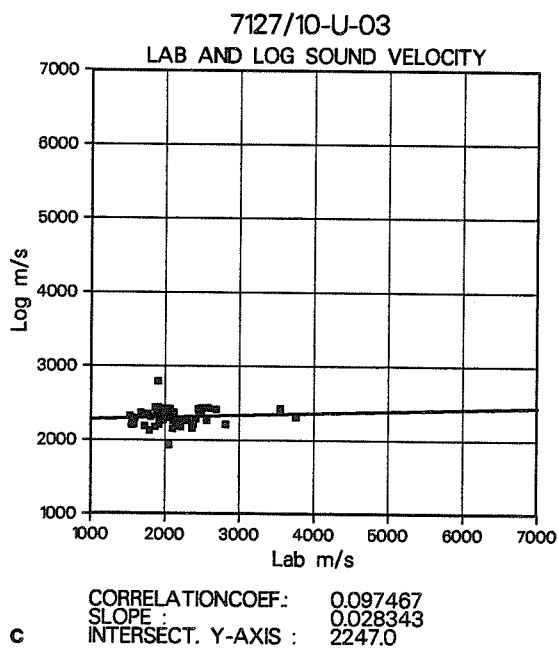
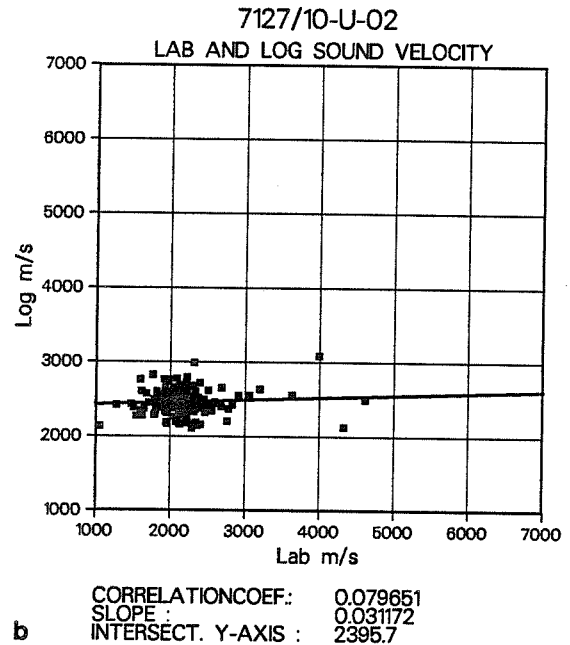
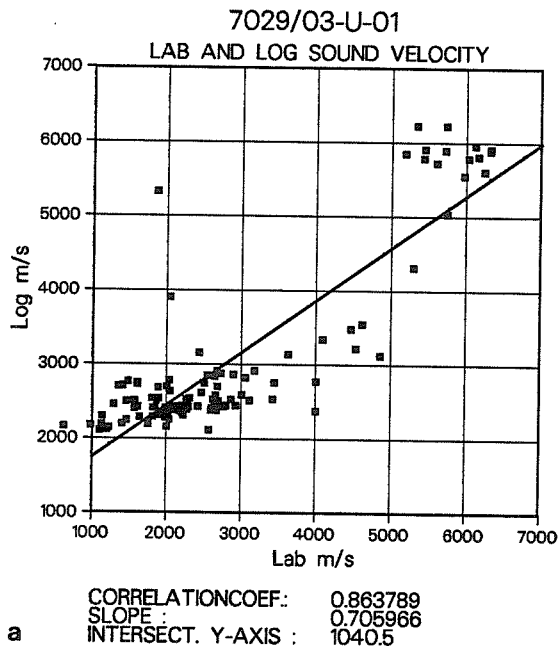
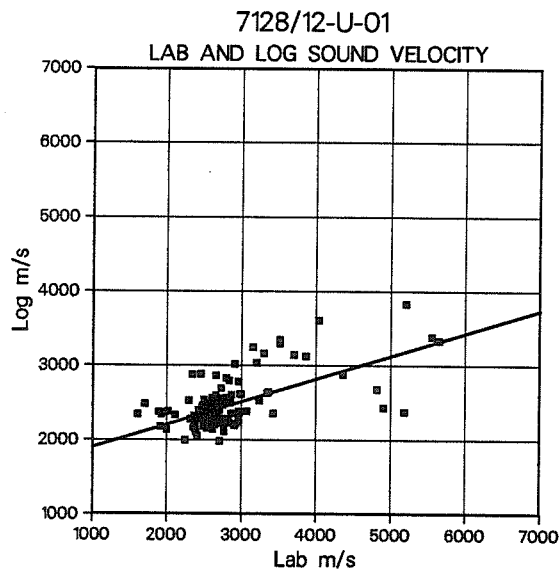
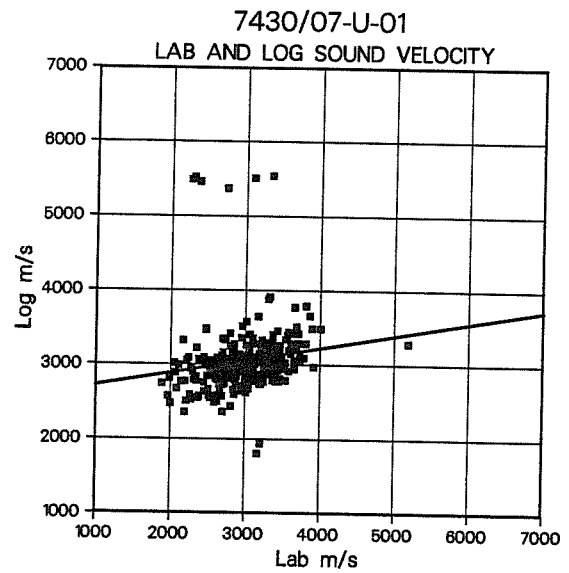


Figure A.5.5.a-d. Crossplot of lab measurements of horizontal sound velocity and sound velocity calculated from the short spaced sonic logs for wells 7029/03-U-01, 7127/10-U-02, 7127/10-U-03 and 7029/03-U-02.

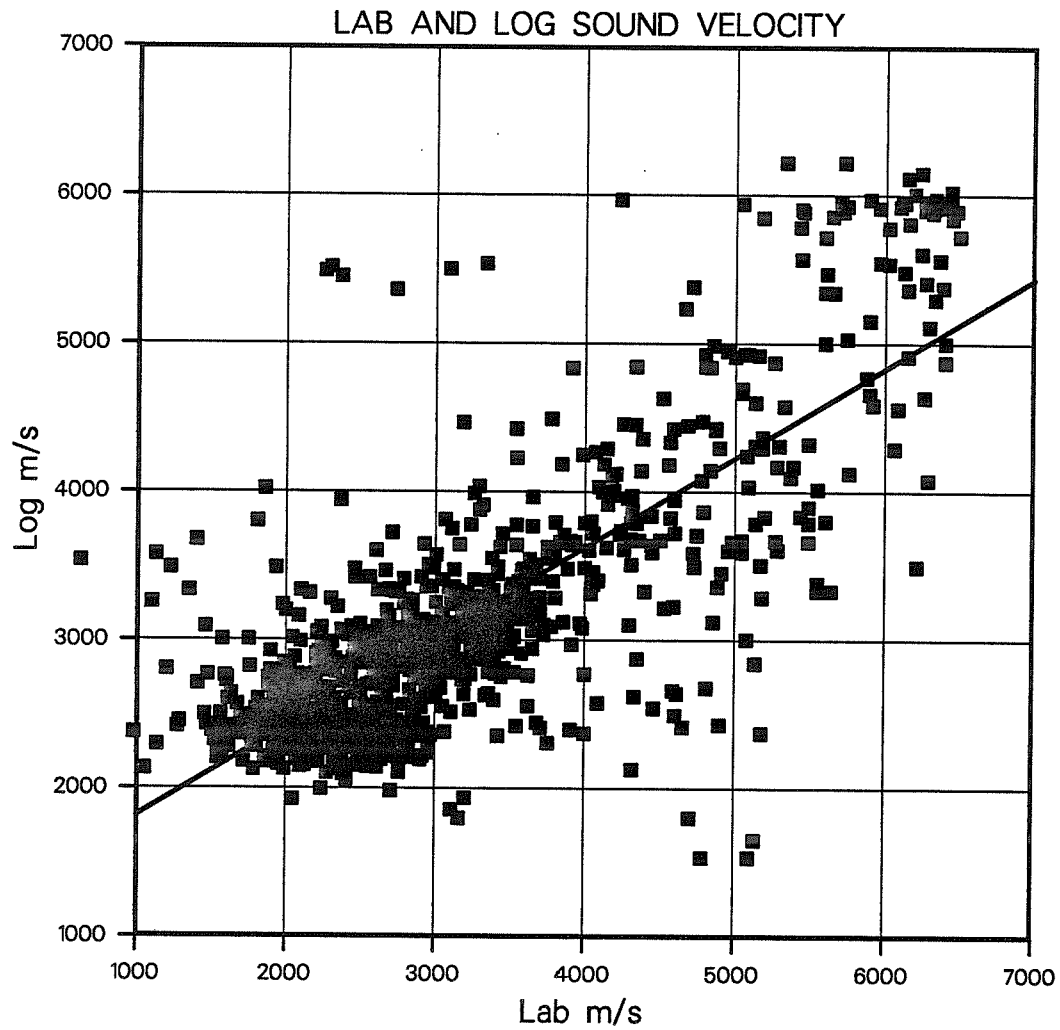


e CORRELATIONCOEF.: 0.616404
SLOPE : 0.306662
INTERSECT. Y-AXIS : 1593.8



f CORRELATIONCOEF.: 0.178142
SLOPE : 0.168478
INTERSECT. Y-AXIS : 2545.9

Figure A.5.5.e-f. Crossplot of lab measurements of horizontal sound velocity and sound velocity calculated from the short spaced sonic logs for wells 7128/12-U-01 and 7430/07-U-01.



CORRELATIONCOEF.: 0.785137
SLOPE : 0.604200
INTERSECT. Y-AXIS : 1206.5

Figure A.5.6. Crossplot of lab measurements of horizontal sound velocity and sound velocity calculated from short spaced sonic logs for all wells.

***** N. Balling's report *****

THERMAL CONDUCTIVITY

Introduction

Thermal conductivity has been measured on 44 bedrock core samples from the IKU-1988 Barents Sea core units. The cores are of cylindrical shape with diameters of about 55 mm and length generally between 100 and 150 mm.

This report contains a description of the measuring technique, measuring conditions and the measuring results. Special emphasis is given to the measurements of any thermal conductivity anisotropy.

Measuring techniques

The measurements were taken by the needle probe method. The probes used have a length of 50 mm and an outer diameter of 1.5 mm. Since all cores are more or less lithified, small holes were drilled with high speed drills for the insertion of the needle probes. The diameter of drills used is 1.5 mm, thus resulting in drill holes of only slightly larger diameter and generally of perfect size for the insertion of the measuring probes.

Measurements were carried out on water saturated samples at room temperature (~20°C) and generally at normal pressure (1 bar). A few samples were measured at slightly higher pressure (10-20 bar) to minimize effect of minor secondary cracks developed along bedding planes during transportation and during drilling of the small holes for the conductivity measurements. Full waver saturation was ensured by keeping samples in water under vacuum for at least 24 hours before measurements.

Generally, for each sample 4 single measurements were carried out; 2 measurements in two mutually perpendicular directions in the "top part" of the sample and 2 measurements in the "bottom part" of the sample. From these measurements conductivity anisotropy may be determined as well as local variations in conductivity. For a few samples (4) only two measurements were carried out due to difficulties in drilling holes into very hard rock materials.

From measurements with the needle placed along the core axis (vertical direction), the horizontal conductivity (k_h) is measured, and from measurements with the needle placed in the perpendicular (horizontal) direction a weighted mean (k_m) of horizontal (k_h) and vertical conductivity (k_v) is measured. As $k_m = (k_h \cdot k_v)^{1/2}$ we obtain k_v as k_m^2/k_h .

During measurements all needle probes used were currently tested in standard material of known conductivity. The needle probe technique used shows a conductivity repeatability generally within 1-3%. Depending on the quality of the core material conductivity results normally show absolute inaccuracy less than 5%.

Results of measurements

Measuring results are summarized in Tables 1 and 2. Generally for each core sample horizontal conductivity (k_h), vertical conductivity (k_v), and the coefficient of conductivity anisotropy ($A = k_h/k_v$) are given.

Table 1 contains sample mean values. In table 2 also the original "top" and "bottom" sets of measuring results are given. The sample values are determined as mean values of "top" and "bottom" sets of measurements.

Also a sample quality code is given (table 2). Quality code 2 is assigned to samples where minor cracks may, to some extent, affect the measuring results. In no cases such cracks are assumed to affect measuring results by more than 5-10%. The effect of cracks may be a minor decrease in conductivity.

For 15 sets of measurements (marked with (a) in table 2) original data sets showed indications of conductivity anisotropy coefficients significantly less than 1 (≤ 0.95). However, inspection of core samples indicated that apparent reversed anisotropy may result from local conductivity variability or local minor cracks rather than well defined conductivity anisotropy. In those cases conductivity values given are determined as mean values of measurements in the different directions (mean value of k_h and k_m) resulting in no resolved conductivity anisotropy.

A few data sets still show $A < 1$. This may not necessarily be due to well defined reversed conductivity anisotropy, but may be due to more complex

anisotropy, local conductivity variability, experimental uncertainty or combined effects. Results for kv with $A < 1$ should be used with caution. Vertical conductivity may here be slightly (5-10%) overestimated.

Generally, "top" and "bottom" sets of measurements show very good agreement, typically within $0.1-0.3 \text{ W m}^{-1} \text{ K}^{-1}$. In some cases differences of about $0.5-0.8 \text{ W m}^{-1} \text{ K}^{-1}$ are observed. Differences greater than $0.3 \text{ W m}^{-1} \text{ K}^{-1}$ are here assumed to be due to real local variability of rock conductivity and not due to experimental uncertainty in relation to cracks etc.

For each of the 7 wells, mean conductivity values are calculated for the actual samples together with standard deviation and standard error of the mean. These values are given mainly for statistical reasons and not to indicate lithologically representative station averages.

As a whole the data sets shows a high degree of internal consistency. Conductivities and the coefficients of conductivity anisotropy are generally well determined. Some core samples (e.g. 7430/01-U-1, 22.55; 7127/10-U-02, 144.59 and 7127/10-U-02, 166.40) show higher than normal local variability of conductivity. Conductivity anisotropy is generally very significant.

Table 1: Thermal conductivity (W/mK)

Sample number		kh(k)	Sample kv(k)	A
7430-10-U-01				
F 45	46.05	1.59	0.71	2.23
F 62	57.23	1.63	0.87	1.86
Mean value		1.61	0.79	2.04
Stand. deviation		0.03	0.11	0.26
Stand. err. of mean		0.02	0.08	0.18
7430/07-U-1				
F 116	22.55	2.59	1.96	1.32
F 117	28.10	1.84	1.49	1.24
F 127	37.43	2.47	1.84	1.35
F 160	71.42	3.66	3.52	1.04
F 181	95.13	2.40	2.02	1.19
F1363	92.22	2.16	2.04	1.06
Mean value		2.52	2.14	1.20
Stand. deviation		0.62	0.70	0.13
Stand. err. of mean		0.25	0.29	0.05
7127/10-U-02				
F 345	100.42	1.30	1.22	1.06
F 361	114.08	1.79	1.37	1.31
F 388	134.37	2.38	1.52	1.57
F 407	144.59	3.15	3.15	1.00 (a)
F 423	157.51	2.21	1.71	1.30
F 444	166.40	2.72	2.31	1.18
F 455	175.28	2.00	1.33	1.50
F 473	182.42	2.14	1.79	1.20
F 496	197.56	3.24	2.91	1.12
Mean value		2.45	2.01	1.27
Stand. deviation		0.53	0.70	0.19
Stand. err. of mean		0.19	0.25	0.07
7127/10-U-03				
F 526	95.46	1.72	1.33	1.29
F 554	116.18	1.83	1.34	1.36
F 568	125.59	2.00	1.10	1.82
F 592	143.15	2.74	2.68	1.02
Mean value		2.07	1.61	1.37
Stand. deviation		0.46	0.72	0.33
Stand. err. of mean		0.23	0.36	0.17
7128/12-U-01				
F 635	86.86	1.93	1.17	1.65
F 671	113.64	2.20	2.20	1.00 (a)
F 693	141.18	1.62	1.48	1.10
F 712	158.95	2.75	2.43	1.13
Mean value		2.13	1.82	1.22
Stand. deviation		0.48	0.60	0.29
Stand. err. of mean		0.24	0.30	0.15

Table 1 (continued):

Sample		kh(k)	Sample kv(k)	A
7029/03-U-01				
F 847	97.66	3.13	3.18	0.98
F 859	116.86	1.95	0.93	2.09
F 890	136.29	3.78	3.53	1.07
Mean value		2.95	2.55	1.38
7029/03-U-02				
F1364	17.00	1.43	1.46	0.98
F1365	21.72	2.04	1.89	1.08
F1366	30.73	3.53	3.62	0.97
F1047	66.90	2.67	2.61	1.03
F1073	77.80	3.05	3.19	0.96
F1110	91.82	3.13	3.13	1.00
F1113	96.02	2.01	1.69	1.19
F1116	104.65	2.17	1.80	1.21
F1367	126.47	3.66	3.31	1.11
F1368	136.75	2.76	2.60	1.06
F1155	158.73	2.81	2.64	1.06
F1162	168.80	3.07	2.91	1.06
F1178	177.51	2.89	2.73	1.06
F1182	192.51	3.27	3.16	1.03
F1198	38.73	2.68	2.63	1.02
F1199	59.40	2.39	2.35	1.02
Mean value		2.72	2.61	1.05

(a): Significant anisotropy not resolved.

Table 2: Thermal conductivity (W/mK)

Sample number	kh(k)	Sample kv(k)	A	kh(k)	Top kv(k)	A	kh(k)	Bottom kv(k)	A	Sample quality(b)
7430/10-U-01										
F 45	1.59	0.71	2.23	1.45	0.65	2.23	1.73	0.78	2.22	1
F 62	1.63	0.87	1.86	1.62	0.80	2.04	1.63	0.95	1.72	2
Mean value	1.61	0.79	2.04	1.54	0.72	2.13	1.68	0.86	1.97	
Stand. deviation	0.03	0.11	0.26	0.12	0.10	0.14	0.07	0.12	0.36	
Stand. err. of mean	0.02	0.08	0.18	0.09	0.07	0.10	0.05	0.09	0.25	
7430/07-U-01										
F 116	2.59	1.96	1.32	2.59	2.38	1.09	2.59	1.53	1.69	1
F 117	1.84	1.49	1.24	1.79	1.47	1.22	1.89	1.51	1.26	2
F 127	2.47	1.84	1.35	2.46	1.93	1.27	1.89	1.51	1.26	2
F 160	3.66	3.52	1.04	3.52	3.50	1.01	3.80	3.53	1.08	1
F 181	2.40	2.02	1.19	2.45	2.09	1.17	2.34	1.95	1.20	2
F 1363	1.16	2.04	1.06	2.27	1.17	1.05	2.06	1.92	1.07	1
Mean value	2.52	2.14	1.20	2.51	2.26	1.13	2.53	2.03	1.29	
Stand. deviation	0.62	0.70	0.13	0.57	0.68	0.10	0.68	0.76	0.24	
Stand. err. of mean	0.25	0.29	0.05	0.23	0.28	0.04	0.28	0.31	0.10	
7127/10-U-02										
F 345	1.30	1.22	1.06	2.59	2.44	1.06				1
F 361	1.79	1.37	1.31	1.69	1.48	1.15	1.88	1.26	1.49	2
F 388	2.38	1.52	1.57	2.46	1.48	1.66	2.31	1.56	1.48	1
F 407	3.15	3.15	1.00(a)	2.78	2.78	1.00(a)	3.52	3.52	1.00(a)	1
F 423	2.21	1.71	1.30	1.97	1.72	1.14	2.46	1.69	1.46	1
F 444	2.72	2.31	1.18	2.61	2.61	1.00(a)	2.84	2.01	1.41	1
F 455	2.00	1.33	1.50	2.15	1.43	1.51	1.84	1.24	1.49	2
F 473	2.14	1.79	1.20	2.10	2.19	0.96	2.17	1.38	1.57	1
F 496	3.24	2.91	1.12	3.30	3.08	1.07	3.19	2.74	1.17	1
Mean value	2.32	2.01	1.27	2.38	2.10	1.19	2.53	1.93	1.38	
Stand. deviation	0.53	0.70	0.19	0.51	0.66	0.26	0.61	0.81	0.20	
Stand. err. of mean	0.19	0.25	0.07	0.18	0.23	0.09	0.21	0.29	0.07	

Table 2: (Continued)

Sample number	kh/k)	Sample kv(k)	A	kh(k)	Top kv(k)	A	kh(k)	Bottom kv(k)	A	Sample quality(b)
7127/10-U-03										
F 526	1.72	1.33	1.29	1.84	1.39	1.32	1.60	1.26	1.27	1
F 554	1.83	1.34	1.36	1.76	1.32	1.34	1.89	1.37	1.39	1
F 568	2.00	1.10	1.82	2.24	1.08	2.07	1.76	1.12	1.58	1
F 592	2.74	2.68	1.02	2.82	2.70	1.04	2.67	2.67	1.00(a)	1
Mean value	2.07	1.61	1.37	2.16	1.62	1.32	1.60	1.26	1.27	
Stand. deviation	0.46	0.72	0.33	0.48	0.73	0.44	0.47	0.72	0.24	
Stand. err. of mean	0.23	0.36	0.17	0.24	0.37	0.22	0.24	0.36	0.12	
7128/12-U-01										
F 635	1.93	1.17	1.65	1.90	1.05	1.81	1.96	1.28	1.52	1
F 671	2.20	2.20	1.00(a)	2.19	2.19	1.00(a)	2.22	2.22	1.00(a)	1
F 693	1.62	1.48	1.10	1.58	1.58	1.00(a)	1.67	1.38	1.21	1
F 712	2.75	2.43	1.13	2.52	2.25	1.00(a)	2.98	2.34	1.27	1
Mean value	2.13	1.82	1.22	2.05	1.83	1.20	2.21	1.81	1.25	
Stand. deviation	0.48	0.60	0.29	0.40	0.65	0.40	0.56	0.55	0.22	
Stand. err. of mean	0.24	0.30	0.15	0.20	0.33	0.20	0.28	0.28	0.11	
7029/03-U-01										
F 847	3.13	3.18	0.98	2.94	2.94	1.00(a)	3.32	3.43	0.97	1
F 859	1.95	0.93	2.09	1.97	0.88	2.24	1.92	0.98	1.96	1
F 890	3.78	3.53	1.07	3.66	3.66	1.00(a)	3.89	3.40	1.15	1
Mean value	2.95	2.55	1.38	2.20	2.38	1.23	2.69	2.49	1.17	
Stand. deviation	0.96	1.16	0.44	0.93	1.18	0.50	1.00	1.15	0.39	
Stand. err. of mean	0.39	0.47	0.18	0.38	0.48	0.20	0.41	0.47	0.16	

Table 2: (Continued)

Sample number	kh/k)	Sample kv(k)	A	kh(k)	Top kv(k)	A	kh(k)	Bottom kv(k)	A	Sample quality(b)
7029/03-U-02										
F1364	1.43	1.46	0.98	1.43	1.48	0.97	1.43	1.43	1.00(a)	1
F1365	2.04	1.89	1.08	1.98	1.69	1.17	2.09	2.09	1.00(a)	1
F1366	3.53	3.62	0.97	3.59	3.61	0.99	3.47	3.64	0.96	1
F1047	2.67	2.61	1.03				2.67	2.61	1.03	1
F1073	3.05	3.19	0.96				3.05	3.19	0.96	1
F1110	3.13	3.13	1.00				3.13	3.13	1.00(a)	1
F1113	2.01	1.69	1.19	2.00	1.63	1.22	2.02	1.74	1.16	1
F1116	2.17	1.80	1.21	2.17	1.94	1.22	2.18	1.66	1.31	1
F1367	3.66	3.31	1.11	3.66	3.31	1.11				1
F1368	2.76	2.60	1.06	2.77	2.77	1.00(a)	2.75	2.43	1.13	1
F1155	2.81	2.64	1.06	2.91	2.60	1.12	2.70	2.68	1.01	1
F1162	3.07	2.91	1.06	3.01	2.84	1.06	3.13	2.98	1.05	1
F1178	2.89	2.73	1.06	2.87	2.55	1.12	2.91	2.91	1.00(a)	1
F1182	3.27	3.16	1.03	3.07	3.03	1.01	3.47	3.29	1.05	1
F1198	2.68	2.63	1.02	2.68	2.63	1.02				1
F1199	2.39	2.35	1.02	2.41	2.39	1.01	2.37	2.31	1.03	
Mean value	2.72	2.61	1.05	2.75	2.57	1.08	2.76	2.63	1.07	

(a): Significant anisotropy not resolved.

(b): Sample quality code used: 1: good; 2: fair; 3: poor.

***** End of the report by N. Balling, University of Aarhus. *****

Calculation of thermal conductivity

The thermal conductivity algorithm (Griffiths 1987) relates thermal conductivity to several log variables based on equations from Goss et al. (1975) modified by curves for variations with porosity (Balling et al., 1981) based on identification of sand, shale and carbonates. The algorithm do this identification with the M-N crossplot together with the gamma log. The porosity used is the calculated total porosity.

The calculated thermal conductivity values are plotted together with the measured values in figures, in each core description Chapter and on summary sheets in Appendix A.7.

In general the calculated values seem to fit well with the measured values in fine-grained rocks and in carbonates. There are, however, some problems with which value of the horizontal or vertical to correlate with when the coefficient of anisotropy is high. In quartz-rich sandstones the calculated values are clearly too low. This is most probably because the algorithm of Griffiths (1987) has not accounted for the change in lithology towards a higher quartz content sandstone, (the thermal conductivity of quartz is two to almost four times as high as of other common rock forming minerals), or the reason might be that the algorithm overcompensate for the porosity of the quartz-rich sandstones porosity (Balling et al. 1981).

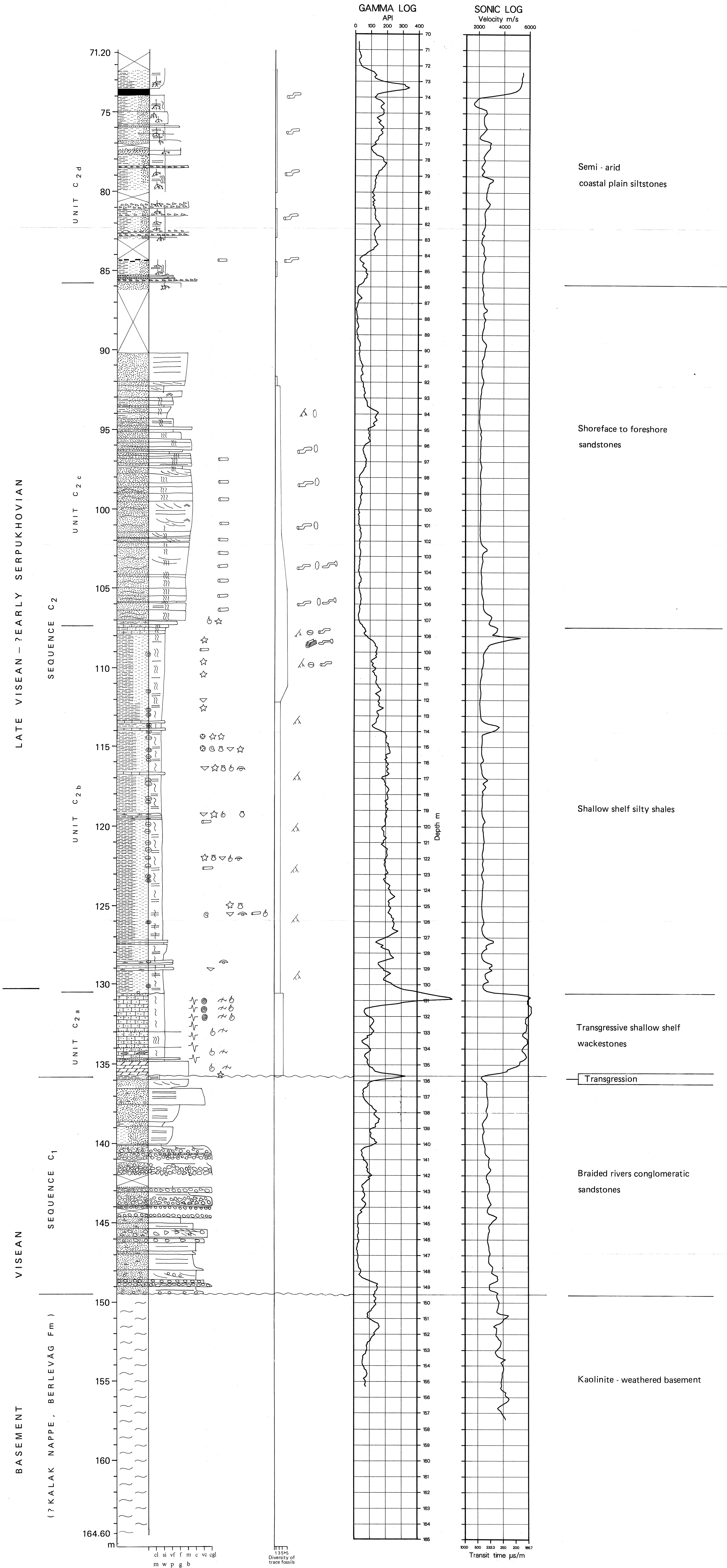
References

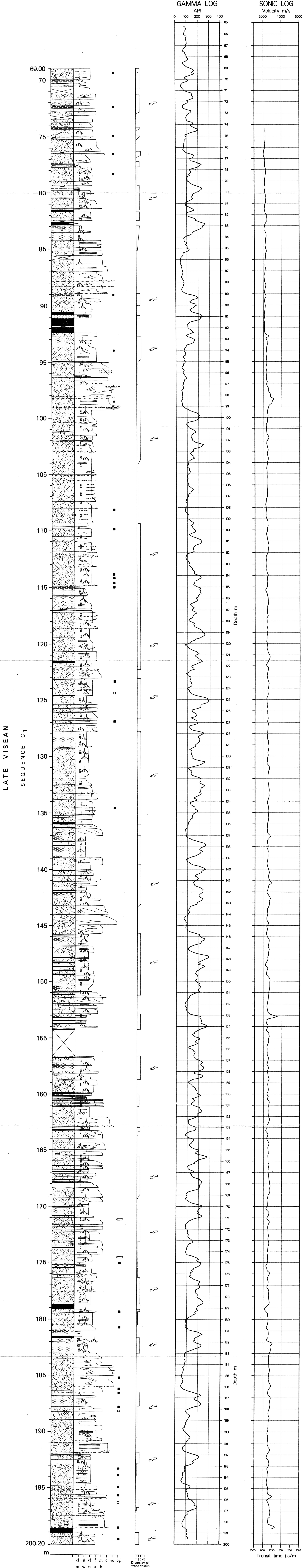
BALLING, N., KRISTIANSEN, J.I., BREINER, N., POULSEN, K.D., RASMUSSEN, R. and SAXOV, S., 1981: Geothermal measurements and Subsurface temperature modelling in Denmark. Department of Geology, Aarhus University: Geoskrifter, No. 16, 172 pp.

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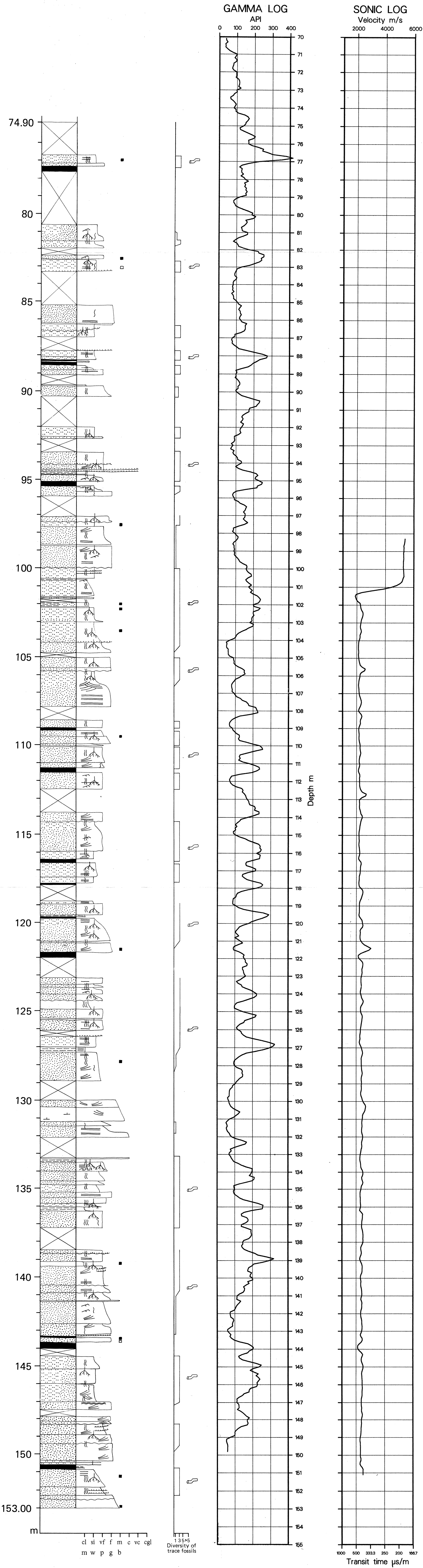
GOSS, R., COMBS, J. and TIMUR, A., 1975: Prediction of thermal conductivity in rocks from other physical parameters and from standard geophysical well logs. SPWLA sixteenth annual logging symposium, june 4-7, 1974, pp 1-21.

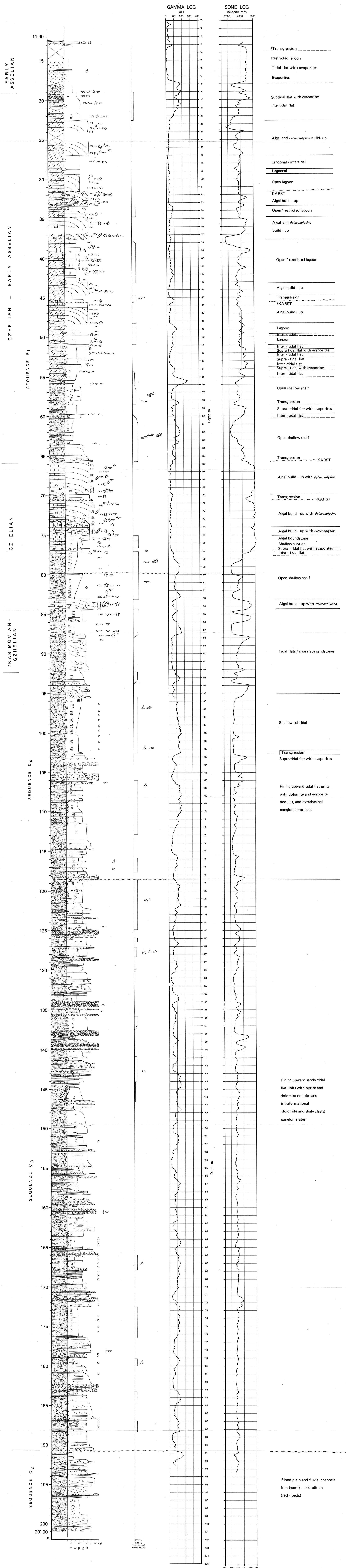
GRIFFITHS, C.M., 1987: COMPULOG software, 1987 update of NULITH module. IKU.

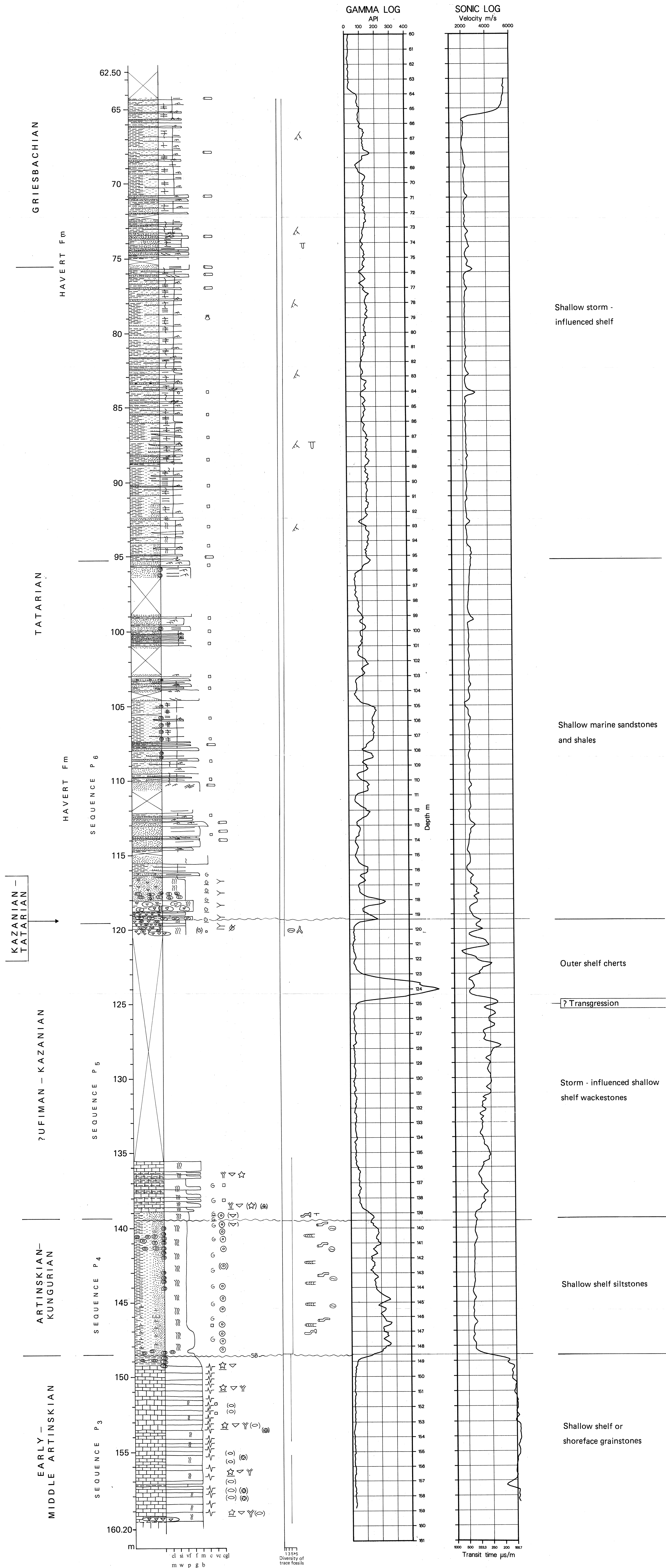




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SEQUENCE C₁

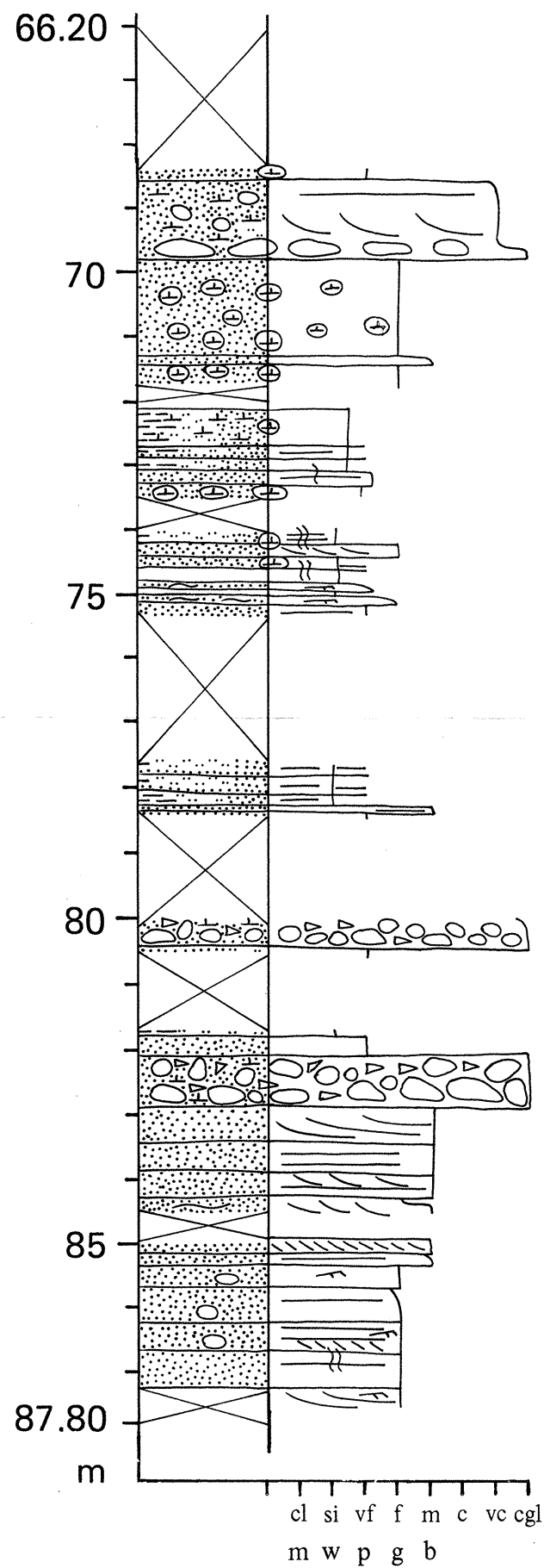






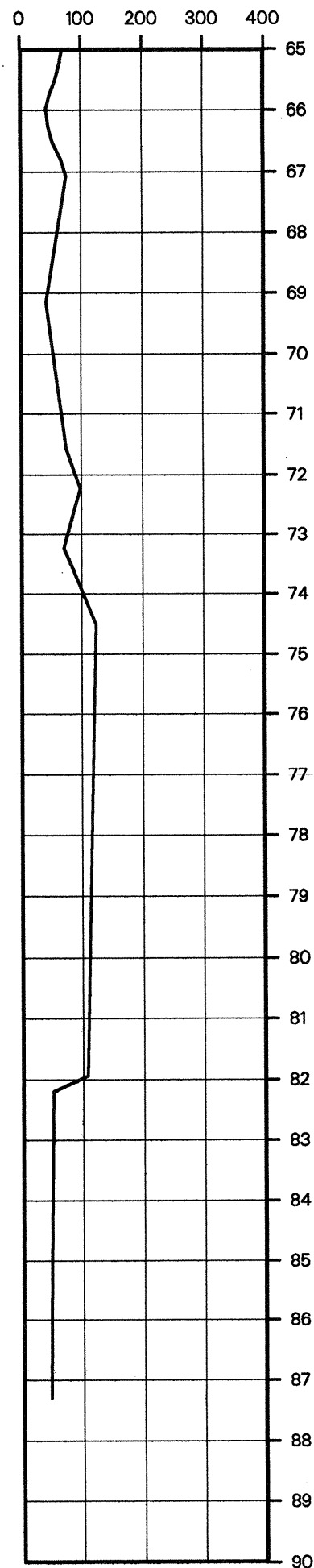
EARLY TRIASSIC

HAVERT Fm



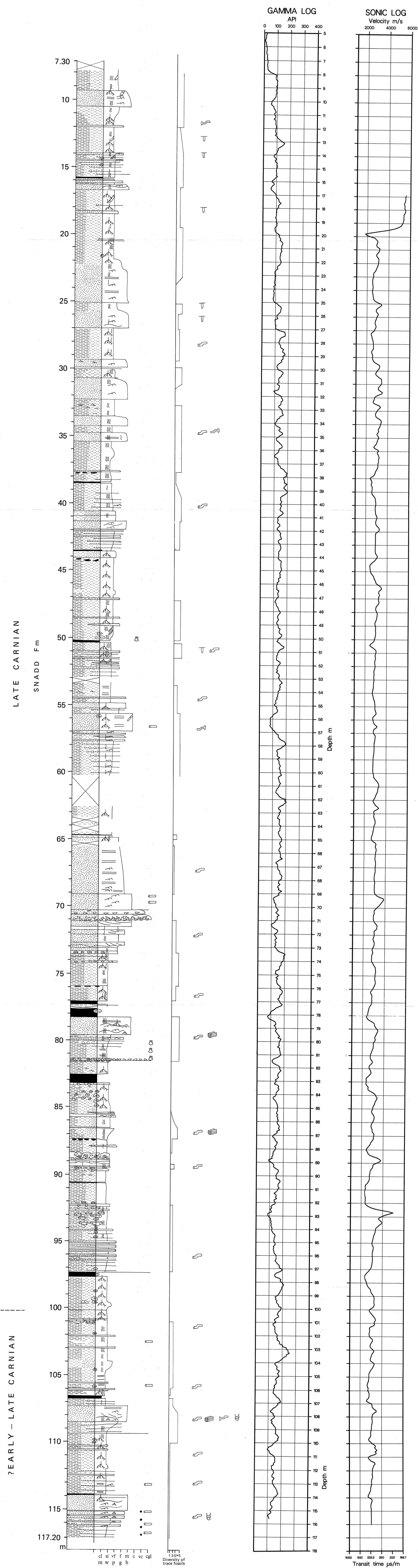
GAMMA LOG

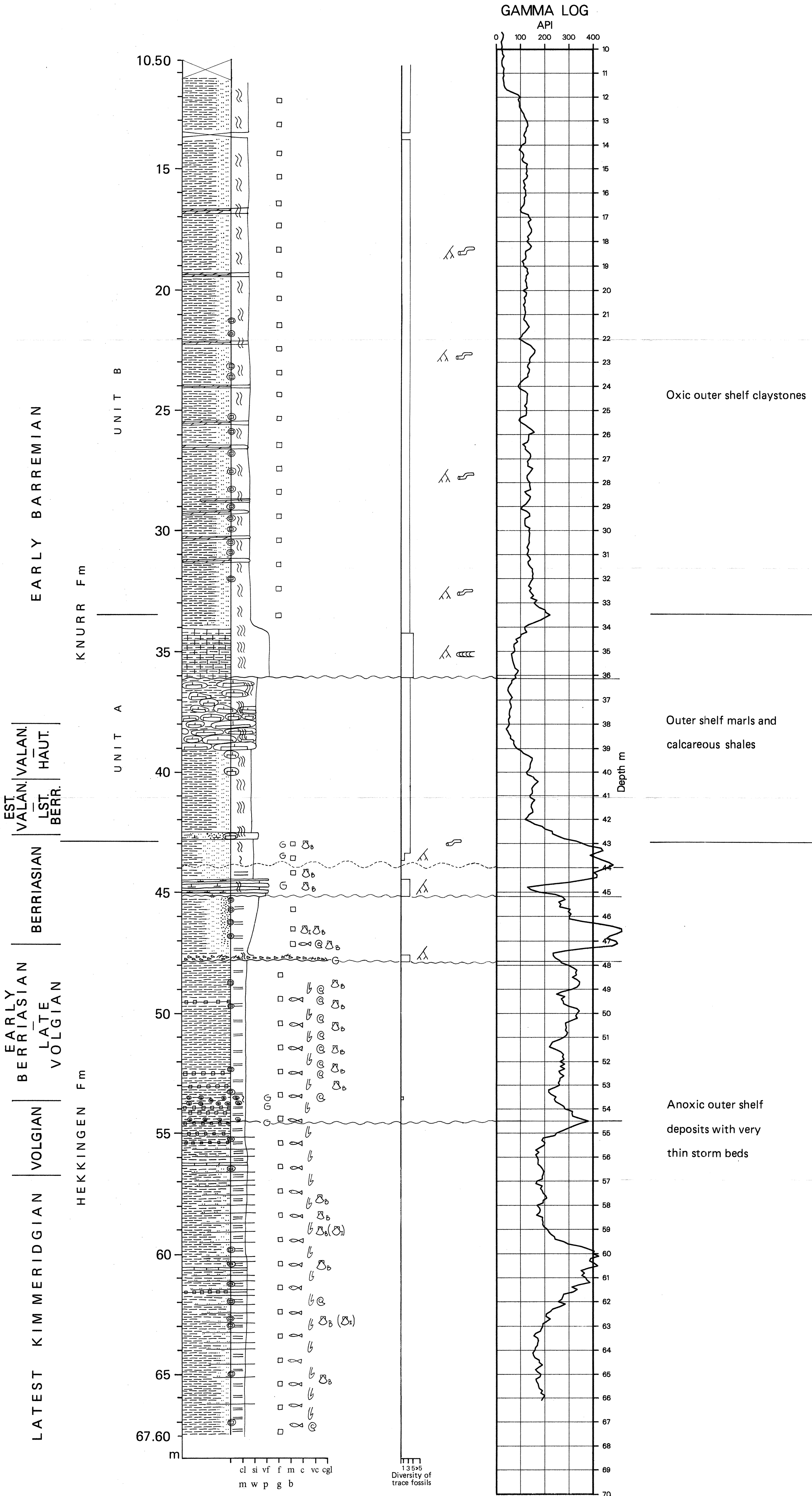
API



Semi - arid
coastal plain deposits
with nodular caliche

Upper shoreface to
foreshore deposits with
pebbly beach ridges





Shallow Drilling Barents Sea 1988

Appendix
volume 1

Field work
Analyses etc.
Core logs
(1:100)



SINTEF
GROUP