

INTRODUCING ARGUS

**An operational remote sensing system
for groundwater exploration**

by

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SUMMARY

The Advanced Resolution Geological Uhf Scanner (ARGUS) system has come of age. This exciting new subsurface remote sensing system was developed by the Norwegian company Scan-Tech in cooperation with the Royal Norwegian Council for Scientific and Industrial Research (NTNF) with the aim to provide the arid world with a practical and cost-effective tool for groundwater exploration. Extensive tests in Norway, Jordan, Ethiopia and Kenya have shown that ARGUS is capable not only of detecting the geometry of deep groundwater bodies, but also of providing information on other parameters considered important by hydrogeologists, such as limestone cavities, aquifer lithology, sediment/weathered basement/bedrock interfaces, water-bearing faults and to a limited extent also water quality. ARGUS can be operated from an airplane or helicopter, or from a surface vehicle. ARGUS is now considered operational and commercially available as a service. A cooperation agreement between Scan-Tech and Euroconsult was signed in 1987.

The application of traditional pulsed radar systems for subsurface measurements has been restricted to shallow depth due to their limited ability to penetrate deep into the ground and their limited signal processing capability.

ARGUS overcomes these shortcomings by sweeping a selected number of frequencies and emitting these into the ground as a continuous wave. This swept frequency approach, combined with sophisticated antenna design and high-precision measurement of amplitude and phase at all emitted frequencies, has made it possible to reduce the operating frequency and thus increase the penetration depth, while at the same time improving the resolution. Furthermore, transmitting one frequency at a time makes it possible to obtain a dynamic range (signal/noise ratio) several orders of magnitude larger than pulsed radar systems. Frequency domain information allows powerful signal processing to be performed on the ARGUS data.

A comparison between Scan-Tech's novel ARGUS groundwater exploration system and traditional geophysical/remote sensing methods shows that the ARGUS system is a very welcome alternative to the variety of groundwater detection methods at the disposal of hydrogeologists, as ARGUS has the most favourable cost-benefit ratio of all systems available today. It combines large penetration depth, detailed information, high survey speeds and advanced signal processing capability with low surveying costs.

1 BACKGROUND

Scan-Tech and the Royal Norwegian Council for Scientific and Industrial Research (NTNF) have developed a novel subsurface exploration system. This system - ARGUS - overcomes, as far as state of the art technology allows, the fundamental shortcomings of traditional subsurface electromagnetic sounding systems.

NTNF has gained international recognition for their research on continuous wave multifrequency radar technology. The joint effort between Scan-Tech and NTNF has developed this research into an exploration system with unique performance in areas like:

- Exploration of subsurface water resources.

- Exploration of temperate and arctic glaciers.
- Exploration of bedrock/geological structures.
- Detection of cracks/cavities in rock and foundations.
- Cost effective (airborne) large area water surveys.

ARGUS has a wide dynamic range and can perform advanced signal processing. It can suppress unwanted returns and zoom in on selected targets, thereby enhancing the readability of weak signals. It is particularly well suited for surveys from the air, an invaluable feature in the survey of the vast, arid regions encountered in combatting desertification.

In 1987, a cooperation agreement was signed with Euroconsult, the Netherlands.

3 STATE OF THE ART

Radars for subsurface measurements have been in use for more than 20 years. These traditional radars are generally of the pulsed type and have met with only moderate success over the years. Their use have been restricted to shallow depths due to their limited ability to penetrate deeply into the ground and due to their limited signal processing capability.

Before setting out to design an improved subsurface exploration system, it is important to identify the bottlenecks. The most fundamental of these are summarized in the following.

a) Soil attenuation

It is apparent from Figure 1 that electromagnetic waves are attenuated in the soil. As the attenuation is seen to increase with frequency, the advantage of using low frequencies is obvious. Unfortunately, however, resolution is reduced with frequency. Further, the necessary size of the antennas increases as the frequency is reduced. A way to obtain the benefits of lower frequencies without loss of resolution and without increasing the antenna size out of proportions is therefore sought.

b) Dynamic range

It is obvious that a system's ability to read weak signals is a determining factor for its penetration capability. Therefore, a new and improved system should have an increased dynamic range (signal/noise ratio) and a reduced noise floor.

c) Signal enhancement

To further improve the quality of existing sub-surface exploration systems, signal enhancement techniques are required. Implementation of a priori information, suppression of unwanted returns, zooming, averaging and other math operations are all particularly desirable.

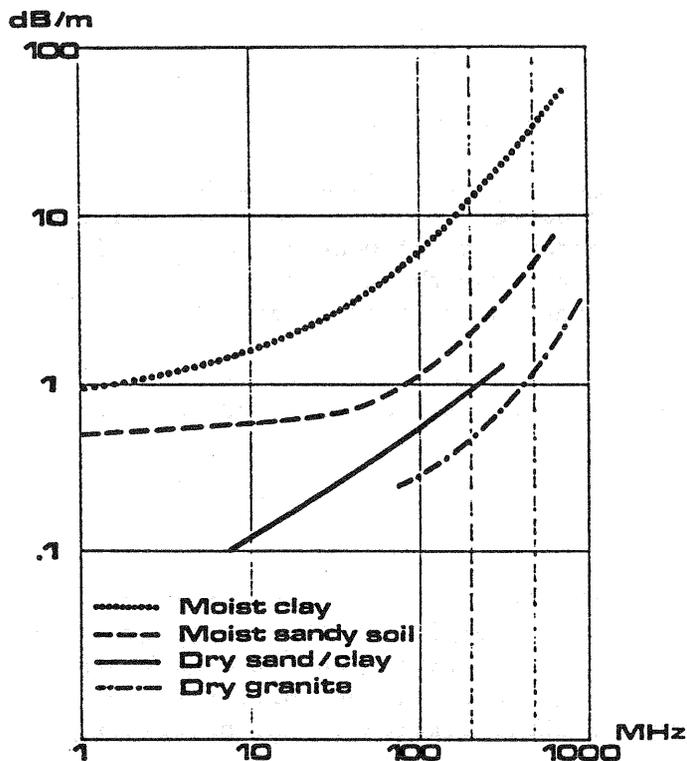


Fig. 1 - Frequency signal attenuation in various soil types.

Scan-Tech's newly developed ARGUS system attempts to overcome these bottlenecks, as far as state-of-the-art technology allows. We shall briefly describe our system in the following.

3 DESCRIPTION OF THE NOVEL SYSTEM

a) General

ARGUS (Advanced Resolution Geological Uhf Scanner) is a monostatic multifrequency electromagnetic exploration system. It has separate transmit/receive antennas which are directive and wide band. It can be operated from an aircraft or from a surface vehicle.

ARGUS is different from pulsed radar systems in that it uses continuous transmission. A selected number of frequencies (max. 1600) are swept and emitted from the transmit antenna into the ground. Based on high precision measurement of amplitude and phase at all frequencies, reflexions received from sub-surface interfaces are detected and analysed by computer. This "frequency domain approach" has several advantages:

- **Deep penetration with improved resolution.** The swept frequency approach and sophisticated antenna design have made it possible to reduce the operating frequency while at the same time improving resolution.
- **Increased dynamic range.** Transmitting one frequency at a time makes it possible to reduce the band width around each frequency. Careful design of the circuitry has further reduced the internal noise level. A dynamic range several decades larger than traditional radar systems is thereby obtained.

- **Advanced signal processing capability.** The availability of accurate frequency domain information has made the implementation of powerful signal processing algorithms convenient.

A high speed computer system is employed so as to allow airborne operation. This is an invaluable feature for rapid and cost effective water surveys of the vast, arid regions where the need for such knowledge has the highest priority.

b) Configuration

ARGUS is composed of 6 parts, as shown in Figure 2: the power supply, the signal generator w/RF-network, the analyzer, the computer, the antennas and the output unit (disc/printer/screen).

For airborne operations ARGUS is contained in a console, but minimum configurations are available if the platform size or operation makes this necessary.

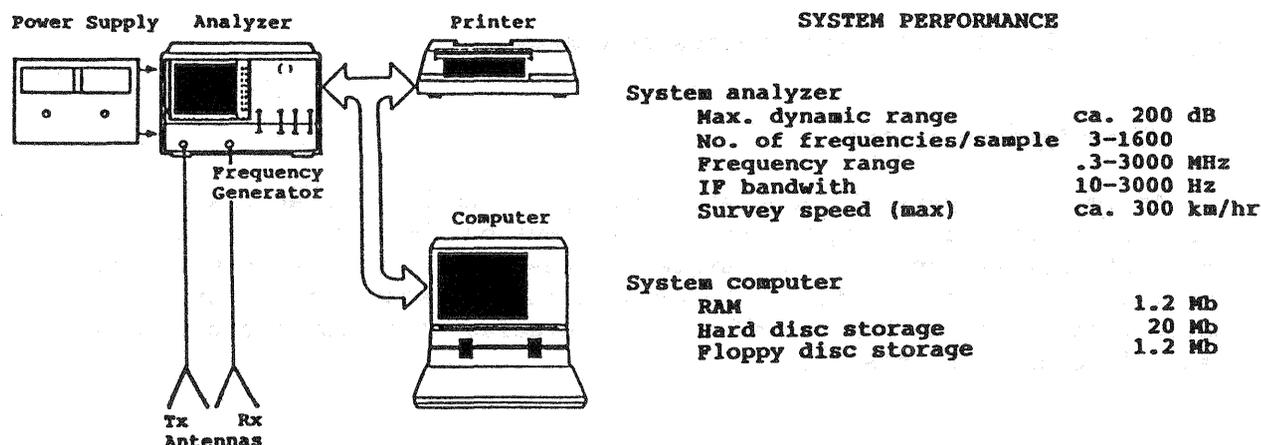


Figure 2. - ARGUS system configuration and performance.

c) Penetration depth

The depth at which a target can be detected is dependent on the wave attenuation in the soil and on the dynamic range of the system. The attenuation again depends on the frequency used and the moisture and salinity of the soil.

Figure 3 shows penetration depth under ideal conditions (dry sand) for our ARGUS system. It is seen that penetration increases from some meters to several hundred meters as the frequency is decreased from about one GHz to a few MHz.

Despite increased attenuation with soil moisture, ARGUS still penetrates tens of meters through moist soil. This makes assessment of the extent of detected water resources feasible.

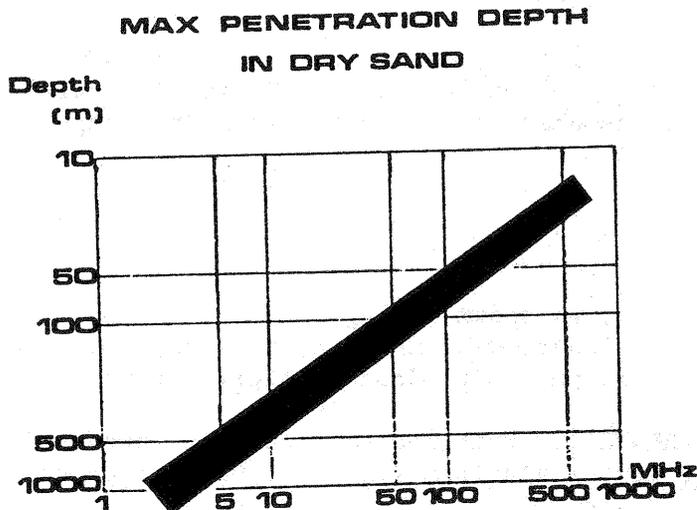


Figure 3 - Penetration depth versus frequency.

d) Navigation system

An important part of large area surveys is to have an accurate positioning system. Among the several systems on the market, we believe satellite navigation to be the system of the future. Our tests with this fully answer our expectations. Loran C is another state-of-the-art navigation system we have under test. Accuracies of a few meters to some tens of meters are obtained.

5 FIELD TEST RESULTS

ARGUS is the result of 2 1/2 years of development, including laboratory tests and field tests in Norway, Africa and the Middle East.

While these early tests were made from a ground based platform, field tests from the air were made for the first time during the regional ISPRS Symposium held at the Jordanian Geographic Center, in Amman, 22-27 October 1987. These were very successful and to the best of our knowledge, this was for the first time in history that groundwater was located by radar technology from a fixed wing aircraft. The aircraft used was a light twin-engined Partenavia Observer, jointly operated by Scan-Tech and Fjellanger Wideroe of Norway.

The penetration and resolution capability already demonstrated is adequate for a large range of applications. In some regions of the world, however, there is a need to penetrate to considerably larger depths (several hundred meters). We feel this is well within the capacity of ARGUS, and further tests to demonstrate this will be performed in the United Arab Emirates in June, 1988.

Some typical test results and the graphic display of the tests are presented in the Annex.

5 EVALUATION

In the preceding sections the ARGUS system was presented, including proof of concept and the results of field tests performed in an operational environment. In this section we would like to present an evaluation of the outstanding features of the system. We do this by comparing the features of ARGUS with the features of the other remote sensing or geophysical methods available for groundwater exploration. Figure 4 shows a matrix with the various remote detection methods presented vertically and the features determining cost-effectiveness and cost/benefit ratio listed horizontally.

Evaluated features include:

- the type of groundwater information generated by the method;
- the degree of detail of the observation;
- survey speed in case of ground survey; possibility of airborne operation;
- cost aspect.

In each method/feature field a letter indicates the qualitative ranking among the different methods of remote groundwater detection. For instance, the system with the lowest operating costs received the relative score "A" in the cost range feature; the next best got a "B", etc.

In this comparison the ARGUS system scores consistently high. Almost all features of ARGUS could be awarded with an "A" rating. If the groundwater information required includes detection of groundwater level, quantitative analysis of aquifer geometry, or an indication of saline/non saline groundwater, then the ARGUS procedure would be by far the most cost-effective method. If more detailed information on water quality required, then, short of actual drilling, the Schlumberger/Wenner method is the only alternative. However, this is a relatively slow and definitely more costly procedure.

The ARGUS method works best in arid regions and where the sub-surface layers have low electric conductivity. Wet clay and humid saline soils, on the other hand, would attenuate the signal considerably due to Foucault currents generated by the electro-magnetic wave in the conducting medium. Penetration is therefore reduced in such environments.

		Physical property measured	Evaluated property	Groundwater ¹ information	Degree of detail	Observation platform	Ground ³ survey coverage (km ² /day)	Cost ³ range	Comments	
Passive methods	Gravimetric	Force of earth gravity	Densities of earth masses.	Specific application: e.g. detection of buried channels, caverns in limestone. (D)	Fair (C)	Ground (B)	0.5 - 12 (B)	Low (A)	Restricted use.	
	Magnetic ⁴	Magnetic field	Magnetic susceptibility	Specific application: e.g. detection of dolerite, with potential fracturing. (D)	Fair (C)	Ground/air ⁶ (A)	0.6-15 (A)	Low (A)	Restricted use.	
Active methods	Seismic	Refraction	Time difference	Shock wave velocities	Aquifer detection and quantitative analyses of its geometry. (B)	Fair/good (B)	Ground (B)	0.2-4 (D)	Medium (B)	In particular for surface to water level and bedrock determination
		Reflection	Time difference	Shock wave velocities	Aquifer detection and quantitative analyses of its geometry. (B)	Fair/good (B)	Ground (B)	0.2-4 (D)	Medium (B)	In particular for surface to water level and bedrock determination. Complex signal.
	Electric ⁴	Profiling	Potential differences	Earth resistivities	Aquifer detection, qualitative analyses of its geometry, and water quality. (C)	Fair (C)	Ground (B)	0.25-6 (C)	Medium (B)	Often used for detection of fractured zones.
		Schlumberger/Wenner	Potential differences	Earth resistivities	Aquifer detection, quantitative analyses of its geometry, and water quality (A)	Good (A)	Ground (B)	0.05-1.25 (E)	High (C)	Best developed method. Automatic interpretation software available.
	Electromagnetic ⁴	Moving source/receiver	Magnetic field	Earth resistivities	Aquifer detection, qualitative analyses of its geometry, and water quality. (C)	Fair (C)	Ground/air ⁶ (A)	0.6-15 (A)	Low (A)	Restricted depth penetration. Often used for detection of shallow fracturing.
		Fixed source	Magnetic field	Earth resistivities	Aquifer detection, qualitative analyses of its geometry, and water quality. (C)	Fair (C)	Ground (B)	0.25-6 (C)	Medium (B)	Often used for detection of fractured zones.
		Argus ⁵	Phase and amplitude return	Dielectric constant	Aquifer detection and quantitative analyses of its geometry. Indication of salinity. (B)	Good (A)	Ground/air ⁶ (A)	0.6-15 (A)	Low (A)	Best results achieved in arid and low saline regions. In particular suitable for surface to water level. Often used for detection of buried channels, caverns in limestone and bedrock overburden interfaces.

¹ Aquifer is defined as a water yielding sub-surface layer

² Ground surface coverage is based on measuring point density of 1 per 1 ha to 1 per 25 ha

³ Cost range for ground survey.

⁴ Extensive expertise available at Euroconsult

⁵ Developed and operated by Scan-Tech (cooperation with Euroconsult)

⁶ Air surveys typically cover 100 - 150 km²/day

Figure 4 - Summary of geophysical methods used for groundwater exploration

7 CONCLUSION

ARGUS provides the hydrogeological community with an invaluable new tool for cost-effective aquifer detection in regions where groundwater is most needed, namely the arid regions. ARGUS is field-proven. The highly detailed information generated by ARGUS includes depth to groundwater level, extent and thickness of aquifer, caverns in limestone, buried channels, and sediment/weathered rock/basement interfaces. The system can be operated from an airplane, helicopter or any 4-wheel drive pick-up. Survey speeds are high, whereas survey costs are low.

ANNEX

Graphs 1 & 2 (ground tests) and 6 & 7 (air tests) are characteristic single shots. The rest show arrays of consecutive single shots, stacked together and intensity modulated in the form of interface profile plots.

a) Tests from the ground (Norway)

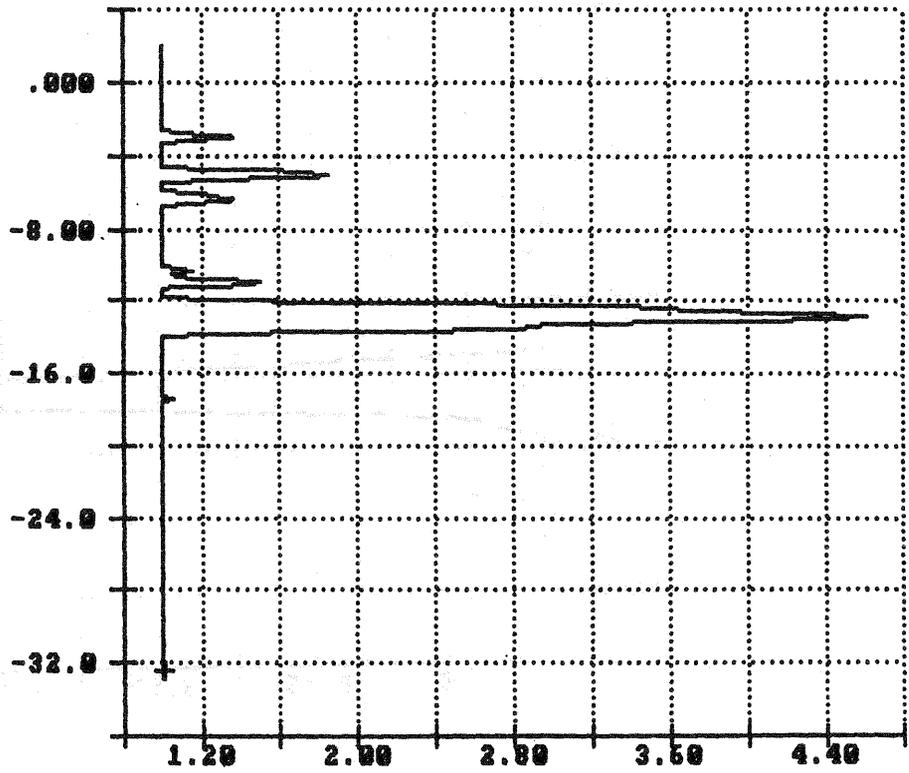
- Graph 1: Groundwater reflexion (at 13 m) in saturated sand top soil (Southern Norway).
- Graph 2: Bottom reflexion (at 100 m) in temperate glacier (Western Norway).
- Graph 3: 60 m long profile of groundwater level (at 13 m) in saturated sand top soil (Southern Norway).
- Graph 4: 400 m long profile of temperate glacier bottom (Western Norway).
- Graph 5: Cavities in Limestone (60 m long profile) (Northern Norway).

b) Tests from the air (Jordan)

- Graph 6: Groundwater reflexion (at 2.5 m) (Azraq, Jordan).
- Graph 7: Groundwater reflexion (at 8 m) (Fidan, Jordan).

ARGUS - FIELD TEST RESULT

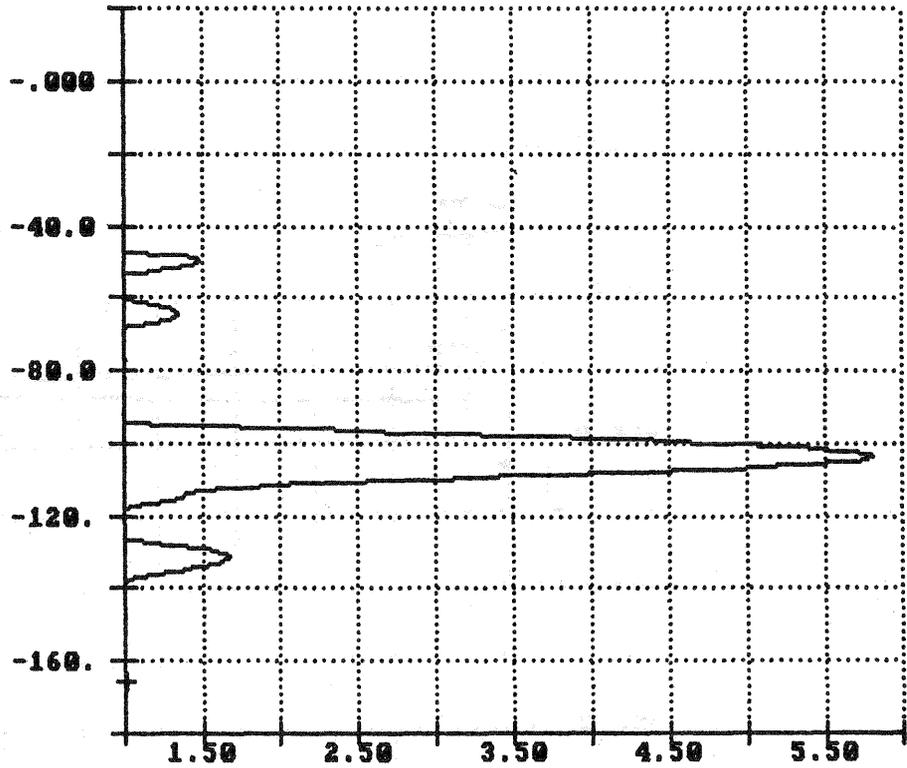
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Ground water reflexion in wet sand top soil

ARGUS - FIELD TEST RESULT

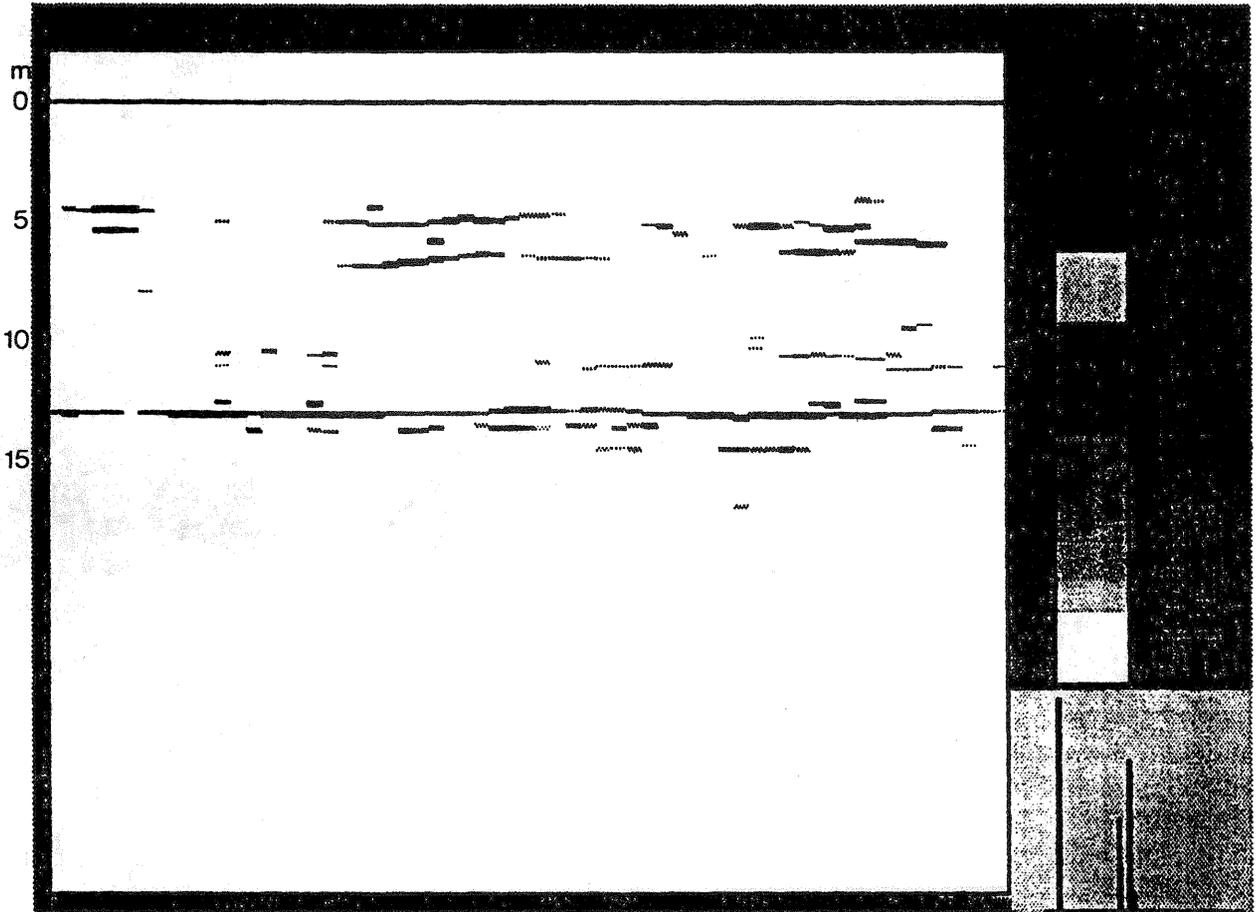
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Bottom reflexion in temperate glacier

ARGUS - FIELD TEST RESULT

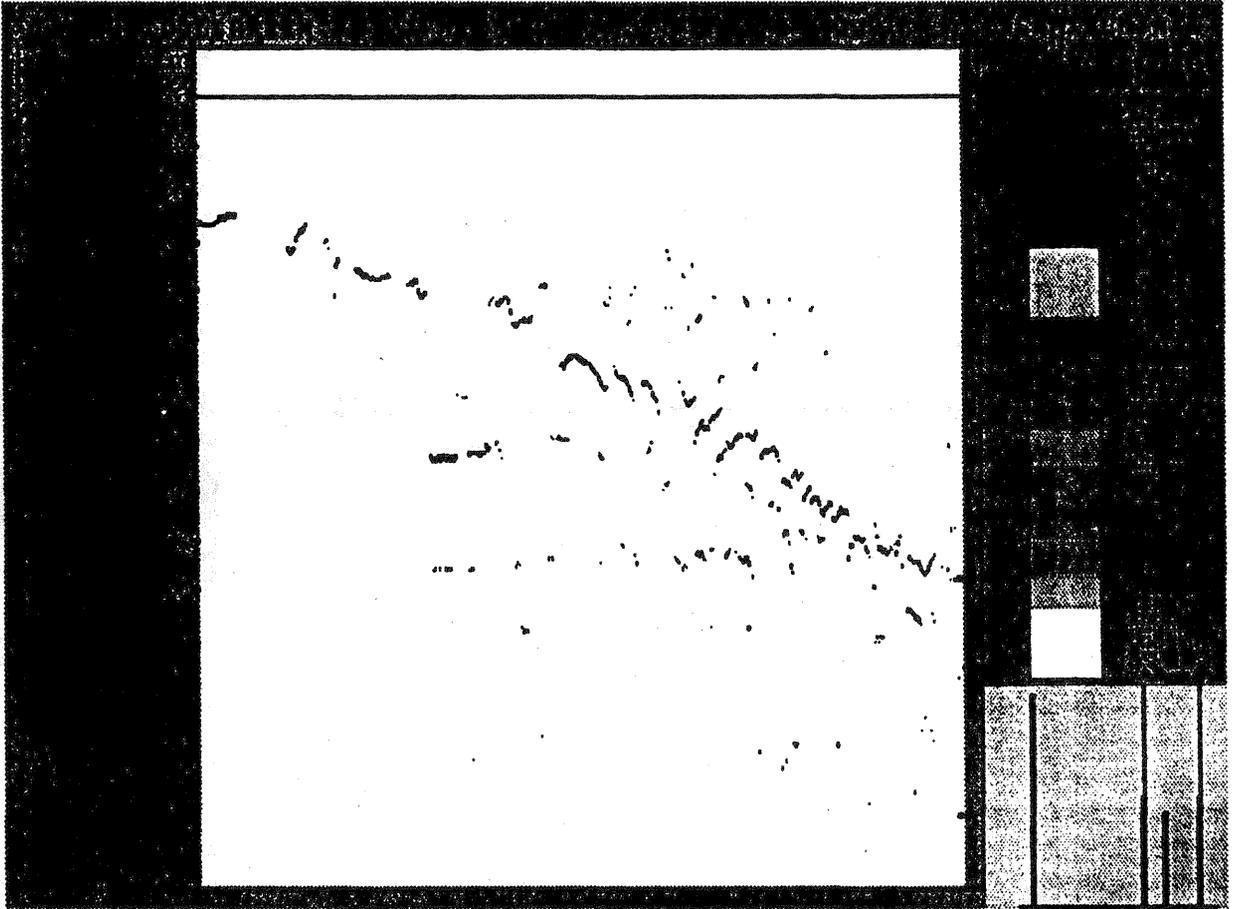
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**Profile of ground water level (60 m long)
in wet sand top soil**

ARGUS - FIELD TEST RESULT

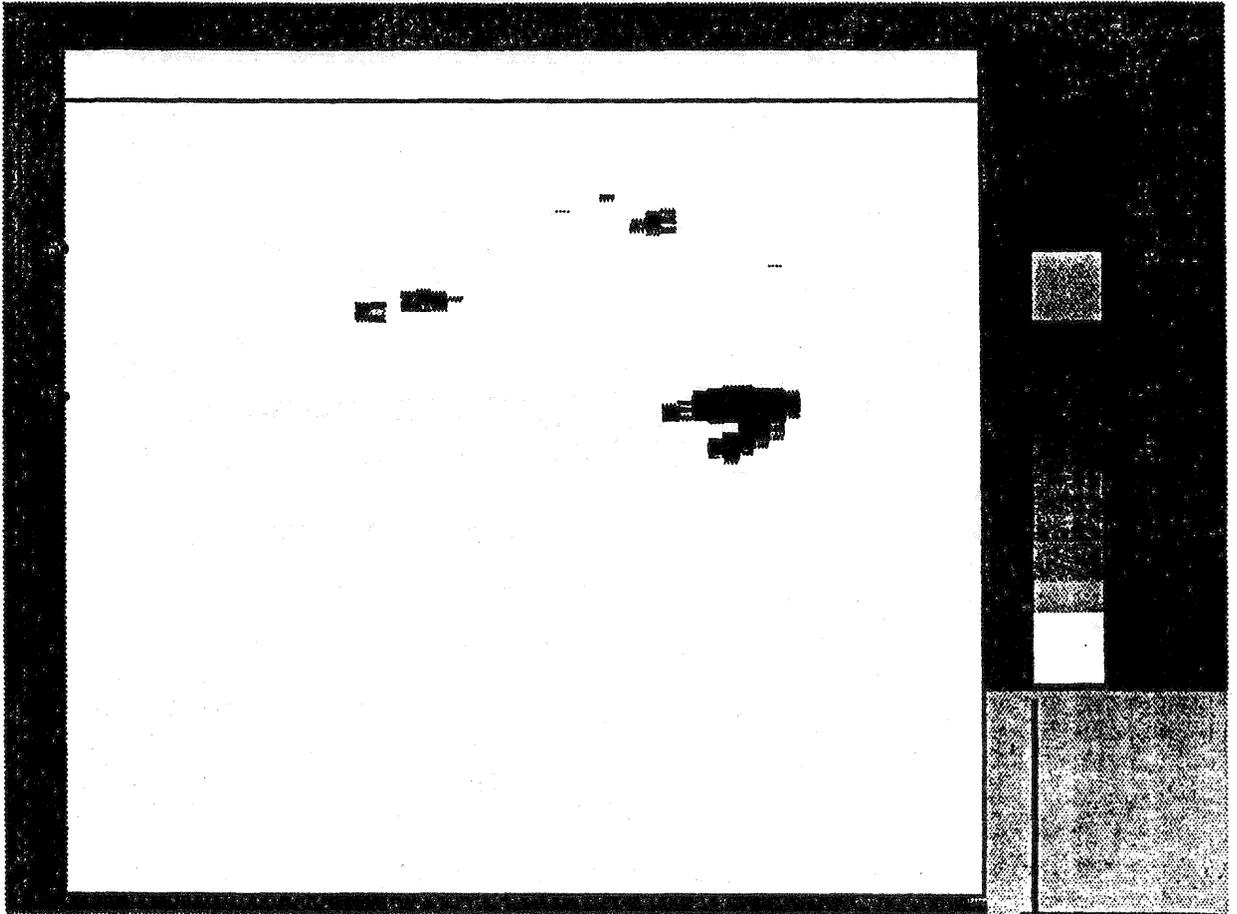
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Bottom profile of temperate glacier

ARGUS - FIELD TEST RESULT

5



Cavities in limestone
(processed data)

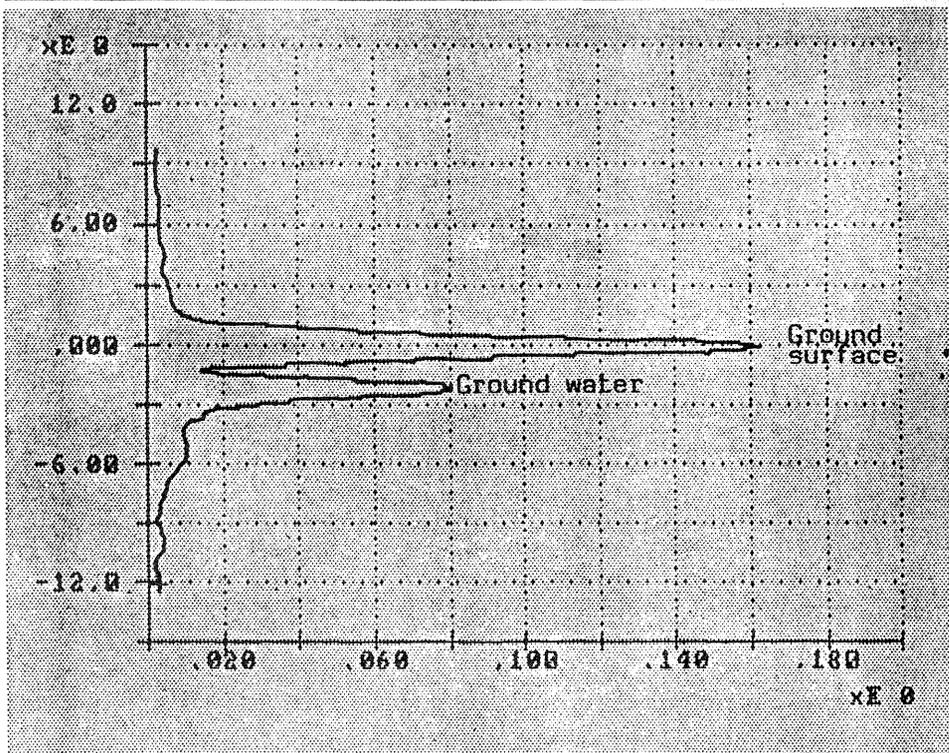
ARGUS - FIELD TEST RESULT

6

SCANTECH A/S
ARGUS
FIELD PLOTS

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OK FLIGHT 19TH OF OCT. 1987 WITH SCAN-TECH LN-LML

Ground water reflexion

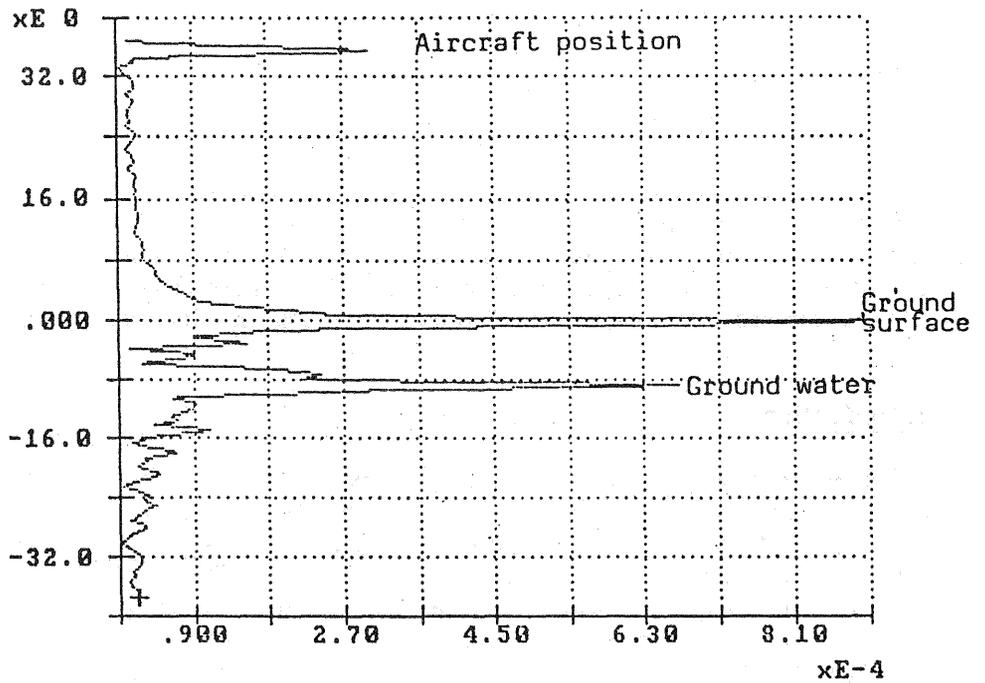
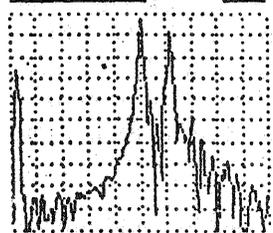
ARGUS - FIELD TEST RESULT

7

SCANTECH A/S
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FIELD PLOTS

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Ground water reflexion