SPECIAL SONAR TECHNIQUES FOR RECORDING A DETAILED, HIGH RESOLUTION CAVERN GEOMETRY

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Abstract

As part of the general monitoring of cavern operations and for calculating the current volume, the geometry of a cavern is determined from sections recorded at specific depths. When recording these sections the survey head measures either horizontally or at any required angle of tilt. In each individual section the cavern shape is detected by point measurements made at discrete angular intervals.

In addition, for determining the shape in certain parts of caverns special sonar techniques are applied that enable the cavity geometry to be measured with a considerably greater survey point density. The spiral technique, in which the cavern shape is sampled spirally, is applied for instance to measure areas with high accuracy, such as in cavern necks, roof structures and cavity constrictions. Special software has been developed for interpreting and spatially presenting the results of these surveys.

Besides carrying out spiral surveys the survey point density can be increased also by reducing the vertical interval between two survey horizons or by using smaller angular intervals when recording a section. If still higher data quality is required sections can be recorded several times and subsequently correlated.

In this paper the execution of these special techniques and the interpretation of the results are explained with reference to practical examples and the advantages the techniques provide for solving operational problems are demonstrated.

1. Sonar Surveys

1.1 Basic measurement principle

Geometric surveying of caverns is made using sonic tools on the basis of travel time measurements. In this method the time taken by an acoustic pulse to travel from the measuring tool to the cavern wall and back is determined, i.e. the measured travel time corresponds to the two-fold distance. To convert the travel time into distance it is necessary to know the acoustic velocity in the medium. This means that the accuracy and reliability of the measured cavern geometry depends directly also on the quality of the acoustic velocity determination.

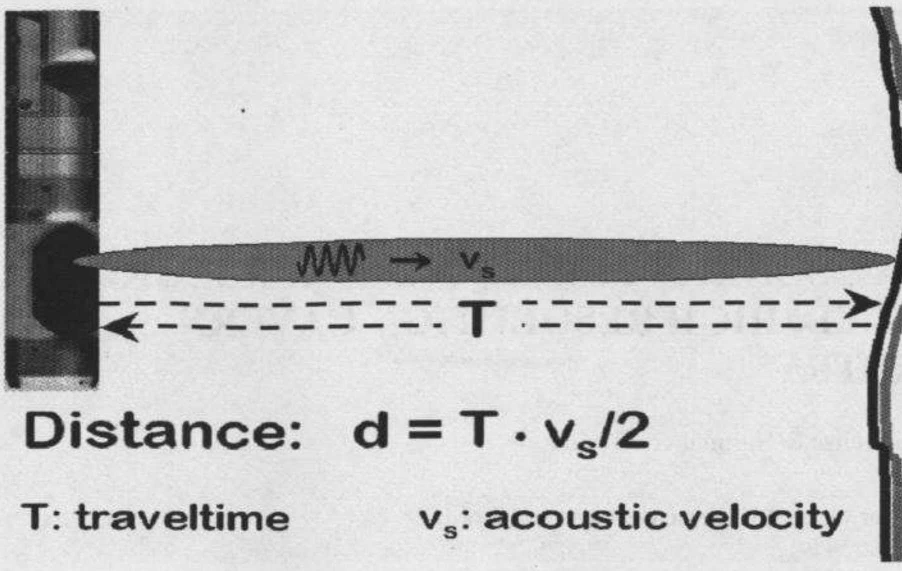

Fig. 1: Distance determination using travel time measurements

Sonic measurements in caverns must be made in widely differing media. The range of media extends from saturated brine to liquid hydrocarbons and natural gas and even to air at atmospheric conditions. The physical conditions in a cavern depend in the first place on the actual medium, which itself is affected by any previous cavern operations as well as by the surrounding rock.

1.2 Physical conditions in caverns

The physical conditions in a cavern, however, are often not sufficiently appreciated with regard to carrying out sonic surveys. And if the parameters are not considered or are only roughly estimated, in particular the acoustic velocity and the temperature, then the results obtained may be inaccurate or even distorted. Indeed, precise measurement results can be obtained only if the physical conditions in a cavern are appropriately considered not only during the actual survey, but also in the interpretation of the results /2/.

The acoustic velocity needed to convert the measured travel times into distances is subject to complex physical relationships but depends essentially on the temperature and density of the medium. Fig. 2 shows the typical ranges of acoustic velocity that can be expected when carrying out cavern surveys in different types of media.

Medium	Acoustic velocity [m/s]
Saturated Brine	1790 – 1900
Water	1450 – 1550
Oil and products	1200 – 1500
Natural gas	390 - 540
Air	330 - 375

Fig. 2: Acoustic velocities in different media

Some of these distinct variations in a specific medium cannot be explained solely by changes in temperature and pressure. In the case of brine the acoustic velocity is strongly dependent on the salinity and the chemical composition. An occurrence of potassium and magnesium in the brine, for instance, tends to make the acoustic velocity higher.

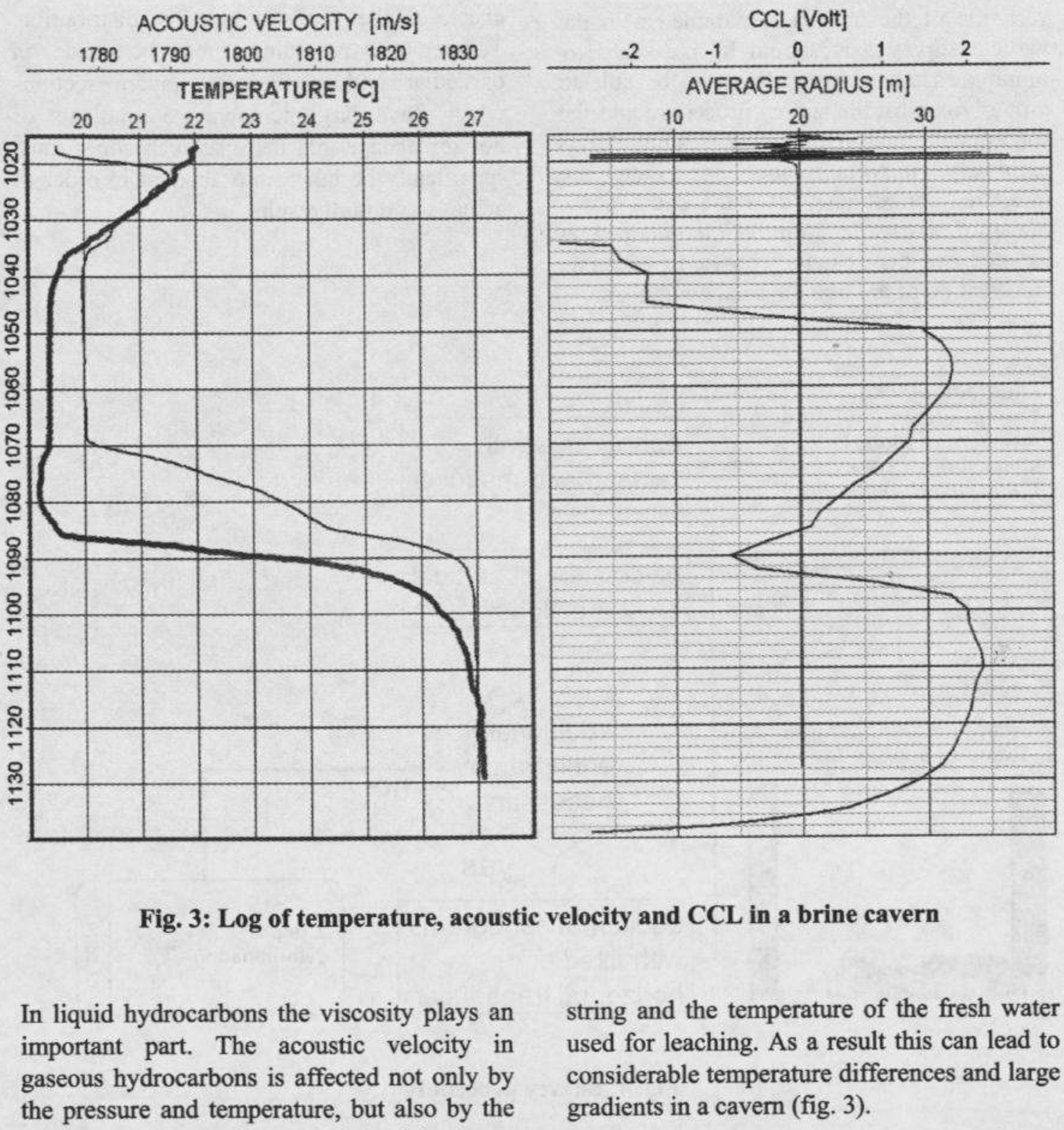

Fig. 3: Log of temperature, acoustic velocity and CCL in a brine cavern

In liquid hydrocarbons the viscosity plays an important part. The acoustic velocity in gaseous hydrocarbons is affected not only by the pressure and temperature, but also by the moisture content and composition of the gas.

Insofar as the medium in a cavern is homogenous and not affected by external influences, a uniform gradient exists with the temperature increasing with the depth. In practice, however, the temperature during a survey is greatly affected by any previous activities that have been carried out in the cavern. In brine caverns the vertical temperature distribution in a cavern depends especially on the position of the brine casing string and the temperature of the fresh water used for leaching. As a result this can lead to considerable temperature differences and large gradients in a cavern (fig. 3).

2. Execution of cavern surveys

2.1 Survey procedure

In order to be able to perform optimal cavern surveying it is essential to find out the physical conditions in the cavern before the actual sonar survey is carried out. The variation of the individual parameters in the vertical survey axis should be measured by running an advance log. So as to be able to properly control the survey procedure and the subsequent interpretation of results, it is extremely important that the data are measured continuously over the entire depth range of a cavern. Information obtained at isolated points cannot provide adequate clarification of the true physical conditions.

To convert the measured travel times into distances it is necessary primarily to know the acoustic velocity over the entire vertical extension of the cavern. In addition, the temperature distribution should also be recorded as it can be used for a plausibility check of the acoustic velocity distribution. Temperature recording must be made in particular with a view to cavern sections which have large temperature gradients or horizontal layering, because such zones must specifically be taken into account in order to achieve optimum results.

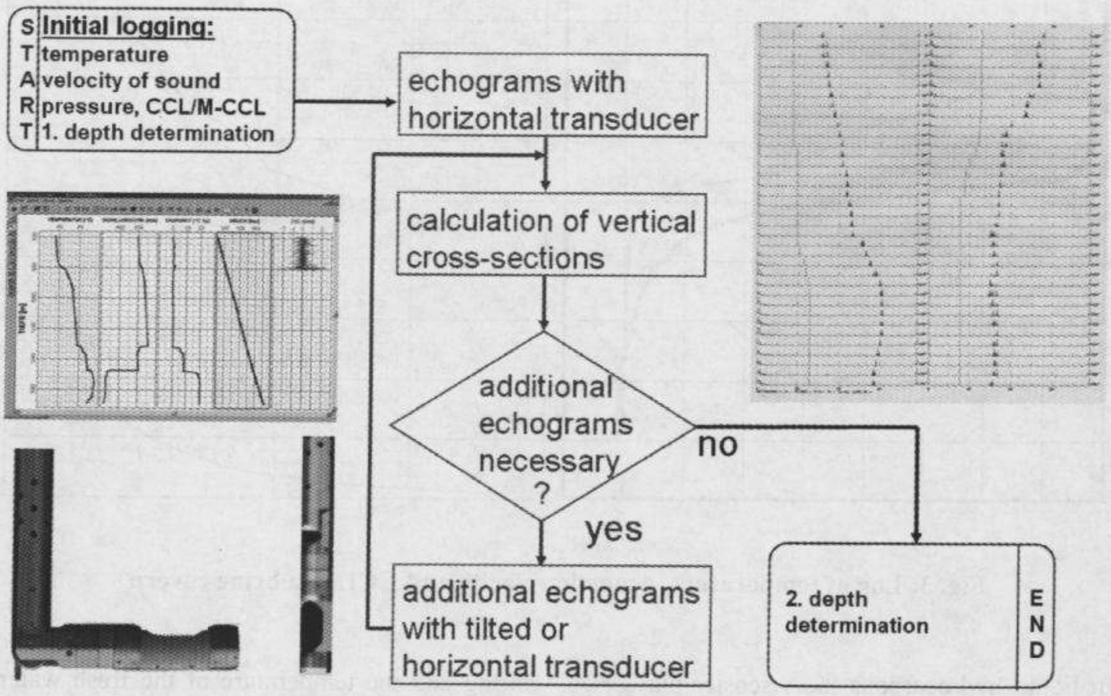

Fig. 4: Survey procedure

If, for example, the temperature gradient is not recorded and the measurements with transducers are performed through a zone in which the temperature greatly varies, the ensuing refraction of the sonic beam would lead to an incorrect determination of the shape and volume of the cavern.

After the initial logging the cavern shape will be surveyed by a multitude of horizontal sections over the entire cavern depth as well as sections with titled sonar head to measure bottom, roof or any other irregularities of a cavern. The surveying principle of SOCON is based on a point by point sampling of the cavern wall. The measuring head is first positioned in the required direction with the required inclination and is maintained there until the point has been measured and all the necessary correlations and plausibility checks have been carried out. It is then moved to the next measuring position. Such a step by step rotation normally causes vibrations which make it impossible to measure. However, this procedure is possible with SOCON tools as they are equipped with gyro stabilizers which stop tool vibration. The following figure gives an overview on the whole survey procedure.

2.2 Tool technology

All echo tools have been developed by SOCON and represent the culmination of 40 years of experience in carrying out ultrasonic cavern surveying. The modular tool design (Fig. 5) contains subsystems for recording all the relevant parameters in a single survey run. Each functional unit, such as transmitter-receiver section, compass, rotation-tilt control, acoustic velocity measurement, fibre-optic gyro /1/ or CCL/Multiple-CCL is equipped with its own processor and is controlled from the main computer at the surface via a digital bus. The advantage of the modular design is that future modifications no longer affect the whole tool but instead just individual modules.

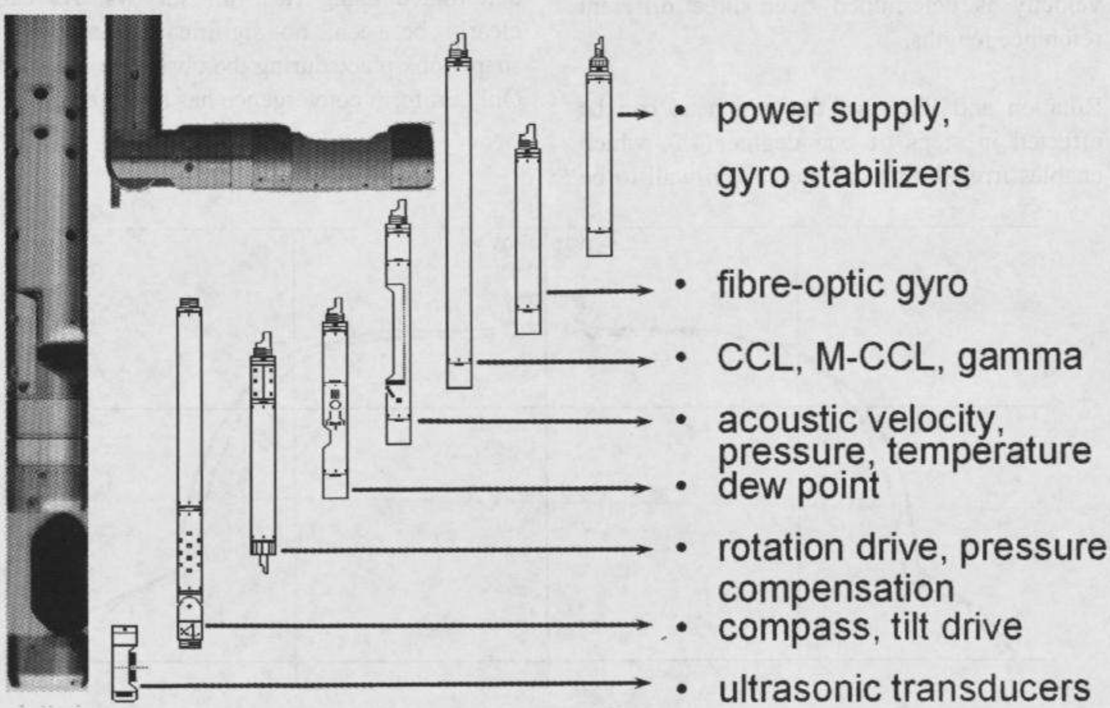

Fig. 5: Modular design of the SOCON echo tools type BSE/BSFII

Such a flexible arrangement as well as the large dynamic range of the transmitter-receiver electronics make it possible to adjust the tool quickly to the prevailing survey conditions. The crucial factor in selecting the proper wavelength for carrying out a survey is the medium in the cavern with its specific sonic wave propagation characteristics. The wavelength in turn affects the size of the angle of beam spread of the sonic lobe and depends on the acoustic velocity in the medium as well as on the measuring frequency.

Moreover, the modular design allows extra modules, for instance for dew-point measurements, to be easily added to the system. Each module represents an individual pressure resistant unit separated from the other modules by bulkheads so as to improve the operating safety and protect the sensitive components.
The tool is equipped with gyro stabilizers to suppress circular motion during surveying that would otherwise occur as a result of the stepwise rotational advance. The acoustic velocity is determined over three different reference lengths.

Rotation and tilting of the tool head can be effected in steps of one degree (1°), which enables irregularities of the cavern wall to be detected with high resolution. A four-conductor cable is required to operate the echo tool, which can used at temperatures between 0°C and 75°C and at pressures of up to 300 bar.

3. SURVEY EXAMPLES

3.1 Full measurement of caverns

The echometric survey of a cavern serves the combined purposes of identifying any changes in shape and also determining the actual cavern volume. The cavern convergence or respectively the cavern growth can be determined by comparing volumes surveyed in successive measurements.
The shape of a cavern can be more or less regular depending upon the geological situation and the specific implementation of individual leaching steps. The spectrum of possible shapes ranges from smooth regular cylindrical and pear-shaped caverns through to highly irregular Christmas tree shapes. Figure 6 illustrates the roof section of a storage cavern having a very regular shape, determined using two full surveys. As can clearly be seen, no significant changes in shape took place during the observation period. Only uniform convergence has occurred.

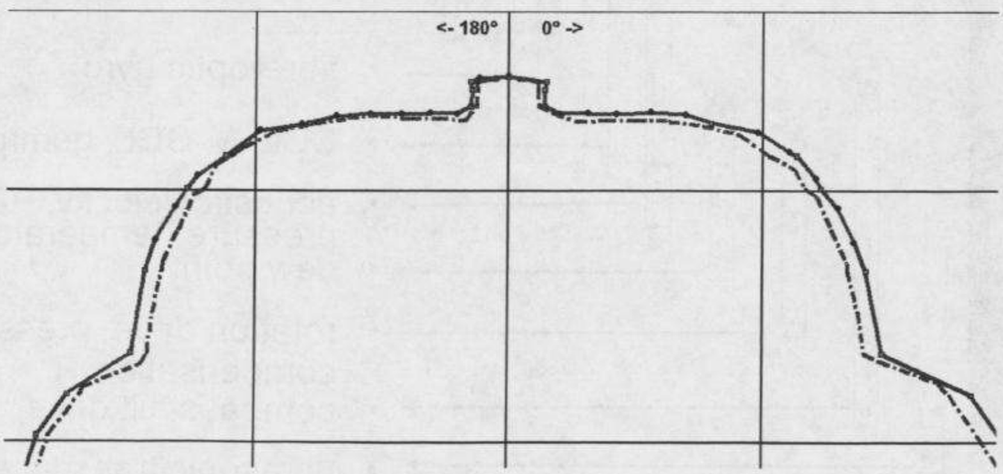

Fig. 6: Convergence in the roof zone of a cavern

Irregularly shaped caverns often have projections protruding from the wall into the cavern. Zones of this kind are obviously subject to relatively high rock stresses because they are only supported by the medium stored in the cavern. In the case of gas storage caverns in particular, where operational requirements often result in very low internal cavern pressures, this support is accordingly also minimal. The fall of such a projection often leaves behind a smoother cavern wall. Figure 7 illustrates a cavern with a somewhat irregular shape, in which spalling has taken place in the roof zone in the period between two full surveys.

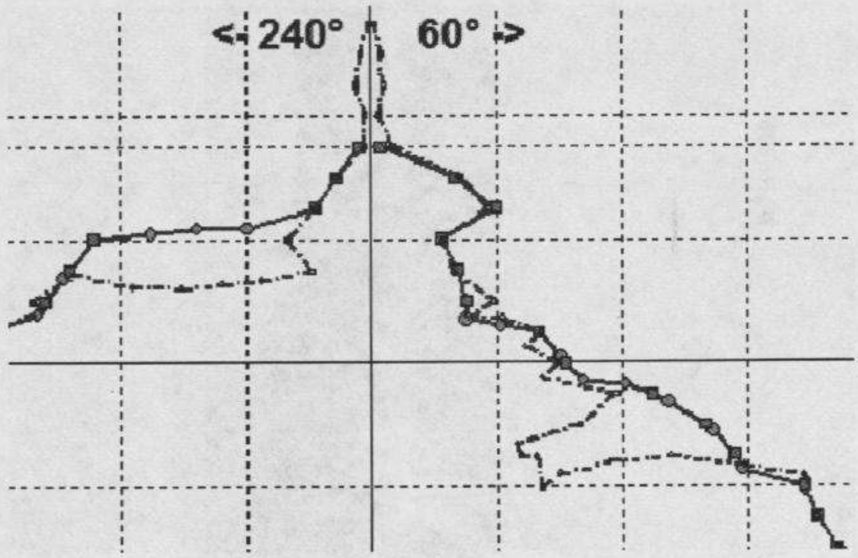

Fig. 7: Changes in a cavern roof zone (previous sonar shown as a broken line)

This example demonstrates the importance of observing and analysing roof developments during the operating phase of a storage cavern. Bearing in mind that even minor changes may be crucial, the demands made on echometric surveillance are correspondingly high.

3.2 Spiral measurements

To increase the survey point density cavern surveys can be carried out as spiral measurements. Whereas the standard method is based on a point-by-point procedure these measurements are made while raising the echo tool and simultaneously slowly rotating it. As a result the cavity is sampled with such a high survey point density that even fine structures on the cavity wall can be resolved.

Very accurate echometric caliper measurements can be achieved in the cavity neck with this method, which, as opposed to the relatively coarse conventional caliper, allows detailed analysis. This is especially important in the critical zone of the cavity neck because here free passage must always be guaranteed. Changes in shape in this zone (Fig. 8) must be followed very closely so that if necessary appropriate measures can be initiated in good time.

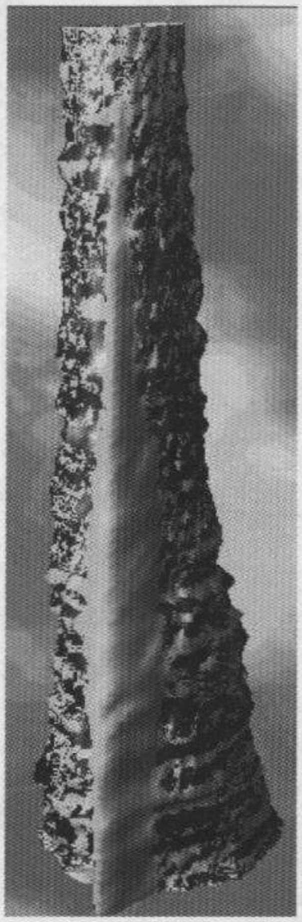

Fig. 8: View of a cavern neck as comparison of two spiral measurements. (Dark grey: initial survey, light grey: following survey)

The transducer head is tilted upwards at a fixed angle during spiral measurements of the roof. This enables pockets in the roof structure to be detected, which is of great importance when the integrity of a cavern roof has to be proofed.

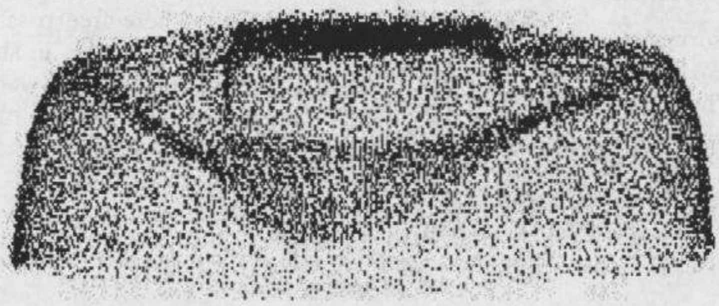

Fig. 9: View of a cavity roof as revealed by spiral measurements

3.3 High resolution measurements

Another method of enhancing the density of survey points in addition to that of spiral measurement is for example to reduce the vertical separation between two measurement horizons. Depending upon the size of the cavern, the distance can be between two and 10 metres. Reducing this to just a few decimetres provides a much more detailed scan of the cavern wall. The resolution can be

further raised by reducing the angular steps between individual measurement sections.
Both of these procedures result in a very large number of individual scan sections such that detailed investigations of this kind are only justified in certain cavern zones.

Figure 10 shows a square of a horizontal section of a cavern surveyed with a vertical measurement horizon separation of only 0.2 metres and with angular steps of 2 degrees. The sonic signals acquired were then further enhanced by employing quadruple correlation together with five-fold recording of each horizontal section. Consequently zones of spalling and convergence could clearly be identified.

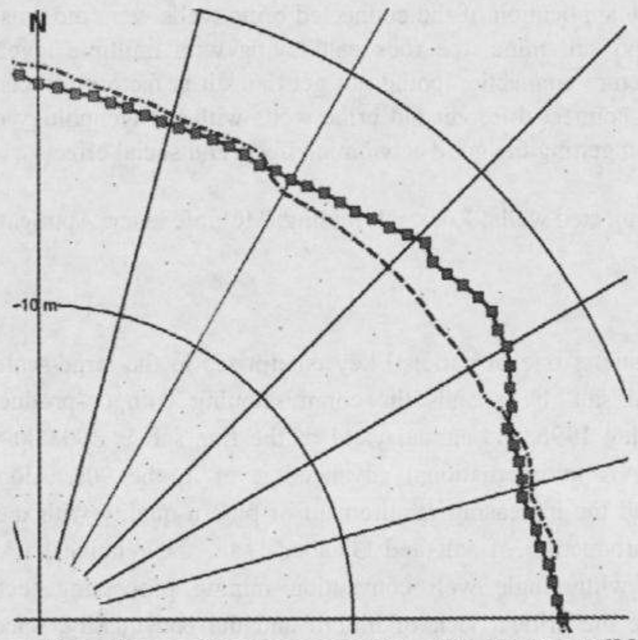

Fig. 10: Identification of spalling and convergence from the cavern wall between two high resolution sonar surveys (previous sonar shown as a broken line)

4. Literature

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/2/ Reitze, A.; von Tryller, H: The Influence of Physical Conditions Inside a Cavern on Execution and Evaluation of Sonar Surveys, SMRI Spring Meeting, Syracuse, New York, USA (2005).