How to Locate Water Hazards in Salt Mines

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ABSTRACT

Monocycle radar was first tested in salt mines in 1969. Experiments since then for other industries have produced major improvements in equipment and technique. It has recently been shown possible to locate and identify a brine channel as small as 10 square inches in cross-section through up to 275 feet of salt. Monocycle radar can resolve separate brine channels as little as 3 feet apart. Large-area reflectors have been located through 735 feet of salt. "Terradar," a locating service for water hazards including neighboring brine cavities, is now commercially available.

INTRODUCTION

Massive salt is almost transparent to long electromagnetic waves. Short waves, including the microwaves, infrared and light, would be expected to be severely scattered by the myriad surfaces of individual crystals. Indeed, this is the reason that natural masses of salt appear white, even though single crystals are perfectly clear. However, radio wavelengths of a meter or more are not appreciably scattered by crystals averaging less than a centimeter across. Only the bulk electrical conductivity affects such waves. Fortunately this is very low for most salt, corresponding to a low moisture content. Our experiments confirm the more extensive measurements of others (Unterberger et al., 1970, 1973), that radio waves in the 50 to 300 megahertz range (1 to 6 meters in wavelength, in air) can be received through hundreds to thousands of feet of natural salt.

Where dry salt is in contact with a large body of liquid brine or brine-saturated porous material, reflection of impinging radio or radar waves will occur. It is only necessary that the reflecting body be comparable to the wavelength in size, or larger. Thus, many of the water hazards likely to be encountered in mining salt should produce good radar reflections. These include adjacent solution-mined cavities, brine-filled exploration holes drilled from the surface, interbedded wet sandstone, and the shale at the flank of a salt dome. Long-wave radar has been applied with great success to probing through polar snow and ice sheets over a mile thick (Rinker et al., 1966). Like salt, glacier ice is a dry, polycrystalline nonconductor which is very transparent to long radio waves. Long-wave radar has also detected salt-dome flanks through at least 900 ft of salt (Holzer, et al., 1972). Such practical results confirm theoretical expectations.

The subject of this paper is exploration through salt with high-resolution "monocycle" radar. This type of radar combines the use of meter wavelengths with ultra-short pulses. The combination enables solids such as salt, ice, coal, limestone and granite to be explored (Cook, 1972, 1973) and reflecting objects as little as a meter apart in range to be resolved and located, at distances from 7 ft to 735 ft through the rock. Monocycle long-wave (VHF) radar was invented in 1958 (Cook, 1960). In experiments beginning in 1969, it has been used to locate a variety of reflectors, including water hazards, in three Gulf Coast dome-salt mines. The assistance furnished by the three mining companies involved is gratefully acknowledged.

METHODS AND OBSERVATIONS

Figure 1 shows an early VHF monocycle mining radar. The present model consists of seven boxes weighing 350 lb total, which can be carried in a sedan automobile, a small mine cage, or a mine jeep, and set up by one man. A setup and the basic measurements can be completed in about 1 hour. More compact equipment is under development which should permit completion of a radar "station" in about 5 minutes. The present transmitter radiates only 0.1 watt peak, in a pulse 5 to 15 nanoseconds long. Greatly improved efficiency expected in the new equipment should double or triple the present working range.

In the first salt mine experiments, direct one-way propagation was obtained through a salt pillar 72 ft thick. The delay time due to the salt, compared to an equal separation of the antennas by air, gave an average "slowing factor" (index of refraction) for the salt of 2.29. This figure has since been confirmed several times, in one-way propagation tests through up to 200 ft of salt. Reflections from the air interface at the opposite side of pillars 72 and 100 ft thick were also clearly recorded. Despite its normal 1 ft-deep irregularities, a pillar wall appears mirror-like to 1-meter waves.

Unfortunately, attempts to locate known brine-filled drill holes and fissures, and the flanks of the dome were not clearly successful in the early experiments, because of equipment reverberations and other "clutter" which made the identification of weak reflections difficult. In the course of subsequent work in coal mines and limestone quarries (Cook, 1973) several methods of suppressing such interference were developed, particularly antenna improvements. Most of our recent success can be attributed to an intense research effort devoted to the clutter problem. In the present equipment, clutter has been suppressed by 50 to 80 dB, relative to our 1969 equipment or comparable monocycle radar equipment developed by others.

Figure 2 shows several examples of VHF monocycle radar echoes recorded (on a storage scope) in a salt mine with the present equipment. The various numbered echoes are shown at several settings of the receiver gain and delay. The most distant was No. 7, in Figure 2c, which occurred 3510 nanoseconds or 735 ft after the moment of transmission, indicated approximately by "L". This reflection corresponds to "R" on Figure 3, which is a room wall 100 ft high, about 735 ± 35 distant through solid salt from radar station "3" on Figure 3 (the nearer rooms are only 10 ft high, so do not interfere). Most of the other reflections correspond in distance to the other room walls seen

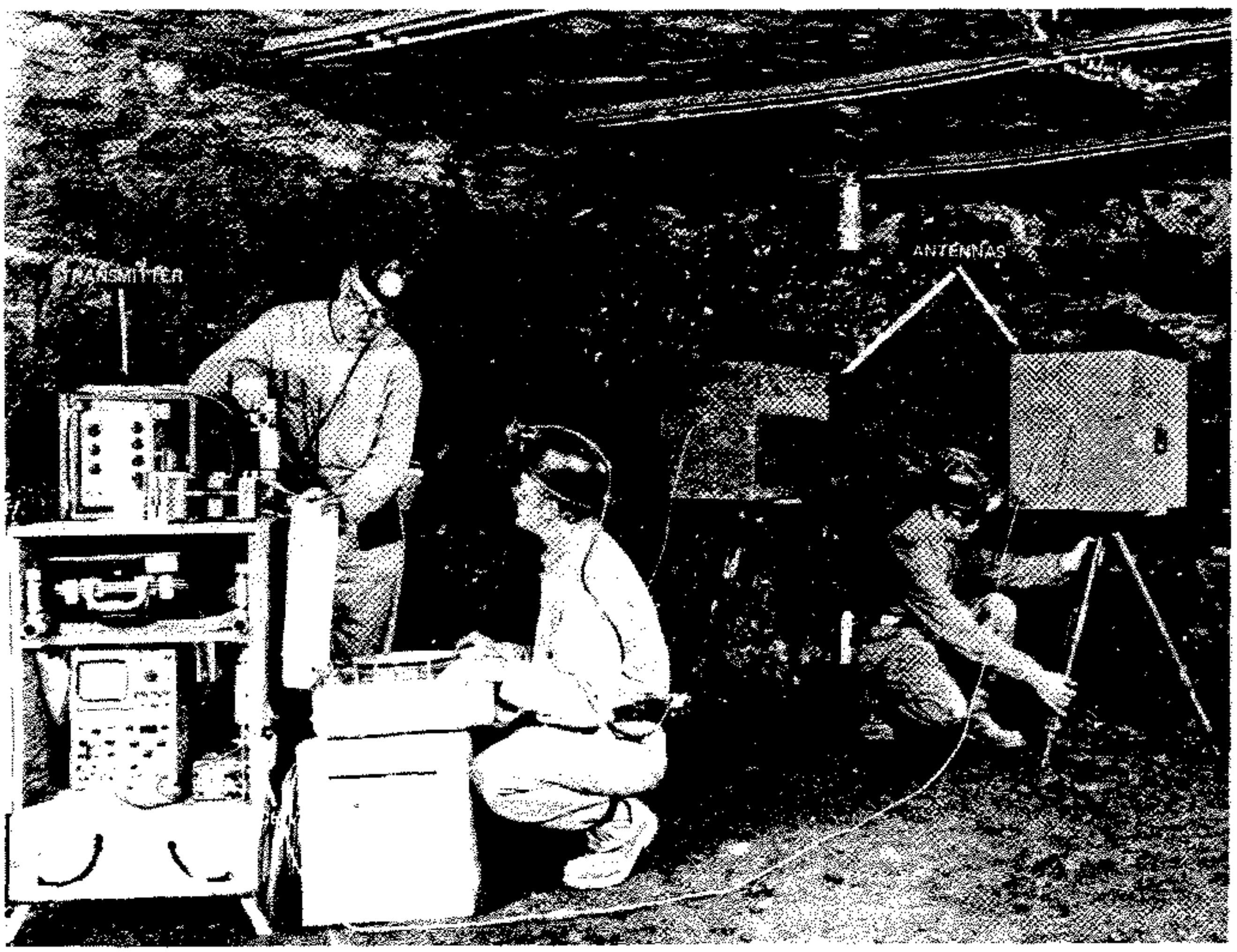
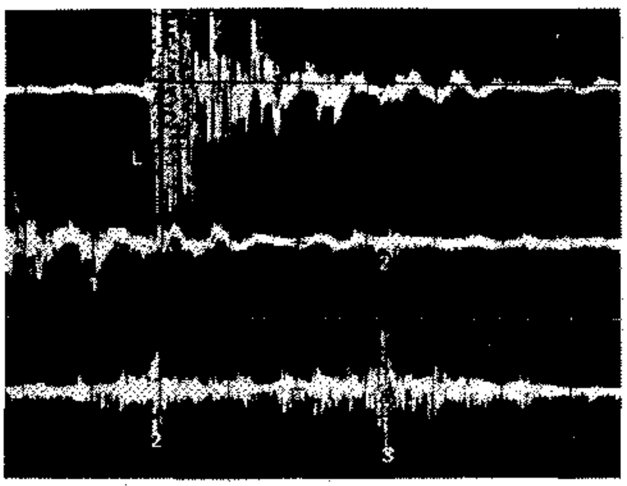
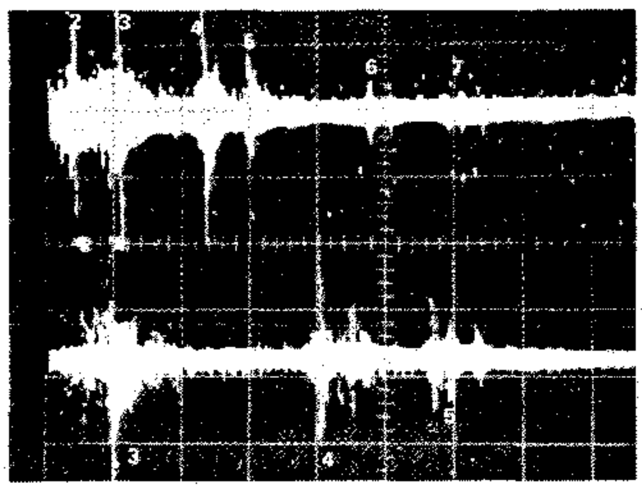


Figure 1. Experimental 1971 Teledyne Mining Radar Setup in Bedded-Strata Mine (U.S. Bureau Mines photo).

(a) Echo from wet drill hole 170 ft away 10 nsec, 5 mV/div.
Upper: with box R antenna.
Lower: with flat R antenna.
(at station O)



(b) Station 3 echoes, time-shifted, 100 nsec, 50 mv/div.



(c) Most distant Station—3 echoes, 20 Mv/div.
Upper: 500 nsec/div,
Lower: 200 nsec/div.

Figure 2. Distant reflections obtained through massive salt.

in Figure 3. Since the radar antenna beams are about 90 degrees broad, all the reflectors are illuminated at once, and their echoes are presented in a single recording. The echoes shown in Figure 2 mean that the working range of the present VHF monocycle mining radar is at least 735 ft for large reflectors through typical dome salt.

At all five radar stations around the large pillar shown in Figure 3, one or two echoes were received from an intermediate distance, which exhibited the peculiarity of appearing only if the antennas were vertically polarized. One of these echoes, at a distance of 170 ft from station ≠0, is shown in Figure 2(a). All other echoes, presumably from room walls, appeared with either vertical or horizontal polarization. The source of the vertically-polarized echo is probably an old oil-exploration drill hole known to be somewhere inside the large pillar; brine leaks have occurred at various points around the pillar. When arcs were struck on Figure 3 from the various radar stations, representing the various apparent distances of the drill hole, approximate agreement was found; the shaded triangle shows the inferred location of the drill hole. A weaker polarized echo indicated a possible brine-filled fissure or

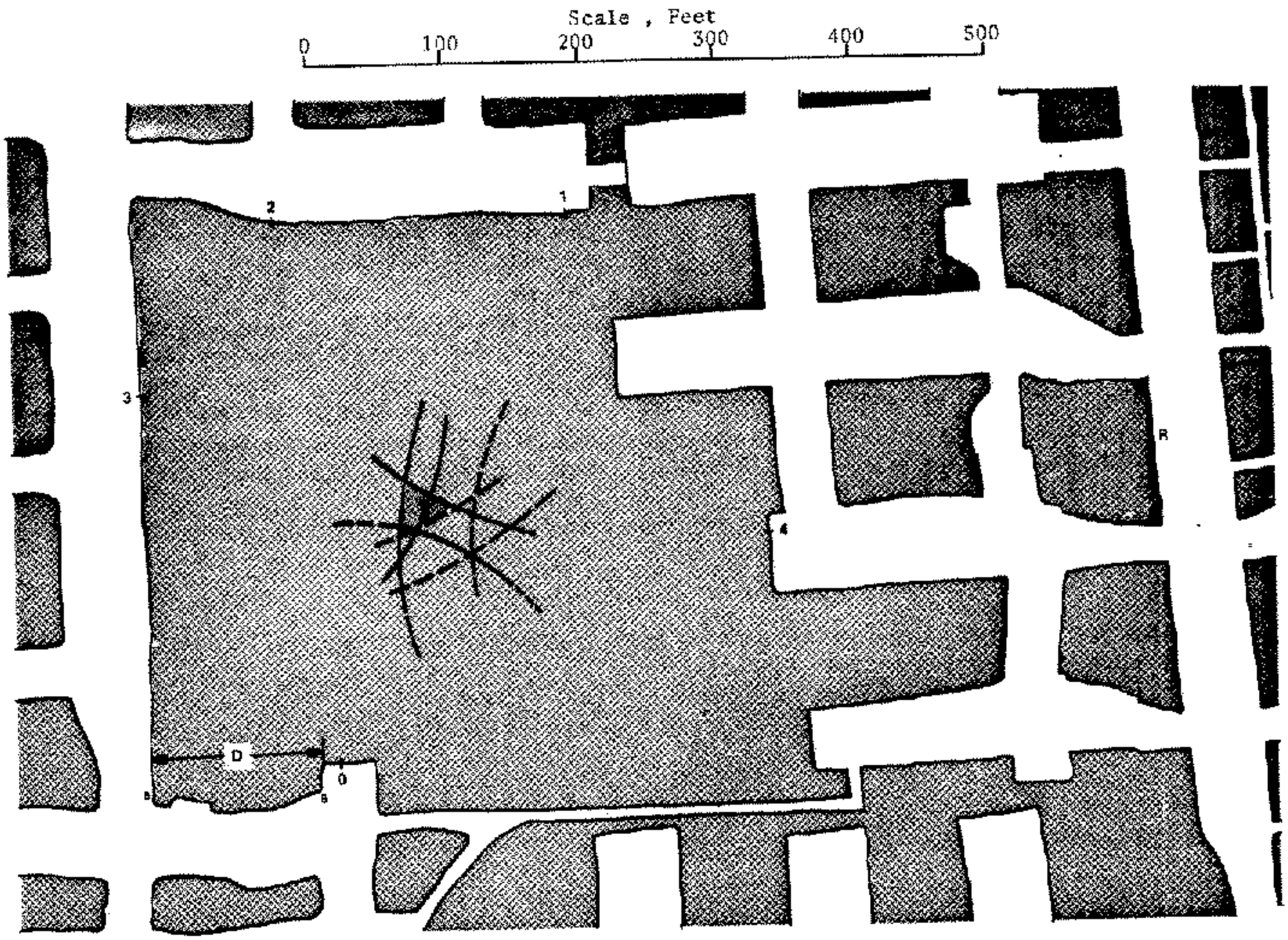


Figure 3. Map of salt mine pillar and drill hole location.

other reflector about 50 ft to the right of the drill hole, on the figure.

The drill hole located in Figure 3 is believed to be about 3 inches in diameter, uncased, and filled with brine from surface waters. Locating it within about 10 ft in an experimental, preliminary survey shows the power of the VHF monocycle radar to pinpoint potential water hazards in salt under favorable circumstances. In a precision radar survey, using accurate values of the local "slowing factor" of the salt, location within 2 ft should be possible. A 3-inch hole or equivalent fissure should be detectable 275 ft away. There would be a good chance of drilling close to it with a horizontal hole, connecting to it by shooting or hydrofracturing, and pumping it full of expanding grout for a permanent seal-off.

Other potential hazards such as solution cavities adjacent to mining can be located and watched through the salt with radar. Since overlying anhydrite and limestone are also reasonably radar-transparent, the sharp advancing top edges of a brine cavity in bedded salt will present a large electrical contrast, and should produce a clear radar echo while still at least 200 ft away from the mine openings. The radar has also located faults filled with wet, porous material (Cook, 1973). Regions of heavy salt contamination by anhydrite and stony salt bands may perhaps also be identified at a distance, since such bands appear to produce small radar echoes, in our experience. Other possible applications will doubtless occur to those engaged in salt mining. The VHF monocycle radar is a detecting and locating tool of high precision and large operating range in salt. Its potentialities are still only partially known.

AVAILABILITY

As of 1973, Teledyne Geotech can provide VHF monocycle radar surveying services out of Dallas on a time-and-expenses basis. This service is named "Terradar." Patented Terradar equipment may eventually be available for purchase.

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