NOTES ON SCIENCE

Terradynamics

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Science research often provides many new tools and techniques which are of practical value to industry. Some, through extensive research, eventually become simplified and useable while other new tools require many years of work before they can be of practical use. But what is *practical use?* When does a particular newly developed scientific tool or method become practical enough to be used in the water well industry, for example?

For those of you who have ever marveled at the apparent simplicity of the present six cylinder gasoline engine, the number of manhours of research and development of such an engine would be astounding. In the drilling industry, for example, thousands of manhours have been devoted to the design of the 3-cone roller bit in common use today. Another example would be the use of borehole geophysics in water well construction. For years, it was primarily a tool for the petroleum industry, a tool so expensive and complicated to use that only the oil industry could afford it. It was practical to use for the petroleum industry only! In recent years, geophysical equipment and its use has become sufficiently simplified—and therefore less costly—that geophysics is now a vital tool for the ground water industry. So by way of conclusion, it is clear that when a particular technique or tool is relatively inexpensive and reasonably simple to either operate or understand, it has reached the stage of being practical! This conclusion is based on the assumption that over the past 50 years, the level of understanding— not necessarily via formal education—has risen to the point that subjects once assumed to be highly complicated by the average man in the 1920's are now considered reasonably simple . . . . at least this kind of process is what human progress is supposed to be.

This article will deal with a highly scientific tool presently under development which has considerable future possibilities for use in ground water development. Neither the idea nor the practical details of its operation are complicated . . . if we first desire to understand and secondly, if we spend a few minutes concentrating not only on the particular tool, but also on what modification of it *could be* of use in some other way—the sky is no longer the limit!

The name of the subject is *Terradynamics. Terra* meaning: the earth, *dynamics* meaning: that branch of mechanics treating the motion of bodies and the action of forces in producing or changing their motion. The tool is a high-speed earth-penetrating projectile for use in rapid subsurface investigations. Projectile penetration of the earth has been studied over the past two centuries. Most of the work, however, had a particular military application in mind, such as the penetration of installations by cannon balls. In one notable instance, a projectile was designed specifically for earth penetration. In the early 1940's a German artillery group developed an 8-inch diameter penetrating round that was fired in high trajectory from a cannon to impact the earth at a velocity of about 1100 feet per second. The results were quite spectacular: The projectile penetrated 50 feet of "loose stone and clay" overburden, then 60 feet of "chalky marl" and still had enough momentum left to completely perforate 2.5 feet of 10,000 psi reinforced concrete.

Scientific studies of large scale earth-penetration events were undertaken by Sandia Corp., Albuquerque, under contract to the U. S. Atomic Energy Commission, in 1962. By June of 1967, the program involved a total of 692 earth-penetration events, of which 382 were instrumented to record the deceleration experienced by the projectiles. The studies have been made in both soil and rock materials. Projectiles have penetrated natural deposits of loose to dense moist sands, dense cemented sands and gravels, as well as bedrock such as dense sandstone, granite, welded tuff, etc.

In the Sandia program, projectiles from 1 to 18 inches in diameter have been used. Penetration approaching 100 feet in depth has been accomplished and depths up 200 to 300 feet in either unconsolidated or consolidated material are reported as possible.

The essential elements of an earth-penetrating projectile are shown in Figure 1. The aerodynamic fins on the tail provide stability while the projectile is falling through the air. These fins shatter upon initial impact. The base of the fins protrudes slightly and acts as a terradynamic fin which aids in maintaining a stable underground trajectory or path.

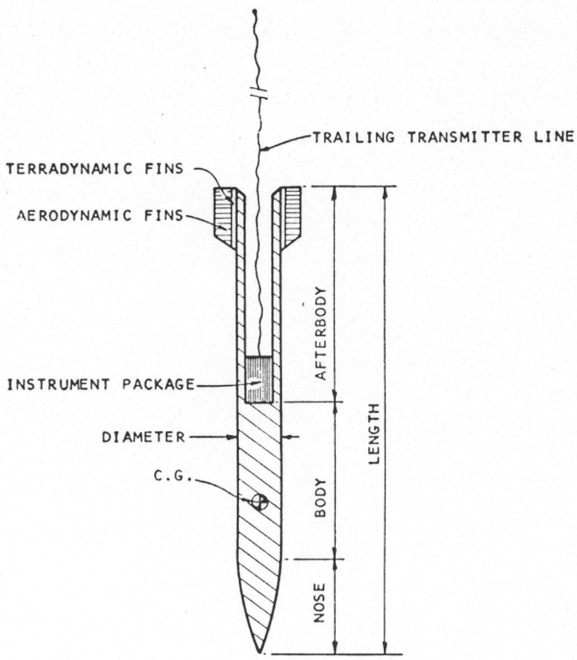

Figure 1. *Details of earth-penetrating projectile.*

The heart of the on-board instrument is an accelerometer which continuously transmits the projectile's deceleration characteristics to a central recording station, which is usually housed either in a recording truck or on light aircraft (see Fig. 2).

When the free-falling projectile initially impacts the ground, the nose slices the soil, causing a small crater. As the projectile contines to penetrate, the aerodynamic fins shear off. When the projectile is well into the earth but still traveling at a reasonable velocity, penetration takes place by the slicing action of the nose. This action shears and compresses a thin zone of material around the projectile, pushing the

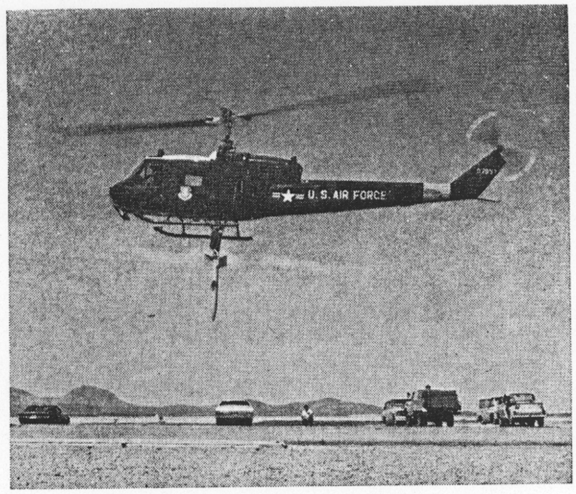

Figure 2. *Ready projectile and supporting ground equipment.*

material away from the projectile body; at all but the lowest velocities, the body has moved past before the earth materials commence to rebound.

As the projectile decelerates to near-zero velocity, the penetration characteristics change. The earth materials start to grip the body of the projectile, greatly increasing the deceleration which stops the projectile. Figure 3 shows the projectile recovery operation for use in studies of soil characteristics and projectile conditions. The total process of penetration occurs over a period of microseconds. Different rock types allow the projectile to pass through them at different velocities, or more correctly, the projectile's velocity is slowed according to the rock type through which the projectile has passed.

Figure 3. *Projectile recovery operation.*

A projectile delivering system consists of a helicopter on light aircraft with a crude bomb sight. For additional depths, the projectile could be delivered by a diving high speed aircraft for added initial velocity.

Figure 4 shows the sequence of events in a typical site investigation. The sketch at the top shows an assumed profile as might exist in a ground water development program in a remote area.

An aircraft equipped with the receiving and recording equipment is shown dropping the projectile. Five units are shown, each in a different stage of the event. *Unit 1* has penetrated to its full depth and has stopped; *Unit 2* is still penetrating and is still broadcasting the decelerations it experiences; *Unit 3* is shown in free fall, acquiring velocity under the pull of gravity; *Unit 4* is shown as it starts to stabilize aerodynamically and as its trailing antenna starts to deploy; and *Unit 5* is shown just as it is released from the aircraft.

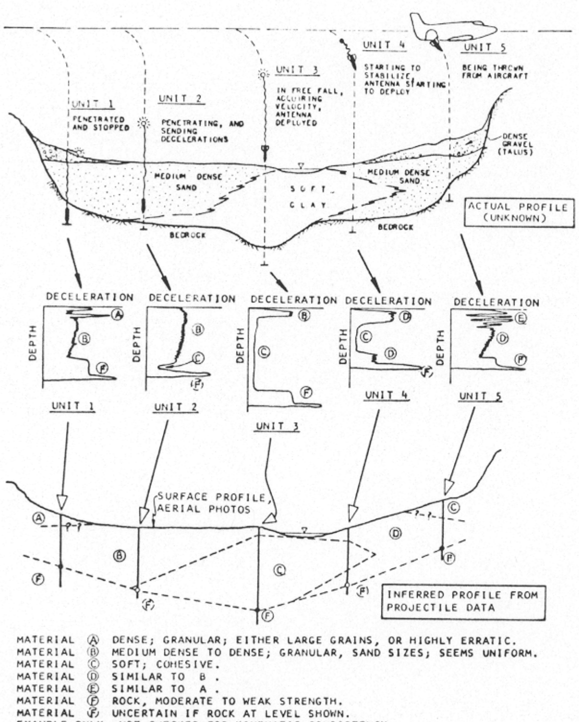

Figure 4. Example of soil investigation using high-speed projectiles

Upon entering bedrock, *Unit 1* would experience a pronounced increase in deceleration (or decrease in acceleration). If additional information on the bedrock is necessary, a second run at higher velocities (higher drop altitude) would be made to penetrate further into the bedrock.

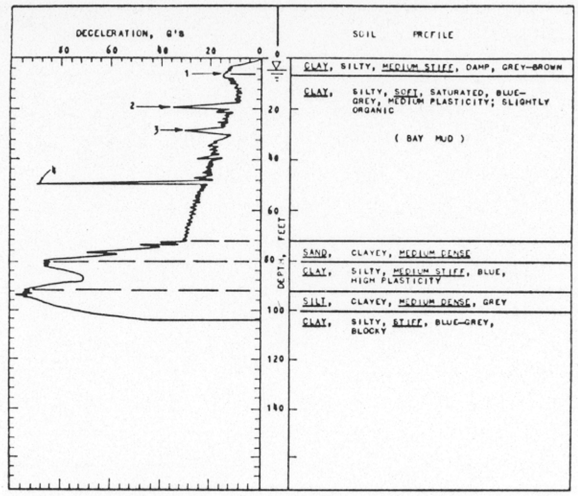

Figure 5. Penetration event in saturated soils.

Figure 5 illustrates the value of the information gained from such tools. Note that at 72 feet a sand is indicated which may be suitable for development as a ground water source, although this particular case suggests that the sand interval may not be a good aquifer since it probably contains considerable amount of clay. However, a major sand channel could be found using this method.

Work on terradynamics indicates that potential applications greatly outweigh its limitations. The following is a brief list of potential applications:

- Subsurface ecological studies in remote and flat area.
- Hydrological studies for location of water table, etc.
- Location of bedrock for reservoir sites.
- Snowfall and glacial measurements.
- Real estate development site surveys.
- Studies of incipient landsliced areas.
- Analysis of ore deposits.
- Emplacing deep sea anchors.
- Basic environmental science studies.
- Extraterrestrial exploration.

Although terradynamics is still a highly complex topic and is not at this date ready for widespread use, it may in the foreseeable future find its place among the many tools that were once highly complicated but are now used with great confidence.

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