ment of men and equipment across the surface of the ground away from established roads. Unlike military construction, cross-country movement has few immediate counterparts in civilian life and, therefore, has been studied almost exclusively in terms of the military application. The special problem in cross-country movement for the earth scientist is the determination of the suitability of areas and types of ground for movement of men on foot or, more commonly, of vehicles equipped with wheels or treads. The basic scientific problem is the determination of significant interrelationships between the elements of terrain that influence movement. The evaluation of the influence is the link between the scientific and applied problems.

For successful attack on the problem of terrain evaluation for special purposes, such as those outlined, it has been necessary to reorient the thinking of geologists, soil scientists, botanists, and climatologists from preoccupation with isolated elements of terrain to a constant awareness of the terrain complex. This necessity is apparent in the purpose of the terrain evaluations, which calls for an exploitation of terrain areas, not terrain elements. At the same time, it becomes necessary to cultivate an understanding of the appropriate combination of elements that will define the essential qualities of a region for a specific use. In some cases, it is quite adequate to limit the consideration to two elements, such as rock and soil, soil and vegetation, soil and climate, or rock and terrain form; but commonly at least three or four elements must be appraised in combination. It has been found also that the significance of any one factor of terrain is commonly a variable. For instance, the significance of slope is not proportional to its steepness. In certain uses of terrain, such as off-road movement of tanks, there is a limit beyond which steepness becomes critical, regardless of other terrain characteristics, but below that limit its significance may be entirely dependent on one or more concomitant features. Thus, a steepness of 30 percent would be highly, or possibly completely, restrictive to movement of tanks, if the soils afford poor traction and large trees require sharp turning. On the other hand, an equivalent steepness would not be a serious obstacle where the soil traction is good and trees are lacking.

A second major problem in making special-purpose terrain evaluations is to find the most effective way to present the results. A familiar graphic approach consists in plotting areal data for each terrain element under consideration on separate transparent sheets. To obtain a composite picture, all the sheets can be superimposed and all boundaries that show through can be traced on a single sheet. By this means, it is hoped to delineate on one map all areas with unique combinations of the different terrain elements considered in the evaluation. The result tends to become complex in appearance and to obscure distinctions between boundaries of primary and subsidiary importance.

To overcome these shortcomings, many ingenious cartographic solutions have been attempted. The most sophisticated solutions are generally too difficult for the nonscientific user. Continual experimentation is going on, therefore, to establish simple formats that translate scientific concepts into terms that will permit the user to read directly qualities of terrain for a designated purpose. It is found, however, that greatest reliability is attributed by the nonscientific user to maps that show the scientific bases of interpretation, but in an unobtrusive manner, so that, if desired, an insight can be gained into the contributing factors. From a scientific viewpoint, this attitude is desirable. It gives the map increased flexibility of use and permits reinterpretation of basic data to accommodate certain changes in the conditions of terrain use without a return to original sources. The research is being conducted by trials with a map of a selected area using the same data in each trial and by applying the same principles to maps of different areas and scales.

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Geological Survey Investigations of the Scurry Reef and "Horseshoe Atoll" in Western Texas

One of the most productive oil-bearing structures in North America is a horseshoe-shaped accumulation of limestone buried more than 6000 ft beneath the plains in western Texas. This structure, called the "Horseshoe atoll" because it resembles modern atolls in size, shape, and some lithologic characteristics, is 70 to 90 mi across and in some places more than 1000 ft thick. Its crest contains irregular mounds, basins, and channels; its flanks, which are indented by sinuous reentrants, slope from the crest at angles generally less than 6° and merge into a broad limestone platform on which the atoll is built.

The highest and most continuous part of the Horseshoe atoll is the southeastern part, which underlies Scurry County and is known as the Scurry reef. Oil was discovered in this reef in 1948. Intensive drilling showed that the Scurry reef is the largest oil-producing limestone reservoir in the Western Hemisphere; it is second only to the East Texas field in proved reserves. Prior to March 1954, 35 smaller fields had also been found in the limestone mounds along the crest of the Horseshoe atoll north and west of the Scurry reef.

The Geological Survey began an investigation of the Scurry reef in 1950 in cooperation with the Bureau of Economic Geology of the University of Texas in an effort to determine the age and lithology of the reef, its relationship to the shale that surrounds and overlies it, the genetic significance of the reef, and the probable origin and paths of migration of petroleum in the reef. The objective of this project was to obtain as much scientific information as possible about the nature and origin of this reeflike mass to aid in recovering the maximum amount of oil from this structure and in exploring for other similar limestone structures. This investigation involved the study of cores, samples, electric logs, and radioactivity logs made available by the oil industry from several thousand wells drilled into the Scurry reef and adjacent parts of the Horseshoe atoll, and it also included the comparison of Foraminifera obtained in cores from the reef with Foraminifera from outcropping rocks of the same age in central Texas. A special study of the reservoirs in the Scurry reef was made in 1951–52 for the Petroleum Adminstration for Defense to provide that agency with information on the availability of oil and gas from the Scurry fields and to assist in exploration, development, and operation.

The Geological Survey investigations of the Horseshoe atoll showed that this structure was a topographically prominent accumulation of fossiliferous limestone on the floor of the Midland basin in western Texas during late Pennsylvanian and early Permian time. Growth of the atoll and the development of porous zones within it were apparently cyclical and were probably related to periodic changes of sea level. Recent studies indicate that the atoll was smothered during early Permian time by mud and silt that entered the Midland basin from the northeast, terminating the growth of the northeastern side of the atoll before growth ended on the southwestern side.

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Serpentine Pipes at Garnet Ridge, Arizona

Garnet Ridge, about 35 mi northeast of Kayenta, Ariz., earned its name from pyrope garnet that occurs in serpentine pipes underlying the ridge. In addition to serpentine, the pipes are choked with rocks derived from a section more than 5000 ft thick and ranging in age from pre-Cambrian to Cretaceous. Garnet Ridge is a low, oval butte, about 3 by 8 mi in size, composed largely of rocks of the San Rafael group (Jurassic) and capped by rocks of the lower part of the Morrison formation. It rests on the southeast-dipping flank of the Comb monocline and is perforated by the pipes where the monocline rises steeply.

There are four pipes; one is at the Ridge crest and is about 1000 ft across; the other three are 2 mi northeast along the strike and make a cluster 1500 by 4000 ft. Material like that in the pipes also occurs a few miles north along Comb monocline at Moses Rock and Mule Ear in Utah. The pipes at Garnet Ridge are irregular in outline and have nearly vertical walls that locally parallel joint sets in the country rock; the cluster of three pipes is elongate parallel to a northwest-trending set of joints. Country rocks around the pipe cluster are downwarped in a syncline about 2 mi long having 160 ft of closure. Deformation at pipe walls has been by fracturing.

The pipes are filled with two kinds of material: (i) large blocks of sedimentary rocks derived from above, and (ii) pulverized serpentine rubble containing pebble and boulder xenoliths of Paleozoic sedimentary rocks and older crystalline rocks derived from below.

The blocks of sedimentary rocks fell from higher positions into the pipes, and some of Late Cretaceous age demonstrate that 1200 ft or more of rocks covered the area when the pipes were formed. Many of the collapsed blocks exceed 100 ft in size; one piece of massive sandstone, several hundred feet below its former position, is 800 ft long. All are angular. Pieces originally far apart stratigraphically are juxtaposed.

The serpentine rubble is squeezed between the collapsed blocks and along joints in the country rock. It contains xenoliths from more than 4000 ft below. The matrix of the rubble is pale grayish green, pulverized serpentine (var. antigorite) containing much calcite and chlorite. Lesser amounts of olivine, chrome-diopside, biotite, hornblende, gypsum, quartz, pyrope garnet, magnetite, and a reddish clay (shown by x-ray analysis to be montmorillonite) are also present. All gradations of magnesian silicates altering the serpentine can be seen in thin section. Mineralogically, this material is similar to the chloritized-calcitized-serpentinized peridotite bodies known in Kansas, Illinois, Virginia, and New York. The pebble and boulder xenoliths in the rubble are not visibly altered; fossiliferous limestones show no recrystallization; red sandstones and black shales are unbleached. Wall rock in contact with the serpentine rubble is altered in a few places, but the alteration was weak and not necessarily contemporaneous with rubble eruption.

Surficial deposits of serpentine rubble, identical in composition to the intrusive rubble, cap a row of knobs that extends half a mile eastward from the pipe at the crest of Garnet Ridge. Lack of feeder dikes under the knobs and the occurrence of slump blocks at the base of the rubble argue against intrusive emplacement. The surficial deposits are large, compared with the amount of rubble in the pipe, and were probably derived from rubble erupting from the pipe. But the field relationships do not entirely disprove the possibility that the surficial rubble was redeposited without eruptions. The knobs are interpreted as the trace of a former valley into which rubble flowed from the pipe. Subsequent erosion, chiefly sedimentation, has lowered the land surface leaving the surficial rubble perched on the knobs. Resistant constituents derived from the rubble, including garnet, are widespread on the erosion surface.

Because the serpentine rubble appears to be associated with pipe formation, which certainly antedates the surficial deposits, two times of serpentine rubble eruption are suggested—the first Tertiary, the second Pleistocene.

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