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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