SHOCK-WAVE ALCHEMY

For the first time, the gemstone garnet has been compressed by a laboratory-generated shock wave into a denser material—a new form that seems to have a crystal structure similar to the titanium ore called ilemenite. The shock wave, which subjects the garnet—of the variety almandine—to the same enormous pressures that rocks undergo at about 375 miles beneath the earth's surface, is produced by a research cannon designed by Thomas Ahrens, associate professor of geophysics. The cannon was constructed using the breech from a three-inch Navy weapon from a destroyer escort but with a 24-foot-long barrel. Unlike the Navy version, this barrel is smooth bored and kept straight to within three-thousandths of an inch over its entire length.

This unique cannon is located at bedrock level in Caltech's shock-wave laboratory. With it, Ahrens is gaining new insight into how the behavior and crystalline structure of minerals change with increasing temperatures and pressures down to 600 miles in the mantle—the 1,800-mile-thick layer of rock between the earth's crust and core. Garnet is a good material for the experiment because there is a considerable amount of it in the mantle.

The cannon fires flat tungsten bullets 1½ inches in diameter into a 120-cubic-foot vacuum tank, and even though the atoms and chemical composition of the garnet remain the same, the shock wave produced by the impact rearranges the atoms so that they are more tightly packed together. The rearrangement of atoms is called a phase change.

Ahrens and his colleagues, research fellow Earl Graham and research engineer John Lower, find it surprising that so dense and hard a mineral as garnet (which has a density of 4.2) is so readily transformed into a more closely packed structure. The resulting mineral has a new structure with specific gravity of about 4.4, which represents an increase of about 5 percent.

Attempts are being made with X-ray diffraction techniques to delineate the new pattern of the atoms, but this is difficult because much of this new phase—which seems structurally similar to ilemenite—is unstable in the laboratory and transforms back into garnet.

The gun used in the Ahrens experiments is instrumented to determine the tungsten bullet's velocity and the speed of the shock wave through the 1/6-inch-thick sample of the garnet. The bullets can travel up to four times faster than those from ordinary rifles, so a typical experiment doesn't last long—about a millionth of a second.

In about half of a recent series of 14 shots fired at increasing bullet velocities, Ahrens and Graham observed the garnet undergoing a complete change of phase. At first the velocity of the shock wave increased with an increase in bullet velocity. However, as bullet velocities continued to increase, the shock-wave velocity first decreased and then increased again. This was the clue that a phase change had occurred.

By using minerals and metals such as garnet as targets, the experimenters can determine what effects the extreme pressure deep in the interior of the earth (and of other planets) has on their mechanical properties and crystalline structure. They can also study effects such as melting and shock-induced phase changes similar to those produced by meteorites impacting the earth, moon, and other celestial bodies. In earlier experiments Ahrens and his group used the gun to transform the mineral enstatite into what was thought to be the garnet structure. They chose to carry out experimentation on enstatite because other researchers had found that it had been transformed into garnet structure in a meteorite, presumably by shock waves induced by a violent impact at some time in its history.

Ahrens and his co-workers have also used the gun technique to produce shock waves in various kinds of glass to change their ability to bend and refract light, and to erase fission tracks on rocks that are produced by radioactive particles. His research is sponsored by the National Science Foundation and the National Aeronautics and Space Administration.

Thomas Ahrens, associate professor of geophysics, loads his converted Navy cannon. At the end of its 24-foot-long barrel is a 120-cubic-foot vacuum tank in which the target mineral is suspended.