

THE DEPTH

CHALLENGER

Artist's conception of a 56-inch diameter sphere mounted on its 16-foot maneuvering sled.

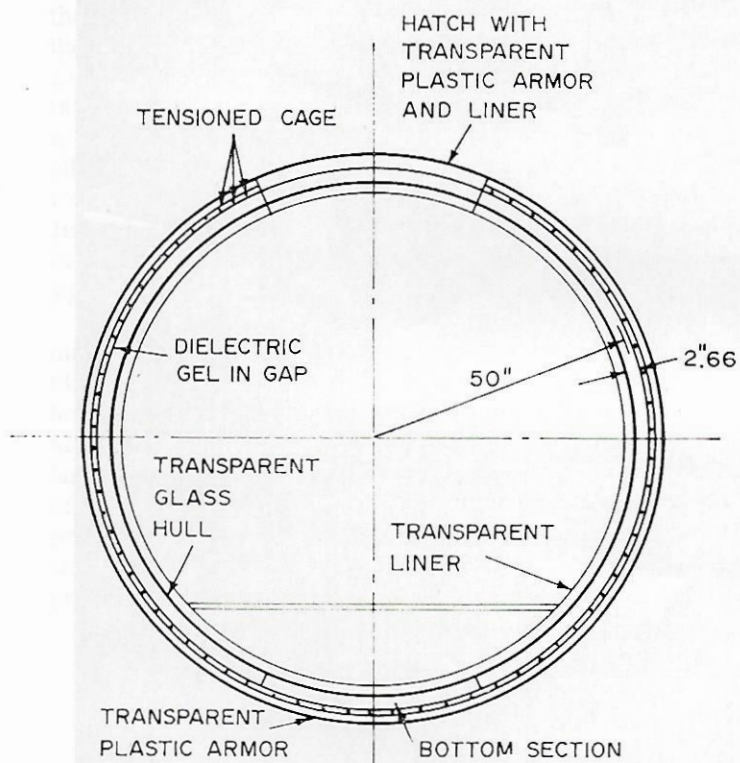
*By John Clarke
Class '68*

A brittle star, its arms twitching, spreading across the firm, grey mud, stops as a tracking light sweeps over and beyond it. An instant later the light returns and fixes on the animal as the whirring bubble slides in close overhead. The sphere hovers briefly then moves off, circling, finally disappearing below a canyon rim. When minutes later the bubble settles to rest on the soft canyon floor, cameras clicking, the two men inside sit gazing, peering, with four miles of water above their heads. These men are new frontiersmen — the oceanographers.

Having so far received less publicity and money than the space frontiers, our conquest of the underwater world is no less important or less exciting than our "conquest" of space. In the past few years, the exploration and exploitation of this 70% of the earth's surface has received strong impetus from reports such as that coming from the Interagency Committee on Oceanography, "A Long Range National Oceanographic Plan, 1963-1972." This report called for the expenditure of \$2.3 billion for marine research and applications over a ten year period. More

recently was the National Academy of Science's report from their committee on oceanography. From this report comes the estimation of \$6 billion a year return on the federal investment by 1980. Half of this would come from the utilization of marine mineral deposits, ocean fisheries, and recreational facilities. The other \$3 billion would come from savings in new transportation methods and weather forecasting. All totaled, a return of \$4.4 billion can be expected for every \$1 billion invested, not including the intangible and unforeseeable values associated with exploration of this sort. Promising such generous rewards, it is no wonder oceanographic research is gaining new interest.

One of the greatest problems preventing our full utilization of the ocean's potential is the inability of research devices to withstand the enormous pressures exerted by deep water. At four thousand feet, the sea exerts one ton of pressure on each square inch of surface. At thirty-five thousand feet, the pressure is more than seven and a half tons per square inch. To date, nothing has been developed with the ideal requirements of 1) withstanding deep sea pressure, 2) containing man for extended periods



(Fig. 3) Tentative design for jacketed glass hull.

of time, and 3) inabling direct visual observation. However, a solution to these problems may soon be met by glass submarines. H. A. Parry, research materials engineer at the Naval Ordnance Laboratory of Silver Springs, Maryland, is currently researching the feasibility of transparent submarine hulls. Perry states that glass provides a unique degree of bouyancy and safety in deep submergence hulls.

To test his original hypothesis, Perry and other NOL scientists set sail in 1964 aboard the Navy research vessel *Gillis* with a cargo of 95 hollow spheres provided by Corning Glass Works and the Pittsburgh Plate Glass Company. Once over the Puerto Rico trench, these spheres were lowered to depths of 300, 7000, 1400 and and 2100

feet. Pentolite charges were set a fixed distance away and detonated. If no leakage of the sphere occurred, the charges were moved closer until the glass finally failed. At this point, a "critical distance" was defined. As can be seen from figure 1, as depth increased the compressive strength of the glass also increased. With metal hulls, the results are just the opposite, as seen in figure 2.

The explanation of these surprising results lies in the fact that although glass has a low tensile strength in the presence of flaws, its compressive strength is extremely high (somewhere on the order of 300,000 psi). Glass is amorphous and covalently bonded, whereas metals are crystalline and metallically bonded. At room temperature the metallic bonds between metal atoms and their neighbors are constantly shifting. However, a covalent bond is quiet stable and can be broken only by a great deal of thermal energy. Furthermore, the amorphous, non-directional quality of glass eliminates the slippage of crystalline surfaces as it occurs in metals under compression.

Just what effect flaws have on these glass spheres was recently determined by Benthos Inc. of Norh Flatmouth, Massachusetts. Using two to eight inch hollow glass spheres supplied by Corning Glass Works, Benthos applied deep scratches with a carbide scriber in approximately one hundred places. These scratches were as much as 2 inches long, 0.06 inches wide, and 0.03 inches deep (1/10 of the wall thickness). The spheres were then placed in a hydrostatic pressure chamber for sixteen hours at 15,000 psi (30,000 ft. ocean depth). The spheres not only remained water tight but were actually improved by the breaking off of sharp edges. Along with a 0.03 inch deep scratch, one sphere receive a 1/4 inch gouge deeper than 1/3 of the wall thickness. This sphere survived down



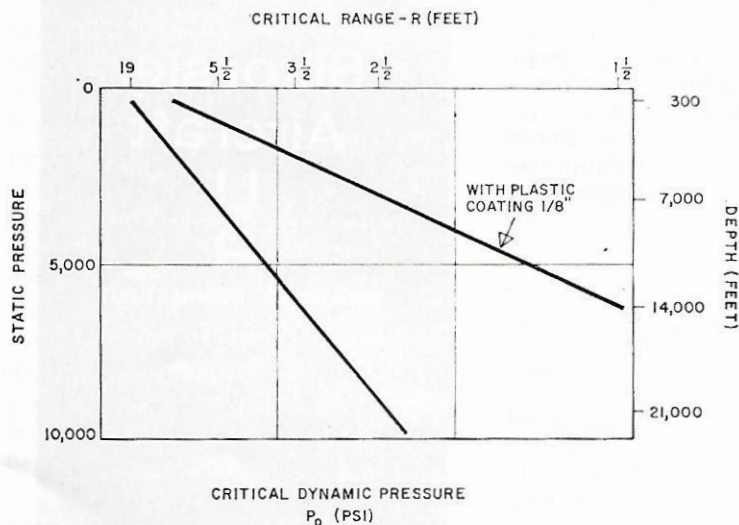
Deeply scratched glass sphere after hydrostatic loading of 16,000 psi for 16 hours.

to 9500 psi, good testimony indeed to the toughness of glass.

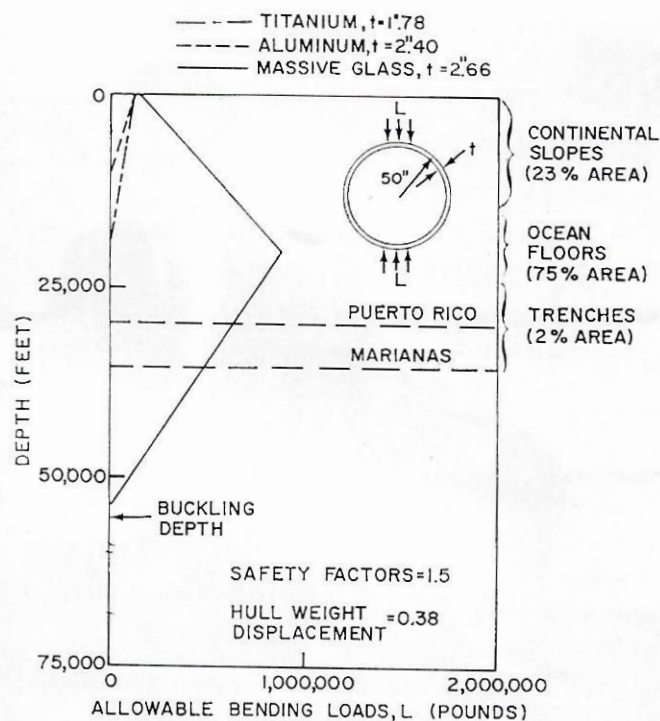
Apparently, the deeper a glass submarine dives, the safer are its occupants; that is, down to an optimum depth of about 21,000 feet where the compressive strength diminishes until buckling finally occurs at a theoretical depth of 55,000 feet. However, the deepest part of the ocean, the Challenger Deep, is a trench descending to only 35,888 feet, so the theoretical limit for glass spheres poses no problem. It will be noted, though, that the compressive strength of conventional spheres at relatively low pressures is in itself rather low. The chances of a mariner surviving an accidental collision on down to a depth of several hundred feet is nil. Obviously, there is a need for either foolhardy scientists or pre-compressed hulls. Fortunately, the latter is fairly simply obtained both mechanically and chemically. A so-called "tension cage" of wire needing would do, as would chill tempering. Ion exchange reactions with molten ionic salt baths favorably change the surface structure. Permanent compression can also be produced by generating small transparent crystals on the glass surface during manufacture to lower the thermal expansion of the outer layer. By these methods, flawed glass spheres of a tensile strength of only 2000 psi can be altered to spheres with a tensile strength of 120,000 psi. To further protect the sphere and its occupants, a clear plastic coating as little as $\frac{1}{8}$ inch thick is quite effective. Plastics under study for this use are the urethanes, polyionomers, acrylics, and polyvinyl chlorides. Just which combination of strengthening methods is most desirable has not yet been determined, but a tentative design for such a sandwich hull is shown in figure 3.

Aside from the sphere itself, the deep diving submarine must contain a propulsion system. This will most likely be made of reversible axial flow pumps. These are hollow shafted electrical pumps powered by batteries housed in pontoons along the sides of the sphere. Two large pumps of five h.p. each could give the craft a speed of better than three knots while four one h.p. thrusters provide directional control. The heavy batteries themselves may be oil coated and left open to the outside pressure, and even mounted on tracks for use as ballast.

A larger, more scientifically useful sub might contain



(Fig. 1) The effect of depth on implosion strength of a 10-inch glass sphere.



(Fig. 2) Theoretical effect of depth on allowable bending loads of spherical shells.

three spheres; one for a control cabin, one for electronics and relays, and one for a nuclear generator or fuel cell. A sub of this size could easily be fitted with appendages for grasping, moving, sampling, etc. — capabilities valuable to salvage and geological exploration.

Electrical circuits could be controlled by components in the cabin connected to the rest of the sub by thin, silver lead-ins placed between the two cabin forming hemispheres. An alternative arrangement would be the placement of photo-relays along the outside of the sphere to be activated by directed light coming from within the transparent cabin.

Submersion of the normally buoyant sub would be affected by flooding the pontoons (for neutral buoyancy) and the addition of two hundred pounds of rock ballast. Once on the bottom, the rock can be mechanically dumped, and the sub would then be able to hover indefinitely. Ascent, other than that provided by the propulsive units, is accomplished by releasing gas-generating chemicals into the pontoons, thus forcing out the water for positive buoyancy. Here, however, lies a problem. If not enough gas is generated, the sub could not provide the power necessary for pumping out water at the tremendous pressures encountered. If such an accident should happen, abandonment would be the only recourse. Fortunately, this is not as suicidal as it sounds. The cabin sphere could simply be released and allowed to float to the surface.

The forming of glass spheres of the size necessary for these subs, is a complicated problem just recently solved by Corning. In a centrifugal molding process, a huge mass of molten glass flows into a rotating, bowl shaped mold which forces the glass upward to form a thin and even hemisphere. The resulting glass bowl is then annealed to remove internal flaws. Mating of the two hemispheres to form a 56 inch diameter cabin is achieved by epoxy resins, or in the case where the entire half of the sphere folds back for a hatch, by high strength steel and rubber o-rings



Two 44½-inch hemispheres used for testing by the U. S. Naval Ordnance Test Station, China Lake, California.

around the circumference of the hull. In either case, seating of the hatch cover requires precision grinding and stop-cock grease as well as the customary o-rings to prevent leakage at great depths.

Keeping a valued scientist alive in a bubble (or as sanitary engineers call it — a closed ecological system) is no longer a problem, thanks to a spin-off from aerospace research. Respiratory wastes can be removed by a "scrubbing system" consisting of lithium chloride, for carbon dioxide absorption, and silica gel, for moisture absorption. A small bottle of oxygen then easily replaces the oxygen consumed.

An added virtue of the glass bubble submarine is its low cost. Raw molten glass costs about \$.40 a pound and fully prepared, pre-stressed glass may run from \$3-\$8 a pound. From this, a two man submarine could be built for as little as \$10,000, making it one of the least expensive and most useful tools known to science.

Along with glass submarines will come a fresh boon to marine research. Having closed the gap in our rank of diving capabilities, this sub will soon be taking man to whatever reaches of the sea he desires. However, this is not to be our only boon to ocean study. Men have already worked and lived for weeks at a time at depths of 80 feet, which though slight compared to 35,000 feet, can have a devastating effect on the human body. Off-shore communities such as the Sea Lab and Conshelf projects have begun clearing the path for man in the sea. And some day soon a diver may breath through an artificial gill and swim as free as a fish.

They say man arose from the sea. Perhaps he is now going back. □

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