

[54] BUOYANT UNDERWATER STRUCTURES

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[58] Field of Search ..... 61/.5, 1, 46.5, 69; 114/.5 X, 16 R, 16 X, 16 E; 52/2

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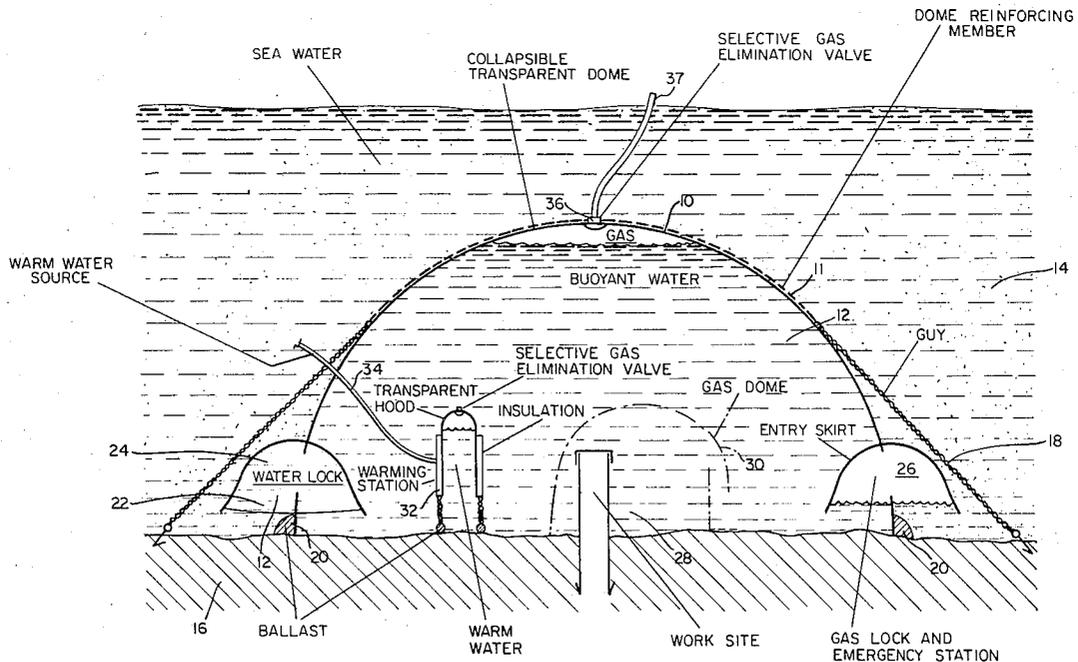
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[57] ABSTRACT

Underwater structures of limited and controllable buoyancy comprise shells, closed at the top and sides, in which is retained a volume of water having a lower specific gravity than that outside said shells. These shells may be flexible and transparent. Further, they may be completely closed and the water therein pressurized to impart rigidity to the structure. Typically, in a salt water environment, the buoyant internal liquid may comprise fresh water or a mixture of fresh water and salt water. A temperature differential between the water inside the shell and that outside may be used to obtain the desired density difference and resultant buoyancy. Access openings may be provided. Such structures may be moored or attached and may be used, for example, to cover an underwater work site and provide better visibility, freedom from underwater currents, etc. Closed, rigidified structures may be used for controlled buoyancy submarine hulls, structural supporting members, etc.

16 Claims, 7 Drawing Figures



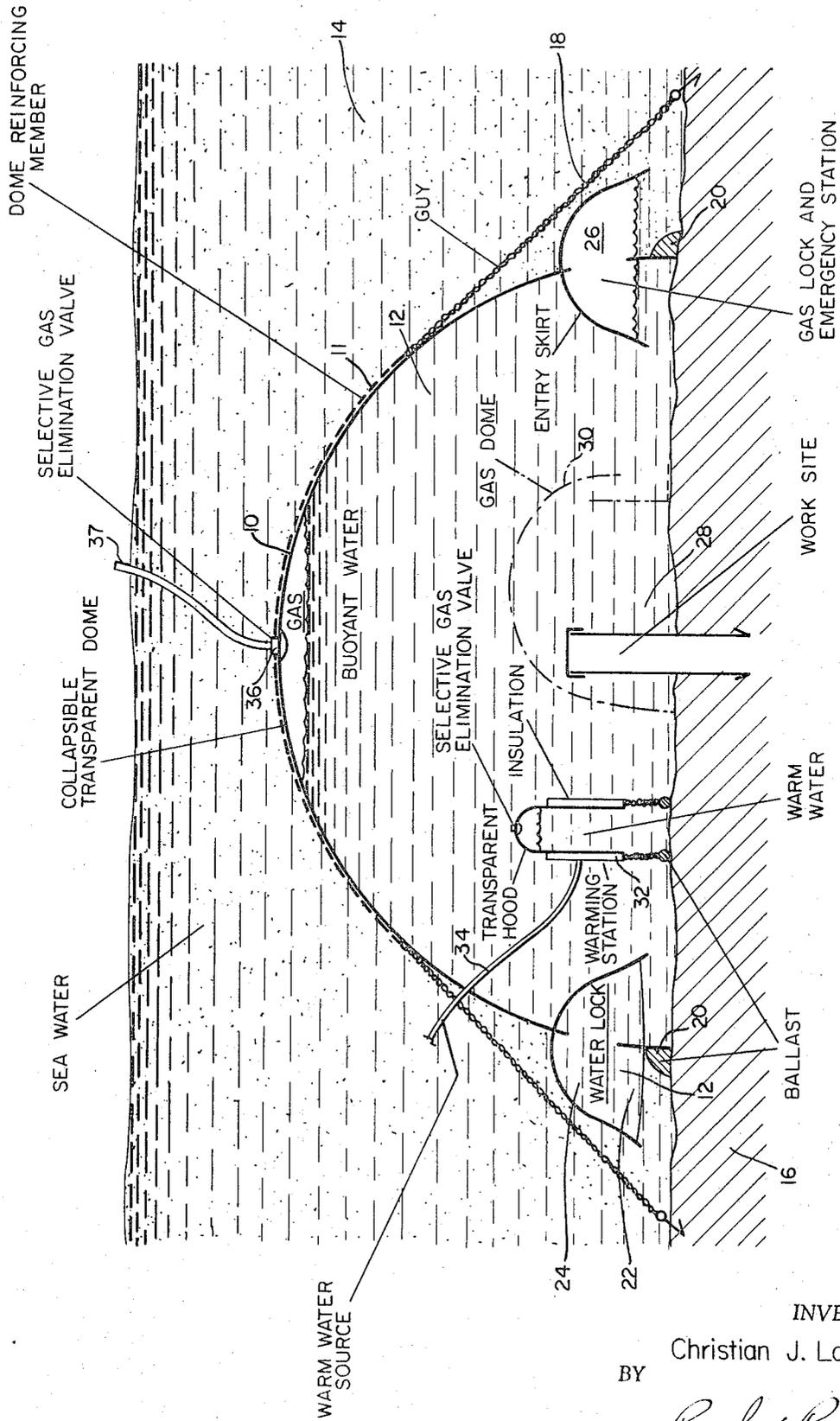
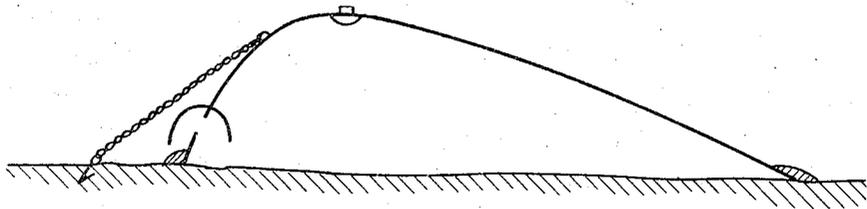
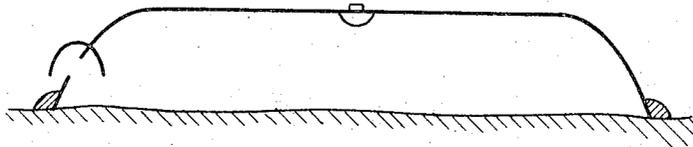


Fig. 1

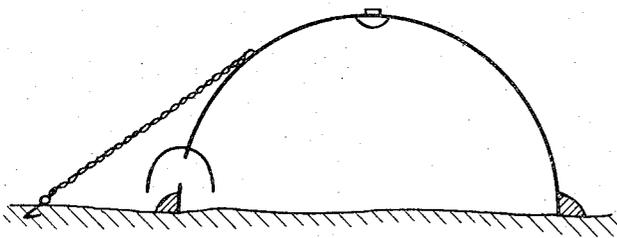
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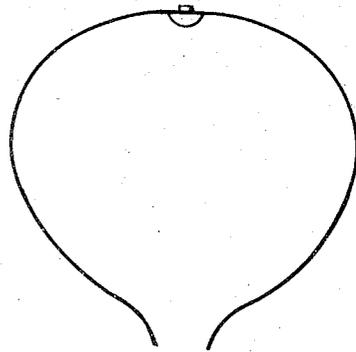
*Fig. 2*



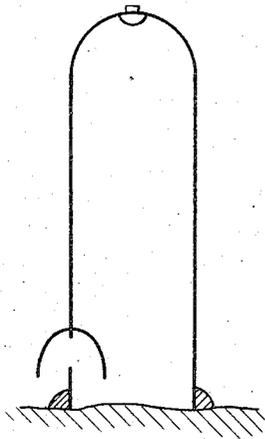
*Fig. 3*



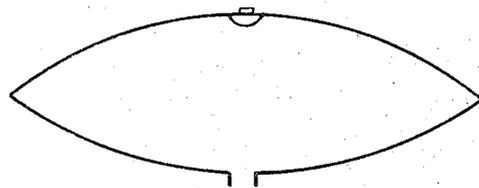
*Fig. 4*



*Fig. 5*



*Fig. 7*



*Fig. 6*

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## BUOYANT UNDERWATER STRUCTURES

This invention relates to underwater structures having slight, but controllable, buoyancy which may be used to provide, within a localized area, a more suitable environment for work or exploration, or alternatively may be used to provide structural support and/or buoyancy.

Poor visibility, resulting from light scattering in turbid water, and underwater currents generally impair coordination and complicate underwater work and/or exploration. Such activities may also require slightly buoyant structures to aid in support or movement of articles underwater or buoyant, rigid structures for structural support in underwater applications.

Various approaches have been made in the prior art to these needs including, for example, rigid structural underwater habitats, in which is maintained a life-supporting atmosphere, submarines, buoyant fluid-filled structures, such as is seen in U.S. Pat. No. 3,496,730—Tsuiji and liquid-filled buoyant floats, such as is disclosed in the background statement of U.S. Pat. No. 3,112,724—Rosen. Rosen indicates, however, that the liquid-filled floats used were not buoyant enough for the purposes intended and Tsuiji is concerned with supporting the buoyant forces produced in a fluid-filled underwater structure wherein the fluid may be "gasoline or oil, etc."

These teachings do not, in the opinion of the present inventor, meet the foregoing needs.

It is therefore an object of the present invention to provide buoyant underwater structures wherein the effects of underwater currents are minimized and visibility is enhanced.

It is a further object of this invention to provide such structures which are of limited and controlled buoyancy.

It is a further object of this invention to provide buoyant underwater structures enclosing an effective work space and having access openings therein.

Still another object of this invention is to provide buoyant, rigid underwater structures which are collapsible, easily transportable and emplaceable, particularly in collapsed form, and which may be used to assist in providing structural support or lifting articles underwater.

Briefly, the present invention comprises water impermeable shells, closed at the top and sides, the interior space of which is occupied by water having a lower specific gravity than that in the water environment surrounding the shell. Such lower specific gravity water may comprise fresh water, partially or fully demineralized sea water, brackish naturally occurring water, mixtures of low mineral content water and sea water, and heated water or sea water. The structure is thus buoyed by the specific gravity difference between the water within the structure and that surrounding the structure.

The structure may be comprised, for example, of a hemispheric transparent flexible shell, surrounding a work or exploration area, such as a well head or mineral deposit. The shell may include downward access openings since the less dense water will tend to rise upward in the shell and will not be lost to any significant extent through the downward openings in the shell.

Within the shell there may also be enclosed gas-filled open bottom enclosures for work in a liquid-free atmosphere.

The shell may be completely enclosed, rather than enclosed only at its top and sides, and the water contained therein may be slightly pressurized to provide rigidification of the shell. Such a rigidified structure may be used as a structural support member. Further, the buoyancy of the underwater structures of the present invention may be used to assist in lifting articles underwater for support or movement thereof.

Preferably, the structures of the present invention are used in a sea water environment with demineralized sea water or fresh water in the structure to provide buoyancy.

This invention may be better understood by reference to the following detailed description, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic view of a hemispherical embodiment of the present invention, including certain optional features thereof;

FIGS. 2-7 are schematic views of various other shapes of underwater structures within the scope of the present invention.

Referring more specifically to FIG. 1, there is shown a hemispherical structure or shell 10, closed at the top and sides thereof and supported by a perforated support member 11, substantially filled by fresh water 12, somewhat less dense than sea water 14 surrounding the structure. As indicated by the legend, the shell structure 10 of this invention may be both flexible and transparent for ease of transportability and erection and for visibility therein. Similarly perforated support member 11 may be flexible and collapsible for purposes of transportability and in situ erection. If the shell structure itself is of relatively tough material, support member 11 may be omitted. Structure 10 is anchored to sea floor 16 by guy wires 18. Ballast 20 may be used to assist in maintaining the position and preventing deformation of structure 10. An access opening 22 in structure 10 includes a canopy 24 extending over the horizontal area outside of opening 22 and below the bottom thereof so that buoyant water trapped in canopy 24 cannot escape and sea water is precluded from entering structure 20 by the presence of the more buoyant water enclosed under canopy 24. In the structure as shown in FIG. 1, there is also provided gas lock and emergency station 26 which may serve as an emergency access opening or as an emergency rehabilitation space for a diver if the gas lock is filled with a life-supporting gas. Gas pressure in the gas lock and emergency station 26 prevents the water level therein from occupying the space in the gas lock.

Similarly, a liquid-free atmosphere surrounding the immediate work site 28 may be provided by an open bottomed, gas filled inner structure 30.

For intermittent warming of divers, whose work effectiveness might otherwise be impaired by a low temperature water environment, an enclosed warm water space may be provided, such as by an insulated warming station 32. Warm water may be provided in warming station 32 by an inlet line 34 from a source external to structure 10 or may be internally generated by a heater within structure 10.

Similarly, the low specific gravity water supporting structure 10 may be provided from an inlet line for that

purpose or may be generated in situ, such as by demineralization apparatus.

Gas, or any light fluid, such as oil trapped in underwater structure 10 is collected at the top thereof. The accumulated gas or light fluid may be removed therefrom by selective gas elimination valve 36 and tube 37 leading to a preselected location such as a collection tank, barge, or simply the water surface for escape to the atmosphere. Tube 37 may, of course, be omitted if the escaping light fluid causes no problems when allowed to escape into the surrounding water. This elimination of the light fluid thus collected prevents undesirable or uncontrollable increases in buoyancy of the structure due to such gas or light fluid concentration. This gas may be generated, for example, by breathing apparatus or emanated from an oil well head within the structure 10. Another light fluid which may be collected is oil escaping from the ocean bottom. On the other hand a gas collection zone may be deliberately maintained to enhance the stability of the structure or to give it self-righting properties. Separate gas or light liquid containers, properly placed in the structure may also be used for the same purpose. A light fluid escape valve may also be used in specific applications such as oil leak control described in more detail below.

Various other generalized shapes of underwater structures within the scope of the present invention are seen in FIGS. 2-7. The access openings in each case are similar to that seen in FIG. 1, except that in FIGS. 5 and 6 the access opening is a downward opening through a bottom enclosure of the structure.

Generally speaking, structural integrity is imparted to the structures of the present invention by the buoyancy of low specific gravity water, as compared to surrounding water, and the upwardly acting forces thereof, on a structure otherwise anchored to a permanent base, such as the ocean floor. In other applications of this invention, however, the structures may define a completely enclosed interior and may be used, for example, as underwater buoys to assist in lifting and moving articles. Further, such structures may, if completely enclosed, be rigidified by a slight pressurization of the low specific gravity water therein. Such rigidified structures may be used for permanent or semi-permanent structural support, such as in the form of toroids or cylindrical columns, or alternatively may be used in portable structures, such as submarine supporting structures, to which would be attached propulsion and guidance means.

The shell material of the underwater structures of the present invention must of course be substantially impermeable to water in order to prevent interchange between the less dense water in the interior thereof and the more dense water on the exterior thereof. For most applications, cost, transportability, and ease of emplacement will probably dictate that the shell structure be of a flexible material. Further, in order to permit whatever natural light is available to illuminate the work area within the structure, the shell material may be transparent or translucent. Polyvinyl or polyolefinic films are typical of the materials which may be used in the shell structure of the present invention. Obviously, ribbing or reinforcement, as shown in FIG. 1, may be required in some cases.

The use of low specific gravity water as a buoyant fluid has several advantages. These include availability and compatibility. As to availability, it should be noted

that water surrounding any proposed underwater structure may be used to provide the necessary less dense water either by heating the water or by demineralizing it in the case of a salt water environment. Moreover, fresh or brackish water from natural sources may be used in any structure located in proximity to a sea coast line. The less dense water thus used for buoyancy is of course completely non-reactive with the water environment, will not contaminate or pollute the environment, and will be equally non-reactive and non-corrosive with other equipment which may be used in or around the structure, such as underwater breathing equipment.

Visibility within the structure is aided by the transparency of water and when necessary, by filtration of the demineralized or heated surrounding water used in the structure to remove turbidity therefrom.

Low density water is also likely to be less expensive than other fluids and, in contrast with gases, incompressible. The latter factor renders the buoyancy of water of reduced specific gravity constant regardless of depth and the structural shapes of the present invention are therefore unaffected by depth. Finally, the buoyancy of the buoyant fluid used in the present invention is easily and predictably controllable by mixing available low specific gravity water with surrounding higher density water or by control of the extent of demineralization or heating used to reduce density. The specific gravity of fresh water is 0.975 times that of ordinary sea water, indicating that 1 cubic foot of fresh water has 1.62 pounds less mass than an equal volume of salt water. This specific gravity difference provides buoyancy for various representative collapsible structures to the extent shown in Table 1. The forces shown in Table 1 are based on the projected horizontal cross sectional area of the upper portion of the structure. These forces may be controlled to provide appropriate balancing of force vectors for desired rigidity, resistance to current and requirement for ballast by the appropriate mixing of fresh and sea water. By such mixing and without dependence upon a gas phase, lift can be adjusted from 0 to the full 1.62 lbs. per cubic ft. buoyancy of fresh water, with no change in shape or size of the desired structure.

TABLE 1

Buoyancy and Supporting Forces in Undersea Work Stations (Fresh water inside structure located in the sea)						
Radius (ft)	Length (ft)	Volume (cu ft)	Area (sq ft)		Buoyancy (lbs)	Lift (lbs/sq ft)
			Base	Roof		
<b>Hemispherical Structure</b>						
5	10	262	79	157	424	5.4
10	10	2,094	314	628	3,392	10.8
15	10	7,069	707	1,414	11,452	16.2
20	10	16,755	1,257	2,513	27,143	21.6
25	10	32,725	1,963	3,927	53,014	27.0
<b>Vertical Cylindrical Structure</b>						
5	10	785	79		1,272	16.1
10	10	3,142	314		5,090	16.2
10	15	4,712	314		7,633	24.3
10	20	6,283	314		10,178	32.4
10	25	7,854	314		12,723	40.5
<b>Horizontal Hemicylindrical Structure</b>						
5	10	393	50	236	637	12.7
10	10	1,571	100	628	2,545	25.5
10	15	2,356	150	785	3,817	25.4
10	20	3,142	200	942	5,090	25.5
10	25	3,927	250	1,100	6,362	25.4

Aside from the use of fresh or demineralized water in a salt water environment another means of obtaining low specific gravity water is by heating. For example, fresh water with a specific gravity of 1.000 at 4°C has a specific gravity of 0.99913 at 15°C. This specific gravity difference may be used to provide a buoyant force, in the structures of the present invention, even in a fresh water environment. At 40°C the specific gravity of fresh water decreases to 0.9923.

In summary, it should be appreciated that the primary requisite of a structure within the scope of the present invention is that it include a shell closed at the top and sides for enclosing and trapping, from upward and outward movement, low specific gravity water, which because of its low specific gravity has some buoyancy as compared to the surrounding water environment. The top and side closures need not be separately identifiable structural components. Indeed they may be a continuous geometric surface, such as a hemisphere.

It should also be realized that complex structures utilizing various forms of the present invention may be used. For example, to prevent deformation of the hemispheric structure shown in FIG. 1, near the base thereof where the structural shell is almost vertical, a circumferentially disposed toroidal member or ribs, comprised of one or more closed tubular structures filled with pressurized low specific gravity water, may be used. Thus, the hemispheric structure and the pressurized, water filled base supporting structures, each separate embodiments of the structures of the present invention, are combined in a unitary and useful complex structure. (Deformation of the bottom of the shell may also be prevented by a conventional structure such as beams or a metallic frame.)

One specific application of the structures of the present invention involves capping of underwater oil or gas leaks. The collapsible shell structure is sunk and preferably extended by first filling with fresh water although the oil or gas itself may be used to open the collapsed structure. Such structures may be emplaced where a leak has occurred or, alternatively, in a general area where leaks may be expected to occur. In the latter case, the structure is then towed to the precise location as soon as a leak occurs.

This is but one example of a variety of applications in which inherent features of structures within the scope of the present invention may be used to good advantage. Generally speaking, these features include:

- a. in collapsed form, structures are of low total mass and volume; this facilitates transportation, towability, ease of submersion, and in situ erection;
- b. controlled positive buoyancy;
- c. erected structure of constant volume, regardless of depth, and easily movable, and
- d. great flexibility as to shape and size.

While this invention has been described with reference to particular embodiments thereof, various other embodiments of the present invention will be obvious to those skilled in the art and all such embodiments are considered to be within the scope of the appended claims, in which the present invention is specifically recited.

What is claimed is:

1. Buoyant structure, totally submerged in an underwater environment, comprised of a shell substantially impermeable to water, said shell having access open-

ings therein, the volume within such shell being occupied by water having a lower specific gravity than that of the underwater environment, said shell being closed at the top and sides thereof.

2. Buoyant underwater structure, as recited in claim 1, wherein the water within said shell is at a higher temperature than that outside said shell.

3. Buoyant underwater structure, as recited in claim 1, wherein the water within said shell has a lower salt concentration than that outside said shell.

4. Buoyant underwater structure, as recited in claim 1, wherein said shell is also closed at the bottom, said bottom closure having an access opening therein.

5. Buoyant structure according to claim 1, wherein the volume within said structure is of sufficient dimension to accommodate divers.

6. Buoyant underwater structure, as recited in claim 1, wherein said shell is also closed at the bottom so as to define a completely enclosed space and wherein the water within said shell is at a higher pressure than that outside said shell at the same depth so as to rigidify said structure.

7. Buoyant underwater structure, as recited in claim 1, wherein said structure includes access openings on the side thereof, the horizontal space adjacent said opening outside said shell being covered above said opening by a substantially water impermeable canopy extending outward from said shell and downward at least to the bottom of said opening, said canopy being open at the bottom.

8. Buoyant underwater structure, as recited in claim 7, wherein said access opening is filled with gas.

9. Buoyant underwater structure, as recited in claim 1, wherein the top of said structure includes an escape valve for any low specific gravity fluid entrapped within said structure which may rise and be collected at the top thereof.

10. Buoyant underwater structure, as recited in claim 9, wherein the outlet of said valve is in communication with a conduit for carrying said escaping low specific gravity fluid to a pre-selected location.

11. Buoyant underwater structure, as recited in claim 1, wherein a gas filled enclosure is located within said structure.

12. Buoyant underwater structure, as recited in claim 6, wherein said rigidified shell comprises a support member integrally combined with a second buoyant structure, said second buoyant structure consisting of a second shell substantially impermeable to water and having an access opening therein, the volume of said second shell being occupied by water having a lower specific gravity than that outside said second shell, said second shell being closed at the top and sides thereof.

13. A buoyant underwater structure, as recited in claim 12, wherein said structure comprises tubular supporting members disposed about the base of said second shell, said second shell having a generally hemispheric shape.

14. Buoyant structure, of limited and controlled buoyancy, totally submerged in an underwater environment, comprised of a shell substantially impermeable to water, the volume within such shell being occupied by water having a lower specific gravity than that of the underwater environment, said shell being closed at the top and sides thereof, said shell being also closed at the

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bottom thereof so as to define a completely enclosed space.

15. Buoyant structure according to claim 14, said structure being rigidified by means of the water within said shell being at a higher pressure than that of the underwater environment.

16. Buoyant structure at least partially submerged in an underwater environment, comprised of a shell substantially impermeable to water, the volume within such shell being occupied by water having a lower spe-

cific gravity than that of the underwater environment, said shell being closed at the top and sides thereof, said shell being also closed at the bottom thereof so as to define a completely enclosed space, wherein the buoyancy of said structure is provided substantially exclusively by the difference in specific gravities between the water within the shell and the water of the underwater environment.

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