

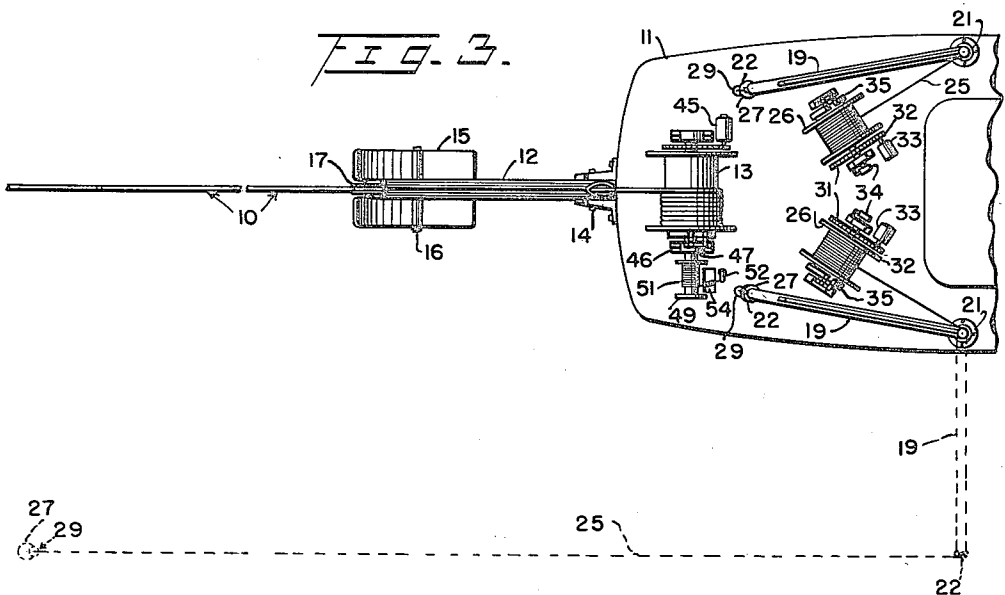
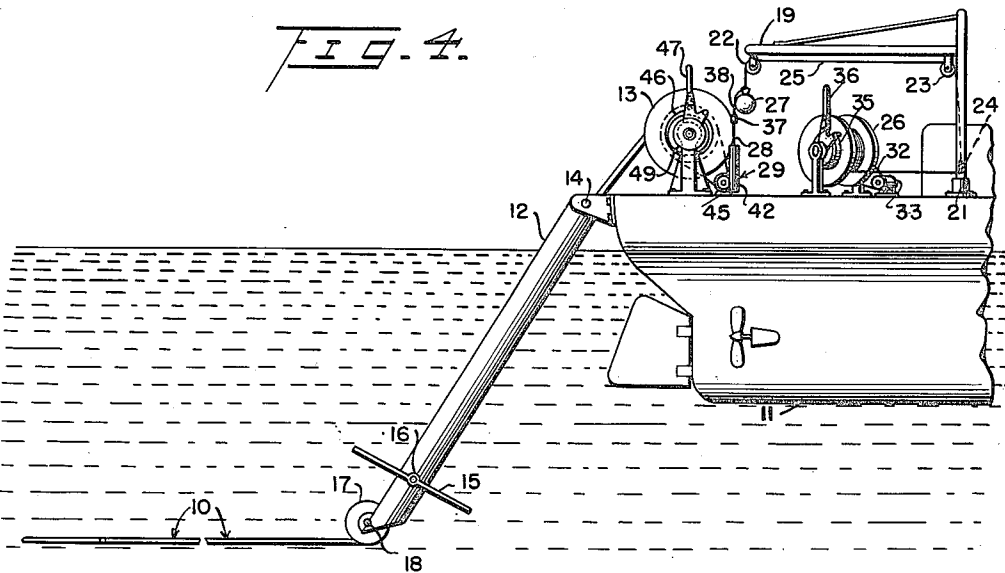
March 29, 1949.

LE ROY C. PASLAY
METHOD AND MEANS FOR SURVEYING
GEOLOGICAL FORMATIONS

2,465,696

Filed Oct. 11, 1947

8 Sheets-Sheet 2



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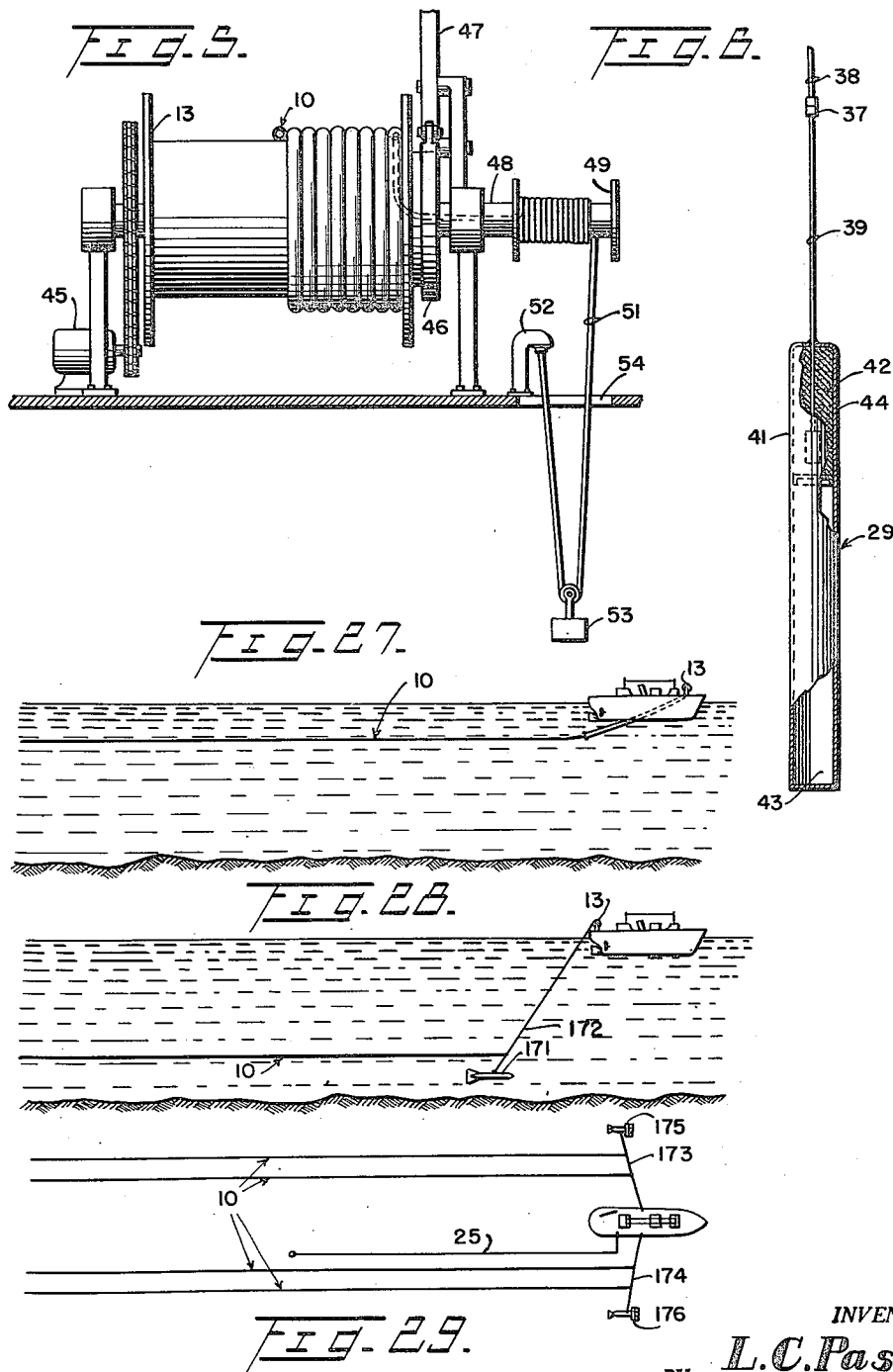
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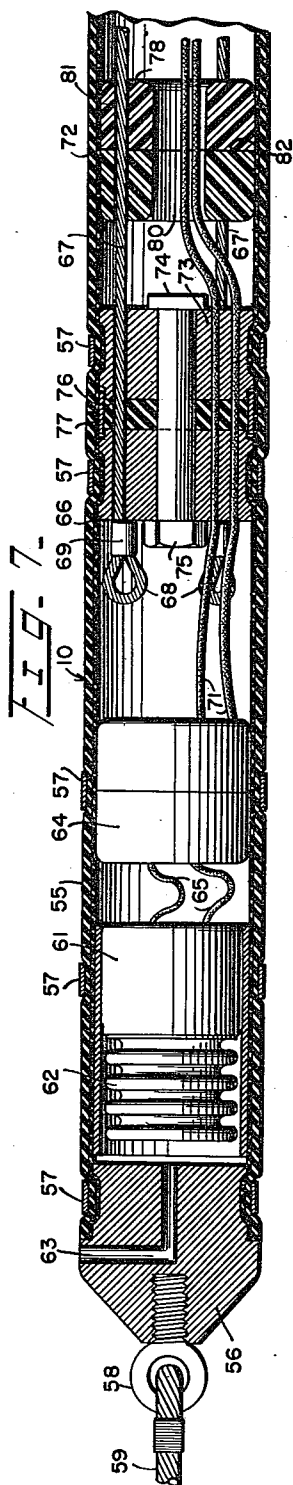
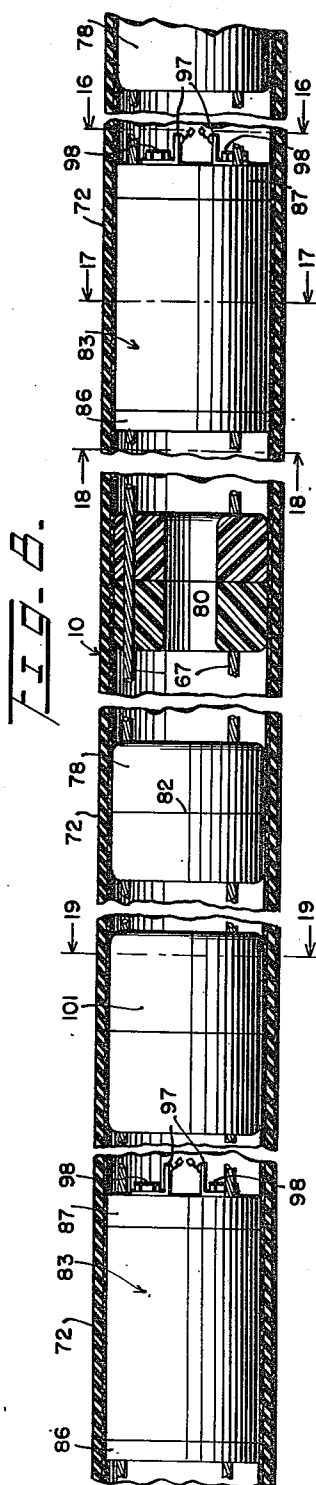
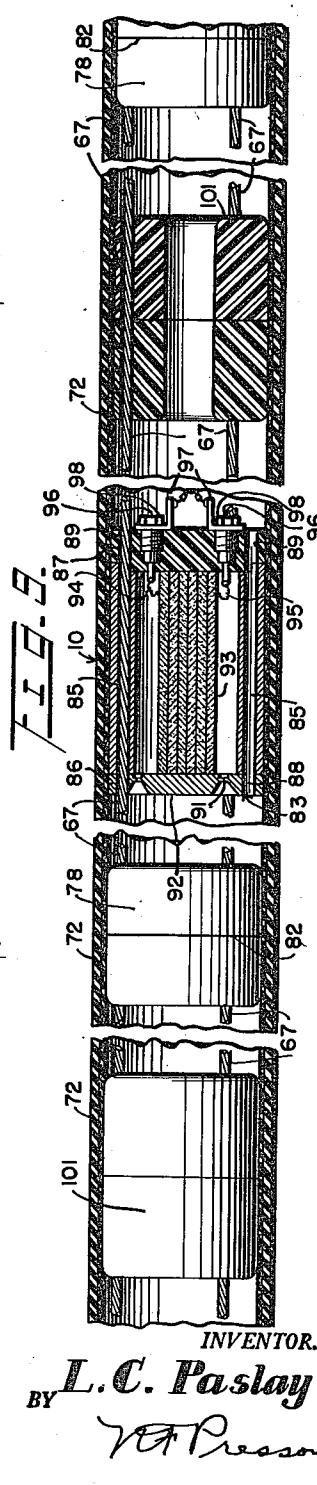
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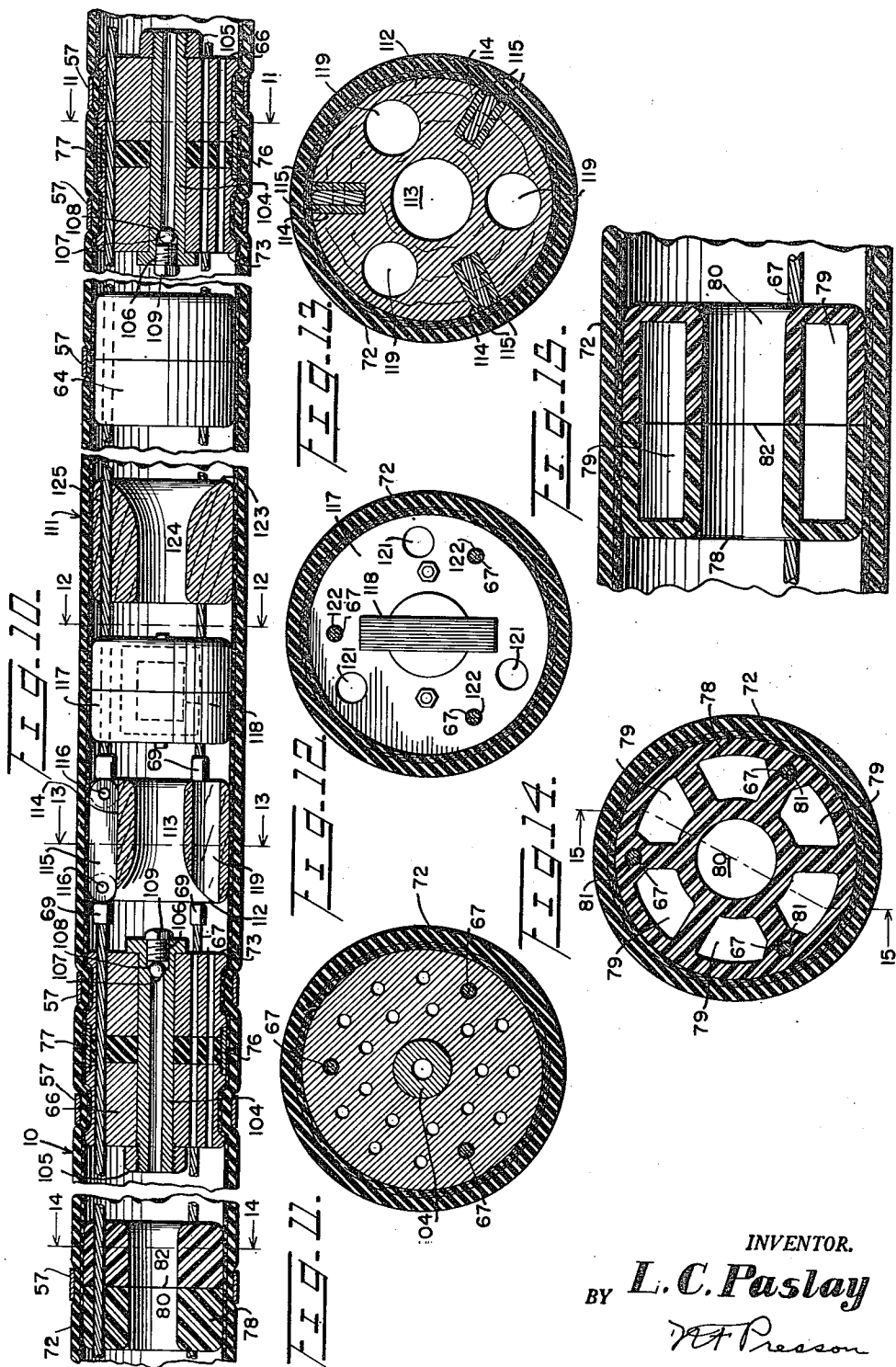
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8 Sheets-Sheet 5



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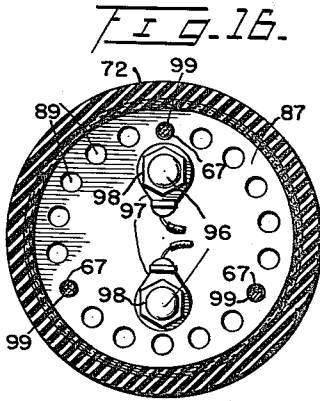
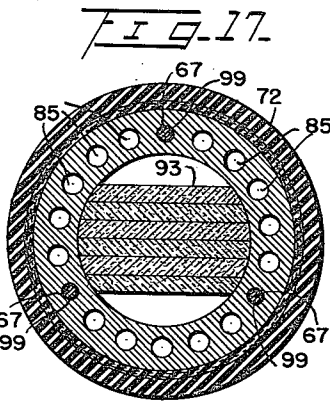
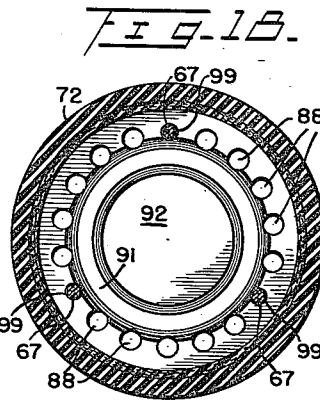
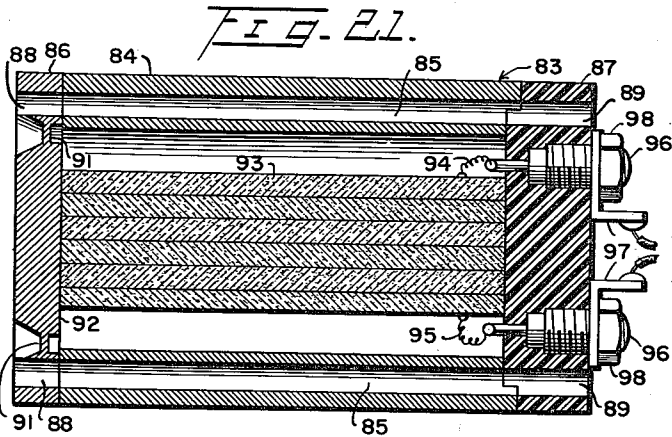
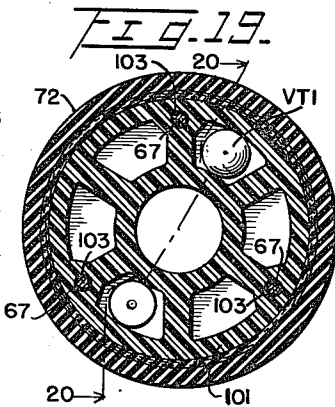
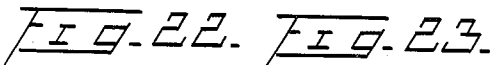
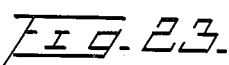
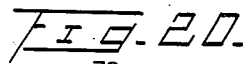
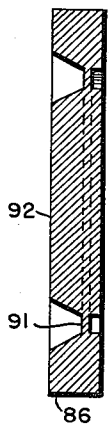
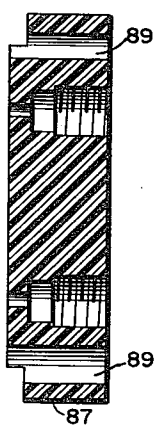
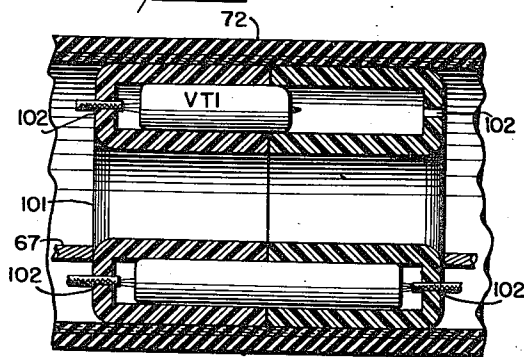
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8 Sheets-Sheet 6



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FIG. 24.

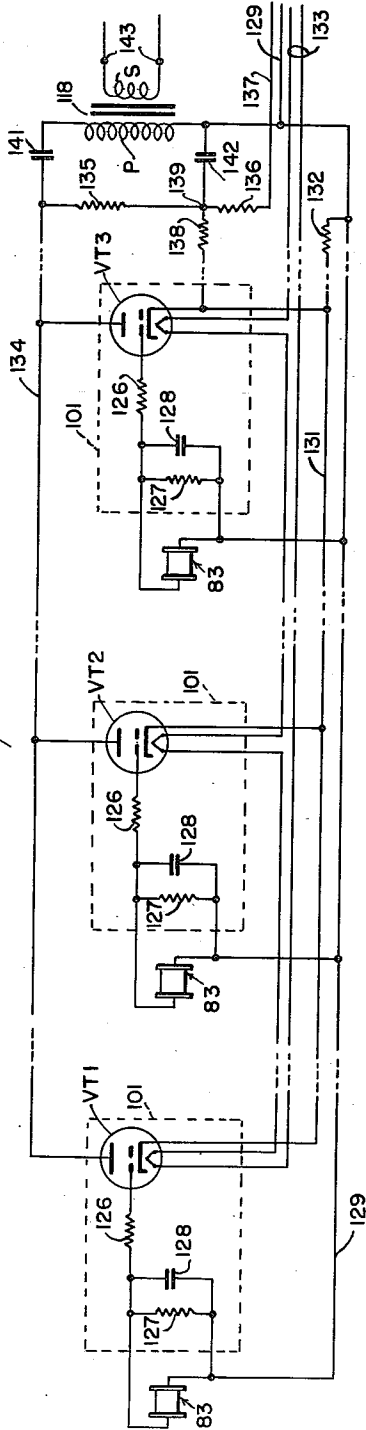
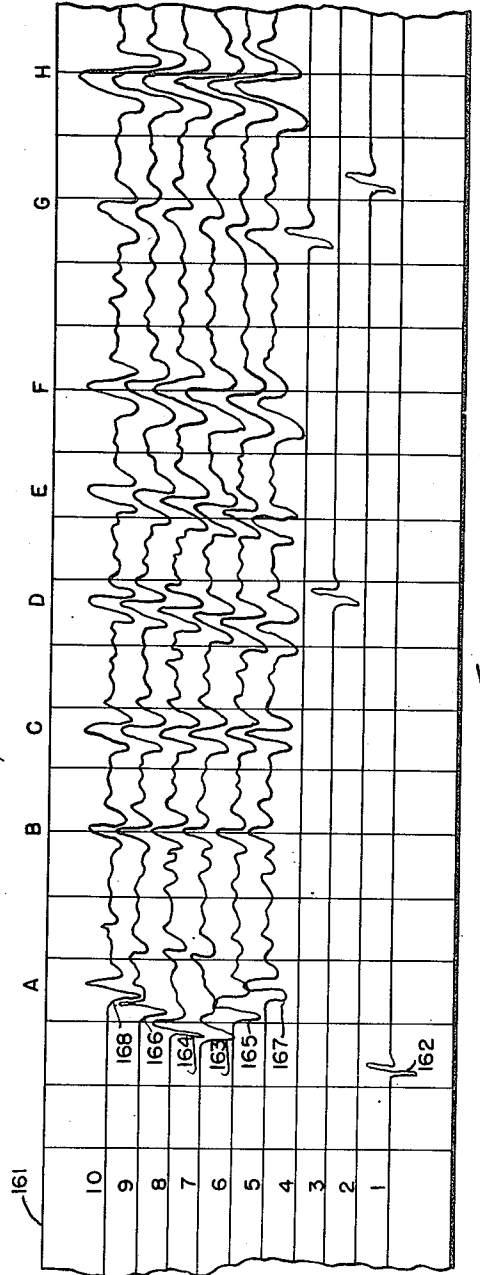


FIG. 25.



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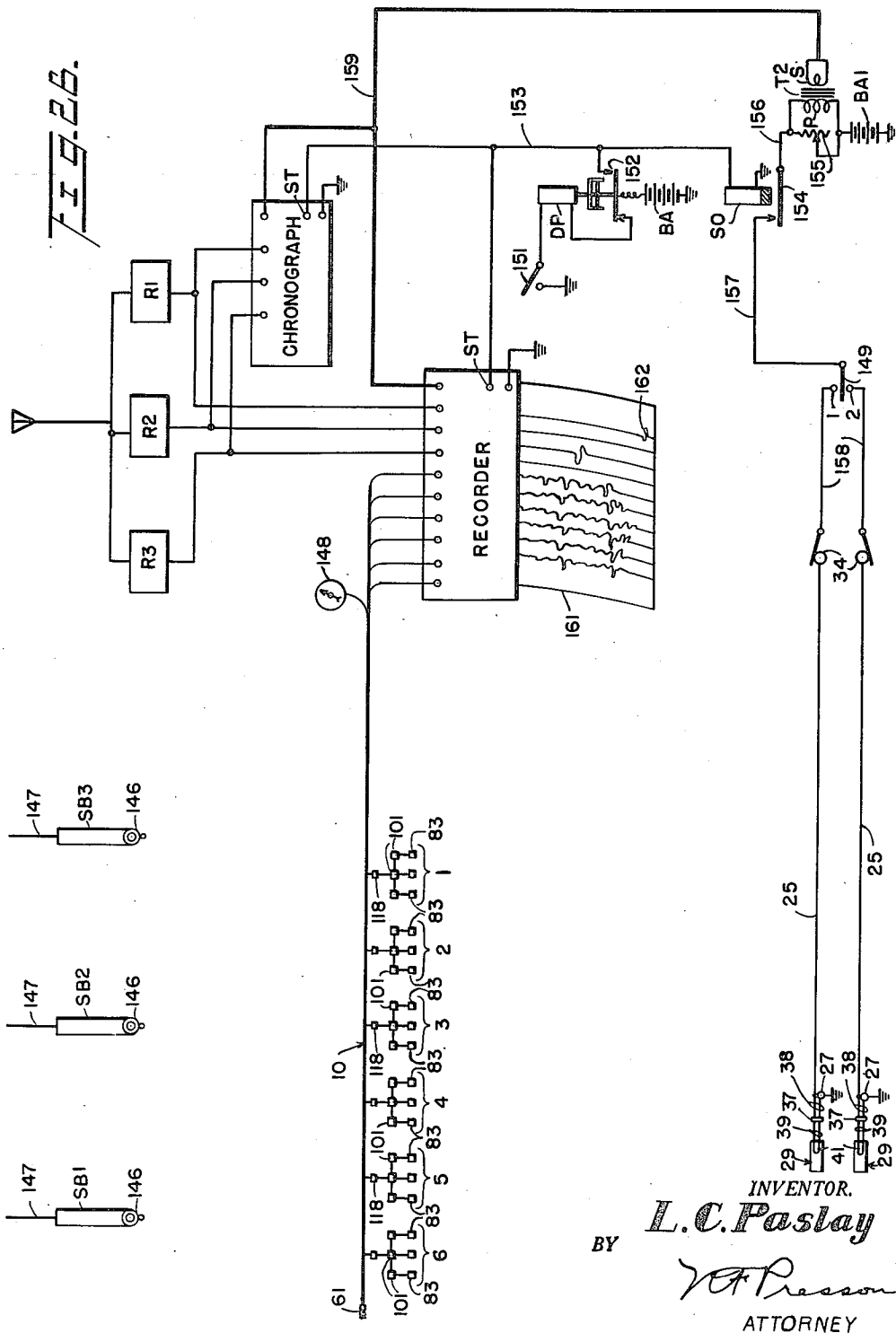
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UNITED STATES PATENT OFFICE

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METHOD AND MEANS FOR SURVEYING
GEOLOGICAL FORMATIONSLe Roy C. Paslay, Dallas, Tex., assignor to Marine
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Application October 11, 1947, Serial No. 779,292

13 Claims. (Cl. 181-0.5)

1

This invention relates to a method and apparatus for detecting underwater deposits of oil and more particularly to a system for surveying subaqueous geological formations and exploring oil-retaining subsurface terrestrial structures by seismic signals detected by a plurality of pressure responsive devices disposed within the aqueous medium.

In systems heretofore devised for making seismic surveys of terrestrial subsurface structures disposed beneath a body of water it has been the general practice to employ seismometers arranged on the bed of the body of water or connected to floats within the water in such a manner as to be actuated vibrationally in response to seismic vibrations received from the bed of the body of water. Such systems have not been altogether satisfactory under the conditions of service for the reason that the seismic vibrations are generally vertical in direction and it has been found necessary, therefore, to maintain the seismometers in a substantially vertical position for the reception of such seismic signals. It has also been found necessary in the case where the seismometers are placed on the bed of the body of water to obtain a good contact between the seismometer and the bed for satisfactory results. In cases where mud or silt predominates sufficiently to form a soft bed or the seismometer is tilted considerably from the vertical, the seismic signals received are often weak and ineffective to actuate the seismometer sufficiently for satisfactory response to such signals.

The system of the present invention possesses all of the advantages of the prior systems and none of the foregoing disadvantages. In accordance with the arrangement of the present invention, the seismic detectors comprise piezoelectric microphonic devices responsive to variations in pressure set up within the surrounding water by the seismic signals without contact of the detectors with the bed of the water and independently of fortuitous motion imparted thereto either by wave movement set up by the seismic signals or otherwise, and while the vessel containing the seismic recording equipment is proceeding along a predetermined course.

It is well known in the art to which the present invention pertains that in a homogeneous medium of infinite extent, a sound wave causes particle velocity v and pressure P related by the equation $P = vpc$ where pc is the acoustical impedance of the medium. When the medium is water, pc has a value of approximately 150,000, p is in dynes/cm.² and v is in cms./sec. From the

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foregoing it will be clearly apparent that the pressure in dynes/cm.² will be much greater than the cms./sec. velocity for a given sound wave. The pressure at the surface of the water is, of course, zero but increases with depth until, in the case of pulses such as are used in seismographic work, substantially full sensitivity is obtained when the depth of submersion of the microphonic detectors is equal to $\frac{1}{2}$ the wavelength of the seismic signal. For reflections of a seismic signal having a frequency of 33 cycles per second, for example, I have found a depth of 12 or more feet to be satisfactory and, furthermore, that the seismic signals are distorted at a depth of 25 feet as a result of interference caused by the reflection of the signals from the surface of the water.

In accordance with the present invention the seismic signals are initiated from explosive charges lowered to the bed of the body of water from opposite sides of a moving vessel and fired by control means on the vessel when the vessel has proceeded along a predetermined course for a distance sufficient to cause a flexible elongated streamer having a plurality of piezoelectric microphonic devices arranged at intervals therein to be positioned above the explosion. The pressure applied to the microphonic devices by the surrounding water in response to seismic signals reflected from subsurface geological formations and tectonic structures within the earth beneath the explosion causes voltage signals to be generated by the piezoelectric elements within the microphonic devices corresponding respectively to the seismic signals received thereby. These electrical signals are amplified and recorded on a moving tape or chart on the vessel in time spaced relation with respect to a start signal recorded thereon as the firing circuit for the initial explosion is closed, the exact geophysical location of the explosion being determined by signals received from a plurality of sono-buoys moored within the vicinity of the explosion, and recorded on the moving chart.

One of the objects of the present invention is to provide a new and improved seismic surveying system in which the seismic signals are detected by pressure responsive devices while being towed through the water by a moving vessel.

Another of the objects is to provide a new and improved seismic signal detecting device adapted to be towed through the water at a predetermined depth of submersion without causing a turbulent condition of the water adjacent the device and which is responsive to variations of pressure of

the surrounding water and is unaffected by motion of the device within the water.

Another object is to provide a new and improved system for underwater exploration of sub-surface geological structures controlled by impulses of pressure through the surrounding water caused by seismic disturbances in which the seismic explosions and pressure signals respectively corresponding to the seismic signals reflected from terrestrial anomalies beneath the water are recorded by suitable apparatus disposed on a vessel while the vessel is under way and without stopping the vessel in its course of travel.

A further object resides in the method of lowering explosive charges to the bottom of the water alternately on opposite sides of the moving vessel and firing these charges in alternate successive order when the vessel has moved a predetermined distance after the charges have been lowered and moored within the water.

Still another object is the provision of a new and improved seismic surveying system for detecting seismic signals by pressure impulses which is economical to manufacture, reliable in operation, durable in service, and in which the detecting devices possess all the advantages of ruggedness, small size, light weight and high signal output.

Still other objects, improvements and advantages will be apparent from the following description, taken in connection with the accompanying drawings, of which:

Fig. 1 is a diagrammatic view of the system of the present invention in accordance with a preferred embodiment thereof;

Fig. 2 is a plan view of the system of Fig. 1;

Fig. 3 is an enlarged view of the stern of the towing vessel showing the detector towing mechanism and the apparatus for lowering the explosive charges into the water;

Fig. 4 is a view in elevation of the structure of Fig. 3;

Fig. 5 is an enlarged detailed view in elevation of the detector streamer winch and the means for continuously establishing a plurality of electrical connections to the streamer;

Fig. 6 is a view of the preferred form of explosive charge partially broken away and partially in section;

Fig. 7 is a sectional view, somewhat enlarged, of the tail section of the detector streamer;

Figs. 8 and 9 are sectional views of one of the crystal and amplifier sections of the streamer;

Fig. 10 is a sectional view of a coupling section of the streamer;

Fig. 11 is an enlarged sectional view taken along the line 11—11 of Fig. 10;

Fig. 12 is an enlarged view taken along the line 12—12 of Fig. 10;

Fig. 13 is an enlarged sectional view taken along the line 13—13 of Fig. 10;

Fig. 14 is an enlarged sectional view taken along the line 14—14 of Fig. 10;

Fig. 15 is a view taken along the line 15—15 of Fig. 14;

Fig. 16 is an enlarged view taken along the line 16—16 of Fig. 8;

Fig. 17 is an enlarged view taken along the line 17—17 of Fig. 8;

Fig. 18 is an enlarged sectional view taken along the line 18—18 of Fig. 8;

Fig. 19 is an enlarged sectional view taken along the line 19—19 of Fig. 8;

Fig. 20 is a view taken along the line 20—20 of Fig. 19;

Fig. 21 is an enlarged central longitudinal sectional view of one of the crystal assemblies;

Fig. 22 is a sectional view of the vibratory end plate of the crystal assembly;

Fig. 23 is a sectional view of the other end plate of the crystal assembly;

Fig. 24 is a circuit diagram of the crystal and amplifier arrangement of one section connected to an output transformer;

Fig. 25 is a chart having recordings thereon corresponding to a seismic operation;

Fig. 26 is a view showing in diagrammatic form a complete electrical circuit suitable for use with the present system;

Fig. 27 is a view showing another detector streamer towing arrangement in accordance with an alternative form of the invention;

Fig. 28 is a view showing the towing arrangement of the detector streamer in accordance with still another alternative form of the invention;

Fig. 29 is a view showing an arrangement suitable for towing a plurality of detector streamers in predetermined spaced relation with respect to the towing vessel, and

Fig. 30 is a view partly broken away of a pressure controlled device for improving the hydrodynamic stability of the towed streamer.

Referring now to the drawings on which like numerals of reference are employed to designate like parts throughout the several views for a more complete understanding of the invention, and more particularly to Figs. 1 and 2 thereof, there is shown thereon in diagrammatic form a preferred embodiment of the system of the present invention, the system comprising a detector streamer indicated generally by the reference numeral 10 towed by a vessel 11 at a predetermined depth of submersion within the water. The streamer is payed out through a streamlined strut 12 from a reel 13. The strut is pivotally secured to the vessel at 14, Figs. 3 and 4, and provided with a depressor or hydroplane 15 secured thereto and adapted to maintain the lower end of the strut at a predetermined depth of submersion within the water while the vessel is under way, the depth of submersion preferably being controlled by the adjusted position of the depressor with respect to the strut although, if desired, a brace, guy lines or the like may be employed to fix the depth of submersion of the strut within the water. The adjustment of the depressor with respect to the strut may be accomplished in any convenient manner as, for example, by the adjusting nut and bolt arrangement indicated at 16, Fig. 4.

The lower end of the strut is provided with a grooved pulley 17 pivotally secured thereto as at 18 for guiding the detector streamer during the paying out operation thereof and for preventing chafing of the streamer at the point of emergence from the strut during the towing operation. The manner in which the detector streamer is payed out through the strut by the reel 13 and the means employed for establishing a continuous metallic circuit to the detector elements within the streamer at all times during the operation of the device will be more clearly apparent as the description proceeds.

There is also provided on the vessel a pair of booms 19 pivotally mounted at 21 and adapted to be swung outwardly from an inboard position above the deck of the vessel to a moved outboard position on the starboard and port sides of the vessel respectively, Figs. 3 and 4. Each boom is provided with a pulley 22 pivotally secured thereto

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at the outer end of the boom and a pair of pulleys 23 and 24 over which is passed a firing line 25 adapted to be payed out by a drum or reel 26. Secured to the firing line 25 is a weight or anchor 27, Fig. 1, having connected thereto by a length of line 28 an explosive charge indicated generally by the numeral 29. Each of the reels or drums 26 is provided with a pulley or sprocket 31 and a belt or chain 32 for establishing an operative connection to a motor 33 whereby the firing line may be retrieved at will by selective operation of the motor after the charge connected thereto has been fired. The firing line comprises a strain core member and an electrical conductor insulated in any suitable manner sufficiently to prevent electrical contact between the conductor and the surrounding water when the firing line is immersed therein, a control connection being continuously established to the firing line by a slip ring arrangement 34 connected to the drum and in electrical connection with the conductor within the firing cable. The drum may be brought to rest at any desired time during the paying out of the firing cable by a brake 35 in response to actuation of the brake lever 36.

The firing line 25 is connected to the weight 27 substantially as shown and provided with a locking type plug and jack arrangement 37 connected to a short length of cable 38 having two conductors therein in electrical connection with the conductor within the line 25 and the weight 27, respectively. The complimentary portion of the plug and jack structure 37 is connected by way of a two-conductor insulated cable 39, Fig. 6, to an electro-responsive detonator 41 arranged within an expendable casing 42 preferably cylindrical in shape and sealed at the ends thereof to form a flotation chamber 43 of sufficient size to render the casing positively buoyant when immersed in water and an explosive charge 44 is arranged about the detonator within one end of the casing. The casing may be composed of any inexpensive material suitable for the purpose such, for example, as cardboard. When the weight 27 is at rest on the bed of a body of water, the explosive charge by reason of its buoyant character will assume the position shown in Fig. 1. From the foregoing, it will be clearly apparent that the charge is preferably fired by a firing circuit employing a single metallic conductor within the firing line and a sea water return to the vessel for the firing current, although, if desired, the firing circuit may comprise an additional conductor within the line 25 in lieu of the sea water return.

The drum or reel 13 employed for paying out the detector streamer is provided preferably with a motor 45 operatively connected thereto in a manner similar to the motors 33 employed for operating the reels 26 and, like the reels 26, reel 13 is provided with a brake 46 adapted to be operated selectively at will and locked in the operated position thereof by any suitable means such, for example, as by the brake lever 47 when a predetermined length of detector streamer has been payed out. The reel 13 is provided with a tubular axle 48, Fig. 5, upon which is secured a reel or drum 49 of lesser diameter than the reel 13 upon which is wound a length of multi-conductor cable 51 having the conductors thereof respectively connected to the conductors within the detector streamer 10. The other end of the cable 51 is connected to a fixed electrical outlet 52, a weight and pulley arrangement generally indicated at 53 being employed to maintain a uniform

tension in the cable 51 at all times, the loop of cable thus formed passing through an aperture 54 within the deck of the vessel. By employing the foregoing pulley arrangement for taking up the slack in the cable 51, the cable does not become fouled with the drum 49, slip rings are not required, and a continuous metallic circuit is invariably maintained between the detecting and depth indicating devices within the detector streamer and the recording and control apparatus including the source of electrical power on board the vessel 11 whereby spurious signals which would otherwise result from improper contact with slip rings are avoided.

The structure of the detector streamer will now be described with particular reference to Figs. 7 through 10. On Fig. 7 is shown the tail section of the streamer, on Figs. 8 and 9 is shown a section of the microphone streamer, hereinafter called a microphone section, and on Fig. 10 is shown a coupling section employed to join together two adjacent microphone sections of the detector streamer. The detector streamer comprises a tail section and a plurality of microphone sections connected together by coupling sections, and an additional section of streamer, hereinafter called the towing section, connected to the coupling section ahead of the leading microphone streamer section and extending through the streamlined strut 12 to the drum 13 about which a length of it is wrapped. In practice it has been found that an over all length of 300 feet is suitable for a microphone streamer section and that a length of 300 feet for the towing section is sufficient to maintain the microphone detectors at a sufficient distance from the vessel to be free of pressure effects within the water caused by the ship's propeller and the movement of the vessel therethrough. The detector streamer may conveniently comprise six microphone sections connected together by five coupling sections and secured to a towing section by a sixth coupling section, the streamer also having connected to the trailing end thereof a tail section. Within each of the microphone sections are located a plurality of piezoelectric microphones and a plurality of amplifying units respectively connected thereto. In accordance with a preferred arrangement of the microphone streamer assembly, three microphones located at the midpoint and 25 feet from each end of the microphone streamer respectively have been found to be satisfactory. While this arrangement is disclosed herein with particularity for the purpose of description, it will be understood that additional microphones spaced at more frequent intervals along the detection streamer may, if desired, be employed advantageously in accordance with the invention herein disclosed without departing from the spirit or scope of the invention.

The tail section, Fig. 7, comprises a length of flexible tubing 55 composed of rubber or any of the synthetic varieties thereof such, for example, as extruded "Vinyl" hose clamped to a tail piece 56 by a clamp 57 substantially as shown. Secured to the tail piece 56 in any suitable manner as by the eye bolt 58 is a length of line 59 to provide, if necessary, a stabilizing control force sufficient to prevent whipping or weaving of the tail section while the streamer is being towed through the water. Sealed within the streamer in any suitable manner as by the clamp 57 illustrated is a control device 61 having a pressure responsive element 62 in communication with the surrounding water as by a duct 63 and adapted to vary the

resistance of an element therein selectively in accordance with the pressure applied to the element 62. An electrical connection between the control device 61 and a separable multiconductor plug and jack 64 is established by the pair of conductors 65 extending therebetween. After assembly of the plug and jack 64, the plug and jack assembly is secured within the streamer as by the clamp 57, illustrated. The other end of the tail section is connected by an additional clamp 57 to a coupling member 66 having a plurality of apertures therein for receiving three strain cables 67. Each of the strain cables is provided with a looped portion 68 clamped at 69 whereby the towing force to the tail section is applied by the strain cables to the coupling member 66 and thence to the tubing 55. The conductors 65 are respectively connected to the pair of conductors 71 by the plug and jack 64 and the circuit comprising these conductors and the control element 61 is continued through succeeding plugs and jacks in the various coupling sections to an indicating device on board the vessel whereby the depth of the hose is continually made manifest at a control station on the vessel.

Each microphone section comprises a length of tubing 72 clamped at one end thereof to a complementary element 73 of the coupling member through which the strain wires and electrical conductors are disposed in apertures respectively corresponding to apertures within the coupling member 66. The members 66 and 73 are clamped together by a bolt 74 and nut 75, a gasket 76 composed of resilient packing material such, for example, as any of the synthetic varieties of rubber suitable for the purpose, being arranged therebetween and adapted to be compressed by the coupling members 66 and 73 as the bolt is tightened thereby to form a seal between the strain wires, the conductors, and the coupling members as the gasket is forced against an annular member 77 composed of brass or the like within which the gasket is disposed.

Each of the microphone sections is filled with a light oil of low viscosity such, for example, as kerosene or a mixture of kerosene and naphtha and provided with a plurality of annular floats 78 spaced at intervals throughout the length of the streamer and fitted snugly therein. As clearly shown on Figs. 14 and 15, each of the floats comprises a plurality of flotation chambers 79 disposed about a cylindrical aperture 80 through which the various electrical conductors are arranged, and provided with a plurality of apertures 81 within which the strain cables are respectively disposed. The strain cables are cemented to each of the float members whereby the float members are employed not only to reduce the specific gravity of the streamer to a value corresponding to the specific gravity of the surrounding water but also to perform the additional function of transmitting the towing force to the cable at different points throughout the length of the streamer. The floats are composed of any material suitable for the purpose such, for example, as a material sold under the trade name of "Lucite" and may conveniently be made in two identical sections and cemented together at 82.

Each of the microphonic crystal assemblies indicated generally by the numeral 83 comprises a cylindrical sleeve 84, Fig. 21, having a plurality of apertures 85 circularly arranged therearound and fitted with a pair of end plates 86 and 87 respectively. The plate 86 is provided with a plurality of apertures 88 adapted to be brought into

alignment with the apertures 85 when the plate is in an assembled position, Fig. 21, and, in like manner, the plate 87 is provided with a plurality of apertures 89 adapted to be aligned with the apertures 85. The apertures are of sufficient size to permit one or more conductors to pass there-through when the microphone section is completely assembled. The plate 86 has a weakened annular section 91 concentrically formed therein to provide a circular central portion 92 adapted to be actuated vibrationally in response to variations in pressure applied thereto by the fluid with which the microphone section is filled.

Arranged within the microphone casing is a plurality of piezoelectric crystals 93 of any type suitable for the purpose such, for example, as crystals composed of ammonium dihydrogen phosphate, the ends of the crystal pack being cemented to the end plate 86 at the vibratory portion 92 thereof and to the end plate 87. A structure is thus provided in which vibrational movements of the central portion 92 of the end plate 86 applies pressure impulses to the crystal pack thereby generating voltages proportional to the strength of the impulses. The crystals are connected by a pair of conductors 94 and 95 to a pair of studs 96 threaded into the end plate 87 and provided with a pair of terminals 97 respectively secured thereto as by the nuts 98. The end plate 87, it will be understood, is composed of any suitable insulating material such, for example, as "Bakelite" or "Lucite," within which the studs 96 are threaded. There is also provided within the microphone housing a plurality of apertures 99 within which the strain cables are arranged, a coating of cement being employed to secure each of the cables to the crystal housing.

The amplifying unit associated with each crystal assembly comprises a casing 101 generally similar to the float structure except for the provision of apertures 102 therein to provide for establishing external electrical connections to the vacuum tube, resistors and the capacitance unit arranged within the casing, Fig. 20. There is also provided within the amplifier casing a plurality of apertures 103 for receiving the strain cables, Fig. 19. The strain cables, it will be understood, are also cemented to the amplifier housing. Three microphone crystal assemblies and three amplifier unit assemblies are preferably arranged within each microphone streamer although, if desired, a greater number of microphone and amplifier assemblies may be advantageously employed without departing from the present invention. The leading end of the microphone streamer is sealed by a coupling member 66, Fig. 10, generally similar to the coupling member employed for establishing a connection between the trailing end of the foregoing detection streamer and the tail section except that, in the instant case, the coupling members 66 and 73 are clamped together by a hollow bolt 104 and nut 105. The bolt 104 is threaded at 106 to receive a fitting whereby the microphone streamer may be filled with fluid after assembly thereof. When a sufficient amount of fluid has been introduced into the microphone streamer, a ball check 107 is forced against a seat 108 by a threaded plug 109 thereby to seal the fluid within the streamer.

In assembling the microphone and amplifier units within the streamer hose, the hose is placed within a pipe of somewhat greater diameter than the hose, sealed to the pipe at the ends thereof and the air within the air chamber thus formed is pumped out until the hose has dilated suf-

sufficiently to allow the amplifiers, microphone assemblies, and floats to be pulled into position within the hose. Air is now allowed to enter the air chamber thereby causing the hose to shrink into tight gripping relation with the amplifiers, microphone assemblies and floats. When this has been done, the hose is disconnected from the outer pipe, fitted with end coupling members and filled with kerosene or a similar fluid until the hose is round and smooth and the floats are just sufficiently tightly gripped by the hose to establish a plurality of towing connections from the strain cables throughout the length of the hose at intervals where the floats are in contact with the inside surface of the hose.

The arrangement of the coupling section will best be understood from a consideration of Fig. 10 in which the coupling section indicated generally by the numeral 111 comprises a short length of flexible tubing secured at the ends thereof to adjacent microphonic sections of the streamer except, in the case of the microphonic streamer nearest the vessel, the coupling section connects the leading end of this microphonic streamer to the towing section of the streamer. This towing section comprises a plurality of floats arranged within a flexible hose at intervals sufficient to impart neutral buoyancy thereto when the towing streamer is filled with fluid, a plurality of strain cables secured to the floats, and a plurality of electrical conductors extending interiorly throughout the length thereof. The forward end of the towing streamer, it will be recalled, is secured to and wrapped about the reel 13.

Within the coupling section is arranged a spacing block 112 composed preferably of wood and having a centrally disposed aperture 113 therein through which the electrical conductors are arranged. The block is recessed at 114 to receive a plurality of links 115 to which the adjacent ends of sections of the strain cable are connected as by the bolts or pins 116.

Mounted within an annular support 117 is a transformer 118 having the primary winding thereof operatively connected to the output of the amplifying tubes of the microphonic section, and the secondary winding thereof connected to a recording element on the vessel. The resistance and capacitance elements associated with the transformer are preferably arranged within apertures 119 formed in the block 112, Fig. 13. The annular support 117 is provided with a plurality of apertures 121 within which the electrical conductors are disposed and a plurality of apertures 122 for receiving the strain cables.

Adjacent the transformer support is an annular spacing member 123 provided with an aperture 124 therein within which the electrical conductors are arranged and a plurality of apertures 125 to receive the strain cables. The electrical conductors are terminated at the plug 64, the complementary portion thereof being connected to additional conductors for continuing the electrical circuits throughout the streamer. The flexible tubing employed for the various sections comprising the detection streamer and the coupling and towing sections may be composed of any of the synthetic varieties of rubber suitable for the purpose, extruded hose composed of a material known in the art as "Vinyl" having been found to be satisfactory for the purpose.

On Fig. 24 is shown a circuit diagram of the crystal and amplifier arrangement of one of the microphonic hose sections connected to an output transformer which is arranged within an adjacent

coupling section. The arrangement comprises, in accordance with a preferred embodiment of the invention, three microphone crystal assemblies 82 respectively connected to the grid control elements of three amplifying electronic devices such as the amplifying tubes VT1, VT2 and VT3 illustrated, the control connection intermediate the microphone and the control element in each case including a resistance element 126. There is preferably connected in parallel with each of the microphone assemblies an R.-C. circuit comprising a resistance unit 127 and a capacitance element 128. The crystal assemblies of each of the sections are connected together and to a common ground by the conductor 129.

The cathode elements of the amplifying tubes within the microphone section are connected together by a conductor 131, the circuit continuing to the ground conductor 129 by way of resistance element 132. The heaters of the amplifier tubes VT1, VT2 and VT3 are connected together in series and to a source of electrical power on the vessel by the pair of conductors 133. The plate elements of the amplifier tubes are connected together by a conductor 134, from whence the circuit is continued by way of resistance elements 135 and 136 to conductor 137 and thence to a source of positive electrical potential on the vessel. A resistance element 138 is connected between the cathode element of the amplifying tube VT3 and the plate supply circuit for the tubes at a point 139 thereon intermediate the resistance elements 135 and 136. The primary winding P of transformer 118 is connected at one end thereof by way of condenser 141 to conductor 134, the other end of the primary winding being connected to grounded conductor 129 and, by way of condenser 142, to the point 139 of the B supply circuit for the tubes. The secondary winding S of transformer 118 is connected by way of the conductors 143 to a recording element of the recorder on the vessel Fig. 26.

The operation of the system will now be described with particular reference to Figs. 1 and 26 on which is shown in diagrammatic form a complete electrical system suitable for use with the invention according to a preferred embodiment thereof. Let it be assumed, by way of example, that the vessel 11 is moving along a course adjacent the sono-buoys SB1, SB2 and SB3, Fig. 1, each of which is secured by a mooring cable 144 to an anchor 145 and provided with a microphone 146 connected to a radio transmitter (not shown) adapted to transmit radio signals received by the microphone over a whip type antenna 147. Each of the radio transmitters is preferably adapted to transmit signals over a radio channel of different frequency respectively corresponding to the frequencies to which the radio receiving devices R1, R2 and R3, Fig. 26, are tuned whereby receiving device R1 responds to signals received from sono-buoy SB1 to the exclusion of signals from sono-buoys SB2 and SB3 and, in like manner, the receiving devices R2 and R3 respond to signals received from sono-buoys SB2 and SB3, respectively.

Let it also be assumed that the detector streamer 10 has been paid out and is being towed by the vessel at a depth of submersion of 12 feet as indicated by the depth indicator 148 controlled by the hydrostatically responsive control mechanism 61 arranged within the trailing end of the detection streamer and, furthermore, that the strut 12 is adjusted by the setting of the depressor 15 thereon to a depth of 12 feet. It will

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now be understood that the detector streamer is submerged to a uniform depth of 12 feet throughout the length thereof by reason of the buoyancy of the streamer which, it will be recalled, is adjusted to the buoyancy of the surrounding water and the detection streamer, therefore, will maintain this depth of submersion regardless of the rate of movement of the vessel through the water or the rate of movement of the detector streamer even though the velocity of the streamer through the water should be reduced to a very low rate of travel or momentarily brought to rest.

Let it further be assumed, for the purpose of description, that the switch 149, Fig. 26, has been moved into engagement with contact 1 thereof and that the explosive charge 29 has been connected to the firing line 25 and has been swung over the side of the vessel by the boom associated therewith and that the weight 27 has caused the explosive charge to come to rest near the bed of the body of water through which the vessel is moving.

When a length of line 25 has been payed out sufficient to cause the seismic explosive shot to occur beneath the central portion of the detector streamer, the firing key 151, Fig. 26, is closed thereby causing a quick-operate slow-release dashpot relay DP to operate. As contact element 152 of the dashpot relay engages its make contact, a circuit from battery BA is closed by way of contact 152 and the make contact thereof to conductor 153, from whence the circuit is continued by way of relay SO to ground thereby causing relay SO to operate. Conductor 153 is also connected to the start terminals ST of the chronograph and recorder illustrated thereby causing both the chronograph and the recorder to be set into operation immediately. Relay SO, it will be noted, is a slow-operate relay and therefore does not close its contacts until a predetermined period of time such, for example, as 2 to 5 seconds has elapsed after the operating circuit to the relay has been closed.

As armature 154 of relay SO engages the make contact thereof, a firing circuit is closed from battery BA1, by way of the primary winding P of transformer T2 in parallel with variable resistor element 155, conductor 156, armature 154 and make contact of relay SO, conductor 157, switch 149 and contact 1 thereof, conductor 158, slip ring 34 of the firing line reel, firing line 25, cable 38, plug 37, one conductor within cable 39, to the electroresponsive detonator 41, from whence the circuit is continued by way of a second conductor within the cable 39 and plug 37 to the weight 27, and thence to ground, thereby causing the detonator 41 to fire and explode the explosive charge 29.

From the foregoing it will be clearly apparent that the recorder and the chronograph are set into operation a predetermined period of time controlled by relay SO before the seismic disturbance is initiated by the explosion of the charge 29 and that the recorder and chronograph will continue in operation for a period of time sufficient to record a signal corresponding to the explosion of the charge 29, pressure signals respectively corresponding to the reflected seismic signals and detected by the pressure responsive microphonic devices within the detection streamer, and the signals received from the sono-buoys SB1, SB2 and SB3.

The momentary flow of current through primary P of transformer T2 in response to the closure of the firing circuit at armature 154 and

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make contact of relay SO causes an impulse to be generated at the secondary winding S of transformer T2 of an intensity controlled by the setting of the variable resistance element 155. This impulse is transmitted by way of the conductors in cable 159 to a pair of recording elements respectively arranged on the chronograph and on the recorder thereby to cause a signal to be recorded on each of the charts associated therewith as an indication of the instant when the seismic shot was fired. It will be understood that the firing circuit is opened at the detonator element as the detonator is fired.

The explosion of the charge 29 causes a pressure impulse to be transmitted to the microphones within the detection streamer directly through the surrounding water. The time of arrival of this first pressure impulse at the groups of microphones within the different microphonic sections of the streamer will vary in accordance with the distance of each of the microphonic sections from the source of the explosion. The microphone sections 3 and 4, being positioned above the explosive charge at the instant of explosion, receive this first pressure signal somewhat in advance of the microphones associated with sections 1 and 6, for example. This condition is clearly shown on Fig. 25 in which ten traces were recorded on a section of movable chart 161 while the chart was moving in the direction of the arrow from right to left, as viewed on the drawing. Trace 1 includes the start signal 162 indicating the time when the explosive shot took place, traces 2, 3, and 4 showing the signals received by the microphones 146 associated with sonobuoys SB1, SB2 and SB3 respectively, and traces 5, 6, 7, 8, 9 and 10 being respectively associated with the microphonic sections 1, 2, 3, 4, 5, and 6 of the detection streamer.

The first pressure signal received by the microphones within microphonic sections 3 and 4 of the detection streamer is shown below the letter A at 163 and 164 of traces 7 and 8 respectively. The first pressure impulse received by the microphones of sections 2 and 5 is shown at 165 and 166 of traces 6 and 9 respectively, and the first pressure impulse received by the microphones within sections 1 and 6 of the detection streamer is shown at 167 and 168 of traces 5 and 10 respectively. The pressure signal received through the water as a result of the first seismic wave caused by the explosion of the charge 29 is shown directly below the letter B and, in like manner, the pressure signals caused by reflections from the geological formations or tectonic structures disposed in successive layers beneath the first subsurface layer are shown beneath portions of the chart respectively corresponding to the letters D, E, F, G, and H. As clearly shown on the chart, the geological structures causing the seismic signals corresponding to D, E, and F, in the example assumed, are tilted or sloping within the earth, whereas the reflecting subsurface layers causing the signals corresponding to A, B, and H, for example, are substantially level.

Whereas on Fig. 25 a sufficient length of chart 161 is shown to permit signals from all of the sono-buoys to be recorded before the chart is brought to rest, under certain conditions of operation of the system the sono-buoys might be at a distance from the explosion sufficient to cause the signals received from one or more of the sono-buoys to be applied to the recording element after the recorder chart has come to rest. The chronograph is employed to record the sono-buoy

signals and particularly such sono-buoy signals as may occur after the chart 161 of the recorder has been brought to rest. This is accomplished by a feature well known in the art of causing the chronograph to operate the chart feeding mechanism thereof for a predetermined period of time after the starting impulse applied thereto has been interrupted.

After the explosive shot has been fired, the firing line 25 is rewound on the reel associated therewith, the anchor 27 is brought aboard the vessel, and another explosive charge is attached to the plug 27 of the retrieved firing line. In the meantime the boom on the opposite side of the vessel is swung outwardly and a second explosive charge and weight 27 are lowered to the bottom, the switch 149 is moved into engagement with contact 2 and the second charge is fired in response to a second operation of the firing key 151. By employing two firing lines in the manner disclosed, an arrangement is provided in which a second charge may be lowered to the bottom while the first charge is on the bottom and before the first charge is fired, thereby greatly increasing the rapidity with which the seismic explosions may be initiated during continuous movement of the vessel. Whereas, in the foregoing example, the operation of the system has been described with reference to six microphone sections, each of the microphone sections having three piezoelectric microphones operatively connected to three amplifier devices individual thereto and the output of the amplifying devices connected in parallel to an output transformer, it will be understood that this has been done for the purpose of description and that, if desired, the number of microphones within the section may be increased, the length of each section may be varied, and the number of output circuits from the microphones may be increased without departing from the principles and scope of the present invention, it being merely necessary to provide a sufficient number of floats within the streamer to maintain the specific gravity of the assembled detection streamer to substantial equality with the specific gravity of the surrounding water.

Furthermore, although in the assumed example just described the detector streamer was payed out through a hawse connected to the stern of the vessel, it will be understood that, if desired, the arrangement of Fig. 27 in which the forward end of the hawse leads to a reel located on the forward part of the vessel may be employed in lieu thereof.

Whether employing either of these arrangements, at moderate towing speeds the detector cable is not required to be additionally payed out to reduce the rate of movement thereof through the water while a seismic surveying operation is in progress by reason of the type of seismic detector employed with the present invention which is responsive only to variations in pressure of the surrounding water and is unaffected by motion. If the towing speed should be increased, however, sufficiently to cause spurious pressure signals to be received by the microphonic detecting devices while the detector streamer is moving at the same rate of travel as the vessel, these undersired signals may be eliminated by momentarily releasing a length of cable from the reel 13 while the seismic surveying operation is in progress, the rate of release of the cable from the reel being sufficient to prevent spurious signals from being detected by the de-

tecting devices without necessarily stopping the forward movement of the cable within the water.

In Fig. 28 is shown still another arrangement for towing the detection streamer in which a hawse secured to the vessel is not required. In this arrangement a streamlined pig 171 composed of heavy material such, for example, as lead is connected by a tow cable 172, preferably of streamlined construction, to which the tow cable of the microphonic detector streamer is connected. With this arrangement the detector streamer is towed well down within the water near but not on the bottom and just before the explosive shot occurs, the pig is lowered to the bottom by paying out an additional length of line from the reel 13 on the vessel thereby stopping the detector streamer which, by reason of its neutral buoyant characteristic, maintains a position of predetermined depth within the water until the pig is drawn up by the reel 13.

On Fig. 29 still another towing arrangement for the detection streamers is disclosed. In this arrangement, two detection streamers are towed on each side of the vessel by a pair of tow lines 173 and 174 having a pair of paravanes 175 and 176 respectively connected thereto. Each of the detection streamers is operatively connected to a recording device whereby the microphones therein are adapted to control a plurality of recording elements in response to variations in pressure of the surrounding water received directly from the explosive shot or reflected from tectonic or geological structures located beneath the body of water. The streamers are separated from each other laterally by a predetermined distance such, for example, as 50 to 100 feet and maintained at a suitable depth of submersion by adjusting the depth of submersion of the paravanes.

By towing a plurality of detection streamers mutually abreast as shown in Fig. 29, an arrangement is provided comprising a directional hydrophone array in which the strength of the desired seismic signals recorded by the recorder on the vessel is increased and the unwanted signals are discriminated against. In such a case the hydrophones of each of the streamers would be connected in parallel and thus would tend to cut out all signals received thereby except those traveling up or down. For example, if each of the four identical streamers were provided with three hydrophones, an array comprising twelve hydrophones connected in parallel would be arranged in a plane rectangle at a predetermined depth of submersion within the water and level with the surface thereof. The array thus formed may be regarded as a directional hydrophone having its maximum sensitivity up and down.

When conducting seismic surveying operations in relatively shallow water, it has been found advisable to fire the shot at a point on the bed or as near as possible to the bed of the body of water. Under these conditions, the explosive charge 29 would be closely coupled to the weight 27 and, if desired, the flotation chamber associated with the explosive charge may be eliminated or rendered ineffective. When conducting seismic surveys of areas beneath a body of water of relatively great depth, it has been found desirable to increase the length of coupling between the explosive charge 29 and the weight 27.

If desired, an improvement in the towing performance of the detector streamer may be effected by employing the device of Fig. 30 as a

drogue secured to the line 59 attached to the trailing end of the streamer. The drogue comprises a streamlined casing 177 adapted to be towed through the water by the line 59 and provided with a vertical fin 178 and a pair of horizontal fins 179 secured to the trailing portion thereof in any well known manner. A movable horizontal fin 181 pivoted at 182 extends on opposite sides of the vertical fin and is employed to change the vertical heading of the device selectively in accordance with the direction and degree of movement of a control arm 183 secured thereto.

There is provided within the casing 177 an expansible bellows 184 secured at one end thereof to the casing as by the support 185 and in communication interiorally with the surrounding water as by the duct 186. The other end of the bellows is movable and connected by a rod 187 to the arm 183 in any suitable manner as at 188 whereby movement of the bellows in response to variations in the pressure of the surrounding water causes angular movement of the fin 181. The rod is slideably supported by a stuffing box 189 secured to the casing 177 to effect a water tight seal therebetween and is additionally supported by the support 190. Disposed between the upstanding portion of the support 190 and the movable end of the bellows is a spring 191 adapted to move the fin 181 downwardly when the pressure within the bellows is reduced. Conversely, an increase in the pressure within the bellows causes the fin to be moved upwardly. The support 189 may be adjusted in any suitable manner to any desired setting corresponding to the depth of submersion desired and clamped in this setting to the bolts 192. A dashpot 193 secured to the rod 187 is preferably employed to prevent rapid action of the depth control mechanism. The device is provided with a quantity of ballast material 194 such, for example, as lead sufficient to provide a neutral buoyancy to the device and to prevent substantial rolling thereof within the water.

In operation an increase in the depth of submersion of the device beyond the predetermined depth at which the device is set causes an increase in pressure applied interiorally to the bellows 184 sufficient to move the fin 181 upwardly and cause the device to rise within the water. Conversely, a decrease in the depth of submersion of the device causes a decrease in pressure applied interiorally to the bellows sufficient to move the fin 181 downwardly and cause the device to sink within the water, such movement of the fin of necessity being slow by reason of the dashpot control applied to the depth control mechanism.

By employing the device of Fig. 30 in the manner disclosed, an additional tension is applied to the tail section of the detection streamer in opposition to the towing force and at a predetermined depth of submersion within the water whereby the detection streamer is invariably maintained substantially level within the water throughout the length thereof regardless of small variations in the buoyancy of the various sections of the streamer and even though the streamer is towed at a relatively slow speed.

Furthermore, I have found that seismometers disposed at intervals within the neutrally buoyant detection streamer may be advantageously employed in lieu of hydrophones to detect seismic signals, especially in cases where the streamer is towed near the surface in shallow water. The

neutrally buoyant streamer may also be advantageously employed, if desired, with other forms of seismic detecting devices such, for example, as magnetostriction condensers or dynamic pressure hydrophones while the streamer is being towed at a predetermined depth of submersion.

Briefly stated in summary, the present invention provides a system for seismic surveying of geological reflecting surfaces disposed beneath a body of water in which the seismic signals are initiated by explosive charges planted in the water from opposite sides of a moving vessel in succession and received by detecting devices responsive to variations in pressure of the surrounding water, in which the seismic or pressure signals are received and recorded while the detecting devices are being towed by the vessel and regardless of the motion of the detecting devices within the water, and in which the detecting devices are arranged within a flexible elongated cylindrical streamer of neutral buoyancy and adapted to respond to pressure impulses received through the surrounding water and caused by seismic disturbances within the earth regardless of the instant position of the microphonic devices or the orientation of the detection streamer with respect to the direction of propagation of the reflected waves caused by the seismic disturbance.

While the invention has been described with particular reference to several examples thereof which give satisfactory results, it will be understood by those skilled in the art to which the invention pertains, after understanding the invention, that various changes and modifications may be made without departing from the spirit and scope of the invention and it is my intention, therefore, in the appended claims to cover all such changes and modifications.

What I claim as new and desire to be secured by Letters Patent of the United States is:

1. A system for seismic prospecting comprising an explosive charge adapted to be launched from a moving vessel and sink within a body of water, means including a cable secured to said charge for firing the charge within the water when a predetermined length of cable has been payed out, an elongated flexible streamer towed by the vessel at a predetermined depth of submersion within the water, a plurality of pressure responsive devices arranged within the streamer and adapted to generate electrical signals in accordance only with pressure impulses received while said streamer is moving through the surrounding water, said pressure impulses respectively corresponding to seismic signals reflected from geological structures beneath the water, and means on the vessel for recording in time spaced relation the explosion of said charge and the signals generated by said pressure responsive devices.

2. In a surveying system for seismic prospecting for geological structures disposed beneath a body of water, in combination, two firing lines having a pair of explosive charges respectively secured thereto, each of said charges being adapted to be fired by a signal received from the line, means including outrigger structure arranged on opposite sides of a vessel respectively for lowering the charges into the water and paying out the lines connected thereto in successive order while the vessel is moving along a predetermined course, a flexible streamer towed by the vessel along the course thereof at a predetermined depth of submersion in the water and having a plurality of

pressure responsive devices contained therein, means including a switching device for applying a firing signal to each of said lines in succession after the charges respectively connected thereto have been lowered into the water for initiating seismic signals to actuate said pressure responsive devices, and means including a pair of reels selectively operable at will for retrieving the lines in successive order when the charges respectively connected thereto have been fired, whereby a substantially continuous survey of the subsurface beneath the course of the vessel is obtained.

3. The method of seismic prospecting for geological structures disposed beneath a body of water which comprises the steps of, towing a plurality of pressure responsive devices within a flexible streamer by a vessel along the course thereof at a predetermined depth, hoisting explosive charges over the side of the moving vessel, lowering the charges into the water and paying out lengths of firing lines attached thereto, firing the charges successively by signals over said lines when a length of line has been paid out corresponding to a predetermined position of each charge with respect to the streamer, receiving seismic signals by pressure impulses transmitted to said pressure responsive devices through the surrounding water corresponding to the reflections of the explosions from terrestrial formations beneath the water, and recording in time spaced relation signals respectively corresponding to said pressure impulses, whereby a substantially continuous survey of the subsurface beneath the course of the vessel is obtained.

4. The method of seismic prospecting for geological structures disposed beneath a body of water which comprises the steps of, towing a plurality of pressure responsive devices within a flexible streamer by a vessel along the course thereof at a predetermined depth, lowering two explosive charges into the water from opposite sides of the moving vessel, paying out in succession a pair of firing lines respectively attached to said charges, firing the charges in successive order by a signal over the line when a predetermined length of line has been paid out, receiving pressure signals transmitted to said pressure responsive devices through the water respectively corresponding to seismic disturbances caused by the explosion of said charges, recording said signals in the same time spaced relation they are received, and retrieving said lines after their charges have been fired, whereby a substantially continuous survey of the subsurface beneath the course of the vessel is obtained.

5. In a seismic system of the character disclosed for surveying from a moving vessel geological formations disposed beneath the bed of a body of water, the combination of a plurality of explosive devices for initiating seismic disturbances, said devices being adapted to be planted on said bed from opposite sides of the vessel and fired in successive order by a pair of lines respectively connected thereto in succession, a flexible streamer towed in the wake of the vessel at a predetermined depth of submersion in the water and having a plurality of piezoelectric devices therein for generating electrical signals respectively corresponding to pressure impulses within the water caused by said seismic disturbances, means for firing said explosive de-

vices when the devices occupy a predetermined position with respect to said streamer, and means on the vessel for recording said signals, whereby a substantially continuous survey of the subsurface beneath the course of the vessel is obtained.

6. A system according to claim 1, in which the pressure responsive devices are piezoelectric hydrophones.

7. A system according to claim 1, in which the pressure responsive devices are piezoelectric hydrophones, and including amplifying means enclosed within the streamer and operatively connected to said piezoelectric hydrophones for amplifying the signals generated by said hydrophones.

8. A system according to claim 1, in which the streamer comprises a plurality of detection sections connected together by coupling sections, a plurality of piezoelectric detection devices responsive to pressure and positioned within each of said detection sections, and means including a quantity of liquid within each of said detection sections for transmitting pressure variations from the surrounding water to the piezoelectric devices.

9. A system according to claim 1, in which the streamer is filled with liquid and includes flotation chambers therein for rendering the buoyancy of the streamer neutral when immersed in the water.

10. A system according to claim 1, including float means within the streamer for adjusting the specific gravity of the streamer to equality with the specific gravity of the surrounding water, and in which substantially all voids within the streamer are filled with a liquid.

11. A system according to claim 1, including a neutrally buoyant drogue secured to the trailing end of the streamer for applying tension thereto sufficient to stabilize the trailing end of the streamer.

12. A system according to claim 1, including a neutrally buoyant drogue secured to the trailing end of the streamer for applying additional tension thereto, said drogue having means controlled by the pressure of the surrounding water for maintaining the drogue continuously at said predetermined depth of submersion while the streamer is being towed by the vessel.

13. The method according to claim 3, in which the towing force applied by the vessel to the streamer is released shortly prior to the firing of each charge and during the period while the recording of the signals is being effected, and thereafter resuming said towing force.

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