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(54) Title: MARINE EXPLORATION VEHICLE

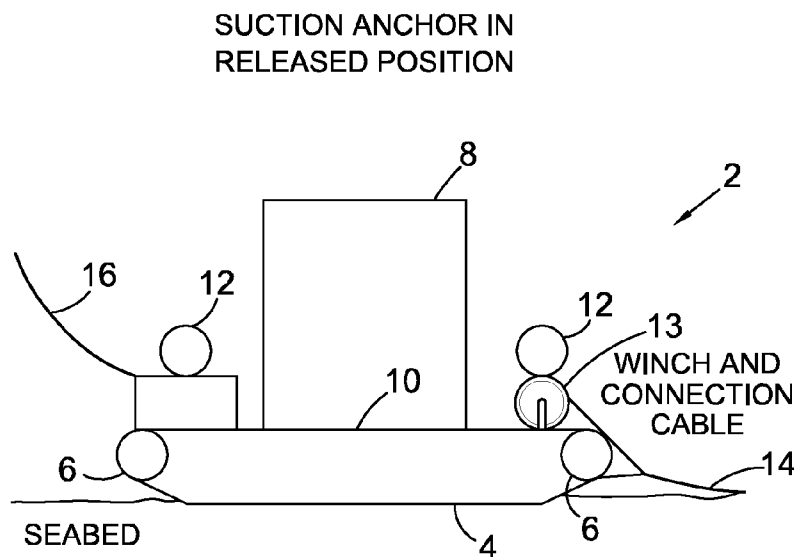


Fig. 1

(57) Abstract: A marine exploration vehicle (2) is provided for use in exploring the seabed of a marine environment, the vehicle comprising: driving means (4) arranged to drive said vehicle from position to position relative to the seabed; a receiver cable (14); and a winch (13) arranged to move said receiver cable.

MARINE EXPLORATION VEHICLE

Field of the invention

- 5 The invention relates to a marine exploration vehicle, and a method of exploring a marine environment.

Background of the invention

- 10 The invention is suitable for the use of shear waves and multi component seismic for the investigation of shallow sediments with respect to imaging and characterization of mechanical properties. Typical applications are (1) geotechnical investigation for offshore wind parks, jack up foundations, pipelines and other seabed structures, (2) drilling geohazards such as shallow gas and shallow water flow and (3) investigation
15 and monitoring of sites for injection of drill cuttings and other waste, produced water, CO₂ or other fluids or gases. In this context shallow means in the approximate depth range 0-1000 m below the seabed.

- 20 The conventional technology for seismic seabed investigation is P waves generated and received in water. The potential for better investigation of shallow sediments by the use of shear waves has been documented both theoretically and by field work on land and offshore. Existing systems generate and receive shear waves on the seabed and utilize both P waves converted to S and pure S waves.

- 25 The July 2002 issue of The Leading Edge contains a series of papers on the current and future technology for identification of shallow water flow. The most important papers from this issue are:

Dealing with shallow-water flow in the deepwater Gulf of Mexico, Ostermeier R M et al
Well planning for SWF and overpressures at the Kestrel well, Bruce B et al

- 30 Shallow hazard detection in the near surface - a coherence cube processing application, Rader B et al

Shallow water flow prediction using prestack waveform inversion of conventional 3D seismic data and rock modelling, Mallick S et al

Geohazard detection and other applications of chimney cubes, Aminzadeh F et al

Prasad, M., 2002, Acoustic measurements in unconsolidated sands at low effective pressure and overpressure detection, *Geophysics*, 67, no. 2, 405-412.

Western Geco/Schlumberger brochure: Enhanced shallow hazard assessment.

5 Western Geco/Schlumberger brochure: Europa field, Gulf of Mexico, A shallow water-flow study.

Huffman, A.R. and Castagna, J.P., 2001, The petrophysical basis for shallow-water flow prediction using multicomponent seismic data: *The Leading Edge*, 20, no. 9, 1030-1052.

The Leading Edge, August 2010, Volume 29:

- Application of shallow shear-wave seismic reflection methods in earthquake hazards studies, James B. Harris, pp. 960-963
- 15 • Near-surface geophysical techniques for geohazards investigations: Some Canadian examples, J. A. Hunter, R. A. Burns, R. L. Good, S. E. Pullan, A. Pugin, and H. Crow, pp. 964-977

20 US Patent No. 6,694,261 – “Method for identification of shallow water flow hazards using marine seismic data” goes beyond established practice for seismic investigation for shallow water flow zones by introducing shear waves in addition to the conventional use of compressional waves. US patent 6694261 is based on compressional waves converted to shear waves in the formation.

25 We also mention US Patent No. 6,374,186, and the following web link:

http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetacgi%2FPTO%2Fsrc_hnum.htm&r=1&f=G&l=50&s1=6,374,186.PN.&OS=PN/6,374,186&RS=PN/6,374,186

30 A sheer wave generator is described in US Patent No. 6,612,397.

A suction anchor is described in US Patent No. 4,432,671 (Shell Oil Company).

35 Multicomponent seismic or shear wave seismic is only possible by using receivers on the seabed. This makes shear wave seismic much more costly to perform than

conventional seismic. Existing multicomponent technology uses normally distributed nodes or a seabed cable with a number of sensors. Placement and possible movement of such systems are time consuming. In practice multicomponent seismic is thereby almost never used in for shallow applications even if the need for such data is increasing.

An example of the increased need is large offshore wind farm developments. Due to the size, geotechnical borings and in situ testing (typically Cone penetration testing-CPT) cannot be done at each location and the design must rely on seismic information to a larger degree. Thereby the shortcomings of P wave seismic to describe mechanical properties is a severe problem. This problem may be reduced with effective collection of multicomponent seismic data.

WO 2009/023071 describes a remotely operated vehicle for acquiring seismic data in icy waters.

WO 03/005062 (Fu-Gro-Udi Limited) describes a remotely operated vehicle for deploying survey apparatus at underwater locations.

Summary of the invention

The invention provides a marine exploration vehicle and method as set out in the accompanying claims.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings.

Brief description of the figures

Figure 1 shows a marine exploration vehicle with a suction anchor in a raised position; and

Figure 2 shows the vehicle of Figure 1, with the suction anchor in a lowered position.

Description of preferred embodiments

Figure 1 shows a marine exploration vehicle in the form of a pulling unit or marine tractor 2 provided with two caterpillar tracks 4 (one of which is visible in Figure 1), each arranged to move around two wheels 6. The tractor 2 incorporates a suction anchor 8, in the form of a, preferably cylindrical, bucket which is open at its bottom 10, but otherwise completely closed.

Two airguns 12 are provided on the tractor 2, together with a winch (13) which is adapted to winch a receiver cable 14. The receiver cable 14 may be provided with seismic and/or electromagnetic sensors (not shown).

A preferred method described here uses a vehicle on the seabed for investigation of the sediments with active shear wave seismic. It can be used for either P waves converted to S or pure S waves or both. Also surface waves may be used. The method consists of two main parts: (1) One or more cables with receiver nodes placed on the seabed connected to (2) a pulling device or a tractor 2. The pulling unit 2 may also carry one or more seismic sources, generating P waves and/or S waves. The pulling unit 2 is remotely operated from the surface, or remotely operated from any place via telecommunication, or autonomous.

The pulling unit 2 is moved by the caterpillar tracks 4. The caterpillar tracks 4 will have the capacity to move the unit but in many cases it will have too little pulling force to move the connected cable(s). This can be illustrated by a seabed consisting of normally consolidated and thereby soft clay. This would be the most likely environment for deep water. In this case the force equilibrium may be estimated by use of an undrained total stress analysis. The resistance from the cable(s) is equal the average undrained shear strength on seabed times the contact area. The pulling force from the tracks is equal their contact area times about the same average undrained shear strength. For reasonable cable length (some hundred meters) and diameters (some centimetres) the contact area of a cable may be about 50-100 square metres. A reasonable contact area for the caterpillar track is about 2-5 square metres. Thus a seabed tractor with caterpillar tracks may be unable to pull the cable.

For this reason a suction anchor 8 is installed on the pulling unit 2. The suction anchor 8 is a bucket with an opening downwards, which penetrates the seabed hydraulically

by lowering the pressure inside the bucket relative to the water pressure, and is lifted up by increasing the inside water pressure in excess of the outside pressure. Suction anchors are used elsewhere for anchoring and foundation purposes. When penetrating the seabed the suction anchor 8 and pulling unit 2 act as an integrated anchor to pull the cable(s) 14. In this position the anchor unit (i.e. suction anchor 8 and/or pulling unit 2) can also serve as an efficient shear wave generator. The pulling force is generated by a cable winch or similar on the pulling unit 2. The seismic cable(s) 14 and the pulling unit 2 may be connected to each other by a cable part which can be winched into or out from the pulling unit 2 according to the following cycle of movement:

Phase 1, Tractor moving

The cable(s) 14 is resting on the seabed. The suction anchor 8 is lifted free from the seabed, the tractor 2 is moves along the seabed, and the connection cable is running out from the tractor 2, so that the cable remains in the same position.

Phase 2, Anchor penetration

The suction anchor 8 penetrates the seabed, first by its own weight, possibly in combination with some pushing mechanism until a sufficient seal is formed with the seabed, then hydraulically. Both tractor 2 and cable(s) 14 are at rest.

Phase 3, Seismic surveying

Seismic signals are sent either from one or more airguns 12, placed in water or on the tractor 2, or by the suction anchor 8 serving as a shear source. Any combination of these signals may be applied. The cable 14 is in receiver mode, lying still on seabed. The tractor 2 is not moving.

Phase 4, Cable moving

The tractor 2 and the penetrated bucket are serving as an anchor and the connection cable is winched into the tractor 2 in order to move the cable 14 towards the tractor 2.

The tractor 2 may then be moved again, and phases 1 to 4 above may be repeated as many times as necessary.

Sub cycles repeating phases 3 and 4 may be applied. A full cycle is achieved when phase 4 is finished.

5 The system may travel in a large variety of patterns on the seabed to cover the investigation area effectively. Normally a 3 D seismic survey would be desirable. The main limitation of the pattern is possible obstacles on the seabed. The turning radius of the tractor-cable system is very small due to the suction anchor 8 and cable winch utility.

10 Video or sonar equipment may be used for navigation. Acoustic transponders may be placed on the seabed to aid the navigation. A pre-survey of the seabed may have been performed and a pattern may have been programmed in advance. Alternatively the unit 2 is remotely controlled in real time or the unit may run by an auto pilot system to run within certain boundaries and guidelines.

15 Energy and communication is provided by a floating vessel (not shown) of moderate size connected to the unit by an umbilical 16. The floating vessel may be manned or unmanned.

20 Shear waves are important to the current method. The current method may use a dedicated shear source on the seabed.

It can also be difficult to analyse multicomponent seismic due to the large variation of the shear velocity near the seabed. To have control of the shear wave velocity and strength near the surface and thereby enable calibration of the results, the tractor may
25 be equipped by remotely operated CPT equipment with a seismic cone (not shown). Cone penetration testing involves a small cone (typically 10 to 15 square centimeters) which penetrates soil or the seabed in order to allow measurement of the resistance to penetration, and usually also measurement of the pore pressure.

30 CPT may use a seismic cone which measures the shear wave velocity of the soil / seabed. Such equipment will give both a continuous strength profile and a direct measurement of the interval velocities of compression waves (P) and shear waves (S). The collection of this information gives a more or less complete set of calibration data
35 for the multi component seismic from the cable at the points along the line at which

CPT is performed, resulting in a continuous 2D profile of engineering parameters directly applicable to foundation design. Note this can be obtained in a single operation. The conventional alternative would be to drag and move a cable on seabed by a vessel and then deploy a geotechnical survey with a seabed frame with CPT. The cost of this combination is so high that it is seldom used. The benefit of the proposed combination of multi component seismic and seismic cone is especially important for large offshore wind power developments such as the Doggerbank project due to the high number of foundation locations.

The system may be used for electromagnetic surveying in combination with or instead of seismic surveying. With electromagnetic surveying a source may be placed on the tractor and receivers on the cable.

The seabed tractor may serve as a platform for other types of data collection in addition to the seismic surveying and thus serve as a seabed laboratory. Such additional types are:

Geotechnical data collection by automated or remotely operated Cone Penetration Testing, CPT. With the suction anchor 8 penetrating the seabed the system will have sufficient reaction force to allow significant penetration of a CPT.

CPT with SEISMIC CONE

Sampling of seabed material by an automatic or remotely operated piston sampler or similar. With a penetrated anchor the system will have sufficient reaction force to allow significant penetration of a sampling device. The samples may be used for a variety of purposes: geotechnical, petrological, chemical, biological. A large number of sample cylinders may be managed by a revolver system or similar.

Mapping of the seabed topography by for instance multibeam echo sounder.

Visual observation of the seabed to describe biology.

Metocean observations (temperature, current, salinity, density etc)

Chemical observations (CO₂, hydrocarbons etc.)

CPT applications are dependent on a fixed platform to obtain sufficient penetration. Such a fixed platform is provided by the tractor 2 with penetrated bucket.

On a strong seabed with limited cable length the tractor 2 may function with no bucket. In stead the weight may be adjusted to a suitable level.

5 The bucket can be used to generate mainly horizontally polarized shear waves. The connection between the tractor 2 and the tracks 4 may be made such that vertical vibration can also be made. This would be beneficial for use of surface waves to characterize the seabed

10 The system provides the combination of a suction anchor 8 and a tractor 2 to enable autonomous movement of a seabed seismic system. Without a penetrating bucket the capacity to pull a seismic cable would be very limited.

15 Another new element is the combination of multi component seismic and seismic cone penetration testing (seismic CPT) providing profiles of velocity data and strength data at certain points to improve analysis of the seismic data and to calibrate the results.

20 The existing seismic systems with receivers on the seabed have too high cost and are thereby rarely used. The benefit of shear wave seismic is thereby too often lost. The high cost is a result of complex and time consuming marine operations involving costly floating vessels to manage equipment on the seabed, especially if a large area needs to be covered.

25 With a vehicle system on the seabed the requirement to support from the surface is significantly reduced. A small boat with a small crew will be sufficient, or alternatively an unmanned or partly unmanned floating unit. This means that seabed seismic with shear waves will be affordable and available to the oil industry and other activity in need of knowledge of the seabed properties.

30 As a result of the complex operation of existing systems, they are dependent on calm weather and very moderate wave conditions. Time used for waiting for weather conditions is thereby often high and this adds to the cost of the operation. The system is much less dependent on weather conditions and the time spent waiting for the weather will be very low. This adds to the cost efficiency.

Due to the low cost to operate, a long duration of the investigation may be allowed, giving an area cover and resolution which is unknown today. In combination with the optional data types described above the seabed tractor may introduce a new area of seabed investigation.

5

The system can provide seismic investigations without the use of an air gun in the water. This may allow access to, and/or increase operational time in, sensitive areas.

10

Other embodiments are possible. For example the pulling unit 2 may be provided with propellers for moving the pulling unit 2 through the water, either instead of or in addition to said caterpillar tracks 4, and the pulling unit need not necessarily move by contact with the seabed. Also in some embodiments an anchor may not be required.

CLAIMS:

1. A marine exploration vehicle for use in exploring the seabed of a marine environment, the vehicle comprising:
 - driving means arranged to drive said vehicle from position to position relative to the seabed;
 - a receiver cable; and
 - a winch arranged to move said receiver cable.
2. A marine exploration vehicle as claimed in claim 1, which further comprises anchor means for anchoring the vehicle to a location on the seabed.
3. A marine exploration vehicle as claimed in claim 2, wherein the anchor means is a suction anchor which is arranged to penetrate the seabed as a result of pressure within the suction anchor being lower than the pressure of the surrounding water.
4. A marine exploration vehicle as claimed in claim 3, which comprises pressure reducing means for reducing the pressure within the suction anchor.
5. A marine exploration vehicle as claimed in claim 3 or 4, wherein said suction anchor has the shape of a receptacle which is open at a lower surface.
6. A marine exploration vehicle as claimed in claim 5, which is shaped as an upside-down bucket.
7. A marine exploration vehicle as claimed in claim 6, wherein said bucket has a generally circular cross-section.
8. A marine exploration vehicle as claimed in any preceding claim, wherein said driving means is arranged to contact the seabed and drive the vehicle along the seabed.
9. A marine exploration vehicle as claimed in claim 8, wherein said driving means comprises at least one caterpillar track.

10. A marine exploration vehicle as claimed in any preceding claim, wherein said cable is provided with seismic sensors.
11. A marine exploration vehicle as claimed in any preceding claim, wherein said cable is provided with electromagnetic sensors.
12. A marine exploration vehicle as claimed in any preceding claim, which is provided with Cone Penetration Testing equipment.
13. A marine exploration vehicle as claimed in claim 12, wherein said equipment includes a seismic cone.
14. A marine exploration vehicle as claimed in any preceding claim, which is provided with at least one airgun.
15. A method of performing marine exploration comprising the steps of:
 - a) placing a remotely operated or autonomous vehicle at a first vehicle position, and a receiver cable at a first receiver cable position, with said receiver cable being connected to said vehicle;
 - b) moving said vehicle to a second vehicle position;
 - c) moving said receiver cable, by means of a winch provided on said vehicle, from said first receiver cable position to a second receiver cable position;
 - d) either before or after step c), activating a source and recording the energy received by said receiver cable from said source; and
 - e) repeating steps b) to d) as required.
16. A method as claimed in claim 15, which further comprises, after step b) and before step c), anchoring said vehicle relative to the seabed;

17. A method as claimed in any one of claims 17 to 19, wherein said anchoring step is performed by a suction anchor which is arranged to penetrate the seabed as a result of pressure within the suction anchor being lower than the pressure of the surrounding water.

18. A method as claimed in claim 17, which further comprises using said suction anchor as a shear wave source.

19. A method as claimed in any one of claims 15 to 18, wherein said step of moving said vehicle includes driving said vehicle along the seabed using driving means which contact the seabed.

20. A method as claimed in any one of claims 16 to 19, wherein said vehicle includes anchor means for performing said anchoring step, and wherein said method further comprises transmitting seismic energy to the seabed using said anchor means.

21. A method as claimed in any one of claims 15 to 20, wherein said vehicle includes driving means for moving said vehicle, and wherein said method further comprises transmitting seismic energy to the seabed using said driving means.

22. A method as claimed in any one of claims 15 to 21, which further comprises using said vehicle as a shear wave source.

23. A method as claimed in any one of claims 15 to 22, wherein said vehicle is a marine exploration vehicle as claimed in any one of claims 1 to 14.

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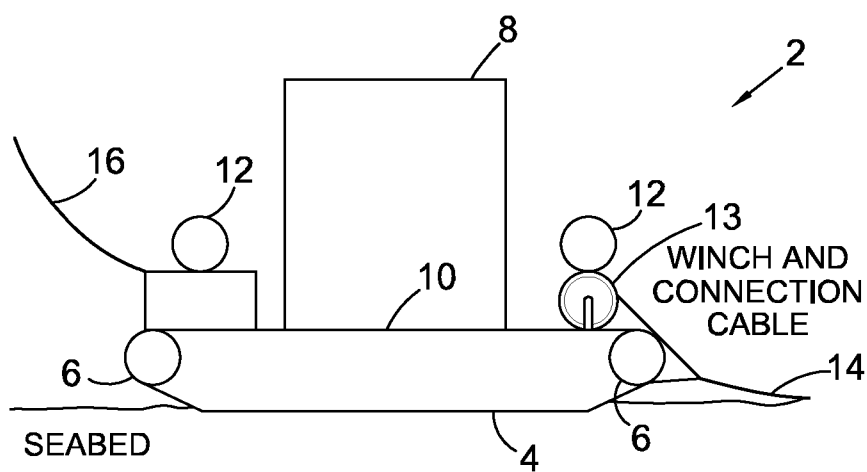
SUCTION ANCHOR IN
RELEASED POSITION

Fig. 1

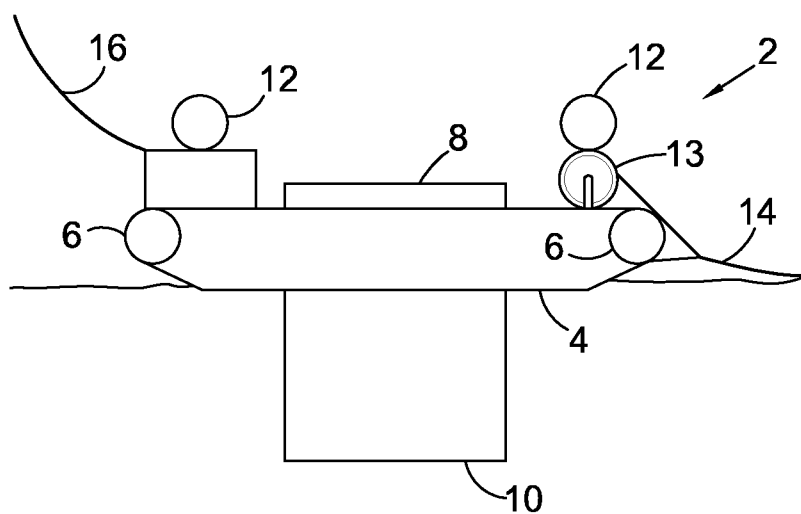
SUCTION ANCHOR IN
PENETRATED POSITION

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. B63C11/42 G01V1/38
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B63C G01V B63G B63H B63B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	----- GB 1 217 163 A (CAMMELL LAIRD & COMPANY SHIPBU) 31 December 1970 (1970-12-31) page 1, line 50 - line 61 figures	1-23
A	----- US 4 730 692 A (FAIR DELBERT W [US] ET AL) 15 March 1988 (1988-03-15) abstract figures	1-23
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Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

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20/10/2011

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Gardel, Antony

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/052426

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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