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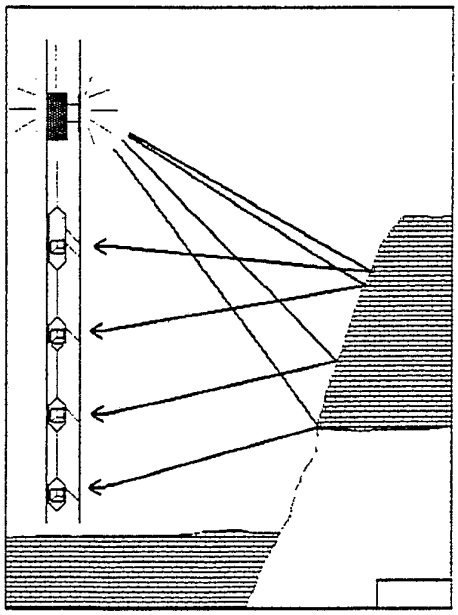
(54) Title: METHOD FOR VERTICAL-SEISMIC PROFILING IN WELLS



(57) Abstract

By this method for vertical seismic profiling in the well-bore there are introduced at least two separate recording-instruments such as 3-component geophones and in addition to these also acoustic signal sources. The signal sources are arranged either over or below or possibly also in between the recording-instruments. The source is run to emit signals with spectra between 0 and 1000 Hz and the generated waves are registered as a function of time. A procedure for using this arrangement is also described.

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Method for vertical-seismic profiling in wells

The invention relates to a new method for vertical seismic profiling (VSP) in drilled wells, whereby both the seismic sources and the signal receiving instrument are located in the well. The intention of the present invention is to perform full wavefield long wavelength acoustic measurements with the source in the well.

In vertical seismic profiling (VSP) the procedure today is to have seismic instruments, such as geophones in the well, usually clamped to the wall by some type of clamping mechanism. Geophones are instruments used to measure movements in the earth. An alternative is to use hydrophones that measures changes in the pressure field. The acoustic source is located near or at the surface at some distance from the top of the well. The techniques used are described for example in:

- Vertical Seismic Profiling, Technique, Applications and Case Histories (A.H.Balch and M.W.Lee, Reidl Publishing Comp., 1984)
- Vertical Seismic Profiling, Vol 14A og 14B of Handbook of geophysical Exploration (B.A.Hardage, Geophysical Press, 1985).

Lately one has developed techniques for using several instruments simultaneously in the well. On the enclosed fig.1 the principle for multi-level measurements is schematically illustrated.

The VSP measurements are made for several reasons. Two of the main ones are;
- to measure the seismic velocity close to the well
- to perform structural mapping of the area close to the well.
A main problem is however that the frequency for the seismic waves that can be utilized is relatively low, a typical upper limit is 80 Hz. This is caused by unelastic attenuation of the higher frequencies when the waves are crossing the overlaying layers. The accuracy and resolution that can be achieved is thus correspondingly low, both for velocity measurements and

for mapping of structural contrasts.

The main alternative to VSP measurements is "sonic"-measurements. Typically one then uses an instrument with the acoustic source and receivers located in one and the same unit. The length of this combined unit can be from 1 to 4 m, sometimes more. The measurements are made by pressure-sensitive instruments. Much higher frequencies are being used then in VSP, that is in the kilohertz range. For more practical details, see:

- A Practical Introduction to Borehole Geophysics (J.Labo, Society og Explor. Geophysecists, 1986).

The disadvantage with these measurements is primarely that because one uses waves with frequencies in the kilohertz range the measurements and thereby the results will be influenced by the well itself and it is not possible to penetrate a substantial distance into the surrounding structures. Also, it is not possible to measure and locate structural features, such as faults close to the well. An exception is microfractures. One may further have some doubts as to how representative the velocities measured are for the corresponding measurements by usual VSP technique. It is still to some extent unclear whether velocities measured in the kilohertz-range are fully relevant for frequencies in the range 0-100 Hz; i.e. the seismic range.

The object of the present with this invention is thus to improve the method used in VSP- measurements in wells such that one in a relative simple way may achieve an improvement on both of the above methods; i.e. perform velocity measurements using relative long wavelengths and at the same time perform measurement of the whole wavefield , thereby being able to perform structural mapping of the area close to the well. In this context close means a few hundred meters away from the well.

This intention is achieved by a method characterised by the claims.

The invention is further illustrated by means of the following description combined with the drawing on which the invention is schematically illustrated. This illustration does not mean any limitation of the scope of invention. On the drawing the figures are showing:

Fig. 1 the principle of using several measure instruments in a well according to prior art (i.e. conventional VPS),

Fig. 2 the principal geometry of measurement used according to the invention,

Fig. 3 the principle for registration of pressure and shear waves along the well profile, according to the invention, and

Fig. 4 and 5 the principle for registration of reflected/ refracted/difracted waves according to the invention.

With the method outlined for this invention one in addition to geophones with directional sensitivity also will have one or several acoustic sources in the well. The principal geometry of the different elements is illustrated on the enclosed fig. 2. The acoustic sources will either be located just over or under the recording-instruments. Using a larger arrangement of instruments one may also have sources in between the different instruments. The distance between the respective units should be between 5 and 30 meter, but this is not a fixed value. Frequencies between 0 and 1000 Hz will be used.

Typical recording-instrument will be the French produced "Multilock" sonde with three-component geophones. The equipment used by RWS consists of one main instrument that is 3.9 m long and has a weight of 102 kg. Under this one has the so called satellite instruments. The weight of each of these are 33 kg and they are 1.0 m long. The instrument accepts pressures up to

1200 bar and temperatures up to 180 degrees Celsius. Each channel will typically be sampled 1000 times per second, thus one will have 3000 samples from each 3-component set per second.

The measurements will be performed through the whole or a large part of the well. This will be achieved by moving the whole arrangement when the measurement at one level is finished, and then repeat the shooting - measurement procedure.

To some extent this arrangement may be considered equivalent to the arrangement used in marine seismic, except that one has 3-component instruments. Thus one aspect of the invention is that one will perform a seismic survey with azimuthal sensitivity in the well. The geometrical considerations valid for such surveys are thus relevant here.

By utilizing this invention one will achieve:

a) A registration of pressure (P) and shear waves (S) that have travelled along the well profile. This will be registered in the frequency range from 0 to 1000 Hz. An illustration is shown on fig. 3. One will thus measure the velocities of the seismic waves, in particular pressure and shear waves, along the well profile in a frequency range that one previously has not been able to measure.

b) One will register waves that are reflected/refracted/difracted because of structural contrasts close to the well. This could be faults or interfaces, including those crossing the well profile. This is illustrated in fig. 4 and 5.
In order to map such structures as illustrated in fig 5, one will have to orientate the instruments, i.e. one has to know in which direction the different instrument-components are pointing. This can be achieved in two different ways. Either by utilizing a gyro instrument hanging under one or several of the 3-component instruments. Or alternatively by utilizing the

signals from a known source at the surface ,see US-PS-2 036 824.

In order to utilize the acquired data in an optimal fashion one will have to distinguish between different wave modes and between different arrival-directions (in the vertical- and horizontal plane). To do this, one will exploite the fact that one has several instruments simultaneously, i.e. a seismic array, and that all of these are 3-component instrument where the orientation can be known. This type of processing has become established theory lately. References are for example
- Cliet og Dubesset (Three component recordings: Interest for land seismic source study, Geophysics, Vol 52, Aug. 1987, 1048-1059),
- Benhama, Cliet og Dubesset (Study and application of spatial directional filtering in three component recordings, Geophysical Prospecting , 36, 591-613, 1988),
- Dankbaar (Vertical Seismic Profiling - Separation of P- and S- waves, Geophysical Prospecting, 35, 803-814, 1987).

This progress in seismic processing implies that one will not have to depend one a particular acquisition geometry whereby one will try to avoid for example that tube waves arrives simultaneously with the wave modes we will utilize.

An additional point is that the so called satellite instruments, i.e. the physical smaller sonde hanging under the main instrument has a better 3-component registration than the main instrument. This has for example been reported by Berteussen et al in a paper presented at the SEG yearly meeting in Los Angeles in 1988. The consequence of this is that one in the future may envisage that the main instrument will include only the electronic modules and that the recording-instruments (the geophones) will be located in satellites only.

As has been mentioned above, the principle for this invention is best illustrated by fig. 2. By this arrangement one will have two or more separate instruments located in a distance

typically between 5 and 30 m from each other. This distance can be changed. One or several acoustic sources will be used. These will be located just above, between or under the instruments. Frequencies in the area best for seismic data will be used, i.e. between 0 and 1000 Hz. One will further use 3-component geophones; possibly one may also add a hydrophone in the sonde. The whole wavefield will be registered, that is the geophone movements will be registered as a function of time. This has become possible by utilizing the special procedure outlined for this invention, and should give data with quality significantly better than one previously has achieved.

CLAIM:

1) A method for vertical-seismic profiling in the well whereby seismic signal sources and receivers for the signals are located in the well simultaneously, characterised in that it in the well is introduced at least two separate measurement-instruments, in particular 3-component geophones giving directional sensitivity and establishing its orientation by utilizing a gyro or by utilizing the signals from a known source at the surface, that the acoustic signal sources are located over, under, or alternatively between the recording instruments, that the source emits seismic signals with frequencies between 0 and 1000 Hz, and that the signals are registered as a function of time on all the recording instruments.

2) Method as outlined in claim 1, characterised by locating the instruments at distances 5 - 30 m from each other, and that the acoustic source(s) are located at similar distances from neighboring instruments.

3) Seismic acquisition equipment for use as described in one or several of the above claims characterised by locating one or several acoustic sources and at least two separate geophones in a well bore, in such a fashion that the source is located either over, under or possibly between the geophones.

4) Utilization of a seismic acquisition equipment a described in claim 4 for vertical seismic profiling in a well.

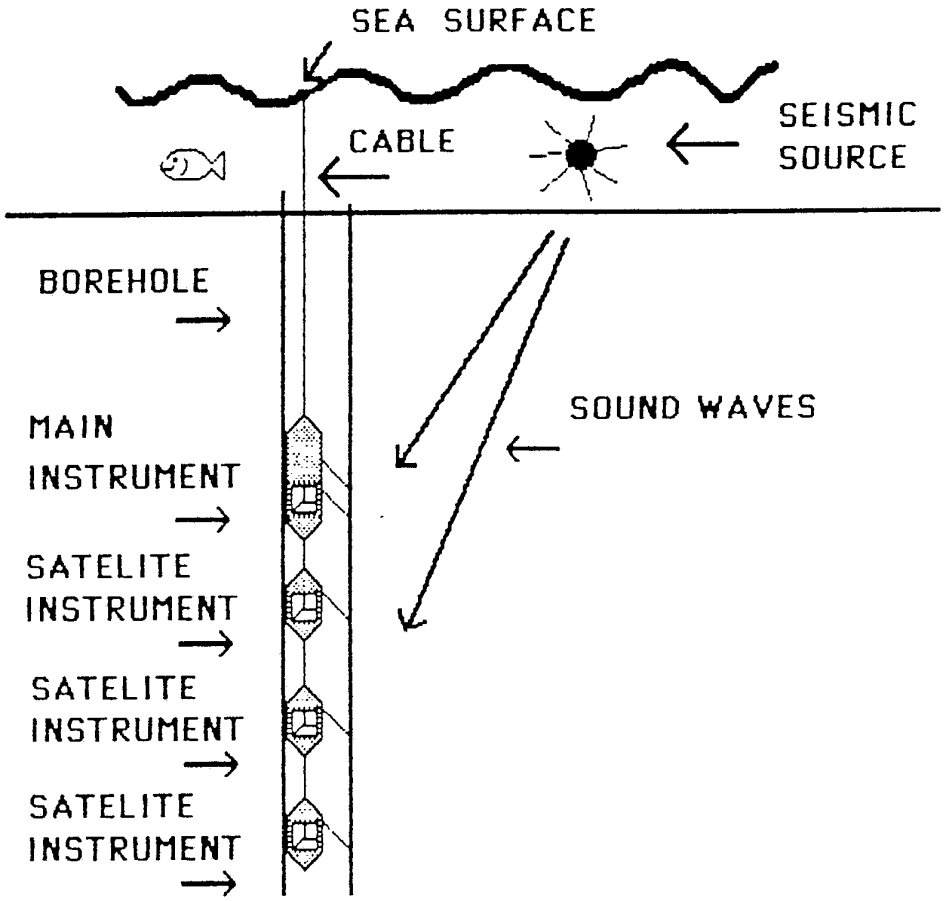
SEA SURFACE
CABLE
SEISMIC SOURCE
BOREHOLE
SOUND WAVES
MAIN INSTRUMENT
SATELITE INSTRUMENT
SATELITE INSTRUMENT
SATELITE INSTRUMENT

Fig. 1

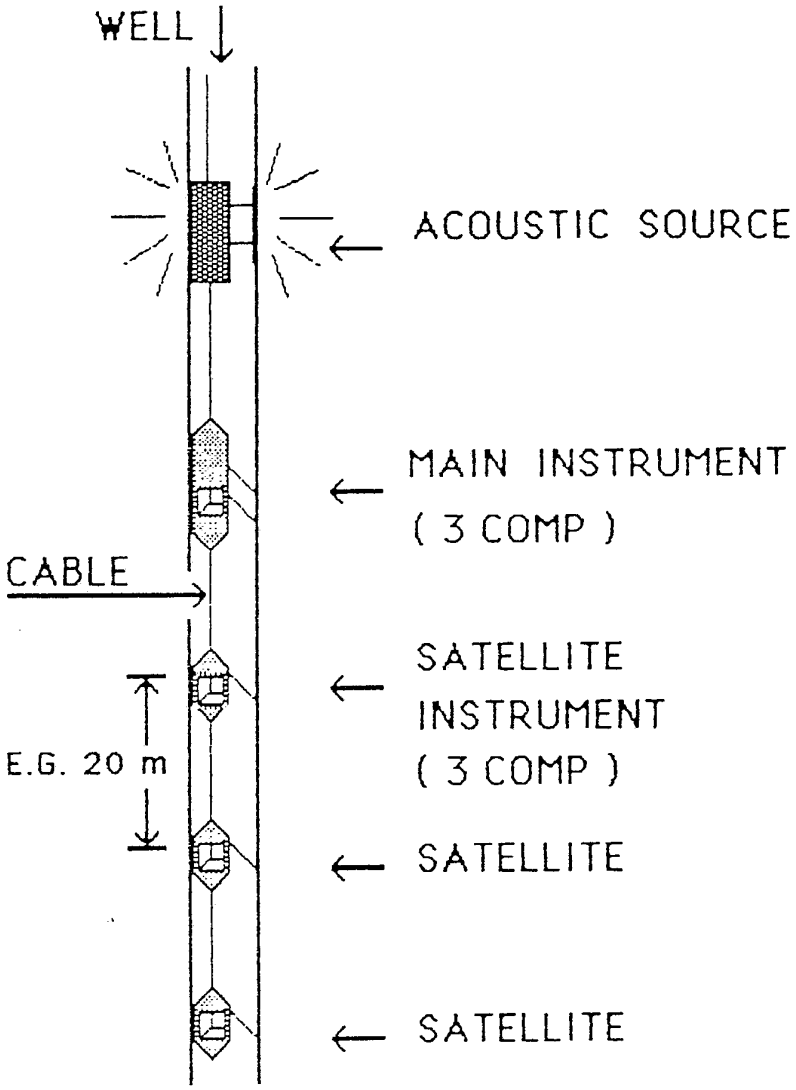
WELL
ACOUSTIC SOURCE
MAIN INSTRUMENT
(3 COMP)
CABLE
SATELLITE
INSTRUMENT
(3 COMP)
E.G. 20 m
SATELLITE
SATELLITE

Fig. 2

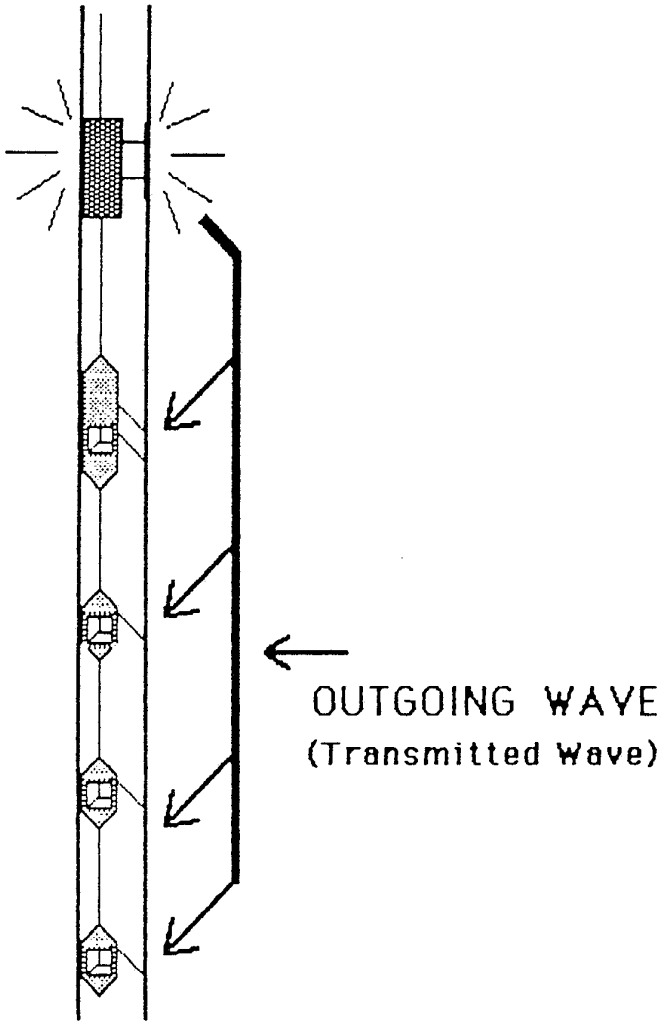

Fig. 3

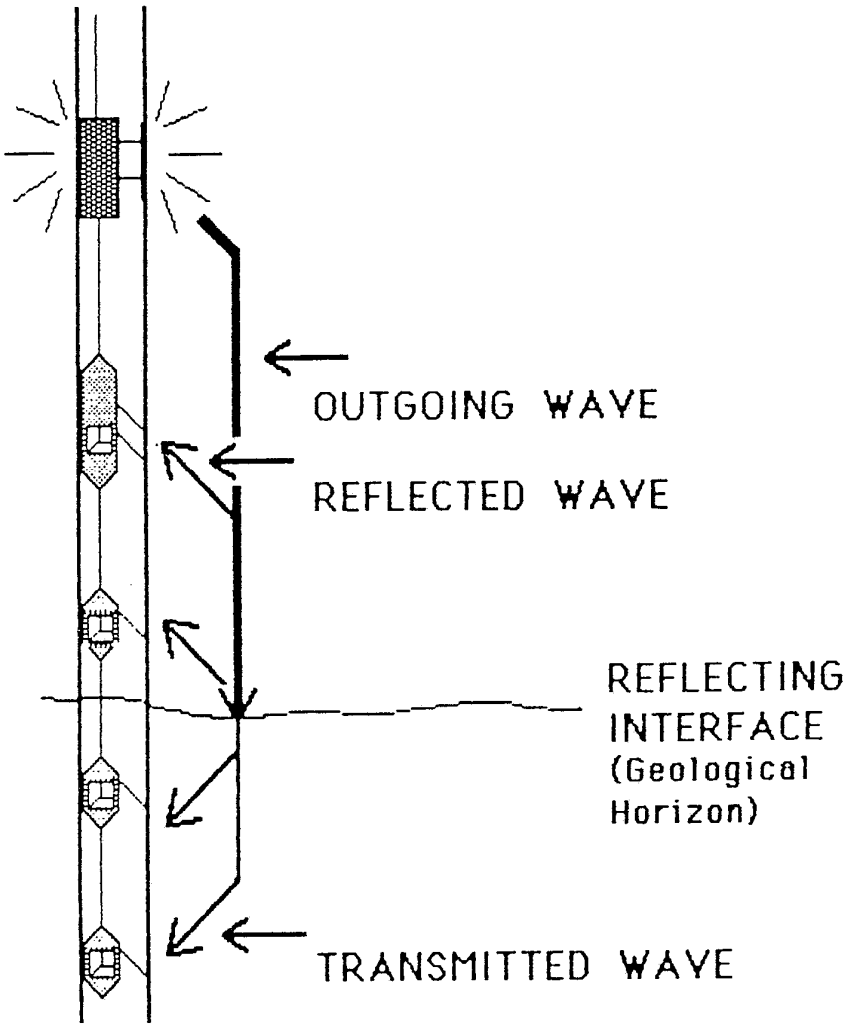
OUTGOING WAVE
REFLECTED WAVE
REFLECTING INTERFACE (Geological Horizon)
TRANSMITTED WAVE

Fig. 4

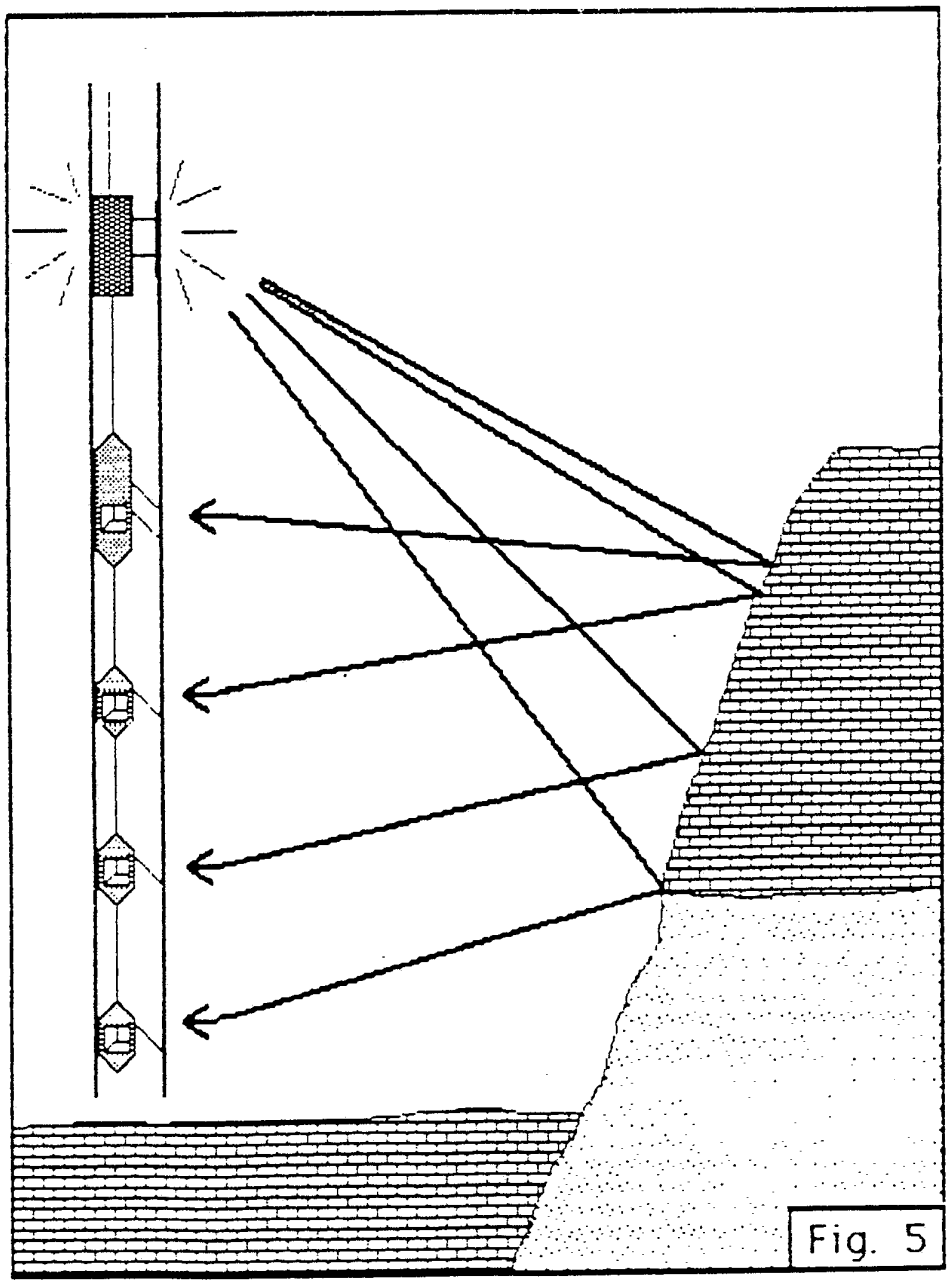

Fig. 5

INTERNATIONAL SEARCH REPORT

International Application No PCT/NO 89/00013

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC4: G 01 V 1/40, E 21 B 49/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC4	G 01 V, E 21 B

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

SE, NO, DK, FI classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [9]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	US, A, 2231243 (R.F. BEERS) 11 February 1941, see page 2, column 1, line 17 - line 69; page 3, column 1, line 14 - line 55; page 3, column 2, line 37 - line 61 --	1-4
Y	US, A, 2718929 (O. WEISS) 27 September 1955, see column 2, line 55 - column 3, line 8 --	1-4
Y	US, A, 4649526 (G.A. WINBOW ET AL) 10 March 1987, see column 8, line 55 - line 66 --	1-4
Y	EP, A3, 0148076 (SCHLUMBERGER LIMITED) 10 July 1985, see page 3, line 22 - page 4, line 18 --	1-4

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
1989-05-22	1989 -05- 24
International Searching Authority	**Signature of Authorized Officer**
Swedish Patent Office	Stefan Svahn

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Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
Y	EP, A3, 0210925 (SCHLUMBERGER LIMITED) 4 February 1987, see column 18, line 34 - column 19, line 45 --	1-4
Y	US, A, 3483505 (J.C. ADAIR ET AL) 9 December 1969, see column 4, line 5 - line 49 --	1-4
Y	US, A, 3073406 (J.A. WESTPHAL) 15 January 1963, see column 2, line 20 - line 46; column 4, line 28 - line 45 --	1-4
A	US, A, 3061037 (J.F. EVANS) 30 October 1962, see column 3, line 7 - line 17 --	1-4
Y	US, A, 4702343 (B.N.P. PAULSSON) 27 October 1987, see column 3, line 2 - line 37; figure 7 --	1-4
Y	US, A, 4706224 (R.M. ALFORD) 10 November 1987, see column 4, line 13 - column 5, line 29 --	1-4

ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO. PCT/NO 89/00013

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 2231243	11/02/41	NONE	
US-A- 2718929	18/06/51	NONE	
US-A- 4649526	10/03/87	GB-A-B- 2145521	27/03/85
		FR-A-B- 2551222	01/03/85
		DE-A- 3429870	14/03/85
		AU-D- 32341/84	28/02/85
		NL-A- 8402564	18/03/85
		CA-A- 1224263	14/07/87
		AU-A- 570715	24/03/88
EP-A3- 0148076	10/07/85	US-A- 4648039	03/03/87
EP-A3- 0210925	04/02/87	JP-A- 62058184	13/03/87
		OA-A- 8369	29/02/88
US-A- 3483505	12/09/69	NONE	
US-A- 3073406	15/01/63	NONE	
US-A- 3061037	30/10/62	NONE	
US-A- 4702343	27/10/87	WO-A- 87/05708	24/09/87
		AU-D- 72056/87	09/10/87
		EP-A- 0263149	13/04/88
		US-A- 4783771	08/11/88
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