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EXPLORATION OF EARTH FORMATIONS ASSOCIATED
WITH PETROLEUM DEPOSITS
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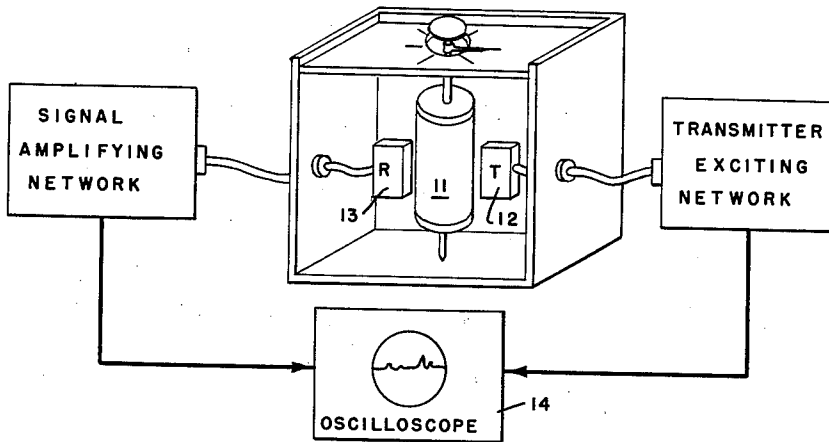


FIG. 1

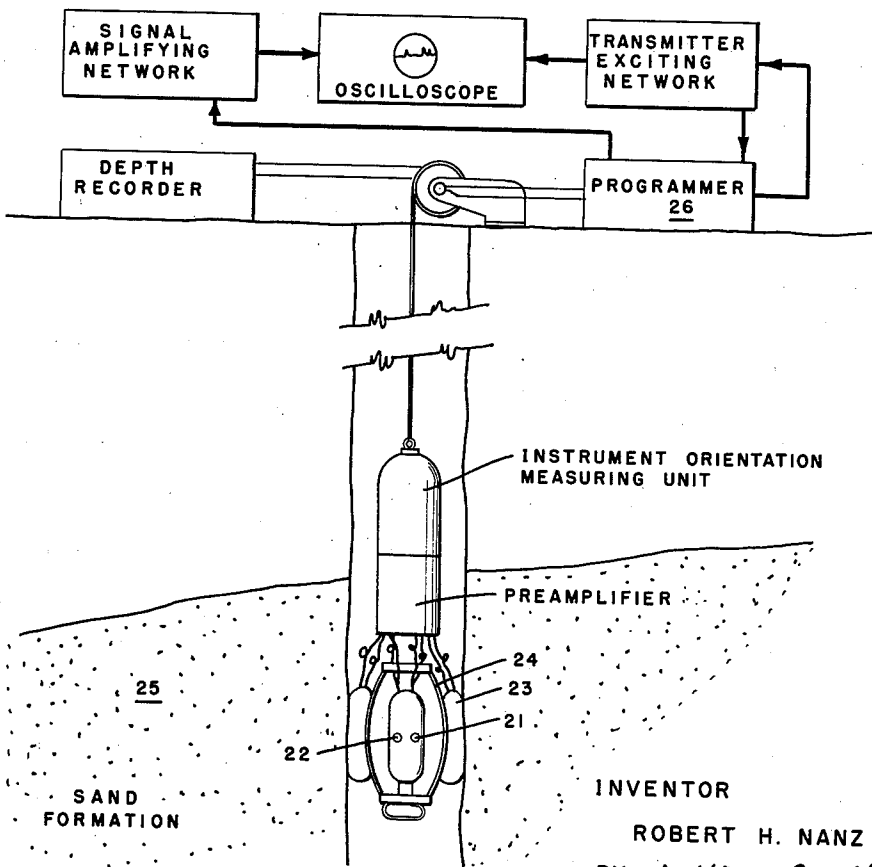


FIG. 2

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EXPLORATION OF EARTH FORMATIONS ASSOCIATED WITH PETROLEUM DEPOSITS**Robert H. Nanz, Houston, Tex., assignor to Shell Oil Company, a corporation of Delaware****Filed Aug. 1, 1958, Ser. No. 752,592****17 Claims. (Cl. 324—13)**

This invention relates to geophysical exploration, and pertains more particularly to a method of locating earth formations associated with petroleum deposits by obtaining from a granular earth formation of primary origin an indication of the geographic direction along which the formation was the most extensive at the time of deposition.

A granular earth formation of primary origin is an aggregation of particles, fragments of minerals, or fragments of older rocks that have been washed away from areas which have been eroded. In formations of primary origin, the geological character is directly related to the character of the particles deposited and the conditions under which they were deposited, as distinguished from an originally integral rock formation which has been fractured or ground into fragments. The granular earth formations of primary origin are often called fragmental, clastic, or detrital rocks, and they vary widely in character depending on the nature of the eroded material, the distance it was transported, the transporting agency, and the like.

Such granular earth formations, particularly those containing grains in the size range including the sands, the smaller pebbles and the coarser silts, are quite frequently associated with petroleum deposits. The petroleum deposits tend to be located in or near such granular formations when the nature and arrangement of the surrounding formation causes the granular formation to become a structural or stratigraphic trap for petroleum. Most of the fragmental reservoir rocks are siliceous, but many are fragmental carbonate rocks such as oolites, calcarenites, coquinas and the like made up of cooids, calcareous grains of silt and sand size and shell fragments that have been only slightly cemented or recrystallized. For simplicity of language in describing the present invention, granular earth formations of primary origin are hereinafter referred to by the term "sands."

Where the surrounding stratigraphy is such that a subsurface sand may form a structural trap, in many cases the location of the portion which is likely to contain oil can be determined by seismic, gravimetric, or the like exploration data, taken in conjunction with the inferences reached by experimental surface and subsurface geologists. But similar determinations have heretofore been much more difficult in the case of sands likely to form stratigraphic or combination stratigraphic and stratigraphic-structural oil traps. In such cases the sand usually comprises a generally horizontal body which sometimes has an area of less than a few square miles and which tapers toward the edges to have a generally lens-shaped or wedge-shaped thinning out of its thickness. The boundaries between such lenticular sand bodies and the enclosing formations may be either sharp or gradational, but they are usually indistinguishable by the seismic, gravimetric, or the like exploration methods.

Heretofore the determination of the trend of such a subsurface lenticular sand has usually required the ac-

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cumulation of sufficient data to predict the regional strike and/or the shore lines of an extensive body of water such as an ocean, lake or sea that existed during the depositional period. In continental alluvial valleys, the primary sands tend to be the most extensive along directions which are generally perpendicular to the regional strike. In the vicinity of a shallow sea, primary sands tend to be parallel to the shore lines that existed during the depositional period. In the vicinity of a deep sea such sands tend to be parallel to the trough of the deep sea basin.

A primary object of the present invention is to provide a process for subjecting a portion of a sand of primary origin to a combination of data-accumulating and data-combining operations that produce an indication of the direction along which the sand was most extensive at the time it was deposited.

A further object is to provide a process for obtaining measurement information that is indicative of the trend of a sand formation associated with oil deposits, and is based on samples that can be obtained from a single well which encounters the sand.

These and other objects of this invention will be understood from the following description taken with reference to the drawing, wherein:

Figure 1 illustrates diagrammatically an instrument for measuring directional acoustic velocities in an earth sample.

Figure 2 is a diagrammatic view of a similar acoustical-measuring apparatus adapted to be lowered into a well with associated apparatus being schematically shown as positioned at the surface adjacent the well.

Although the present invention is not dependent upon any particular theory or mode of operation, it is, at least in part, premised upon the discovery that, in a statistical sense, the positions assumed by individual sand grains as they come to rest is indicative of the average direction of sand transport. The relation between the direction of sand transport and the trend of the sand bed is established by the environment in which the deposition occurs. Therefore, it is possible to determine the trend of a sand formation by selecting the proper masses of the grains composing the sand, determining the predominant direction of common alignment among sufficient numbers of the elongated grains within such masses, and algebraically summing directions that correspond with the grain alignments in the manner dictated by the environment in which the grains were deposited.

In general, the primary sands that are of the greatest interest to the petroleum industry (and which are the most difficult to map when their outlines are covered by more recent sediments) are composed of grains that were deposited by air or water currents moving over or along topographical structures such as river beds, beaches, submarine bars or deep sea troughs. In the regions within such sand beds in which the positions of the grains most accurately reflect the trend of the sand bed, the bedding planes are substantially horizontal, i.e., have dips of less than about 10 degrees.

In its broadest aspects, the present process comprises the following steps:

The method of the present invention may be carried out in the following manner. First, the portions of the sand formation in which the measurements are to be made should be selected so as to meet the following qualifications. The measurements can be made on a core sample which has been brought to the surface or can be made in situ within the formation. In either event, the portion selected should be a part of the sand formation in which the bedding planes were substantially horizontal at the time of deposition, e.g., a portion in which the dip of

the bedding planes was less than about 10°. The portion selected should also be one containing more than several thousand and preferably several million grains that have the same orientation relative to each other that they had at the time they were deposited within the sand formation. Where the selected portion is contained in a core which is removed from the sand formation, the core, or the procedure by which it is removed, should be such that it is possible to determine how the core sample was geographically oriented within the formation.

Second, statistically significant measurements are made of the directions of common orientation among the elongated grains within at least one sample. These measurements are preferably based on a directional property which is affected by the relative orientation in directions paralleling the bedding plane of at least a plurality of thousands or millions of grains. Such measurements make it possible to determine the geographic direction of the common alignment among the grains in a sample whose orientation within the formation is known; such an analysis of the sample shows the geographic direction of the common alignment among the grains within the sand formation.

Third, the environments in which the grains were deposited are determined and directions that relate to the grain orientations in a manner dictated by the depositional environments are algebraically added. The depositional environments are determined to be predominantly of the beach, river bed, shallow marine, deep marine, sand dune, alluvial fan, or the like type of depositional environment in which a transporting fluid deposits the grains it is moving. The determinations can be effected by means of one or more of the known procedures based on the sorting of the grains, the nature and amounts of microfossils, the chemical composition and properties of the sand components, etc. An algebraic summation is compiled from directions which correspond to the directions of the grain orientations in manners dictated by the environments in which the grains were deposited, e.g., directions perpendicular to the direction of common alignment among grains deposited on a beach, and parallel to those of grains deposited on an offshore portion of a sea bottom or in a river bed.

The grain orientation measurements necessarily correspond to points along the 360 degrees of geographic azimuth through which the line of the grain orientation extends, e.g. a north-east south-west orientation corresponds to a line extending through 45 and 225 degrees. The above-described algebraic summations amounts to adjusting the measured orientations by adding 90° or 0°; with 90° being added where the depositing current was wide compared to the distance it traveled, such as a wave lapping on a beach, and 0° being added where the depositing current was narrow compared to the distance it traveled, such as a river, a deep sea trough or the like.

In general, the sampling step can be performed by means of the conventional equipment and procedures. Samples are normally obtained from a plurality of wells although considerable information can be obtained from samples taken in a single well. In a preferred practice, substantially the full extent of the sand formation is cored in a manner providing a substantially intact cylinder which is several inches in diameter. The way in which the core was oriented within the sand bed is determined by means of an azimuth and/or inclination reference mark placed on the core before it was broken free of the formation, or by measuring the direction of remanent magnetism of the core and correlating it with the earth's magnetic field at the time of deposition, or the like methods. The available portions of the core are studied in respect to the position of the bedding planes and a series of substantially aliquot samples are selected from regions in which the bedding planes of the formation were substantially horizontal when deposited.

The measurements of the directions of common align-

ment among the sand grains can, although with considerable difficulty, be essentially manually practiced by a microscopic examination of sections cut so that they reveal parallelism with bedding planes. However, to avoid the time and effort of visually and manually completing sufficient measurements to obtain values which are statistically representative of the billions of grains in the formation, it is highly desirable that the measurements be based upon a property such as the response of the sample to directionally applied stresses. A wide variety of systems can suitably be used for applying and measuring directional stresses which are affected by a common orientation of the elongated sand grains.

In a preferred embodiment of the invention, the responses to directionally-applied stresses are measured in a portion of the sand formation which meets the qualifications described above. The stresses are applied along lines that extend through the sand in a plurality of directions that are substantially parallel to the bedding planes.

A sand is a composite body amounting to a matrix of closely adjacent solid materials and, thus, is a body in which the masses associated with the various components exist in states of rest or motion dictated by the physical and chemical arrangement of the body. A stress is a force brought about by a physical agent which produces or tends to produce a deformation in a body. In the present process the stress can comprise one or more of a wide variety of electrical, pressure, thermal or the like forces that tend to cause deformations in the portions of the sand body that are encountered along the specified directions.

Measurements are made of the directions along which the stresses are applied and the variations in the ways the sand responds to the stresses. The direction along which there is an anomalous response corresponds to the direction along which there is a predominant common alignment of the elongated sand grains.

Numerous kinds of devices and techniques can be used in the stressing and measuring operation. For example, in a capacitance type of electrical system the stresses can be applied by the charge on the plates of a capacitor which is arranged so that the materials along a line extending through the sand comprise the capacitor dielectric, and the measurements can comprise measurements of the capacitances exhibited along different directions. In a conductance system the stressing can comprise creating a potential difference along such a line and the measuring can comprise measuring the conductivities exhibited along different directions. In an acoustic form of a pressure system the stressing can comprise generating acoustic impulses at the end of such lines and the measuring can comprise measuring the velocities at which the impulses are propagated or the amounts by which they are attenuated in different directions. In a thermal system the stressing can comprise creating a temperature gradient along such lines and the measurement can comprise measuring the thermal conductivity or diffusivity along different directions. For ease in describing the present invention, specific reference will be made to only three of the several kinds of such systems that can suitably be used.

When such a stressing and measuring operation is performed in situ within the sand formation, the directions of stressing can conveniently be measured in terms of geographic directions so that the direction along which there is an anomalous response corresponds directly to the geographic direction of predominant common alignment of the elongated grains within the sand formation. When such an operation is performed on a core of the sand formation, it is generally preferable to measure separately the geographic orientations the core had within the sand formation, then measure the direction relative to the core along which the stressing of the core gives an anomalous response and, from the two measurements, determine the geographic direction of the predominant

common alignment of the elongated grains within the sand formation.

One suitable system for applying and measuring directional stresses which are affected by the common orientation of the elongated grains comprises the capacitance system described in copending application Serial No. 753,177, filed August 1, 1958. In using this system, a generally cylindrical core sample of the sand formation is rotated between the plates of a capacitor. The sample is cut so that its long axis is substantially perpendicular to the bedding planes. When the capacitor plates on each side of the sample are charged an electrical stress is applied along the path extending through the sample. As the sample is rotated, the stresses are applied along a plurality of different directions relative to the sample. Measurements of the variations in the capacitances and measurements of the relative directions along which the capacitances are measured indicate the relative direction along which there is an anomalous response.

Another means for applying and measuring directional stresses comprises the acoustic system shown in Figure 1. This system is operated in a similar manner. A cylindrical core sample 11 is rotated between transducers 12 and 13 for transmitting and receiving acoustic impulses and, by means of an oscilloscopic display 14 of the electrical signals produced at the moments of transmission and reception, measurements are made of the way the propagation velocity of the acoustic energy varies as the direction of propagation is varied. The oscilloscope, the transducers, and the associated circuitry can comprise units of the types that are used in well logging systems, as long as the units are arranged to function in the manner described above. During each measurement, the excitation of the transmitter produces a pressure pulse on one side of the sample thus creating a pressure differential and a resulting physical stress along the line extending through the sample. The rapidity with which such a stress is equalized by the propagation of pressure waves through the sample is one measure of the way in which the sample responds to the stresses.

An analogous acoustic system for applying and measuring acoustically-produced directional stresses to portions of a sand formation surrounding the borehole of a well is shown in Figure 2. In using this system a plurality of pairs of transmitters 21 and receivers 22 are mounted in holders 23 which are pressed by springs 24 against the wall of a hole extending through the portion of the sand 25 in which the measurements are to be made. A surface located programmer sequentially connects each pair to the transmitter-exciting and signal-amplifying networks and the oscilloscope. The instrument orientation measuring unit measures the geographic direction of the lines that extend between the transmitter and receiver of each pair and thus measures the directions along which the acoustic impulses are successively propagated through the sand formation. In subsurface situations in which the bedding planes are essentially normal to the well bore, the direction along which the acoustic impulses propagate at an anomalous velocity correspond to the directions along which there is a predominant common alignment of the elongated grains within the sand formation. If desired, a single transmitter and receiver may be rotatably mounted in the borehole to scan the borehole wall in a plane, normal to the borehole.

With respect to the compilation of an algebraic sum of directions that relate to the grain orientations in a manner dictated by the depositional environments of the sand grains, there are, in general, four commonly occurring types of sand formations which, singly or in combination, are likely to form stratigraphic traps for oil: beach sands, offshore shallow marine sands, deep marine sands, and continental alluvial sands.

The ability of a stream of water to transport solid materials decreases with any drop in the velocity of the

stream. As the velocity begins to decrease, the particles tend to settle out, with the deposition of the larger and heavier particles preceding that of the smaller and lighter particles. It is likely that the heavier end of an elongated and asymmetrical grain is the first portion of the grain to contact or to come to rest as a result of a contact with an immovable substance at the bottom of the stream, and the remainder of the grain swings into an alignment in which it is most nearly streamlined with respect to the current flow.

Beach sands are formed along the shore line of the sea where the incoming waves refract as they reach the shallower water and the wave fronts become about parallel to the trend of the shore line. The swash of the waves on the beach slope creates currents approximately normal to the beach trend, and the long axis of the grains tend to become aligned parallel to these currents. In the course of time a common type of beach tends to advance further and further into the area occupied by the sea. This seaward accretion of a beach sand is usually, if not always, accompanied by a corresponding accretion of an offshore marine sand which is formed in shallow water at a level slightly below the level at which the beach sand is formed. In a beach sand the bedding planes are generally substantially horizontal, but the direction of common alignment among the grains is substantially perpendicular to the shore line. A beach sand is generally most extensive in the direction followed by the shore line along which the bulk of the grains are substantially simultaneously deposited, and is generally relatively narrow in the direction normal to the shore line along which the beach grows at the very slow rate of the seaward accretion. In such an environment the transporting current is wide in relation to the distance over which it moves the grains.

Offshore marine sands comprise sands deposited on an offshore portion of a sea bottom. They are usually formed of grains transported either by longshore currents that occur in the relatively shallow water near the shore line or by currents that may be termed "density" currents that may have no direct relation to either the depth of the water or the direction of the shore line. The longshore currents often occur at relatively very little distances from the shore line. Even in five feet of water approximately three hundred feet from the shore line and one hundred feet seaward of the small breaking waves, long-shore currents have been observed to transport a one-inch thick layer of fine sand in a direction paralleling the shore line. The grains transported by the longshore currents are deposited in horizontal beds and are oriented parallel to the direction in which their sand beds are the most extensive. In this and numerous other environments the transporting current is narrow in relation to the distance over which it moves the grains. The combined action of the lapping waves and the longshore currents often forms relatively long, narrow barrier islands paralleling the shore lines of a sea. At the time of deposition such barrier islands are composed of an upper layer of beach sands containing grains oriented normal to the trend of the island and a lower layer of marine sands containing grains oriented parallel to the trend of the island.

Where the topography of a sea bottom is irregular, underwater currents that transport sand grains tend to move along from the highs to the lows. Such "density or turbidity" currents tend to be guided by gravity down the slopes of submarine canyons to fill in the depressions within the sea bottom. The sands formed by the density or turbidity currents comprise substantially horizontally bedded deposits in which the predominant common orientation of the grains parallels the trend of the deposits.

Many of the continental alluvial sands are formed as a sand-laden stream moves along through the canyons or across the coastal plains on a land mass. The alluvial

deposition of sand is generally the greatest on point bars which tend to have a preferred orientation generally paralleling the trend of the river valleys.

The alluvial sands are in part horizontally bedded deposits in which the predominant orientation of the grains is parallel to the trend of the deposit.

Example I

The importance of conducting grain orientation measurements that are representative of the direction of common alignment among a statistically significant number of grains was tested by comparing microscopic measurements with the dielectric constant measurements obtained by the instrument described in the above-mentioned copending patent application. Test plugs were cut from two levels within a core of a subsurface sand and the directions of the common orientation of their grains were measured by the dielectric constant measuring procedure. Thin sections were then cut from the top and middle of each of the test plugs and subjected to visual measurements.

In each case, the dielectric constant measurements involve the orientation of about ten million grains, whereas the visual measurements involve the number of grains indicated. The directions of common alignment obtained by the measurements are reported in terms of 0 to 180 degrees relative to a reference mark turned to a position corresponding to zero degrees.

UPPER LEVEL

Plug	Number of grains	Visual, ¹ direction (degrees)	Dielectric constant, ² direction (degrees)
1-----	481	28	96
2-----	534	77	108
3-----	498	93	90
4-----	503	85	118
5-----	511	29	93
6-----	514	169	89
7-----	535	21	92

¹ Weighted Average for 3576 grains—66°.

² Average for 35,000,000 grains—98°.

LOWER LEVEL

Plug	Number of grains	Visual, ¹ direction (degrees)	Dielectric constant, ² direction (degrees)
1-----	496	94	92
2-----	470	58	81
3-----	535	96	85
4-----	475	91	91
5-----	480	62	84
6-----	497	91	84

¹ Weighted Average for 2953 grains—84°.

² Average for 30,000,000 grains—86°.

NOTE.—Weighted average visual measurement based on 6,529 grains—84°. Average dielectric measurement based on 65,000,000 grains—92°.

It is apparent that the individual visual measurements varied to an extent making many measurements a necessity. The performance of the visual measurements based on 6,529 grains required about twenty man-days.

Example II

A barrier island of modern origin was sampled to obtain cores that had known orientations and contained masses of grains which were oriented relative to each other in the same way they were oriented within the sand formation. In each case, the grain orientations were measured by performing enough microscopic measurements to obtain results which were, to a reasonable extent, statistically representative of the orientation of the grains in the regions within the formation from which the samples were taken.

In the case of cores that were taken from near the surface of the beach at a series of points that extended along the major portion of the length of the barrier island, the

measurements of each core yielded directions having an average which was substantially perpendicular to the trend of the beach at the point at which the core was taken.

In the case of samples taken from a depth near the vertical center of the island, they were obtained from a series of points that extended along the major portion of the length of the island but varied in distance from the center line of its longest dimension. The measured directions of common alignment among the grains from each point averaged out to a direction parallel to the longest dimension of the island. The depths at which the latter group of samples were taken made it likely that they were each deposited on an offshore portion of the sea bottom.

Example III

A modern river sand was sampled in a manner designed to simulate the sampling conditions which would result from the drilling of three wells through a reservoir sand of alluvial origin. When a sufficient number of microscopic measurements of the grain orientation were performed to provide a somewhat statistically representative result, the average of the directions measured was essentially parallel to the trend of the alluvial body and the axis of sand deposition.

Example IV

In the initial stage of the development of an oil field in Mississippi, the first well encountered an oil-containing sand which could be identified as a continental alluvial sand. A second well was drilled some one thousand feet east of the first well, without the benefit of grain orientation measurements to indicate the sand trend. The second well failed to encounter the oil-containing sand. A third well was drilled about an equal distance north of the first well and did encounter the oil-containing sand.

The third well was cored and the cores were subjected to a grain orientation analysis using both the relatively very rapid dielectric constant measuring method described in the above-mentioned copending patent application, and also a series of microscopic measurements. The measurements based on the dielectric constant indicated a substantially north-south trend for the oil-containing sand, and the microscopic measurements, although the results of the various individual measurements were rather widely scattered, averaged to a direction which was in fairly good agreement.

At about this stage in the development of the field, a different group drilled a fourth well which was located about one thousand feet west of the third well. The fourth well failed to encounter the oil-containing sand and thus verified the north-south trend that had been indicated by analyzing the cores of the third well in accordance with the process of the present invention.

Example V

In a West Coast field in which several wells encounter a subsurface sand which is indicated by paleoecological studies to be a deep-sea sand, a number of samples were analyzed for both grain orientation and a number of other features likely to be indicative of the trend of the sand bed. Among thirty-five sand cores available for grain orientation measurements, reproducible measurements were obtained by the above-mentioned dielectric constant method on thirty-two of the samples. In the case of twenty samples, it was possible to split the samples along laminations to reveal the alignments of fragments or impressions of fragments, and the direction of common alignment of the fragments were found to correspond to the results of the sand grain orientations. In a very small percentage of the samples available from the field, cross laminations were discernible. The conclusions based on all of the available data regarding sedimentary facies relationships were in accord with the grain orientations and the meager cross lamination data that was available. It is apparent that the sand involved was deposited by "density

or turbidity" currents flowing first down a canyon and then on along the bottom of a deep-water portion of a sea.

Example VI

The correspondence of the acoustic measurements with the microscopic and the dielectric anisotropy measurements of grain orientation was tested by comparative measurements. A series of cores of subsurface sands in which the grain orientations had previously been measured by the microscopic and dielectric anisotropy methods were remeasured with an acoustic system of the type shown in Figure 1. In these measurements the cores and a pair of barium titanate, piezoelectric, transmitting and receiving transducers were immersed in a commercially available turbine oil. The cores were mounted between Lucite core-holding discs and were rotated by hand.

The test established that there was an excellent agreement between the direction of the anomaly in the acoustic velocity and the direction of maximum dielectric constant, or the direction of predominant common alignment of the elongated grains.

I claim as my invention:

1. A method of geophysical surveying for determining the geographical trend of a formation substantially made up of fluid-transported and deposited grains, said method comprising the steps of selecting a portion of sand of known orientation containing substantially horizontally-bedded elongated grains in fixed orientation to each other, measuring the geographic direction along which there is predominant common alignment among statistically significant numbers of the grains, and adjusting the measured geographic direction by 90 degrees to obtain the direction of a line paralleling the geographic trend of a sand formation where the grains were deposited by a current which was wide in comparison to the distance it traveled.

2. A method of geophysical surveying for determining the geographical trend of a formation substantially made up of fluid-transported and deposited grains, said method comprising the steps of selecting a portion of sand of known orientation containing substantially horizontally-bedded elongated grains in fixed orientation to each other, measuring the geographic direction along which there is predominant common alignment among statistically significant numbers of the grains determining the manner in which the grains were originally deposited to make up the formation, and adjusting the measured geographic direction by 90 degrees to obtain the direction of a line paralleling the geographic trend of a sand formation where the grains were deposited by a current which was wide in comparison to the distance it traveled.

3. A method of geophysical surveying for determining the geographical trend of a formation substantially made up of fluid-transported and deposited grains, said method comprising the steps of selecting a portion of sand of known orientation containing substantially horizontally-bedded elongated grains in fixed orientation to each other, stressing at least a selected portion of said formation sand along paths extending into said portion in a plurality of directions substantially parallel to the bedding plane of said portion, determining the directions of maximum response to said applied stresses, and adjusting the directions of maximum response by 90 degrees to obtain the direction of a line paralleling the geographic trend of a sand formation where the grains were deposited by a current which was wide in comparison to the distance it traveled.

4. A method of determining the geographic trend of a subsurface and formation composed of grains that were transported and deposited by fluid currents, said method comprising sampling the formation, determining the geographic direction of common alignment among statistically significant numbers of elongated grains that are oriented in the way in which they were oriented within the sand formation, and adjusting the measured geographic direc-

tion by 90 degrees to obtain the direction of a line paralleling the geographic trend of a sand formation where the grains were deposited by a current which was wide in comparison to the distance it traveled.

5. A method of geophysical surveying for determining the geographical trend of a formation substantially made up of fluid-transported and deposited grains, said method comprising the steps of selecting a portion of sand of known orientation within a well borehole, said sand containing substantially horizontally-bedded elongated grains in fixed orientation to each other, stressing at least a selected portion of said formation sand along paths extending into said portion in a plurality of directions substantially parallel to the bedding plane of said portion, determining the directions of maximum response to said applied stresses, and adjusting the directions of maximum response by 90 degrees to obtain the direction of a line paralleling the geographic trend of a sand formation where the grains were deposited by a current which was wide in comparison to the distance it traveled.

6. A method of geophysical surveying for determining the geographical trend of a formation substantially made up of fluid-transported and deposited grains, said method comprising the steps of cutting from cores taken from a plurality of wells portions of sand of known orientation containing substantially horizontally-bedded elongated grains in fixed orientation to each other, measuring the geographic direction along which there is predominant common alignment among statistically significant number of the grains, determining the manner in which the grains were originally deposited to make up the formation, and adjusting the measured geographic direction by 90 degrees to obtain the direction of a line paralleling the geographic trend of a sand formation where the grains were deposited by a current which was wide in comparison to the distance it traveled.

7. A method of geophysical surveying for determining the geographical trend of a formation substantially made up of fluid-transported and deposited grains, said method comprising the steps of selecting in a plurality of wells portions of sand containing substantially horizontally-bedded elongated grains in fixed orientation to each other, determining the orientation of said selected portions of sand, stressing at least a selected portion of said formation sand along paths extending into said portion in a plurality of directions substantially parallel to the bedding plane of said portion, determining the directions of maximum response to said applied stresses, and adjusting the directions of maximum response by 90 degrees to obtain the direction of a line paralleling the geographic trend of a sand formation where the grains were deposited by a current which was wide in comparison to the distance it traveled.

8. In the geophysical exploration method, a combination of the steps of sampling a subsurface sand bed by removing at least one sample which has a determinable geographic orientation within a portion of the sand bed in which the bedding planes are substantially bedded grains that have the same orientation relative to each other that they had within the sand bed, determining the grain orientation among the horizontally bedded grains in at least one such sample by measuring in a plane substantially parallel to the bedding plane the geographic direction along which there is a common alignment among a statistically significant number of grains when the sample is aligned in the direction in which it was aligned within the sand bed, determining the environment in which the grains were deposited, and compiling an algebraic summation of directions perpendicular to the direction of the common orientation of grains deposited in an environment in which the transporting current was wide in relation to the distance over which it moved the grains and directions parallel to the common orientation of grains deposited in an environment in which the transporting current was narrow in relation to the distance over which it moved the grains.

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9. The method of claim 8 in which the direction of common alignment of the grains within a sample is determined by measuring the variations in the transmissivity of the sample toward a form of energy that is responsive to the alignment of the grains and is transmitted through the sample in various directions substantially parallel to the bedding planes of the grains.

10. The process of claim 8 in which the direction of common alignment among the grains within a sample is determined by measuring the variation in the transmissivity of the sample toward high frequency electrical energy which is flowing between the plates of a capacitance cell and passing through at least a portion of the sample in various directions substantially parallel to the bedding planes of the grains.

11. The process of claim 8 in which the direction of common alignment among the grains within a sample is determined by measuring the variation in the transmissivity of the sample toward high frequency acoustic energy which is flowing between a pair of transducers and passing through at least a portion of the sample in various directions substantially parallel to the bedding planes of the grains.

12. In the method of geophysical prospecting according to which oriented formation samples are systematically recovered over an area to be investigated and subjected to an analysis for the determination of the grain orientation therein, the steps of stressing at least a selected portion of each of said formation samples along paths extending through said sample in a plurality of directions substantially parallel to the bedding planes and determining the directions of maximum response to said applied stresses.

13. A method of geophysical surveying which comprises the steps of taking samples of earth formations at spaced intervals over the area to be surveyed, determining the manner in which the particles making up the earth formation were originally deposited by a body of water earlier in geologic time, and determining the general direction of the shoreline of said body of water at least within the area where the samples were obtained by measuring the grain particle orientation of said samples and correlating the same with reference to the manner in which the particles were originally deposited.

14. A method of geophysical surveying for determining the direction of a geographical trend of a formation surrounding a borehole comprising: selecting a portion of the borehole in which the formation is encountered on all sides of the borehole; stressing said selected portion of the formation along paths extending into said selected portion in a plurality of directions substantially parallel to the bedding planes of the formation; measuring the response of the formation to the applied stress, and determining the direction along which said formation exhibits a maximum response to said applied stress.

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15. A method of geophysical surveying for determining the geographical trend of a formation substantially made up of fluid-transported and deposited grains, said method comprising the steps of selecting a portion of a formation surrounding a borehole, said formation being a sand formation of known orientation containing substantially horizontally-bedded elongated grains in fixed orientation to each other, measuring the geographic direction along which there is predominant common alignment among statistically significant numbers of the grains, and adjusting the measured geographic direction by 90 degrees to obtain the direction of a line paralleling the geographic trend of a sand formation where the grains were deposited by a current which was wide in comparison to the distance it traveled.

16. A method of geophysical survey for determining the geographical trend of a formation substantially made up of fluid-transported and deposited grains, said method comprising the steps of selecting a portion of a formation surrounding a borehole, said formation being a sand formation of known orientation containing substantially horizontally-bedded elongated grains in fixed orientation to each other, measuring the geographic direction along which there is predominant common alignment among statistically significant numbers of the grains, determining the manner in which the grains were originally deposited to make up the formation, and adjusting the measured geographic direction by 90 degrees to obtain the direction of a line paralleling the geographic trend of a sand formation where the grains were deposited by a current which was wide in comparison to the distance it traveled.

17. A method of geophysical surveying for determining the geographical trend of a formation substantially made up of fluid-transported and deposited grains, said method comprising the steps of selecting a portion of a formation surrounding a borehole, said formation being a sand formation of known orientation containing substantially horizontally-bedded elongated grains in fixed orientation to each other, stressing at least a selected portion of said formation sand along paths extending into said portion in a plurality of directions substantially parallel to the bedding plane of said portion, determining the directions of maximum response to said applied stresses, and adjusting the directions of maximum response by 90 degrees to obtain the direction of a line paralleling the geographic trend of a sand formation where the grains were deposited by a current which was wide in comparison to the distance it traveled.

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