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[11] 3,580,334

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[54] **METHOD FOR PREVENTING DEFORMATION IN A WELL CASING**
7 Claims, 6 Drawing Figs.

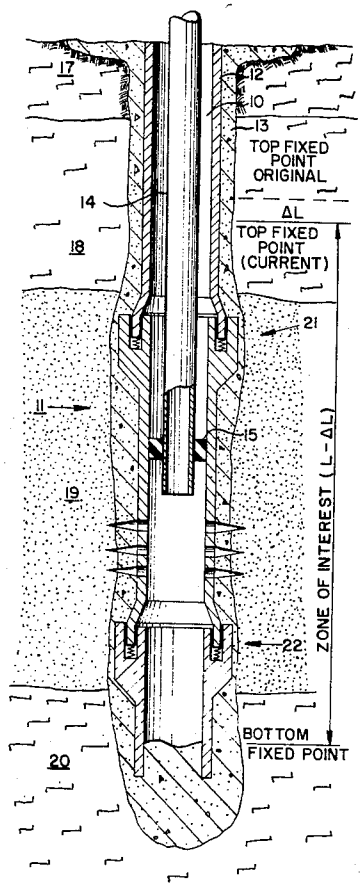
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[51] **Int. Cl.** ..... **E21b 17/08;** , E21b 49/02, G01n 3/10
[50] **Field of Search** 166/250, 315, 242; 73/94, 151

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ABSTRACT: A method for preventing deformation of the casing of a well bore hole extending into a reservoir interval within a subterranean hydrocarbon-bearing earth formation wherein such deformation is caused by the compaction of the reservoir interval in which unconsolidated sand therein compacts when the fluid pressure of the interval is reduced. A core sample is extracted from the interval containing a substantially undisturbed portion of unconsolidated sand typical of that contained in the interval. The extent of vertical compressibility of the cored sample is measured relative to its orientation within the reservoir interval and its lateral confinement in the configuration it exhibits under an isostatic compressive force equaling that existing within the interval. The vertical extent of the sand contained within the interval and the extent of reservoir interval compression that would result from a vertical compression of the sand contained in the reservoir interval by an amount corresponding to the measured compressibility of the core sample are determined. The portion of the well casing to be disposed against the interval is equipped with slip couplings adapted to provide an extent of slip having a selected degree of correspondence with the predetermined extent of reservoir interval compressibility.



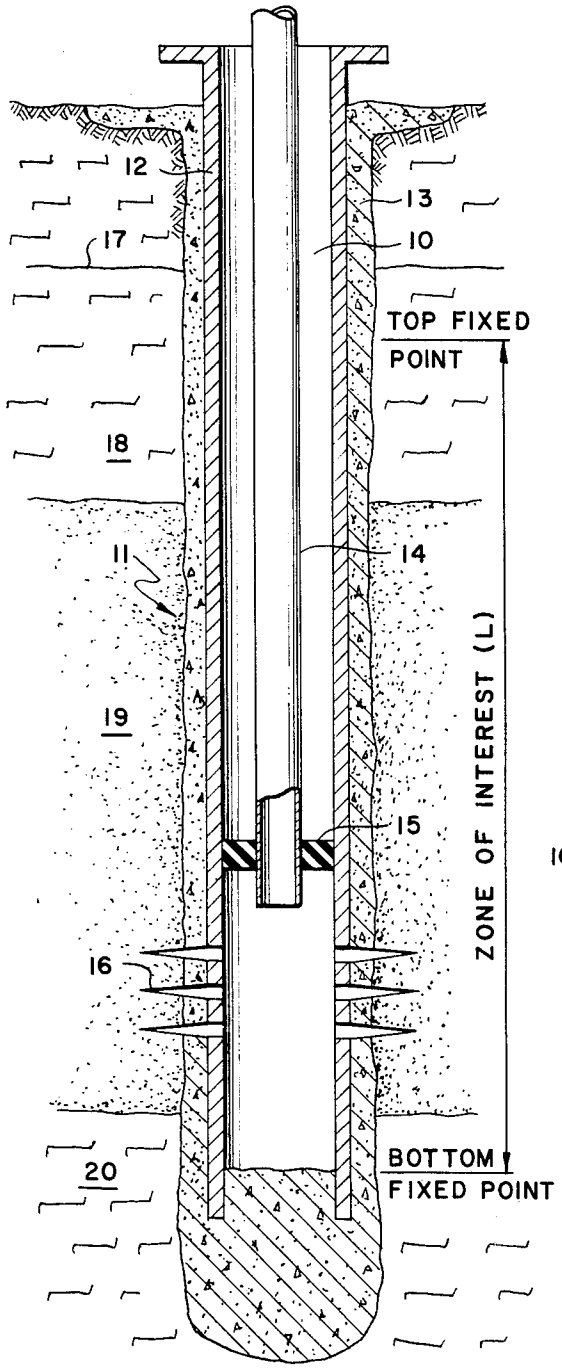


FIG. 1

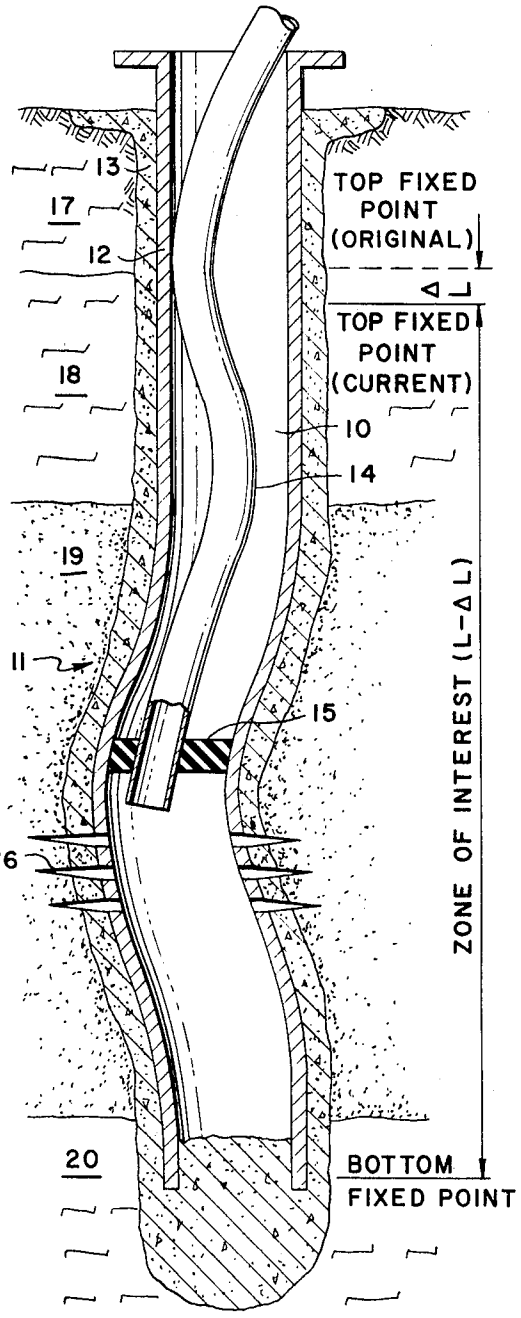


FIG. 2

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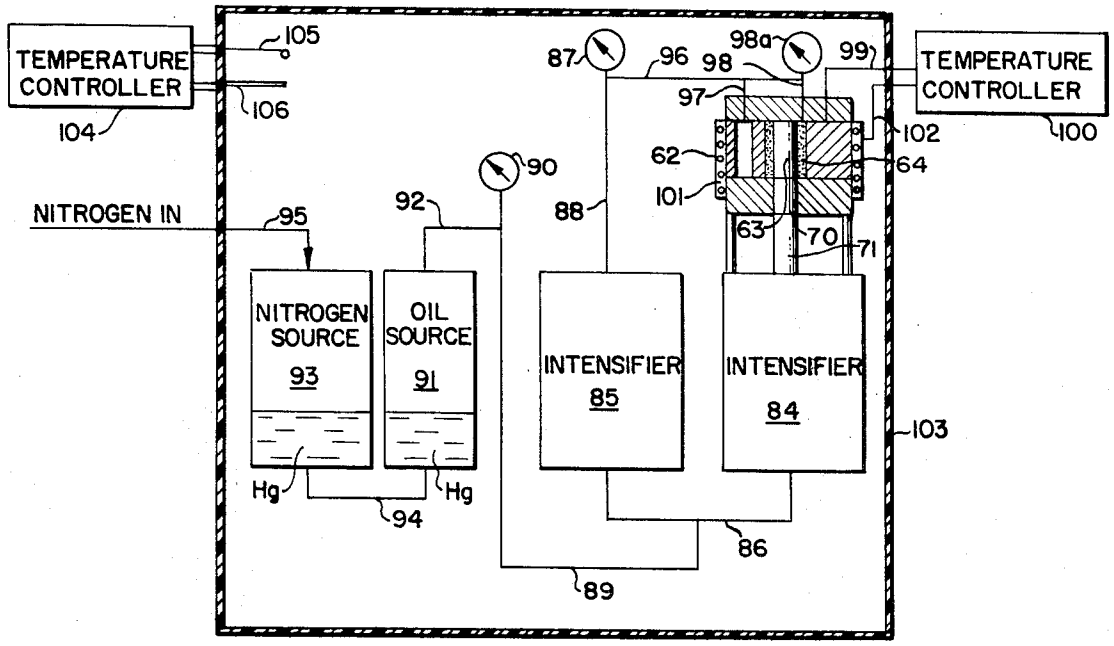


FIG. 3

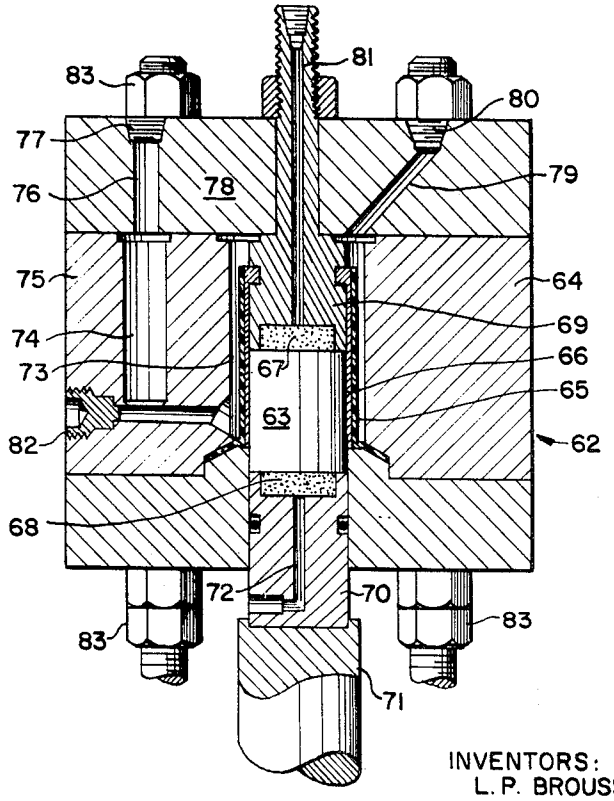


FIG. 4

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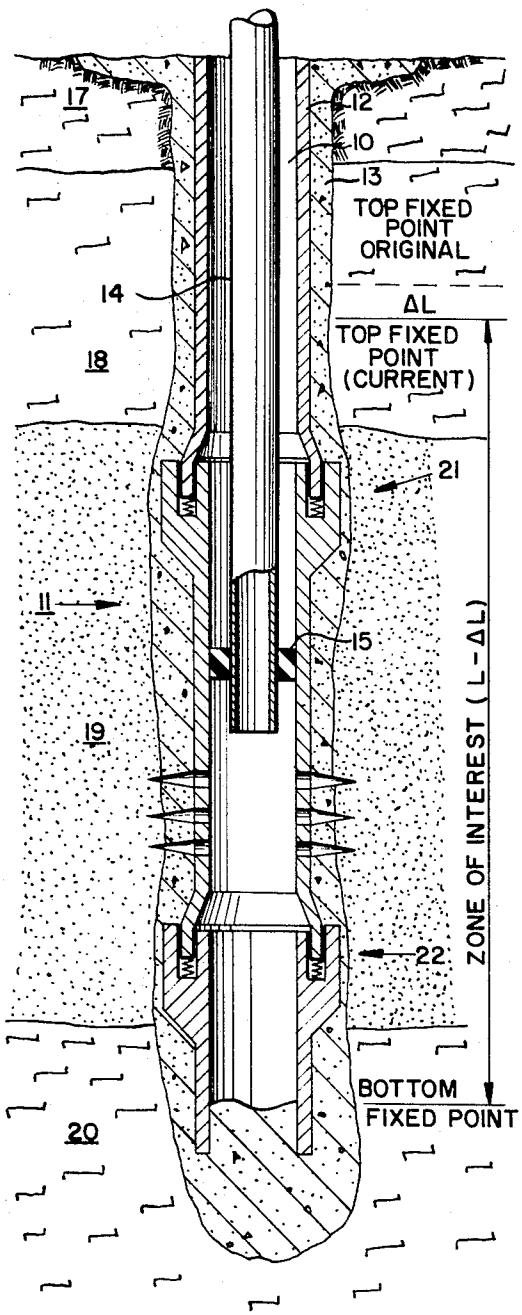


FIG. 5

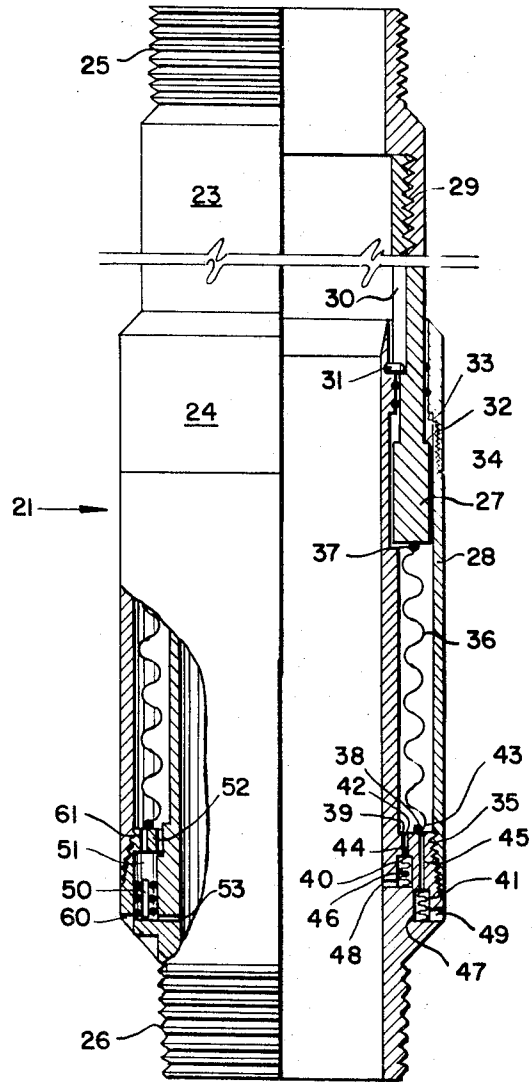


FIG. 6

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METHOD FOR PREVENTING DEFORMATION IN A WELL CASING

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to well completion; and, more particularly, to a method for preventing buckling of a well casing adjacent to areas susceptible to compaction.

2. Description of the Prior Art

In Louisiana oil fields, certain oil-bearing formations have shown a tendency to compact after substantial amounts of oil have been removed therefrom. This causes severe problems in regard to the casing and tubing in the wells extending into these formations. In bending, the cement surrounding the well casing cracks and sand is produced. Such bending is detrimental to the working of such wells since it is impossible to run tools and devices down the bent well to carry out remedial operations.

The determination of how much deformation will take place in well casings extending into such formations is important. Providing for too little slip would lead to expensive casing failures and providing for too much slip would lead to excessive installation expense.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a method for preventing buckling of well traversing areas susceptible to compaction.

It is a further object of this invention to provide a method for determining the extent of deformation that is to take place in a well casing extending into a reservoir interval susceptible to compaction when its fluid pressure is reduced.

These and other objects are preferably accomplished by extracting a core sample from the interval containing a substantially undisturbed portion of unconsolidated sand typical of that contained in the interval. The extent of vertical compressibility of the cored sample is measured relative to its orientation within the reservoir interval and its lateral confinement in the configuration it exhibits under an isostatic compressive force equaling that existing within the interval. The vertical extent of the sand contained within the interval and the extent of reservoir interval compression that would result from a vertical compression of the sand contained in the reservoir interval by an amount corresponding to the measure compressibility of the core sample are determined. The portion of the well casing to be disposed against the interval is equipped with slip coupling means adapted to provide an extent of slip having a selected degree of correspondence with the predetermined extent of reservoir interval compressibility. The method described hereinabove is applicable to any reservoir interval that contains unconsolidated said that becomes compacted when the reservoir fluid pressure is reduced. Preferably, such a method is used in conjunction with determinations of the amount of shale contained in a reservoir interval and the amount by which it will be compressed during a selected production time interval.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a vertical sectional, partly schematic, view of a well in accordance with the teachings of the present invention;

FIG. **2** is a vertical sectional, partly schematic, view of the well of FIG. **1** subject to buckling;

FIG. **3** is a schematic illustration of a method of testing a sample in accordance with the teachings of our invention;

FIG. **4** is a detail of a portion of the illustration of FIG. **3**;

FIG. **5** is a vertical sectional, partly schematic, view of the well of FIG. **1** wherein the well casing is provided with slip coupling means in accordance with the teachings of the present invention; and

FIG. **6** is a vertical, partly sectional, view of the expansion joint means of FIG. **5**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawing, FIG. **1** shows a well borehole **10** extending into a subterranean oil-bearing formation **11**. Well borehole **10** includes a casing **12** cemented therein by cementing, as at **13**. Well borehole **10** may also include a tubing string **14** and a packer **15** as is well known in the art for working well borehole **10**. The well casing **12** may also be perforated with perforations **16** extending through casing **12**, cement **13** and into formation **11**, as is well known in the art.

Oil-bearing formation **11** may, for example, be divided into an upper sand-shale area **17**, a lower shale area **18**, a still lower sand area **19** and a bottom shale area **20**. For the purposes of this discussion, it will be assumed that oil-sand area **19** is highly susceptible to compaction. As illustrated in FIG. **1**, the zone of interest, i.e., the area in which any buckling of casing **12** is likely to occur due to sand compaction, comprises a top fixed point adjacent to shale area **18** and a bottom fixed point adjacent to the bottom of sand area **19**. Thus, axial load on casing **12**, prior to production, is substantially negligible.

Referring now to FIG. **2**, after production of well borehole **10** through perforations **16** and up tubing string **14** past packer **15**, a significant amount of compaction of the sand in the oil-sand area **19** has taken place. Thus, as can be seen in FIG. **2**, casing **13** cement **13** and tubing string **14** show a serious amount of buckling adjacent to sand area **19**. The axial load on casing **12** is high, in the order of, for example, 560,000 to 1,100,000 pounds. The top fixed point has shifted by an amount ΔL to a lower fixed point. Due to the axial loads on casing **12**, causing deformation takes place. Such deformation renders the working within well borehole **10** very difficult and expensive.

Such casing buckling may be prevented by cutting a section of the cemented casing **12** adjacent to the sand area **19** by means of pipe cutters or the like, well known in the art. The cut section of the casing **12** may be so cut as to destroy it for all practical purposes so that the cut pieces fall to the bottom of well borehole **10**. This results in shortening the pipe string or casing in the area of compaction, thus relieving the axial stress on casing **12**. After cutting, an internal sleeve may be installed between the horizontally cut sections of casing **12**, alternatively, the cutaway portion may be otherwise sealed such as by injection of epoxy resin or other suitable sealing means. Nevertheless, the above operation is expensive and alignment of the two casing sections may be difficult once the casing **12** is cut or destroyed. In addition, said consolidation of sand area **19** is limited and in some cases may be impossible once the casing **12** is destroyed.

Preferably, however, in accordance with the teachings of the present invention, formation **11** is logged by techniques well known in the art so as to determine the upper and lower limits of sand area **19**, i.e., the potentially productive zone. When a rock sample of a subterranean earth formation is brought to the earth's surface, it undergoes isostatic expansion. Prior to the measurement of compressibilities, which are representative of reservoir conditions, the original in situ stress condition must be restored by isostatic compression. Subsequent measurement of reservoir compressibility requires lateral confinement and further compression in the vertical plane only.

For consolidated rock, this sequence of events may simply be enacted by surrounding the sample with fluid, raising the fluid pressure to the desired level and subsequently applying a vertical load by means of a piston arrangement. With unconsolidated material, however, this latter stage quickly results in shear failure as the fluid cannot keep the material in place.

However, if the sample is compressed, during the isostatic loading stage, by a vertical load transmitted by a piston and an equal side load transmitted by a "special fluid" through a thin sleeve of a material adapted to withstand high temperatures, such as Viton, a synthetic rubber copolymer manufactured by E. I. DuPont de Nemours and Co., and onto the sample is

compressed to the desired in situ conditions, the fluid can be made to harden after which the piston may be used to further load the sample in the vertical direction. The "special fluid" may be any material for which volume change during hardening and compressibility after hardening are negligible. For example, an Epon-saturated silicon carbide may be used, Epon being an epoxy resin manufactured by Shell Oil Company.

Referring once again to FIG. 2, when fluids are withdrawn from the zone of interest, L, a reduction takes place in the pore fluid pressure accompanied by an increase in effective stress and compaction of the reservoir rock. The compressibility of an unconsolidated sand is highly dependent on sand grain arrangement. Such arrangement must thus be closely preserved. To minimize disturbances due to handling, core sections which are extracted means well known in the art, are frozen as with dry ice, immediately upon surfacing and before removal from the core extracting means, as, for example, from a core barrel. Sample core specimens for compressibility determinations are then drilled in liquid nitrogen from the frozen core material and placed in dry ice. Before measuring their compressibilities, the grains in these samples are restored to their in situ proximity by restoring the in situ stresses.

A preferred method is to take the frozen sample specimens, thaw them under an isostatic stress of a few hundred p.s.i. and subsequently load them isostatically while measuring the resulting changes in pore volume. The plot of pore volume versus isostatic stress was found to exhibit a distinct "knee" at an isostatic stress corresponding to the vertical effective stress which had been calculated from:

$$\sigma_v = s - p \qquad (1)$$

where:

σ_v = vertical effective stress

S = vertical stress

p = pore fluid pressure as will be discussed further hereinbelow. Thus, the samples "remember" their in situ effective stress indicating no serious grain disorientation during coring, freezing, drilling, and isostatic loading.

Referring now to FIG. 3, a schematic diagram is shown of preferred apparatus for allowing isostatic compression of unconsolidated sand samples to be followed by axial compression under lateral confinement. A compression cell **62** is shown containing a core sample **63** therein. A sleeve **64** is shown surrounding core **63**. As seen in detail in FIG. **4**, sleeve **64** preferably includes an inner metallic sleeve **65**, such as copper foil, and an inner sleeve **66**, of a material such as Viton. Porous frits **67** and **68** are disposed within cell **62** at the top and bottom of core **63**, respectively. A fixed piston **69** is disposed within cell **62** above upper frit **67**. A moving piston **70** is disposed within cell **62** below lower frit **68**. A loading linkage **71** is connected to piston **70** for coupling cell **42** to the apparatus of FIG. **3**. A passageway **72** extends through piston **70** for permitting air to escape therefrom. The space **73** directly outside the outer sleeve **66** preferably contains silicon carbide particles therein to decrease the compressibility of the cured material of sleeve **66** as will be discussed further hereinbelow. A reservoir **74**, filled with the "special fluid," such as Epon-saturated silicon carbide as discussed hereinabove, is disposed within the outer wall **75** of cell **62**. A suitable passageway **76**, normally closed by a plug **77**, is disposed in the upper wall **68** of cell **62** for introducing the Epon material into reservoir **74**. In like manner, a suitable passageway **79** is disposed in upper wall **68** communicating with space **73** and normally closed by a plug **80**, for introducing the silicon carbide and Epon fluid into space **73**. A passageway **81** extends through piston **69** for introducing fluid into cell **62**. Finally, a cleaning plug **82** may be disposed in the wall **75** of cell **62** for access to the interior thereof. Suitable bolts **83** are connected to cell **62** for coupling the cell **62** to the apparatus of FIG. **3**.

Referring once again to FIG. **3**, the loading linkage **71** of cell **62** is coupled to a first intensifier **84** which is in turn coupled to a second intensifier **85** through line **86**. Intensifier **85** is coupled to a conventional pressure gauge **87** through line **88**. Line **86** is connected to a line **89** coupled to both a conventional pressure gauge **90** and an oil supply **91** through line **92**. Oil supply **91** is coupled to a nitrogen supply **93** through line **94**. Liquid mercury is preferably disposed at both the oil and nitrogen supplies. A nitrogen inlet line **95** is coupled to nitrogen supply **93** for introducing nitrogen thereto.

Line **96**, coupled to line **88**, connects gauge **87** and intensifier **85** to cell **62** through lines **97** and **98**. Line **98** is also coupled to a conventional pressure gauge **98***a*. A thermocouple line **99** coupled cell **62** to a temperature controller **100**. Temperature controller **100** is in turn coupled to a heater **101** surrounding cell **62** through line **102**. The entire apparatus is preferably housed in a suitable enclosure **103**, such as a Lucite box. A second temperature controller **104** is coupled to enclosure **103** and includes a thermocouple **105** and a heater **106** for controlling the temperature within enclosure **103**.

In operation, referring to FIG. **3**, the core sample **62** is compressed by a vertical load transmitted by piston **70** and an equal side load transmitted by the special Epon fluid within reservoir **74** (FIG. **4**) through the two thin sleeves **65** and **66** onto core sample **63**. The outer sleeve **66** serves as a fluid seal while inner sleeve **65** prevents the material of sleeve **66** from flowing into the sample **63**. As discussed hereinabove, the space directly outside of sleeve **66**, i.e., reservoir **74**, preferably contains silicon carbide particles with the Epon fluid occurring the void spaces between the particles. Preferably, this special fluid is a mixture of Epon 1031, Epon 828 and Nadic Methyl Anhydride, a curing agent, in a proportion by weight of 1:1:1.8. The viscosity of this mixture prior to curing is sufficiently low for the purposes set forth herein. Thus, the Epon remains in a liquid state at room temperature, and is in contact with Epon in a storage reservoir (not shown). The pressure applied to the Epon in the reservoir may be read on pressure gauge **87** (FIG. **3**) and the transmittance of pressure through the Epon may be checked by means of pressure gauge **98**.

When the sample **63** has been compressed to the desired isostatic stress level at approximately room temperature, the Epon may be hardened by raising the temperature through controller **10**, lines **99** and **102** and heater **101**. If, for example, the sands of interest originate from reservoirs with temperatures above 160° F., at 160° F., the Epon hardens in about two weeks; at higher temperatures, the hardening process takes less time. Thus, by raising the temperature of sample **63** to reservoir temperature, a condition may be induced which allows subsequent axial compression under lateral confinement, and, at the same time, achieves an in situ temperature condition. After the Epon sets up, the sample is then contained by solid vertical boundaries.

DETERMINATION OF SAND COMPRESSIBILITY

The compressibility of formation **19** may be determined from the foregoing data. As discussed hereinabove, assuming a formation reservoir of alternating sand and shale beds and neglecting gravitational effects within the reservoir, it may be assumed that the vertical stress, s, due to the weight of the overburden and the pore fluid pressure, p, are constant throughout. The part of the vertical stress due to the overburden weight that is not carried by the pore fluid pressure

$$\sigma_v = s - p \qquad (1)$$

is supported by the rock matrix. This vertical stress σ_v which is called the effective stress, is mainly responsible for the state of compaction of the rock.

Assuming that the pore fluid pressure in a sand or shale bed is decreased, with s constant, an increase in effective stress

$$\Delta\sigma_v = \Delta p \qquad (2)$$

and compaction of the bed is caused according to

$$\Delta h/h = c\Delta\sigma_v \qquad (3)$$

where h is bed thickness, and c represents the compressibility of the bed material. The compressibility is assumed constant in the effective stress range σ_v to $\sigma_v + \Delta\sigma_v$.

In equation (3), the conditions on the vertical boundaries must be specified. Assume no horizontal movement, i.e.,

lateral confinement at every point in the reservoir, and using elastic theory, it has been discovered that, for infinite depth of burial, the compaction at the center of a reservoir approaches the compaction under conditions of lateral confinement when the ratio of the radial extend of the reservoir to its thickness (r_e/h) approaches infinity. For r_e/h=50 (e.g., radial extend 2,000 ft., total reservoir thickness 40 ft.), the compaction at the center of the reservoir is still 99 percent of the compaction under lateral confinement. It appears that, for finite depths of burial, compaction at the center of the reservoir, though frequently considerably less, is never much greater than compaction under lateral confinement. Thus, the assumption with regard to equation (3) of lateral confinement, tends to yield upper bound values for reservoir compaction.

Assuming that we have an instantaneous fluid pressure decrease in the sand, the corresponding increase in effective stress is given by equation (2), and the resulting compaction by equation (3) which in this case reads

$$\Delta h/h=\Delta\sigma_v \qquad (4)$$

where Δh is the compaction of an individual sand bed or total compaction of the sand, depending on whether h represents the thickness of an individual bed or total sand thickness. For practical purposes, this compaction can be assumed to occur immediately.

In the foregoing an instantaneous and uniform pressure decrease in the sand (i.e., the pressure drop is the same throughout the entire reservoir) has been assumed. The assumption of uniformity appears reasonable when the sand permeability is high, so that pressure drawdown towards the well bore is small. Uniformity in the vertical direction implies pressure communication between the individual sand beds.

Thus, in the discussions hereinabove, the sand compressibility of the sample may be determined, by means of equation (4) above, using vertical displacements resulting from additional piston loading. The flexible sleeve **66** minimizes the reduction of the effective piston load due to friction between sample **63** and the walls of reservoir **74**.

An increase in vertical load results in an increase in radial stress exerted by the sample **23** of the cured Epon. The compressibility of the cured Epon has been found to be lower than that of unconsolidated sand. In addition, the presence of silicon carbide decreases the compressibility of the cured Epon when, due to some radial compression of the cured Epon itself, the silicon carbide particles establish closer contact allowing them to carry an increasing portion of the additional radial stress. However, with some slight horizontal movement still possible, measured sand compressibilities may be somewhat high, but the error can be expected to decrease with increasing vertical stress.

After the compressibility of the sample **63** has been determined, slip couplings are installed in casing **12** of FIGS. **1** and **2** adjacent, i.e., opposite, above or below, the interval **19**. Such slip couplings are placed and are of such a length so as to provide an extent of slip having a selected degree of correspondence with the predetermined extent of reservoir interval compressibility. Thus, as shown in FIG. **5**, a first slip coupling **21** is shown disposed adjacent the base of sand area **19**.

Although two such slip couplings are shown in FIG. **5**, obviously one or more couplings may be installed in the well casing **12** within the well borehole **10**. Also, as is well known in the art, short sections in a string of pipe or casing, known as "subs," may be installed in a well casing. Here, the "sub" is the slip coupling which, as will be discussed further hereinbelow with reference to FIG. **4**, is a telescoping section in the casing **12**. The "subs" (i.e., couplings **21** and **22**) are disposed adjacent to sand area **19** which is susceptible to compaction. If necessary to assure the proper location of couplings **21** and **22** in the well borehole **10** with respect to the productive zone or zones, such as sand area **19**, a collar locator log, as is well known in the art, may be taken prior to cementing the casing **12** in place. After the appropriate slip coupling or couplings are installed, casing **12** is cemented and the productive zones, such as sand area **19**, are perforated in a conventional manner, as at perforations **16** with appropriate sand consolidation techniques being applied, where applicable. Pattern perforating for use with more sophisticated sand consolidation placement tools may be effected in a conventional manner as the coupling or couplings do not reduce drift through the casing **12**. Thus, as seen in FIG. **5**, axial loads induced on casing **12** by compaction of sand area **19** between fixed casing points and by packer forces and/or other forces associated with conventional oil well production practices, are absorbed by slip couplings such as couplings **21** and **22**, thus precluding buckling of casing **12**. Although only one such sand area susceptible to compaction has been shown, obviously a plurality of such vertically spaced areas or strata may be traversed by well borehole **10** with appropriate slip couplings installed as required.

Referring now to FIG. **6**, a slip coupling in accordance with the teachings of this invention is illustrated. Obviously, all the slip couplings may be similar to slip coupling **21** illustrated in FIG. **6** and described hereinbelow.

Slip coupling **21** includes an inner member **23** slidably mounted in an outer member **24**. Thus, member **23** telescopes into member **24**. The upper end of inner member **23** includes a threaded portion **25** for connecting coupling **21** to a standard casing coupling (not shown). In like manner, the lower end of outer member **24** includes a like threaded portion **26** for connecting coupling **21** to a standard casing coupling (not shown). In this manner, the slip coupling **21** may be connected at any desired location in casing **12**.

Inner member **23** includes an outer circumferential skirt portion such as cylinder **27**, preferably of steel or similar material adapted to extend downwardly into a chamber **28**, also preferably of steel, extending circumferentially of outer member **24**. Cylinder **27** may be threaded onto the outer wall of inner member **23** as indicated by threads **29**; alternatively, cylinder **27** may be integral with inner member **23**, if desired. In either case, the outer surface of cylinder **27**, adapted to slide downwardly into chamber **28**, is coated to prevent cement bonding of the inner member **23** in chamber **28**. Suitable bonding materials may include a pliable rubber sleeve, rubber base material, etc.

A slot **30** extends longitudinally of cylinder **27**. A pin **31** fixed in position in chamber **28** is adapted to slidably engage slot **30** so as to prevent rotation and/or premature movement of inner member **23** with respect to outer member **24**. Obviously, a plurality of such pins and mating slots may extend circumferentially of chamber **28** and cylinder **27**, respectively.

The upper movement of cylinder **27** with respect to chamber **28** is limited by stop means **32** on cylinder **27**, adapted to engage mating stop means **33** in chamber **28**. A plurality of O-rings seal cylinder **27** and chamber **28** so as to exclude debris from the coupling **21**. If desired, chamber **28** may comprise an integral member, or, as shown in FIG. **6**, be formed of sections threaded to outer member **24** as at threads **34** and **35**, respectively, to form an integral chamber for cylinder **27**.

A bellows **36** is disposed in chamber **28**, fixed at one end **37** by brazing or other means well known in the art on cylinder **27** and the other end **38** to an abutment wall **39** disposed at the lower end or bottom of chamber **28**. Bellows **36** provides a pressure seal between inner member **23** and outer member **24**. Bellows **36** is preferably of a thin-walled multi-ply material resistant to corrosion, such as monel metal. The sealed bellows chamber, that is, the portion of chamber **28** between cylinder **27** and abutment wall **39**, is preferably filled with a noncompressible fluid, such as oil, to prevent well bore fluids such as mud or cement from obstructing bellows movement and to lubricate the cylinder and chamber walls.

A pair of valve chambers **40** and **41** are disposed below abutment wall **39**. Ports **42** and **43**, respectively, lead from the bellow chamber to the respective chambers **40** and **41**. Spring-loaded check valves disposed in chambers **40** and **41**, respectively, with springs **46** and **47**, respectively, fixed at one end to

their respective valve and the other end to the bottom wall of their respective chambers. Relief ports **48** and **49** are formed in chambers **40** and **41**, respectively, for allowing displacement of the noncompressible chamber fluid when movement of casing **23** occurs due to axial loading as discussed hereinabove.

Conventional piston-type equalizers, such as equalizer **50**, to provide for the internal pressure within the bellows chamber are preferably disposed in an equalizer chamber **51** below abutment wall **39**. An outlet port **52** connects chambers **51** with the inner bellows chamber and an inlet port **53** is disposed at the lower end of the chamber **51**. A similar arrangement is utilized to provide for the external pressure within the bellows chamber. In this equalizer chamber (identical to **51** except for ports) an outlet port **61** connects the equalizer chamber with the outer bellows chamber and an inlet port **60** is disposed at the lower end of the equalizer chamber. The purpose of the pressure equalizer is to equalize the pressure on either side of the bellows with respective pressures outside and inside the casing **24** without allowing external fluid, such as cement, to enter the sealed bellow chamber.

Thus, in operation, as illustrated in FIG. **5** and discussed hereinabove, as axial load is placed on casing **12** as a result of compaction of the sand in sand area **19**, slip couplings **21** and **22**, previously installed in casing **12** by means of treads **25** and **26**, respectively, provide a mechanical means for relieving axial loads on casing **12**, thus providing a maximum chance for sand consolidation and a minimum chance for complicated and expensive workovers, especially offshore, associated with casing deformation due to buckling.

Thus, as the casing **12** is disposed to buckle due to axial stress, inner member **23** of slip coupling **21** telescopes downwardly into outer member **24** while maintaining a seal therebetween due to O-rings **34**. Pin or pins **31** slide in a slot or slots **31**, thereby preventing rotation and/or premature movement between members **23** and **24**. Bellows **36** provides a high pressure seal, thereby permitting installation of like couplings opposite all potentially productive zones in formation **11** along with a minimum chance of casing leakage. Such a leakproof connection in a producing zone is important so as to prevent excessive gas production from the top of the producing zone and water production from the base of the producing zone. Check valves **44** and **45**, along with equalizer **50**, provide an appropriate integral relief system allowing displacement of the noncompressible chamber fluid when casing movement occurs.

In summary, the slip couplings of the present invention, properly installed in well casing and of a length in accordance with the determination of the compressibility of the formation as discussed hereinabove, provide casing relief with minimum resistance adjacent to formations susceptible to compaction. The external coating of the upper cylinder **27** prevents cement adhesion and the oil-filled/sealed bellows chamber excludes cement and other foreign material. The low resistance to movement offered by the bellows **36**, preferably multi-ply, and the oil-lubricated cylinder and chamber walls insures minimum resistance to movement with maximum relief of axial casing loads.

In completing a field scale pattern of wells into the same reservoir interval, the method of our invention may be used on each well, with measurement information obtained from cores or logs of one well containing a typical portion of the sand being used to determine the extent of travel for the slip couplings to be used in other wells.

We claim:

1. A method for preventing deformation of the casing of a well borehole extending into a reservoir interval within a subterranean hydrocarbon bearing earth formation, the deformation being caused by the compaction of the reservoir interval in which unconsolidated sand therein compacts when the fluid pressure of the reservoir interval is reduced, said method comprising the steps of:

extracting a core sample from said interval containing a substantially undisturbed portion of unconsolidated sand typical of that contained in the reservoir interval;

measuring the extent of the vertical compressibility of the cored sand sample relative to its orientation within the reservoir interval and its lateral confinement in the configuration it exhibits under an isostatic compressive force equaling that existing within the reservoir interval;

determining the vertical extent of said sand that is contained within the reservoir interval;

determining the extent of reservoir interval compression that would result from a vertical compression of the sand contained in the reservoir interval by an amount corresponding to the measured compressibility of the core sample; and

equipping the portion of said well casing to be disposed adjacent said reservoir interval with slip coupling means adapted to provide an extent of slip having a selected degree of correspondence with the predetermined extent of reservoir interval compressibility.

2. The method of claim **1** including the step of fixing said casing firmly in position in said well borehole after equipping said well with said slip coupling means.

3. The method of claim **1** wherein the step of providing said well casing with slip coupling means including providing said casing with at least one slip coupling means disposed adjacent to substantially the top of the interval susceptible to compaction and at least one slip coupling means disposed adjacent to substantially the bottom of the interval susceptible to buckling.

4. The method of claim **1** wherein the step of measuring the extent of vertical compressibility of the sample comprises the step of placing both a vertical load and a side load equal in pressure on said sample, said vertical load being carried out by a piston and said side load being carried out by a fluid of a hardenable material adapted to withstand high temperatures.

5. The method of claim **4** wherein the step of placing a side load using a fluid includes the step of applying epoxy resin-saturated silicon carbide to said sample.

6. The method of claim **1** wherein the step of measuring the extent of vertical compressibility of the sample comprises the steps of:

placing both a vertical load and a side load equal in pressure on said sample;

increasing the pressure on said sample; and

measuring the pressure at each increment of pressure on said sample.

7. The method of claim **6** including the step of determining the compressibility of said sample from the following equation

$\Delta h/h = c\Delta\sigma_v$

where Δh is the compaction of the core sample;

h is the thickness of the core sample;

c is the compressibility of the core sample; and

$\Delta\sigma_v$ is the increase in effective stress of the core sample.