Baker Hughes INTEQ

Directional Surveying

Drilling & Evaluation Technologies

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General

The advent of Baker Hughes INTEQ has produced numerous needs for varying levels of education, skill building, personnel development and training across the

workforce.

It is well recognized that raising the **education** and **training** of the workforce are two different areas that need to be addressed in parallel. The cross-training issues (skill transfer) relate more specifically to the field per-sonnel and is a longer term project. Available technical programs can be utilized to accomplish this cross-training.

This instrument that can be used across the organization to raise the competency and understanding to a common level.

- It will assist sales, support and management personnel that will hear and have a reason to
- discuss such topics on a daily basis.
- It is not for highly technically oriented personnel who need an in-depth knowledge of the subject.
- It is for use prior to and with the appropriate fundamentals course and to briefly familiarize the reader with concepts, tool types and related industry jargon and definitions.

Purpose

To provide a foundation for developing understanding and competency in the technology of directional surveying.

User Groups

The groups which this training document is designed for:

- Non-customer contact technical personnel and other professionals
- Customer-contact sales and service professionals

Objective

Key performance objectives are:

- Score of at least 90% on DSCC (Directional Surveying Competency Check)
- Complete a Fundamentals of Directional Surveying Training Program

Objectives

After reading this primer, the reader will be able to:

- Explain the role of the surveyor at the rigsite
- Explain what survey tools measure
- State four reasons for surveying wellbores
- Explain the differences between different types of survey tools
- Read a survey report
- Plot survey coordinates on a well plan
- Explain what is meant by Dogleg
- Explain what is meant by Toolface
- Explain what is meant by Highside
- Explain what is meant by Vertical Section
- Explain what is meant by Closure

Reasons for Taking Surveys

Surveys are Taken:

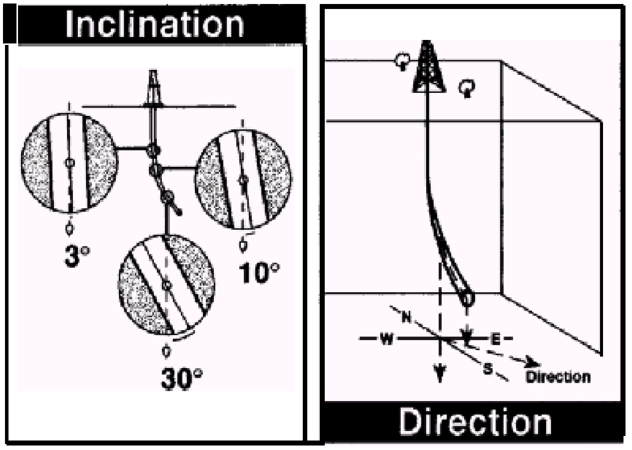
- to permit calculation of well coordinates at a series of measured depths, thereby accurately specifying the wellpath and the current location.
- to measure the inclination and direction at the bottom of the hole and hence determine where the well is heading.
- to determine the orientation of tool face of deflection tools or steerable systems.
- to locate dog legs and allow calculation of dogleg severity values.

Accurate Knowledge of the Course of a Borehole is Necessary:

- to hit geological target areas.
- to avoid collision with other wells, especially during platform drilling.
- to define the target of a relief well in the event of a blowout.
- to provide a better definition of geological and reservoir data to allow for optimization of production.
- to fulfill the requirements of local legislation.

What do Survey Instruments Measure?

Most survey tools measure the inclination and direction of the borehole at a particular depth.



A wellbore "Direction" measurement can be expressed in several formats. The two most commonly used in directional drilling and surveying are:

1. Quadrant
2. Azimuth

For example, the Quadrant method states direction in the following manner,

N 45 W, or S 38 E or N 63 W etc.

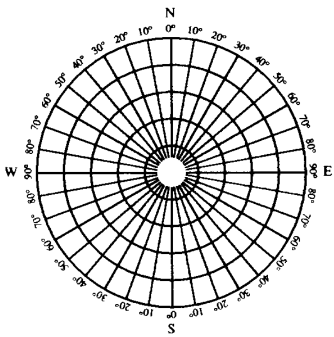
This is the same manner in which we would read a standard magnetic compass.

And the Azimuth method states the direction in the following manner,

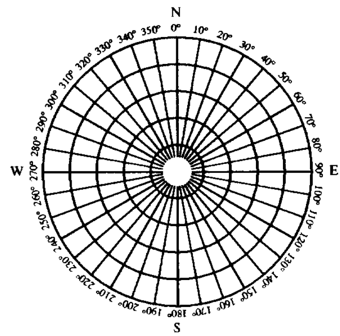
45, or 142, or 197 etc.

This takes the direction and expresses it as if it is converted to a 360 degree circle, measured in a clockwise angle from the North reference.

Quadrature



Azimuth



Azimuth is clearer and more easily handled in calculations and is therefore the method recommended by INTEQ, but quadrant is made available for specific customer requirements.

Definitions

- The inclination of a borehole at a point is the angle between the borehole axis and the vertical.
- The azimuth of a borehole at a point is the direction of the borehole on the horizontal plane, measured as a clockwise angle (O”-360”) from the North reference. These two components along with depth are used to calculate borehole coordinates.

The exceptions to the above are Inertial Navigation Systems. This type of survey tool measures components of acceleration along three axis when the tool is moving. These measured accelerations are integrated twice with respect to time to give first velocities and then displacements. These displacements are the borehole coordinates.

Role of the Surveyor at the Rigsite

Baker Hughes INTEQ directional surveyors are among the industries best equipped and trained. Their thorough pre-planning and knowledge of the range of survey technologies is a major contributor to the successful completion of any direc-tional survey job.

The role or function of the directional surveyor can be categorized into some broad areas:

- They ensure that the appropriate magnetic or gyroscopic instrumentation is delivered to the wellsite. Thorough compliance with calibration and quality control checks is also confirmed.
- At the rigsite, the surveyor is responsible for running the instrumentation into the wellbore. The instrumenta-tion will acquire downhole information of borehole attitude and toolface position and either transmit the data to the surface or store it for retrieval on return to the surface. Earlier technologies record inclination and Azimuth (direction) of the wellbore at various depths, the measured depth (M.D.) being recorded at surface. The new inertial navigation technologies record changes in position.
- Using the survey data, the surveyor performs mathematical field calculations to determine the wellbore position and profile. He then generates a field report for the client's representative. On his return to the office the survey is certified, by another qualified surveyor. The final computer generated report is then delivered to the customer.
- The surveyor also assists the directional driller or other service representative, by providing him with tool recorded data to orient downhole tools such as: motors, whipstocks etc. These same measurements can also be used by the surveyor for core orientations.

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Exercises

1. Directional surveys are used to: (select all ***correcf answers)***

   a. Comply with legal requirements

   b. Select the best drilling assemblies to drill a horizontal well

   c. Assist in the evaluation of reservoir characteristics

   d. Determine the most popular type of tool being used for a certain drilling environment.

   e. Determine the exact surface location of the drilling rig

   f. Assist side tracking operations

   g. Verify that the directional drilling program is producing the desired well profile

   h. Obtain accurate well bore position

   i. Determine tool orientation

   j. Place the drilling rig within the proper lease lines

2. Accurate knowledge of well bore position is necessary to: ***(select all correct answers)***

   a. to hit geological target areas

   b. to avoid collision with other wells, especially during platform drilling

   c. to define the target of a relief well in the event of a blowout

   d. to provide a better definition of geological and reservoir data to allow for optimisation of production

   e. to fulfill the requirements of local legislation

3. Survey instruments measure:

   a. The horizontal direction of the well bore as an angle from vertical

   b. The angle of the well bore with reference to vertical and the horizontal direction with reference to North.

   c. Inclination with reference to North

   d. Components of acceleration along 2 axis when the tool is moving

4. Which of the below is & a function of the surveyor at the rig site?

   a. Generation of survey field reports for the client's representative

   b. Selection of the proper survey instruments for delivery to the rigsite

   c. Selection of proper survey instruments to locate lease lines

   d. Operate instrumentation to acquire bore hole attitude and/or tool face positionof a relief

Surveying Concepts and Terms

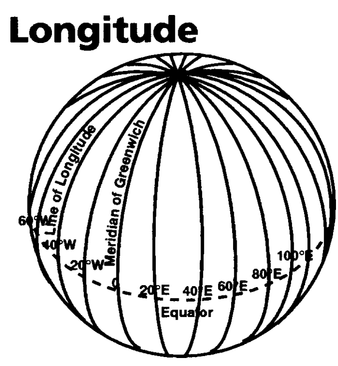
Mapping the Earth

Latitude and Longitude

Because the earth is a sphere, it has no begin-ning, no end and no edge. There are two reference points-the poles.

*L*ines of longitude are lines drawn through the poles north and south, and are called merid-ians. They measure distance east and west of the prime meridian which was established near Greenwich, England. This line is univer-sally accepted as the 0° line. Longitude measures 0° to 180° east and 0° to 180° west from the Greenwich Meridian. This is why we may refer to the “Eastern Hemisphere” and “Western Hemisphere.” On the other side of the earth, 180°, we have the international date line.

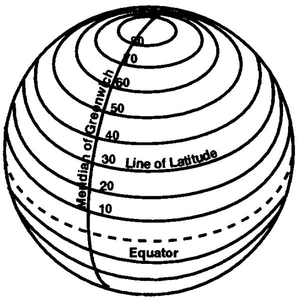
Lines of latitude are lines drawn around the earth parallel to the Equator. They are called parallels and measure the distance north and south of the equator. They are equally spaced in degrees, not miles. One degree of latitude equals about 70 miles. Most globes show only parallels and meridians at 15° intervals.Since the earth is flattened at the poles there is a small difference in the length of one degree.



Because a circle has 360° and a half circle 180°, from the equator to each of the poles is 90°. Latitude measures 0° to

90° north, from the equator to the North Pole; and 0° to 90° south, from the equator to the South Pole.

Latitude



Mapping Different Projections

In order to be useful, downhole data must be related to surface positions and/or elevations. It is therefore necessary to be able to identify precise surface positions.

Changing the globe into a map is not simple, however. Imagine cutting a globe in half and trying to flatten the two hemispheres. They would wrinkle, and their shapes would distort. In fact, every map has some distortion. A map can show either the correct size of countries or the correct shapes of small areas, but not both.

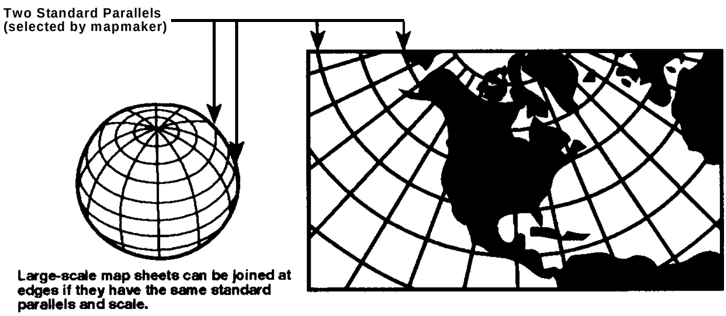
There are many ways to project a round globe onto flat paper. Imagine a glass globe with lines etched on it. Lines running parallel to the equator are called paral-lels of latitude; those connecting the Poles are called meridians of longitude.

There are different kinds of map projections:

Mercator, Conic, Polyconic, Lambert's Conformal and others. As an example, Mercator's projection is based on a cylinder with all the meridians and parallels as straight lines, and the scale is true only at the equator. It is valuable for navigators even today. Conic projec-tions are made as if a cone were placed over the globe. On Mercator's maps parallels are straight lines; with conic projections they appear as curved lines.

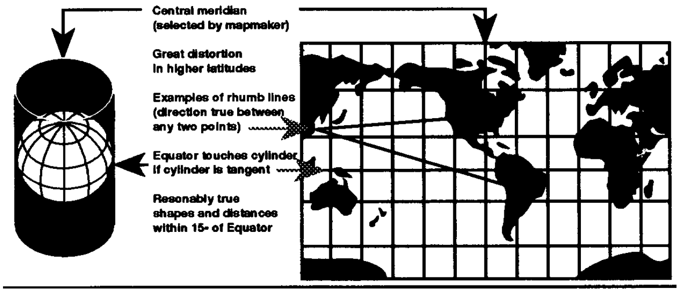
Lambert’s maps are often used for military purposes and are the basis of U.S. aeronautical charts. This kind of map is very accurate over small areas. Regardless of the method of constructing a particular map, certain features are the same, and these are the ones we deal with every day.

Conical Projection



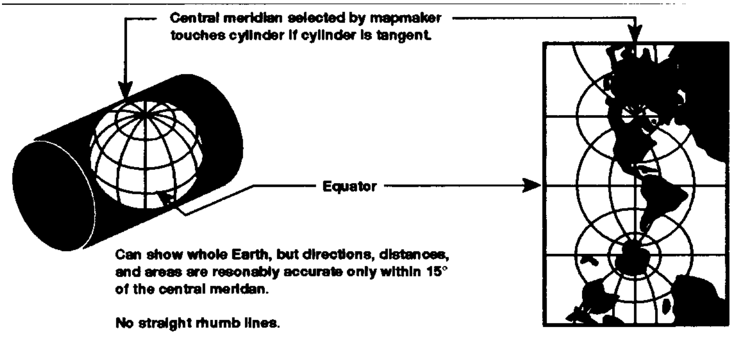
CONIC PROJECTION. A Lambert Conformal Conic map is made by projecting the globe onto a cone. The latitude lines where the cone and globe touch, shown darker than the others, are called the standard paral-lels. The word conformal” means that this map represents the shape of limited areas accurately. Conic maps are used to show parts of the globe that run primarily east and west in the middle latitudes. The United States would be one example.

Mercator Projection



Cylindrical (Mercator) Projection

The mercator projection map is very commonly used. It is best for navigating at sea because a line connecting any twopointsgives the best possible compass direction between them. For areas close to the Equator, this type of map accurately represents the shape, but it badly distorts the relative sizes of landmasses the nearer they are to the North and South Poles. Alaska, for example, looks about half the size of South America on such a map, while in fact. South America is more than 11 times bigger.

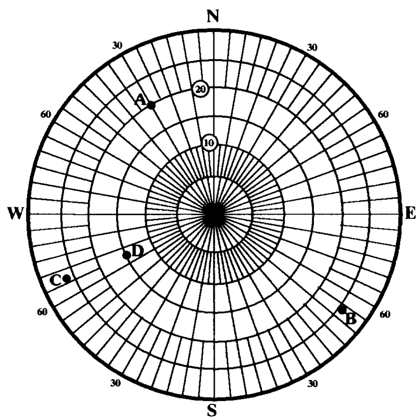


Transverse Mercator Projection. This projection is similar to the Mercator, but the orientation of the cylinder on which the globe is projected is different. Note that one meridian line on the globe touches the surface of the cylinder. Along that line and up to 15 degrees on either, side, distortion is not excessive, but at greater distances from that line, distortion becomes a serious problem. This projection is used by the United States Geological Survey for many quadrangle maps drawn at scales of 7.5 minutes to one degree on a side.

Geometry

Polar Coordinates

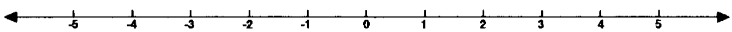
For some applications, it is often more convenient to use a POLAR Coordinate system. In the directional drilling industry, this system defines the location of a point as a distance away from the origin (or POLE), and a direction away from the origin. Although you may never see points plotted on a polar graph, you will hear polar coordinates being used to represent a location. When bottom hole closure is calculated, it is in the form of a polar coordinate. The following is a polar coordinate system that has been adapted for the directional industry.



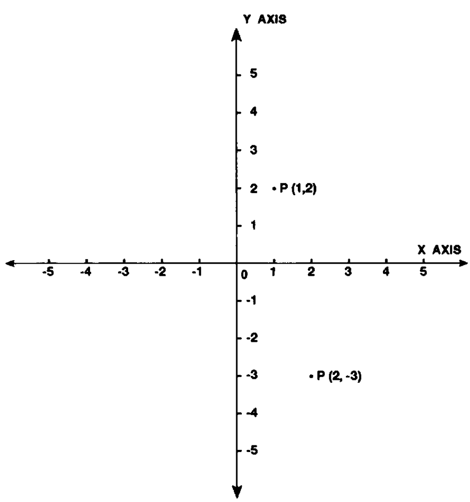
Four points have been plotted as examples. Point A is twenty feet from the pole in a direction of N30W. The polar coordi-nate for point A is stated as 20’ @ N30W. Point B is 27’ @ S54E, point C is 27’ @ S66W and point D is 15’ @ S66W.

Coordinate Geometry

Science and applied mathematics often use the idea of associating points with numbers. In working with scaled rulers, numbers are associated with points on the scale. Maps associate points on the map with pairs of numbers along the sides of the map. An association between points on a line and numerical values is a NUMBER LINE. The number associated with a point on a number line is the COORDINATE of the point. The point is the GRAPH of that number. The number line is an AXIS with the 0 point being its ORIGIN. Every real number can be associated with exactly one point on the number line.

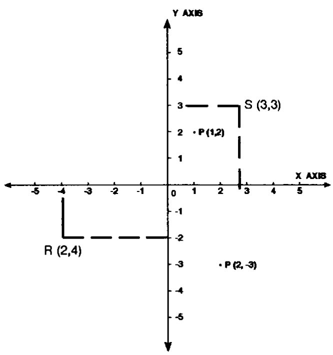


In 1637 Rene Descartes, a French mathematician and philosopher, developed a method of associating the points on a plane with pairs of numbers. By drawing two number lines or axes, perpendicular at the 0 point or origin, a RECTANGULAR COORDINATE system is formed. A point on this coordinate.



plane is associated with a pair of numbers called an ORDERED PAIR. The first number in the pair corresponds to the projection of the point on the horizontal or X AXIS. The second number corresponds to the projection of the point on the vertical or Y AXIS. Points P and Q are associated with the ordered pairs (1,2) and (2,-3) respectively. Such ordered pairs are called RECTANGULAR COORDINATES.

This rectangular coordinate system has been adapted to the directional drilling industry for several purposes. The easiest application to understand is for determining bottom hole location relative to the well head. In this instance, a rectangular coordinate system is set up using a North/South axis in place of the Y axis, and an East/West axis in place of the X axis. This eliminates the need for negative numbers, however, negative with pairs of numbers.



numbers may be used to indicate South and West. Ordered pairs are still used to define a point on the graph. The North or South coordinate is stated first, and then the East or West coordinate. Each coordinate must also have a direction as well. For instance, points R and S are S2, W4 and N3, E3 respec-tively. This is the way the bottom hole location is plotted on the horizontal view of a directional well proposal.

It is important to note that each point is represented by a pair of numbers. If the point is five units due north of the origin, its coordinates are N5, EO or N5, WO.

Borehole survey references

With the exception of the inertial navigation systems, all survey systems measure inclination and azimuth at particular measured depths (depths measured ‘along hole’). These mea-surements must be tied to fixed reference systems so that the borehole course may be calculated and recorded. The reference systems used are:

- Depth references
- Inclination references
- Azimuth references

Depth References

There are two kinds of depths:

- Measured depth or ‘Along Hole Depth’ is the distance measured along the actual course of the borehole from the surface reference point to the survey point. This depth is always measured in some way e.g. pipe tally or wireline depth counter.
- True Vertical Depth (TVD) is the vertical distance from the depth reference level to a point on the borehole course. This is normally a calculated value.

In most drilling operations the Rotary Table (RT) elevation is used as the working depth reference (BRT or RKB). This is also referred to as derrick floor elevation. For floating drilling rigs the rotary table elevation is not fixed and hence a mean rotary table elevation has to be used.

In order to compare individual wells within the same field, a common reference must be defined and always referred to. When drilling a relief well into a blow-out well, the difference in elevation between the wellheads has to be accurately known. Offshore, mean sea level is sometimes used. Variations in actual sea level from MSL can be read from tide tables or can be measured.

Inclination References

The inclination of a well-bore is the angle (in degrees) between the local vertical and the tangent to the well bore axis at a particular point. The convention is that 0° is vertical and 90° is horizontal. The vertical reference is the direction of the local gravity vector and would be indicated by, for example, a plumb bob.

Azimuth Reference Systems

For directional surveying there are three azimuth reference systems:

- Magnetic North
- True (Geographic) North
- Grid North

All ‘magnetic type’ tools initially give an azimuth (hole direction) reading referenced to Magnetic North. However, Magnetic North is constantly changing; therefore, the final calculated coordinates are always referenced to either True North or Grid North in order to obtain a stable reference.

True (Geographic) North

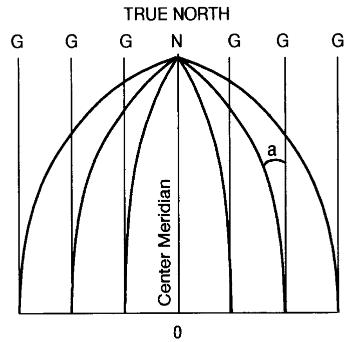
This is the direction of the geographic North Pole which lies on the axis of rotation of the Earth. The direction is shown on maps by the meridians of longitude.

Grid North

During drilling operations we are working on a curved surface, i.e. the surface of the Earth, but when we calculate horizontal plane coordinates we assume we are working on flat surface. Obviously it is not possible to exactly represent part of the surface of a sphere on a flat well plan. Corrections have to be applied to the measurements. The principal projection systems are described on the next page.

Universal Transverse Mercator

In the transverse mercator projection the surface of the spheroid chosen to represent the Earth is wrapped in a cylinder which touches the speroid along a chosen meridian. (A meridian is a circle running around the Earth passing through both geographic North and geographic South Poles.) The meridians of longitude converge towards the North Pole and therefore do no produce a rectangular grid system. The grid lines on a map form a



rectangular grid system, the Northerly direction of which is determined by one specified meridian of longitude. This direction is called Grid North. It is identical to True North only for the specified meridian.

The relationship between True North and Grid North is indicated by the angle ‘a’ in the figure. Convergence is the angle between grid north and true north for the location being considered.

Magnetic Declination

Magnetic declination is the angle between true north and magnetic north at any point on the earth. Since a compass reacts to the horizontal component of the earth's magnetic field, it is used to measure direction from magnetic north. Magnetic north is not a stationary point on the earth, and is not located in the same place as true north. At present, it is in northern Canada, close to Lougheed Island.

The geographic north pole is the point in the northern hemisphere at which the earth's spin axis cuts the surface of the earth. It is used as the north reference when direction is reported with respect to "true north".

Magnetic instruments that are used to determine bore hole direction use magnetic north as their north reference, but direction is never reported with respect to magnetic north. If direction is to be reported with respect to true north, a correction to our magnetic reading will be required.

This correction compensates for the difference in the direction between magnetic north and true north at the location where the measurement is being taken, and is called the "magnetic declination correction". Declination will change with both location and time. Time is important since magnetic north is slowly moving. To determine the direction of the magnetic declination correction, it is necessary to know if magnetic north lies east or west of true north from the location where the directional

measurement is being taken. As can be seen on the previous page diagram, there are places on the earth where the direction to true north and magnetic north is identical. Declination is reported as either east declination or west declination. The report will state the size of the angular correction along with the word east or west. Another way of stating declination is to report the angular measurement as either a positive or negative number. A positive number indicates an east declination while a negative number indicates a west declination.

East Declination:

East declinations occur when magnetic north lies to the east of true north with respect to the location under consideration. For North and South America this will be true for any location that is west of the zero declination line (e.g., Texas, Alaska, California, Mexico, etc.). An east declination correction is applied by changing (moving) the magnetic reading in a clockwise direction around the compass card. If direction is being reported using azimuth, the declination value is added to the magnetic reading. If direction is reported using quadrature, the declination value is added in the northeast and southwest quadrants (since the numbers get larger in a clockwise direction), and the value is subtracted from the magnetic reading in the southeast and northwest quadrants (since the numbers get smaller in a clockwise direction). For example:

The declination of a location in Prudoe Bay, Alaska in 1994 is 30°. (30° East)

> A magnetic survey is read as S42°E (138° azimuth).
>
> The declinated direction is S 12°E (168° azimuth).

Another magnetic survey at the same location is read as S21°W (201° azimuth).

This declinated direction is S5 1°W (231° azimuth).

West Declination:

West declinations occur when magnetic north lies to the west of true north with respect to the location under consideration. For North and South America this will be true for any location that is east of the zero declination line (e.g., New York, Georgia, Venezuela, Brazil, etc.). A west declination correction is applied by changing (moving) the magnetic reading in a counter-clockwise direction around a compass card. If direction is reported using azimuth, the declination value is subtracted from the magnetic reading.’ If direction is reported using quadrature, the declination value is subtracted in the northeast and southwest quadrants (since the numbers get smaller in a counter-clockwise direction), and the value is added to the magnetic reading in the southeast and northwest quadrants (since the numbers get larger in a counter-clockwise direction). For example:

The declination for a location in the North Sea, in 1994 is -5.0°. (5° West)

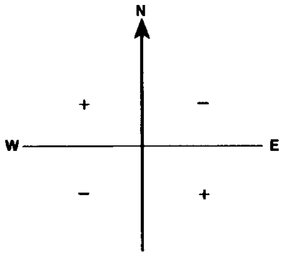
A magnetic survey is read as S42°E (138° azimuth).

The declinated direction is S47°E (133° azimuth).

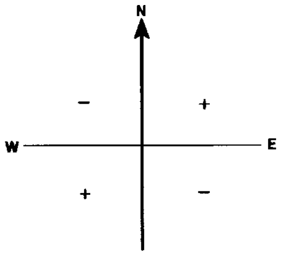
Another magnetic survey at the same location is read as S21°W (201° azimuth).

This declinated direction is S16°W (196° azimuth).

Dependent upon the quadrant, the east and west declination can be either positive or negative when borehole directionis expressed in quadrant bearings.



West Magnetic Declination Correction



East Magnetic Declination Correction

Grid Convergence

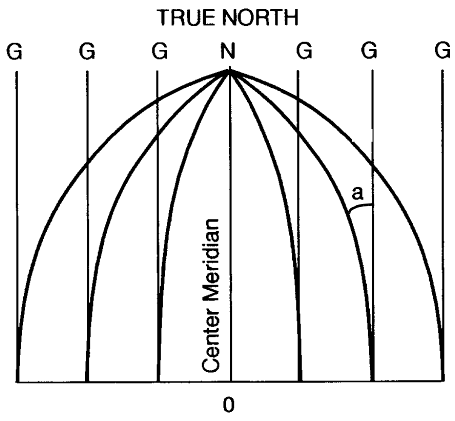
Whenever maps are created, coordinates must be converted from a sphere (the Earth) to a flat surface. Most maps in use today utilize the transverse mercator projection. This projection shows the meridians of longitude as vertical lines on a rectangular map, and the Northerly direction is Grid North. In reality, only the center meridian corresponds to true north, all other meridians converge to the center meridian at True North. The angle between the rectangular grid and the actual meridian as it bends toward the center meridian is known as Grid Convergence, which is defined as follows: Convergence is the angle between grid north and true north for the location being considered.

Example:

True North Reading = N52E

Grid Convergence = 1 .5° E

Grid Azimuth = 52° - 1.5° = N50.5E

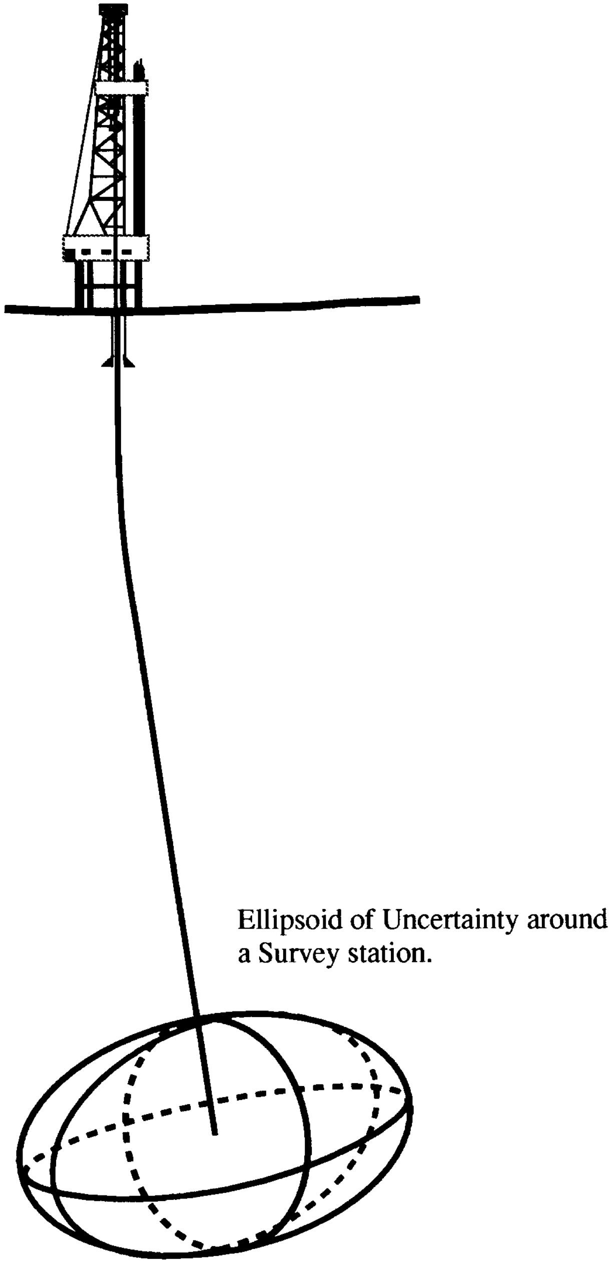


Ellipsoids of Uncertainty

Any measurement has some uncertainty associated with it. If we measure the length of a room our measurement will not be exact, no matter how many decimal places we report. Several factors will affect the quality of our measurement. How well calibrated is the tape measure, how accurately can we read it, are we holding it under the correct tension, etc. It is possible to investigate these errors and come up with a likely uncertainty for any measurement using this method, e.g. O.OSft/lft.

A directional survey is a measurement in three dimensions and is therefore subject to measurement uncertainties in all three dimensions, resulting in a volume of uncertainty. For any given point along the survey this volume will take the form of an ellipsoid. Since, in the past most people have been interested in the uncertainty in the horizontal plane, they often use the term “ellipse of uncertainty” instead.

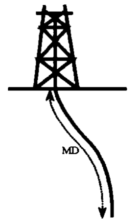
The different survey tool types have different systematic errors which would calculate out to produce varying ellipsoid sizes. This is one reason why at the outset of the well, it is important to chose the correct survey program and appropriate survey tools to produce the desired accuracies to enable the well bore to intersect the target.


Ellipsoid of Uncertainty around
a Survey station.

Surveying Terms and Definitions

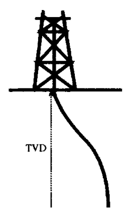
Measured Depth (MD)

The distance measured along the actual course of the bore hole from the surface reference point to the survey point.



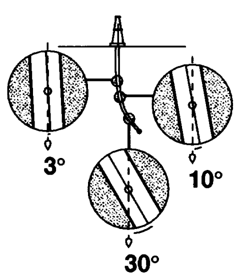
True Vertical Depth (TVD)

The vertical depth is the vertical distance from the depth reference level to a corresponding point on the borehole course.



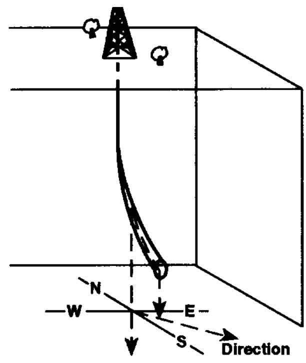
Inclination (drift)

The angle (in degrees) between the local vertical (local gravity vector as indicated by a plumb bob) and the tangent to the well bore axis at a particular point. By oilfield convention, 0° is vertical and 90° is horizontal.



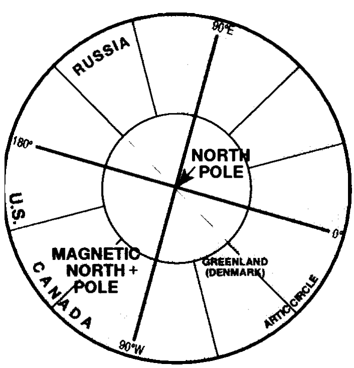
Azimuth (hole direction)

The azimuth of a borehole at a point is the direction of the borehole on the horizontal plane, measured as a clockwise angle (0°-360°) from the North reference. This reference can be the True, Magnetic or Grid North, and is measured clockwise by convention. All magnetic tools initially give Azimuth reading referenced to Magnetic North. However, the final calculated coordinates are referenced to either True North or Grid North.



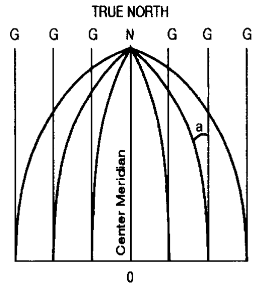
True North

The direction of the geographic north pole which lies on the axis of rotation of the earth.



Grid North

The directional north on a map. Grid North is identical to True North only at specified meridians. All other points must be corrected for convergence (the angle between Grid North and True North at any given location).



Magnetic North

The direction of the horizontal component of the Earth's magnetic field at a selected point on the Earth's surface.

High Side

High side is the side of the wellbore directly opposite the pull of gravity. The point representing high side is an important reference for toolface orientation. It is important to note that with 0° of inclination, there is no high side. In this condition, the sides of the wellbore or survey tool are parallel with the gravity vector and there is no point of intersection from which a high side can be defined. Another important concept is that without inclination (0°), the wellbore has no horizontal direction. That is, the axis of the wellbore would be represented as a point and not a line on the horizontal plane. Without inclination, there is no high side and without a high side, there is no direction.

Tool (downhole)

Anything which is made up as part of the drilling assembly or run into the borehole. Mud motors, MWD collars, survey tools, etc., are all examples of downhole tools.

Toolface

This term is used in connection with deflection tools or steerable motors, and can be expressed in two ways.

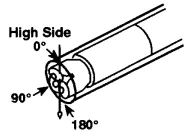
Physical - The place on a deflection tool, usually marked with a scribe line, that is positioned to a particular orientation while drilling, to determine the future course of the wellbore.

Conceptual - Rigsite use of the term “toolface” is often used as a shortening of the phrase “toolface orientation”. For example “toolface” can be the orientation (expressed as a direction either from North OR topside of the hole) of the navigation sub of a steerable motor.

Toolface Orientation

The angular measurement of the toolface of a deflection tool with respect to either up (highside) or north.

Highside Toolface Orientation



Highside Toolface

Highside toolface (sometimes referred to as gravity toolface) indicates whether the toolface of a deflection tool is facing up (0°), down (180°), or at any angle from 0° to 180° to the left or right of highside (0°). This type of orientation is used when the hole has an inclination of 3° - 5° or greater.

Magnetic Toolface

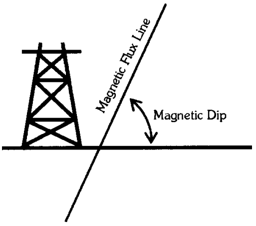
Magnetic toolface indicates the orientation of the toolface of a deflection tool as an angular measurement from north (direction). This type of toolface is reported when the borehole has less than 3° - 5° of inclination.

Magnetic Interference

Changes in the Earth's magnetic field in the vicinity of the survey tool caused by the presence of casing or other tubulars in the well bore or adjacent wells, or by magnetic properties within the formation itself.

Magnetic Declination Correction

The angular correction in degrees used to convert a magnetic bearing to a True North bearing.



Magnetic Dip

The angle of intersection, as measured down from horizontal, of the Earth's magnetic flux lines and the horizontal plane (representing the Earth's surface).

Dog Leg

The total curvature of the wellbore (the combination of changes in inclination and direction), between two survey stations. Dog leg is measured in degrees.

D.L. = co^{-1} [$\sin I_1 \sin I_2$, $\cos(A_2\text{-}A_1)$ + $coI_1 \cos I_2$

where: I_1 and I_2 are two successive inclination measurements. A_1 and A_2 are two successive direction measurements.

I_1 = Previous Inclination

I_2 = Current Inclination

A_1 = Previous Azimuth

A_2 = *Current Azimuth*

Dog Leg Severity

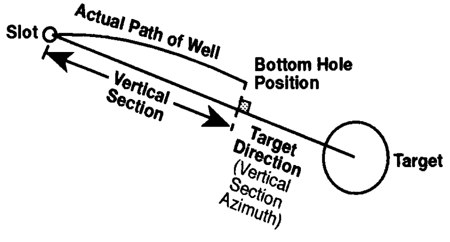
The amount of dog leg normalized to a standard interval (usually 100 ft. or 30 meters). Dog leg severity is reported as degrees per 100 ft. or degrees per 30 meters. In normal conversations this is often referred to as “dog leg” which may be confusing to the beginning student. It is desirable to keep dogleg severities as low as possible in conventional drilling (less than 4° - 5°/100ft). High dog leg severities may lead to hole problems such as key seats, stuck pipe, or drill pipe and casing wear.

$$\text{D.L.S.} = \frac{\text{D.L.} \times 100}{\text{C.L.}}$$

where:
D.L. is the dog leg calculated between two survey stations
C.L. is the measured depth between the two survey stations

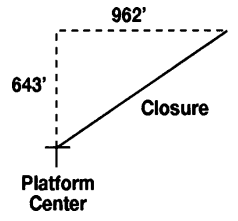
Vertical Section

On a well plan, the vertical profile usually corresponds t o a plan in a plan defined by the direction straight from the slot to the target. This direction is referred to variously as “vertical section azimuth” or “proposed bottom hole location (PBHL)” or “plan of proposal” or “target direction”. In this case, the total horizontal deviation of the well projected onto this plane is called vertical section. Consider the horizontal plan of a well, in the following diagram.



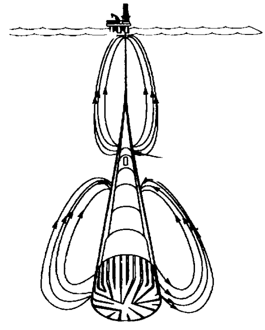
Closure

This is defined as a straight line drawn from the rig reference point to any rectangular coordinate in the horizontal plane (usually used to define the bottom of the well bore). The length and direction of the line will be calculated. For example, if the surveyed position is 643'North, 962'East, the closure can be calculated using the Pythagrean theorem and trigonometry to be 1157.11' at N56.24°E.



Drill String Interference

A condition which occurs when extraneous magnetic forces cause a magnetic compass to read incorrectly. Such interference can be caused by the proximity to steel collars.



Fish

Any object accidentally left in the wellbore during drilling or workover operations and which must be recovered or bypassed before work can proceed.

Accelerometer

Accelerometers are used to measure the earth's local gravitational field. Each accelerometer consists of a magnetic mass (pendulum) suspended in an electromagnetic field. Gravity deflects the mass from its null position. Sufficient current is applied to the sensor to return the mass to the null position. This current is directly proportional to the gravitational force acting on the mass. The gravitational readings are used to calculate the hole inclination, toolface, and the vertical reference used to determine dip angle.

Magnetometer

Magnetometers are used to measure the earth's local magnetic field. Each magnetometer is a device consisting of two identical cores with a primary winding around each core but in opposite directions. A secondary winding twists around both cores and the primary winding. The primary current (excitation current) produces a magnetic field in each core. These fields are of equal intensity, but opposite orientation, and therefore cancel each other out such that no voltage is induced in the secondary winding. When the magnetometer is placed in an external magnetic field which is aligned with the sensitive axis of the magnetometer (core axis), an unbalance in the core saturation occurs and a voltage directly proportional to the external field is produced in the secondary winding. The measure of voltage induced by the external field will provide precise determination of the direction and magnitude of the local magnetic field relative to the magnetometer's orientation in the borehole.

Exercises

1. Parallels of latitude:
   a. Are lines connecting the poles
   b. Distorts size from one area to another
   c. Are made by projecting the globe into a cylinder
   d. Are lines running parallel to the equator
2. In order to be useful, down hole data must be:
   a. In conical form
   b. Projected into Mercator
   c. Related to a surface position or elevation
   d. In Azimuth format
3. Longitude:
   a. Must pass through Greenwich, England
   b. Is called the prime meridian
   c. Is divided into 180 degrees in the Eastern Hemisphere and 180 degrees in the Western Hemisphere.
   d. Longitude lines are all exactly 70 miles apart.
4. Lines of latitude
   a. May be called meridians
   b. Are measured from 0° to 90°, with 90° being the North or South pole
   c. Are measured in 180° from Greenwich, England to the international date line
   d. Are all exactly 70 miles apart

5. The angle between grid north and true north is called:
   a. Declination
   b. Convergence
   c. A degree of latitude
   d. Azimuth
6. An example of a polar coordinate is:
   a. 2Oft@ N45E
   b. p(56,35)
   c. N5, E7
   d. 2x35
7. An example of a rectangular coordinate is:
   a. 20ft@N45E
   b. N5,E7
   c. 2x35
   d. N25E
8. With the exception of inertial systems, all survey systems measure _____________ and _____________ at particular measured depths.
9. Measured depth is always measured in some manner while _____________ depth is normally a calculated value.
10. RKB is:
    a. A measurement of TVD
    b. A depth reference
    c. Normally placed at the bottom of the well bore
    d. Can be obtained from tide tables
11. If a well bore has an inclination of 25°, there is an angle of 25° between a tangent to the well bore axis and _____________.

12. The three North reference systems generally used in directional surveying are _____________ North, _____________ North, and _____________ North.

13. Declination is a correction:

    a. From Magnetic North to Grid North or True North

    b. To latitude

    c. From Magnetic North to True North

    d. From Grid North to Magnetic North

14. If a well bore survey has a Magnetic Azimuth of 123°, and the declination for that location is 2 East, the True North Azimuth is:

    a. 121°

    b. 123°

    c. 125°

    d. 100°

15. An Ellipsoid of uncertainty is an attempt to define the volume of uncertainty around any given survey point. This uncertainty is caused by _____________ errors inherent in different types of survey tools.

16. Tool face provides a reference point for linkage with the bottom hole assembly. This is used to change the _____________ and _____________ of the well bore as it is drilled.

17. The amount of wellbore curvature between two points is called:

    a. Closure

    b. Dog leg

    c. Target Direction

    d. Dog leg severity

18. Point “A” in figure 1 is defined as the ____________ of the well bore:

    a. Low side

    b. Inclination

    c. Dog leg

    d. High side

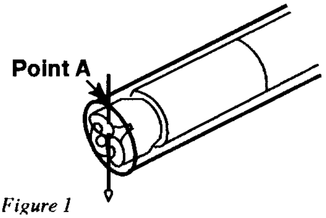


Figure 1

19. Drill string magnetism can cause:

    a. Improper motor operation

    b. Compass readings to be incorrect

    c. Dog legs to increase

    d. Measured depths to be incorrect

20. The total horizontal deviation of the well projected onto the plane of proposal is called ____________ ____________.

21. ____________can be the straight line distance from the rig reference point to the bottom of the well bore on the plan view.

22. If "B" in figure 2 represents the along hole depth (measured depth) of a well bore, “A” represents:

    a. RKB

    b. TVD

    c. Inclination

    d. Azimuth

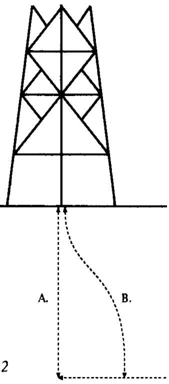


Figure 2

23. The azimuth in figure 3 could be:

    a. 25

    b. 360

    c. 135

    d. 270

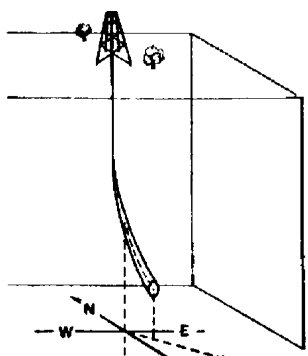


Figure 3

24. In figure 4 the angle between the plum bob (representing vertical) and the well bore axis is called_____________.

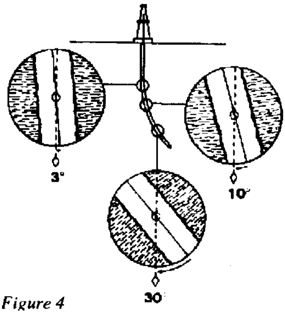


Figure 4

25. In figure 5 "A" represents Magnetic North while "B" represents ______________North.

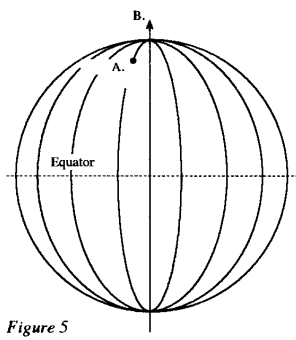


Figure 5

26. In figure 6 a survey taken in Point A would have a East or West declination.

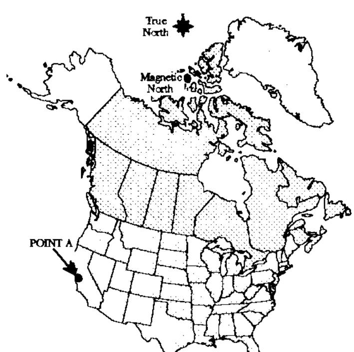


Figure 6

27. Locate the following Rectangular Coordinates in figure 7:

    a. N5,W3

    b. S2.E4

    c. 4, -3

    d. -1,-l

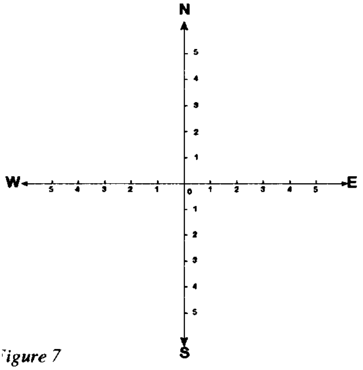


Figure 7

28. Locate the following Polar Coordinates in figure 8:

    a. 25ft.@N30E

    b. 15 ft. @ N

    c. 17 ft. @ 285°

    d. 27ft.@? 110°

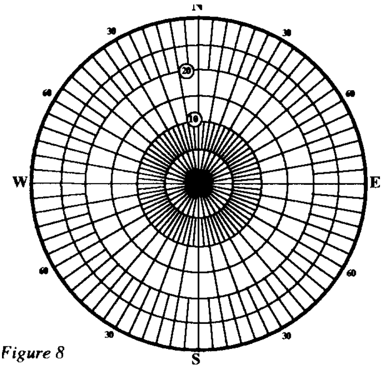


Figure 8

•Notes•

Surveying Tools
Tool Types

Magnetic Versus Gyroscopic

Directional data such as borehole attitude and toolface can be acquired during a survey using either magnetic or gyroscopic survey instruments. These magnetic or gyroscopic instruments can be further classified as either “conventional” or “high end.” Conventional instruments use mechanical angle units combined with magnetic compasses or directional gyroscopes, and film-based cameras to record the instrument readings. High end instruments utilize inertial grade accelerometers combined with magnetometers or rate gyro sensors, and solid-state memory electronics or surface communication electronics and conductive wirelines.

Magnetic Instruments

Both conventional and high end magnetic instruments are designed to take stationary readings of the earth’s magnetic field. Therefore, they require spacing away from the drillstring and BHA to minimize interference with the earth’s magnetic field. This spacing is achieved with non-magnetic running gear and non-magnetic drill collars during drilling. Magnetic instruments are not designed to be used in casing, or when other large sources of interference are close by. Existing cased wellbores will often affect magnetic survey instruments including an MWD. In most cases, ranges of 20-75 ft of space between wells are needed to avoid magnetic interference. 15° intervals.Since the earth is flattened at the poles there is a small difference in the length of one degree.

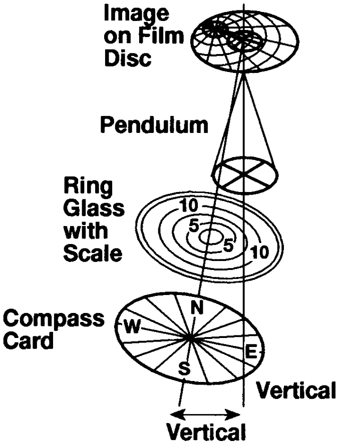
Gyroscopic Instruments

Conventional gyroscopic instruments are designed to take stationary readings referenced to the initial directional gyro alignment, which is preserved by using mechanical gimbals. High end rate gyroscopic instruments are designed either to take stationary readings based on the rate gyroscopic response to the earth's rotation, or to take readings of the sensor outputs as the tool moves through the wellbore. These sensor outputs are referenced to the original sensor alignment to calculate tool attitude. There are special high end gyroscope instruments, but these are available only on a limited basis and are beyond the scope of this section.

Magnetic Tools

Magnetic Single Shot

Magnetic survey instruments use a magnetic compass to measure the direction of a wellbore in relation to magnetic north. Magnetic instruments determine both direction and inclination using a plumb bob or drift arc that is designed to seek the low side of the hole. To measure inclination and direction, the instrument camera photographs the attitude of the plumb bob in reference to a calibrated angle indicator and in reference to a compass. These parameters and the measured depth of the survey station are used to calculate the well's position. Single-shot surveys, which photograph the instrument at a single position, are often used by the directional driller to track the bit's progress while drilling is underway. The compass unit of a magnetic survey instrument is placed in a non-magnetic drill collar (NMDC) to isolate the compass from the drillstring's magnetic interference. Placement of the instrument within the NMDC varies with the wellbore attitude, latitude, and the bottomhole assembly. Magnetic survey directional readings also must be adjusted for the difference between local magnetic North and True North or Grid North. The amount of correction varies geographically and with time.



The Basic Instrument Components

There are four basic components which make a magnetic single shot instrument:

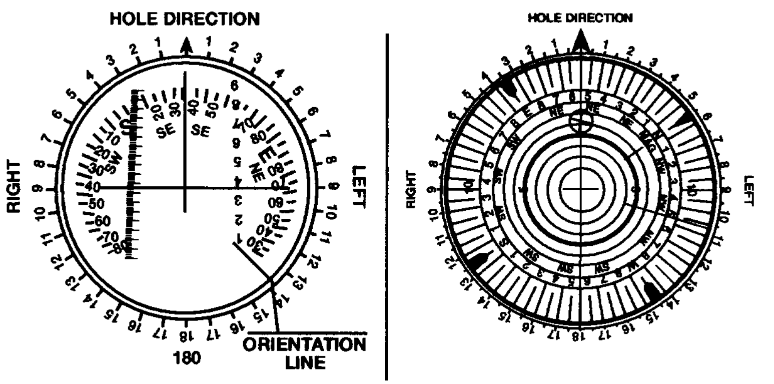
- Compass/angle unit
- Camera
- Timing device
- Battery pack

The compass/angle unit is the sensor and gives a reading of inclination, hole direction and in some circumstances tool face.

Baker Hughes INTEQ has two complete ranges of single shot instrument, E type and R type. These two sets of instruments are different in size but otherwise fairly similar.

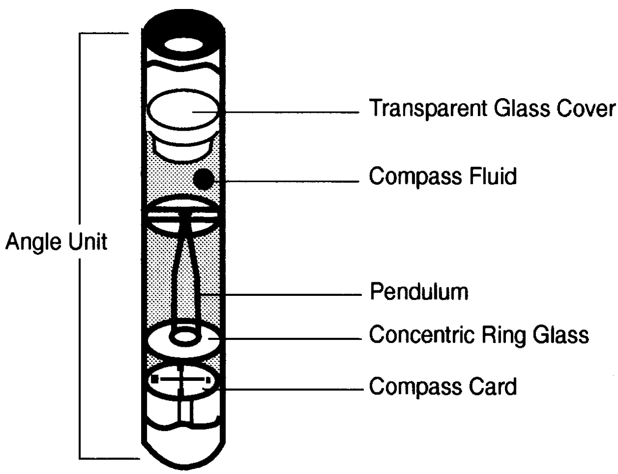
The E type instruments are smaller and fit inside a l-3/8” (1.375”) pressure barrel, whereas the R type (“regular”) instruments fit inside a l-3/4” (1.75”) pressure barrel. The heat shield available for the E instruments has an OD of l-3/4” whereas the heat shield for the R instruments has an OD of 2- 1/8”.

The components of the angle-measuring unit are shown on the following page. All the parts are sealed in a fluid chamber to provide a cushioning effect.



The pendulum remains vertical when the instrument is lying at an angle. The distance between the cross-hair of the pendulum and the central axis of the tool gives a measure of the inclination. A glass plate with concentric rings provides a scale to allow direct reading of the inclination from the disc.

The magnetic compass aligns itself to Magnetic North. In high northern latitudes, where the Earth's magnetic field dips steeply, the card must be kept level by a compensating mechanism. When the cross-hair of the pendulum is photographed on top of the compass card, the hole can be read by projecting a straight line from the center of the image through the cross-hair on to the compass rose. Depending on the expected inclination of the hole there are different sizes of angle units with scales of 0-10°, 0-20° or 15-90°. On surface the disc is extracted from the instrument barrel, developed and read. Normally the lowest angle unit range should be used to measure maximum hole inclination to maximize accuracy.

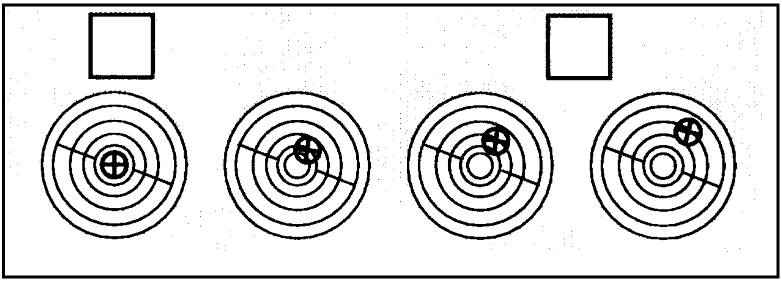


Magnetic Multishot

Multi-shot surveys provide a more comprehensive picture of the well's path. This type of survey is normally run when the drilling assembly is being tripped out of a hole, either for a bit change or a wiper trip. As the name implies, a succession of surveys are taken at regular depth intervals (typically stand lengths) through the open hole section. The tool is located downhole in a non-magnetic drill collar with the bottom of the tool landed on a baffle plate.

There are two instrument sizes available corresponding to two sizes of downhole tool. The standard magnetic multishot instruments fit inside the same 1.75" OD barrel that is used for R single shot. The mini-multishot instruments fit inside a 1.375" OD barrel. This is not the same barrel as is used for E single shot because the complete mini-multishot instrument is considerably longer than the E single shot. However, the other items of running gear, i.e., spacer bars, etc., are common to both systems. Heat shields are available for both the standard and the mini magnetic systems.

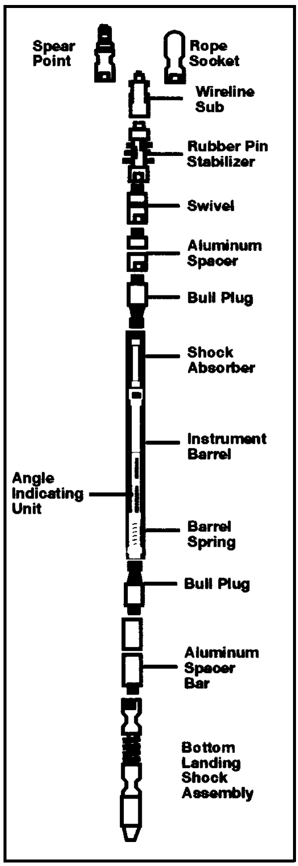
Sample of multishot film with succession of survey film shots



Electronic Magnetic Surveyor (EMS)

The EMS is the latest technology in downhole magnetic surveying, achieving new standards of magnetic survey accuracy using tri-axial accelerometers and magnetometers to measure a variety of downhole parameters.

In addition to hole inclination and direction, it also calculates the magnetic dip angle and field strength at each survey station. These values are used to determine downhole magnetic interference, providing a good measure of survey validity. In addition, EMS measures downhole temperature and is modeled for a range from 0° to 125°C.



The EMS system is armed at the surface, then run like a standard multi-shot. The EMS tool can be programmed for either the single-shot, multi-shot or core orientation mode, with variable delay times and station intervals set at the surface. Survey data for as many as 1023 data points can be stored.

Surface equipment includes a rugged portable computer which processes results, and a system printer. Following the survey, the tool is reconnected to the system computer, which processes the data and generates a survey report at rigsite.

Because it uses an electronic memory to store survey data, the system eliminates many of the error sources associated with camera-based systems, such as data entry error, or misinterpretation of data.

Wireline Steering Tool

A wireline steering tool is a survey tool used to give continuous surface readout of survey data while drilling with a downhole navigational assembly.

An electronic probe is run into the hole on a conductor line and is seated in an orienting sub just above the motor. Within the probe are the electronic sensors that measure hole inclination, azimuth and toolface. The survey results are transmitted from the probe via the conductor line to the surface, where a computer analyzes the signal and gives a digital display of the angles measured.

This method of surveying offers several advantages over single shots.

- Rig time is saved by eliminating the large number of wireline trips required to take surveys and to check orientation.
- Continued monitoring will reduce the risk of the well straying off course, and therefore reduce the number of correction runs.
- Owing to better control, the well path should be smoother, with fewer dog-legs.

The advent of MWD tools has meant limited usage of this type of tool, however special applications such as Short Radius drilling & Air drilling do utilize this technology.

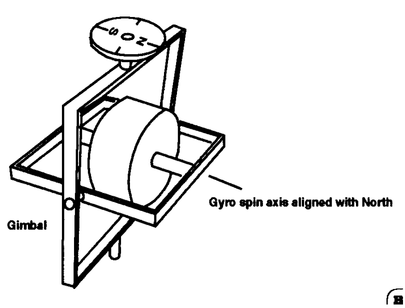
Gyroscopic Tools

Gyro Single Shot

Survey instruments which use magnetic compass cards to measure direction cannot be used in a cased hole because the presence of the steel casing will give erroneous results. This may be true when surveying in open hole when there are cased wellbores nearby. When kicking off a directional well from a multiwell platform, a magnetic single shot may be unreliable owing to the close proximity of adjacent wells. Under these circumstances the magnetic compass can be replaced by a gyroscopic compass that will not be affected by the presence of magnetic fields. This tool configuration is then known as a gyro single shot.

Gyro Multishot

Once a string of casing has been run in the hole, the trajectory of the cased borehole can be provided by a gyro multishot survey. The gyro multishot is run on wireline and the surveys are taken while running into the hole. This is to reduce the error caused by gyro drift, which becomes significant over longer times. Gyro drift does not increase uniformly with time. To correct the survey results for the effect of gyro drift a series of drift checks are made both running in and coming out of the hole. The gyro is held stationary for a few minutes, allowing a number of pictures to be taken at the same point. A drift correction chart can then be drawn up to adjust the raw survey results.



Seeker

In the Seeker, a rate gyro is mounted in a revolving gimbal with a single accelerometer. The gyro measures the earth's rate of rotation at each survey station, and the accelerometer measures the force of gravity. This information is transmitted via wireline to the surface where the system computer determines hole direction and inclination independently for each station.

Seeker requires no surface orientation, which speeds the survey and eliminates a potential source of survey error. In addition, Seeker's rate gyro is not subject to conventional gyro drift, so drift checks and drift corrections are not needed.

By rotating its sensor package at each survey station, the tool allows gyro and accelerometer bias terms to be averaged from the signal, further enhancing survey accuracy.

Seeker's standard 2" OD barrel permits surveys in drill pipe, deep hole and production tubing, making it one of the most versatile high-accuracy survey systems available.

Rigs

The Ring Laser Inertial Guidance Surveyor (RIGSTM) is a high-accuracy, high-speed surveying system that gathers survey data continuously as the sensor is run through the well bore. RIGS is a three-axis inertial navigation system. With the help of advanced wireline measurement techniques, it is accurate to l-2 ft/ 1,000 ft of hole surveyed with the maximum error at horizontal being 2.6 ft/ 1,000 ft. Results are three times more accurate and are completed in about one-half the time of rate gyro surveys.

The RIGS system achieves its high level of accuracy by com-bining strapdown inertial navigation technology and a sophisti-cated mathematical model with advanced wireline measurement techniques.

At the beginning of each survey, the downhole assembly is aligned at the wellsite and the system derives a true North reference by measuring the earth's rotation. Then, as the instrument moves through the hole, the RIGS INS sensor measures changes in its position in 3-dimensional space, generating coordinates for north/south, east/west and down along the trajectory of the wellbore.

This inertial navigation method eliminates errors (typically 1 ft/ 1000 ft) encountered in point-to-point welbore survey calculation methods used with rate gyros and conventional survey systems.

A precision wireline depth measurement system and a casing collar locator are used to verify sensor depth. Limiting wireline depth measurement errors to less than 0.5 ft/ 1000 ft. Roller centralizers keep the tool aligned with the well's axis, assuring accurate readings. They also guard the tool against shock and vibration. The system's technical capabilities, combined with extensive QC analysis of every survey procedure, yield lateral uncertainties of typically l-2 ft./ 1000 ft of hole surveyed.

Not only is RIGS extremely accurate, but it is also the fastest way to survey a cased welIbore down to 7-inch casing.

For example, the average alignment time for the RIGS sensor is about 12 minutes. A 3-minute drift check is performed for verification of initial parameters. Then, the downhole assembly is run into the hole at 300 ft/ minute, collecting data as it moves from surface to TD. At bottom, an inertial drift check is performed with the tool at rest for just another three minutes. The RIGS tool is then retrieved - without stopping - at 300 ft per minute, taking a second, completely independent wellbore survey. A final 3-minute drift check is performed at completion.

Tool Selection Factors

A number of factors will influence survey tool selection, not the least of which is the accuracy required for a given survey application. Accuracy, in this sense, is not to be confused with precision; precision survey instruments may provide measurements that are inaccurate to some degree. Some applications, such as relief well drilling, require greater accuracy than others.

Accuracy requirements also will be determined in part by target size, since hitting a smaller or well-defined target requires a greater degree of accuracy. In addition, survey depths will affect the accuracy of some magnetic and gyroscopic instruments, as will the latitude of the well.

Factors Influencing Survey Tool Selection

- Target Size: The size of the target determines, in part, the accuracy requirements
- Latitude of Well: The latitude of the well will affect magnetic instruments, as well as the accuracy of rate gyroscopic survey tools, with accuracy decreasing with increases in latitude.
- Target Direction: East/West surveys require special procedures for both magnetic and north seeking gyroscopic sensors.
- Type of Drilling InstaIlation: Magnetic interference is inherent in some multi-well installations.
- Rig Costs: Rig cost will affect the cost-effectiveness of high end survey instruments, e.g., measurement-while-drilling is generally more cost-effective when rig costs are higher.
- Maximum Inclination Planned: Some survey tools have upper inclination limits, beyond which they are not operational.

- Formation and Hole Conditions: Hot, open or small holes limit the use of some tools.
- Well Budget: Like rig cost, this factor determines in part the cost-effectiveness of some survey tools.
- Survey Depths: The accuracy of a survey is affected by survey depth.
- Hole Temperature: All tools have operational limits.
- Open or Cased Hole: Affects the use of magnetic instruments.

Exercises

1. INTEQ defines conventional survey tools as having (among other things):

    a. Gyro sensors

    b. Magnetic sensors for low end and gyro sensors for high end

    c. Mechanical angle units and film based cameras

    d. Inertial grade accelerometers

2. Magnetic instruments require spacing from the drill string and BHA to minimize interference from _____________ _____________ _____________.

3. Ranges of _____________ to _____________ feet of space are needed to avoid magnetic interference when using magnetic survey instruments around existing casing.

4. One disadvantage of a conventional gyro is that it must have an _____________ _____________ _____________ _____________ which is preserved by using mechanical gimbals. A high end rate gyro, on the other hand, takes readings based on the earth's _____________ _________ _____________.

5. Magnetic single shot surveys photograph the instrument at a single position and may be used to:

    a. Perforate the casing

    b. Track the bit's progress while the well is being drilled

    c. Survey inside casing

    d. Eliminate the need for a non-magnetic drill collar.

6. The basic components which make up a conventional single shot instrument are:

    a. _____________

b. _____________

c. _____________

d. _____________

7. Magnetometers are used for the same purpose that a _____________ is used in a conventional survey instrument:

   a. Pendulum and ring glass with scale

   b. Compass card

   c. Timing device

   d. Battery pack

8. Accelerometers are used for the same purpose that a _____________ is used in a conventional survey instrument.

   a. Pendulum and ring glass with scale

   b. Compass card

   c. Timing device

   d. Battery pack

9. A multi-shot survey:

   a. Consists of several single shots

   b. Is a succession of surveys taken at regular depth intervals

   c. Can only be performed in a 1.75” OD pressure barrel

   d. Must be run using a film based camera

10. A survey tool that is used to give continuous surface readout of survey data

    a. Gyro multi-shot

    b. EMS

    c. Wireline steering tool

d. Seeker

11. In addition to inclination and direction, the Electronic Magnetic Surveyor calculates _____________ _____________ and _____________ _____________ at each survey station.

12. Gyroscopic Tools are used instead of magnetic tools when:

    a. Increased accuracy is needed

    b. The magnetic dip angle is too low

    c. Casing has been run or magnetic interference is present

    d. When the rotation of the earth is from east to west

13. A rate gyro survey is normally more accurate than a conventional gyro survey because:

    a. It requires no surface orientation

    b. Drift corrections are not needed

    c. It is not subject to sensor bias and misalignment sometimes found in conventional gyro systems

    d. All of the above

14. A Seeker must be run instead of a RIGS when:

    a. Surface alignment is not possible

    b. Accuracy is of up most importance

    c. There are time constraints

    d. The casing is less that 7 inch

15. The Ring Laser Inertial Guidance Surveyor (RIGS)

    a. Is the most accurate of the survey systems discussed

    b. Is run into the hole at 300 feet/minute

c. Derives True North reference by measuring the earth's rotation

d. All of the above

16. Some of the factors influencing survey tool selection are:

a. _______________

b. _______________

c. _______________

d. _______________

e. _______________

f. _______________

g. _______________

Surveying Calculations

Surveying Calculation Methods

Introduction

The results of a directional survey are given in terms of azimuth and inclination of a borehole at a certain depth. This information must then be analyzed to calculate the actual position of the wellbore at that survey station relative to the surface location. In order to do this the incremental distances between the successive survey stations must be calculated. With the coordinates of the upper station known, the coordinates of the lower station can be found by addition. The horizontal coordinates of a point are referred to as the “Northing” (or latitude) and the “Easting” (or departure).

The inclination and azimuth at each survey station define two vectors that are tangential to the wellbore trajectory. The inclination vector lies in the vertical plane, while the azimuth lies in the horizontal plane. The only other piece of information available is the course length (the difference in survey depths) between the two stations. It is necessary therefore to assume some kind of idealized wellpath between the upper and lower stations. Various different kinds of geometrical models have been used, with each model generating a number of mathematical equations. The assumed wellpath may simply be a straight line joining the two survey stations or it could be some kind of curved line defined by the end points.

The accuracy of the final coordinates will naturally depend on how well the assumed trajectory used in the model approximates to the actual trajectory in the borehole. The position of the wellbore must be known precisely at critical stages during drilling (e.g. when kicking off near existing wells). An operating company will usually adopt one method of calculating the wellbore position and apply this model to all surveys throughout the length of the well. In order to be consistent it is important that same model be applied to all other wells drilled from that platform.

Existing instrumentation cannot precisely define the borehole between two stations. There are an unlimited number of different models and related formulas that could be derived. It is therefore important to note there is no single correct answer.

Three of the most common models are described as follows:

Average Angle Method

The average angle method assumes the borehole is parallel to the simple average of both the drift and bearing angles between two survey stations. This method is fairly accurate and calculation is simple enough for field use with a non-programmable scientific calculator, but theoretical justification for the average angle method, also known as “angle-averaging method’ is rather difficult.

Radius of Curvature method

This is one of the most accepted methods. Using sets of angles measured at the upper and lower ends of sections along the surveyed course length, the radius of curvature method generates a space curve representing the wellbore path. For each survey interval, the method assumes that the vertical and horizontal projections of the curve have constant curvature. These calculations are usually handled by a programmable calculator or computer.

Minimum Curvature Method

The inclination and azimuth at each survey station define two vectors that are tangential to the wellbore trajectory. The inclination vector lies in the vertical plane, while azimuth lies in the horizontal plane. The only other piece of information available from a survey is the course length (the difference in survey measured depths) between the two stations. It is necessary, therefore, to assume some kind of idealized wellpath between the upper and lower stations. Various different kinds of geometrical models have been used, with each model generating a number of mathematical equations.

The accuracy of the final coordinates will naturally depend on how well the assumed trajectory used in the model approximates the actual trajectory of the borehole.

Change in Measured Depth

Msrd Depth	Incl °	Azm °	Δ MD	Dogleg °	RF	Δ North	Δ East	Δ Vert	TTL TVD Depth	TTL North	TTL East	Vert Sect	Dogleg Sevrty
3,425	8.00	285.00							3,402.00	6.25	– 12.58		
3,522	10.75	282.00	**97**										

$$\Delta\ MD = MD_2 - MD_1$$

$$\Delta\ MD = 3{,}522 - 3{,}425$$

$$\Delta\ MD = 97$$

Dogleg

Msrd Depth	Incl °	Azm °	Δ MD	Dogleg °	RF	Δ North	Δ East	Δ Vert	TTL TVD Depth	TTL North	TTL East	Vert Sect	Dogleg Sevrty
3,425	8.00	285.00							3,402.00	6.25	– 12.58		
3,522	10.75	282.00	97	**2.79**									

$$\text{D.L.} = \cos^{-1}[\sin I_1 \times \sin I_2 \times \cos(A_2 - A_1) + \cos I_1 \times \cos I_2]$$

$$\text{D.L.} = \cos^{-1}[\sin 8.0 \times \sin 10.75 \times \cos(282.00 - 285.00) + \cos 8.0 \times \cos 10.75]$$

$$\text{D.L.} = \cos^{-1}[\sin 8.0 \times \sin 10.75 \times \cos(-3) + \cos 8.0 \times \cos 10.75]$$

$$\text{D.L.} = \cos^{-1}[0.02592355 + 0.97288926]$$

$$\text{D.L.} = \cos^{-1}[0.99881281]$$

$$\text{D.L.} = 2.792$$

Ratio Factor

Msrd Depth	Incl °	Azm °	Δ MD	Dogleg °	RF	Δ North	Δ East	Δ Vert	TTL TVD Depth	TTL North	TTL East	Vert Sect	Dogleg Sevrty
3,425	8.00	285.00							3,402.00	6.25	– 12.58		
3,522	10.75	282.00	97	2.79	**1.0002**								

Note: *R.F. is simply a smoothing factor used in the following calculations. It has no other significance.*

$$\text{R.F.} = \tan\left(\frac{\text{D.L.}}{2}\right) \times \frac{180}{\pi} \times \frac{2}{\text{D.L.}}$$

$$\text{R.F.} = \tan\left(\frac{2.792162}{2}\right) \times \frac{180}{\pi} \times \frac{2}{2.792162}$$

$$\text{R.F.} = \tan(1.396081) \times 41.040440$$

$$\text{R.F.} = 024371 \times 41.040440$$

$$\text{R.F.} = 1.0002$$

Change in North/South Coordinate

Msrd Depth	Incl °	Azm °	Δ MD	Dogleg °	RF	Δ North	Δ East	Δ Vert	TTL TVD Depth	TTL North	TTL East	Vert Sect	Dogleg Sevrty
3,425	8.00	285.00							3,402.00	6.25	– 12.58		
3,522	10.75	282.00	97	2.79	1.0002	**3.63**							

$$\Delta North = [(\sin I_1 \times \cos A_1) + (\sin I_2 \times \cos A_2)]\ [R.F. \times (\Delta MD \div 2)]$$

$$\Delta North = [(\sin 8.0 \times \cos 285.0) + (\sin 10.75 \times \cos 282.0)]\ [1.0002 \times (97 \div 2)]$$

$$\Delta North = [0.03602 + 0.03878]\ [48.5097]$$

$$\Delta North = [0.0748]\ [48.5097]$$

$$\Delta North = 3.63$$

Change in East/West Coordinate

Msrd Depth	Incl °	Azm °	Δ MD	Dogleg °	RF	Δ North	Δ East	Δ Vert	TTL TVD Depth	TTL North	TTL East	Vert Sect	Dogleg Sevrty
3,425	8.00	285.00							3,402.00	6.25	– 12.58		
3,522	10.75	282.00	97	2.79	1.0002	3.63	**–15.37**						

$$\Delta\text{East} = [(\sin I_1 \times \sin A_1) + (\sin I_2 \times \sin A_2)]\ [\text{R.F.} \times (\Delta\text{MD} \div 2)]$$

$$\Delta\text{East} = [(\sin 8.0 \times \sin 285.0) + (\sin 10.75 \times \sin 282.0)]\ [1.0002 \times (97 \div 2)]$$

$$\Delta\text{East} = [-\ 0.13443 - 0.18245]\ [48.5097]$$

$$\Delta\text{East} = [-\ 0.31688]\ [48.5097]$$

$$\Delta\text{East} = -\ 15.37$$

Change in TVD

Msrd Depth	Incl °	Azm °	Δ MD	Dogleg °	RF	Δ North	Δ East	Δ Vert	TTL TVD Depth	TTL North	TTL East	Vert Sect	Dogleg Sevrty
3,425	8.00	285.00							3,402.00	6.25	– 12.58		
3,522	10.75	282.00	97	2.79	1.0002	3.63	– 15.37	**95.70**					

$$\Delta \text{Vert} = [\cos I_1 + \cos I_2)] [\text{R.F.} \times (\Delta \text{MD} \div 2)]$$

$$\Delta \text{Vert} = [\cos 8.0 + \cos 10.75] [1.0002 \times (97 \div 2)]$$

$$\Delta \text{Vert} = [1.97272] [48.5097]$$

$$\Delta \text{Vert} = 95.70$$

Total TVD

Msrd Depth	Incl °	Azm °	Δ MD	Dogleg °	RF	Δ North	Δ East	Δ Vert	TTL TVD Depth	TTL North	TTL East	Vert Sect	Dogleg Sevrty
3,425	8.00	285.00							3,402.00	6.25	– 12.58		
3,522	10.75	282.00	97	2.79	1.0002	3.63	– 15.37	95.70	**3,497.70**				

$$\text{TTL TVD}_2 = \text{TTL TVD}_1 + \Delta\text{Vert}_2$$

$$\text{TTL TVD}_2 = 3{,}402.00 + 95.70$$

$$\text{TTL TVD}_2 = 3{,}497.70$$

Total North/South Coordinate

Msrd Depth	Incl °	Azm °	Δ MD	Dogleg °	RF	Δ North	Δ East	Δ Vert	TTL TVD Depth	TTL North	TTL East	Vert Sect	Dogleg Sevrty
3,425	8.00	285.00							3,402.00	6.25	– 12.58		
3,522	10.75	282.00	97	2.79	1.0002	3.63	– 15.37	95.70	3,497.70	**9.88**			

$$\text{TTL North}_2 = \text{TTL North}_1 + \Delta\text{North}_2$$

$$\text{TTL North}_2 = 6.25 + 3.63$$

$$\text{TTL North}_2 = 9.88$$

Total East/West Coordinate

Msrd Depth	Incl °	Azm °	Δ MD	Dogleg °	RF	Δ North	Δ East	Δ Vert	TTL TVD Depth	TTL North	TTL East	Vert Sect	Dogleg Sevrty
3,425	8.00	285.00							3,402.00	6.25	– 12.58		
3,522	10.75	282.00	97	2.79	1.0002	3.63	– 15.37	95.70	3,497.70	9.88	**– 27.95**		

$$\text{TTL East}_2 = \text{TTL East}_1 + \Delta\text{East}_2$$

$$\text{TTL East}_2 = -12.58 - 15.37$$

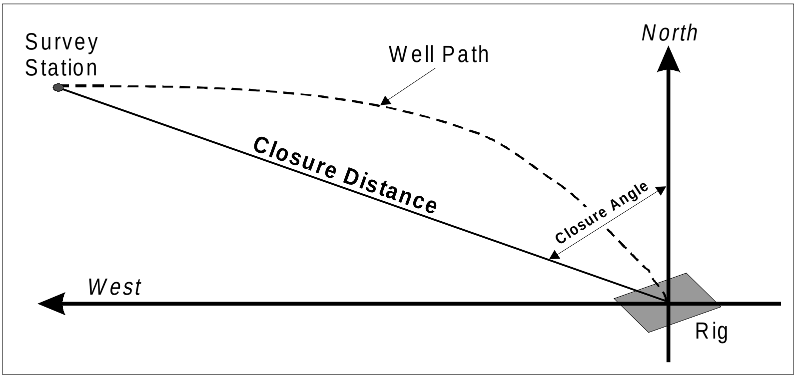
$$\text{TTL East}_2 = -27.95$$

Closure

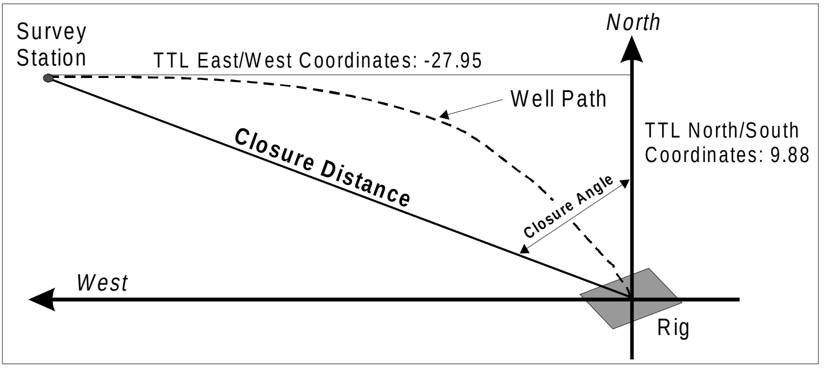
Closure is the *distance* and *direction* of a straight line drawn from the rig reference point to a rectangular coordinate in the horizontal plane.

The rectangular coordinate is usually the North/South and East/West coordinates calculated at a survey point, e.g., N9.88', W27.95'.

Closure is typically reported only once, for the bottomhole location. However, closure must be calculated at each survey station because both closure distance and closure direction are used in the calculation of Vertical Section.



Closure Distance and Closure Angle Calculations



Closure Distance

$$\text{C.D.} = \sqrt{(N/S)^2_{\textbf{total}} + (E/W)^2_{\textbf{total}}}$$

$$\text{C.D.} = \sqrt{(9.88)^2_{\textbf{total}} + (-27.95)^2_{\textbf{total}}}$$

$$\text{C.D.} = \sqrt{878.8169}$$

$$\text{C.D.} = 29.6448$$

Closure Angle

$$C.A. = \left|\tan^{-1}\left[\frac{(East/West)_{total}}{(North/South)_{total}}\right]\right|$$

$$C.A. = \left|\tan^{-1}\left[\frac{-27.95}{9.88}\right]\right|$$

$$C.A. = |-70.53|$$

$$C.A. = 70.53$$

CLOSURE: 29.64 ft. @ N70.53°W (quadrature) or

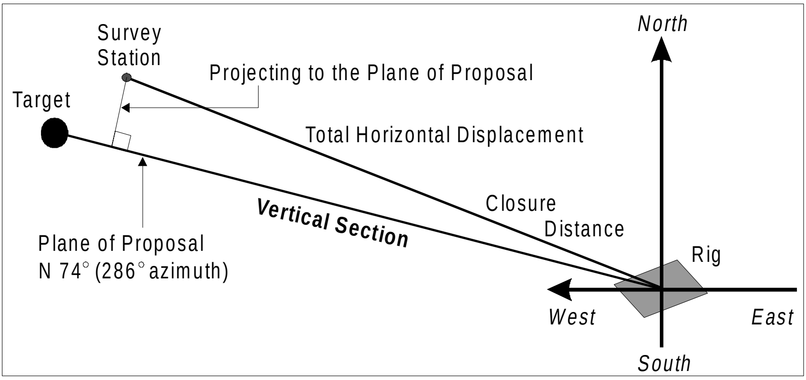
29.64 ft @ 289.47° (azimuth)

Vertical Section Definition

Vertical Section is the total horizontal deviation of the well projected onto the plane of proposal. On a well plan, the vertical profile usually corresponds to a plan in a plane defined by the direction straight from the slot to the target. This direction is often referred to as:

- vertical section azimuth,
- proposed bottomhole location (PBHL),
- plane of proposal, or

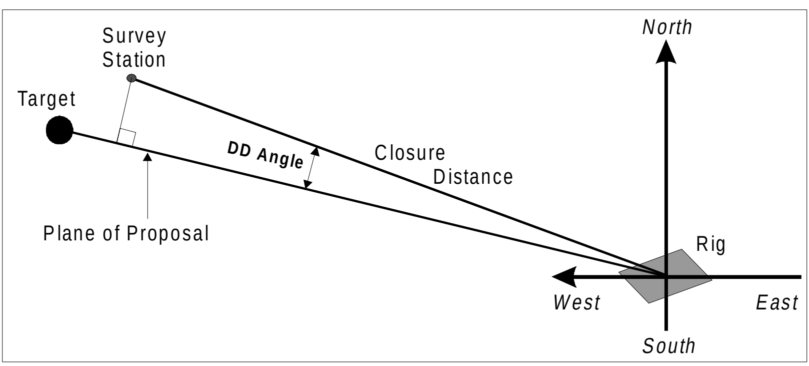
- target direction.



Directional Difference (DD)

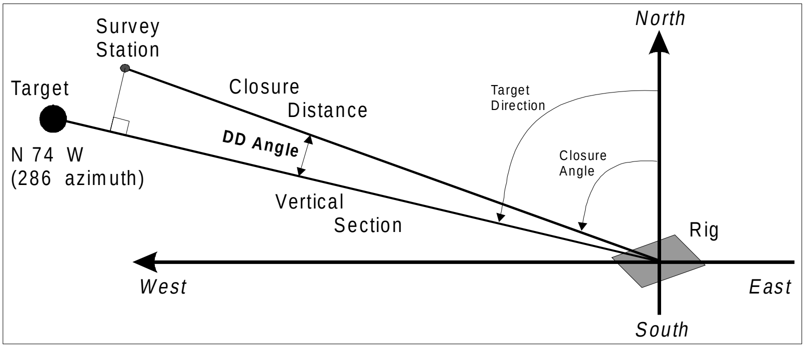
Directional Difference (DD) represents the angle between the closure and the target direction (plane of proposal). Using DD, closure distance, and a simple trigonometric function, Vertical Section can be calculated.

To calculate DD, both *target direction* and *closure direction* must be expressed in quadrature or both must be expressed in azimuth.



CLOSURE: 29.64 ft. @ N70.53°W (quadrature) or

29.64 ft @ 289.47° (azimuth)



$$DD = Direction_{target} - C.A. \quad (or)$$
$$DD = Direction_{target} - C.A.$$

$$DD = 74° - 70.53° \qquad DD = 286° - 289.47°$$

$$DD = 3.47° \qquad DD = -3.47°$$

Vertical Section

Msrd Depth	Incl °	Azm °	Δ MD	Dogleg °	RF	Δ North	Δ East	Δ Vert	TTL TVD Depth	TTL North	TTL East	Vert Sect	Dogleg Sevrty
3,425	8.00	285.00							3,402.00	6.25	– 12.58		
3,522	10.75	282.00	97	2.79	1.0002	3.63	– 15.37	95.70	3,497.70	9.88	– 27.95	**29.59**	

$$V.S. = C.D. \cos(DD)$$

$$V.S. = 29.6448 \times \cos(-3.47)$$

$$V.S. = 29.6448 \times 0.9982$$

$$V.S. = 29.59$$

Dogleg Severity

Msrd Depth	Incl °	Azm °	Δ MD	Dogleg °	RF	Δ North	Δ East	Δ Vert	TTL TVD Depth	TTL North	TTL East	Vert Sect	Dogleg Sevrty
3,425	8.00	285.00							3,402.00	6.25	– 12.58		
3,522	10.75	282.00	97	2.79	1.0002	3.63	– 15.37	95.70	3,497.70	9.88	– 27.95	29.59	**2.88**

$$\text{D.L.S.} = \frac{\text{D.L.} \times 100}{\text{Course Length}}$$

$$\text{D.L.S.} = \frac{2.792 \times 100}{97}$$

$$\text{D.L.S.} = 2.88$$

Exercises

Survey Calculations Methods

Match the best response from the right column for each statement in the left column.

1. Assumes that the vertical and horizontal projections of the curve have constant curvature.
2. INTEQ standard calculation method.
3. Complex calculations, needs a computer or programmable calculator.
4. Assumes the well bore is a spherical arc with minimum curvature between survey stations.
5. Is fairly accurate and is simple enough for field use with a non-programmable calculator.

a. Radius of Curvature

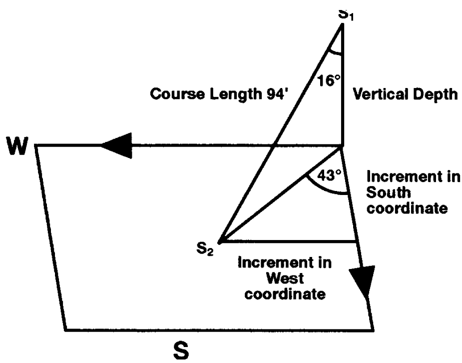
b. Minimum Curvature

c. Average angle

1. ______ 2. ______ 3. ______ 4. ______ 5. ______

Average Angle Calculations

In this method, each course length is assumed to be a straight line. The hole direction is taken to be the average of the directions at the survey stations at the beginning and end of the course length. Similarly, the drift angle (inclination of wellbore from vertical) is the average of the values at the beginning and end of the course length. Clearly, this method yields less accurate results if applied over long course lengths. Consider the following example:



The surveys at succesive “stations” are:

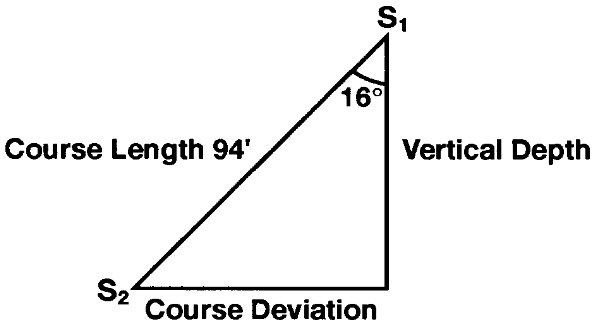
Total Total Total

INC DIR TVD N/s EYW

Sl 7564 15.0° S42°W 7534.76 - 66.22 - 63.56

S2 7658 17.0° S44°W _____ _____ _____

Over the 94’ course length between these survey stations, the average inclination is taken as 16.0° and the hole direction as S43.OW, i.e., the average values. Now consider the vertical plan.



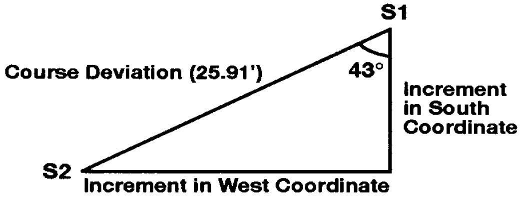
The average inclination is 16°. Using elementary trigonometry,we obtain:

$$\cos 16° = \frac{\text{vert depth}}{\text{courselength}}, \text{ vert depth} = 94 \cos 16° = 90.36$$

$$\sin 16° = \frac{\text{course deviation}}{\text{course length}}, \text{ course deviation} = 94 \sin 16° = 25.91$$

Of course, the values are only the increments in vertical depth and deviation over the 94’ course length we are considering. Therefore, to obtain TVD at station S2, we must add the increment in VD of 90.36’ to the TVD at station Sl.

Having found the course deviation (horizontal deviation), we can now find the increments in the south and east coordinates. Consider the horizontal plan shown.



Horizontal Plan View

From this figure, it can be clearly seen that:

$$\frac{\text{Increment in}}{\text{South coordinate}} = \text{Course Deviation x cos } 43° = 18.95$$

$$\frac{\text{Increment in}}{\text{West coordinate}} = \text{Course Deviation x sin } 43° = 17.67$$

These increments must be added to the south and east coordinates at survey station 2.

				Total	**Total**	**Total**
	MD	**INC**	**DIR**	**TVD**	**N/S**	**E/W**
S1	7564	15.0	S42°W	7534.76	-66.22	-63.56
S2	7658	17.0	S44°W	7534.76	-85.17	-81.23

The application of these calculations to successive survey stations and the continual addition of the incremental results eventually will produce a series of coordinates that can be plotted on the well plan and provide a graphical representation of the well bore.

Additional important calculations are made to produce:

- Vertical Section
- Closure
- Dog Leg
- Dog Leg Severity

but the calculation of these is beyond the scope of this fundamental text. More information on these calculations is available from the Magnetic and Gyroscopic Surveying manual.

•Notes•

Competitors Comparative Tool Data

HIGH-END GYROSCOPIC SURVEY TOOLS
COMPETITOR & BAKER HUGHES INTEQ COMPARATIVE DATA

	SPERRY SUN	SCHLUMBERGER	GYRODATA	SCIENTIFIC DRILLING CONTROLS	BAKER HUGHES INTEQ	BAKER HUGHES INTEQ	BAKER HUGHES INTEQ
Tool Name	G-2	GCT	Gyrodata	Finder	Seeker	Rigs	FINDS
Type	North Seeking	Continuous attitude	North Seeking	Continuous attitude	North Seeking	Inertial	Inertial
Application	Multishot	Multishot	Orientation/Multishot	Orientation/Multishot/ Steer	Orientation/Multishot	Multishot	Multishot
O.D.	2.6" w/o H. Shield 3.0" w/ H. Sheild	3 5/8"	1 3/4" for orientation 2 1/2" w/o H. Shield 3 1/2" w/ H. Shield	2"	2" Standard 3" w/H. Shield	5 1/4"	10 5/8"
Temp. Limits	185°F w/o H. Shield 600°-8 hrs	250°F Standard 300°F High Temp	200°F w/o H. Shield 500° - 10 hrs	210°F w/o H. Shield Various Heat Shield Options available	210°F w/o H. Shield Various Heat Shield Options available	Speed generally negates temp. limitation	167°F
Pressure	12,000 PSI w/o Heat Shield 15,000 PSI w/ Heat Shield	20,000 PSI	20,000 PSI	16,000 PSI	2" – 16,000 PSI 3" – 26,000 PSI	15,000 PSI	7,000 PSI
Run Speed	2–300' / min 10 secs. / station 15 min. alignment	250' / min continuous 45 min-1hr alignment	250' / min	Catwalk align. 250' / min 60-75 secs/station up to 15° Inc. Then high speed initialization for ± 15 mins, then continuous	Catwalk align. 250'/min 60-75 secs/station	12 min. align. 3 min QC check 300'/min continuous	30 min. align. 250'/min 1 min run, 1 min stop
Special Features	CCL Special Technique to survey over 70°	CCL Lock arm for align. Run w/ logging tools.	Run w/ logging tools	Steering Mode			
Limitations					70° Inc. Max.		
General Comments	No orientation capability & limited deployment	No orientation capability Long alignment time. Operators lack survey knowledge.		Long initialization prior to continuous mode. Accuracy less than later generation tools.			

Competitor Matrix

Sperry Sun	*Schlumberger*	*Gyrodata*	*Scientific Drilling Controls*
• Good range of survey services. • Recognized as survey company. • Target specific geographic markets. • In-house manufacturing. • Capable of Integrated Solutions Marketing	• Surveying is limited to GCT and some conventional (Anadrill). • High Latitude monopoly. • Limited survey expertise. • Package survey with logging.	• High-End Gyro and EMS only. • Survey is their only product line. • Aggresive sales. • Lack development capital. • Can enter and leave markets relatively cheaply.	• Near full range of survey products. • Survey focused. • Dedicated Sales force. • Lack development capital. • Can enter and leave markets relatively cheaply.

Magnetic Multishot Field Sheet

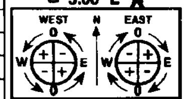
MAGNETIC MULTISHOT FIELD SHEET

COMPANY TRAINING DEPARTMENT
RIG / PLAT ____
LEASE ____ WELL NO. ____
OBJECTIVE ____
FIELD ____
SURVEYOR ____
JOB NO. ____ DATE ____
CO. REP. ____

STND NO.	SHOT NO.	MEASURED DEPTH	CSE. LGTH	INCL. ANGLE	OBSERVED DIRECTION	DEC. COR.	CORRECTED DIRECTION	REMARKS
15	77	6815		2.50	S 25.0 W			
14	75	6909		2.66	S 47.0 W			
13	73	7002		2.74	S 43.5 W			
12	71	7096		4.49	S 40.0 W			
11	65	7190		6.24	S 38.5 W			
10	62	7283		8.50	S 38.5 W			
9	59	7377		10.25	S 39.0 W			
8	57	7471		12.00	S 36.5 W			
7	55	7564		15.00	S 37.0 W			
6	53	7658		17.00	S 39.0 W			
5	51	7752		18.25	S 38.5 W			
4	48	7845		20.75	S 38.0 W			
3	46	7939		22.50	S 38.5 W			
2	43	8033		24.25	S 38.5 W			
1	39	8126		25.75	S 39.0 W			
AU	24	8220		27.50	S 39.0 W			
DOK	21	8260		28.25	S 39.5 W			
TD		8273						

SHEET 1 OF 1

☐ 5.00° E ☒



NMDC LGTH 29.33
BAFFLE:
BELOW NMDC 0
ABOVE BIT 1
A.U. SPACING 12
LAST FLASH 92

TTL. DEPTH 8273
BHA LENGTH 646.73
SGLE/DBLE ----------
KELLY DOWN 40
STANDS 81
AV. STND LGTH 93.66

NOTES / CALCULATIONS

13 3/8" Casing @ 6740'

BAKER HUGHES INTEQ

Survey Calculation Field Sheet

SURVEY CALCULATION SHEET

BAKER HUGHES INTEQ — TRAINING DEPARTMENT

COMPANY: TRAINING DEPARTMENT
LEASE / AREA: ______ WELL NO. ______
FIELD: ______
RIG / PLATFORM: ______
JOB NO.: ______ DATE: ______
SURVEYOR: ______

TYPE OF SURVEY: STANDARD MULTISHOT
TARGET DIRECTION: S 45 W DECLN.: 5.00° E
CALCULATION METHOD: AVERAGE ANGLE
REMARKS: ______

Measured Depth	Inclination Angle	Hole Direction	Course Length	Average Inclination Angle	Vertical Depth	Course Deviation	Average Hole Direction	CO-ORDINATES N(+)/S(-)	CO-ORDINATES E(+)/W(-)	True Vertical Depth	Total Vertical Section	TOTAL CO-ORDINATES N(+)/S(-)	TOTAL CO-ORDINATES E(+)/W(-)	Dog Leg Severity
6,721	2.25	N 88.00 W								6,699.00	-2.31	1.25	2.02	
6,815	2.50	S 30.0 W	94	2.375	93.92	3.90	S 61.00 W	-1.89	-3.41	6,792.92	1.44	-0.64	-1.39	2.61
6,909	2.66	S 52.0 W	94	2.580	93.90	4.23	S 41.00 W	-3.19	-2.78	6,886.82	5.66	-3.83	-4.17	1.06
7,002	2.74	S 48.5 W	93	2.700	92.90	4.38	S 50.25 W	-2.80	-3.37	6,979.72	10.02	-6.63	-7.54	0.20
7,096	4.49	S 45.0 W	94	3.615	93.81	5.93	S 46.75 W	-4.06	-4.32	7,073.53	15.95	-10.69	-11.86	1.88
7,190	6.24	S 43.5 W	94	5.365	93.59	8.79	S 44.25 W	-6.30	-6.13	7,167.12	24.73	-16.99	-17.99	1.87
7,283	8.50	S 43.5 W	93	7.370	92.23	11.93	S 43.50 W	-8.65	-8.21	7,259.35	36.66	-25.64	-26.20	2.43
7,377	10.25	S 44.0 W	94	9.375	92.74	15.31	S 43.75 W	-11.06	-10.59	7,352.10	51.97	-36.70	-36.79	1.86
7,471	12.00	S 41.5 W	94	11.125	92.23	18.14	S 42.75 W	-13.32	-12.31	7,444.33	70.09	-50.02	-49.10	1.93
7,564	15.00	S 42.0 W	93	13.500	90.43	21.71	S 41.75 W	-16.20	-14.46	7,534.76	91.77	-66.22	-63.56	3.23
7,658	17.00	S 44.0 W	94	16.000	90.36	25.91	S 43.00 W	-18.95	-17.67	7,625.12	117.66	-85.17	-81.23	2.21
7,752	18.25	S 43.5 W	94	17.625	89.59	28.46	S 43.75 W	-20.56	-19.68	7,714.71	146.12	-105.73	-100.91	1.34
7,845	20.75	S 43.0 W	93	19.500	87.67	31.04	S 43.25 W	-22.61	-21.27	7,802.37	177.14	-128.34	-122.18	2.69
7,939	22.50	S 43.5 W	94	21.625	87.38	34.64	S 43.25 W	-25.23	-23.74	7,889.76	211.77	-153.57	-145.92	1.87
8,033	24.25	S 43.5 W	94	23.375	86.29	37.29	S 43.50 W	-27.05	-25.67	7,976.04	249.05	-180.62	-171.59	1.86
8,126	25.75	S 44.0 W	93	25.000	84.29	39.30	S 43.75 W	-28.39	-27.18	8,060.33	288.34	-209.01	-198.77	1.63
8,220	27.50	S 44.0 W	94	26.625	84.03	42.13	S 44.00 W	-30.30	-29.26	8,144.36	330.46	-239.31	-228.03	1.86
8,260	28.25	S 44.5 W	40	27.875	35.36	18.70	S 44.25 W	-13.40	-13.05	8,179.72	349.16	-252.71	-241.08	1.96

Closure = 349.26 ft. @ S 43.65 W

Answer Key

Introduction

1.

a. Comply with legal requirements

c. Assist in the evaluation of reservoir characteristics

f. Assist side tracking operations

g. Verify that the directional drilling program is producing the desired well profile

h. Obtain accurate well bore position

i. Determine tool orientation

2.

a. to hit geological target areas

b. to avoid collision with other wells, especially during platform drilling

c. to define the target of a relief well in the event of a blowout

d. to provide a better definition of geological and reservoir data to allow for optimisation of production

e. to fulfill the requirements of local legislation

3.

b. The angle of the well bore axis with reference to vertical and the horizontal direction with reference to North.

4.

c. Selection of proper survey instruments to locate lease lines.

Surveying Concepts

1.

d. Are lines running parallel to the equator

2.

c. Related to a surface position or elevation

3.

c. Are divided into 180 lines in the Eastern Hemisphere and 180 lines in the Western Hemisphere.

4.

b. Are measured from 0° to 90°, with 90° being the North or South pole.

5.

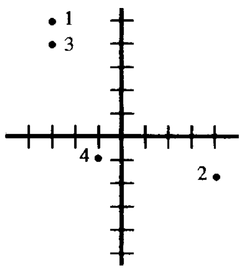
b. Convergence

6.

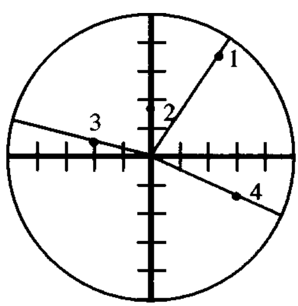
a. 2O ft @ N 45 E

7. b. N5, E7
8. Inclination, Azimuth
9. True Vertical
10. b. A depth reference
11. Vertical
12. Magnetic, True and Grid
13. c. From Magnetic North to True North
14. c. 125”
15. Systematic
16. Inclination, Azimuth
17. b. Dog leg
18. d. High side

19. b. compass readings to be incorrect
20. Vertical Section
21. Closure
22. b. TVD
23. c. 135
24. Inclination
25. True
26. East
27.



28.



Tools

1. c. Mechanical angle units and film based cameras
2. Drill string magnetism
3. 20.75
4. Initial Directional Gyro Alignment; Rate of Rotation
5. b. Track the bit’s progress while the well is being drilled
6.
   a. Compass and angle unit
   b. Camera
   c. Timing Device
   d. Battery Pack

5. b. Compass card
6. a. Pendulum and ring glass with scale
7. b. Is a succession of surveys taken at regular depth intervals
8. c. Wireline steering tool
9. Magnetic Dip and Field Strength
10. c. Casing has been run or magnetic interference is present
11. d. All of theabove
12. d. The casing is less than 7 inch
13. d. All of the above
14.
    a. Target size
    b. Latitude of Well
    c. Target Direction
    d. Type of Drilling Installation

e. Rig cost

f. Maximum Inclination Planned

g. Formation and Hole Conditions

Survey Calculation Methods

1. a. Radius of Curvature
2. b. Minimum Curvature
3. a. Radius of Curvature; b. Minimum Curvature
4. b. Minimum Curvature
5. c. Average Angle

Questions to Ask

References

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•Notes•

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