The influence of geodetic datum on seismic data for petroleum exploration

Ricardo Lomba de Araujo, PETROBRAS S/A, Brazil

This paper was prepared for presentation at the 8th International Congress of The Brazilian Geophysical Society held in Rio de Janeiro, Brazil, September, 14 -18, 2003.

Abstract

This paper presents the concepts of Geodetic Datum,also known as Reference System, its use in field surveying of seismic data and how errors affect the petroleum exploration

Introduction

To introduce the paper, it is important to show what is geodesy. The Webster Dictionary defines geodesy as "that branch of applied mathematics which determines by observation and measurement the exact positions of points and the figures and areas of large portions of the earth's surface, the shape and size of the earth, and the variations of terrestrial gravity." To study the earth characteristics we need a coordinate system. To define a coordinate system we need to know the earth shape.

Earth shape history

Over the years, man has been concerned about the earth's shape and size and how to represent it on a map. After the flat disc theory, the spherical shape was the most widely accepted and the size of the this sphere was first determined by Eratosthenes in his classic work (circumference of the earth = 25,000 miles). Another ancient measurement of the size of the earth was made by Posidonius, who computed the circumference of the earth as 24,000 miles. Revising the figures of Posidonius, Ptolemy, another Greek philosopher, determined 18,000 miles as the earth's circumference. The maps of Ptolemy strongly influenced the cartographers of the middle ages.

It was not until the 15th century that his concept of the earth's size was revised. During that period the Flemish cartographer, Mercator, made successive reductions in the size of the Mediterranean Sea and all of Europe which had the effect of increasing the size of the earth. In the course of the 17th century, Picard and Cassini (Frenchmen) performed some measurements and concluded that earth was egg-shaped (obviously due to observational errors). The intense controversy between French and English scientists (English claiming that the earth must be flattened, as Newton and Huygens had shown theoretically and the Frenchmen defending their own measurement and were inclined to keep the earth egg-shaped) was settled once and for all, when the French Academy of Sciences sent a geodetic expedition to Peru in 1735 to measure the length of a meridian degree close to the Equator and another to Lapland to make a similar measurement near the Arctic Circle. The measurements conclusively proved the earth to be flattened, as Newton had forecast.

Earth surface

Besides the facts had proven that the earth is flattened, it is necessary to establish a mathematical figure where calculations could be made. The actual topographic surface is the surface on which actual earth measurements are made. But It is not suitable, however, for exact mathematical computations because the formulas which would be required to take the irregularities into account would require a prohibitive amount of computations.

Looking for an appropriated surface and considering that the surface of a liquid in balance is a surface along which the gravity potential is everywhere equal and to which the direction of gravity is always perpendicular and that approximately 70% of earth surface is covered by water, some scientists claimed the use of a surface, named geoid. The geoid coincides with that surface to which the oceans would conform over the entire earth. As a result of the uneven distribution of the earth's mass, the geoidal surface is irregular and therefore, also not suitable for exact mathematical computations.

While the sphere is a close approximation of the true figure of the earth and satisfactory for many purposes, to the geodesists and to more accurate measurements, a more exact figure is necessary. Since the earth is in fact flattened slightly at the poles, the geometrical figure used in geodesy that most approximate the shape of the earth is an ellipsoid of revolution. The ellipsoid of revolution is the figure which would be obtained by rotating an ellipse about its shorter axis. Resuming, we can say that we have three different earth surfaces as shown in figure 1.

Datum or reference system

Established the ellipsoid as the mathematically defined regular surface, we still have to define its dimensions. An ellipsoid of revolution is uniquely defined by specifying two dimensions. Geodesists, by convention, use the semi major-axis (a) and flattening (f), which indicates how closely an ellipsoid approaches a spherical shape. Fixed the ellipsoid size, the last thing to do is to establish where the ellipsoid is located related to the earth topographical surface. We can say that, depending on the earth region you want, there could be a better-fitted ellipsoid, as shown in figure 2. Therefore, there are several ellipsoids used in geodesy.

The older ellipsoids were named for the individual who derived them and the year of development is given. The international ellipsoid was developed by Hayford in 1910 and recommended by the International Union of Geodesy and Geophysics (IUGG) for international use in 1924. The GRS-67 ellipsoid was recommended by the IUGG 1967 meeting. It is used in South America for the South American Datum 1969, and also in Australia. Others ellipsoids currently used are: the Clarke-1880, Clarke-1866, Bessel-1841, Airy-1830, Everest-1830,Krassowsky-1940 and GRS-80.

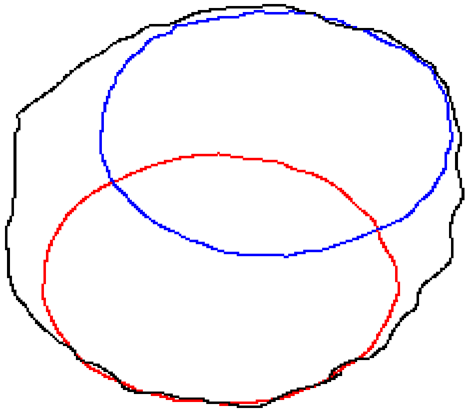

Figure 2 - Best fitted ellipsoid

When we define an ellipsoid and its position related to the earth (or its orientation) we are defining a reference system or a geodetic datum. Therefore, a horizontal geodetic datum consists of an ellipsoid (size and shape = semi-major axis and flattening), the longitude and latitude of an initial point (origin) and an azimuth of a line (direction) to some other triangulation station.

There are different methods of orientation: single astronomic station datum orientation, astro-geodetic datum orientation and gravimetric datum orientation. The study of these methods is outside the scope of this paper.

Geodetic Coordinates

Since we already have a datum, it is now possible to define a coordinate system. The basic coordinate system is known as geodetic coordinates (latitude and longitude).

There are some specials lines and plans that we should define. Considering the earth as an ellipsoid, the plan that is orthogonal to the shorter axis and contains the center of the ellipsoid is called the Equator. As will be seen, the Equator is the origin for latitude measurements. Any plan that contains the minor axis is called a meridian. A special one, the meridian through a place near London, named Greenwich, is used as the origin for geodetic longitude.

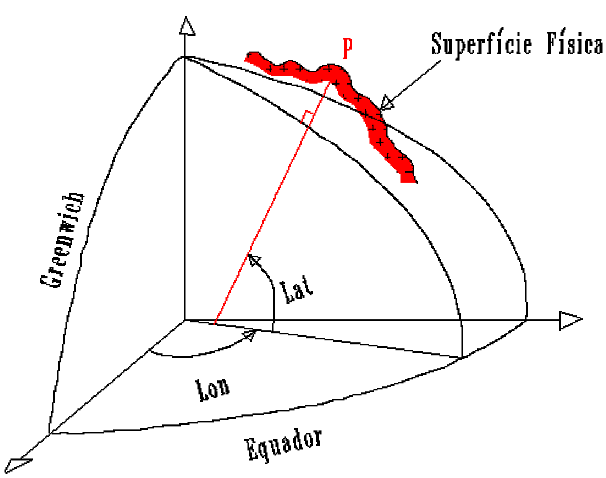

Figure 3 : Geodetic coordinates

Geodetic latitude of a point is the angle between the straight line that goes by the point and is orthogonal to the ellipsoid surface and the Equator plan. Geodetic longitude is the angle between the point meridian and the Greenwich meridian. Figure 3 shows the geodetic coordinates.

As seen above, the straight line that goes by the point and is orthogonal to the ellipsoid surface is the most important line to define latitude and longitude. It is important to notice that, if the ellipsoid is changed (in size or orientation) and the topographic surface is static, latitude and longitude will also change. Therefore, geodetic coordinates are extremely dependent on the ellipsoid size and orientation. This means that every point on the earth surface has a different coordinate on each datum. And this is the major source of erros in geodesy.

Datums used in Brazil

The official datum to be used in Brazil is the South American Datum 1969. In 1965 the Working Group for the Study of the South American Datum was asked by the Committee for Geodesy of the Cartographic Commission of the Pan American Institute of Geography and History (PAIGH) to establish one consistent geodetic datum for the entire continent of South America. In June 1969, the "South American Datum 1969 (SAD-69)" was accepted by the Commission at the IX General Assembly of PAIGH in Washington, D.C. This datum is computed on the GRS 67 Ellipsoid. CHUA, the National datum point of Brazil was taken to be the origin.

Although the official reference system of Brazil is the SAD-69, there are several others datums used in Brazil. Córrego Alegre (International ellipsoid 1924 or Hayford ellipsoid) was the official datum before SAD-69 and there are still lots of data referred to this datum. Another used datum is Aratu. When Petrobras began to work on the northeast of Brazil, there wasn't any fundamental geodetic network in this region. So, Petrobras created its own datum, named Aratu. This datum uses the Hayford ellipsoid and its orientation was done using the single astronomic station datum orientation. Also before SAD-69, there was the Provisional South America Datum of 1956 (PSAD-56). And today, as all around the world, there is the World Geodetic System 1984 (WGS-84) and the less known SIRGAS (in portuguese: "Sistema Referencial Geocêntrico para as Americas" - Reference Geocentric System for the Americas). Figure 4 shows the regional distribution for the datums used in Brazil.

Map Projections

Usually, another last step is to project points located on the ellipsoid surface onto a plan or a mathematical figure that can be transformed in to a plane, like a cylinder or a cone. This is called a cartographic projection. With this process we now have the points in a cartesian coordinate system. The most known cartographic projection is the Universal Transverse Mercator – UTM, where a transverse cylinder is used. Another important map projection is the Polyconic. As the cartesian projection coordinates are mathematically derived from geodetic coordinates, they also are directly dependent on the datum.

How datum error affect the oil exploration data

Although there are formulas to change coordinates from one datum to another (Molodensky Datum Transformation Formulas, where the major parameters are the shifts between the centers of the two ellipsoids), several common mistakes may occur when manipulating geospatial data. One of then is to mix coordinates from different datums. Since datum is a reference system, you should never mix coordinates referred to different references systems. This usually happens when combining old and new data or combining data from different sources. Another mistake can occur when you don't know the datum of your data and just suppose what datum is it. Moreover, special attention must be taken in account when transforming from one datum to another, since others problems may occur. The fact that the Aratu datum requires different parameters (X, Y and Z shifts) according to the region of Brazil may causes the use of wrong parameters. Someone that had worked with Aratu at the northeast area of Brazil may use northeast parameters at the south region. Another mistake may occur when using computer programs with parameters imbedded. In most cases these programs use the parameters published by the National Imagery and Mapping Agency (NIMA), wich are a few different from those recommended by the Instituto Brasileiro de Geografia e Estatística (IBGE), the official government agency for Geodesy and Cartography. The above mistakes can make you point to a wrong target. For example, suppose that you got seismic data that is really referred to WGS-84 and you are informed that it is referred to Aratu datum. You work on it and suggest a new well location, at an X Y coordinate. Then, you give this coordinates to the surveyor and tell him that they are referred to Aratu. The result is that the well will be drilled 200 m away the location you really wanted. Figure 5, extracted from NIMA's home page, shows an analog target error due to datum error.

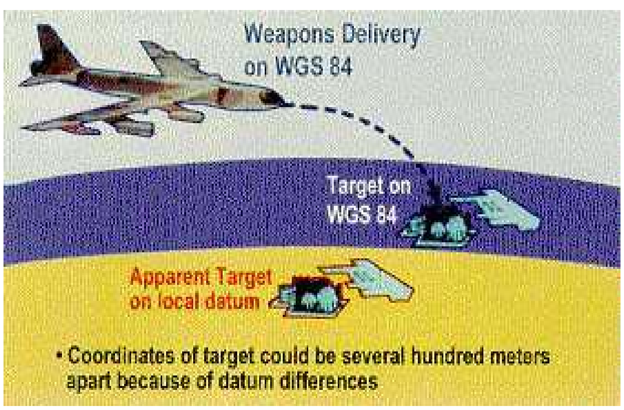

Figure 5: target error due to datum error

Table 1 shows the order of magnitude of the errors that occurs when considering a coordinate referred to one datum instead the correct one. The table lists the five most used datums in Brazil (Aratu, WGS-84,SAD-69, PSAD-56 e Córrego Alegre) and the errors for each pair. It shows that errors vary from 10 to 370 m. using data referred to Aratu as it was referred to WGS-84 (or vice-versa) causes positioning errors of 210 m. The same error occurs when using Aratu data as it was SAD-69. Certainly, drilling a well 200 m away from the correct location can result in a wrong reservoir determination or in a well without oil. And, obviously, it would also result in money wasting. Mixing data fro different datums will led to the same magnitude of errors.

	ARATU	WGS 84	SAD 69	PSAD 56	CÓRREGO ALEGRE
ARATU	----	210 m	210 m	305 m	205 m
WGS-84	210 m	---	60 m	370 m	10 m
SAD-69	210 m	60 m	---	310 m	55 m
PSAD-56	305 m	370 m	310 m	---	360 m
CÓRREGO ALEGRE	205 m	10 m	55 m	360 m	---

Table 1: magnitude of datum errors

Using Aratu to WGS-84 shifts from a wrong region can led to errors of 20 m (example: using the shifts from the northeast region at Campos Basin region). Using NIMA's shifts instead of IBGE's shifts results in less large errors, about 4 meters.

Summary and Conclusions

Although datum and map projections are very important in petroleum exploration, geologists are not used to handle with them. Using a wrong datum can led you to a wrong interpretation and can result in spending yours company money. Be aware about what datum is used and don't mix data with different datum. Include datum as a common parameter of your project and coordinates

References

DMA Technical Report,1983, Geodesy for the layman
Araújo,Ricardo L., R. J., 1991, Noções básicas de cartografia e geodésia : apostila interna da Petrobras.

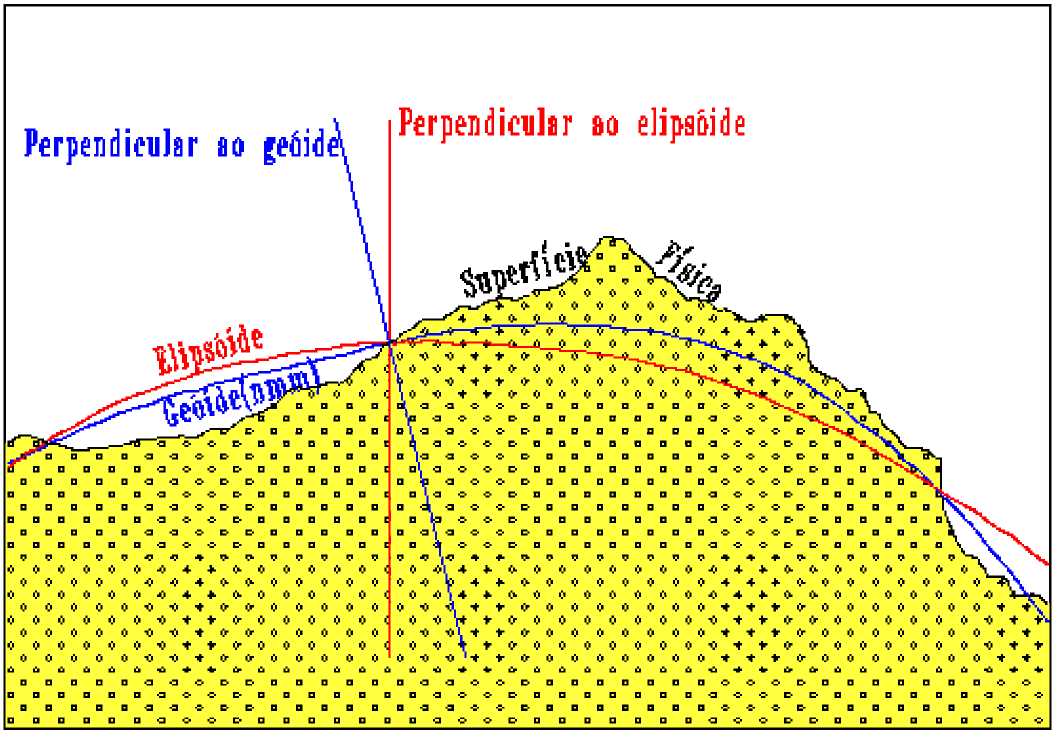

Figure 1: The three surfaces used in geodesy

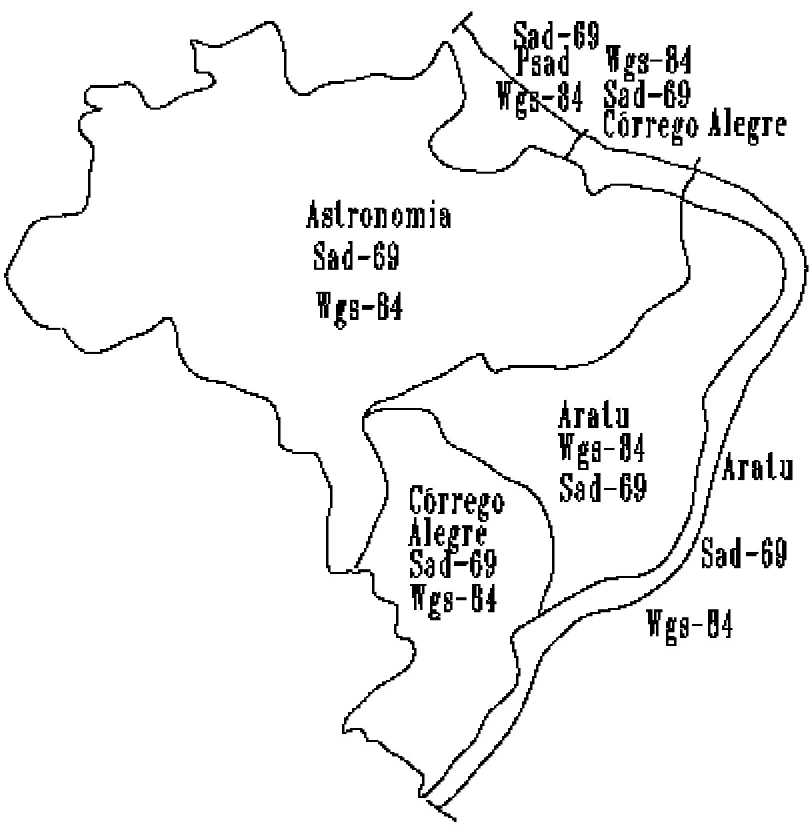

Figure 4: Datums used in Brazil