Chapter 3

Surface Geophysical Petroleum Exploration Methods

3.1 Introduction

Surface geophysical techniques determine density, magnetic, and acoustical properties of a geologic medium. Three geophysical methods used in petroleum exploration comprise magnetic, gravimetric, and seismic (including refraction/reflection) techniques. The magnetic and gravity methods are used only in primary surveys where little is known of the subsurface geology and/or the thickness of sediments of potential prospective interest. The seismic reflection method is universally used for determining the underground geological structure of a reservoir rock in a certain area. The method(s) selected will depend on the type of information needed, the nature of the subsurface materials, and the cultural interference.

3.2 Magnetic Survey

A magnetic survey is primarily used to explore for oil and minerals. Magnetic exploration is based on the fact that the earth acts as a magnet. Any magnetic material placed in an external field will have magnetic poles induced upon its surface. The induced magnetization (sometimes called polarization) is in the direction of the applied field, and its strength is proportional to the strength of that field. The location of an area in relation to the magnetic poles is measured by the inclination of the earth's field or the "magnetic inclination" (USGS, U.S. Army, 1998).

Aeromagnetic Surveys were developed in wartime to overcome the problem of detecting submerged submarines from aircraft; they have since gained considerable success in petroleum and mineral exploration. Both the aeromagnetic surveys and the airborne radioactivity surveys can be classified as "remote sensing techniques." The advantages of the use of airborne surveys over ground instruments are the speed of the surveys and the possibility of reaching otherwise inaccessible areas.

3.3 Gravimetric Survey

Variations in gravity depend upon lateral changes in the density of earth materials in the vicinity of the measuring point. Many types of rocks have characteristic ranges of densities, which may differ from other types that are laterally adjacent. Driscoll (1986) stated that the earth's gravitational attraction at a particular site is a function of the density of the surface sediments and the underlying rock units. The density variations may be attributed to changes in rock type (porosity or grain density), degree of saturation, fault zones, and the varying thickness of unconsolidated sediments overlying the bedrock. Thus an anomaly in the earth's gravitational attraction can be related to a buried geological feature, e.g., a salt dome or other deposit which has limited horizontal extent. Actually, all geophysical surveys concentrate on the discovery of "anomalies" in the rocks which overlie or surround possible petroleum accumulation.

F.A. Assaad, *Field Methods for Petroleum Geologists*,

3.4 Seismic Exploration Survey

3.4.1 General

The word "seismic" refers to vibrations of the earth, including both earthquakes and artificially created sound waves that penetrate into the earth. Sounds measured are in the frequency range of about 10–100 cycles s^{-1}. The depths investigated for a sound to travel into the earth and return are as much as 16 km.

Seismic investigations depend on the fact that elastic waves (or seismic waves) travel with different velocities in different rocks. It is possible to determine the velocity distribution and locate subsurface interfaces where the waves are reflected or refracted by generating seismic waves at a given point and observing the times of arrival of those waves at a number of other points (or stations) on the surface of the earth.

Seismic surveys which are based on the velocity distribution of artificially generated seismic waves in the ground are produced by hammering on a metal plate, by dropping a heavy ball, or by using explosives. Energy from these sources is transmitted through the ground by elastic waves, which are so called because, when the waves pass a given point in the rock, the particles are momentarily displaced or disturbed, but immediately return to their original position or shape after the wave passes.

3.4.2 Seismic Refraction Methods

Seismic refraction methods were originally developed to locate concealed masses of salt plugs (e.g., in Algieria, Mexico, and Germany), and to trace major anticlinal axes in massive limestones (e.g., in Iran) which could not be located with surface geology. In both cases, the resulting shock waves caused by the explosives travel faster through salt and limestone than through the associated sedimentary rocks. Seismic refraction is also a useful reconnaissance tool for determining the depth of a high velocity metamorphic or igneous basement below a small sedimentary basin, etc.; each geologic formation has a characteristic seismic velocity that affects the arrival time.

3.4.3 Seismic Reflection Method

The seismic reflection method depends on the echo sounding principle and is a special tool for oil and gas exploration; it records reflected shock waves from a number of successive beds and their angle of inclination along the line of observation. The method uses a seismic wave produced by a weight dropping, a hammer blow, or another seismic source that is reflected off the bedrock and returns directly to the geophone, where the elapsed time is recorded. Hammer stations are usually at 9.1 m or less from the geophone to maximize the reliability of the reflected wave energy. The operator strikes a hammer plate at five to ten sites that are within 9.1 m of the geophone. The seismic signals received from these sites are summed automatically by the seismograph, canceling out the surface waves and other extraneous impulses, and the primary reflected wave is prominently displayed on the cathode ray tube (Driscoll 1986).

3.4.3.1 Multiple Reflections and Marine Exploration

Special ships allow rapid surveying in marine exploration where the presence of water as the medium for inducing the shock waves give remarkably good results. A system known as vibroseis employs a non-impulsive sound source with transmitters like huge loudspeakers with their diaphragms pressed against the ground. Because the seismic signal is quite unrecognizable until it is "pulse-compressed" by the correlation process, the vibroseis input can be regarded as a degenerate form of seismic impulse. Degeneration of a seismic impulse often occurs naturally in its travel through the earth, the commonest form being reverberation in a "ringing layer." Ringing is often a big problem in marine exploration. The shot has two very good reflecting interfaces immediately above and below it, namely, the sea surface and the sea bed. The downward traveling impulse from the shot is followed closely by a reflection from the sea surface, and when reaching the sea bed, it is partially reflected back to the surface, only to be once again sent on a downward course. Therefore the initial downward wave has three "ghosts" following it, leading to an endless process; this process continues as part of the more general problem of multiple reflections (Tarrant 1973).

3.4.3.2 Seismic Profiling of Diapiric Structures

The reflecting seismic process records reflections from acoustic discontinuities in the subsurface by generating a sound wave near the surface and detecting the reflected energy return from subsurface discontinuities.

Features associated with salt domes identified by seismic sections are radial faulting, the doming of overlying strata, the dip of sediments on the flank, nonconformity and wedging effects, and the development of rim synclines. A modeling process permits accurate interpretation of these features, e.g., piercement diapirs, salt dome structures at different stages of development, and associated geologic phenomena, thus increasing success in drilling for hydrocarbon reserves.

3.5 Land-Satellite Images in Salt Dome Exploration

Evaporites, including salt domes, are formed by the evaporation of brines because of dryness in arid conditions; they are normally interbedded with carbonate rocks together with red and green shales in cyclical sequences. In some parts of the world, buried evaporite beds lie several hundreds of meters beneath the ground surface, and have generated salt plugs or salt domes which have moved upwards through the overlying beds and probably appear on the surface in "diapiric" or piercing plastic flow, e.g., the Zechstein of North Germany, the Triassic of the Gulf region and Algieria, as well as the Miocene of the Suez Canal of Egypt.

Normal aerial photographs can be used to detect certain geological and ecological features peripheral to many ore deposits or oil and gas fields. Landsat images can be used by adapting remote sensing methods to the images; early space imagery displaced extended structural elements such as closed anticlines, domes, intrusive bodies, folded mountain belts, fault zones, and regional joint patterns.

Remote sensing data obtained from satellite images are most beneficial to proper and more accurate interpretations of the earth's surface. The use of aircraft to obtain data in locating a resource target considerably reduces the cost of exploration, but the use of spacecraft to obtain remote sensing information reduces the overall cost of the ground survey even further; and therefore "the higher we go, the deeper we can see" (Trollinger 1968).

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