Practical Petroleum Geology

Second Edition

THE UNIVERSITY OF TEXAS AT AUSTIN · PETROLEUM EXTENSION SERVICE

Contents

Units of Measurement

Throughout the world, two systems of measurement dominate: the English system and the metric system. Today, the United States is one of only a few countries that employ the English system.

The English system uses the pound as the unit of weight, the foot as the unit of length, and the gallon as the unit of capacity. In the English system, for example, 1 foot equals 12 inches, 1 yard equals 36 inches, and 1 mile equals 5,280 feet or 1,760 yards.

The metric system uses the gram as the unit of weight, the metre as the unit of length, and the litre as the unit of capacity. In the metric system, 1 metre equals 10 decimetres, 100 centimetres, or 1,000 millimetres. A kilometre equals 1,000 metres. The metric system, unlike the English system, uses a base of 10; thus, it is easy to convert from one unit to another. To convert from one unit to another in the English system, you must memorize or look up the values.

In the late 1970s, the Eleventh General Conference on Weights and Measures described and adopted the Systeme International (SI) d'Unites. Conference participants based the SI system on the metric system and designed it as an international standard of measurement.

The Rotary Drilling Series gives both English and SI units. And because the SI system employs the British spelling of many of the terms, the book follows those spelling rules as well. The unit of length, for example, is metre, not meter. (Note, however, that the unit of weight is gram, not gramme.)

To aid U.S. readers in making and understanding the conversion system, we include the table on the next page.

English-Units-to-SI-Units Conversion Factors

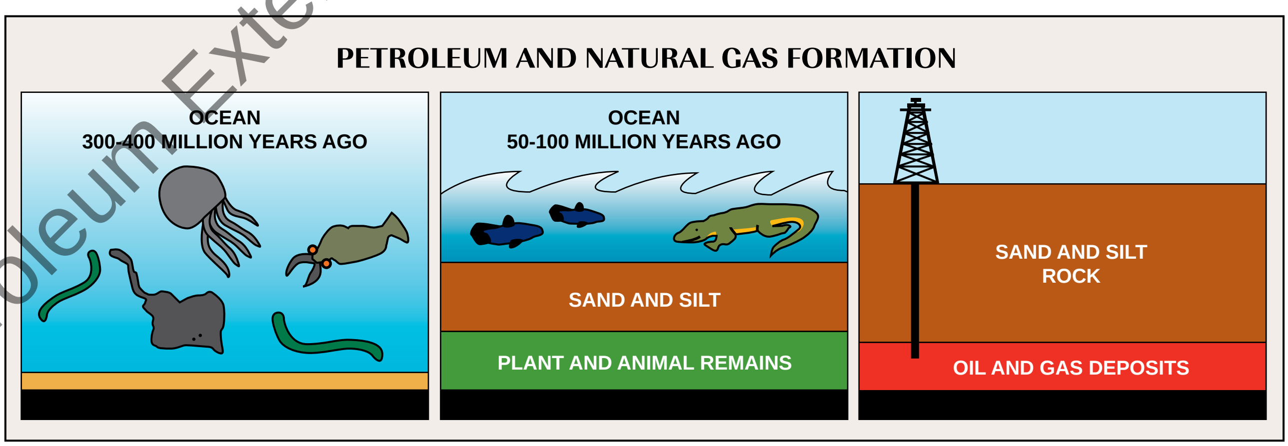
Quantity or Property	English Units	Multiply English Units By	To Obtain These SI Units
Length, depth, or height	inches (in.)	25.4	millimetres (mm)
		2.54	centimetres (cm)
	feet (ft)	0.3048	metres (m)
	yards (yd)	0.9144	metres (m)
	miles (mi)	1609.344	metres (m)
		1.61	kilometres (km)
Hole and pipe diameters, bit size	inches (in.)	25.4	millimetres (mm)
Drilling rate	feet per hour (ft/h)	0.3048	metres per hour (m/h)
Weight on bit	pounds (lb)	0.445	decanewtons (dN)
Nozzle size	32nds of an inch	0.8	millimetres (mm)
Volume	barrels (bbl)	0.159	cubic metres (m^3)
		159	litres (L)
	gallons per stroke (gal/stroke)	0.00379	cubic metres per stroke (m^3/stroke)
	ounces (oz)	29.57	millilitres (mL)
	cubic inches ($in.^3$)	16.387	cubic centimetres (cm^3)
	cubic feet (ft^3)	28.3169	litres (L)
		0.0283	cubic metres (m^3)
	quarts (qt)	0.9464	litres (L)
	gallons (gal)	3.7854	litres (L)
	gallons (gal)	0.00379	cubic metres (m^3)
	pounds per barrel (lb/bbl)	2.895	kilograms per cubic metre (kg/m^3)
	barrels per ton (bbl/tn)	0.175	cubic metres per tonne (m^3/t)
Pump output and flow rate	gallons per minute (gpm)	0.00379	cubic metres per minute (m^3/min)
	gallons per hour (gph)	0.00379	cubic metres per hour (m^3/h)
	barrels per stroke (bbl/stroke)	0.159	cubic metres per stroke (m^3/stroke)
	barrels per minute (bbl/min)	0.159	cubic metres per minute (m^3/min)
Pressure	pounds per square inch (psi)	6.895	kilopascals (kPa)
		0.006895	megapascals (MPa)
Temperature	degrees Fahrenheit (°F)	$\frac{°F - 32}{1.8}$	degrees Celsius (°C)
Mass (weight)	ounces (oz)	28.35	grams (g)
	pounds (lb)	453.59	grams (g)
		0.4536	kilograms (kg)
	tons (tn)	0.9072	tonnes (t)
	pounds per foot (lb/ft)	1.488	kilograms per metre (kg/m)
Mud weight	pounds per gallon (ppg)	119.82	kilograms per cubic metre (kg/m^3)
	pounds per cubic foot (lb/ft^3)	16.0	kilograms per cubic metre (kg/m^3)
Pressure gradient	pounds per square inch per foot (psi/ft)	22.621	kilopascals per metre (kPa/m)
Funnel viscosity	seconds per quart (s/qt)	1.057	seconds per litre (s/L)
Yield point	pounds per 100 square feet (lb/100 ft^2)	0.48	pascals (Pa)
Gel strength	pounds per 100 square feet (lb/100 ft^2)	0.48	pascals (Pa)
Filter cake thickness	32nds of an inch	0.8	millimetres (mm)
Power	horsepower (hp)	0.75	kilowatts (kW)
Area	square inches ($in.^2$)	6.45	square centimetres (cm^2)
	square feet (ft^2)	0.0929	square metres (m^2)
	square yards (yd^2)	0.8361	square metres (m^2)
	square miles (mi^2)	2.59	square kilometres (km^2)
	acre (ac)	0.40	hectare (ha)
Drilling line wear	ton-miles (tn•mi)	14.317	megajoules (MJ)
		1.459	tonne-kilometres (t•km)
Torque	foot-pounds (ft•lb)	1.3558	newton metres (N•m)

Introduction

Any examination of the subject of *petroleum geology* must first begin with a brief consideration of where the petroleum came from in the first place.

The popular *organic theory* states that the hydrogen and carbon that make up petroleum come from the remains of microscopic organisms that lived in the rivers and seas covering the Earth's surface millions of years ago. As these organisms died, they fell to the ocean floor and mixed with silt, sand, and mud. Eventually, a thick body of *sediments* enriched by the organic remains accumulated on the bottom of the ocean.

Over a very long period of time, the great weight of the overlying sediments pushed the lower layers deep into the Earth and changed the bottom beds into rock. In such an environment, the high heat and intense *pressure*—along with bacteria, chemical reactions, and other forces—had a profound effect on the organic remains. The remains were transformed into petroleum, which subsequently found a home within the rock's small porous spaces (fig. i.1).



Source: U. S. Department of Energy, Energy Information Administration

Figure i.1 Petroleum formation

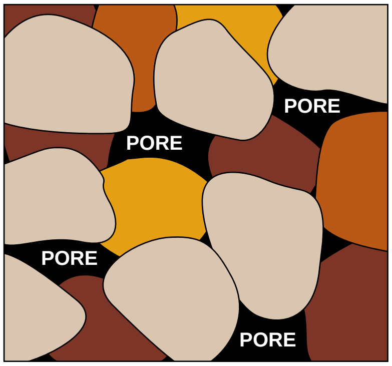


Figure i.2 Porosity within rock (magnified view)

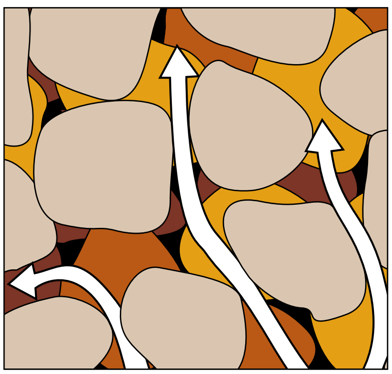


Figure i.3 Connected pores resulting in permeability (magnified view)

One common misconception about the nature of petroleum is that it exists in large underground formations that are similar to flowing rivers and lakes. Instead, most petroleum is found within rocks. Some rocks have a high *porosity* and allow for a large amount of petroleum to reside in the pores. Other rocks have few pores, which allows for less petroleum (fig. i.2).

Over time, as the Earth shifted, *folds*, *faults*, and other formations opened new channels through which the petroleum in the rock layers could flow. Rock layers with high *permeability* allowed the petroleum to flow more easily through the rock's pores, whereas rock layers with low permeability had the opposite effect (fig. i.3).

Eventually, the petroleum moved around and became trapped by impervious layers of rock. These areas—called *traps*—kept the *hydrocarbons* within porous layers of rock, thereby forming *reservoirs*. A reservoir's size is determined by the amount of oil and gas it contains. A reservoir might be broad and shallow, narrow and deep, or any variation in size. And it is these reservoirs that drillers want to find and tap.

Armed with this knowledge of the origins of petroleum, we can now focus on the main topic of the book: petroleum geology.

In this chapter:

- The principle of uniformitarianism
- Geologic time and the origins of the Earth
- Plate tectonics and the effects of a mobile crust
- Types of rocks and minerals

1
Basic Concepts of Geology

What comes to mind when you hear the word *geology*? We tend to think of geology in terms of landscapes too vast to fully comprehend—volcanoes, mountain ranges, canyons—created by forces beyond our control. We also tend to think of the beauty and power of the natural world—such as the landscapes in Arches National Park or the eruption of Mount St. Helens (figs. 1.1 and 1.2).

Figure 1.1 Arches National Park

In this chapter:

- The means by which sedimentary rock is formed
- The transport and deposition of sedimentary particles
- Lithification and classification of sedimentary rocks
- The principles of stratigraphy

2
Sedimentation

Because nearly all of the world's supply of petroleum is found in sedimentary rock, it is the most interesting type of rock for petroleum geologists. To understand the correlation between petroleum and sedimentary rock, we must learn more about *sedimentation*—in other words, how sedimentary particles are formed, transported, deposited, and transformed into the great sheets of rock that cover most of the world's land area.

ORIGINS OF SEDIMENTARY PARTICLES

The process by which sedimentary rock is formed can perhaps best be demonstrated by examining its smallest unit—the sedimentary particle. As does the rock as a whole, the individual particle embodies the history of both its source material and the changes it undergoes on the Earth's surface.

Clastics

Sediments are classified primarily by grain size (table 2.1). Gravel, sand, and silt particles can be of a variety of minerals—quartz and feldspar are common—while clay particles are microscopic platelets of various hydrous aluminum silicates. Gravel, sand, and silt are mostly noncohesive; that is, they do not stick together. Clay, on the other hand, is very cohesive; its particles are attracted to one another by minute electrical charges and *adsorb* water readily, causing clay to swell.

In this chapter:

- The origins of petroleum
- Primary and secondary migration of petroleum
- The methods by which petroleum accumulates
- Types of traps and their characteristics

3
Oil and Gas Accumulation

For most of the time that humans have been aware of oil and natural gas, these substances were thought of as minerals that had formed out of nonliving rock, such as gold, sulfur, and salt. Although oil had an odor suggesting organic matter and although natural gas burned like swamp gas, most of the gas and oil escaping from the ground seemed to come from solid rock deep beneath the surface, where nothing lived.

However, beginning about two centuries ago, the geologic insights of scientists such as James Hutton, Charles Lyell, and others showed that the rocks in which oil was found were once loose sediment piling up in shallow coastal waters where fish, algae, plankton, and corals had once lived. As a result of such insights, it seemed possible that oil and gas had something to do with the decay of dead organisms, just as coal, with its leaf and stem imprints, seemed to be the fossilized remains of swamp plants.

Later advances in microscopy revealed that oil-producing and oil-bearing rocks often contain fossilized creatures too small to be seen with the unaided eye. Chemists discovered that carbon:hydrogen ratios in petroleum are much like those in marine organisms and that certain complex molecules are found in petroleum *source rocks* that are otherwise known to occur only in living cells. But it was the fact that most could be shown to have originated in an environment rich with life that clinched the organic theory of the origin of petroleum.

In this chapter:

- Collecting data using survey tools and databases
- The evolution of seismic surveys and interpretation
- Types of well logs and core samples
- Contour maps and digital models

4 Exploration

In the past, exploring for petroleum was a matter of good luck and guesswork. In the early days of exploration, drilling near oil or natural gas seeps where hydrocarbons were present on the surface was the most successful method for finding hydrocarbons under the ground. Today, petroleum *explorationists* with extensive geologic training use sophisticated technologies and scientific principles and guidelines to find oil and gas.

Surface and subsurface geologic studies drive the discovery of oil and gas. *Seismic data*, *well log* data, aerial photographs, satellite images, gravity and magnetic data, and other geologic data provide information that help determine where to drill an exploratory well. Specialists examine rock fragments and *core* samples brought up while drilling the exploratory well and run special tools into the hole to get more information about the formations underground. By examining, correlating, and interpreting this information, explorationists can accurately locate subsurface structures that might contain hydrocarbon accumulations worth exploiting.

SURFACE GEOGRAPHICAL STUDIES

In relatively unexplored areas, petroleum explorationists study the topography of the surrounding land. The natural and manmade features on the surface of the land can help explorationists to draw conclusion about the character of underground formations and structures based largely on what appears on the surface.

In this chapter:

- Summary of an economic analysis
- Mineral rights and estimated reserves
- Regulation and taxation considerations
- Cash flow analysis, present value concept, and risk analysis

5
Economics

When the ultimate decision of whether to drill is made, other data are evaluated along with all of the preliminary geophysical and geologic evidence. Many of these added considerations are financial and practical ones. A modern geologist has to be acquainted with the factors influencing *wellhead* and product pricing, transportation costs, fluctuations in supply and demand, associated political situations, and regulation and taxation, as well as the current costs of drilling.

All of these factors are balanced and weighed. Much of this type of evaluation is done at the managerial level of the operating company; however, because the geologist is often concurrently evaluating physical evidence, the two types of data become closely related. Therefore, some economic and legal knowledge on the part of the geologist is required.

In this chapter:

- Methods for logging
- Formation testing
- Completion methods and equipment
- Initiation of flow and exploration success

6 Monitoring the Well

The commitment to drill an exploratory well sets in motion a long chain of events. Well plans are engineered, and the site is surveyed and prepared for the drilling rig (fig. 6.1).

Figure 6.1 Surveying using a global positioning system

In this chapter:

- Productivity, efficiency, and types of maps
- Mathematical estimation of reserves
- Models and simulation
- Recovery improvement

7 Field Development

EXPANDING AND MAINTAINING PRODUCTIVITY

Developing a field requires a solid grasp of regional geology and reliable well data. It is desirable to have a single geologist or a single team working on development because so much depends on the previous history of each drilled well. While the exploration program might call for perhaps three wells to locate the structural crest along a simple anticlinal structure, the development program moves to account for the complexities of the reservoir. Productivity within the structure will vary.

Selecting Well Sites

Selecting sites for the wells to succeed the discovery well requires the geologist to visualize the reservoir below the surface. Generally the position expected to be structurally highest will be drilled first. This and the next few well sites are commonly picked on the basis of the seismic picture. As wells are drilled, formation velocity surveys of the reflecting surfaces are made downhole. These surveys enable the seismic maps to be expressed more accurately in terms of depth; as a result, a better picture of the structural high can be generated. As subsurface contour maps are developed by the geologist, these maps replace the seismic picture for decision-making purposes.

Afterword

A substantial portion of the process of delivering petroleum to the companies who sell it in its various forms and, subsequently, to the consumers who buy it takes place long past the point when a geologist need be involved. But no part of the industry would exist if the petroleum were not first discovered where it had been slowly forming and collecting within the Earth for millions of years. And it is within this discovery phase that an understanding of petroleum geology is essential.

The petroleum geologist knows that the Earth is an ever-changing place and that the forces at work today have been at work for all of the billions of years of our planet's history. The petroleum geologist knows how organic matter was transformed in oil and gas over vast lengths of time. The petroleum geologist knows the properties of the rocks wherein the oil and gas hide and the irregularities within such rocks. The petroleum geologist knows how petroleum accumulates and migrates and the kinds of areas where it becomes trapped. The petroleum geologist knows how to explore formations and the ways in which to narrow the odds in favor of discovery. And based in part on these things that the petroleum geologist knows, companies in search of undiscovered oil and gas can analyze the economics of a venture, test the formations being drilled, and develop fields to meet the worldwide demand for oil and gas.

As was said at the outset of this book, unique challenges present themselves with each new drilling endeavor, and each well comes with its own particular set of traits. But in an inherently unpredictable field, the importance of the petroleum geologist and the knowledge she or he brings to bear remains constant.

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