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Types of Rocks

The earth's crust is made up of three types of rock: igneous, sedimentary, and metamorphic. *Igneous rocks* have crystallized from a hot, molten liquid. *Sedimentary rocks* are composed of sediments, particles that were deposited on the surface of the ground or bottom of the ocean or from salts that precipitated out of water. *Metamorphic rocks* have been recrystallized from other rocks under high temperatures and pressures.

Igneous Rocks

Igneous rocks form when a molten melt has cooled. Two types of igneous rocks are plutonic and volcanic, depending on where they formed. *Plutonic* igneous rocks crystallized and solidified while still below the surface of the earth. Because the solid rocks that surround the cooling plutonic rocks are good insulators, plutonic rocks often take thousands of years to solidify. When given a long time to crystallize, large mineral crystals grow. Plutonic igneous rocks are easy to identify because the mineral grains are all large enough to be seen by the naked eye (plate 2-1). Plutonic igneous rocks formed as hot liquids that were injected into and displaced preexisting rocks in the subsurface (fig. 2-1). Because of this, now solidified plutonic rock bodies are called *intrusions*. *Volcanic* igneous rocks crystallize on the surface of the earth as lava. As the lava flows out of a volcano, it immediately comes in contact with air or water and rapidly solidifies. The rapid crystallization only allows very small crystals to form that are difficult to distinguish with the naked eye. In general, igneous rocks are harder to drill than sedimentary rocks. Buried lava flows and intrusions are occasionally encountered when drilling through sedimentary rocks for gas and oil and slow the drilling down.

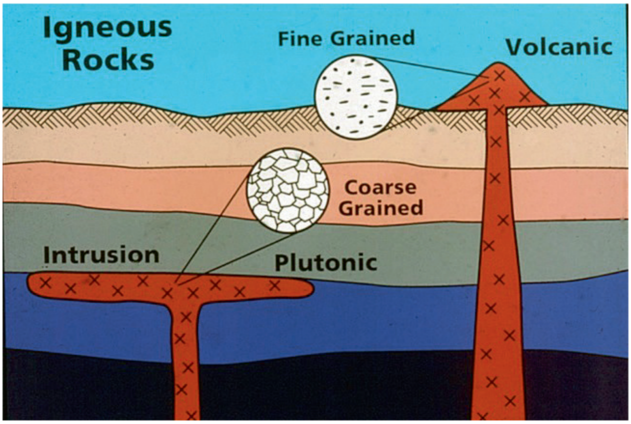

Fig. 2–1. Igneous rocks showing an intrusion of plutonic igneous rocks into sedimentary rock layers and volcanic igneous rocks on the surface along with microscopic views of coarse-grained plutonic and fine-grained volcanic rocks

Sedimentary Rocks

Sedimentary rocks are composed of three types of sediments. *Clastic sediments* are whole particles formed by the breakdown of rocks and were transported and deposited as whole particles. Boulders, sand grains, and mud particles are examples. *Organic sediments* formed biologically such as seashells. *Crystalline sediments* are formed by precipitation of salt out of water. As these sediments are buried in the subsurface, they eventually become solid, sedimentary rocks. Sedimentary rocks are the rocks that are drilled to find gas and oil. They are the source and reservoir rocks for gas and oil.

Loose sediments (*unconsolidated sediments*) become relatively hard sedimentary rocks (*consolidated sediments*) in the subsurface by the processes of natural cementation and compaction. No matter how some sediments such as sand grains are packed together, there will be *pore spaces* between the grains (fig. 2–2). Once the grains have been buried in the subsurface, the pore spaces are naturally filled with groundwater that can be very salty. Under higher subsurface temperatures and pressures, chemicals often precipitate out of the subsurface waters to coat the grains, and some eventually grow together to bridge the loose grains. This process, called *natural cementation*, bonds the loose grains into a solid sedimentary rock. The most common cement is the mineral calcite ($CaCO_3$). Also, as the sediments are buried deeper, the increasing weight of overlying rocks exerts more pressure on the grains. This compacts the sediments and also solidifies the rock.

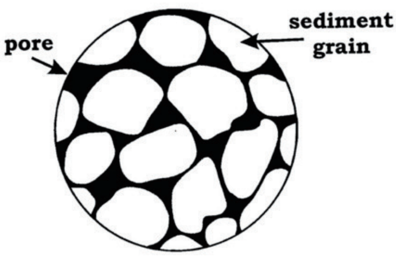

Fig. 2–2. Microscopic view of pores between sediment grains

Clastic sedimentary rocks often consist of three parts when examined under a microscope (fig. 2–3). First, there are sediment grains such as sand. Second, there are natural cements that coat and bond the grains together. Third, there are spaces called *pores*. In the subsurface, these pores are filled with fluids, usually water, but sometimes gas or oil.

There is an enormous amount of water below the surface in sedimentary rock pores called *groundwater* (fig. 2–4). Groundwater is described by salt content in parts per thousand (*ppt*). *Fresh water* contains so little salt (0–1 ppt) that it can be used for drinking water. *Brines* are subsurface waters that contain more salt than

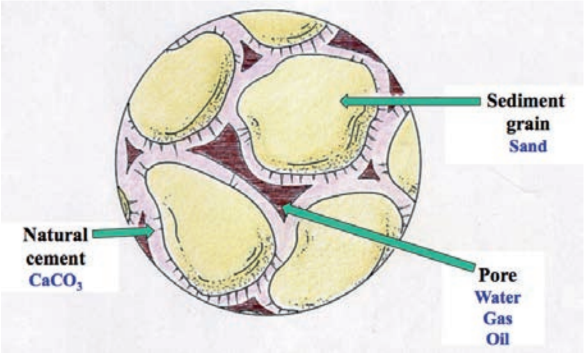

Fig. 2–3. Microscopic view of clastic sedimentary rock

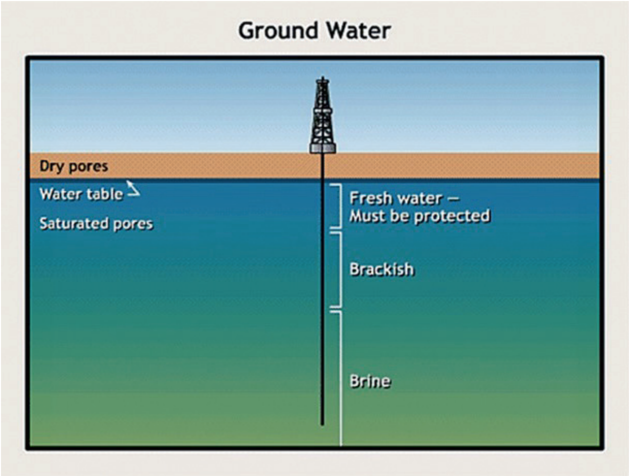

Fig. 2–4. Groundwater

seawater (35–300 ppt). *Brackish waters* are mixtures of fresh waters and brines (1–35 ppt). Below the surface is a boundary called the *water table* separating the dry pores filled with air above and pores filled with groundwater below. The water table can be on the surface or very deep depending on how much rain falls in that area. Just below the water table, the groundwater is usually fresh because of rainwater that percolates down from the surface. Deep waters, that have occupied the rock pores for a very long time, are salty. In general, the deeper you drill, the more saline the water is. When a well is drilled, completed, and producing, near-surface fresh waters that are or can be used for drinking or irrigation are protected from pollution by law throughout the world.

The size of clastic grains that make up an ancient sedimentary rock is important. The rock is often classified according to the grain size. Sandstones are composed of sand-sized grains, whereas shales are composed of fine-grained, clay-sized particles. Also, the size of the grains controls the size of the pore spaces and the quality of the oil or gas reservoir. Larger grains have larger pores between them. It is easier for fluids, such as gas and oil, to flow through larger pores and into a well. Clastic grains in sedimentary rocks are classified by their diameters in millimeters (fig. 2–5). They are called *boulder, cobble, pebble, granule, sand, silt*, and *clay-sized* particles. The finest grains (sand, silt, and clay-sized) are the most common.

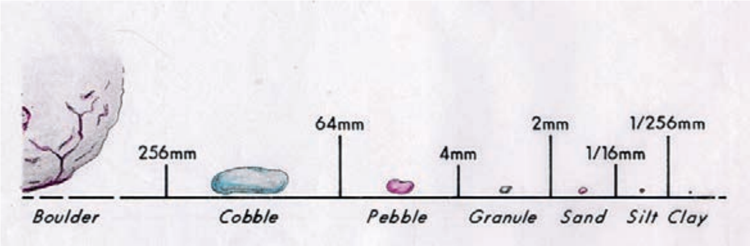

Fig. 2–5. Grain sizes in millimeters (1mm = 1/25th in.)

Sedimentary rocks are identified by their characteristic layering called *stratification* or *bedding* (plate 2–2). As sediments are deposited, there are frequent variations in the amount and composition of sediment supply such as the rise and fall of sea level that cause the layering. All these layers are assumed to be originally deposited horizontal in water.

Plate. 2–2. Dolomite Mountains of Italy (courtesy of Robert Laffi, Paola Ronchi, and American Association of Petroleum Geologists)

Geologists can interpret how ancient sedimentary rocks were deposited by looking for clues. *Lithology* (rock composition) is an important clue. Sand grains, mud particles, and shell beds each form different sedimentary rocks, and each was originally deposited in a very different environment. *Sedimentary structures* such as ripple marks, mud cracks, and flow marks that are preserved in sedimentary rocks (plate 2-3) help visualize the environment in which the rock was deposited. Another aid to interpretation is *fossils*, preserved remains of plants and animals.

Plate. 2–3. Preserved ripples in an ancient, Colorado sandstone rock

Metamorphic Rocks

Metamorphic rocks are any rocks that have been chemically altered by high heat and pressure. Marble ($CaCO_3$), a metamorphic rock, is formed from the sedimentary rock limestone ($CaCO_3$). Since temperatures and pressures become greater with depth, a rock often becomes metamorphosed when buried deep in the earth.

Structure of the Earth's Crust

The earth is estimated to be about 4.5 billion years old. Even the sedimentary rocks that generated and hold gas and oil are millions to hundreds of millions of years old. Where did these sedimentary rock layers come from? During that vast expanse of geological time, sea level has not been constant. Sea level has been rising and falling. During these fluctuations in sea level, sediments were deposited in layers. Sands and seashells were deposited along the ancient beaches. Mud was deposited in the seas offshore. These ancient sediments form the sedimentary rock layers that are drilled to find gas and oil. The rise and fall in sea level have occurred in numerous cycles (fig. 2–6). The longest cycles occurred every few

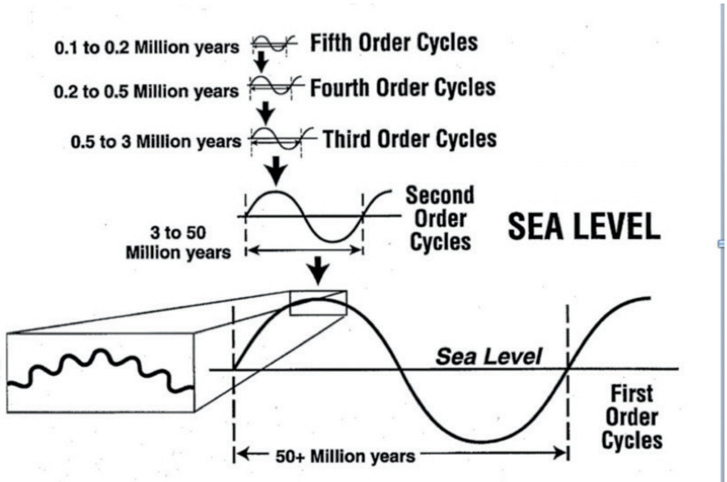

Fig. 2–6. Sea level cycles (Hyne, 1995)

hundred million years. There are shorter cycles within the large cycles and even shorter cycles within them. At least five orders of sea level rise and fall cycles have occurred, with the shortest occurring every few tens of thousands of years. The freezing and melting of glaciers caused the shortest cycles.

Exploration, drilling, and oil production have been very rewarding with several offshore fields in the Norphlet Sandstone buried on the bottom of the northern part of the Gulf of Mexico southeast of New Orleans, Louisiana. The sandstone was originally described in 1922 from an outcrop on land in far southern Arkansas. It underlies thousands of square miles of Louisiana, Mississippi and Alabama on land and extends offshore into greater than 7,500 ft. (2286 m) water depth. It was originally deposited about 170 million years ago as extensive sand dunes when the ancestral Gulf of Mexico shoreline was located to the south of where it is today. Sea level rises and falls, mountains rise, and ocean bottoms sink. What was originally land millions of years ago can be under the ocean today and vice versa.

In a typical section of the earth's crust such as at Tulsa, Oklahoma, about 3000 to 5000 ft. (900 to 1525 m) of well-layered sedimentary rocks is underlain by older metamorphic or igneous rocks (fig. 2–7). There are about one hundred layers of sedimentary rocks. Sands form the rock sandstone. Muds form the rock shale. Seashells form the rock limestone. The unproductive rocks for gas and oil, usually igneous and metamorphic rocks underlying the sedimentary rocks, are called *basement rocks*. When drilling a well encounters basement rock, drilling is usually stopped.

In some areas of the earth, there are no sedimentary rocks. They were originally there but have been removed by natural forces, and the basement rock is

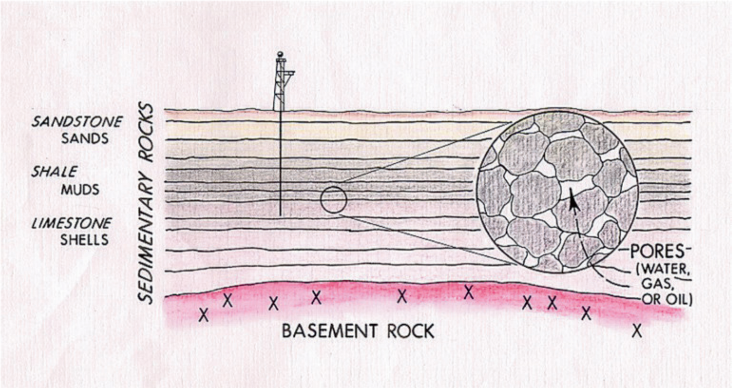

Fig. 2–7. Cross section of earth's crust

now exposed on the surface. These areas are called *shields*, and there is no gas or oil there. Every continent of the world has at least one shield area (fig. 2–8). A shield, such as the Canadian Shield in eastern Canada, tends to be a large, low relief area. Ore minerals such as iron, copper, lead, zinc, gold, and silver are mined from basement rock in shield areas. All the gas and oil in Canada on land is located to the west of the Canadian Shield where there are thick sedimentary rocks. The southwest portion of Saudi Arabia is a shield (fig. 2-9). All the Saudi Arabian oil fields are located in sedimentary rocks to the northeast of the Arabian Shield.

Fig. 2–8. Map of world showing location of shields in black where unproductive rocks for gas and oil occur on the surface

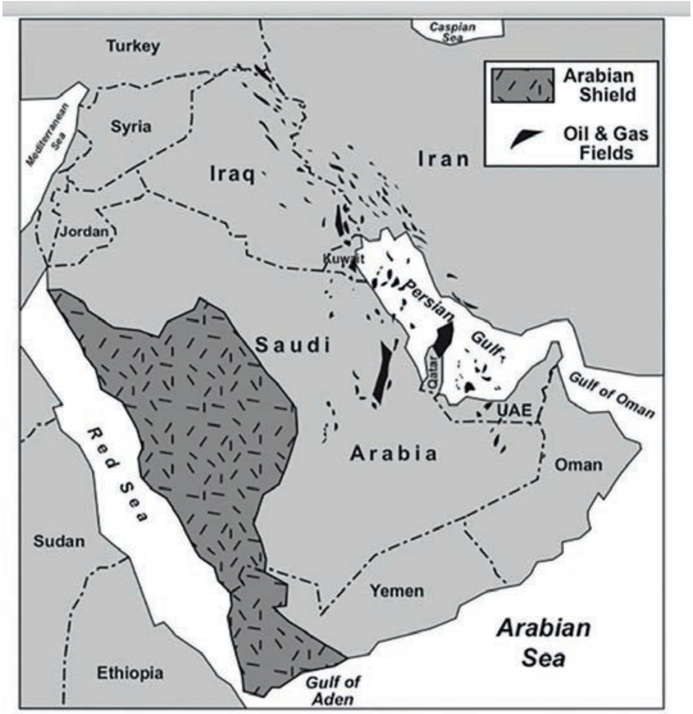

Fig. 2–9. Map of Arabian shield and oil fields (modified from Z.R. Beydoun, 1991)

In other areas called *basins*, the sedimentary rocks are very thick. Most basins have been filled in with sedimentary rocks and are dry land today. Some basins, however, are partially filled with sedimentary rocks and parts are still covered with water such as the Gulf of Mexico basin. The Caspian basin (Caspian Sea) has about 85,000 ft. (26,000 m) of sedimentary rock fill. However, 20,000 ft. to 40,000 ft. (6,000 m to 12,000 m) of sedimentary rocks is typical of many basins. Basins such as the Gulf of Mexico and the Anadarko basin of southwestern Oklahoma are large areas that are often more than 100 miles (160 km) across. Most gas and oil are found and produced from sedimentary rock basins. Because of the thick sedimentary rock fill, most basins have source rocks that have been buried deep enough in the geological past to generate gas and oil (fig. 2-10). The deep part of the basin where the organic matter is heated (cooked) to form gas and oil is called the *kitchen*. After the gas and oil is generated, some of it migrates upward into the overlying rocks where it can be trapped. The trap, such as an anticline, is a relatively small feature compared to the basin. Numerous traps can occur along the flanks of the basin. There are about 500 sedimentary rock basins in the world. Of the well-explored and drilled basins, about 50% are very productive. Those productive basins have about 70,000 conventional producing fields (~60% oil and 40% gas fields). About 70% of the world's discovered conventional oil and