Introduction: Geology

The geologic understanding of the pay and the surrounding formations plays an important part in the design of well completions and stimulations. The brief introduction given here will only give a glimpse of the subject matter in the field. This treatment of geology is very simplistic; reference articles and books are available for every segment.

The type of formation, composition, strength, logging basics, leakoff sites and other parameters may be available from a detailed geologic investigation. This information is useful for pay zone identification, fluid and additive selection, longevity of fluid contact, and selecting casing points.

There are several major classifications of rocks of interest to the petroleum industry: sandstones, carbonates (limestone and dolomite) evaporites, and shales are only the major groups. Several others, such as mudstones, siltstones and washes, are subdivisions of the major classifications.

Sandstones are predominately silicon dioxide and may have various amounts of clay, pyrite, calcite, dolomite or other materials in concentrations from less than 1% to over 50%. Sandstone formations are generally noted for being a collection of grains. The grain size may range from very small, silt sized particles (5 microns) to pea size or larger. The grains fit together to form a matrix that has (hopefully) some void space between the particles in which oil or other fluids may accumulate. The grains are usually held together by a cement that may be clay, silica, calcite, dolomite, or pyrite. Some cementation of the grains is critical for formation strength; however, excess cementation reduces porosity and permeability.

Sands are deposited in a variety of depositional environments that determine the initial sediment/rock properties. The depositional environment is simply what type of surroundings and forces shaped the deposits. In the following descriptions of depositional environment, the energy level is labeled as either high or low depending upon the level of force that accompanied the deposition of the sediments. High energy deposits are those with sufficient wind or current to move large pieces of debris while low energy is sufficient to move only the smaller particles. The importance of energy is described later. Common depositional environments are:

1. Deltas - These mouth of river deposits provide some of the larger sandstone deposits. Because of the enormous amount of natural organic material swept down the river systems, the deltas are also rich in hydrocarbons. Quality of the reservoir rock deposits may vary widely because of the wide variations in the energy level of the systems.

2. Lagoonal deposits - May be regionally extensive along the shores of ancient seas. Lagoonal deposits are low energy deposits that are hydrocarbon rich. Permeability may vary with the energy and amount of silt.

3. Stream beds - A moderate to low energy deposit with some streaks of high energy along the fast flowing parts of the streams. Stream beds are known to wander extensively and chasing these deposits with wells requires very good geologic interpretation, plus a lot of luck. The deposit volumes are also limited and frequently deplete quickly.

4. Deep marine chalks - These are often the most massive deposits available, built up at the bottom of ancient seas by the death of millions of generations of plankton-sized, calcium fixing organisms. They can be very consistent, thick deposits. Natural fracturing is common.

5. Reefs - These formations were built in the same manner as the reefs of today, by animals that take calcium from the sea water and secrete hard structures. Because of the cavities remaining from the once living organisms, reefs that have not undergone extensive chemical modification are among the most permeable of the carbonate deposits.

6. Dunes - The effects of desert winds on the sands have a shaping effect that can be seen in the arrangement of the grains. These deposits may be massive but are usually lower energy. Permeability may vary considerably from top to bottom.

7. Alluvial fan - Zones of heavy water run-off such as from mountains are extremely high energy runoffs. Common constituents of these formations may range from pebbles to boulders and cementation may be very weak. Formations such as the granite washes are in this classification.

8. Flood plains - Occur along lower energy rivers and form during flood stages when the rivers overflow the banks and spill into adjacent low areas. Flood plain deposits are mostly silt and mud.

The level of energy with each type of deposit can be visualized by their modern depositional counterparts. The importance of energy is in the sorting of the grains and the average size of the grains. As seen in the description of permeability in the preceding section, a rock with larger grains and the absence of very small grains leads to high permeability. When small grains are present, the permeability is much lower. When there is a mixture of the very large and very small grains, such as in some alluvial fans, the permeability can be very low. The extent of grain differences in a formation is termed the "sorting", with well sorted formations having similar sized grains and poorly sorted formations showing a very wide size range.

The events that happen after the deposit is laid down are also factors in well completions and may have a devastating effect on reservoir engineering. Some of these forces are active for a short period in geologic time such as faulting and salt domes, and others like salt flows and subsidence, are active during the productive life of the well. The faulting, folding and salt movement make some reservoirs difficult to follow. Continuous forces are often responsible for formation creep in open holes, spalling, and casing sticking and collapse problems. Although these geologic movement factors cannot be easily controlled, the well completion operations can be modified to account for many of them, if the problems are correctly identified early in the project life.

Chemical modifications also influence the reservoirs, though much less drastically than the uplift forces of a salt dome, for example. Most carbonates (not including the reefs) are laid down by accumulation of calcium carbonate particles. Limestone may recrystallize or convert to dolomite by the addition of magnesium. Because the limestone is soluble in ground water and very stable (resistant to collapse), the limestones are often accompanied by locally extensive vugs or caverns which form from ground water flow. Recrystallization or modification by the water as is flows through the rock may also lead to a decrease in porosity in some cases.

When dolomite forms, a chemical process involving the substitution of magnesium for part of a calcium in the carbonate structure generally shrinks the formation very slightly, resulting in lower microporosity but slightly higher porosity through the vugs or the natural fracture systems. Other types of dolomitization are possible. The carbonates are marked by a tendency towards natural fractures, especially dolomite. The chalk formations may be almost pure calcium carbonate, are reasonably soft (low compressive strength) and may have very high porosities on the order of 35-45%, but relatively low permeabilities of less than, typically, 5 md.

The third formation of interest is shale. These formations are laid down from very small particles (poor sorting) that are mixed with organic materials. The organic material is often in layers, pools, or ebbs. The shales may accumulate in deep marine environments or in lagoonal areas of very low energy resulting in almost no large particles being moved. The shales are marked by high initial porosity and extremely low permeability. Shales often serve as a seal for permeable formations. The shales are also extremely important, since they are the source for the oil that has been generated in many major plays. Oil leaves the shale over geologic time and migrates into the traps formed in sandstones, limestones and other permeable rocks.

The evaporites are deposits that are formed by the evaporation of water. Deposits such as anhydrite are usually accumulations of dried inland seas and serve as extensive local geologic markers and sealing formations. They are extremely dense with almost no porosity or permeability.

When a deposit of oil and gas is found, it usually has its origins elsewhere and been trapped in a permeable rock by some sort of a permeability limiting trap. The trapping mechanism is too extensive to be covered in a short explanation on geology, but the major traps are outlined in the following paragraphs.

1. Trapping by a sealing formation is common and accounts for some major fields. These occurrences, called unconformity traps, are where erosion has produced a rough topography with peaks and valleys. Like the rolling terrain of the surface, most formations are rarely flat; they have high and low points and may have a general rise in a direction. If an extensive sealing formation is laid down in top of the sandstone (or other pay), and the sand is exposed to migrating oil from a lower source over geologic time, the oil will accumulate in the higher points of the pay and trend "uphill" toward the point where the hill drops off or another sealing event stops the migration. Tracking these deposits is best accomplished with as complete a structural map as can be constructed. These maps of the formations highs and lows compiled from seismic and drilling data indicate the better places to drill a well - small wonder that the maps are among the most closely guarded secrets of an oil company.

2. Faulting is an event that shifts a large block of the formation to a higher or lower position. The

misalignment of the zones often provides contact with sealing formations and traps the hydrocarbon. There are several types of faulting depending on the action and movement of the rock. In areas of extensive tectonic plate movements, faulting may be extensive.

3. Folding is an uplift or a drop of part of the formation where the breaks associated with faults do not occur. The formation maintains contact with itself, although it may form waves or even be turned completely over by the event. Complete turnover is seen in the geologic overthrust belts and accounts for the same formation being drilled through three times in one well, with the middle contact upside down. Vertical wells directly on the fold will penetrate the formation horizontal to the original plane of bedding. Although these wells offer increased local reservoir quantity when they are productive, the problems with directional permeability and sweep in a flood are often substantial.

4. Salt domes cause uplift of the formation and result in numerous small or large fields around their periphery. Faulting is often very wide spread. Brines in these areas are frequently saturated or oversaturated and evaporated salt formations, stringers and salt-fill in vugs are common. Because of the uplift of some formations from deeper burial, the productive formations may be over pressured.

5. Stratigraphic traps (permeability pinchouts) are a change in the permeability of a continuous formation that stops the movement of oil. These deposits are very difficult to observe with conventional seismic methods. This effect, combined with a sealing surface to prevent upward movement of fluid forms numerous small reservoirs and a few massive ones. Permeability pinchout may also explain poor well performance near the seal. Laminated beds with permeable sands sandwiched between thin shales are a version of the pinchout or Stratigraphic trap. These deposits may be locally prolific but limited in reservoir and discontinuous. Linking the sands is the key to production.

The age of a formation is dated with the aid of fossils which are laid down with the matrix. The age of a formation is important to know if the formation has a possibility of containing significant amounts of hydrocarbon. In most cases, very old formations such as the pre-Cambrian and Cambrian contain very little possibility for hydrocarbons unless an uplift of the structure has made the formation higher than an oil-generating shale, and oil has migrated into a trap inside the formation.

Formation Sequences and Layering

Formations are almost never homogeneous from top to bottom. There is a considerable amount of variation, even in a single formation, between permeability and porosity when viewed from the top of the zone to the bottom. When formations are interbedded with shale streaks, they are referred to as a layered formation. The shale streaks, often laid down by cyclic low energy environments, may act as seals and barriers and form hundreds or thousands of small isolated reservoirs within a pay section. Many times, the layering is too thin to be spotted by resistivity or gamma ray logs. When a formation is known to be layered, the completion requirements change. Perforating requirements may rise from four shots per foot to 16 shots per foot, and in many cases, small fracturing treatments may prove very beneficial even in higher permeability formations.