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# ENGLISH for the Students of PETROLEUM 3

Dr. Mahmood Farrokhpey

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# English

for the Students of

# Petroleum

Dr. Mahmood Farrokhpey

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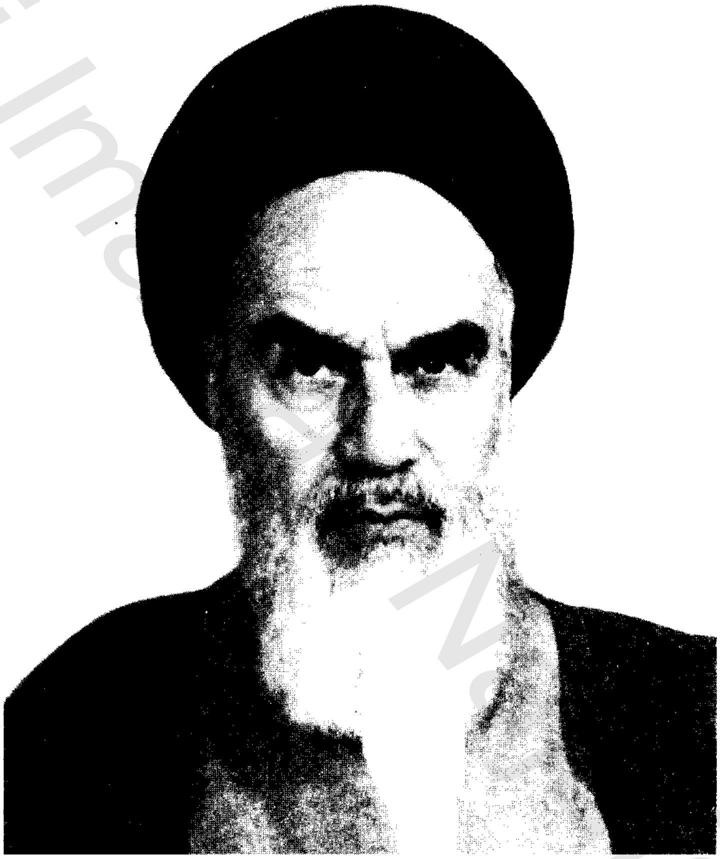
In the Name of Allah

the Compassionate, the Merciful



پیشتر احتیاج به زبان - زبانهای خارجی - نبود امروز احتیاج است به این، یعنی جزو برنامه تبلیغات مدارس باید زبان باشد و زبانهای زنده دنیا، آنهایی که در همه دنیا شایعتر است.

صحیفهٔ نور، ج ۱۸ ، ص ۹۹

## سخن «سمت»

یکی از اهداف مهم انقلاب فرهنگی، ایجاد دگرگونی اساسی در محتوا و شیوهٔ تدوین کتب درسی دانشگاهها، بخصوص در زمینه علوم‌انسانی بوده است. به همین جهت شورای عالی انقلاب فرهنگی در تاریخ ۶۳/۱۲/۷ تأسیس «سازمان مطالعه و تدوین کتب علوم انسانی دانشگاهها» را که به اختصار «سمت» نامیده می‌شود، تصویب کرد تا اختصاصاً به این مهم بپردازد.

این سازمان با توجه به نیاز دانشجویان، در فرصتی خاص، علاوه بر تدوین متون آموزش زبان خارجی در مرحله عمومی، نیمه تخصّصی و تخصّصی برای علوم انسانی، در محدودهٔ خاصی به تدوین کتب آموزش زبان تخصّصی سایر رشته‌ها پرداخت که کتاب حاضر یکی از آنهاست.

این کتاب برای دانشجویان رشتهٔ نفت در مقطع کارشناسی به‌عنوان منبع اصلی درس زبان تخصّصی به ارزش ۲ واحد تدوین شده است. امید است علاوه بر جامعهٔ دانشگاهی، سایر علاقه‌مندان نیز از آن بهره‌مند شوند.

دشواری چنین کاری بر دانشمندان و صاحبنظران پوشیده نیست و به همین جهت مرحلهٔ کمال مطلوب آن، باید بتدریج و پس از پیشنهادهای اصلاحی ارباب نظر به دست آید و انتظار دارد که این بزرگواران از این همکاری دریغ نورزند.

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# Unit 1

*Section One: Reading Comprehension*

## Origin of Petroleum

For many years, the manner in which petroleum has been formed in nature has been a matter of scientific controversy. Many theories have been offered, partially confirmed by field or laboratory evidence, but even today authorities are not in agreement. The various theories are usually classified into two groups: (1) the inorganic theories and (2) the organic theories. The former attempt to explain the formation of petroleum by assuming geochemical reactions between water, carbon dioxide, and various inorganic substances, such as carbides and carbonates of the commonly occurring metals. The organic theories assume that petroleum has evolved from decomposition products of vegetable or animal organisms that lived in sea waters of previous geologic periods, their remains accumulating in sediments formed along ocean shores and on the continental shelves.

The inorganic theories present possible, in some cases plausible, explanations, and laboratory evidence has been offered in support of some of them; but materials and conditions necessary for the reactions assumed apparently do not characterize the environment in which petroleum is usually found. While it is possible that some oil accumulations have been derived from inorganic sources, it seems improbable that any very large part of the world's petroleum can be explained by these processes.

On the other hand, there is abundant evidence, both in nature and from the laboratory, that most, if not all, accumulations of petroleum have been derived from organic remains of sea weed, diatoms, foraminifera, algae, plankton, fish, and other marine organisms. Marine sediments commonly contain from 1 to 2 percent of organic matter, and in some regions, certain formations yield much higher percentages. Some authorities note that formations associated with certain petroleum deposits contain from 5 to 10 percent of organic matter. The field evidence suggests that the remains of former marine life–either animal or vegetable or both–accumulating along ocean shore lines or in comparatively shallow lagoons and estuaries were covered by accumulating sediments and subjected to decomposition by anaerobic bacteria, resulting in formation of minute disseminated particles of 'protopetroleum'. This intermediate product was then gradually converted, over geologic time, by catalytic processes to the liquid and gaseous hydrocarbons which, after migration and accumulation, form the oil and gas reservoirs that we exploit today.

Laboratory studies have shown that certain types of anaerobic bacteria are capable of decomposing fats, fatty acids, proteins, cellulose, and other forms of organic matter with formation of methane and higher-molecular-weight hydrocarbons. Certain types of clay, abundant in nature, may serve as catalytic agents in bringing about polymerization and other chemical readjustments in hydrocarbon molecules. Some authorities suggest that radioactivity may have played a heretofore undisclosed role in the transformation of the parent organic material. Others have noted the occasional association of oil and gas with oil shale and coal deposits and have suggested that they may have been derived from these materials. While hydrocarbon oils may be retorted from coal and oil shale, they apparently differ from petroleum in that coal and oil shale are generally associated with fresh-water sediments while petroleum is nearly always found in sediments of marine origin.

The exact mechanism by which the parent organic material is transformed into petroleum has not as yet been fully explained, but field studies suggest that the essential conditions are: (1) an organic source material accumulated along ocean shores and continental shelves in marine or brackish waters (clays or marls, fine sands, dolomites, and chalks are possible source rocks); (2) prompt covering of the organic material by accumulating sediments; (3) exclusion of oxygen and presence of bacteria capable of living in such an environment and of converting the parent organic material into hydrocarbons; and (4) temperatures that do not exceed 150°C and depths of less than 5,000 ft (distillation and thermal cracking reactions such as are used in oil-refining operations and in the retorting of shale oil are not likely to play a part because of the temperature limitation.) The hydrocarbons have been formed, for the most part, in sedimentary formations in close proximity to the reservoir rocks in which we now find them. Only where open fault planes exist may they travel far from the source beds in which they were formed. Variations in the physical and chemical properties of crude petroleums are due to variations in the character of the source materials and in the environmental conditions under which they were formed and accumulated.

In seeking for an explanation of the origin of petroleum, we should not entertain any theory that would require the assumption of abnormal environmental conditions, for petroleum is of widespread occurrence in many regions and throughout long periods of geologic time. Petroleum has undoubtedly been formed under conditions commonly prevailing in nature, which have resulted in its formation repeatedly in the same areas. Recent studies have indicated that the same natural processes that were responsible for the formation and accumulation of petroleum reservoirs from which we now produce our supply are continuing today in regions where conditions are favorable. However, the processes of formation and accumulation are exceedingly slow and geologic time will be necessary for their completion.

It is apparent that, whatever may be the theory accepted in explanation of the origin of petroleum, the oil is originally widely scattered through the containing rocks. It must subsequently be subjected to an agency which will effect a concentration of these disseminated particles before the formation of a deposit of commercial proportions becomes possible. Since the dimensions of petroleum deposits are relatively small in comparison with the areas over which the small particles of oil were originally formed, it is evident that this 'migration' of petroleum may necessitate movements over considerable distances. The rocks in which accumulation occurs are seldom those in which the petroleum was formed, and accumulations are occasionally found in formations stratigraphically unrelated with those containing the parent material.

## *Part I. Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. The problem of petroleum genesis has always been a topic of research interest.

........ 2. All petroleum researchers have now agreed unanimously that petroleum has been derived from inorganic sources.

........ 3. It is now amply clear that petroleum is the product of the organic remains of plants and animals.

........ 4. The details of how petroleum is expelled from the source sediment and how it accumulates in the reservoir are still uncertain or at least understood only in broad outline.

........ 5. Practically all present-day thinkers on oil origin have come to the conclusion that petroleum is always associated with sedimentary rocks.

........ 6. According to the passage, natural processes and conditions are no longer available nowadays for the formation of petroleum.

........ 7. According to the inorganic theories, all petroleum appears to have originated in brackish to full marine sediments.

........ 8. The organic theories assume that petroleum is formed through the function of inorganic substances.

........ 9. Over long periods of time carbohydrates and proteins are probably destroyed by bacterial action leaving the fatty acids.

........ 10. Catalytic processes were responsible for changing the earlier forms of petroleum into the present-day petroleum.

**B. Choose a, b, c, or d which best completes each item.**

1. Based on a wealth of field observations by geologists, some of the conditions necessary for the formation of petroleum have been .......... .
   a. the development of a basin or depression in the earth's crust
   b. in close association with sedimentation
   c. probably not necessary
   d. all of the above
2. Coal and oil shale differ from petroleum in that .......... .
   a. the latter is located in marine sediments
   b. the former is found in marine sediments
   c. oil-producing bacteria are living in severe conditions
   d. inorganic source materials accumulate along ocean shores

3. In explaining the origin of petroleum, we should .......... .

a. disregard any theory which describes the accumulation of organic material

b. abandon any theory which deals with the development of a sedimentary basin

c. always look for a theory which assumes unnatural conditions for the creation of petroleum

d. abandon looking for a theory which entails unnatural environmental conditions

4. According to the passage, .......... .

a. petroleum has been stationary since its creation by favorable geological conditions

b. petroleum, gas, and liquids have migrated and gathered in places appropriate for retention

c. petroleum and sedimentary rocks are not related in any possible way

d. petroleum is generated due to the geological underground conditions

5. As we gather from the text, .......... .

a. at one time drilling for petroleum was a hit-or-miss affair and only one out of one hundred wildcat wells struck oil

b. chemical engineering and petroleum processing have in a very real sense grown up together

c. there is general agreement that petroleum was formed from organic matter near the shore

d. over long periods of time, carbohydrates and proteins stay unchanged by bacterial action

6. The conversion of protopetroleum into the present-day petroleum .......... .

a. is not yet fully known to experts

b. will never be known to us

c. is evident to any beginning researcher

d. has not yet been even considered

7. Among factors responsible for the changing of parent organic material into petroleum we could consider .......... .

a. decomposing fats
b. radioactivity
c. polymerization
d. marine life

### C. Answer the following questions orally.

1. How many kinds of theories have been offered for the origins of petroleum?
2. What is the assumption of the organic theories?
3. How was the protopetroleum converted into the present-day petroleum?
4. What is the function of some anaerobic bacteria?
5. What are the essential conditions of the transformation of parent organic material into petroleum?

## *Part II. Language Practice*

### A. Choose a, b, c, or d which best completes each item.

1. The organic theories assume that petroleum has evolved from decomposition products of .......... .
   a. vegetable or animal organisms
   b. marine sediments
   c. fatty acids
   d. algae
2. Certain types of .......... may serve as catalysts in bringing about polymerization.
   a. plankton
   b. clay
   c. fish
   d. sea weed
3. Petroleum is of .......... occurrence in many regions.
   a. rare
   b. partial
   c. widespread
   d. high
4. The inorganic theories attempt to explain the formation of petroleum by assuming geochemical reactions between .......... .
   a. water
   b. carbon dioxide
   c. inorganic substances
   d. all of the above
5. Petroleum has undoubtedly been formed under conditions .......... .
   a. predictable
   b. spectacular
   c. prevailing in nature
   d. rare in nature

**B. Fill in the blanks with the appropriate form of the words given.**

**1. Stimulate**

a. In biology, a .......... is anything which acts on and causes a reaction in a living thing.

b. Pain .......... have important biological and survival functions.

c. Praise always .......... him to further efforts.

**2. Percept**

a. As it grew lighter, he was .......... to the objects in his surroundings.

b. Some psychologists specialize in the study of .......... .

c. A .........., in technical use, is a sense impression or sense datum, an impression of something external gained through one of the physical senses.

**3. Synthesize**

a. In the context of the science of chemistry, a .......... is the production of a chemical compound by the union of elements or simpler compounds.

b. A .......... compound is a compound synthesized in an artificial way.

c. A chemist may attempt to .......... two elements into a single compound.

**4. Corrode**

a. A substance (inorganic in most contexts) .......... when it is slowly destroyed by chemical action.

b. Iron bridges are painted to protect them from .......... .

c. Certain acids and alkalis (e.g., caustic soda) have a strongly .......... action.

**5. Neutralize**

a. In chemistry, a .......... substance is one which is neither acid nor alkaline.

b. To .......... something is to destroy or counteract its activity or effect.

c. They are in a state of armed .........., i.e., they are ready to fight if attacked.

## C. Fill in the blanks with the following words.

| | | | |
|---|---|---|---|
| distillation | segregated | chemical | boiling |
| respective | indication | customary | crude |
| percentages | fractions | volatile | adopt |
| hydrocarbon | petroleum | distilled | analyzed |
| fractional | | | |

Distillation is an important physical process to which petroleum is subjected in refining and in isolating its various components to determine their composition or suitability for different purposes. Since petroleum is a/an .......... of a large number of hydrocarbons of varying .......... points, the more .......... constituents of low boiling points are .......... first when heat is applied in the .......... process, and the higher-boiling .......... are evolved in succession as their .......... boiling points are reached. Because of the difficulty of making .......... analyses of petroleum, it is .......... in classifying various .......... oils to subject them to .......... distillation, reporting, as a rough .......... of their values for refining purposes, the percentages of distillate obtained between stated boiling points.

Chemical analysis of .......... is difficult and tedious. No crude petroleum has yet been completely .......... to the point where all its individual .......... components have been .......... and identified. In classifying crude petroleums, we must therefore .......... some less cumbersome procedure.

## D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. The gases are frequently explosive, and the lighter, more volatile liquids, surrounded by an inflammable blanket of their own vapor, are readily ignited and will be completely consumed by the resulting flame.

b. The flash point, or that temperature at which inflammable gases are given off.

c. All hydrocarbons are inflammable, whether in the solid, liquid, or gaseous state, though the solid and heavy, viscous liquid forms are relatively less so, because of the difficulty of securing admixture with the necessary air to support combustion.

d. The fire point, or the temperature at which the liquid will burn.

e. And the calorific value are thermal properties which enter as important variables in testing petroleum and petroleum products for specific purposes.

| 1 | 2 | 3 | 4 | 5 |
| --- | --- | --- | --- | --- |
| | | | | |

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*Section Two: Further Reading*

# Accumulation of Petroleum

## Expulsion of Petroleum From the Source Rock and Accumulation

Geologists have recognized three necessary requirements for an oil deposit: (1) source sediments; (2) a permeable rock of sufficient porosity to serve as a reservoir; and (3) a trap of some type, associated with the reservoir, which will prevent the petroleum from migrating away and being lost, and which will facilitate accumulation.

Sediment types and the geochemical environments favorable to the generation of crude oil are not uncommon in nature and, for this reason, widespread formation of petroleum must be assumed to be occurring even at the present day. However, the development of an available reservoir rock and trap, predating accumulation, is a much rarer event and is usually the controlling factor in the overall process of formation of an oil deposit. Because of the importance of this aspect of the problem, it is considered briefly here, although not strictly a part of the origin question.

As the thickness of a sedimentary deposit increases, the weight of the overlying sediments becomes considerable. The result of this increase in overburden is that the muds begin to lose water and any other fluid materials contained in them to the more permeable, interfingering sand zones, mentioned earlier. The loss of fluids from the muds results in a substantial reduction in thickness and permeability. A typical mud section of 100 ft thickness containing about 75 percent by volume of water and 25 percent by volume of fine-grained minerals will have been reduced to some 40 ft of shale by the time it has been buried to a depth of 5,000 ft; the density will have risen from an initial 1.4 to 2.0 and the water content will have been reduced to about 42 volume percent. Under 8,000 ft of overburden, the resulting shale will have a thickness of some 30 ft and a water content of approximately 20 volume percent, or about 10 percent of the original water content of the mud; the density will now be about 2.4. The sand zones, being relatively incompressible, will retain their shape and permeability.

Exactly how and at what time the hydrocarbons are expelled from the mud and how they are segregated in the reservoir rock to form deposits of oil has been debated at length. Presumably the oil is carried along as an extremely fine dispersion in the water, possibly as an emulsion. Actually the volumes of water expressed from muds during shale formation are so huge that one can hardly escape the conclusion that a considerable amount of hydrocarbon material must be removed in aqueous solution; it would seem likely that hydrocarbons so expelled would be swept out through the permeable zones and be irretrievably lost.

Once the oil has been transferred to the reservoir rock, it is free to move under any force which may be applied. At the now greatly reduced hydraulic gradient, gravitational forces are thought to become predominant, causing the oil, gas, and water to become segregated in the upper parts of the porous stratum, according to their relative densities. Favorable locations where the oil can accumulate may be anywhere along the path of fluid travel, and it is believed that, in some instances at least, the oil may migrate a considerable distance from its source before being trapped.

An attempt to find in young sediments a situation in which oil is currently migrating and accumulating has been reported recently by Kidwell and Hunt. A study of the clays and interbedded argillaceous sheet sands on the Pedernales anticline of the Orinoco River delta in Venezuela has revealed hydrocarbon contents of 40 to 55 ppm. One lenticular sand at 110 ft depth showed the presence of free gas and some 160 ppm of liquid hydrocarbons, mostly aromatic in character. Carbon 14 data established that the sand body was deposited about five thousand years ago. Pressure measurements indicated a gradient in the muds upward toward the laterally continuous sands and downward toward the Pleistocene contact, from which it is inferred that both beds are acting as conduits for escape of the fluids to the outcrops.

While the porous zones adjacent to a compacting mud are commonly sand and while sands thus form important reservoir rocks, almost any porous and permeable stratum will suffice. A very common reservoir rock is a porous or fractured limestone, especially of the reef (bioherm) type; a less frequent occurrence is a fractured shale or even igneous or metamorphic rock. Many geologists are of the opinion that oil found in at least some reef structures is indigenous because of the large concentration of organisms in them, and because, in some instances, there is no other obvious source of the oil.

Traps, in which oil may accumulate, are found in great variety. A trap may consist simply of a sand lens surrounded by relatively impermeable rock, such as shale. One of the earliest recognized forms is the anticline, produced by folding of a rock sequence. Oil may also accumulate against a slippage plane in the rocks (fault) where the displacement has been sufficient to bring the permeable zone up against an impermeable rock. Often sufficient oil escapes along such a fault to create a seep at the surface. A third type of trap, found frequently along the coastline of the Gulf of Mexico and elsewhere in the world, is the salt dome. A large plug of salt, rising under the sediment load by virtue of its relatively low density, from some deeply buried salt stratum, distorts the surrounding sediments to seal off permeable zones, into which oil may be moving. A gradual change in rock character (facies change) may also provide a trap for oil; thus, a permeable sand may become increasingly 'dirty' in character, finally merging into an impermeable shale which may be quite indistinguishable from the shale zones above or below the sand. Because of the absence of any pronounced feature or rapid change in rock properties, this stratigraphic type of trap is one of the most difficult to locate.

## *Comprehension Exercises*

**A. Put "T" for true and "F" for false statements. Justify your answers.**

........ 1. From the text it is understood that geochemical environments do not allow any crude oil to be formed any more.

........ 2. When a stratum of shale, clay, or sand is laid down under water, its percentage porosity is high, but as additional strata are superimposed, their weight operates to compact the mineral particles, reducing the pore space between and thus expelling a portion of the contained fluids.

........ 3. Globules of oil flowing in underground water channels may be trapped in the reservoir rock.

........ 4. Water, gas, and oil will become segregated in the reservoir rock by reason of their specific gravity.

........ 5. From the passage it is understood that gas pressure, gravity, hydraulic pressure developed by flowing water in subterranean channels, earth pressure, and the compaction of sediments are among the forces at work in nature which bring about migration and accumulation of petroleum.

........ 6. As soon as hydraulic pressure increases, gravitational forces increase rapidly as well.

........ 7. Although sands are common gradients of reservoir rocks, any permeable strata will do the job as well.

........ 8. Unless the oil-containing stratum is covered by a cap rock, the oil will escape to overlying formations until it encounters an impervious stratum. Salt domes and anticline serve as taps in which the oil and gas tend to accumulate.

........ 9. It is impossible for oil to accumulate in faults.

........ 10. The role of the trap is to prevent the petroleum from migrating and getting lost.

## B. Choose a, b, c, or d which best completes each item.

1. As the thickness of a sedimentary deposit increases, the weight of the overlying sediments becomes .......... .

a. small b. permeable

c. negligible d. enormous

2. It is believed that the oil may .......... a considerable distance from its source before being trapped.

a. be found b. migrate

c. be located d. accumulate

3. Traps, where oil accumulates, have .......... .

a. a sand lens shape b. the fault shape

c. the salt dome shape d. all of the above

4. A very common reservoir rock is .......... or fractured limestone.

a. a metamorphic b. a permeable

c. a segregated d. a porous

5. Now experts have realized that .......... is the controlling factor in formation of an oil deposit.

a. the development of an available reservoir rock and trap

b. a permeable rock of sufficient porosity

c. the loss of fluids from the muds

d. the volume of water expressed from muds

## C. Write the answers to the following questions.

1. What usually constitutes a common reservoir rock?
2. What happens when the thickness of a sedimentary deposit increases?
3. What does the loss of fluids from the muds result in?
4. What happens to the oil as soon as it is transferred to the reservoir rock?
5. What did carbon 14 data reveal regarding the site of the Orinoco River delta in Venezuela?
6. Why do several geologists believe that oil found in some reef structures is indigen?
7. Why do sand zones retain their shape and permeability?
8. How are hydrocarbons carried when they are expelled from the mud?
9. What did pressure measurements indicate in the study related to the Orinoco River delta?
10. What are the minimum requirements for an oil deposit?

### A. Translate the following passage into Persian.

## Recovery Techniques

The actual useful size of reserves is dependent upon the recovery techniques used. Ashburn, in 1887, estimated that wasteful production techniques in Pennsylvania and New York oil fields would ultimately result in the recovery of only 11 to 12 percent of the oil present. If methods now available had been used then, 2 to 2½ times more oil would have been taken out than was actually recovered by natural flow and pumping. The key to the problem is proper conservation and utilization of reservoir energy. Oil is usually underlaid with water under considerable pressure and overlaid with gas. Withdrawal of oil from the proper place at a sufficiently low rate allows the pressure to be maintained, saving much pumping energy.

Natural gas or $CO_2$ can be returned to repressure wells. In one instance, a slower rate of oil production and recycling natural gas at 9.6 MPa enabled a net recovery of 70 percent of the oil originally present. This is twice the amount recoverable without repressuring. Natural high-pressure $CO_2$ is often piped long distances to use in oil fields. Air is not suitable for repressuring, because it causes deterioration in the quality of the oil produced.

### B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.

1. anticline ..............................
2. aqueous solution ..............................
3. brackish waters ..............................
4. buoyant force ..............................
5. capillarity ..............................
6. catalytic processes ..............................
7. compaction of sediments ..............................
8. condensation ..............................
9. conduits ..............................

10. diastrophism ..............................
11. diatoms ..............................
12. dispersion ..............................
13. disseminated particles ..............................
14. distillation ..............................
15. dolomites ..............................
16. emulsion ..............................
17. fault planes ..............................
18. fine-grained minerals ..............................
19. foraminifera ..............................
20. inundated globules of oil ..............................
21. lenticular sand ..............................
22. marine sediments ..............................
23. metamorphic rock ..............................
24. oil shale ..............................
25. parent organic material ..............................
26. porous stratum ..............................
27. reef ..............................
28. salt dome ..............................
29. solubility ..............................

# Unit 2

*Section One: Reading Comprehension*

# The Nature of Petroleum

## Chemical Constitution

Petroleum is a collective term which describes the whole range of solid, liquid, and gaseous compounds of carbon and hydrogen which are naturally formed and sealed up in the rocks of the earth's crust. The chemical composition of petroleum is not fixed and includes variable amounts of the different molecules from the heaviest solid hydrocarbons up to propane ($C_3H_8$) the lightest which occurs as a liquid, and ethane and methane ($C_2H_6$ and $CH_4$) both of which are gases at atmospheric temperatures and pressures. The most usual compositions found are those with the molecular arrangements $C_nH_{2n-2}$ (the paraffins), $C_nH_{2n}$ (the olefines) and $C_nH_{2n-6}$ (the benzines or aromatics). Crude oils are roughly classified according to the preponderant series and are referred to as being 'paraffinic' (or having a paraffin base) when the paraffin series form a major proportion of the mixture. These are the lighter, generally greenish coloured and more fluid crudes. Heavy black viscous crudes are known as 'asphaltic' or asphaltic base crudes and give a dark residue after distillation. Also included as impurities are sulphur and minute quantities of other elements.

## Physical Properties

The specific gravity of crude petroleum ranges from 0.7 for very light crude oils, up to more than 1 for some solid bitumens. The normal range however is between 0.8 and 0.9, with most crudes being in the range of 0.82 to 0.85. In British practice it is usual to refer to the specific gravity, and of course this quantity is required for any calculations of volumes and weights. In American practice a second scale is used known as the API gravity and is read in degrees. This avoids the use of a wholly decimal figure and indicates lighter crudes by a higher number and it therefore reads the opposite way round to the specific gravity. The conversion factor from specific gravity to API gravity can be calculated from the formula:

$$API = \frac{141.5}{S.G.} = 131.5$$

10° API is equivalent to a specific gravity of 1.

Most crude oils at some stage in their production need to be pumped along pipelines. The important properties for ease of pumping are the viscosity and the wax content. Under reservoir conditions the viscosity of most crude oils is much less than it would be at the surface because of the dissolved gas and the higher temperature which exists underground. After gas has been removed and at normal surface temperatures crude oil viscosities range from about 10 to 100 centipoises.

In absolute units the viscosity is expressed as a force measured in dynes. In the c.g.s. system viscosity is measured in 'poises', one poise being one dyne-second per square centimeter while the viscosity of water at 68°F (20°C) is defined as one-hundredth of a poise (one centipoise).

The experimental determination of the absolute viscosity is a delicate laboratory experiment, but standard industrial viscosimeters have been developed, all of which measure the time of outflow of a standard volume of crude through a standard orifice at a standard temperature. Three instruments are in common use, the Redwood, the Saybolt, and the Engler, and readings obtained from them may be readily converted into absolute units by reference to established charts or formulae.

Most crude oils contain some wax. This has a tendency to solidify as the temperature of the crude oil drops from reservoir to surface temperature and is sometimes deposited in the well bore, in pipelines and even in the formation pore spaces of the oil-bearing rocks. Artificial heating of pipelines sometimes has to be undertaken to maintain crudes with high wax contents in a fluid state, while wax deposited in well bores requires specialised equipment for its removal. The wax itself is, of course, a valuable product and most refineries include a wax recovery and purification plant for the production of paraffin wax.

## Analysis

Because of the mixed nature of crude petroleum, its examination in the laboratory is difficult and tedious although several standard methods of analysis have been evolved to suit various purposes. The usual preliminary laboratory method is a straight distillation under atmospheric pressure. In this a definite quantity, usually 100 ml., of the crude to be examined, is placed in a flask and heated from room temperature to 300°F (149°C) at a standard rate. The temperature at which the first drop of distillate forms at the end of a condenser attached to the neck of the flask is noted and thereafter the volume of liquid collected for each 10°F rise in temperature is taken. When 300°F is reached, the volume of residue remaining is also noted. From the results of this distillation a boiling point or distillation curve is plotted and these curves give an easy method both of distinguishing between different crudes and of assessing the value of any crude for the various refining processes through which it must pass before useful products can be obtained from it.

For more specialised purposes, more exact distillations both of the whole crude or of parts of it, are made sometimes under reduced pressure in order to avoid 'cracking' or the breaking down of heavy molecules into several lighter ones, which, if it occurred, could give a false impression of the constitution of the crude oil. Chemical analysis may also be used to determine the proportions of the various carbon and hydrogen molecules present. Physical tests to detect the properties of the various 'cuts' are also informative and can produce surprising results. As an example, two of the great oilfields of the Middle East are at Burgan in Kuwait and Wafra in the Neutral Territory to the south of it. Both these fields are similar in geological environment and the oil is found in both places in sandstone rocks called 'the Burgan Sands' of Middle Cretaceous age (80 million years). It might, therefore, be expected that the two crudes were derived from similar sources though the Wafra crude actually contains a smaller quantity of the lighter constituents than does that from the Burgan Field. It was found, however, that gasoline produced by straight distillation from Wafra crude has an octane rating (which is a measure of its 'anti-knock' properties) of 2 or 3 points higher than that produced from Burgan crude. Although the reason for this difference is not fully understood at present, it is suspected that at least some part of one of the two crudes must have been derived from a different source from the remainder.

## Impurities

Crude petroleums contain various impurities, the chief of which are sulphur compounds. Sulphur occurs both as a pure substance dissolved in the crude, as hydrogen sulphide ($H_2S$) a gas, or as a complex compound with carbon and hydrogen. Crude oil is called 'sweet' when the percentage of sulphur is low and 'sour' when it is high. 'Sour' crude causes difficulties in refining and is normally of lower value than 'sweet' crude, the limit being reached when the residue, which is used as heavy furnace fuel, has a sulphur content of about 5 percent. Most of the sulphur compounds are heavy and therefore are concentrated in the residues. Crudes which have sulphur contents of between 2-3 percent give fuel oil cuts with about 4 percent sulphur. The presence of sulphur in oil used for industrial heat or for vehicle fuels causes an increase in the proportion of $SO_2$ and $SO_3$ in the atmosphere. Normally this is easily dissipated, but in intensely industrialised areas and particularly where the atmospheric temperature inversions, which allow 'smog' or fog to develop, occur, concentrations which are actually dangerous to life can build up. Oil is not the only or the worst source of atmospheric sulphur however–all the fossil fuels contain sulphur and the control of atmospheric pollution is a universal problem.

Other impurities do not seriously impair the utility of the crude in which they are contained but rare metals, such as vanadium, titanium, etc., occur in minute quantities in some crudes and often their detection gives a valuable indication of the provenance of the crude itself. Some other elements also occur in small quantities; nitrogen for instance is usually present in quantities less than 0.1 percent and is probably contained in the gases dissolved in the crude. Oxygen may be present either as free oxygen dissolved in the crude or combined with carbon and hydrogen in compounds called phenols, fatty acids or naphthenic acids. Helium is found in the natural gases of many fields, particularly in America and as it is a product of radioactive disintegration, its presence has led to the belief that radioactive energy plays a part in petroleum formation. Carbon dioxide is also normally present in petroleum gas and may be due to the chemical action of igneous rocks on limestones.

## Uses

The modern story of petroleum starts in Scotland in the mi... the

Industrial Revolution when the need was felt for improved lubrication for the new machines and more easily obtainable illuminants. James Young started the distillation of cannel coal and bituminous shale about 1850 and it is now generally accepted that the first well specifically for petroleum was drilled in Pennsylvania in 1859. The second half of the nineteenth century saw the development of petroleum as a source of kerosine (or paraffin), as an illuminating oil and of mineral lubricating oils. With the twentieth century the internal combustion engine produced a demand for gasoline and gas oil (diesel oil) and a vast improvement in the properties of lubricating oils. Development of these products has been continuous and even now improved gasolines are continually being introduced, whilst lubricants are every year proving that it is possible to operate machines under conditions and loads that were impossible only a decade or so ago.

## *Part I. Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. Among the hydrocarbon series, making up natural gas and crude oil are the paraffins, naphthenes ($C_nH_{2n}$), and aromatics.

........ 2. Impurities associated with petroleum include nitrogen, carbon dioxide, and hydrogen sulphide.

........ 3. Water is almost always present in the formation of crude oil.

........ 4. The words 'paraffinic' and 'asphaltic' as used in the classification of crude oil refer to the dominant elements in the crude oil structure.

........ 5. Physical properties are generally used to define the broad categories of crude oil.

........ 6. Among physical properties of crude oil are color, density, and viscosity.

........ 7. In the scale known as API gravity the higher the number of API, the heavier is the crude.

........ 8. Wax content and viscosity of the crude do not contribute to the pumping of the crude oil.

........ 9. Darcy units are used to determine the amount of crude oil viscosities.

........ 10. The determination of absolute viscosity does not seem to be an easy job.

**B. Choose a, b, c, or d which best completes each item.**

1. As the temperature of the crude oil drops from reservoir to surface temperature, the wax content of the crude causes it .......... .

   a. to liquefy　　b. to magnify

   c. to solidify　　d. to terrify

2. The ratio of the volume of produced gas to that of produced oil is a useful .......... in distinguishing one class of the crude from another.

   a. property　　b. classification

   c. information　　d. parameter

3. Sometimes pipelines are heated so as to keep the crudes with high wax content in .......... state.

   a. a condensed　　b. a distilled

   c. a fluid　　d. a gaseous

4. The analysis of crude oil in the laboratory is not easy because of .......... nature of crude petroleum.

   a. the simple　　b. the mixed

   c. the artificial　　d. the gaseous

5. The ratio of carbon and hydrogen in crude oil is sometimes determined through .......... analysis.

   a. laborious　　b. physical

   c. mathematical　　d. chemical

6. The percentage of sulphur in the so-called 'sweet' crude oil is .......... that in 'sour' crude oil.

   a. higher than　　b. the same as

   c. lower than　　d. none of the above

7. The presence of too much sulphur in the vehicle fuels is .......... public life.

   a. an asset for　　b. of no significance to

   c. a threat to　　d. none of the above

8. Smog is an abbreviation for .......... .

   a. smoke plus fog　　b. sulphur plus oxygen

c. sulphur plus methane    d. sulphur plus methane plus oxygen

**9.** Sulphur is an element which is found in all .......... .

a. nutrients    b. diets

c. fossil fuels    d. substances

### C. Answer the following questions orally.

1. When did man become aware of petroleum in recent years?
2. When was petroleum recognized as a source of kerosine?
3. For the first time, what kind of engines demanded gasoline and gas oil?
4. Who started the distillation of cannel coal and bituminous shale?
5. Do impurities in crude oil seriously damage its utility?

## *Part II. Language Practice*

### A. Choose a, b, c, or d which best completes each item.

**1.** The properties of crude oil and .......... gases have been extensively studied over the past several decades.

a. sulphur    b. cyclic hydrocarbons

c. hydrocarbon    d. sweet

**2.** The most common form of reservoir liquid is .......... .

a. black oils    b. oil sands

c. volatile oils    d. none of the above

**3.** The analysis of reservoir and of well performance depends upon .......... properties of the fluids in the formation and in the well.

a. the chemical    b. the mechanical

c. the physical    d. the marine

**4.** The specific gravity of bitumens is .......... that of methane.

a. equal to    b. more significant than

c. higher than    d. lower than

**5.** The breaking down of heavy molecules into several lighter molecules is referred to as .......... .

a. sweetening    b. cutting

c. purifying    d. cracking

**6.** In order to determine the ratio of carbon and hydrogen molecules, .......... are used.

a. chemical analyses
b. physical tests
c. both a and b
d. none of the above

7. Among the impurities in crude petroleum, sulphur compounds are found as .......... .

a. a complex compound
b. a pure substance
c. a gas
d. all of the above

8. Some believe that radioactive energy has a role in petroleum formation. The basis of this assumption lies in the fact that .......... is found in the natural gases of many oil fields.

a. helium
b. paraffin
c. carbon dioxide
d. benzine

9. The presence of carbon dioxide in petroleum gas may be due to the chemical action of .......... rocks on limestone.

a. weathered granite
b. fresh granite
c. basement granite
d. igneous

## B. Fill in the blanks with the appropriate form of the words given.

**1. Exhaust**

a. We .......... something (e.g. a supply of food) when we use it up completely.

b. The coal is .......... when it is all used.

c. By the end of the week everyone was in a state of .......... .

**2. Isolate**

a. A chemist .......... a substance when he separates it from other substances with which it is combined or mixed.

b. Every organism is structurally .......... from its environment by some kind of covering such as a shell, a skin, or a membrane (a very thin skin).

c. The condition of being isolated or the action of isolating is .......... .

**3. Mine**

a. .......... is the operation of digging below the earth's surface.

b. A .......... is a substance which is not part of a living animal or plant.

c. Mining is carried out by .......... .

**4. Fertile**

a. Plentiful supplies of grain and vegetables depend on the .......... of the soil.

b. A means of improving the fertility of the soil is the use of .......... .

c. A .......... soil is a soil which contains the necessary chemical substances.

**5. Propose**

a. At the last committee meeting, Mr. Green .......... that in future, members should refuse to deal with stores which charged more than ten percents a pound for potatoes.

b. Various .......... have been made for bringing the war to an end.

c. I will cooperate in any plan .......... by you.

## C. Fill in the blanks with the following words.

| | | | |
|---|---|---|---|
| performance | gradients | factors | stress |
| properties | geologist | effects | crust |
| environment | structure | items | point |
| compressibility | production | geometry | |

The behavior of a reservoir–and of the wells drilled to produce it–depends not only on the properties of the oil and gas, but also on a series of .......... that may be loosely termed the '.......... of the ..........'. Amongst these are such .......... as capillary-pressure .........., the reaction of rock when subjected to high .........., pressure and temperature .......... at the shallower levels in the Earth's .......... and the influences of the .......... as pressures are reduced by fluid withdrawals.

Setting the stage for all studies of reservoir .......... is the physical nature of the reservoir itself, its location, .........., lithology, internal .........., chemical make-up and extent. This is the starting .........., the field of study of the petroleum .......... and a subject that, unfortunately but of necessity, receives short shrift in a book having as its central theme the way in which reservoirs and wells behave once .......... has commenced.

**D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.**

a. For broad geologic reasons we are fairly certain that petroleum deposits will eventually be found in some regions that are not now known to contain them.

b. The petroleum must be discovered before it can be of any use to society.

c. Both the amount and the location of undiscovered petroleum are, of course, unknown.

d. A test well drilled in the hope of discovering a new pool is called a *wildcat well.*

e. We cannot say in advance, however, at what depth or at what exact location these deposits will be discovered.

f. The actual location and size of a deposit in the earth are determined only by drilling test wells into the deposit and by producing the content of the reservoir.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| | | | | | |

*Section Two: Further Reading*

## Reservoir Traps

The first essential element of a petroleum reservoir, you will recall, is the reservoir rock, and the second is the existence of connected pore spaces that are collectively capable of holding and storing petroleum. The third element is the oil, water, and gas–which are either in motion or are capable of moving–that occupy the connected pore spaces. The fourth element is the trap–the place where oil and gas are barred from further movement.

Since oil and gas are lighter than water, and since the reservoir rocks generally have a regional slope, though often slight, the petroleum moves through the water both vertically and laterally until it is barred by an impervious or less pervious rock. The impervious stratum that overlies the reservoir rock is called the *roof rock*. A roof rock that is concave as viewed from below prevents the oil and gas from escaping either vertically or laterally, thus localizing the pool of oil and gas. Such an external barrier is a *structural trap*. A lateral lessening of permeability due to facies changes, truncations, and other stratigraphic changes will, together with the roof rock, form an interior barrier, or *stratigraphic trap*.

Structural traps are the result of changes in the form of the reservoir rock; stratigraphic traps are the result of changes in the continuity of the rock. *Fluid barriers* occur where a difference in fluid potentials causes a down-dip flow of water to oppose the up-dip migration of petroleum. Increased fluid potential gradients usually exist where the flow space is constricted; for example, where a formation thins or where permeability is reduced.

The simplest and commonest way for a permeable underground formation to become a trap is to be folded into an anticline. An anticline is the most readily mapped of the common traps and can frequently be mapped at the surface. The close association of oil and gas pools with anticlinal folds was noted early and led to what has long been known as the *anticlinal theory* of oil and gas occurrence. Geologists everywhere searched for anticlines and domes on which to drill—almost to the exclusion of any other kind of trap. Consequently the anticlinal theory has had such a predominant place in exploration that it warrants a brief review of its development and of its gradual change into the more modern *trap theory*.

## The Anticlinal Theory

Although petroleum in various forms has been known since man made his earliest records, it was not until petroleum attained economic importance that much serious thought was given to why, how, and where it accumulated into pools. The discovery of oil by E. L. Drake in western Pennsylvania, in 1859, marked the beginning of the modern oil industry even though oil had previously been mined and obtained from wells at a number of places in various parts of the world. Drake demonstrated that drilling for oil could be successful, and the amount of oil he produced, though small compared with modern production, showed the world that drilling was the most effective way to obtain oil. From that time forth, the main question in the minds of every prospector for oil was where to put down the drill. Thought on this subject was greatly stimulated by the increasing demand for petroleum, and down to the present time it has constituted the core of petroleum geology.

A variety of theories have attempted to explain the conditions that result in an oil and gas pool in order to predict where such conditions may be found and where discoveries may be made. Of these the anticlinal theory has received the most serious and continued attention. The development of the anticlinal theory in geologic thinking is itself an interesting subject, but it can only be touched on here. The theory was conceived even before Drake's discovery, and, having been modified and expanded through the years, it is fundamentally as true today as when first proposed.

The term 'trap' was first introduced by McCollough in 1934 and applied to containers as diverse in character as those due to asphalt seals, lenses, local porosity variations, truncation, and overlap, especially in homoclinal dip areas, as well as to folding and faulting. Continued recognition of the fact that structural deformation is only one of several ways in which a trap may be formed, and that a large number of pools have accumulated in traps formed in other ways, increases the desirability of using a more inclusive term than 'anticlinal theory'. The term 'trap theory' is now more commonly used, and the geometrical configuration that holds in the oil is now commonly called a 'trap', whatever its shape or cause may be. Its essential characteristic is that the oil and gas are capable of accumulating and being held in it.

The importance of the oil-water contact in defining the trap has led to some modification of former ideas that assumed the water table to be either level or nearly level. It is now recognized that in some regions, where there is a fluid potential gradient, the oil-water contact is distinctly tilted. The tilt affects the position of the pool with respect to the rock boundaries, displacing it varying distances in the direction of water movement, even to the point of flushing the pool completely out of the trap.

## Classification of Traps

Numerous classifications of reservoir traps have been proposed. Clapp's final classification contained the following main headings: (1) anticlinal structures, (2) synclinal structures, (3) homoclinal structures, (4) quaquaversal structures, or 'domes', (5) unconformities, (6) lenticular sands, (7) crevices or cavities irrespective of other structure, and (8) structures due to faulting. Heroy classifies traps as (1) depositional traps, (2) diagenetic traps, and (3) deformational traps. Wilson classifies traps as (1) closed reservoirs: (a) reservoirs closed by local deformation of strata, (b) reservoirs closed because of varying porosity of the rock (no deformation of strata necessary other than regional tilting), (c) reservoirs closed by combination of folding and varying porosity, (d) reservoirs closed by combination of faulting and varying porosity; and (2) open reservoirs (none of commercial importance).

No classification is entirely satisfactory, for many traps are unique and would not fit readily into any but an extremely detailed classification. The following scheme, however, is believed to be as useful as any. Although simple, it includes a place for most kinds of traps known to contain oil and gas in commercial quantities. It is not all-inclusive, but the exceptions will be pointed out as they occur. The classification divides the traps broadly into three basic types: (1) structural traps, (2) stratigraphic traps, and (3) combinations traps (combinations of these two).

**Structural Traps.** A structural trap is one whose upper boundary has been made concave by some local deformation, such as folding or faulting or both, of the reservoir rock. The edges of a pool occurring in a structural trap are determined wholly or in part by the intersection of the underlying water table with the roof rock overlying the deformed reservoir rock.

**Stratigraphic Traps.** A stratigraphic trap is one in which the chief trap-making element is some variation in the stratigraphy or lithology, or both, of the reservoir rock, such as a facies change, variable local porosity and permeability, or an up-structure termination of the reservoir rock, irrespective of the cause. The areal extent of a pool occurring in a stratigraphic trap is determined wholly, or in large part, by some stratigraphic variation associated with the reservoir rock. The pool may rest on an underlying water table, which may be either level or tilted, or it may completely fill the voids in the reservoir rock with no produceable underlying reservoir water. The flow of water down-dip through the restricted permeability that forms the stratigraphic barrier to up-dip movement of the petroleum probably is an important element in the trapping of petroleum in many stratigraphic traps.

**Combination Traps.** Between these extremes–there is an almost complete gradation–traps are found that illustrate almost every imaginable combination of structure and stratigraphy. Traps in which structure or stratigraphy is clearly the most influential factor can readily be classified as structural or stratigraphic types. As the middle ground between a structural and stratigraphic trap is approached, however, it becomes increasingly difficult to decide the relative importance of each. Traps in this middle group–traps formed by both structural and stratigraphic causes in roughly equal proportions–are best called combination traps.

## *Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. Many oil fields have been found in positions which could not have been on anticlines.

........ 2. In the early years of the oil industry, oil was found simply by drilling a hole in the ground.

........ 3. The area of Pennsylvania was the scene of the first petroleum 'boom'.

........ 4. An anticline is the simplest type of oil trap.

........ 5. The general acceptance of the anticlinal theory and the understanding of some of the natural phenomena causing the accumulation of petroleum into reservoirs saw a great acceleration in the rate at which new oil and gas fields were discovered.

........ 6. A trap is a place where oil and gas are not hindered from further movement.

........ 7. Petroleum, being lighter than water, moves only laterally until it is stopped by an impervious rock.

........ 8. One important aspect of structural features such as anticlines is that the structure generally extends vertically through a considerable thickness of sedimentary formations.

........ 9. According to the passage, the anticlinal theory does not enjoy popularity anymore.

........ 10. A trap is characterized by its upward convex shape in combination with a porous reservoir rock with a relatively impermeable sealing cap rock above.

## B. Choose a, b, c, or d which best completes each item.

1. Anticlinal structures are the most common type of .......... .
   a. geological features b. sedimentation
   c. petroleum fields d. traps
2. Traps can be formed either by such local deformation activities as folding or faulting or from .......... depositional patterns.
   a. sedimentary b. artificial
   c. productive d. geological
3. Nowadays the term .......... theory is preferred than the previous term 'anticlinal theory' because of the fact that structural deformation is only one of several causes for the formation of traps.
   a. sub-surface b. entrapment
   c. trap d. geothermal
4. The general categories of reservoir traps are .......... traps.
   a. structural b. combination
   c. stratigraphic d. all of the above
5. Hydrocarbons are almost certainly formed from .......... material, large-scale deposits of which were gradually buried by subsequent sedimentation.
   a. organic b. acid
   c. inorganic d. alkaline
6. Structural traps that result chiefly or altogether from .......... are of widely varied shapes.
   a. drilling b. folding
   c. flooding d. saturating
7. The formation of stratigraphic traps is related to sediment deposition or erosion and is thus distinguished from formation of structural traps,

which originate from .......... .

a. folding
b. corroding
c. faulting
d. both a and b

### C. Write the answers to the following questions.

1. Why is not there any satisfactory classification of traps?
2. What are the topics which Clapp includes in his definition of traps?
3. What did the term 'trap' originally include?
4. What does the 'trap theory' imply now?
5. When was petroleum seriously studied?

❂ ❂ ❂

*Section Three: Translation Activities*

### A. Translate the following passage into Persian.

## Changes With Depth

Many folds and other structures change in shape, size, or amplitude, or shift their position laterally, in passing from the surface or shallow depths down to the reservoir rock. Folding at the surface or at shallow depth is therefore not always a reliable guide in searching for petroleum pools that are trapped in reservoir rocks at great depths, for it frequently does not parallel the deeper folding. Seismic mapping in advance of drilling, applied to the prospective reservoir rock or to some formation close to it, may show the deep structure to be completely out of harmony with the known shallow structure. Or a test well located on the crest of a surface fold may find no evidence of folding at the level of the reservoir rock. In either case doubt is thrown on the accuracy of the data, and many such differences are not necessarily due to the poor quality of the geophysical measurements or the well records; they are sometimes due to actual downward changes of structure. Many discrepancies between shallow and deep structure cannot be foretold, but some can be anticipated, or at least suggested as probable, if the geologic history of the region is known.

**B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.**

1. anticlinal ............................
2. condenser ............................
3. cracking ............................
4. crevices ............................
5. deformational traps ............................
6. depositional traps ............................
7. diagenetic traps ............................
8. disintegration ............................
9. distillate ............................
10. domes ............................
11. faulting ............................
12. folding ............................
13. fracturing ............................
14. furnace fuel ............................
15. gradients ............................
16. homoclinal ............................
17. impervious ............................
18. lubricating oils ............................
19. prospector ............................
20. purification plant ............................
21. solidify ............................
22. stratigraphic traps ............................
23. stratigraphy ............................
24. structural traps ............................
25. trap ............................
26. truncation ............................
27. viscosimeter ............................
28. viscous crudes ............................

# Unit 3

*Section One: Reading Comprehension*

## Subsurface Geology

The total footage of holes drilled each year by the petroleum industry of the world amounts to some hundreds of millions of feet. Of the total footage drilled, approximately one-fifth consists of wildcat wells drilled in the search for new pools, and the other four-fifths consists of wells drilled to develop previously discovered pools and fields. This great footage does not merely represent holes in the ground; because of the information it discloses, it actually represents so many feet of geologic column investigated. Over the years this huge drilled footage forms a vast store of geologic data with which to work; it is the chief basis for our understanding of the combination of underground stratigraphy, structure, and geologic history that is called *subsurface geology*–to distinguish it from surface geology.

The purpose of subsurface mapping in the geology of petroleum is to find traps that contain oil and gas pools, and, once a pool is found, to bring to bear the geologic evidence and concepts that aid most in its efficient development and production. The more of the geology of an area a geologist can know, the better job he should be able to do; so every bit of evidence becomes grist for his mill. While the information obtained from wells forms the heart of the data upon which subsurface geology depends, other information comes from geophysical surveys, pressure and temperature surveys, and the production history of producing oil and gas pools. All these diverse kinds of information fit together when correctly interpreted, and their coordination becomes the particular job of the petroleum geologist who is searching for new pools or extensions of known pools.

We are dealing with a great number of variables in subsurface geology, but it is doubtful if we can ever evaluate more than a fraction of them. Each pool may be thought of as a unique situation, resulting from a combination of many geological, chemical, and physical phenomena, most of which cannot be understood until after the pool has been discovered and developed. To one standing at the surface of the ground and attempting to locate a pool miles underground, even with all of the tools that have been developed, the chances of missing the target far outweigh the chances of hitting it. It is as though one were searching for a needle in a haystack with the aid of a small magnet. The magnet helps enormously when one gets near the needle, but to get near it one needs to use all of the clues there are before opening up the stack of hay, for from without all sides look alike. This helps explain the old adage that "oil, like gold, is where you find it."

One thing to bear in mind with regard to subsurface maps is that they are never finished. They may be thought of as progress maps or contemporary maps, only as complete as the data that are available when they are made. Where new wells are being drilled or old holes being re-examined, new information becomes available, and the maps are added to and corrected. The gross, or regional, geologic conditions may be deduced in some areas from only a few well records, and for that reason subsurface maps of all kinds are valuable, even those based on only a few scattered control points. Clues to regional arching, regional facies changes, or regional unconformities may give valuable advance notice of the favorable areas for further exploration. The new information that comes along from year to year from added wells merely fills in the details of the maps, and progressively closer detail is obtained with addition of more and more well data.

Regional subsurface geologic mapping is geologic reconnaissance mapping, and it is approached in the same way as surface geologic reconnaissance. This means that in the early stages of any subsurface work a careful and detailed study should be made of the local area for which the most complete geological data are available, such as an oil field or an area for which a concentration of good well logs is available. In such areas one can learn the habits of the rocks, their stratigraphic relations, the potential reservoir rocks, the position and nature of the unconformities, the time of folding and faulting, the changes in folding with depth, and the facies changes in the section of rocks being mapped. The nature of the petroleum content should also be studied; we want to learn what type of reservoir energy exists; what the direction and rate of the water movement might be; what effect the reservoir fluids have on the electric and radioactive logs, what order of petroleum reserves to expect, in barrels of oil and cubic feet of gas per acre-foot; and what the recovery factors are. Having made such a detailed case-history study, the geologist goes from the known to the unknown with much greater assurance that he will make the best possible application of the many scattered bits of data that make a regional frame of reference useful, even necessary, to the most successful exploration. Careful spot studies thus result in more accurate regional and local predictions.

Most of the basic data of the geology of petroleum and the work of the petroleum geologist are obtained from drilling both wildcat wells and development wells. It is worth while to consider the kinds of information that it is possible to obtain from a single hole or test well.

## *Part I. Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. Of all the wells drilled each year by the petroleum industry four-fifths are drilled in the search for new pools.

........ 2. The data obtained from drilling are the basis of our knowledge about the geologic history of the underground formations.

........ 3. Oil geologists employ the term 'subsurface geology' to distinguish it from surface geology.

........ 4. Exploration did not stop in areas where surface mapping could give little further help and once the surface had yielded up its secrets, men began to find methods of probing beneath the surface.

........ 5. Nowadays oil geology has become a specialized science in its own right.

........ 6. Surface geology, which after all is the foundation of all geological exploration, continues to be useful since new territory is now still being opened up and the first step is always a surface geological investigation.

........ 7. We can always understand and evaluate all the factors involved in subsurface geology.

........ 8. Subsurface mapping in the geology of petroleum attempts to locate traps that contain oil pools and to find ways for the efficient development and production of oil.

........ 9. We may look at any oil pool as a combination of geological, physical and chemical phenomena.

........ 10. With the advanced tools available to a geologist, he may locate a pool miles underground with precision.

## B. Choose a, b, c, or d which best completes each item.

**1.** A great deal is now known about the conditions under which oil accumulations occur, .......... .

a. but still it is not yet possible to say definitely that an oil field does actually exist underground

b. and it is possible to locate the exact location of an oil field

c. but it is not still worth while endeavoring to do underground research

d. but the majority of the oil fields which could be identified from surface geology have been discovered

**2.** In subsurface geology, the nature of the petroleum content should also be studied; this includes knowledge about .......... .

a. the type of reservoirs

b. the direction of underground water movement

c. the type of recovery factors

d. refinery factors

**3.** The .......... provide the petroleum geology with basic data.

a. porosity and permeability factors

b. potential reservoir rocks

c. drillings of wildcat wells

d. pressure and temperature surveys

**4.** Case-history studies enable the geologist .......... .

a. to interpret the data correctly

b. to restudy the information obtained from wells

c. to go from known to unknown

d. to go from unknown to known

5. In the light of new information concerning oil wells .......... .
   a. the geologist can make his maps up-to-date
   b. regional subsurface geologic mapping becomes possible
   c. the total footage of holes drilled becomes enormous
   d. subsurface maps become complete
6. The information from geological surveys and pressure and temperature surveys are useful only if they are .......... .
   a. interpreted in equipped office
   b. correctly interpreted
   c. interpreted on the spot
   d. quickly interpreted
7. Regional subsurface mapping is geologic reconnaissance mapping. Here 'reconnaissance' means 'exploration of the area for .......... purposes'.
   a. oil refinery
   b. oil discovery
   c. military
   d. logging
8. If a geologist knows the geological features of the area, he .......... .
   a. can do a better job
   b. may survey the maps
   c. can interpret information easily
   d. may cooperate with his colleagues
9. In subsurface geology, a lot of variables .......... .
   a. are likely to create danger
   b. should be avoided
   c. are dealt with
   d. should be taken out of list
10. Clues to regional arching .......... .
   a. may give valuable information about further exploration
   b. could disappoint the researchers
   c. may render exploration useless
   d. could be expensive to get

## C. Answer the following questions orally.

1. What should the oil geologist do in the early stages of subsurface work?
2. What is an oil geologist looking for when he studies the petroleum content?
3. Where does information come from besides that obtained from wells?
4. Why should each pool be considered as a unique situation?
5. What does the adage "oil, like gold, is where you find it" mean?

## *Part II. Language Practice*

### A. Choose a, b, c, or d which best completes each item.

1. In the area of well logs, a geologist can learn the habits of .......... .

   a. rocks  b. logs
   c. wells  d. reservoirs

2. The preparation of subsurface maps could be regarded as .......... job.

   a. a finished  b. an unfinished
   c. a successful  d. a rewarding

3. Spot studies carried out carefully may result in .......... local predictions.

   a. efficient  b. accurate
   c. detailed  d. applicable

4. The information obtained from wells constitutes .......... part of the needed information.

   a. the negligible  b. the small
   c. the main  d. the unexpected

5. Where new wells are being drilled, new information becomes .......... .

   a. necessary  b. valuable
   c. available  d. scarce

6. In the geology of petroleum, subsurface mapping is carried out to locate traps that contain .......... .

   a. oil pools  b. geological fossils
   c. diverse information  d. historical data

7. It was noticed that there was more chance of finding an oil well in .......... than on the hillside.

   a. a mountain crest  b. a rough surface
   c. a creek bottom  d. a steep side

8. The new information obtained each year from new wells completes the previous .......... .

   a. data  b. maps
   c. files  d. case-studies

9. If no well is .........., no oil will be found.

   a. discovered  b. mapped
   c. known  d. drilled

## B. Fill in the blanks with the appropriate form of the words given.

**1. Success**

a. Events are .......... when they come one after the other.

b. A .......... of events, periods, etc. is a number of events, periods, etc. coming one after the other in time and order.

c. Events follow in .......... when they follow one after the other.

**2. Essence**

a. Fresh air and sleep are .......... for health.

b. What are the .......... of good techniques of writing?

c. In spite of what he says in public, his attitude is .......... hostile.

**3. Detail**

a. A .......... is a small separate thing or item which enters into the construction of something, such as a painting or a novel.

b. We describe something in .......... where we describe its details.

c. A .......... description is one which supplies not only essential facts or the main points, but which gives information about the details.

**4. Signify**

a. The .......... of his theory is that it does not recognize any real boundary between anthropology and psychology.

b. The suffix /-ide/ when added to the name of a chemical element .......... a substance consisting of that element united to another.

c. An amount is .......... if it is important.

**5. Dominate**

a. A .......... factor in a situation is one which has more influence than others.

b. A person .......... others when he has authority or influence over others.

c. This boy is completely .......... by his father.

## C. Fill in the blanks with the following words.

| | | | |
|---|---|---|---|
| subsurface | intrusive | analysis | beneath |
| reservoirs | petroleum | personal | bites |
| associated | favorable | regional | spot |
| considerations | | | |

Quite commonly all the pools in a given area are found to be .......... with similar geologic features. In one they may be associated with .......... salt plugs; in another, with .......... sand patches, bars, channels, and similar .........., in still another, they may all underlie a/an .......... surface of unconformity. A region of which this is true is called a/an .......... province.

When study of geologic conditions gives reason to believe that oil and gas lie .......... the surface, the decision to drill (or not to drill) a test well is based on economic .......... . If the decision is .........., the exact location of the well is, in the final .........., determined by the .......... opinion of the petroleum geologist. As the drill .......... into the surface at the selected .......... the petroleum prospect has begun.

**D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.**

a. Although geologists working on the surface can sometimes collect large numbers of fossils it is very rarely possible for the well-site geologist to do so because most of his samples are obtained from the very small pieces of rock chipped off by the drilling bit or from the relatively larger pieces recovered whilst coring.

b. An important exception to this rule, however, is provided by very small fossils which can only be studied under the microscope.

c. So important have they become in oil field work that many palaeontologists confine their studies entirely to them.

d. In order to get a reasonable idea of the average individual existing at any horizon it is therefore really necessary to collect as many examples of the particular fossil in which we are interested as is possible.

e. The most important of these are the Foraminifera which are, fortunately, not only very small but also very numerous, especially in the shallow epicontinental seas.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| | | | | |

# Geophysical Exploration for Hydrocarbons

Geophysical methods for exploring for hydrocarbons are usually subdivided into *potential* methods and *seismic* methods. Potential methods measure variations in the gravity and magnetic fields and predict the gross geologic features of a basin. Seismic methods provide detailed information on the structure and stratigraphic features of the sedimentary layers and in some cases can locate hydrocarbons directly.

Magnetic measurements are usually made with an airborne magnetometer, which gives rapid coverage of large areas and provides information on the major features of the igneous basement underlying the sedimentary rocks in the basins. Estimates of depth to basement are the primary quantitative measurements obtained from magnetic surveys; thus, the gross features of the basin framework are established. Ground magnetic measurements provide detail on igneous intrusives that may trap hydrocarbons.

Gravity measurements are usually made at ground stations and provide information about the gross features of the sedimentary section. These measures are very effective in delineating salt structures. In the early days of salt dome exploration, after Spindletop, gravity measurements successfully pinpointed domes and led to the discovery of a number of fields. Even now gravity contour maps are effective in locating deep-seated salt structures that often are reflected into the overlying sedimentary layers, and help to isolate areas over which to conduct reflection seismic surveys. Because seismic surveys are very expensive compared to gravity methods, it makes economic sense to isolate areas of potential hydrocarbon accumulation.

Gravity measurements are made routinely at sea during the course of making seismic surveys, since they add only small increment to the survey cost, and provide valuable information about salt and other stratigraphic features. Airborne gravity methods are also used for rapid reconnaissance and gross measurements of the gravitational field. Gravity measurements from a moving platform are affected by the erratic motions of the platform, and the two effects are separated by special filtering techniques that preserve the gravity and filter out the effects due to motion of the platform.

Gravity and magnetics are potential methods; that is, they are passive. They depend on measurement of the natural magnetic and gravity fields of the earth. They are ambiguous in that an anomaly with a potential method may arise from a variety of bodies at a variety of depths in the earth. Because the potential methods are ambiguous, quantitative measurements of the nature of the body causing the anomaly must come from outside information. Such information can come from drilling contacts, seismic results, or reasonable geologic limitations. In spite of such ambiguities and lack of precision, magnetic and gravity measures can impose very definite limits on geologic interpretations and can thereby make specific and useful contributions to the overall exploration picture.

Seismic methods provide detailed information on structural and stratigraphic features and in some cases, fluid content, by use of refractions and reflections. The earliest seismic measurements used first arrivals that travel the least-time refraction path from source to receiver to gain knowledge of the near-surface layers. As the source-to-receiver distance increases, the first arrivals dig deeper and deeper into the earth, giving information on successively deeper layers. The reflection method is now the most widely used geophysical method and operates on the principle of recording back-scattered energy from targets, as do radar and sonar. The targets in the reflection method are changes in the acoustic impedance of the subsurface, which give structural, stratigraphic, and hydrocarbon information about the subsurface.

The seismic method is much more direct in its relation to geology than are the potential methods, because one can map reflections and directly correlate the reflections with geologic strata, giving a relatively accurate measure of their depth and possibly even their stratigraphy. In some cases, however, correlation with geology may be uncertain or misleading, and in such cases, gravity and magnetics may contribute by establishing bounds on possible correlations and provide lithological information.

The seismic method is by far the most widely used geophysical method for hydrocarbon exploration, and it is also the most expensive. Expenditures for the seismic method and its associated data processing account for 95% or more of the total expenditures for petroleum exploration geophysics, and gravity and magnetics are relegated to the remaining 5% or less. As a rough rule of thumb, the relative costs per unit area of magnetic, gravity, and seismic methods stand in the ratio of 1 to 10 to 100.

From the beginning of geophysical exploration for hydrocarbons in the 1920s, methods using magnetic, gravity, and seismic principles are the basis for practically all the geophysical work up to the present time. Many other methods have been conceived and tried in a limited way, but none has persisted to the extent that field operations have been carried out on a scale comparable with that of the three primary methods. As is true in any area as complicated and mystifying as the hunt for hydrocarbons, many quack techniques and procedures that have little or no scientific merit have been proposed and tested–and sometimes even suggest a measure of success. It is for this reason that geophysicists have earned the label of 'doodlebuggers'.

## *Comprehension Exercises*

**A. Put "T" for true and "F" for false statements. Justify your answers.**

........ 1. Geophysical mapping is essentially a kind of subsurface mapping in advance of drilling.

........ 2. Geophysical mapping consists in measuring various physical properties of rocks.

........ 3. The measurements of geophysical mapping are translated into geologic data.

........ 4. Potential methods provide information on stratigraphic features of the sedimentary layers.

........ 5. Seismic mapping is the most precise of the geophysical methods.

........ 6. Many geophysical electrical and radioactive phenomena are utilized in obtaining the basic well-log data.

........ 7. The seismic method is very common and not very expensive.

........ 8. Geophysical surveying has been instrumental in mapping the structures that have trapped a great many oil pools.

........ 9. Gravity, magnetic, and radioactive methods are unable to determine the precise position of the anomaly being mapped.

........ 10. Potential methods are more direct in their relation to geology than seismic methods.

**B. Choose a, b, c, or d which best completes each item.**

**1.** The practical value of geophysical methods in the geology of petroleum consists in their ability to measure the physical properties of rocks that are related to .......... traps in reservoir rocks.

a. existing  b. depositional
c. potential  d. diagenetic

**2.** A local variation or irregularity in the normal pattern is called a geophysical .......... .

a. miscalculation  b. anomaly
c. analogy  d. residue

**3.** Seismic method is .......... times costlier than magnetic method.

a. five  b. one hundred
c. ten  d. twenty-five

**4.** The .......... of a seismic survey is determined largely by an accurate knowledge of the velocity of the reflecting or refracting waves through the intervening rocks.

a. variability  b. measurement
c. dependability  d. validity

**5.** Despite their shortcomings, magnetic and gravity measures can make useful contributions to .......... activities.

a. the exploration  b. the discovery
c. the refinery  d. the measurement

**6.** After all pertinent corrections have been applied to the measurement of any property, the residual local anomaly is considered to be due to some geologic phenomenon, the correct interpretation of which depends on .......... .

a. the regional geology
b. the local geology
c. the experience and ability of the geologist
d. all of the above

7. Gravity measurements are generally carried out .......... .

a. on hill-sides b. on land

c. in cannyons d. at sea

8. By making use of refractions and reflections, seismic methods can supply us with information on .......... features.

a. structural b. accurate

c. gravitational d. magnetic

9. The reflection method operates on the principal of .......... .

a. thermodynamics b. magnetism

c. gravity d. radar

10. Magnetic, gravity, and seismic methods are the basis for all .......... work.

a. quantitative b. exploratory

c. geophysical d. geochemical

## C. Write the answers to the following questions.

1. Why is the seismic method much more direct in its relation to geology?
2. What do potential methods measure?
3. What kind of instrument is used in magnetic measurements?
4. Why are the areas of potential hydrocarbon accumulation isolated?
5. What is meant by 'outside information' as used in the text?

❂ ❂ ❂

*Section Three: Translation Activities*

## A. Translate the following passage into Persian.

# The Petroleum Geologist Work

The actual discovery of a pool is made by the drill, but the proper location of the wildcat well to test a trap, the depth to which it should be drilled, and the detection and outlining of the oil or gas pool from what is revealed by that well and others, are wholly geologic problems. They constitute the essence of the geology of petroleum and are the most important work of the petroleum geologist. He may need to consider only a simple combination of stratigraphy and structural geology, or he may have to take account of a complex combination of data, involving such various fields as stratigraphy, sedimentation, paleontology, geologic history, fluid flow, structural geology, petrography, geophysics, geochemistry, and metamorphism. In addition to all this, he may have to draw on his own and other people's knowledge of many related sciences, such as physics, chemistry, biology, and engineering. He must do his best to work out the geology of an area from what is visible or what can be mapped at the surface, and from all available well and geophysical data for depths ranging up to three miles or more below the surface. His prediction, however, may often be based on the most fragmentary data, some of which are obtained by specialists or experts who may or may not have a working knowledge of geology, or by geologists who have worked with no thought of the petroleum possibilities of the region. This information is assembled on maps and cross sections, and fitted together in the mind of the petroleum geologist, where it is interpreted and translated into the best place to drill a well that will penetrate a trap below the surface of the ground and thereby enable the well to test the trap's content.

**B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.**

1. acoustic impedance ............................
2. facies ............................
3. formation lithology ............................
4. geologic strata ............................
5. gross features ............................
6. igneous basement ............................
7. igneous intrusives ............................
8. isopach ............................
9. lithological information ............................

10. potential method ..............................
11. reconnaissance mapping ..............................
12. reflection method ..............................
13. regional arching ..............................
14. regional unconformities ..............................
15. seismic method ..............................
16. sonar ..............................
17. subsurface geology ..............................
18. survey geology ..............................
19. test well ..............................

# Unit 4

*Section One: Reading Comprehension*

## Methods of Oil Exploration

Crude oil is found in alternating layers of porous and impermeable sedimentary rock. The oil flows through the porous layers into reservoirs and is trapped by impermeable layers of cap rock above. The cap rock often rises in dome structures or anticlines.

The probable location of oil fields can be determined by geologists who have a knowledge of the structure or *horizons* of the earth.

The usual initial attack on a region to be explored is conducted by magnetic surveys. These make use of a sensitive instrument called a magnetometer which detects small local perturbations in the earth's magnetic field. A magnetic survey can be conducted by aircraft using MAD (magnetic airborne detection) equipment developed during World War II to search for submerged submarines.

The magnetometer is more responsive to igneous rock than to sedimentary rock because the former contains more magnetite. The usual procedure is to obtain magnetometer readings on a grid pattern and to draw contours of equal magnetic field strength. These contour maps indicate the varying depths at which sedimentary rock changes to igneous rock, thus providing clues to the probable location of oil reservoirs.

Gravity surveys make use of sensitive instruments called gravimeters that are transported in boats or jeeps. The gravimeter measures the earth's gravitational field and is more responsive to the denser igneous rock than to sedimentary rock. When gravimeter measurements are plotted on a grid pattern, contours of an equal gravitational field can be drawn that map the interface between sedimentary rock and igneous rock.

Seismic methods are used to narrow the search once a primary region has been defined. An explosive charge is detonated in a shot hole and sends out shock waves that are reflected or refracted at the interfaces of layers of rock. The shock waves are received by special microphones, called geophones, located at various distances along radial lines emanating from the shot hole. The reflections are passed through special wide-band electronic amplifiers and used to drive the pens of multiple chart recorders called oscillographs. Pulses indicate that the shock wave has been reflected or refracted from an interface between rock layers. A knowledge of the speed of mechanical vibration in various kinds of rock allows a geophysicist to determine the location and depth at which each rock interface exists. Seismic exploration permits charting the horizons of the earth and visualizing the alternating layers of porous and impermeable sedimentary rock and the anticlines that furnish evidence of a subsurface oil reservoir.

The presence of hydrocarbons in sand or in air entrapped beneath the surface helps locate oil that exists near the surface. These analytical techniques are known generally as geochemical methods.

Advantage can also be taken of the fact that oil-bearing sands conduct electricity better than ordinary earth. Measurements of minute earth currents can thus detect the presence of oil near the surface. These techniques are known as telluric methods.

Exploration methods merely insure that a region is a likely location of a subsurface oil reservoir. But in the oil business, the only real proof is in the drilling. Drilling exploratory wells is known as wildcatting, in contrast to drilling field wells in proven producing areas.

In a recent year, almost 10,000 wildcat wells were drilled in the United States for a total footage of close to 50 million feet. These wells produced nearly 350 million barrels of crude oil, averaging over seven barrels per foot of wildcat well drilling.

A great deal of information can be gained in the course of exploratory drilling. Acquisition of this information is called well logging. Chemical analysis of mud samples pumped down the drill hole to cool the bit will indicate the presence of hydrocarbons. Occasionally, a core sample taken with a hollow bit will be subjected to a more complete examination. Ultraviolet light is used to detect the presence of oil in drilling samples.

In addition to core samples and mud analyses which comprise the chemical log, an electric log is kept to record the minute earth currents that flow between layers of porous and impermeable rock. An electric log will indicate the presence of oil by the decreased resistance of oil-bearing rock strata.

Two types of radioactivity logs may be kept. A passive radioactivity log measures radioactive emissions from the rock strata through which the drill hole passes. This method uses a scintillation counter. Oil-bearing strata have a characteristically higher level of radioactivity than ordinary rock.

An active log uses a radioisotope in the drill hole and a scintillation counter that measures the amount of absorption by the rock. Oil-bearing rock strata display a higher absorption of radioactive emission than does ordinary rock. Active logs can be used to audit a drill hole after it has been cemented; passive and electric logs cannot be used in this case.

Drill holes are cemented to prevent the incursion of sand, water or brine. Cement is pumped down between the wall of the drill hole and the casing.

A caliper log is also kept. This records the diameter of the bore hole, and thus measures the permeability of the rock strata.

## *Part I. Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. The initial search to locate crude oil is done through the use of a specific magnetic instrument.

........ 2. The magnetic content of igneous rocks makes them appropriate targets for oil explorations.

........ 3. The gravimeter detects the small local disturbances in the earth's magnetic field.

........ 4. Crude oil is found in permeable rocks.

........ 5. An important factor necessary for oil accumulation in subsurface areas is a trapping mechanism.

........ 6. Magnetic measurements are usually made with an airborne magnetometer, which gives rapid coverage of large areas and provides information on the major features of the igneous rocks under the ground.

........ 7. Gravity contour maps can depict the layer between sedimentary rock and igneous rock.

........ 8. An electric log is based on the common observation that oil-bearing sands conduct electricity better than ordinary earth.

**B. Choose a, b, c, or d which best completes each item.**

1. Among the common geophysical methods available for exploring oil, we may refer to .......... .
   a. gravity surveys, which measure variations in the gravity
   b. magnetic surveys, which measure changes in the magnetic fields
   c. seismic surveys, which provide detailed information on the structure of sedimentary layers
   d. all of the above
2. The measurement of small earth currents can lead the researcher to the presence of oil, because .......... .
   a. oil-bearing sands are weaker conductors of electricity than ordinary earth
   b. earth currents are not related to the presence of subsurface oil supply
   c. oil-bearing sands conduct electricity better than ordinary earth
   d. oil-bearing sands are the indication of the presence of oil
3. Well logs are run in holes to measure properties of the rocks in order to determine the volume of oil in place. Among the following logs .......... have been referred to in the passage.
   a. passive radioactivity logs, chemical analysis logs
   b. chemical logs, electric logs, radioactivity logs
   c. active radioactivity logs, chemical logs
   d. acoustic logs, radioactive logs, electric logs
4. According to the passage, an electric log can show the presence of oil because .......... .
   a. oil-bearing rock layers are good insulators
   b. rock layers which contain oil can let electric currents pass more easily
   c. oil-bearing rock layers contain ample supply of oil
   d. the sedimentary rock beneath the surface is not an obstacle for the researcher
5. In the beginning stages of their hunt for hydrocarbons, persistent wildcatters employed .......... .
   a. seismic methods
   b. gravity measurements
   c. magnetic measurements
   d. none of the above

### C. Answer the following questions orally.

1. How does the seismic method work?
2. Where is crude oil found?
3. How does a magnetometer help the experts in oil exploration?
4. What kind of information can be gained in the course of drilling?
5. What does a passive radioactivity log measure?
6. How does a geophysicist determine the location of each rock interface?
7. What are the telluric methods?
8. How does the electric log show the presence of oil?

## *Part II. Language Practice*

### A. Choose a, b, c, or d which best completes each item.

1. The oil flows through the porous layers into .......... .

   a. drill holes　　b. shot holes
   c. reservoirs　　d. casings

2. The presence of hydrocarbons in sand or in air entrapped beneath the surface helps locate oil that exists .......... .

   a. in porous sediment　　b. in drill hole
   c. far from impermeable rock　　d. near the surface

3. Oil-bearing sands conduct electricity better than .......... .

   a. ordinary earth　　b. impermeable sediments
   c. porous sediments　　d. igneous rock

4. Oil-bearing strata have a characteristically higher level of .......... .

   a. permeability　　b. radioactivity
   c. porosity　　d. productivity

5. Pulses indicate that the shock wave has been reflected or .......... from an interface between rock layers.

   a. drawn　　b. received
   c. refracted　　d. conducted

### B. Fill in the blanks with the appropriate form of the words given.

**1. Alter**

a. I must .......... the sleeves of this coat; they are too long.

b. I will not accept this report unless there are considerable .......... .

c. Tom reads the first paragraph, Dick reads the second, Tom reads the third, and so on. They read .......... .

**2. Approximate**

a. Your story .......... to the facts we already know.

b. Three thousands students each year would be an .......... .

c. It costs .......... $ 300; I can't remember exactly.

**3. Associate**

a. The things and objects around us are .......... with our uses and purposes for them.

b. We .......... places and houses with the people who live there.

c. We think of places and houses in .......... with the people who live there.

**4. Convert**

a. England .......... to a decimal currency system in 1971.

b. .......... to gas central heating will save you a lot of money.

c. .......... currencies are currencies that can be exchanged for those of other countries.

**5. Expose**

a. Silver darkens when it is .......... to light.

b. Frequent .......... to X-rays is harmful.

c. That unfortunate remark .......... his ignorance of the subject.

## C. Fill in the blanks with the following words.

| | | | |
|---|---|---|---|
| prohibitively | formations | connate | cores |
| resistivity | reservoir | logging | shale |
| recognition | porosity | logs | data |
| equivalent | | | |

*Logging.* One of the difficulties encountered in drilling is recognition of the possible oil and gas content of formations penetrated while sinking the well. Such recognition is possible by examining .......... taken from the well but this is usually slow and expensive. Within recent years, methods have been developed for securing .......... information by electrical .......... of the formations encountered. Electrical .......... and self-potential data were first employed to differentiate sand or .......... beds, to estimate bed thickness, and to plot underground .......... contours. It was later found that oil-bearing .......... frequently showed higher resistivity than did surrounding strata. Still later came .......... that electric .......... were useful (particularly when employed with core data) in determining figures of value for .......... engineering purposes, such as .......... water salinity, water saturation, and the .......... and fluid permeabilities of the formation. Quantitative interpretation of electric log .......... has been so successful that such logging is an almost universal accompaniment of oil well drilling.

**D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.**

a. The free surface of the rock face can be increased in several ways.

b. It often happens that oil flow from the rock is obstructed by clogging of one sort or another.

c. Once a producing horizon has been located, it can usually be isolated by cementing behind the casing; the well casing and cement can then be perforated at the proper depth and the oil withdrawn.

d. A less drastic means, effective in limestones and lime-bonded sandstones, is the treatment of the rock face with relatively dilute hydrochloric acid suitably inhibited against metal corrosion.

e. A method developed in the early days involved exploding a charge of nitroglycerin or similar violent brisant material at the well bottom.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| | | | | |

# Gas Reservoirs

## History of Reservoir Engineering

Crude oil, natural gas, and water are the substances which are of chief concern to petroleum engineers. Although these substances sometimes occur as solids or semisolids, usually at lower temperatures and pressures, as paraffin, gas-hydrates, ices, or high pour-point crudes, in the ground and in the wells they occur mainly as *fluids*, either in the *vapor* (gaseous) or in the *liquid* phase, or, quite commonly both. Even where solid materials are used, as in drilling, cementing, and fracturing, they are handled as fluids or slurries. The division of the well and reservoir fluids between the liquid and vapor phases depends mainly upon the temperature and pressure. The state or phase of a fluid in the reservoir usually changes with pressure, the temperature remaining substantially constant. In many cases the state or phase in the reservoir is quite unrelated to the state of the fluid when it is produced at the surface. The precise knowledge of the behavior of crude oil, natural gas, and water, singly or in combination, under static conditions or in motion in the reservoir rock and in pipes and under changing temperature and pressure, is the main concern of petroleum engineers.

As early as 1928 petroleum engineers were giving serious consideration to gas-energy relationships and recognized the need for more precise information concerning physical conditions as they exist in wells and underground reservoirs. Early progress in oil recovery methods made it obvious that computations made from wellhead or surface data were generally misleading. Sclater and Stephenson described the first recording bottom-hole pressure gauge and thief for sampling fluids under pressure in wells. It is interesting to note that this reference defines bottom-hole data as referring to positive measurements of pressure, temperature, gas-oil ratios, and the physical and chemical nature of the fluids. The need for accurate bottom-hole pressures was further emphasized when Millikan and Sidwell described the first precision pressure gauge and pointed out the fundamental importance of bottom-hole pressures to petroleum engineers in determining the most efficient methods of recovery and lifting procedures. With this contribution the engineer was able to measure the most important basic information for reservoir performance calculations, *reservoir pressure*.

The study of the properties of the rocks and their relationship to the fluids they contain in both the static and flowing states is called *petrophysics*. Porosity, permeability, fluid saturations and distributions, electrical conductivity of both the rock and the fluids, pore structure, and radioactivity are some of the more important petrophysical properties of rocks. Fancher, Lewis, and Barnes made one of the earliest petrophysical studies of reservoir rocks in 1933, and in 1934 Wycoff, Botset, Muskat, and Reed developed a method for measuring the permeability of reservoir rock samples based on the fluid flow equation discovered by Darcy in 1856. Wycoff and Botset made a significant advance in their studies of the simultaneous flow of oil and water, and of gas and water in unconsolidated sands. This work was later extended to consolidated sands and other rocks, and in 1940 Leverett and Lewis reported research on the three-phase flow of oil, gas, and water.

It was early recognized by the pioneers in reservoir engineering that before the volumes of oil and gas in place could be calculated, the change in the physical properties of bottom-hole samples of the reservoir fluids with pressure would be required. Accordingly in 1935 Schilthuis described a bottom-hole sampler and a method of measuring the physical properties of the samples obtained. These measurements included the pressure-volume-temperature relations, the saturation or bubble-point pressure, the total quantity of gas dissolved in the oil, the quantities of gas liberated under various conditions of temperature and pressure, and the shrinkage of the oil resulting from the release of its dissolved gas from solution. This data made the development of certain useful equations feasible, and it also provided an essential correction to the volumetric equation for calculating oil in place.

The next significant development was the recognition and measurement of connate water saturation, which was considered indigenous to the formation and remained to occupy a part of the pore space after oil or gas accumulation. This development further explained the poor oil and gas recoveries in low permeability sands with high connate water saturation, and introduced the concept of water, oil, and gas saturations as percentages of the total pore space. The measurement of water saturation provided another important correction to the volumetric equation by correcting the pore volume to hydrocarbon pore space.

While temperature and geothermal gradients had been of interest to geologists for many years, engineers could not make use of this important data until a precision subsurface recording thermometer was developed. Millikan pointed out the significance of temperature data in applications to reservoir and well studies.

From this basic data Schilthuis was able to derive a useful equation, commonly called the Schilthuis material-balance equation. It is a modification of an earlier equation presented by Coleman, Wilde, and Moore, and is one of the most important tools of reservoir engineers. Basically it is a statement of the conservation of matter, and is a method of accounting for the volumes and quantities of fluids initially present in, produced from, injected into, and remaining in a reservoir at any stage of depletion. In reservoirs under water drive the volume of water which encroaches into the reservoir also enters into the material balance on the fluids. Although Schilthuis proposed a method of calculating water encroachment using the material-balance equation, it remained for Hurst and, later, van Everdingen and Hurst to develop methods for calculating water encroachment independent of the material-balance equation, which applies to aquifers of either limited or infinite extent, in either steady-state or unsteady-state flow.

Following these developments for calculating the quantities of oil and gas initially in place or at any stage of depletion, Tarner and Buckley and Leverett laid the basis for calculating the oil recovery to be expected for particular rock and fluid characteristics. Tarner, and, later, Muskat presented methods for calculating recovery by the internal or solution gas drive mechanism, while Buckley and Leverett presented methods for calculating the displacement of oil by external gas, cap drive and water drive. These methods not only provided means for estimating recoveries for economic studies, but they also explained the cause for disappointingly low recoveries in many fields. This discovery in turn pointed the way to improved recoveries by taking advantage of the natural forces and energies, and by supplying supplemental energy by gas and water injection, and by unitizing reservoirs to offset the losses which may be caused by competitive operations.

## *Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. When it is under low temperatures and pressures, crude oil occurs mainly as a fluid in subsurface locations.

........ 2. While the temperature remains constant, the pressure in the reservoir changes the state of a fluid.

........ 3. Early petroleum engineers realized that calculations based on surface data were not conclusive.

........ 4. A well-calculated account of the reservoir pressure is irrelevant in determining the best methods of crude oil recovery.

........ 5. Petrophysics is the study of the relationship between rock and its fluid contents.

........ 6. The study of Schilthuis did not deal with the decrease of oil production due to the release of dissolved gases from crude oil.

........ 7. Millikan's thermometer made it possible for petroleum engineers to realize the relationship of subsurface temperature data and oil recovery.

........ 8. The equation of Schilthuis describes the quantity of fluids in a reservoir contents at any given moment.

### B. Choose a, b, c, or d which best completes each item.

1. The study of the properties of the rocks and their relationship to the fluids they contain is called .......... .

   a. geophysics  b. atomic physics
   c. biochemistry  d. petrophysics

2. Before the volumes of oil and gas in place could be calculated, the change in .......... properties of bottom-hole samples of the reservoir fluids with pressure would be required.

a. the physical b. the chemical
c. the electrical d. the distributional

**3.** Among some of the important petrophysical properties of rocks are .......... .

a. porosity b. permeability
c. fluid saturations d. all of the above

**4.** The state of a fluid in the reservoir usually changes with pressure, .......... remaining unchangeable.

a. the gas-oil ratio b. the pressure gauge
c. the temperature d. the bottom-hole pressure

**5.** Tarner's discovery pointed the way to improved recoveries by .......... .

a. taking advantage of the natural forces
b. supplying supplemental energy by gas injection
c. unitizing reservoirs to offset the losses caused by competitive operations
d. all of the above

## C. Write the answers to the following questions.

1. What does the division of the well and reservoir fluids between the liquid and vapor phases depend on?
2. What are some of the petrophysical properties of rocks?
3. What was the contribution of Wycoff and Botset?
4. What was considered essential prior to the calculation of volumes of oil in subsurface areas?
5. Why was the measurement of water saturation significant?
6. What did the measurements of Schilthuis include?
7. Who brought up the significance of geothermal factor in reservoir studies?
8. What is material-balance equation? Why is it important?
9. What was the contribution of Tarner-Buckley-Leverett?

### A. Translate the following passage into Persian.

## Petroleum Reservoirs

Oil and gas accumulations occur in underground *traps* formed by structural and/or stratigraphic features. Fortunately they usually occur in the more porous and permeable portions of beds, which are mainly sands, sandstones, limestones, and dolomites, in the intergranular openings, or in pore spaces due to joints, fractures, and solution activity. A *reservoir* is that portion of a trap which contains oil and/or gas as a single hydraulically-connected system. Many hydrocarbon reservoirs are hydraulically connected to various volumes of water-bearing rock called *aquifers*. Many reservoirs are located in large sedimentary basins and share a common aquifer. In this case the production of fluid from one reservoir will cause the pressure to decline in other reservoirs by fluid communication through the aquifer. In some cases the entire trap is filled with oil or gas, and in this case the trap and the reservoir are the same.

Oil and gas are displaced to the wells by (a) fluid expansion, (b) fluid displacement, natural or artificial, (c) gravitational drainage, and/or (d) capillary expulsion. Where there is no aquifer, and no fluid is injected into the reservoir, the hydrocarbon recovery is brought about mainly by fluid expansion; however, in the case of oil it may be materially aided by gravitational drainage. When there is water influx from the aquifer or where, in lieu of this, water is injected into selected wells, recovery is accomplished by the displacement mechanism, which again may be aided by gravitational drainage or capillary expulsion.

### B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.

1. aquifers ..............................
2. bottom-hole pressure gauge ..............................
3. bubble-point pressure ..............................

4. connate water ..............................
5. fluid saturation ..............................
6. lifting procedures ..............................
7. logging ..............................
8. permeability ..............................
9. petrophysics ..............................
10. pore structure ..............................
11. porosity ..............................
12. slurries ..............................
13. wildcat ..............................
14. viscosity ..............................

# Unit 5

*Section One: Reading Comprehension*

## Reservoir Engineering

Within recent years the technology involved in maintaining conditions for maximum oil recovery from a field has been studied intensively under the name of reservoir engineering. Perhaps the most important requirement is the maintaining of pressure in the reservoir. In the undisturbed formations, the pressure is due to gas associated with the oil (in solution, with or without additional gas separated at the top of the formation–gas cap) or to water at the bottom or sides of the oil body in the reservoir, or to both. If wells penetrate this system and are allowed to flow unchecked, the natural pressure is likely to be dissipated while there is still a good deal of oil unproduced. This situation can be helped by control of the rate and method of oil removal; it is important that oil be withdrawn at such a rate that natural water at the edges of the formation will have time to keep orderly pace with production. Another way of increasing recovery involves judicious introduction of extraneous gas or water into the formation. Intelligent control depends in any case on adequate information. Necessary basic data on the equilibrium behavior of hydrocarbon mixtures under reservoir conditions have been supplied by American Petroleum Institute Research Project 37. Knowledge of the composition and viscosity of the reservoir fluid, the temperatures and pressures, with their distribution in the formations, the relative permeability of the rock to oil, gas, and water, and the relative viscosity of these phases are of great value in reservoir studies. Adequate information of the sort outlined makes it possible to treat a reservoir system by the known laws of vapor-liquid equilibrium and to predict its history under certain schedules of production.

Within recent years deeper drilling to zones of higher pressure and temperature has led to discovery of reservoirs from which a single phase can be withdrawn containing large proportions of normally gaseous hydrocarbons with much lower amounts of very light crude oils; the latter might be present up to, say, 4 gal per 1,000 cu ft. An early example of this reservoir type is the Kettleman Hills field in California; most of those known in the United States are located on the Gulf Coast of Lousiana and Texas. The product is distinguished from ordinary gas-cap fluids by the fact that the light oil content is recoverable as condensate when pressure is reduced on the sample; this is, of course, contrary to the usual separation of liquid from a homogeneous vapor-gas mixture (existing under less severe conditions) when pressure is increased. The reservoirs are therefore known as 'condensate' reservoirs. Adequate information is not available in all cases on the actual nature of the oil deposit. There is not much doubt that the single phase withdrawn exists as such in the reservoir, since this can be confirmed by laboratory duplication. Some cases are oil bodies in communication with gas caps, at such high pressure and temperature that retrograde condensation of liquid hydrocarbons occurs when pressure is reduced on the gas-cap material. Other cases may represent gas caps physically separated from their accompanying liquid oil, or even complete reservoirs of abnormally light crude oil vaporized into large proportions of gaseous hydrocarbons. The common factor in all these possible cases is the very high pressure and temperature which induce the existence of a single phase containing rather nonvolatile hydrocarbons which condense as liquid when pressure is reduced. Since decreasing pressure allows condensation, it is important that pressure be maintained during exploitation. This can be done by withdrawing gas-phase material, recovering the condensate liquid, and returning the stripped gas to the formation; the process is known as recycling.

Since the prevailing formation pressure represents the energy available for producing oil from a reservoir, the conserving of such pressure is for this second reason highly important. It is more desirable to maintain such pressure than to restore it. However, where operating pressure has declined, it can usually be built up again by pumping in enough gas; in extreme cases a single phase condition can be erstored. It will be obvious that in most cases the gas from the formation, stripped of liquid hydrocarbons, will be employed.

When pressure is well dissipated and production has become difficult, secondary recovery methods may be applied. While the repressuring just described qualifies under this head, the more familiar method is water flooding. This involves establishing or renewing water pressure to displace oil from the rock pores while pushing the oil to recovery wells. It is important that the composition of the water be controlled to avoid precipitation of insoluble materials and the swelling of bentonite clays, followed by their dispersal in the formation, where they might interfere with flow of oil. Bacterial contamination of certain kinds is also undesirable.

Over a period of years, attempts have been made to improve the results of water flooding by including additive agents in the water injected. Many of these were doomed to failure by disregard of the elementary inorganic chemistry of the formations and of the water contained. More recently water-soluble detergents, particularly of the non-ionic type, have given moderate improvements in recovery. It has been pointed out by Muskat that the real function which additives might perform is the lowering of the interfacial tension between water and oil. It is sometimes supposed that the tension between oil and rock is the significant one; actually, in most reservoirs the rock is water-wet rather than oil-wet.

In order to overcome difficulties of producing some of the heavy, very viscous oils known, or the heavier materials left in spent reservoirs, it has been proposed that such heavy oils can be heated to a less viscous condition and pushed ahead to output wells by *in situ* combustion of part of the oil; air or oxygen is fed down certain wells with the idea that an advancing combustion wave can be maintained in the rock, moving toward recovery wells. It has been suggested that burning of less than 15 percent of the oil in place will be sufficient to produce the rest. The project is related to underground gasification of oil and coal, which has been under study for some years.

Any formation producing a wax-bearing oil, and the well piping carrying such oil, may be exposed to clogging by deposited wax. This is encouraged by the change in concentration resulting from evaporation of light fractions and by the probable drop in temperature the evaporation involves. The wax will carry with it any silt or other solid particles suspended in the oil. There is likely also to be a good deal of resinous and asphaltic material in the deposit. It is not unlike the rod wxa of the early days of the industry. Control methods include mechanical scraping, use of solvents, and application of heating. Wax content varies a great deal from one crude to another, and the wax-clogging problem may be serious in one location and non-existent in others.

A common obstruction forming in piping under critical conditions of temperature, pressure, and composition is caused by hydrocarbon hydrates. These are complexes, presumably clathrate in nature, between water and the lower paraffins, up to butane; they are relatively stable at low temperatures and high pressures. The remedies are dehydration, injection of compounds like the lower alcohols, or heating at critical points of accumulation.

## *Part I. Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. Reservoir engineering deals with oil recovery from a field.

........ 2. Reservoir rocks are locations in which oil and gas are accumulated and stored by nature.

........ 3. Oil and gas never migrate from the 'source rocks' in which the parent organic matter was deposited.

........ 4. One of the ways to secure an increase in recovery involves the application of external gas or water into the production process.

........ 5. Secondary recovery methods are employed in those cases where pressure is scattered.

........ 6. The most important function of the additive agents in the injected water is the lowering of tension between water and oil.

........ 7. In reservoir engineering it is necessary to maintain pressure.

........ 8. Restoring pressure in the reservoir is more desirable than maintaining it.

........ 9. The laws of vapor-liquid equilibrium have a great impact on a reservoir system.

### B. Choose a, b, c, or d which best completes each item.

1. An oil and gas reservoir may be defined as a body of porous and permeable rock containing oil and gas through which fluid may move toward recovery openings under .......... .

a. the pressures that exist b. dissipated natural pressure

c. the pressures that can be applied d. both a and c

**2.** Knowledge of the properties of the reservoir rock is important in determining .......... .

a. storage capacity

b. resistance to flow

c. the rate at which fluids may enter the wells

d. all of the ablve

**3.** The permeability of a reservoir rock is a measure of .......... .

a. the storage capacity of a rock

b. the size and shape of the pore spaces

c. the resistance offered to movement of fluids through its pore spaces

d. the depth of oil-bearing strata

**4.** Water flooding is employed .......... .

a. to renew water pressure to displace oil from the rock pores

b. to maintain desirable pressure in the pores

c. to lower the density of natural gas

d. to filter oil through certain types of clay

**5.** In order to eliminate the production of heavy oils, .......... .

a. these heavy oils can be heated

b. these heavy oils are pushed ahead to output wells

c. air or oxygen is fed down the wells

d. all of the above

**6.** Where pressure in the reservoir decreases .......... is/are employed.

a. water-soluble detergents

b. additive agents

c. gas from the formation

d. elementary inorganic chemicals

**7.** In a process known as 'recycling' .......... .

a. gas-phase material is withdrawn

b. condensate liquid is recovered

c. the stripped gas is returned to the formation

d. all of the above

### C. Answer the following questions orally.

1. How is the production of deposited wax stopped?
2. What does the wax contain?
3. What do control methods include?
4. Under what conditions are the hydrocarbon hydrates somewhat stable?
5. What has deeper drilling to zones of higher pressure and temperature led to?
6. What happens if wells penetrate the reservoir?

## *Part II. Language Practice*

### A. Choose a, b, c, or d which best completes each item.

**1.** The most important requirement for maximum oil recovery is the maintaining of .......... in the reservoir.

a. high temperature  b. fluid
c. water  d. pressure

**2.** More recently .......... have given moderate improvements in the recovery of petroleum.

a. ionic-type detergents  b. water-soluble detergents
c. gaseous hydrocarbons  d. liquid hydrocarbons

**3.** The technology involved in maintaining conditions for maximum oil recovery is called .......... .

a. reservoir engineering  b. oil exploration
c. drilling  d. secondary recovery

**4.** The wax will carry with it any .......... or other solid particles suspended in the oil.

a. silt  b. coal
c. rock  d. gas

**5.** A common obstruction forming in piping under critical conditions of .......... is caused by hydrocarbon hydrates.

a. pressure  b. composition
c. temperature  d. all of the above

## B. Fill in the blanks with the appropriate form of the words given.

**1. Efficient**

a. An apparatus, a mechanism, or an operation is .......... when it performs its function with the least possible waste of energy.

b. A factory is .......... organized when it is efficient.

c. In physics and engineering, .......... is a technical term and represents something which can be measured.

**2. Associate**

a. We .......... a person with his name, or an idea with the word or symbol for it.

b. We are working in .......... with a number of local companies to raise money for the homeless.

c. A known word is .......... with its meaning in our minds.

**3. Success**

a. Events are .......... when they come one after the other. When we say the school team won four .......... games, we mean that the team won four games, one after the other.

b. A .......... of events, periods, etc. is a number of events, periods, etc. coming one after the other in time and order (e.g. a .......... of wet days).

c. Events follow in .......... when they follow one after the other.

**4. Illustrate**

a. That outburst was an .......... of his bad temper.

b. When an artist .......... a book, he draws or paints pictures which are included in the book and which help to make it more interesting.

c. An .......... is an example, a diagram, etc. used to make something clear.

**5. Durable**

a. The .......... of an event, an affair, a process, etc. is its time dimension, the time for which it lasts.

b. A material is .......... if it is strong enough to last for a long time.

c. A man can .......... pain, suffering, cold, heat, hunger, etc., when he is physically or mentally strong for it.

## C. Fill in the blanks with the following words.

| | | | |
|---|---|---|---|
| agitation | viscous | emulsification | asphaltic |
| content | emulsion | encroach | proportions |
| pressure | absorbed | accumulation | residue |
| flowing | likely | observation | constituents |
| emulsions | minimizes | occur | samples |
| emulsifying | | | |

*Emulsions and Emulsion Breaking.* Practically all petroleum in situ is in contact with so-called connate water dispersed in the pores of the reservoir, and at least a little of this brine, or perhaps edge or bottom water, is produced simultaneously with the oil. Larger .......... of water may .........., particularly as the reservoir .......... drops, and when this happens, the water is very .......... to come to the surface emulsified with the oil. It seems probable that the .......... are formed by the .......... involved in the production–pumping, or .......... through small orifices, and anything which .......... such agitation reduces the extent of .......... .

It is a matter of observation that emulsions practically never .......... with light gravity paraffinic oils, but are common with those of heavy .......... type. Poineer work on the nature of the emulsions was done by Sherrick. He was able to show that they are always of the water-in-oil type and that in his .......... the water particles were negatively charged. He suggested that the .......... and stabilizing agents are silt particles carrying films of .......... asphaltic material. He also studied the influence of salt .......... in the water on the nature and size of the electric charge on the water particles. It was later shown that a/an .......... can practically always be broken by removing the asphalt by one means or another. The importance of asphaltic .......... was indicated by the .......... that the oil recovered from an emulsion was more .........., of heavier gravity, and showed a higher carbon .......... value than the unemulsified part of the same oil; this would indicate .......... of asphalt from the crude into the emulsion.

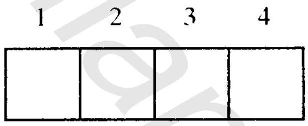
## D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. The openings in rocks are, for the most part, of capillary size, and through capillary attraction they exert a selective action on the two fluids, drawing water into close-grained rocks and displacing petroleum which is forced into rocks having larger pore spaces.

b. Although it would appear difficult to explain the extensive migrations of petroleum that have occurred in some instances as due to the operation of differential capillarity, it seems reasonable to assume that this force may be instrumental in effecting local segregations of water and oil.

c. Lenticular segregation of oil in sands may be explained on this basis, and capillarity may assist in forcing petroleum out of the rocks in which it is formed, into more permeable rocks, where gas, hydrostatic, hydraulic, and earth pressure may be effective in bringing about the major concentrations.

d. Water has a surface tension about 2½ times that of petroleum; therefore capillarity is proportionately effective in its lifting power.




*Section Two: Further Reading*

## Transformation of the Organic Matter Into Petroleum

Perhaps the least well understood phase of petroleum genesis is the chemistry of the transformation of the organic matter into petroleum. While several possible sources of hydrocarbons are recognized, it is impossible at the present time to evaluate their relative contributions, except in qualitative fashion.

The discovery of prolific bacterial growths in at least the upper layers of recent sediments suggested immediately that, in addition to providing the protective reducing environment, biological activity might possibly be a generating agent for crude oil. It can be said that bacteria preferentially attack carbohydrates and proteins, leaving the more refractory substances such as certain of the lipides, insoluble proteins, lignins, and other complex materials, collectively known as aquatic humus. The result of this activity is the synthesis of simpler compounds such as carbon dioxide, hydrogen, hydrogen sulphide, ammonia, fatty acids, alcohols, and amines. An important inorganic bacterial reaction in recent sediments is the reduction of sulphate ion to sulphide. Stone and ZoBell noted that, except for the production of methane, bacteria tend to leave organic compounds bearing carboxyl, hydroxyl, amine, and sulfhydryl groups, rather than to accomplish the complete removal of oxygen, nitrogen, or sulphur atoms required to produce hydrocarbons. From the observation that tyrosine could be fermented to yield either phenol or *p*-cresol, Machamer and Stone reasoned that phenylalanine might be made to yield benzene or toluene. Working with the same cultures, no trace of either hydrocarbon could be detected. The abundant production of methane originally suggested that the higher paraffins might be so produced, but careful analysis of the products of a wide variety of microbial fermentations failed to show anything more than trace amounts of ethane or higher paraffins.

A small amount of hydrocarbon is synthesized by bacteria as a part of their cell substance. Carbon tetrachloride extracts of cultures of autotrophic bacteria which used molecular hydrogen as the sole source of energy and carbon dioxide or carbonate as the sole source of carbon were demonstrated by ZoBell to contain at least 25 percent of paraffinic and cycloparaffinic hydrocarbons. It appears likely that this is, at least, one of the sources of some of the heavier hydrocarbons in recent sediments.

The possibility that biocatalysts or enzymes are involved in the formation of hydrocarbons cannot be discounted at the present time. A wide variety of such organic catalysts are produced by bacteria, and it may be possible that, under the prevailing low-temperature anaerobic conditions, these substances may be preserved to function for a time after the organisms which produced them ceased to exist.

Some years ago, Lind and Bardwell suggested that the natural radioactivity of sediments might be involved in the generation of petroleum. While their proposed mechanism of methane polymerization has now been discounted, the work did point up an interesting source of energy for the possible transformation of organic material to hydrocarbon.

As the result of extensive investigations by Bell, Goodman, and Whitehead, Russell, Beers and Goodman, and Beers, it became evident that shales in general were considerably richer in radioactive elements than were other sedimentary rock types. It was further shown that thorium, uranium, and potassium are associated with the finer-grained constituents and more carbonaceous materials, suggesting that radioactive bombardment might alter this organic material and possibly produce appreciable amounts of hydrocarbon.

Since alpha particles account for more than three-quarters of the energy liberated by naturally occurring radioactive elements, first attention was devoted to them. The possible mechanisms by which these particles might induce chemical reaction were reviewed by Sheppard who also carried out the first approximate calculation of the radiochemical conversion of organic material to petroleum under certain hypothetical, sedimentary conditions. Extensive work by Sheppard and Whitehead, Honing, Sheppard and Burton, Whitehead, Goodman, and Breger, Burton, Breger and Burton, and Breger provided the data required to render these calculations quantitative. It was demonstrated that aliphatic fatty and naphthenic acids can be decarboxylated to the parent hydrocarbons by alpha or the equivalent deuteron radiation. A variety of light saturated and olefinic hydrocarbons is also produced, along with carbon dioxide, carbon monoxide, water, and hydrogen; a portion of the hydrogen reacts with the olefins to yield saturated products. In a summary of the work, Whitehead concluded that some $3\times10^{-7}$ g of hydrocarbon material might be expected to be produced per gram of typical, organic-rich marine shale per million years as a result of the radiation from the uranium and thorium series and from potassium. It thus appears that radioactivity can account for only a very small fraction of the observed residual hydrocarbon contents of ancient marine sediments, and an even smaller portion of the total amount of petroleum which must have been generated in those sediments.

The thought that at least a part of the hydrocarbons of petroleum has been formed by some long-term thermal reaction was voiced at an early date. By 1888, Engler had demonstrated that the pressure distillation of fats would yield an oily material of high olefin content and somewhat later outlined in a rather broad way what was probably the first of the organic theories of petroleum genesis. This highly unsaturated material, called protopetroleum by Engler, was believed possibly to have formed from the fatty components of the organic debris in sediments by mild thermal cracking and polymerization; paraffins were thought to form by decarboxylation of fatty acids, while the olefins isomerized to cyclic hydrocarbons.

While these early ideas are no longer held–Engler, himself, recognized the difficulties these concepts implied–there appears no reason why low-temperature decarboxylations, deaminations, cyclizations, hydrogenations, isomerizations, or other type reactions might not proceed under the conditions known to exist in nature. Thus, at relatively low temperatures (200° to 250°C), polyene structures can be cyclicized to produce aromatic hydrocarbons. For example, *m*-xylene has been found in the pyrolysis products of bixin and capsanthin, while other carotenoids have yielded, in addition to *m*-xylene, toluene and 2,6-dimethyl-naphthalene. Cyclization and polymerization reactions have been noted to occur in the same temperature range for several unsaturated fatty acids of marine organisms. Considering the composition of the source material and the generally reducing conditions, such polyene-type reactions may well contribute substantially to the naphthene-aromatic fraction of crude oil.

Chemical reactions of the type suggested become particularly attractive when it is realized that the clays and other fine-grained minerals, which are always present in the sediment, may act as catalysts for both synthesis of hydrocarbons and for the degradation of the organic source material to hydrocarbons. In an early paper on the subject, Brooks suggested that any of several naturally occurring minerals might be active in promoting polymerization; in later publications the idea was further developed to include hydropolymerization, isomerization, and cyclization to explain the variety of hydrocarbon types present in petroleum. A carbonium ion mechanism was suggested, following Whitmore's proposal to account for acid catalysis.

Because of the time factor involved, there have been very few attempts to demonstrate that the fine-grained mineral components of sediments might aid catalytically in the formation of petroleum. For the most part, the catalytic activity of minerals in the earth has been inferred from their properties under cracking or near-cracking temperatures. The extrapolation of kinetic data over wide ranges of conditions is, of course, a highly questionable procedure. Also, as Van Nes and Van Westen point out, there is no assurance that the structural changes known to occur in clays at high temperatures (about 300°C) do not fundamentally alter their catalytic nature; certainly the hydrocarbons obtained at the two temperature extremes cannot be the same by virtue of their difference in thermodynamic stability. Recognizing these difficulties, Frost and coworkers conducted their experiments with clays and other mineral types at temperatures ranging from 130°C up to a maximum of 275°C, using appropriately long periods of contact. Essentially, he showed that, at these temperatures, alcohols could be dehydrated, water split out of ketones, olefins polymerized, and hydrogen transfer induced. The apparent absence of hydrogen in natural gases and sediments is not inconsistent with low-temperature reactions of the type described, according to Van Nes and Van Westen, since it is known that, in low-temperature cracking, hydrogen production drops rapidly with temperature.

## *Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. The thought that a part of the hydrocarbons of petroleum has been formed by long-term thermal reactions is a recent one.

........ 2. At relatively high temperatures, polyene structures can be cyclicized to produce aromatic hydrocarbons.

........ 3. Radioactivity can account for only a very small fraction of the residual hydrocarbon contents of ancient marine sediments.

........ 4. The possibility that enzymes are involved in the formation of hydrocarbons cannot be discounted at the present time.

........ 5. As a part of their cell substance, a small amount of hydrocarbon is synthesized by bacteria.

........ 6. Although several possible sources of hydrocarbons are recognized, it is impossible at the present time to evaluate their relative contributions.

........ 7. For several unsaturated fatty acids of marine organisms, cyclization and polymerization reactions have been noted to occur in the same temperature range.

........ 8. Alpha particles account for half of the energy liberated by naturally occurring radioactive elements.

........ 9. Paraffins were thought to form by decarboxylation of fatty acids.

........ 10. Bacteria usually attack carbohydrates and proteins, leaving the more refractory substances such as lipides, insoluble proteins and other complex materials.

## B. Choose a, b, c, or d which best completes each item.

**1.** The least well understood phase of petroleum .......... is the chemistry of the transformation of the organic matter into petroleum.

a. extraction b. refinery
c. genesis d. deposit

**2.** The assumption that hydrocarbons make up a normal component of recent sediments is now .......... .

a. completely rejected b. accepted without doubt
c. accepted with some considertaions d. not considered at all

**3.** The natural .......... of sediments might be involved in the generation of petroleum.

a. radioactivity b. isomerization
c. growth d. reaction

**4.** A significant inorganic bacterial reaction in recent sediments is the reduction of sulphate ion to .......... .

a. sodium b. sulphur
c. ammonia d. sulphide

**5.** It is accepted that .......... activity is a generating agent for crude oil.

a. chemical b. organic

c. biological d. molecular

**6.** The .......... and fine-grained minerals may act as catalysts for the degradation of the organic source material to hydrocarbons.

a. sulphurs b. organic debris

c. clays d. fatty acids

**7.** There have been very few attempts to demonstrate that the fine-grained mineral components of sediments might help .......... in the formation of petroleum.

a. transformationally b. catalytically

c. temporarily d. generally

**8.** As a rule, .......... activity of minerals in the earth has been inferred from their properties under cracking temperatures.

a. the productive b. the liberating

c. the refractory d. the catalytic

**9.** At high temperatures, alcohols could be .......... .

a. dehydrated b. destabilized

c. polymerized d. degraded

**10.** It is now shown that thorium, uranium, and .......... are associated with the finer-grained constituents.

a. sodium b. carbon

c. potassium d. nitrogen

## C. Write the answers to the following questions.

1. What phase of petroleum generation is generally less well understood?
2. What is left after bacteria attack carbohydrates and proteins?
3. At what temperature ranges did Frost and his coworkers conduct their experiments?
4. How is the catalytic activity of minerals in the earth inferred?
5. What is protopetroleum composed of?

**A. Translate the following passage into Persian.**

# Expulsion of Petroleum From the Source Rock and Accumulation

Geologists have recognized three necessary requirements for an oil deposit:

1. Source sediments.
2. A permeable rock of sufficient porosity to serve as a reservoir.
3. A trap of some type, associated with the reservoir, which will prevent the petroleum from migrating away and being lost, and which will facilitate accumulation.

From the discussion in the foregoing sections it is evident that sediment types and the geochemical environments favorable to the generation of crude oil are not uncommon in nature and, for this reason, widespread formation of petroleum must be assumed to be occurring even at the present day. However, the development of an available reservoir rock and trap, predating accumulation, is a much rarer event and is usually the controlling factor in the over-all process of formation of an oil deposit. Because of the importance of this aspect of the problem, it is considered briefly here, although not strictly a part of the origin question.

As the thickness of a sedimentary deposit increases, the weight of the overlying sediments becomes considerable. The result of this increase in overburden is that the muds begin to lose water and any other fluid materials contained in them to the more permeable, interfingering sand zones, mentioned earlier. The loss of fluids from the muds results in a substantial reduction in thickness and permeability. A typical mud section of 100 ft thickness containing about 75 percent by volume of water and 25 percent by volume of fine-grained minerals will have been reduced to some 40 ft of shale by the time it has been buried to a depth of 5,000 ft; the density will have risen from an initial 1.4 to 2.0 and the water content will have been reduced to about 42 volume percent. Under 8,000 ft of overburden, the resulting shale will have a thickness of some 30 ft and a water content of approximately 20 volume percent, or about 10 percent of the original water content of the mud; the density will now be about 2.4. The sand zones, being relatively incompressible, will retain their shape and permeability.

**B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.**

1. additive agents ..............................
2. aquatic ..............................
3. autotrophic ..............................
4. catalytical ..............................
5. combustion ..............................
6. condensate ..............................
7. deposit ..............................
8. dispersal ..............................
9. evaporation ..............................
10. organic ..............................
11. polymerization ..............................
12. recovery ..............................
13. reservoir ..............................
14. saturation ..............................
15. wax-clogging ..............................

# Unit 6

*Section One: Reading Comprehension*

# Reservoir Rocks

## Lithology

The sedimentary rocks in which most hydrocarbon reservoirs occur are essentially the products of erosion. The study of the formation of these rocks is called sedimentation. Wind, water, and ice are the sources of forces that wear away the earth's surface to create sediments. As the ancient high parts of the topography were eroded away, the resulting sediments were subsequently deposited at lower elevations in the form of pebbles, sand, and mud.

Not only most reservoir rocks, but also the rocks in which oil was formed, were created by erosion. Most of these source rocks (such as black shales) were deposited in an ocean environment, but some were probably formed in fresh water.

The formation of carbonate rocks involved processes other than the deposition of sediments produced by erosion. Limestone reefs were formed by marine organisms, and some other carbonate formations evidently were created by the precipitation of calcium carbonate from sea water. Still other limestone beds can be identified as the shell remains of ancient sea life. All of these carbonate deposits were modified to some extent by factors including compaction and tectonic forces, as well as solution or precipitation from percolating mineralized water.

In addition to the clastic rocks (such as sandstone) and the carbonates (such as limestone and dolomite), hydrocarbon deposits are occasionally found in fractured shale, anhydrite, evaporites, igneous rock, and metamorphic rock.

Numerous methods for determining lithology from well logs have been developed. These techniques should be used in conjunction with other methods of rock identification, such as the study of regional geologic information, and the examination of drill cuttings and cores.

The Gamma Ray log records the natural radioactivity of rock. Since most shales are substantially more radioactive than most sandstones and carbonate rocks, the Gamma Ray log is frequently used to identify shales. The Spontaneous Potential log, which measures electric potential in the well-bore, may also be used for this purpose in many areas.

**Porosity**

From the viewpoint of the petroleum engineer, the two most important properties of a reservoir rock are porosity and permeability. Porosity is a measure of the storage capacity of a reservoir. It is defined as the ratio of void space to bulk volume, and it may be expressed as either a percent or a fraction. In Equation form:

$$\phi = \text{void space/bulk volume} = (\text{bulk volume}-\text{grain volume})/\text{bulk volume}$$

Example: Calculate the porosity of a sandstone sample where the following information is available from core analysis:

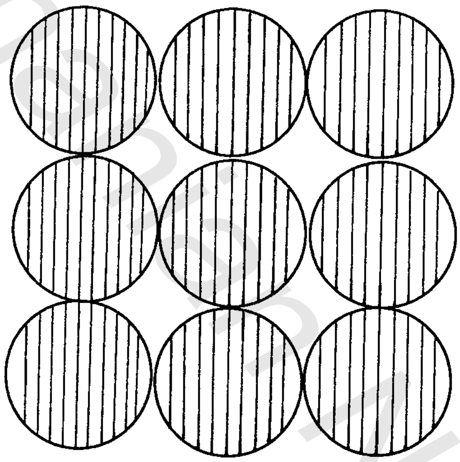
bulk volume of sample = 9.9 cc
weight of dried sample = 20 gm
sand grain density = 2.67 gm/cc

The grain volume may be calculated by dividing the weight of the dried sample by the sand grain density, and the porosity may be determined from:

$$\phi = [9.9-(20/2.67)]/9.9 = 0.243 = 24.3\%$$

Porosity may be classified according to its origin as either primary or secondary. Primary or original porosity is developed during deposition of the sediment. The intergranular porosity of sandstones and oolitic porosity of limestones are examples of primary porosity. Secondary porosity is caused by some geologic process subsequent to formation of the deposit. These changes in the original pore spaces may be created by ground stresses, water movement, or various other types of geological activities after the original sediments were deposited. Ground stresses are known to create fractures, and water movement may cause solution cavities, precipitation, or clay swelling to occur. Clay swelling, precipitation, compaction, recrystallization, and granulation are processes that may decrease primary porosity. Fracturing or the formation of solution cavities often will increase the original porosity of the rock.

From a petroleum engineering viewpoint, two types of porosity may be measured: total or absolute porosity, and effective porosity. Total porosity is the ratio of all of the pore spaces in a rock to the bulk volume of the rock. Effective porosity is the ratio of interconnected void spaces to the bulk volume. Thus, only the effective porosity contains fluids that can be produced from wells. For granular materials such as sandstone, the effective porosity may approach the total porosity; however, for shales and for highly cemented or vugular rock such as some limestones, large variations may exist between effective and total porosity. For example, a shale may have a total porosity of approximately 40%, and an effective porosity less than 2%.

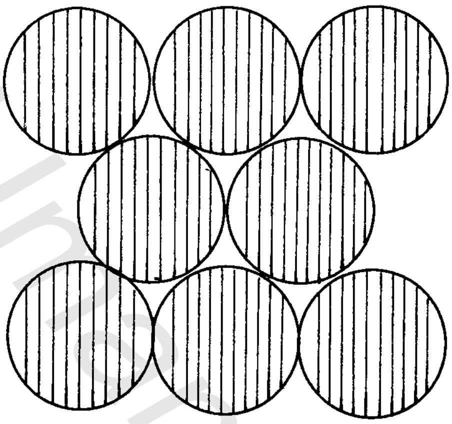


48% Porosity

**Figure 6-1.** Cubic packing of spherical grains.

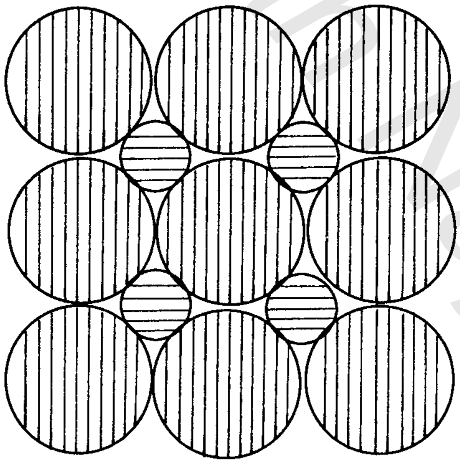
For a uniform rock grain size, porosity is independent of the size of the grains. Porosity would be the same whether the grains were all the size of peas or all the size of oranges, as long as they were arranged in the same manner. A maximum theoretical porosity of 48% is achieved with cubic packing of spherical grains, as shown in Figure 6-1. Rhombohedral packing, which is more representative of reservoir conditions, is shown in Figure 6-2; the porosity for this packing is 26%. If a second, smaller size of spherical grains is introduced into cubic packing as shown in Figure 6-3, the porosity decreases from 48% to 14%. Thus, porosity is dependent on the grain size distribution and the arrangement of the grains, as well as the amount of cementing materials. Not all grains are spherical, and grain shape also influences porosity. A typical sand is illustrated in Figure 6-4.

The porosity of a reservoir rock may be determined either by core



26% Porosity

**Figure 6-2.** Rhombohedral packing of spherical grains.



14% Porosity

**Figure 6-3.** Cubic packing with two grain sizes.

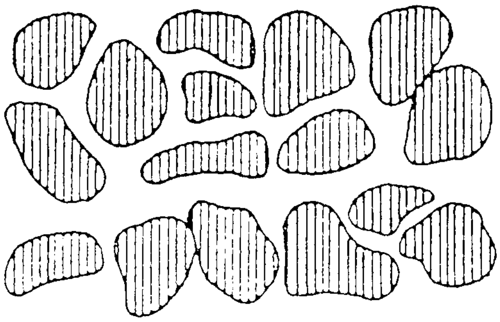


**Figure 6-4.** Typical sand with irregular grain shapes.

analysis, or by an appropriate logging technique. The question as to which source of porosity data is more reliable cannot be answered without reference to a specific interpretation problem. Both core analysis and log interpretation will yield correct porosity values under favorable conditions. The core analysis porosity determination has the advantage of being unambiguous; no assumptions need be made as to mineral composition, borehole effects, etc. However, since the volume of the core is less than the rock volume which is investigated by a logging device, porosity values derived from logs are frequently more accurate in heterogeneous reservoirs.

Actually, there is no entirely satisfactory method for determining porosity of a petroleum reservoir which is not homogeneous. For example, consider a hypothetical reservoir which is developed on 160-acre spacing. Assume that every well is cored and that every core is recovered and analyzed. If the core diameter is 3.5 inches, then a measurement of porosity will be made on less than one millionth of one percent of the reservoir. From a statistical standpoint this is hardly an adequate sampling. The use of porosities derived from well logs would effect only a small improvement in this situation; the radius of investigation of well logging devices ranges from one or two inches up to a maximum of a few feet, depending primarily on the type of logging tool and characteristics of the rock.

## *Part I. Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. Erosion is one of the factors for the creation of the sedimentary rocks necessary for most hydrocarbon reservoirs.

........ 2. Sedimentation refers to the characteristics of wind and water.

........ 3. Many other processes, besides the deposition of sediments produced by erosion, contribute to the formation of carbonate rocks.

........ 4. The two most essential elements of a reservoir rock are porosity and permeability.

........ 5. The rock must contain pores or voids to store petroleum and these pores must be interconnected.

........ 6. The majority of petroleum accumulations are found in clastic reservoir rocks.

........ 7. Two different kinds of porosity can be identified in sedimentary rocks, primary (or intergranular) and secondary porosity.

........ 8. An increase in porosity is paralleled by an increase in permeability.

........ 9. Permeability is a measure of the storage capacity of a reservoir.

........ 10. Granulation may increase the primary porosity.

## B. Choose a, b, c, or d which best completes each item.

**1.** Fracturing often will increase .......... .

a. the interconnection of the grains

b. the essential granulation of the rock

c. the original permeability of the rock

d. the original porosity of the rock

**2.** The porosity of carbonate rocks is .......... .

a. often more than that of sandstones

b. frequently somewhat less than that of sandstones

c. usually less than that of limestones

d. often more than that of shales

**3.** If the size of rock grains were the same, porosity would .......... .

a. increase b. suffer

c. not be affected d. be affected

**4.** Porosity depends on .......... the grains.

a. the size distribution of

b. the arrangements of

c. the amount of cementing materials among

d. all of the above

5. Porosity, a measure of the storage capacity of a reservoir, is expressed in .......... form.
   a. the fraction  b. a percentage
   c. the average  d. either a or b
6. Primary porosity is decreased because of .......... .
   a. compaction  b. granulation
   c. recrystallization  d. all of the above
7. Core analysis and logging technique are used .......... .
   a. to decrease primary porosity
   b. to determine the porosity of reservoir rock
   c. to increase secondary porosity
   d. to determine the formation of solution cavities
8. It is significant that more than 40% of giant oil and gas fields are found in carbonates; this is because of their .......... porosity.
   a. high  b. low
   c. original  d. secondary
9. Core analysis and log interpretation both are used to determine porosity values, but .......... .
   a. the latter is not ambiguous at all
   b. the former is nearly unambiguous
   c. the latter is always dependable
   d. the former is not reliable
10. Sandstones commonly have a primary porosity which is largely dependent on .......... .
   a. the packing characteristics
   b. variation in size of the grains
   c. the shape of the grains
   d. all of the above

## C. Answer the following questions orally.

1. Why are the porosity values derived from logs more accurate in heterogeneous reservoir?
2. How were limestone reefs formed?
3. Which factors have modified the carbonate deposits?

4. Which methods should be used in determining lithology from well logs?
5. What does Spontaneous Potential log measure?

## *Part II. Language Practice*

### A. Choose a, b, c, or d which best completes each item.

1. The study of the formation of the sedimentary rocks is called .......... .
   a. sedimentation b. precipitation
   c. recrystallization d. granulation
2. Carbonates include .......... .
   a. igneous rock b. clastic rock
   c. mineralized water d. limestones
3. Most reservoir rocks were created by .......... .
   a. corrosion b. erosion
   c. deposition d. compaction
4. Among the processes which decrease primary porosity is .......... .
   a. packing b. cementing
   c. clay swelling d. fracturing
5. Any permeable and porous rock may act as .......... for oil and gas.
   a. a reservoir b. a capillary attraction
   c. a storage d. a well-bore
6. Sandstones commonly have a primary .......... which is largely dependent on the packing characteristics and on the variation in size and shape of the grain.
   a. saturation b. porosity
   c. permeability d. accumulation

### B. Fill in the blanks with the appropriate form of the words given.

1. **Erode**
   a. A solid substance is .......... when it is gradually rubbed away and reduced by external forces.
   b. Wind and water cause .......... in rocks and soil.
   c. Water can be considered one of the nature's strong .......... forces.

**2. Drain**

a. Soil is .......... when water is removed from soil by being allowed to fall away from the soil to a lower level.

b. The action or result of draining the soil is called .......... .

c. The .......... of soil may cause erosion.

**3. Conserve**

a. When we do not waste good soil, i.e., when we do not allow it to be eroded, we .......... the soil.

b. The .......... of minerals is important because supplies of many important minerals are exceedingly limited.

c. When we are in short of time, we usually use .......... foods.

**4. Render**

a. A compound has been synthesized which will .......... cotton cloth waterproof.

b. Before the gases are discharged into the atmosphere, they must be .......... harmless.

c. Nowadays the procedures for .......... wounds sterile are much simpler than they used to be.

**5. Emit**

a. A volcano .......... smoke.

b. When .........., neutrons travel at high velocity.

c. Radioactive .......... are very dangerous.

## C. Fill in the blanks with the following words.

| | | | |
|---|---|---|---|
| feature | capacity | sedimentary | interval |
| spill | accumulate | exploration | sense |
| outflow | column | structural | enclose |
| faults | residual | | |

A trap is a geological .......... which enables migrating petroleum to .......... and be preserved for a certain time .......... . Traps occur in fundamentally different forms and can .......... very different volumes of pore space and hence petroleum. The maximum total holding .......... or closed .......... of a trap is the volume between its highest point and the 'spilling plane' or .......... level at the bottom. Traps are rarely completely full, i.e., the petroleum column rarely extends down to the point at which it would .......... out of the trap. Furthermore, traps are never full in the .......... that all available pore space in the reservoir rock is occupied by petroleum. There is always a certain .......... amount of water, which cannot be displaced by migrating petroleum.

Traps can be formed either by tectonic activity such as .........., folds, etc. (structural traps) or from .......... depositional patterns (stratigraphic traps). The majority of known oil fields is found in .......... traps, but structural traps are easier to locate by current geophysical and geological .......... techniques.

## D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. They may be due to depositional features such as a sand-body embedded in and sealed by shales in a transgressive sequence, or a porous reef rock buried by dense limestones and shales.

b. Such traps are commonly referred to as stratigraphic traps.

c. In the context of oil migration and accumulation, however, such complex classifications are not necessary because most traps can be described in common geological terms, and in reality many traps bear features that make them difficult to classify.

d. Numerous and quite elaborate classifications of oil-field traps have envolved.

e. Causes for the formation of traps are numerous.

f. Traps formed by tectonic events such as folding or faulting are referred to as structural traps.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| | | | | | |

# Compaction

## Compaction, Porosity of Clastic Sediments, and Abnormally High Pressures

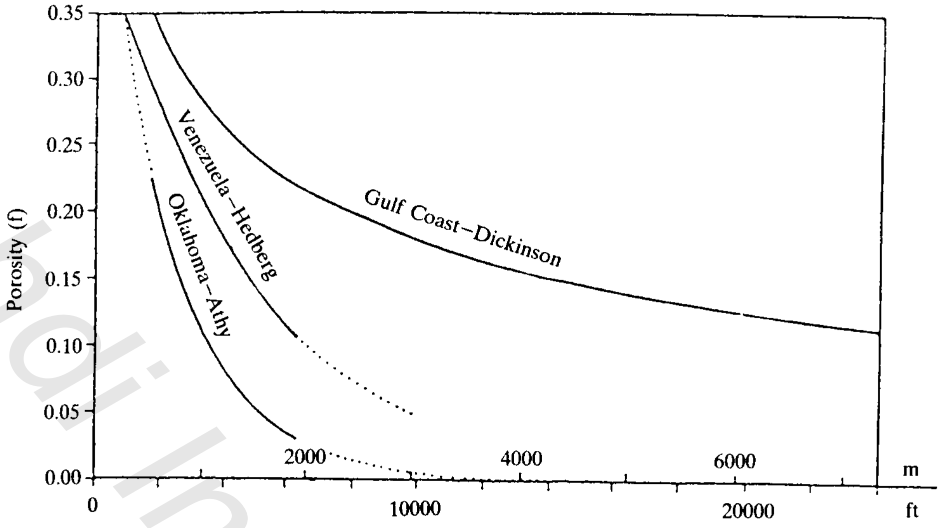
Compaction in sediments results in an increase in bulk density and loss of porosity with increasing effective pressure, temperature, and time. The rate of compaction is largely governed by material properties of a sediment (both physical and chemical) and by the rate at which liquid pore fluid can be expelled. Because compaction causes fluid flow through sedimentary rocks, it is commonly considered to be an important factor in petroleum migration. This kind of fluid flow, however, would be restricted in carbonate-type rocks and from this point of view, carbonates and argillaceous sediments behave differently. The transport of fluid through interconnected pores of a rock is dependent on permeability, which varies considerably, although no rock is absolutely impermeable. The dynamics of fluid flow is commonly determined from Darcy's Law. Hubbert (1940) gave a correct mathematical expression of Darcy's Law:

$$Q = -\frac{K}{\mu}\sigma A\frac{\delta\phi}{\delta l}$$

where,

- A = cross sectional area of the rock through which the flow is measured ($cm^2$),
- K = intrinsic permeability (darcy),
- Q = volume flux per unit time ($cm^3s^{-1}$),
- $\mu$ = dynamic viscosity of the fluid (centipoise),
- $\sigma$ = density of the fluid (g $cm^{-3}$),
- $\frac{\delta\phi}{\delta l}$ = hydrodynamic gradient along the flow path, l.

For convenience in geological context, permeability is usually expressed in millidarcies (md$=10^{-3}$ darcy) or even microdarcies ($\mu$d$=10^{-6}$ darcy). Darcy's Law is valid for laminar flow, where inertial forces are negligible compared to viscous forces. During viscous flow, there is an interaction




f = volume of pores / volume total rock

Depth (meters and feet)

**Figure 6-5.** Depth-porosity relationship as determined for samples from three different basins: Tertiary sediments of the Gulf Coast; Tertiary sediments of Eastern Venezuela; Pateozoic sediments of Oklahoma.

between the liquid moving through the porous rock and the surface or the inner pore space of the rock.

For clastic sediments, plots of porosity versus depth show a more or less exponential relationship. There is initially a very rapid loss in porosity at relatively shallows depths, and with further increasing overburden pressure, the rate of loss in porosity diminishes. Semilogarithmic plots of the depth-porosity relationship result in a straight line, the slope of which varies within certain limits from basin to basin. This basic fact about compaction of sediments was recognized by Athy (1930) and Hedberg (1926, 1936). They derived empirical equations for the porosity-depth relationship of sediments, where the depth of burial or overburden pressure was placed in the exponent. Figure 6-5 shows such porosity-depth relationships, as measured on samples from three different basins: Tertiary sediments of the Gulf Coast (Dickinson, 1953), Tertiary sediments of Eastern Venezuela (Hedberg, 1936), and Paleozoic sediments of Oklahoma (Athy, 1930). Hubbert and Rubey (1959) have shown on a theoretical basis that the effective compressive stress equals the maximum differential pressure, which is composed of the overburden pressure minus the internal fluid pressure.

Compaction may be delayed in thick shale sequences with little or no sand or silt intercalations (Chapman, 1972). In such sequences the escape of pore waters cannot keep pace with subsidence, and abnormally high fluid pressures may build up, especially in the central zone of thick shales. Impedance of fluid escape may also be caused by unusually effective seals such as impermeable evaporites. Another important cause of abnormally high pressures is the generation of methane and other low molecular weight hydrocarbons in organic-rich shales (Hedberg, 1974). Abnormal pressures, however, are transitory, and indicate that equilibrium has not been attained. Abnormal perssures, therefore, occur more frequently in young Tertiary sedimentary sequences than in older Mesozoic or even Paleozoic basins.

Compressive stress is widely accepted as a primary cause for porosity reduction and abnormally high pressures, but these effects have not gone undisputed, Bradley (1975) has argued that compression by overburden alone cannot cause abnormal pressures at present drilling depths. Accordingly, the extra load is transferred to the sediment below the seal and not to the interstitial pore fluid within the sealed-off portion of a water-saturated sediment. Pressures deviating from hydrostatic, according to Bradley (1975), are mainly caused by temperature changes. This is in line with observations and considerations by Barker (1972) and Magara (1974), who discuss the effect of water expansion with increasing temperature, and its influence on fluid pressures in buried sediments.

It is surprising that for many years the effect and role of temperature has almost been neglected when considering compaction. The behavior of water, its specific volume, its viscosity and capacity as a solvent, are all temperature-related. Bradley (1975) remarks that porosity loss in nature is caused by a group of interrelated chemical processes dependent on reactivity, temperature, surface area, and pressure. He calls these processes 'lithification'. It refers to all processes whereby porosity is reduced in sandstones which become cemented, to shales, which are compacted, and to limestones, which recrystallize.

## Compaction of Carbonates

In the context of this discussion carbonates are referred to as sedimentary rocks containing more than 50% by weight of carbonate minerals and less than 50% detrital minerals (clays and quartz). Some carbonate source rocks may be composed almost entirely out of carbonate material (less than 5% clay minerals). Carbonates are chemically more reactive than silicates and, hence, during compaction behave differently than clastic sediments. The porosity reduction in clastic sediments is more strongly influenced by mechanical and physical rearrangements of mineral grains than generally encountered in carbonates or evaporates. Chemical processes dominate the porosity and permeability reduction of carbonates.

The initial or primary porosity of fine-grained carbonate sediments corresponds to porosites observed in clastic sediments. There is experimental and empirical evidence that at lower overburden pressures, up to a depth of about 100 m to 300 m, compaction occurs as in clastic sediments. With increasing depth of burial, chemical diagenesis becomes more important. It stabilizes the rock fabric, mainly due to solution and cementation processes and is much more pronounced in carbonates than in clastic sediments. Recrystallization of carbonate-type source rocks is an important process with respect to petroleum generation and migration. With increasing burial, recrystallization converts initially fine-grained sediments into coarse-grained rocks. In this way, finely disseminated bitumen and other foreign material such as clay minerals become concentrated at grain boundaries and in intergranular spaces. This is an important step in bitumen concentration in carbonate rocks. On the other hand, it is known that in reservoir rocks, organic material may hinder chemical diagenesis of the mineral rock skeleton. It is not clear how this affects source rocks.

There is evidence for very early lithification of certain carbonate sediments. Ginsburg (1957) pointed out that in carbonate muds most of the water may be lost within the first meter of burial. Hollmann (1962) describes the underwater consolidation of limestones. Deeply buried carbonate rocks frequently do not show signs of advanced gravitational compaction, as it is demonstrated by intact macrofossils and microfossils, and sometimes by relatively high porosity values. Carbonate rocks, in addition to primary porosity, may develop a pronounced secondary porosity after deposition as a consequence of dissolution processes. Secondary porosity results from modification of primary porosity and, therefore, the two frequently cannot be clearly distinguished (Aoyagi, 1973). It should also be mentioned here that dolomitization often increases porosity because the molar volume of CaMg $(CO_3)_2$ is smaller than the volume of $CaCO_3$.

Finally, it should be emphasized that there are many argillaceous limestones (e.g., marls) and many calcareous shales. These hybrid sediments have a mineralogical composition intermediate between those of pure carbonates and clays. Many of these hybrid sediments have very high organic contents and appear to be petroleum source rocks (Hunt, 1967).

## *Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. Compaction depends only upon the difference between the vertically applied stress (overburden) and the internal stress (fluid pressure).

........ 2. Compaction can conveniently be measured in the laboratory by increasing the vertical stress on a rock sample while keeping the fluid pressure in the pores constant.

........ 3. Compaction will be much more pronounced for shallow, unconsolidated reservoirs than for the deeper, more competent sands.

........ 4. Permeability does not have any effect on the transport of fluid through the pores of a rock.

........ 5. The generation of methane and some other hydrocarbons in organic-rich shales may lead to tremendous high pressures.

........ 6. The abnormal pressures are permanent.

........ 7. Abnormal pressures occur in Paleozoic basins.

........ 8. Marls and many calcareous shales have a sedimentary composition intermediate between pure carbonates and clays.

........ 9. The porosity and permeability reduction of carbonates is not influenced by chemical processes.

........ 10. Due to increasing burial, recrystallization changes fine-grained sediments into rough-grained rocks.

**B. Choose a, b, c, or d which best completes each item.**

1. It is necessary to experimentally determine the compressibility of shallow reservoir sands in order to estimate to what degree compaction will enhance the hydrocarbon .......... .
   a. location  b. occurrence
   c. discovery  d. recovery
2. The withdrawal of liquid or gas from a reservoir results in a reduction in the fluid .......... .
   a. permeability  b. pressure
   c. porosity  d. saturation
3. The rate of .......... is dependent on physical and chemical properties of a sediment.
   a. compaction  b. stress
   c. pressure  d. saturation
4. From the text it can be inferred that the bulk or pore compressibility of a reservoir is not constant but will continually change as fluids are withdrawn and the grain pressure .......... .
   a. decreases  b. increases
   c. changes  d. is constant
5. The main cause for porosity reduction is .......... .
   a. temperature change  b. recrystallization
   c. compressive stress  d. the depth of burial
6. Compaction is believed to be an important factor in petroleum .......... .
   a. discovery  b. market
   c. analysis  d. migration
7. The specific volume and the viscosity of water are directly related to .......... .
   a. compaction  b. pressure
   c. temperature  d. granulation
8. The more the depth of burial, the more important the chemical .......... becomes.
   a. process  b. strength
   c. diagenesis  d. concentration

9. Porosity .......... at shallow depths.

a. decreases b. increases

c. remains constant d. changes

**C. Write the answers to the following questions.**

1. How does compaction occur?
2. What do abnormal pressures indicate?
3. What is lithification?
4. Where do abnormal pressures frequently occur?
5. What is the transport of a fluid through interconnected pores of a rock dependent on?

❂ ❂ ❂

*Section Three: Translation Activities*

**A. Translate the following passage into Persian.**

## The Overburden Pressure

A reservoir thousands of feet underground is subjected to an overburden pressure caused by the weight of the overlying formations. Overburden pressures vary from area to area depending on factors such as depth, nature of the structure, consolidation of the formation, and possibly the geologic age and history of the rocks. Depth of the formation is the most important consideration, and a typical value of overburden pressure is approximately one psi per foot of depth.

The weight of the overburden simply applies a compressive force to the reservoir. The pressure in the rock pore spaces does not normally approach the overburden pressure. A typical pore pressure, commonly referred to as the reservoir pressure, is approximately 0.5 psi per foot of depth, assuming that the reservoir is sufficiently consolidated so the overburden pressure is not transmitted to the fluids in the pore spaces.

**B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.**

1. argillaceous sediments ..............................
2. bulk volume ..............................
3. chemical diagenesis ..............................
4. clastic rocks ..............................
5. compaction ..............................
6. disseminate ..............................
7. dolomitization ..............................
8. elevation ..............................
9. equilibrium ..............................
10. exponential relationship ..............................
11. fractured shale ..............................
12. granular materials ..............................
13. igneous rocks ..............................
14. inertial forces ..............................
15. lithification ..............................
16. lithology ..............................
17. logging technique ..............................
18. macrofossils ..............................
19. metamorphic rocks ..............................
20. microfossils ..............................
21. percolating ..............................
22. precipitation ..............................
23. recrystallize ..............................
24. sedimentation ..............................
25. semilogarithmic plots ..............................
26. swelling ..............................
27. tectonic forces ..............................

# Unit 7

*Section One: Reading Comprehension*

## Primary Migration

### Rock Porosity

Sedimentary rocks consist (except for the chemically formed or altered limestones and other chemically deposited rocks such as salt and anhydrite) of discrete grains. The individual grains are separated by spaces whose sizes depend on the size and shape of the grains and on the range of sizes of the grains. For instance, a sand in which the grains have been well sorted so that the range of size is small will have about one-third of its bulk volume occupied by intergranular space. The actual size, though not the proportion, of the spaces will depend upon the size of the grains as can be seen by comparing the packing of a number of tennis balls and a number of marbles and comparing the free spaces between them.

In nature a well-sorted sand is a fairly rare occurrence and normally there is a large proportion of fine material as well as the larger grains. This fine material packs into the spaces between the larger grains and so reduces the amount of free intergranular space.

The proportion of free space between the grains to the bulk volume of the rock is known as the 'Porosity' of the rock. It depends primarily on the degree of sorting, i.e., the more even the size of the grains the higher the porosity and vice versa (ignoring the question of cementation) up to a practical maximum of about 33 percent.

In those rocks which are not granular in texture, porosity may still occur if the rock is fractured, contains joints or has very well marked bedding planes. Sometimes porosity is developed by solution after the rock has been formed and occasionally the spaces once occupied by the soft parts of buried animals are subsequently filled with oil.

### Permeability

For a fluid to be able to make its way through the pore spaces of a rock these pores must be connected with one another and the degree of interconnection is expressed as the permeability of the rock. It is measured by forcing a standard fluid (normally air or distilled water) through a block of rock and is expressed in arbitrary units called 'Darcys' after Henry Darcy who developed a formula for the flow of water through filter beds in 1856. According to this formula, rock has a permeability of one Darcy when a plug of one square centimetre cross section area and one centimetre long passes one millilitre per second of fluid of viscosity one centipoise at a pressure difference between the ends of one atmosphere (14.7 lb/in$^2$ or 76 cm of mercury). Normally the Darcy is too large for practical use in oil geology and permeabilities are usually expressed in millidarcys (one thousandth of a Darcy). Permeability as well as porosity is often provided by fractures, joints or bedding planes. The Asmari Limestone which forms the chief reservoir rock in Iran owes its permeability almost entirely to a well developed system of fractures. It is now possible to improve natural permeabilities either by widening existing passages by solution with acid or by creating new ones by fracturing the rocks by the application of very high hydraulic pressure.

## Compaction

If oil has been formed either in large concentrated quantities in a source rock or dispersed in small amounts throughout any rock, it is probable that its formation occurs fairly soon after deposition while the rock is in an unconsolidated condition not far below the sea bed. The grains of rock material are probably not in actual contact but are separated by a mixture of water and the newly formed or forming oil. Now, as more and more sediment is deposited, its weight will compress the material underneath and squeeze out the contained fluids. These can, of course, escape either upwards, downwards or sideways. In the case of clays or shales, however, which are by far the most common of the source rocks, the grains are platy and offer much more resistance to upward or downward movement than they do to sideways travel. The mixture of water and oil will therefore usually be squeezed out sideways.

The normal pattern in a bed of rock being laid down in a sedimentary basin is, starting from the shore line, a more or less coarse grained detrital rock such as sand which passes through finer and finer gradations until further away from the shore it becomes a fine mud. At the point where the supply of land-derived material ceases the bed will consist wholly of a chemical deposit of material coming out of solution in water, or of the accumulation of the shells of sea animals.

It will therefore be more difficult for the water and entrained oil to be squeezed out towards the centre of the basin than towards the land because the porosity of the rock would probably decrease in that direction. 'Primary' migration would, therefore, normally be expected to move the water and oil towards the more open and porous rocks of the near-shore zones (the littoral zone.)

Further beds are deposited as time goes on and will exert pressure on the beds beneath them. It has been noticed that in many areas where sedimentary deposition is going on at the present time there is a continuing downward bending of the crust which will allow a vast thickness of rocks to be laid down at any one point. This down-bending also has the effect of extending the area of the basin of deposition so that a locality which at one period was receiving near-shore deposits would, some time later in the cycle, be further from the shore and covered by finer-grained and less pervious material. Eventually the downward movement ends and may be followed by uplift. This naturally will cause shoaling and recession of the sea so that at the end of the cycle near-shore deposits might occur once more.

The water and oil expressed from the clays must enter the more porous rocks early in the geological history of the beds concerned since its movement is caused by the compaction or squeezing together of the clay particles as they are buried under the load of the later sediments. By far the greatest volume of fluid expelled will be water which will continue to flow through the beds until it can escape back to the sea or, when composition is finally completed, remain entrapped as formation water.

## *Part I. Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. The release of petroleum compounds from solid organic particles in source beds and their transport within and through capillaries and narrow pores of a fine-grained source bed has been called primary migration.

........ 2. In nature, the appearance of sands of equal size and shape is a common phenomenon.

........ 3. Porosity is a measure of the amount of void space compared to the total volume of the rock.

........ 4. Pores in the subsurface are normally water-saturated and hence any movement of petroleum compounds takes place in the presence of aqueous (water) pore fluid.

........ 5. 'Darcys' are units for the measurement of rock porosity.

........ 6. Permeability, unlike porosity, is the result of fractures.

........ 7. Nowadays, natural permeability is enhanced by fracturing the rocks through the application of high hydraulic pressure.

........ 8. The mixture of water and oil is squeezed out either upward or downward.

....... 9. The oil expelled from a source bed passes through wider pores of more permeable porous rock units.

**B. Choose a, b, c, or d which best completes each item.**

**1.** When oil has reached porous beds, its movement will be .......... .

a. slow b. complete
c. fast d. downward

**2.** Such movement may be due to .......... .

a. primary migration b. distribution of hydrocarbons
c. loss of hydrocarbons d. active water

**3.** Usually the unit of permeability, i.e., Darcy, is not very .......... .

a. common b. frequent
c. handy d. useful

**4.** The gravity load causes sediments .......... and to lose porosity.

a. to compact b. to enlarge
c. to loosen d. to expand

**5.** The individual grains are separated by .......... .

a. equal space between them b. hydraulic pressure
c. intergranular space d. vast space

**6.** The permeability of the Asmari Limestone in Iran is due to .......... .
a. the peculiarities of geology    b. a system of sedimentary rocks
c. a system of passages    d. a system of fractures

**7.** Petroleum compounds are generated from finely .......... organic matter in source beds.
a. fractured    b. assimilated
c. disseminated    d. distributed

**8.** The more even the size of the grains, the higher .......... .
a. the permeability    b. the porosity
c. the viscosity    d. the velocity

**9.** As more and more sediment is deposited compaction will .......... .
a. weaken    b. lower
c. rise    d. disappear

### C. Answer the following questions orally.

1. What do sedimentary rocks consist of?
2. What is the ratio of free space between the grains to the bulk volume of the rock called?
3. What is the definition of permeability?
4. How is compaction defined?
5. What are the individual grains separated by?

## *Part II. Language Practice*

### A. Choose a, b, c, or d which best completes each item.

**1.** The rock in which oil is found is called .......... rock.
a. a reservoir    b. a magnetic
c. an igneous    d. a porous

**2.** A well-sorted sand will have .......... of its bulk volume occupied by intergranular space.
a. one-fourth    b. almost all
c. one-third    d. almost none

**3.** The pore space, or void space, is expressed as a fraction or percentage of the total volume of the rock and is called its .......... .
a. fluid content    b. porosity
c. roof rock    d. permeability

4. As more and more sediment is deposited, its weight will compress the material underneath and squeeze out the container fluids in different directions. These directions will be .......... .

a. upwards
b. sideways
c. downwards
d. all of the above

5. .......... of a reservoir rock is due chiefly to the increasing weight of the overburden.

a. Cementation
b. Permeability
c. Compaction
d. Sedimentation

6. Increase in temperature decreases the viscosity of a liquid, and .......... varies inversely with the viscosity.

a. the porosity
b. the compaction
c. the permeability
d. none of the above

7. It has been found that with variable grain sizes, the permeability .......... as the shapes of grains depart from those of true spheres.

a. increases
b. does not change
c. decreases
d. none of the above

8. The nearest approach to uniform grain size is found in .......... .

a. well-sorted sand grains
b. well-rounded sand grains
c. both a and b
d. neither a nor b

9. Sedimentary rocks consist of discrete .......... .

a. planes
b. marbles
c. grains
d. clays

10. The actual size of intergranular space will depend on .......... of the grains.

a. the depth
b. the length
c. the width
d. the size

11. Clays and shales are the most .......... source rocks.

a. fundamental
b. common
c. appropriate
d. natural

12. Permeability is measured by forcing air or distilled water through a block of .......... .

a. limestone
b. rock
c. ice
d. clay

## B. Fill in the blanks with the appropriate form of the words given.

**1. Certain**

a. It is .......... that when there is a big increase in unemployment figure, wages do not increase and sometimes decrease.

b. He is .......... the only person who can help you.

c. We will lose the game, that is a .......... . That horse is a .......... (i.e., is certain to win).

**2. Involve**

a. This work .......... a great deal of expense.

b. A large percentage of the population was .......... in the war.

c. The paper included many problems .......... mathematical calculations.

**3. Provide**

a. Our local authority .......... the people with many facilities.

b. A workingman .......... food and clothes for his family.

c. During the floods, the government organized the .......... of food, clothes, and shelter.

**4. Access**

a. In modern times few parts of the interior of North America are .......... (the word is negative).

b. .......... to some parts of South America is still difficult.

c. Science and knowledge should be .......... to everybody.

**5. Initiate**

a. The .......... monthly payment is the first in a series of payments.

b. We .......... a plan, a scheme, an undertaking, a process, a project, etc., when we actively start it.

c. He came .......... to spend a few days, but eventually he stayed for a whole month.

## C. Fill in the blanks with the following words.

| | | | |
|---|---|---|---|
| argillaceous | restricted | porosity | rocks |
| permeability | properties | compaction | increase |
| determined | migration | pressure | fluid |
| interconnected | impermeable | | |

Compaction in sediments results in a/an .......... in bulk density and loss of .......... with increasing effective .........., temperature, and time. The rate of .......... is largely governed by material .......... of a sediment (both physical and chemical) and by the rate at which liquid pore .......... can be expelled. Because compaction causes fluid flow through sedimentary .........., it is commonly considered to be an important factor in petroleum .......... . This kind of fluid flow, however, would be .......... in carbonate-type rocks and from this point of view, carbonates and .......... sediments behave differently. The transport of fluid through .......... pores of a rock is dependent on .........., which varies considerably, although no rock is absolutely .......... . The dynamics of fluid flow is commonly .......... from Darcy's Law.

## D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. There is initially a very rapid loss in porosity at relatively shallows depths, and with further increasing overburden pressure, the rate of loss in porosity diminishes.

b. Semilogarithmic plots of the depth-porosity relationship result in a straight line, the slope of which varies within certain limits from basin to basin.

c. For clastic sediments, plots of porosity versus depth show a more or less exponential relationship.

d. They derived empirical equations for the porosity-depth relationship of sediments, where the depth of burial or overburden pressure was placed in the exponent.

e. This basic fact about compaction of sediments was recognized by Athy (1930) and Hedberg (1926, 1936).

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| | | | | |

# Basin Development

Movement of the oil, however, once it has reached porous beds, will be very slow since we now find it entrapped in reservoir rocks which, in many cases, have been folded or fractured by earth movements which must have occurred well after compaction had ended.

This bending or fracturing is the last chapter in the story of the sedimentary basin. In the beginning a piece of the earth's surface is warped down allowing the sea to flood over it and drainage on the adjacent land still above sea level to develop debouching into it. Rivers then bring down masses of rock waste which would soon fill up the basin but for the fact that its weight assists the forces causing the down-warping and helps sinking to continue and the area of the basin to increase. Eventually, however, a halt is called. The strains and stresses within the earth readjust themselves and the new sediments are raised up, compressed sideways and stretched out again sometimes repeatedly. As a result of these movements, the rock beds are now no longer level but are bent upwards into anticlines, downwards into synclines and are broken by faults of various kinds.

## Froces Causing Oil Movement

If a globule of oil in the pore spaces of a sandstone is imagined, it will appear something like the picture at Figure 7-1 and the forces acting on it will be the buoyancy due to the difference in weight between it and the water it displaces plus any pressure difference dut to flow of the water round it.

The forces opposing any movement will be those due to the size of the pores through which it will have to move. These forces can be calculated accurately for conditions at the surface and are of the same order as the forces available to produce movement. We cannot, of course, be sure that the conditions several thousands of feet down in the earth's crust are the same as those we can simulate at the surface. All the evidence available does, however, indicate that the higher temperatures and pressures existing will make the movement of oil more rather than less easy. Moreover, the forces causing

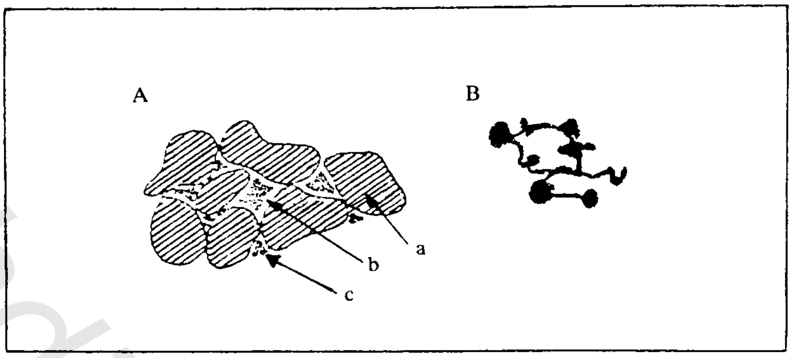



**Figure 7-1.** (A) The position of oil globules in the pore spaces of a sandstone. The sand grains are normally water wet and a thin film of water is present separating the sand grains from the oil: (a) sand grains; (b) water film; (c) oil globule. (B) The shape of a globule of oil occupying several pore spaces with the surrounding sand grains and water film removed.

movement are dependent upon the size of the globule of oil–the larger the body of oil the greater will be the pressure differential and the buoyancy force while the forces of resistance are dependent only upon the pore size and are therefore constant. If then the original very small globules, or some of them, can be caused to move, they will join with others until a whole body of oil is in movement.

Oil must be formed, in source rocks at least, after the rocks have been deposited and before they are vertically compressed by the weight of the material being deposited above them, because the first movement of primary migration, in which the oil moves from the source to the reservoir rock, can probably only be accomplished by the squeezing action of the overburden.

Once oil has moved into rocks which are permeable or if it is in fact formed in such rocks, the movement of formation waters aided by buoyancy forces are probably enough to allow movement to continue for long periods and to allow the concentration of dispersed and minute droplets of oil into vast accumulations of petroleum provided the initial size of the droplets is above a certain minimum.

The force due to buoyancy alone is probably insufficient to cause movement particularly where the pore spaces are small. It is necessary for some additional driving force to act and this is probably due to circulation of the formation water. Movement of formation water will, of course, go on so long as the rocks are being compacted and this may well continue for a very long time–a long time geologically speaking. However, there is evidence that movement of these underground waters does in fact continue long after compaction has ceased and indeed it is probable that the direction and velocity of such movements may change from time to time.

The actual causes of such movements are not fully understood, no doubt the same forces which cause folding and fracturing of the crustal rocks and which allow of the gentle subsidence of geosynclines play a part in causing formation water to flow through the rocks. Some movements too are probably due to convection currents.

The movement of oil through permeable rocks is important, not only in the migration of oil into reservoirs but also in its movement in the reservoir towards the producing wells.

For the general reader, however, it is only necessary to know that for oil movement to occur in a porous rock which is no longer being compacted, each individual oil globule must be over one metre in length and must therefore extend over a large number of pore spaces. This fact is perhaps the most telling argument for the existence of source rocks, though, indeed, there is no need for them to be especially rich in organic material or in petroleum, but merely to be rocks which will be mechanically compressed and will squeeze out their contained fluids during compaction. The result of such squeezing would allow the building up of large continuous oil bodies where the source rock gave place to an incompressible sand or limestone. Furthermore, such bodies of oil in movement through the pore spaces of the reservoir rock could well collect any finely disseminated oil which might have been formed in the reservoir rock itself.

Once begun, migration will continue vertically under buoyancy until some horizontal impermeable barrier is encountered, or laterally under hydrodynamic forces until a vertical barrier is reached, or until the oil reaches a position where buoyancy or the hydrodynamic forces are insufficient to overcome the capillary pressure.

## *Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. As a result of geophysical forces, the rock beds are no longer level but are changed into anticlines.

........ 2. An important physical parameter increasing with depth is pressure.

........ 3. The physical and chemical conditions that prevail in source and reservoir rocks change with depth of burial.

........ 4. Higher temperature and pressure make the movement of oil less easy.

........ 5. The smaller the body of oil, the greater will be the buoyancy force.

........ 6. The force of buoyancy alone is sufficient to cause movement of petroleum.

........ 7. We now know the actual causes of the movement of underground waters.

........ 8. The increase in temperature with burial depth is a consequence of the transfer of energy from the interior of the earth to the surface where it is dissipated.

........ 9. The only opposing forces on the way of petroleum movement will be the size of the pores through which it will have to move.

........ 10. We can for sure make a simulation of the conditions several thousands of feet down in the earth's crust.

### B. Choose a, b, c, or d which best completes each item.

1. The forces which cause the petroleum movement depend upon the size of .......... globule.

   a. organic    b. inorganic
   c. oil    d. water

2. The force caused by buoyancy is not sufficient for the petroleum movement. The additional driving force may be due to .......... of the formation water.

   a. ceasing    b. continuation
   c. circulation    d. termination

3. Movement of formation water will continue so long as the rocks are being .......... .

a. compacted b. encountered
c. formed d. dispersed

4. For oil movement to occur it is not necessary for the source rocks to be rich in .......... .

a. limestone b. organic material
c. porosity d. inorganic material

5. As soon as oil reaches porous beds, its movement will be .......... .

a. terminated b. fast
c. backward d. slow

6. Under hydrostatic conditions, oil and gas would simply rise, according to the principles of .......... .

a. buoyancy b. hydrostatic
c. thermodynamics d. tectonic

7. Thermal conductivity is not only affected by mineralogical composition, but also depends to a great extent on .......... .

a. porosity b. both a and b
c. permeability d. neither a nor b

8. The movement of underground waters continues long after compaction has .......... .

a. begun b. continued
c. stopped d. changed

9. Due to the continuous readjustments of strains and stresses within the earth, the new sediments rise up and the rock beds are not .......... any more.

a. rough b. level
c. broken d. vertical

10. The movement of oil through permeable rocks is significant, .......... .

a. for its migration into reservoirs
b. for its movement towards the producing wells
c. for its discovery
d. both a and b

**C. Write the answers to the following questions.**

1. What do the forces causing petroleum movement depend upon?
2. What does 'basin development' refer to?
3. Why do the rock beds bend upwards (anticlines) or downwards (synclines)?
4. How long does the movement of these underground waters last?
5. What do the molecules of oil collect in their movement through the pore spaces of the reservoir rock?

❂ ❂ ❂

*Section Three: Translation Activities*

**A. Translate the following passage into Persian.**

## Different Migration Processes

The distinction between primary and secondary migration was initially not based on the recognition of different migration processes, but only on its occurrence in pores of different sizes and lithology and possibly in a different state of distribution. The loss of hydrocarbons out of a trap is frequently called dismigration.

Petroleum compounds are generated from finely disseminated organic matter in source beds, thus, the first appearance of petroleum is also in a dispersed form. Processes of primary and especially secondary migration, which finally lead to the formation of petroleum accumulations must, therefore, encompass mechanisms that concentrate dispersed petroleum compounds.

The specific gravities of gas and oil, the latter generally between 0.7 and 0.9 g $cm^{-3}$, are considerably lower that those of saline pore waters. This is why gas and oil pools are mostly found in structural highs where reservoir rocks of suitable porosity and permeability are covered by a dense, relatively impermeable cap rock such as an evaporate or a shale. A reservoir rock sealed by a cap rock in the position of a geological high, such as an anticline is known as a structural petroleum trap. Other types of traps such as sand lenses, reefs and pinch-outs of more permeable and porous rock units, are known as stratigraphic petroleum traps. In all these situations, the changes in permeability and porosity determine the location of an oil and/or a gas accumulation.

**B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.**

1. buoyancy ..............................
2. capillary pressure ..............................
3. cementation ..............................
4. convection currents ..............................
5. crustal rocks ..............................
6. deposition ..............................
7. dismigration ..............................
8. dispersed form ..............................
9. disseminated oil ..............................
10. evaporate ..............................
11. faults ..............................
12. intergranular space ..............................
13. littoral zone ..............................
14. pinch-outs ..............................
15. primary migration ..............................
16. recession ..............................
17. reefs ..............................
18. secondary migration ..............................
19. shale ..............................
20. shoaling ..............................
21. structural highs ..............................
22. subsidence ..............................
23. synclines ..............................

# Unit 8

*Section One: Reading Comprehension*

# Well Logging

## Geological Logging

In normal geological well logging, a sample of the rocks cut by the bit is taken every few feet, say every 5 or 10 ft, during the whole time the well is drilling. These samples are examined by the geologist under a binocular microscope, either when wet after the mud has been washed off, or after being dried, according to the personal preference of the individual geologist. A foot by foot description of the lithology is then written out and a geological graphic log made up using standard symbols which are more or less generally recognised for each type of formation. Bit cuttings suffer from one big drawback; they can be contaminated by cavings from the upper parts of the hole already drilled. This is particularly noticeable when shaly formations are being drilled. Naturally, a good well site geologist will soon gain experience in being able to detect which samples are coming from the bottom of the hole and to a certain extent will be able to discount the cavings. However, changes in lithology are often gradual, the change from one type to another perhaps occurring over an interval of between about 20 to 50 ft, and it is often difficult to decide the actual position of a formation boundary from cuttings alone. It is usual practice to take the first recorded occurrence of a new type of rock to be the upper boundary.

After an examination under the binocular microscope a selection of cuttings is made of those believed to be from the true bottom of the hole and thin sections of them are mounted on microscope slides for examination under the petrological microscope. This type of microscope enables the thin rock slices to be looked at by transmitted light so that their crystal structure can be determined. The microscope is also constructed so that plane polarised light can be transmitted through the slide, so enabling the geologist to determine the different minerals which occur. The descriptions of these are added to the graphic log where they are appropriate. In limestones and dolomites for example it is also possible to see fossils in the thin sections and the identification of these helps to establish the ages of the rock and to provide points of correlation for comparison with other wells and with stratigraphic sections measured on the surface.

## Drilling Speed Logs

It was found very early in the development of rotary drilling that the speed of drilling was very sensitive to the type of formation being drilled. In fact, by altering the speed of rotation, the weight on the bit and the mud velocity, the driller can make progress just as fast whatever the formation he is drilling. However, when the drill passes from one formation to another, the driller can often locate the position of the new formation top by the behaviour of the drill. It is usual, therefore, for a penetration log to be taken, in which the driller records either the time taken for his drill to penetrate a standard thickness of rock, for example, each 5 ft or even each single foot of rock, or the distance penetrated in some standard length of time, say, each 15 min or 1 hr.

On modern drilling rigs there is often an automatic recorder which, in addition to recording continuously the speed of penetration, also records the weight carried by the bit, its speed of rotation and the mud velocity.

Automatic logs are useful not only to the geologists in helping them to interpret the log made up from examination of the cuttings, but also to the drilling engineers who are always looking for ways to improve the performance of the rigs under their charge. These logs record all the time lost on changing bits, adding new stands of drill pipe and making repairs and adjustments to the rigs. They therefore provide a most useful indication of the efficiency of each rig.

## Depth Measurements

The depth of the bottom of the hole must, of course, always be known very accurately and the driller maintains a record of the length of each stand of drill pipe. Since the drill pipe is in tension in the hole, it must be measured as it hangs in the derrick and, although at first the length of each stand is measured as it lies on the pipe rack beside the drrick, it is usual for it also to be measured when being pulled out of the hole immediately before each string of casing is run.

The logs described above are commonly made for each well drilled. Geophysical science has, however, provided us with additional and very valuable means of checking these logs and even of measuring the actual rock properties and their fluid content. These logs can be divided into four groups. The first group consists of the mechanical logs which measure the diameter of the hole and its inclination from vertical; the second group, those which measure various electrical properties and responses of the rocks; the third group depends on measuring the speed of sound in the rocks; the fourth group, logs which record various radioactive properties and reactions. We will deal with each of the groups separately in the next Section.

## *Part I. Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. Inferred from the passage, well logs are run in holes to measure properties of the rocks that can be interpreted in terms of lithology, to evaluate formations, to estimate the volume of hydrocarbons in place, and to estimate the recoverable hydrocarbons volume.

........ 2. Logs can be subdivided into three basic types: (1) electric logs; (2) acoustic logs; and (3) radioactive logs.

........ 3. In drilling, the driller will notice that changes in lithology are sudden and unpredictable.

........ 4. One of the difficulties encountered in drilling is the recognition of the possible oil and gas content of formations penetrated while sinking the well.

........ 5. The behaviour of the drill will help the driver to identify the boundary of each formation layer.

........ 6. Automatic logs are useful only to the geologists in helping them to interpret the log.

........ 7. Logs enable the scientists to acquire geochemical information of the rocks and their oil content.

........ 8. The electrical logs measure radioactive properties of the rocks.

........ 9. Microscopes will help the geologists to determine the kinds of minerals.

**B. Choose a, b, c, or d which best completes each item.**

1. Automatic logs are employed to help .......... .
   a. the drillers to improve the function of their rigs
   b. the geologists to interpret the log
   c. the geologists to adjust their rigs
   d. all of the above
2. Because the drill pipe is in tension in the hole, the depth bottom of the hole must be measured .......... .
   a. when the geologist is away
   b. when the drill pipe is pulled out of the hole
   c. as the drill pipe hangs in the derrick
   d. none of the above
3. Drilling engines must sometimes be shut down for .......... .
   a. cooling	b. repairs
   c. replacement	d. practice
4. A geologist should make samples of .......... .
   a. regular depth intervals
   b. major lithologies
   c. the rocks lying at the base of the well
   d. both a and b
5. A great deal of information can be gained in the course of exploratory drilling. Acquisition of this information is called .......... .
   a. well logging	b. chemical analysis
   c. impermeable rock	d. telluric method
6. The identification of the microfossil content of the drill cuttings is important because they are .......... .
   a. of various kinds
   b. scattered in wide geographic regions

c. recovered as discrete particles in the process of cutting

d. all of the above

7. In order to maintain a record of the length of each stand of drill pipe, a driller must .......... .

   a. use a very disciplined procedure

   b. use a very rigid chain of command

   c. dismiss any room for error

   d. all of the above

8. During the process of drilling, oil and gas may penetrate into the well. To avoid this problem, a geologist should .......... .

   a. take a sample of the rocks cut by the bit every few feet

   b. examine the samples under a binocular microscope

   c. make up a geological graphic log

   d. all of the above

### C. Answer the following questions orally.

1. What is one shortcoming of the bit cutting?
2. What happens when the speed of rotation is altered?
3. How are the automatic logs useful?
4. When is the appropriate time for measuring well-depth?
5. How many kinds of logs are there? Give a short description of each.

## *Part II. Language Practice*

### A. Choose a, b, c, or d which best completes each item.

1. Bit cuttings have one great .......... .

   a. significance     b. advantage

   c. fault     d. none of the above

2. Radioactive logs measure either induced or natural Gamma Ray and neutron .......... .

   a. properties     b. explorations

   c. analysis     d. identification

3. Hydrocarbon zones are identified with the resistivity log because salt water has very low resistivity compares to .......... .

   a. stratigraphic interpretations     b. multiple reflections

c. seismic records    d. hydrocarbons

4. Neutron logs are used primarily to delineate porous formations and .......... their porosity.
   a. to analyze    b. to determine
   c. to postpone    d. to combine
5. The caliper log measures .......... of the borehole and points out regions where the borehole has excess diameter due to washouts.
   a. the length    b. the depth
   c. the diameter    d. the area
6. The function of the automatic recorder on modern drilling rigs is to record .......... .
   a. the speed of penetration    b. the load carried by the bit
   c. the speed of rotation    d. all of the above
7. The driller may do drilling in any formation if he .......... .
   a. selects the right speed of rotation
   b. adjusts the weight on the bit
   c. alters the mud velocity
   d. all of the above

## B. Fill in the blanks with the appropriate form of the words given.

**1. Corrode**

a. Iron bridges are painted to protect them from .......... .

b. An inorganic substance .......... when it is slowly destroyed by chemical action.

c. Certain acids and alkalis (e.g., caustic soda) have a strongly .......... action.

**2. Deteriorate**

a. When a substance .........., it changes in such a way that it loses its good or useful qualities and so loses its value.

b. We speak of the .......... of food and food substances.

c. Organic foods such as fruit, meat, and eggs can only be preserved by special processes such as drying and refrigeration which prevent them from .......... .

**3. Synthesize**

a. A chemist can produce a chemical compound by .......... elements.

b. A .......... compound is a compound synthesized in an artificial way.

c. .......... is the opposite of analysis.

**4. Adjust**

a. You cannot see through a telescope unless it is .......... to your sight.

b. The screws of this sewing machine need .......... .

c. The dentist can .......... the size of his drill to the size of the hole in a tooth.

**5. Attract**

a. The earth .......... other bodies in space towards itself.

b. The .......... or attracting force of which the earth exerts is called the force of gravity.

c. We considered the scenery .......... .

## C. Fill in the blanks with the following words.

| | | | |
|---|---|---|---|
| complementary | offering | shallow | basin |
| stratigraphic | organic | designed | rocks |
| available | limited | adjacent | coring |
| identification | strata | rim | |

When a new exploration program is .......... in a more or less unknown area, only a/an .......... amount of general geological information is normally available. This, of course, applies nowadays only to certain remote areas and offshore regions. Sample material of the most important .......... and lithologic units represented in the .......... must be collected, outcrops at the .......... of the basin being a readily accessible source. A careful study of the .......... information on the sedimentary filling of the basin (a facies analysis) might result in a preliminary .......... of one or more potential source .......... or source rock sequences. A source rock-identification program using .......... geochemical techniques to analyze available sample material should help to define potential source rocks more clearly. At the same time, neighboring nonsource rock .......... should also be checked for porosity and permeability, and their role in .......... possible migration avenues. If little or no sample material is available, a limited sampling program may be started to obtain surface samples and .......... unweathered core samples from a few .......... drill holes (up to 100 m depth) at strategic locations. In offshore basins, information from .........., comparable strata on land, and sometimes samples taken from the sea bottom by dredging or shallow .......... may be helpful.

## D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. If for no other reason than the force of gravity, gas, oil, and water in a closed container will separate because of differences in their specific gravities, gas will rise to the top, and water will settle at the bottom, with oil forming an intermediate layer.

b. The third factor necessary for hydrocarbon accumulation is a trapping mechanism.

c. So it happens in the earth.

d. If the reservoir rock is wrinkled, the hydrocarbons will migrate to the top of the wrinkle; if the reservoir rock is faulted, they will migrate to the face of the fault; if the reservoir rock is truncated or pinched out updip, they will migrate to the termination of the reservoir rocks.

e. Over millions of years, the hydrocarbons will migrate to depositional basins.

f. If the reservoir rock abuts updip against an impervious barrier such as salt dome, they will migrate to the flanks of the dome, but they will accumulate at these locations only if an impervious barrier exists above to create a trap.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| | | | | | |

# The Mechanical Logs

**Caliper Logs.** The caliper log makes a continuous recording of the diameter of the hole from bottom to top. It does this by measuring the deflection of a number of spring-loaded arms which are symmetrically mounted round the outside of a steel torpedolike tube which is lowered down the hole and pulled up again on a cable. The cable has as its core a number of electrical conductors although the most modern logs take advantage of the fact that frequency modulation of electrical signals allows a number of separate signals to pass along a single conductor simultaneously. Their cables therefore have only one conductor.

The caliper log is usually run after the drill pipe has been withdrawn from the hole and before a casing string is run.

**Borehole Inclination Surveys.** It is always useful, and often vital, to know the actual direction in which the hole is drilling. It is normally assumed that an oil well is vertical, but in actual fact it very rarely is so although, with good drilling practice, the deviation from vertical should never be more than about 1° per 1000 ft. In reservoirs in which the wells have to be drilled very closely in order to obtain full drainage, and particularly in reservoirs being developed by more than one operator, the true position of the bottom of the hole is very important. In some cases, also, it is impossible to drill vertically. For instance, in reservoirs which are located under highly developed towns or industrial plants it is necessary to start the wells at convenient positions on the surface and drill the wells at an angle, so that the actual drainage is uniformly spaced over the whole reservoir. In order to do this, instruments which can measure the inclination and the direction of the hole have been developed.

**Temperature Logs.** An additional log which is not really 'mechanical' in its action but which is most conveniently dealt with in this section is the 'temperature' log. This log records the temperature of the mud in the borehole. Under normal circumstances the temperature of the rocks increases at about 1°F for each 50 ft of depth (1°C for each 90 ft or 27.5 m) and, after a mud-filled borehole has remained undisturbed for several hours, the mud will reach the same temperatures as the rocks at the same level. When casing is set in the borehole it is surrounded by a cement sheath in order both to give the steel casing additional strength and to provide protection against corrosion by the fluids contained in the rocks. When cement sets it gives out heat and therefore if a temperature log is run inside casing a few hours after the cement has been placed it will record abnormally high temperatures opposite intervals where the casing is surrounded by cement. The temperature log should therefore, show the position of the top of the cement and give an indication of whether the cement sheath is uniform below it.

### The Electrical Logs

Dry rock of almost any chemical constitution is almost a perfect insulator against the passage of an electric current. On the other hand, very few rocks are completely dry and in nearly all of them the spaces between the grains of rock are filled with either brine, oil or gas. Brine is a good conductor of electricity and both oil and gas are poor ones. The resistivity of any substance to the passage of an electric current is measured in ohms per square unit of cross section area per unit length. In other words, a wire with a cross section area of 1 $cm^2$ will have exactly half the resistance of a wire with a cross section of $\frac{1}{2}$ $cm^2$. In the case of a rock, the area of the conductor is proportional to the connected porosity which contains the conducting water. If oil or gas is also present the conductivity will be reduced in proportion to the pore space occupied by oil or gas.

**Resistivity and Self-Potential Log.** The mechanical measurement of the formation resistivity was made possible by an invention of the Schlumberger brothers who developed an instrument to record this property as it was pulled up the borehole. In the original logs the sonde, as the instrument is known, was pulled up the hole by hand winch, but now an elaborate recording truck combines an accurately measured and mechanically controlled cable with the necessary electronic amplifying and photographic recording apparatus.

In the normal electrical log the thickness of formation which the current load for the resistivity measurement passes through is quite large–64 in. for the long normal curve. Also, the current is unconfined and therefore it will move through the path of lowest resistance. Measurements may therefore be seriously affected by the properties of the mud in the borehole and by formations above and below the bed being measured, because the current path may be distorted.

## Velocity Logs

A recent development in well logging is the 'sonic log' or velocity log. This log records the time taken for a sound wave to traverse a known length of formation and, as the time taken for sound to travel between two points in the rock is inversely proportional to its velocity in the rock, the sonic log provides a measurement of the velocity of sound in the rocks. These measurements have two uses. Firstly, they are of great use in the interpretation of seismic records, and secondly, they give an accurate indication of rock porosity.

The sonic log is an additional tool for measuring formation porosity, even in very hard formations such as massive limestones. The speed of sound in rock depends upon the rock density, its porosity and the fluid filling the rock pores. The rock density and the fluid are usually well enough known or can be measured and analysed easily, and a simple linear relationship can then be obtained between the sonic log value and the rock porosity. In soft sands the sonic log has to be corrected for the degree of compaction in order to obtain the porosity value and therefore it is, perhaps, not so effective as it is in hard rocks.

## Radioactivity Logs

A further modern development in logging techniques has been the application of radioactivity measurements to borehole surveys. The Gamma Ray log records the natural radioactivity in the formations. This is due to the presence in the rocks of traces of the radioactive elements uranium, thorium and potassium. Shales are in general more highly readioactive than either sandstones or limestones and the Gamma Ray log is of great assistance in lithological correlation because of the ease with which different shale beds can be identified by the level of radioactivity. Another form of radioactivity log is the neutron log which records the emission of secondary gamma rays from the formation when it is bombarded with neutrons from an artificial source. The intensity of the response to this log depends mainly on the concentration of hydrogen atoms in the formation, a high rate of response being obtained with low hydrogen concentrations. The hydrogen concentration itself is dependent on the quantity of liquid present, since both crude oil and water have about the same hydrogen concentration and both are much higher than that of the rocks themselves. The neutron log is therefore chiefly responsive to alterations in the porosity of rocks since this directly affects the proportion of fluid present, but it will also indicate the presence of gas. The identification of gas arises because petroleum gas contains an appreciably lower concentration of hydrogen than either oil or water. Therefore formations with equal porosities will give a higher counting rate for formations which contain gas than for those which contain oil or water.

## *Comprehension Exercises*

**A. Put "T" for true and "F" for false statements. Justify your answers.**

........ 1. Caliper logs record the diameter of the borehole, and thus measure the permeability of the rock strata.

........ 2. The temperature log is recorded as the tool is lowered into the well, so temperature of fluids in the borehole can be measured before the fluids are disturbed by the logging tools.

........ 3. Wet rock is a perfect insulator against the passage of an electric current.

........ 4. The actual direction in which the hole is being drilled is not vital.

........ 5. In reservoirs which are under populated areas, it is nearly impossible to drill vertically.

........ 6. The temperature log is recorded as the tool is lowered into the well, so temperature of fluids in the borehole can be measured before the fluids are disturbed by the logging tools.

........ 7. Drilling, coring, logging, and testing are the activities that find hydrocarbons in a well or discover their absence.

........ 8. The first well logs used in oil exploration were the electric logs that measure the self-potential and the resistivity.

........ 9. Acoustic logs measure the velocity of compressional waves.

........ 10. Resistivity logs are used to determine fluid content in porous media.

**B. Choose a, b, c, or d which best completes each item.**

1. The circulation of relatively cool drilling mud, in a well, will .......... the temperature throughout the well.
   a. record　　b. raise
   c. reduce　　d. improve

2. Advantages can be taken of this important fact that .......... sands conduct electricity better than ordinary earth.
   a. dry　　b. wet
   c. oil-bearing　　d. desert

3. Exploration methods merely insure that a region is a likely location of a subsurface oil .......... .
   a. tank　　b. reservoir
   c. spill　　d. transportation

4. .......... is pumped down between the wall of the drill hole and the casing.
   a. Oil　　b. Water
   c. Tar　　d. Cement

5. The Gamma Ray log is principally a lithologic log that measures the natural .......... of rocks.
   a. porosity　　b. permeability
   c. radioactivity　　d. fluid content

6. Neutron logs respond to .......... content of the formation, and in clean formations containing water or oil, the neutron logs are used to identify the fluid content.
   a. the carbon　　b. the hydrogen
   c. the oxygen　　d. the brine

7. Under normal conditions, the acoustic (sonic) velocity increases with .......... .
   a. depth　　b. seismic records
   c. wavelength　　d. rock porosity

8. One important use of velocity logs is in identifying .......... zones and the hydrocarbons that fill them.
   a. dense　　b. rugged
   c. mountainous　　d. porous

9. Quantitative interpretation of electric log data has been so successful that such .......... is an almost universal accompaniment of oil well drilling.

a. drilling b. logging

c. cementing d. exploring

10. There is a linear relationship between the acoustic log value and the rock .......... .

a. velocity b. symmetry

c. porosity d. industry

**C. Write the answers to the following questions.**

1. When is the caliper log usually run?
2. How is the resistivity of any substance to the passage of an electric current measured?
3. Why is the sonic log not effective in soft sands?
4. What makes it possible for the Gamma Ray log to record the natural radioactivity in the formations?
5. In borehole inclination surveys, how much should the degree of deviation from vertical be?

❂ ❂ ❂

*Section Three: Translation Activities*

**A. Translate the following passage into Persian.**

## Correct Sampling of Crude Oil

The importance of the correct sampling of crude oil which usually contains light hydrocarbons cannot be overstressed. Properties like the specific gravity, distillation yields, vapour pressure, hydrogen sulphide content, and octane numbers of the gasolines are affected by the light hydrocarbon content so that suitable cooling or pressure sampling methods have to be used and care taken during the subsequent handling of the oil in order to avoid the loss of any volatile components. In addition, adequate records of the circumstances and conditions during sampling have to be made, for example, in sampling from oilfield separators, the temperatures and pressures of the separation plant and the atmospheric temperature would be noted.

**B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.**

1. bit ..............................
2. borehole ..............................
3. brine ..............................
4. cavings ..............................
5. deflection ..............................
6. deviation ..............................
7. distillation yields ..............................
8. emission ..............................
9. fracture ..............................
10. inclination ..............................
11. massive ..............................
12. modulation ..............................
13. oil viscosity ..............................
14. petrological microscope ..............................
15. polarised light ..............................
16. resistivity ..............................
17. rigs ..............................
18. rotation ..............................
19. seismic records ..............................
20. sonic ..............................

# Unit 9

*Section One: Reading Comprehension*

# Crude Oil and Its Relation to the Rocks

For an oil reservoir to be formed rocks with three different properties must be present. Firstly the oil must be formed and the rock in which this occurs is called a 'source rock'. Secondly it must be retained in a rock which is sufficiently porous and permeable for the oil to flow into wells; such rocks are 'reservoir rocks'.

## The Formation of Oil

Although no one has yet been able to show how oil is formed, it is generally accepted that it is a decomposition product of various forms of organic debris. The evidence on which this opinion is founded is worthy of careful examination, for even now responsible opinions are advanced seeking to show an inorganic origin.

It might be thought that there is little point in discovering the mode of formation of oil and it is true that even if the process were known it might have little direct influence on the amount of new oil found. Nevertheless the search for petroleum in process of formation will and must continue, because, although the quantities of crude oil already discovered, and the quantities we can reasonably expect still to be discovered in the future, are sufficient for the world's need for many years, the total quantity of crude is finite and sometime it will be necessary for an alternative to be found. An understanding of the natural processes of formation might enable synthetic processes to be developed which might well be able to produce petroleum or something very like it from animal or plant material which could be farmed to provide a constant and annually renewable supply.

The evidence provided by the crude oil itself is somewhat ambiguous.

Some oils and natural gases contain significant proportions of helium which is normally a product of radioactive decomposition. However, it is more likely that the conditions suitable for the entrapment of oil are also favourable for the retention of helium and two migrating streams of completely different origin have been mixed during their passage through the rocks.

Nickel and vanadium occur as inorganic constituents of some petroleums and it has been found that some fishes concentrate vanadium from sea water and certain plants tend to concentrate nickel from the surrounding soil. Nitrogen, a constituent of plants, is also present in some crude oils. Perhaps the chief argument for an organic stage in the formation of petroleum is the presence of porphyrins in some crudes. Porphyrins are only known to occur naturally in living tissues, both animal and plant, and moreover they are not stable at high temperatures. Their occurrence in petroleum is both an indication that animal or vegetable matter formed the base from which the crude was formed, and that the process went on at temperatures below about 200°C at which they break down.

A further and very important fact is that crude petroleum is optically active. It is one of the particular attributes of material produced by living organisms that it is optically active while inorganic methods of synthesis, as far as we know, produce only optically inactive though otherwise indistinguishable compounds. Optical activity is the ability to alter the direction of polarisation of polarised light. Normal light may be regarded as consisting of pulsations or 'waves' in all directions. Plane polarised light, however, consists only of pulsations in one plane (Figure 9-1).

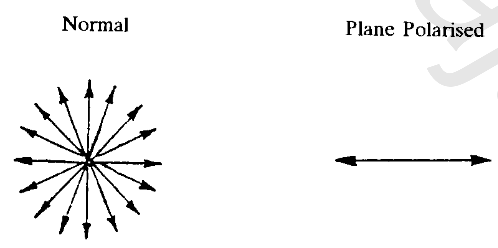



**Figure 9-1.** Diagram to illustrate the difference between the directions of wave movement in normal and plane polarised light.

It has been suggested by one school that the earth was formed by the agglomeration of cold inter-stella particles which contained all the known elements. This theory has been elaborated to claim that petroleum is formed from the carbon and hydrogen present in the original particles by the action of pressure, heat and possibly radioactivity, and that a stream of petroleum is constantly migrating upwards from the earth's core into the crust. It is an attractive idea, evidently more attractive to physical scientists than to followers of the biological and geological disciplines, and it will not satisfy many petroleum geologists. Certainly it does not explain the presence of the porphyrins or the optical activity of petroleum.

The more generally accepted theory is that bacterial decay, in the absence of oxygen, acting upon animal or vegetable remains in a marine environment, causes a chemical change in which the carbohydrates in the base material are changed into new molecules making up petroleum. This theory has several advantages. It provides an explanation for the existence of compounds of organic origin in crude oil; it explains why there is no oil that has been proved to be indigenous to igneous or metamorphic rocks or to sedimentary rocks older than the Cambrian and allows the trace impurities to be reasonably included.

## *Part I. Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. The problem of petroleum genesis has long been a topic of research interest.

........ 2. It is now clear that the formation of petroleum is associated with the development of fine-grained sedimentary rocks.

........ 3. 'Source rock' is sufficient for the formation of petroleum.

........ 4. Petroleum is the product of the organic remains of plants and animals incorporated in the sediments at the time of deposition.

........ 5. Essential to the genesis of petroleum is the development of a basin or depression in the earth's crust in which the potential source sediments may accumulate.

........ 6. As planktonic organisms die, their remains fall to the bottom to be incorporated into the sediments.

........ 7. The presence of porphyrins in some crudes ensures us of the fact that there was an inorganic stage in the formation of petroleum.

........ 8. Porphyrins occur naturally in the plant and animal dead tissues.

........ 9. According to one theory bacteria act upon animal or vegetable remnants in a marine environment to make up petroleum molecules.

........ 10. It is found that radioactivity was crucial in the formation of petroleum.

**B. Choose a, b, c, or d which best completes each item.**

**1.** Plane polarised light consists of waves which are propagated .......... .

a. vertically b. in all directions

c. in one direction d. horizontally

**2.** The occurrence of porphyrins in petroleum indicates that .......... .

a. the conditions suitable for the entrapment of oil are rare

b. animal or vegetable matter was the source of crude

c. the formation of a basin is extremely complex

d. organic material deposited in petroleum will be destroyed quickly

**3.** One of the conditions for the formation of oil in the source rock is that .......... .

a. the rock should be porous

b. temperature should be appropriate

c. there should be active bottom currents

d. the bottom waters should run smoothly

**4.** 'Cap rocks' .......... .

a. cause the organic material to deposit

b. prevent the oil from escaping upwards

c. prevent the multiplication of the already existing enormous numbers of bacteria

d. save the bottom muds from disintegration

**5.** Optical activity refers to the ability .......... .

a. to look for the metal constituents in the crude

b. to distinguish the inorganic source of crude

c. to change the direction of polarisation of polarised light

d. to look at normal light as a combination of pulsations

6. On the basis of chemical examinations of oil-bearing sediments .......... .
   a. the role of bottom muds was emphasized
   b. it was found that a great part of the organic matter was complex nitrogen containing material
   c. it was established that oxygen was the dominant element
   d. it was found that nitrogen was not included in crudes
7. It appears likely that micro-organisms are an important agency in .......... .
   a. discovering the mode of formation o oil in the geological times
   b. refining crudes into different oil products
   c. rising the depth of muds in sediments
   d. altering hydrogen concentration in sediments
8. Some believe that petroleum is the product of the organic remains of plants and animals. However, the details of how this transformation takes place and the mechanisms by which petroleum is expelled from the source sediment and accumulates in the reservoir rock .......... .
   a. remain to be explored
   b. are vividly shown
   c. are still uncertain
   d. are not investigated yet

### C. Answer the following questions orally.

1. Why should the search for petroleum in process of formation be continued?
2. How can an understanding of the natural processes of oil formation help man today?
3. Why is the evidence provided by the crude oil itself somewhat ambiguous?
4. What kinds of metals are found as the inorganic constituents of petroleum?
5. What does the presence of porphyrins in the crude oil signify?

## *Part II. Language Practice*

### A. Choose a, b, c, or d which best completes each item.

1. Oil is formed in the rock which is called .......... rock.
   a. an igneous
   b. a source
   c. a reservoir
   d. a clastic

2. Oil must be prevented from escaping upwards from the reservoir rocks by .......... rock.

a. a permeable b. a porous

c. an impermeable d. a sedimentary

3. Practically all petroleum appears to have originated in full .......... .

a. solid-type bitumen b. igneous strata

c. fine-grained limestones d. marine sediments

4. .......... is normally a product of radioactive decomposition.

a. Helium b. Vanadium

c. Petroleum d. Nickel

5. It is improbable for oil to have been found in .......... .

a. barren deserts b. sedimentary basins

c. sedimentary rocks d. metamorphic rocks

6. Compounds of .......... origin are found in crude oil.

a. organic b. unnatural

c. natural d. artificial

7. Some recent descriptions of petroleum occurring within the body cavities of fossil shellfish have provided supporting evidence that oil can be formed from .......... .

a. plant decays b. animal remains

c. surrounding soils d. living organisms

8. Of all possible source substances .......... can be said almost certainly to have contributed to the formation of crude oil.

a. hydrocarbons b. micro-organisms

c. nitrogens d. sediments

9. Apparently all of the porphyrin in crude oil is complexed with metal, of which .......... is the most important.

a. iron b. vanadium

c. copper d. nickel

## B. Fill in the blanks with the appropriate form of the words given.

**1. Accurate**

a. .......... work is a work which is careful and correct.

b. High standards of .......... are necessary for a scientist if he wishes to do his work well.

c. The definitions are formed .......... .

**2. Approximate**

a. Five inches is the .......... length of this line.

b. If the line is 4.999 inches long, we can say that its length is .......... 5.00 inches.

c. When we see 2.0, we know that something has been measured, and that the result of the measurement is .......... two units. We know that the .......... is to the nearest tenth of a unit.

**3. Convention**

a. Driving .......... have the force of law, but they are obviously not laws of nature.

b. We say that a man is .......... if he accepts and practices the customs of his social group.

c. If he does not accept such customs, we say he is .......... .

**4. Distinct**

a. When it is a fine day, objects in the distance can be seen clearly and separately; they are .......... .

b. Those objects can be seen .......... .

c. How many roads are there on the maps? You cannot see where one road begins and another ends. There is no basis for .......... .

**5. Precise**

a. You can reduce the error by making a more .......... measurement.

b. All measurement is approximate because its accuracy depends on the scale of units used and the .......... of the measuring instrument.

c. It does matter how .......... you measure something.

## C. Fill in the blanks with the following words.

| | | |
|---|---|---|
| geological | reservoir | bedding |
| fragmented | deposits | debris |
| weathering | porosity | coral |

Detrital limestones, as their name implies, are formed from ..........

material derived from other sources. Limestone rocks like any others are subject to the normal forces of ......... and give rise to calcareous gravels and sands (calcarinites). Limestones are known which show traces of ripple marks and current ........., features which can only be developed in fairly granular material such as sand. Many shell ........., although primarily of organic origin, are broken up and transported from their original place of deposition by wave or current action. The ......... from dead coral reefs is pounded into fragments by the action of the ocean swell and forms a ......... sand around the original reef. All these types of fragmental limestone are known in the ......... record and many of them are highly porous and permeable forming excellent ......... rocks in just the same way as do silica sands. They are, however, rather more apt to suffer later alteration and to lose more of their ......... and permeability by secondary deposition in their pore spaces.

**D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.**

a. The most usual cap rock is a shale or mudstone and, particularly where the reservoir rock is sandstone, it is normal to find a cap rock of shale.

b. Solution porosity is developed in the limestone and the subsequent deposition of gypsum, anhydrite or salt forms a seal over a potential oil reservoir.

c. Many different types of rock can form cap rocks.

d. In many limestone reservoirs an evaporate acts as a cap rock. It is probable that evaporate basins are often formed on top of limestone surfaces which have been exposed to atmospheric erosion and weathering.

e. The Arab Zone Limestone of Saudi Arabia has several producing members, and beds of anhydrite act as cap rocks while the Arab Zone itself is overlain by the Hith Anhydrite in which about 200 ft of anhydrite acts as a trapped reservoir.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| | | | | |

# Stratigraphic Reservoir Traps

Stratigraphic trap is a general term for traps that are chiefly the result of a lateral variation in the lithology of the reservoir rock, or a break in its continuity. A permeable reservoir rock changes to a less permeable or to an impermeable rock; it is truncated by an unconformity, and overlapped; or it changes along its bedding; and the boundary between the two kinds of rocks chiefly determines the extent of the reservoir. This boundary may be sharp, or it may be gradational; the condition may be either local or regional in extent; and the change in permeability may be wholly responsible for the trap or only partly so.

Nearly all stratigraphic traps, indeed, have some structural elements, the only exceptions being some of those in isolated lenses and organic reefs, which generally are traps without regard to the regional dip or to any arching or deformation. There is no sharp demarcation between structural traps and stratigraphic traps, and some traps are determined in about equal measure by stratigraphic and structural causes; they might be classed as stratigraphic by some geologists and as structural by others. For that reason, it is useful to set up an intermediate class of combination traps.

Stratigraphic traps may be conveniently divided into two general classes. *Primary stratigraphic traps*, formed during the deposition or diagenesis of the rock, include those formed by lenses, facies changes, shoestring sands, and reefs. *Secondary stratigraphic traps* have resulted from later causes, such as solution and cementation, but chiefly from unconformities.

## Primary Stratigraphic Traps

Primary stratigraphic traps are a direct product of the depositional environment–that is, of the character of the material in the reservoir rock and the conditions under which it was being deposited. The impervious, concave upper boundary surface of these traps, as well as the effective pore space, is essentially the result of primary sedimentary processes. Such traps have also been called 'depositional' traps and 'diagenetic' traps.

The effectiveness of a primary stratigraphic trap is chiefly determined by the shape and attitude of the reservoir formation. The trap may be completely localized by the lenticular shape of the porous and permeable body of rock that becomes the reservoir, as shown in Figure 9-2(a), or it may be partly localized by the configuration of the impermeable up-dip edge of a portion of the reservoir rock, superimposed on a homoclinal dip, as shown in Figure 9-2(b). All gradations and combinations of these general conditions are found.

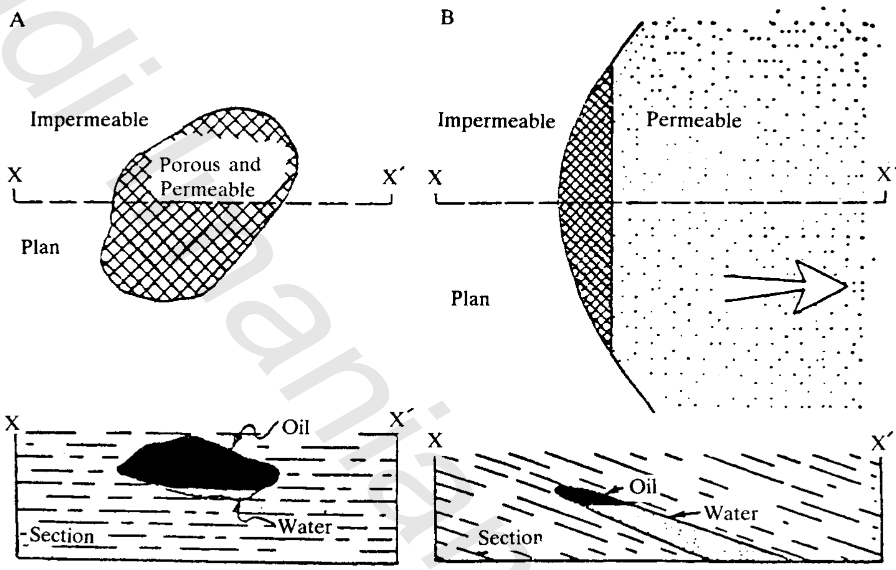



**Figure 9-2.** Sketches showing (A) typical lens-type traps completely surrounded by impermeable rocks and (B) an irregular up-dip edge of permeability on a homoclinal regional dip. Arrow shows direction of dip.

*Primary stratigraphic traps* may be divided into two general groups: (1) lenses and facies of clastic and igneous rocks; (2) lenses and facies of chemical rocks, including biostromes, organic reefs, and bioherms.

**Lenses and Facies in Clastic Rocks.** Some reservoirs are in thin lenticular bodies of porous and permeable clastic rock enclosed in impermeable sediments. Their areal extent generally does not exceed a few square miles, although there are a number of exceptionally large ones. Most commonly the lens consists of clastic material–sandstones, arkoses, coquinas, and the special class of weathered, brecciated, and redeposited igneous and metamorphic rocks known as 'basalt' and 'serpentine'. Turbidites, while often difficult to recognize, probably account for many lenticular sandy deposits, especially on the seaward side of rapidly filling depositional basins.

The boundary between a lens and the enclosing rock may be either sharp or gradational. Lenses may be contemporaneous with the enclosing sediments, or they may have formed slightly earlier. By an increase in area, lenses grade into what might be termed restricted facies deposits, which, in turn, grade into deposits of normal facies.

A facies change is a lateral gradation (or less commonly an abrupt change) within a formation or group of rocks, resulting from the contemporaneous deposition of rocks of differing character. If the difference is lithologic, we have a *lithofacies change*; if the difference is in the fossil content, we have a *biofacies change*. Lithofacies gradations from permeable to impermeable rocks are the cause of many traps that contain oil and gas pools. Since lithofacies gradations are more widespread than lenses, often being regional in extent, they are more important in regional analyses. 'Facies' may be used as a group term to include several formations, individual sand lenses, or organic reef deposits, such as the sandy facies of the Cherokee formation (Pennsylvanian) of Oklahoma and Kansas, and the reef facies of the Upper Devonian of Alberta. When a sandstone grades into a shale up a homoclinal dip, or a permeable dolomite gives way, up the dip, to an impervious limestone, the up-dip edge of permeability may mark the critical edge of a single trap or of a group of traps.

The oil and gas pool may completely fill the porous part of a sand lens; it may occupy only the high portion of the lens; or, if the regional structure is monoclinal, it may accumulate in irregularities along the regional up-dip edge of permeability. One thing to remember in exploration is that, where one such primary stratigraphic trap is found to contain oil, there may be others like it nearby, for the conditions that determine the presence of facies and lens traps are commonly of regional extent, and the local phenomena are likely to be repeated over wide areas.

## *Comprehension Exercises*

**A. Put "T" for true and "F" for false statements. Justify your answers.**

........ 1. Some geologists distinguish between stratigraphic and structural traps.

........ 2. Stratigraphic traps are mainly caused by depositional features.

........ 3. 'By depositional features' is meant the character of the material in the reservoir rock and the condition for its deposition.

........ 4. Tectonic events bring about structural traps.

........ 5. Typical examples for stratigraphic traps are carbonate reefs.

........ 6. Unconformities are the cause of the formation of primary stratigraphic traps.

........ 7. Typical examples for structural traps are anticlines, fault traps, and traps associated with salt dome.

........ 8. The majority of petroleum accumulations are found in clastic reservoir rocks, such as sandstones.

........ 9. The formation of stratigraphic traps is related to sediment deposition or erosion and is thus distinguished from formation of structural traps, which originate from tectonic events.

........ 10. Stratigraphic traps are due to depositional features such as a sandbody embedded in shales, or a porous reef rock buried by dense limestones and shales.

**B. Choose a, b, c, or d which best completes each item.**

**1.** The deposition of rocks of differing character results in .......... .

a. a metamorphic rock b. a turbidite
c. a facies change d. an organic reef

**2.** Secondary stratigraphic traps are mainly caused by .......... .

a. unconformities b. lenses
c. facies changes d. reefs

**3.** Some reservoirs are located in porous and permeable clastic rock embedded in .......... sediments.

a. lithological b. impermeable
c. porous d. permeable

**4.** Facies is a general term and includes all of the following formations except .......... .

a. sandy facies
b. sand lenses
c. reef facies
d. biofacies changes

**5.** The lens consists of all of the following except .......... .

a. coquinas
b. biostromes
c. sandstones
d. arkoses

**6.** The word 'contemporaneous' as used in this passage means .......... .

a. long time after
b. existing at the same time
c. existing before something
d. previous time

**7.** Causes for the formation of traps are numerous. They may be due to .......... reef rock buried by dense limestones and shales.

a. a porous
b. a closed
c. an igneous
d. a moving

**8.** The trap caps are mainly caused by the function of .......... .

a. secondary sedimentary processes
b. primary sedimentary processes
c. stratigraphic factors
d. geological features

**9.** Where oil is located in a primary stratigraphic trap, explorers can be sure to find other traps .......... .

a. nowhere in the vicinity
b. farther away
c. nearby
d. scattered around

**10.** The .......... and attitude of the reservoir formation determine the effectiveness of a primary stratigraphic trap.

a. kind
b. length
c. shape
d. size

## C. Write the answers to the following questions.

1. Why is it useful to set up an intermediate class of combination traps?
2. When are the primary stratigraphic traps formed?
3. How are the primary stratigraphic traps formed?

4. Why are lithofacies gradations considered important?
5. What does lens usually consist of? (Note: the plural of *lens* is *lenses*.)

❂ ❂ ❂

*Section Three: Translation Activities*

**A. Translate the following passage into Persian.**

## The Difference Between Stratigraphic Traps and Structural Traps

Stratigraphic traps present different problems of exploration than structural traps. In a structural feature, for example, thick sections of rocks, possibly containing several potential reservoir rocks, are deformed and thereby have a number of opportunities to trap pools, one above another. Stratigraphic traps, on the other hand, seldom have any relation with either overlying or underlying reservoirs, but may be repeated laterally. A test well on a structural feature frequently has several potential objectives, whereas a test well on a stratigraphic feature generally has only one. Stratigraphic phenomena generally extend over wide areas or along elongated trends, and the discovery of one offshore sand bar, channel filling, sand patch, or organic reef therefore strongly suggests that others will be found in the region.

Structural features may be determined in many ways, either from the surface by surface mapping or geophysics, or at depth by subsurface mapping. Potential stratigraphic traps, however, generally have to wait to be visualized until enough wells have been drilled to supply the needed stratigraphic information. This means that more test wells have to be drilled in search of stratigraphic pools than in search of structural pools. In fact, careful attention to details of the sedimentation, oil and gas showings, and stratigraphy of an area offers about the best consistent approach to prospecting for pools in stratigraphic traps. This is not to say that the structure of such an area should not be mapped, for it may combine with stratigraphic variations to form traps; but most structural effects of local stratigraphic phenomena are small and difficult or impossible to interpret correctly.

Even after discovery, there are few clues to the size of the pool, or the direction in which it will extend; stratigraphic pools, in fact, are frequently a succession of surprises. An early understanding of the stratigraphic environment, sedimentary history, and the fluid potential environment of a newly productive area is of the most help; it may point to truncated reservoirs, shoestring sands, sand patches, facies changes, fluid barriers, or organic reefs as the cause of the trap, and from this information the pattern of the reservoir and the size of the pool may be anticipated and exploration guided with fewer dry holes.

## B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.

1. agglomeration ............................
2. biofacies change ............................
3. calcareous gravels ............................
4. channel filling ............................
5. clastic rocks ............................
6. coquinas ............................
7. detrital limestone ............................
8. elongated trends ............................
9. entrapment of oil ............................
10. homoclinal dip ............................
11. lateral variation ............................
12. lenticular shape ............................
13. lithofacies gradations ............................
14. mudstone ............................
15. offshore sand bar ............................
16. optically active ............................

17. organic debris ..............................
18. organic reef ..............................
19. polarisation ..............................
20. pore spaces ..............................
21. pulsation ..............................
22. radioactive decomposition ..............................
23. sand patch ..............................
24. shoestring sands ..............................
25. source rock ..............................
26. structural features ..............................
27. structural traps ..............................
28. weathering ..............................

# Unit 10

*Section One: Reading Comprehension*

## Branches of Petroleum Industry

Several branches or divisions of the oil and gas industry are identified in this Section as a way of giving a bird's eye view of the scope of activities encompassed.

*The exploration for and finding of oil and gas deposits* is where the industry starts. This area encompasses the fields of geology and geophysics, which deal with the layers of the earth wherein oil and gas may have been trapped under pressure in the earth. Exploration rights for the minerals in the earth are leased from the mineral right owner, government or private. Land departments handle the legal work of acquisitions of leases. Once geophysical and geological studies identify a prospective site and an expected horizon to contain the oil and gas, a drilling permit is obtained. Drilling proceeds on the wildcat or exploratory well site, frequently with the employment of a drilling contractor. When the potential horizon is reached, drill stem tests, cores, and logs are obtained to assess the prospects for commercial production. After oil and gas are found, the wellbore is cased, followed by installation of flow and separation equipment at the wellhead.

*Development and production* follow the finding of a commercially valuable deposit of oil and gas; development wells are drilled and tested. Arrangements are made for separating and gathering the oil and gas produced from the wells; such a production system is shown in Figure 10-1. Crude oil or condensate is readied for the market by assuring that the water content is low (0.2 percent) and the volatile hydrocarbons are removed. The gas is sent to processing plants or possibly compressed and returned to the producing reservoir. Geological and engineering studies are made of the deposit or reservoir.

*Reservoir engineering* is the term adopted in the 1930s for detailed consideration of the quantity of oil and gas in a reservoir, and for finding the best ways to recover oil and gas, i.e., the location of wells, rates of production, and monitoring of reservoir pressure. The capillary retention of oil by the porous rock prevents a direct recovery of a high fraction of the liquid. Water influx at the edges or underneath the oil, called *water drive*, may be a factor in oil recovery. Understanding the physical behavior of the oil with dissolved gas is especially important for condensate-producing reservoirs, and also in $CO_2$ flooding projects. Oil and gas reservoirs normally have a pressure gradient of 0.46 psi/ft (10.4 kPa/m) of depth; pressures of 3000 to 8000 psia (20.7 to 55.2 MPa) are common for oil and gas reservoirs from 6000 to 15,000 feet (1829 to 4572 m).

*Processing of gas for liquids recovery, dehydration, and sweetening* takes place on the streams gathered from a central or leased separation facility. This technology is quite different from reservoir or production engineering in that its processes are carried out in surface vessels. These processes extract the liquefiable constituents and produce propane-butane and LP (liquefied petroleum) products–natural gasoline or a composite NGL (natural gas liquid). The Gas Processors Association, through meetings and annual reports, provides advances in these technologies. Before gas is sent to pipelines, it needs to have a low water vapor content (2-44b/MMcf or $3.2\text{-}6.4\times10^{-5}$ kg/$m^3$) so it will not form liquid water in the transcontinental pipelines taking it to market. Natural gas and liquid water can form solid gas hydrates that impede flow.

*Natural gas pipelines* carry the fuel gas to northern and eastern markets at the rate of some 14 trillion cubic feet per year ($396\times10^9$ $m^3$/year) with much of the gas going to space heating of homes, schools, hospitals, and commercial buildings. The market load in good part is tied to the outside ambient temperature. Liquid products also are carried by pipeline in common carrier systems serving refineries and petrochemical plants.

*Underground storage of gases and liquids.* Gas storage fields were developed near the market to reduce the need for large-diameter pipelines to service winter gas demands in cold weather. When depleted gas fields were available as in Michigan, Ohio, West Virginia, New York, California, etc., they were repressured. By drilling many wells and installing a gathering system, compressors, and gas dehydration facilities, large volumes of gas are

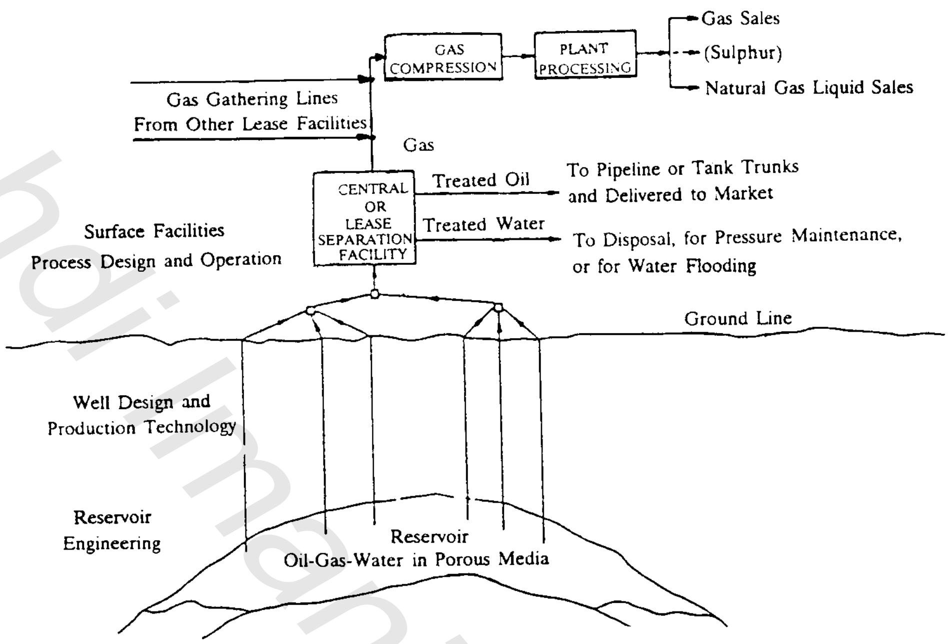



**Figure 10-1.** Diagram of oil and gas production system.

withdrawn each winter and new gas is injected the following summer, giving rise to the cycle.

*Aquifer storage* was developed and grew most rapidly in Illinois since it lacked natural gas reservoirs near the market area. Gas companies devised storage in structures on water sands at 1000 feet (305 m) or more in depth. The term *aquifer storage* refers to the water zone in which the gas resides.

Salt occurs in layers in the earth or in salt domes. Solution mining of salt by dissolving it with injected water creates a salt cavity. Techniques were developed in the 1950s for creating and using salt cavities for liquid propane, LP gas, and other liquid storage underground. The gas industry began to use such cavities for storing natural gas in the 1960s. Where there is no salt, mined cavities in granite, shale, or limestone are used for LP storage.

Other divisions of the petroleum (oil and gas) industry include *secondary oil recovery* and *enhanced oil recovery*. Secondary oil recovery generally refers to gas injection or water flooding after primary recovery, and enhanced oil recovery refers to more recent procedures such as thermal steam injections, polymer flooding, and $CO_2$ flooding. Since natural gas and carbon dioxide injection are used for extra oil recovery, this segment of oil production is a part of gas processing.

*Offshore technology* is the new discipline of drilling for and producing oil from reservoirs below bodies of water. Some 40 years ago, hundreds of wells were drilled in 80 feet (24 m) of water in Lake Maracaibo, Venezuela, and compression plants for separating oil and processing gas were built on platforms over the water. In intervening years, such drilling below Gulf Coast waters offshore has grown in volume of oil and gas produced and in depths of water for drilling. In the last 25 years, the North Sea has been seismically investigated for structures, and many reservoirs have been found.

## *Part I. Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. The oil industry starts with the finding of oil and gas deposits.

........ 2. Drilling permit is given when arrangements are made for separating and gathering the oil and gas produced.

........ 3. Processing of gas for liquids recovery is different from reservoir engineering.

........ 4. The solid gas hydrates which are produced by natural gas can stop the flow of oil.

........ 5. The market accepts crude oil when the water content is high.

........ 6. In order to reduce the need for large-diameter pipelines, gas storage fields were developed.

........ 7. After primary recovery, gas is injected into the oil well.

........ 8. Offshore technology refers to gas processing techniques.

........ 9. After finding a commercially valuable deposit, development and production follow.

........ 10. Water flux underneath, the oil is an important factor in oil recovery.

**B. Choose a, b, c, or d which best completes each item.**

1. Finding of oil and gas deposits is where the oil industry .......... .
   a. finishes b. returns
   c. begins d. ends
2. Reservoir engineering is the term adopted for .......... .
   a. drilling the ground
   b. finding the best techniques to recover all gases
   c. processing of gas for liquid recovery
   d. developing a commercially valuable deposit of oil
3. Gas storage fields were established near the market .......... .
   a. to reduce the need for large-diameter pipelines
   b. to explore further the gas production system
   c. to produce oil from reservoirs below bodies of water
   d. to find the best ways to recover oil and gas
4. Thermal steam injection is included in .......... .
   a. the drilling procedures on the wildcat
   b. the flooding projects
   c. the secondary oil recovery
   d. the enhanced oil recovery procedure
5. As soon as geological studies identify a prospective site, .......... .
   a. a drilling permit is issued
   b. a development plan is divised
   c. a crude oil well is identified
   d. a land department handles the legal work
6. The word 'wildcat' refers to .......... .
   a. a site for exploration
   b. a cat
   c. a leopard
   d. a place where volatile hydrocarbons are burned
7. Gas storage is devised on water sands .......... .
   a. at 305 meters or more in depth
   b. at 900 feet or more in depth
   c. at 300 meters or more in depth
   d. at unknown depth

8. The wellbore is cased .......... .

a. before oil and gas are found

b. if the well is drilled properly

c. after oil and gas are found

d. if the well contains a lot of gas

9. Propane-butane is produced from .......... .

a. productive materials b. liquefiable constituents

c. sweetened products d. separated constituents

10. Drilling for oil from reservoirs below bodies of water is referred to as .......... .

a. aquifer storage b. inland techniques

c. offshore technology d. storage capacity

## C. Answer the following questions orally.

1. What was the word reservoir engineering devised for?
2. What does 'water drive' refer to?
3. What do engineers do after oil and gas are found?
4. Where does processing of gas for liquids recovery take place?
5. How are liquid products carried?

## *Part II. Language Practice*

### A. Choose a, b, c, or d which best completes each item.

1. This area .......... the fields of geology and geophysics.

a. encourages b. encompasses

c. accompanies d. proceeds

2. Oil production follows the finding of .......... valuable deposit of oil.

a. a commercially b. a communicated

c. a commercial d. a commerce

3. Before gas is sent to pipelines, it needs to have a low water vapor .......... .

a. intend b. contend

c. contain d. content

4. In .......... years, such drilling below Gulf Coast waters offshore has grown in volume.

a. international
b. intermediate
c. interviewing
d. intervening

5. Salt occurs in layers in the earth in salt .......... .
a. domes
b. deems
c. dams
d. dines

6. Oil and gas reservoirs normally have a pressure .......... of 0.46.
a. gradient
b. graduate
c. graded
d. graduation

7. The gas is sent to processing .......... .
a. recovery
b. plan
c. plants
d. equipment

## B. Fill in the blanks with the appropriate form of the words given.

**1. Product**

a. She .......... a hot meal for us within 20 minutes.
b. Africa's long-term .......... capacity is low.
c. He is a .......... of an intellectual background.
d. His announcement .......... a violent reaction among the crowd.

**2. Employ**

a. He is .......... on the oil rigs.
b. The oil company has training schemes to make more people .......... .
c. The oil firm has over 500 .......... .
d. The expansion of the factory means the .......... of sixty extra workers.

**3. Explore**

a. Columbus discovered America but did not .......... it.
b. His .......... led him into the deserts of Central Asia.
c. They have decided on an .......... expedition up the Amazon.
d. Marcopolo was one of the great .......... of the world.

**4. Separate**

a. When the partnership ended, we went our .......... ways.
b. The engineers .......... gas from water.
c. .......... from his friends made him sad.
d. It is better to cook the stuffing .......... from the turkey.

**5. Compose**

a. I'm .......... a formal reply to the letter.

b. Water is .......... of oxygen and hydrogen.

c. Beethoven was a great world's .......... .

d. The engineers desire to analyze the exact .......... of the soil.

## C. Fill in the blanks with the following words.

| | | | |
|---|---|---|---|
| burial | generated | migrated | sedimentary |
| remains | metamorphism | movement | deposits |
| started | consolidation | | |

The origin of petroleum from organic matter in .......... rock is set forth by Tissot and Welte. As early as $2500\times10^6$ years ago, .......... of bacteria and primitive algae were deposited in pre-Cambrian rocks. Photosynthesis of plants from $CO_2$ and $H_2O$ by sunlight, forming glucose and oxygen, .......... some 2 billion years ago and reached a high yield at the time of coal .......... such as those in the Carboniferous age.

When the organic matter was buried, but still shallow, a process of diagenesis took place often including .......... of sediments. Temperature increased with depth of .........., forming kerogen with generation of methane gas. The word catagenesis is used for the process by which oil and gas were .......... at high pressure due to great depths. At great depths metagenesis of organic matter (kerogen) to anthracite coal and .......... of mineral phases also occurred.

Oil and gaseous constituents formed in source beds .......... and were trapped in structures covered by impervious caprocks. Buoyancy of the lower-density oil and gas in water causes upward migration, preventing water .......... from carrying the finely divided oil globules along.

## D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. These uncommon instances were traditionally classified as failures, i.e., the gases had little or no economic value, and areas known to contain them were commonly avoided during further drilling.

b. Second, the increase in the price of oil in the 1970s has made some of these enhanced recovery operations economically viable.

c. In the search for oil and gas during the past century, other gases (helium, nitrogen, carbon dioxide) have been encountered.

d. First, research has shown that the injection of $CO_2$ into some 'watered-out' reservoirs can substantially increase oil recovery.

e. However, two factors have made carbon dioxide ($CO_2$) an attractive resource target in some areas.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| | | | | |

*Section Two: Further Reading*

# Reservoir Description of Sandstones

## Introduction

The biggest challenge for hydrocarbon explorers and producers now and in the future is to significantly improve hydrocarbon recovery from newly and previously discovered reservoirs. A key to achieving this goal is to compile detailed reservoir descriptions of sandstone reservoirs. A reservoir description is a comprehensive picture of the three-dimensional distribution and continuity of the rocks, pores, and fluids of the reservoir and aquifer system, including barriers to fluid flow.

When is a reservoir description needed? The need starts during the exploration phase, when reservoir analogues are needed for play development and prospect evaluation. The need intensifies once a discovery is made and is being appraised as to the best estimates of hydrocarbons in place, recoverable reserves, drive mechanism, and rates of production. As a reservoir or field goes through the typical 'life cycle' of discovery, appraisal, planning, develop-

**Table 10-1.** Key factors in reservoir analysis.

| | |
|---|---|
| EXPLORATION PHASE | |
| ● Seismic Characteristics | ● Hydrocarbon Migration Paths |
| ● Trap Configuration | ● Reservoir Volume |
| ● Sand-Body Geometry | ● Nature of Seals |
| APPRAISAL PHASE | |
| ● Hydrocarbons in Place | ● Production Rates |
| ● Reserves | ● Aquifer Size and Strength |
| PLANNING PHASE | |
| ● Optimum Depletion Plan | ● Location and Number of Wells |
| ● Location and Number of Platforms | |
| DEVELOPMENT PHASE | |
| ● Policies on Completions and Workovers | ● Optimum Distribution of Injection and Production |
| RESERVOIR MANAGEMENT (SURVEILLANCE) PHASE | |
| ● Infill Wells | ● Redistribute Injection |
| ● Workover Wells | ● Improved Recovery Methods |
| ● Surveillance Program | |

ment, and reservoir management or surveillance, a more complete reservoir description is both necessary and possible. Some of the critical factors to be evaluated (Table 10-1) and questions to be answered (Table 10-2) in the analysis of a reservoir during its life cycle give insight into the requirements of an effective reservoir description. Fulfilling these requirements means shortening the time of a reservoir's life cycle, the goal of which is to optimize hydrocarbon recovery.

**Table 10-2.** Some typical questions in reservoir analysis.

1. What does the reservoir look like–geometry and continuity of pore space and fluids?
2. Will the reservoir have an effective natural water drive? Is there an aquifer and what is its size, geometry, continuity, and strength?
3. Where should wells and platforms be located?
4. Where and how should wells be completed? Where should perforations be shot?
5. Will recoveries be better by water or gas displacement?
6. Will water or gas injection be needed and when?
7. Will enhanced recovery processes be needed and when?

## Reservoir Description

The principal geophysical, geological, and petrophysical contributions to reservoir description are the external geometry of the reservoir; the internal geometry of the reservoir, including the distribution of fluid-flow barriers and pay types and intervals; the distribution of porosity, permeability, and capillary pressure-saturation properties; the aquifer extent, continuity, permeability, and thickness; and the distribution of clay and framework minerals, both grains and cements. Prediction of the reservoir description attributes requires that the physical processes which formed them be understood. Detailed studies of Holocene and ancient sand bodies in outcrops, cores, and the subsurface demonstrate clearly that most reservoir properties are the direct result of facies variations which are in turn controlled by depositional systems, their associated sedimentary processes, and the subsequent histories of diagenesis, burial, and structural deformation.

In the reservoir description process, a critical first step is the recognition of all correlative reservoir layers or subzones and the intervening dense, impermeable or low-permeability strata. Knowledge of the depositional and diagenetic processes controlling both the reservoir and the nonreservoir rock units is essential to the degree of confidence in correlating these units from well to well. Genetic sequence analyses of sand bodies and seismic facies, coupled with knowledge from well-documented outcrop studies, can add significantly to interwell correlations. Flow test and production data dovetailed with the three-dimensional picture of the reservoir-nonreservoir framework provide the best reservoir description of continuity-discontinuity of porosity, permeability, capillary properties, vertical and horizontal fluid-flow barriers, and fluids. All zones of unusual permeability contrast, especially zones of very high permeability, are critically important to all recovery processes.

The reservoir description for all displacement recovery processes should include the determination of net pay types, their continuity, and an estimate of the percent of pay that will be floodable based on the well spacing. This determines recovery estimates, the decision to infill, and the well spacing needed if infilling is desirable.

In sand bodies, shales are the dominant fluid-flow barriers and their distribution is the result of depositional environment and the associated sedimentary processes. Shales of all sizes must be described and mapped because of their influence on reservoir performance. Shale beds that are continuous between several wells both divide the hydrocarbon column into smaller and separate production intervals and act as vertical permeability barriers. These continuous shales can also help primary performance by preventing gas and water coning. Shales that are not continuous between wells also reduce vertical fluid flow. In reservoirs with primary gas-cap expansion drive, discontinuous shales lower effective vertical permeability and entrap oil on the shale bed tops, thus reducing oil recovery. In water or gas injection processes that are typical of pressure maintenance or enhanced recovery, discontinuous shales usually inhibit gravity segregation and thereby increase reservoir sweep efficiency.

A reservoir description, especially one made during appraisal, needs a correct assessment of the potential aquifer size (pore volume), continuity, and strength (pressure, thickness, and permeability). The aquifer's external and internal properties are derived from knowledge of the depositional environments, geophysical mapping, and flow tests. With knowledge of the aquifer properties, a reservoir engineer can estimate the potential importance of a natural water drive or the need for and the timing of pressure maintenance by water or gas injection. When the pore volume of a reservoir, a strong natural water drive results; however, if this pore-volume ratio is only 10, pressure maintenance by water or gas is required.

## Summary

A reservoir description is a comprehensive picture of the three-dimensional distribution and continuity of the rocks-pores-fluids of the reservoir and aquifer system, including barriers to fluid flow. A good reservoir description designed to answer key reservoir performance questions is a fundamental tool for appraisal, planning, development, and reservoir management (surveillance) phases of production. In exploration, detailed reservoir description studies provide critical data needed by the explorationist to estimate reservoir, barrier, and seal quality and distribution from seismic data, well logs, cores, and samples.

### *Comprehension Exercises*

**A. Put "T" for true and "F" for false statements. Justify your answers.**

........ 1. The need for a reservoir description starts during the exploration phase.

........ 2. The aquifer's external and internal properties are derived from knowledge of the depositional environments, etc.

........ 3. The external geometry of the reservoir does not contribute to reservoir descriptions.

........ 4. The recognition of all correlative reservoir layers is critical for reservoir description process.

........ 5. A reservoir description needs a correct assessment of the potential aquifer size.

........ 6. A reservoir description is not a fundamental tool for appraisal and planning.

........ 7. Hydrocarbon recovery from reservoirs is the biggest challenge for hydrocarbon explorers.

........ 8. In sand bodies, shales are important barriers.

........ 9. Shales must be described because of their effect on reservoir performance.

........ 10. In exploration, reservoir description studies provide important data needed to estimate reservoir.

**B. Choose a, b, c, or d which best completes each item.**

1. A reservoir description is .......... picture of the three-dimensional distribution.

   a. a comparing　　b. a comprehension
   c. a comprehensive　　d. a comprehend

2. The need for a reservoir description .......... as soon as a discovery is made.

   a. intensifies　　b. optimizes
   c. continues　　d. drives

**3.** The life cycle for a reservoir includes .......... .

a. discovery
b. appraisal
c. planning and development
d. all of the above

**4.** Prediction of the attributes of a reservoir description requires that physical processes be .......... .

a. criticized
b. neglected
c. forgotten
d. understood

**5.** In reservoirs with primary gas-cap expansion drive, discontinuous shales .......... effective vertical permeability.

a. lower
b. raise
c. analyze
d. provide

**6.** All zones of very high permeability are .......... to recovery processes.

a. important
b. barriers
c. not important
d. irrelevant

**7.** Reservoir analogues are needed for .......... evaluation.

a. continuous
b. prospective
c. prospect
d. entire

**8.** When the pore volume of an aquifer is at least .......... times the pore volume of a reservoir, a strong natural water drive results.

a. 20
b. 10
c. 1000
d. 100

## C. Write the answers to the following questions.

1. When will enhanced recovery processes be needed?
2. Where should platforms be located?
3. What does permeability mean?
4. When is a reservoir description required?
5. What is a reservoir description?

**A. Translate the following passage into Persian.**

# The Development of the Fault-Block Shape

## Introduction

The structural evolution of normal fault blocks governs the shape, size, and distribution of potential reservoir rocks in many extended terrains. Seismic data offer good information on the configuration of major faults, but resolution limits observation of structures that accommodate displacement along major fault planes and distortion within major fault blocks. Restored sections indicate that subsidiary structures must contribute to the structural evolution of fault blocks, but such complexity is difficult to document using seismic data alone. One way to gain a better understanding of the development of the fault-block shape is to study the geometry of small-displacement fault arrays in naturally deformed rocks and the geometry and kinematics of faults in scaled physical models.

This Section describes faults in an outstanding three-dimensional exposure in Tertiary sedimentary rocks from the Basin and Range province in Arizona and compares them with fault geometries in physical models. Because experimental models are created under known conditions of displacement and imposed bulk strain, similarities in geometry between models and the outcrop can be used to refine the interpretation of fault kinematics. The results lend insight into the way in which normal faults interact to produce fault block shapes and how, in larger fault blocks, fault complexity that is below seismic resolution may control reservoir compartmentalization and heterogeneity.

## Geologic Setting of Fault Example in Arizona

The study area in west-central Arizona is in the Basin and Range province of the southwestern United States, a region transacted by numerous Tertiary detachment faults (e.g., Wernicke, 1981). These faults are large-displacement, low-angle normal faults that have been uplifted and warped into broad, undulating surfaces. The extension and lateral displacement of upper-plate rock was accommodated by the formation of numerous upper-plate fault zones. The Lincoln Ranch basin of the eastern Buckskin Mountains is above the Buckskin detachment fault in a domain of northeast-dipping normal faults.

**B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.**

1. capillary ..............................
2. compartmentalization ..............................
3. depleted gas fields ..............................
4. deposits ..............................
5. diagenesis ..............................
6. fault ..............................
7. gaseous constituents ..............................
8. gas storage fields ..............................
9. generation ..............................
10. instal ..............................
11. metamorphism ..............................
12. offshore technology ..............................
13. oil recovery ..............................
14. reservoir rock ..............................
15. sediments ..............................
16. structural deformation ..............................
17. thermal steam injection ..............................

# Unit 11

*Section One: Reading Comprehension*

# Marine Petroleum Pollution

## Overview

The study of petroleum pollution in the ocean deals with two potentially opposing aspects of man's activities: on the one hand is pollution arising from activities undertaken to meet man's needs–the extraction, transport, and use of petroleum for energy and chemical feedstocks–and on the other hand is the strong desire to preserve living marine resources both for current uses and for a legacy for future generations.

In this examination of marine petroleum pollution we recognized this duality and attempted to examine it from a broad and, at times, somewhat distant perspective, without bias whenever possible, so as to avoid pitfalls of misinterpretation. Petroleum is a naturally occurring substance, derived from organic materials once living but since transformed into a complex mixture of chemicals, consisting mainly of hydrocarbons and small amounts of other organic compounds. A small amount of petroleum has seeped into the world's oceans for at least centuries and probably millions of years, and portions of the oceans have accommodated long-term influx of some petroleum into their communities and ecosystems.

The modern influx of petroleum into the marine environment is on a different scale, occurring more rapidly and over a wider area, and probably is of a different kind. The product entering the oceans today, both from chronic effluent release and runoff and from sudden catastrophic spills, represents a sudden and significant input of contaminants when viewed against the much longer, but much lower, continuous presence of seepage petroleum. Also, the chemical composition of this modern petroleum input often differs from that of the seepage oil, the latter being altered by the degradation processes, both physical/chemical and microbial, occurring in the marine sediments and crustal layers. In this context it must be noted that inputs of petroleum are not the only sources for many of the compounds of concern. For example, combustion of coal yields several polynuclear aromatic hydrocarbons similar to or also found in petroleum. Finally, modern petroleum input to the oceans is no longer restricted to the seep locations but now includes many waters formerly held unpolluted and pristine. Even those areas themselves free of oil exploration and production activity are nonetheless subject to potential pollution resulting from petroleum tanker traffic.

Our mandate from the Ocean Sciences Board (now the Board on Ocean Science and Policy) was to review the accomplishments since the 1975 NRC Report, *Petroleum in the Marine Environment*, to arrive at conclusions on the basis of our newer understanding of the behavior and fate of petroleum in the marine environment, and in the end to make recommendations concerning possible further research. We recognize potential environmental problems requiring further study as well as areas where much less concern is required, either as a result of new findings or because investigations are essentially completed.

Inevitably, the potential impact of petroleum as part of, or together with, other contaminants in the marine environment was considered. While in some instances petroleum itself is readily seen as the identifiable pollutant, as for example, in tanker spills or in known cases of chronic petroleum pollution, there are many regions where petroleum hydrocarbons are thought to form part of a more general pollution threat to the health of those environments. Waters near or receiving the effluent of urban and industrial regions serve here as primary examples.

## General Advances: (1973-1983)

Progress in oil-pollution-related research during this past decade has been impressive. Knowledge and understanding of its problems have come about in each of the areas identified in the 1975 NRC Report. Most significant of the advances in these areas are the reduction in the uncertainties regarding the rates of input and amounts of marine petroleum pollution, the increasing sophistication of the analytical methodology applied to chemical and biological studies, clearer identification of the various processes acting on petroleum in the oceans, and the clear identification of problem areas in the effects of petroleum on biota.

**Inputs**

There is now a better understanding of the data base with respect to input of petroleum into the world's oceans, especially for urban runoff, which is a major source. Progress has been made also in the design and implementation of procedures for measurement of atmospheric inputs of petroleum hydrocarbons to the marine environment, although more data are needed. In addition, over the past 8 years there has been a better definition of the various sources of input, which has led to the recognition and elimination of the problem of double bookkeeping, i.e., including a particular source in more than one category in previous estimates. These advances came as a result of the discussion and deliberations of the 1973 workshop, the recommendations from which were carried forward to the present effort.

## *Part I. Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. Oil companies are not concerned about the safety of ocean marine life.

........ 2. The writers of the present research have used their specific bias.

........ 3. Petroleum is a natural substance based on the organic materials no longer in existance.

........ 4. The seeping of oil into the world's oceans has taken place only in the last 25 years.

........ 5. The new oil seepage is probably the same as the old seepage of oil into the oceans.

........ 6. Combustion of coal is as dangerous to the environment as the seepage of oil.

........ 7. The tanker spills are considered among pollutants to the marine life.

........ 8. Research on oil as an important source of marine pollution in the last decade has not been significant.

........ 9. The methodology used today for the study of oil pollution is very sophisticated.

........ 10. The measurement of atmospheric inputs of petroleum hydrocarbons to the marine environment has progressed lately.

**B. Choose a, b, c, or d which best completes each item.**

1. The deliberations on the 1973 workshop .......... .
   a. caused the present progress in marine life studies
   b. did not have any effect on the present studies
   c. discouraged the scientists on marine life studies
   d. were forgotten in the coming decades
2. There is now a better understanding of the data base .......... .
   a. with respect to different kinds of pollutants to the environment
   b. with respect to petroleum seepage into the world's oceans
   c. regardless of the indifference of oil tank owners towards the safety of marine life
   d. with respect to the number of weekly passage of oil tankers
3. Petroleum pollution in the ocean arises from .......... .
   a. the extraction, transport, and use of petroleum for energy
   b. the mismanagement of oil companies' executives
   c. the negligence of governmental agencies
   d. the examination of marine petroleum pollution
4. The modern seepage of oil into the marine environment .......... .
   a. is the same as the old seepage of oil in the last decades
   b. is not really different from previous ones
   c. is different from the old kind of seepage
   d. is not discussed in the present article
5. A small amount of petroleum has seeped into the world's oceans .......... .
   a. since the industrial revolution
   b. since modern times
   c. since the beginning of the 20th century
   d. for at least centuries
6. Modern petroleum seepage into the oceans .......... .
   a. is no longer restricted to the seep locations
   b. is restricted to the seep locations
   c. does not concern the oil companies
   d. is no longer considered important

7. The study of petroleum pollution in the ocean deals with two aspects of man's activities which are .......... .
   a. activities to preserve living marine resources
   b. plans carried out for man's economic advance
   c. activities done to provide for man's needs
   d. both a and c
8. Catastrophic spills of oil into the oceans are .......... .
   a. considered among ocean contaminants
   b. too frequent for scientists to stop
   c. no longer taken care of
   d. not as hazardous to marine life as previously thought
9. Petroleum is derived from .......... .
   a. organic materials
   b. inorganic materials
   c. organic materials once living
   d. the combustion of coal
10. Nowadays the measurement of atmospheric inputs of petroleum hydrocarbons to the marine environment .......... .
   a. has not progressed enough
   b. has progressed a lot
   c. is not considered important
   d. is not taken seriously

### C. Answer the following questions orally.

1. Why do the authors consider marine petroleum pollution so important?
2. What is petroleum derived from?
3. What factors contribute to marine pollution?
4. Is petroleum pollution in the ocean a recent catastrophy?
5. How does combustion of coal contribute to environment pollution?

## *Part II. Language Practice*

### A. Choose a, b, c, or d which best completes each item.

1. The study of petroleum pollution in the ocean deals with two .......... aspects of man's activities.
   a. opposite
   b. similar
   c. identical
   d. potential
2. Advances have been made in .......... of procedures for measurement of the contamination to marine environment.

a. the recommendation
b. the implication
c. the implementation
d. the elimination

3. The chemical .......... of this modern petroleum input often differs from that of the oil seepage.
a. interpretation
b. combustion
c. creation
d. composition

4. Modern petroleum seepage into the oceans is no longer .......... the seep locations.
a. restricted to
b. reserved for
c. received from
d. represented

5. The potential .......... of petroleum as a part of other contaminants in the marine environment is seriously considered today.
a. increase
b. impact
c. basis
d. result

6. In some .........., petroleum itself is readily seen as the recognized pollutant.
a. instants
b. constancies
c. instances
d. constructs

7. These progresses came as a result of .......... of the previous workshop.
a. the additions
b. the implementations
c. the deviations
d. the deliberations

8. Combustion of coal produces several polynuclear .......... hydrocarbons.
a. probable
b. restricted
c. altered
d. aromatic

## B. Fill in the blanks with the appropriate form of the words given.

**1. Pollution**

a. The .......... of our beaches with oil spills is serious.
b. Oil tankers release .......... into the oceans everyday.
c. Rivers are .......... with chemical waste from fact.
d. Every spot of the ocean is subject to potential .......... .

**2. Consider**

a. That is a carefully .......... decision.

b. Have you .......... how to get there?

c. Please give the matter your careful .......... .

d. He is always very .......... towards other people.

**3. Receive**

a. Your membership card will be dispatched on .......... of the completed application form.

b. He has .......... a good education.

c. .......... pronunciation refers to the standard form of language.

d. He was bought a new .......... .

**4. Restrict**

a. Fog severely .......... visibility.

b. Some families are .......... to having one child.

c. The shop sells a very .......... range of books.

d. She finds living with her aunt rather .......... .

**5. Recognize**

a. I .......... him from the photograph you showed me.

b. He has won international .......... in the field of tropical medicine.

c. He was barely .......... as the boy I had known at school.

d. He was .......... to be the lawful heir.

## C. Fill in the blanks with the following words.

| | | | |
|---|---|---|---|
| waterborne | scenarios | surface | spilled |
| proceedings | properties | analyses | actual |
| countermeasure | characterization | | |

*Spilled Oil Characterizations.* As the behavior and environmental fate of .......... oil are dependent on the physical and chemical .......... of the oil and the meteorological/oceanographic conditions, there is a need for full .......... of an authentic sample of the source of oil and a series of oil samples from the water's .......... and from oiled beaches. These oil samples will serve as reference materials for environmental .......... and also may be used in damage assessment studies and in judicial .......... . In addition, rapid analytical information should be obtained during offshore spill .......... to predict the physical, chemical, and toxicological properties of oils after being .......... and as they may impact sensitive shorelines. Offshore and shoreline .......... strategies often hinge on the knowledge of the physical properties of spilled oil, .......... and predicted.

**D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.**

a. Water samples, however, are impractical to freeze and can be solvent extracted aboard ship or preserved in the dark with a bacterial retardant (chloroform, methylene chloride, mercuric chloride, sodium azide).

b. However, care should be exercised in the choice of preservation technique. Samples obtained for multiple use in chemical and biological studies should be preserved in a manner that does not mitigate against certain measurements; e.g., sodium azide would not be acceptable for samples to be used in a variety of biochemical or physiological studies.

c. Volatilization of hydrocarbon components and microbial and photochemical oxidation of organic matter in samples are the primary concerns to be addressed in postsampling preservation.

d. All samples (sorbents, filters, sediments, tissues) should be frozen at −10° to −20°C after collection.

e. ASTM Method D 3325-78 presents a standard method for storing waterborne oil samples.

f. The effects of long-term (months to years) storage of samples under 'preserved' conditions is largely unknown, although Medeiros and Farrington (1974) determined that, after 18 months of storage of oil-spiked cod liver lipid extract, analytical results for some major hydrocarbons were unchanged.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| | | | | | |

# Geology and Earth Sciences

Geology is an extensive and growing body of knowledge; elements of its language should be acquired by all workers dealing with the layers of the earth and their contained fluids. Important topics include the history of the earth; the sedimentary processes forming shale, sandstones, and carbonate rocks; and earth surface movements creating present rock forms. The nature of the structural traps in which oil and gas deposits occur deserves study, as do possible methods of oil and gas accumulation. Knowledge of the various modes by which buoyant liquids and gases are trapped in pools helps in their location and in the confinement of fluids in artificially developed earthen storage reservoirs.

Companion earth sciences such as geophysics and geochemistry deserve the attention of engineers. The nature of temperature and pressure increases with depth within the rocks of the earth is basic information in reservoir engineering. Oil and gas science is developing through the integration of earth sciences and engineering.

## Earth Sciences

Study of the nature of the earth's crust and of its ability to accumulate petroleum under pressure is important background for the engineer in the producing branch of the natural gas industry. Geology treats all phases of the earth's history, including the processes by which reservoirs were created. It is fortunate that many of the processes that produced the earth's crust are still in evidence, permitting a reconstruction of the processes by which most reservoirs were formed.

There are several branches of geology and related earth sciences. Their nomenclature makes frequent use of such terms as *geo* earth; *petro*, rock; and *lithos*, stone; and suffixes like *-logy*, science or discourse; and *-graphy*, description. Physical geology is a study of the processes affecting the earth's surface, such as action of wind, water, ice, and atmosphere. Historical geology endeavors to trace the events in the history of the earth, including the formation of the earth's crust. The origin of life and the evolution of plant and animal forms are included. Structural geology treats the processes by which the position and shape of the various members of the earth's crust are determined, and the forces that have brought about both surface and subsurface structures. Stratigraphy covers the character, sequence relationship, distribution, and origin of sedimentary rocks.

Several branches of geology deal with the recognition of rock according to type and age. The study of rocks to determine their character and constitution is termed *lithology*. *Paleontology* and *micropaleontology* classify information about life in past geologic ages by studies of fossils and microfossils. *Mineralogy*, *petrography*, and *petrology* deal with the physical properties, chemical properties, classification, and identification of minerals or rocks and with their genesis.

*Sedimentation* is the process of depositing solids at the bottom of a fluid, and the term is frequently used to describe the deposition of particles of rock from bodies of water. Sedimentary rocks are rocks that have been deposited by this process. Essentially all petroleum is contained in sedimentary rock. *Geohydrology* or ground water geology, combines the principles governing water movement through porous media and the geology of the earth's crust with respect to the ability of the various strata to conduct water.

*Geophysics* is the application of the principles of physics to problems of the earth. The study of the transmission of shock waves generated either by natural causes, such as earthquakes, by explosions, or by machines is an example. These principles are utilized in the seismic method of searching for structures. The reflection of elastic waves at the interface between layers of rock with different physical properties permits the mapping of the interface. Other methods of making physical measurements at the earth's surface to find the nature of its subsurface employ the magnetic field, the gravitational field, and the electrical properties of the earth, principally its electric resistivity. These methods usually depend upon anomalies or irregularities in the earth's crust.

*Geochemistry* is the application of the principles of chemistry to the study of the earth. The search for petroleum by analyzing soils for hydrocarbons is considered a geochemical method. The physical chemistry of molten rock and the chemistry of its disintegration and recrystallization are included.

*Diagenesis* processes are those by which chemical reactions take place in the earth. Magnesium brine reacts with $CaCO_3$ (limestone) to form $CaMg(CO_3)_2$ (dolomite). Another example is the disintegration of shales at temperatures of 200 to 220°F (93-105°C) at the interface between normal pressure rocks and geopressured rocks. Geochemists study the steps during the conversion of organic material to oil and gas–a maturation process. The recent observation that Michigan reefs have no connate water exemplifies the need for more knowledge of the inorganic chemistry of earthen materials and for the integration of engineering and geological knowledge.

## Historical Geology

Historical geology reconstructs the successive events in the history of the earth since it was in the molten condition. Geologic time scales have been devised to indicate the periods of time during which various layers of the earth's surface were formed. The point at which cooling of the earth's surface led to water precipitation is the zero point on a geologic time scale with respect to sedimentary processes. The erosion by rain and wind of the surface that protruded and the covering of the bottom of adjacent shallow water with the eroded material is believed to be the most active process in the creating of porous rock. The uplifting of areas of the continents to permit erosion while an adjacent area was submerged required movements of the earth's crust now observed only slightly during earthquakes. The geologic time scale has received considerable attention using isotopic dating methods with accuracies of the order of ±5 percent for sedimentary rock. Carbon-14, ($C^{14}$) dating is used for relatively recent times as in archeology. The absolutes of time scale are not important to engineers.

## *Comprehension Exercises*

### A. Put "T" for true and "F" for false statements. Justify your answers.

........ 1. Geology studies earth surface movements creating present rock forms.

........ 2. The temperature within the rocks of the earth does not provide the engineers with basic information.

........ 3. Many of the processes that produced the earth's crust are not in evidence any more.

........ 4. Physical geology deals with the study of the processes influencing the earth's surface.

........ 5. Historical geology tries to study the formation of the earth's crust.

........ 6. The shapes of the earth's crust are studied in structural geology.

........ 7. The distribution of sedimentary rocks is studied in structural geology.

........ 8. In lithology, the character and constitution of rocks are studied.

........ 9. The process of depositing solids at the bottom of a fluid is termed 'petrology'.

........ 10. Sedimentary rock holds all petroleum.

## B. Choose a, b, c, or d which best completes each item.

**1.** Paleontology classifies information about life in past geologic ages by studies of .......... .

a. sandstones b. rocks
c. microfossils d. fossils

**2.** The study of the transmission of shock waves generated by earthquakes is carried out by .......... .

a. micropaleontology b. geophysics
c. stratigraphy d. petrography

**3.** The application of the principles of chemistry to the study of the earth is done by .......... .

a. geochemistry b. geology
c. lithology d. mineralogy

**4.** The creating of porous rock is done through .......... .

a. the erosion by rain and wind
b. the cooling of the earth's surface
c. the formation of the layers

d. the deposition of sediments

**5.** The geologic time scale is considered important through the usage of .......... .

a. petrological methods — b. elastic waves

c. geochemical methods — d. isotopic dating methods

**6.** The .......... of branches of geology makes use of such terms as /geo-/ and /petro-/.

a. application — b. principle

c. nomenclature — d. nomination

**7.** In order to determine the character and constitution of rocks, researchers refer to .......... .

a. paleontology — b. lithology

c. stratigraphy — d. mineralogy

**8.** Ground water geology or .......... studies water movement through porous media.

a. geohydrology — b. geophysics

c. geology — d. petrology

**9.** .......... studies the conversion of organic material to gas and oil.

a. Geochemistry — b. Geophysics

c. Lithology — d. Paleontology

## C. Write the answers to the following questions.

1. Which two branches of human knowledge contribute to the formation of oil and gas science?
2. Which branch of geology deals with the study of rocks?
3. Where is petroleum contained?
4. What topics does the geochemical method cover?
5. Which branch of geology reconstructs the successive events in the history of the earth?

**A. Translate the following passage into Persian.**

# The Geologic Characteristics of a Large $CO_2$ Accumulation

This Section discusses the geologic characteristics of a large $CO_2$ accumulation. In addition, the important factors, some serendipitous, in development of this type of resource are discussed. Some of these factors are large accumulation size, high purity of the $CO_2$ gas, excellent recovery efficiency and producibility (requiring fewer source wells), nearby fields amenable to $CO_2$ floods that had existing infrastructures (requiring the drilling of fewer drainage wells), and the development of technology that allowed the safe use of corrosive $CO_2$ in oil-field operations. Although recent oil-price declines have led to increased caution and project delays, several fields are undergoing succesful $CO_2$ floods. The $CO_2$ accumulation described in this Section is the largest of the $CO_2$ fields in the area, which could play a major role in recovering additional oil from fields in the Gulf of Mexico area. Thus, $CO_2$ accumulations in the right place and at the right time may become exploration targets in the future.

High-purity $CO_2$ occurs in central Mississippi, in an area north and east of the intrusive Jackson igneous dome (Studlick et al., 1987). Several salt-cored anticlinal and domal structures contain large volumes of $CO_2$ within the Jurassic (Kimmeridgian/Oxfordian) Buckner, Smackover, and Norphlet formations. The largest of these structures, the Pisgah anticline, has estimated reserves of more than 4 TCFG ($1.1 \times 10^{11}$ $m^3$). The Norphlet Formation contains about one-third of these reserves. Carbon dioxide for tertiary $CO_2$ floods is being transported from the Pisgah anticline to several mid-dip Cretaceous Tuscaloosa fields in southwestern Mississippi and to a Miocene field in South Louisiana.

**B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.**

1. archeology ..............................
2. conversion ..............................
3. diagenesis processes ..............................
4. elastic waves ..............................
5. erosion ..............................
6. genesis ..............................
7. isotopic dating ..............................
8. nomenclature ..............................
9. oil deposits ..............................
10. petrography ..............................
11. protruded ..............................
12. shock waves ..............................

## References


Barwis, J. H. et al. (1990). *Sandstone Petroleum Reservoirs.* New York: Berlin Heidelberg.

Board on Ocean Science and Policy (1985). *Oil in the Sea, Inputs, Fates, and Effects.* Washington DC: National Academy Press.

Craft, Benjamin C. & M. F. Hawkins (1959). *Applied Petroleum Reservoir Engineering.* Prentice-Hall.

Fox, A. F. (1984). *The World of Oil.* New York: Pergamon Press.

Katz, Donald L. & Robert L. Lee (1990). *Natural Gas Engineering: Production and Storage.* McGraw-Hill.

Koederitz, L. F. et al. (1989). *Introduction to Petroleum Reservoir Analysis.* Houston. Gulf Publishing Company.

Larsen, R. M. (Ed.) (1992). *Structural and Tectonic Modelling and Its Application to Petroleum Geology.* Amesterdam: Elsevier.

Levorsen, A. I. (1985). *Geology of Petroleum.* Delhi: CBS Publishers.

Sengbush, R. L. (1986). *Petroleum Exploration: A Quantitative Introduction.* Boston: D. Reidel Publishing Company.

Tissot, B. P. & D. H. Welte (1984). *Petroleum Formation and Occurrence.* New York: Springer-Verlag.

William, A. Gruse (1980). *Chemical Technology of Petroleum.* New York: McGraw-Hill.







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