

In a discussion of an IPS as an assessment unit, Ulmishek (1986, p. 62) states that

An IPS is purely an assessment unit; its application for other purposes is limited. As an assessment unit, however, it has significant advantages over two other such units that are widely used in practice: the play, or petroleum zone, and the basin.

He later observes (1986, figure 3D, p. 66) that when an analysis of drilling statistics is carried out by IPS, rather than by drilling depth in a basin, it becomes clear that poorly explored IPSs have potential for undiscovered commercial oil and gas accumulations.

Ulmishek's (1986) paper either states or implies several points. (1) The IPS is similar to the oil system of Dow (1974) and the hydrocarbon machine of Meissner et al. (1984) (although neither is referenced). (2) The major factors (source rock, trap, reservoir rock, and seal) are the same as the essential elements of Meissner et al. (1984). (3) All major factors are stratigraphic in nature except for trap, which is mainly structural. (4) Major factors are distinguished from processes (generation, accumulation, and preservation) when referring to the assessment unit (IPS). The process of migration is absent, and preservation is an addition when compared to Meissner et al. (1984). (5) The IPS is only considered an assessment unit. (6) The paper points to "two other such units that are widely used in practice: the play, or petroleum zone, and the basin." (7) Breaking out the drilling statistics so that new IPSs are more clearly identified is a sage observation.

Magoon's Petroleum System

Magoon (1987) first used the term *elements* to refer to source rock, migration path, reservoir rock, seal, and trap and explains that the elements "must be placed in time and space such that a petroleum deposit can occur." To identify a petroleum system, Magoon (1987) relied on oil-source rock correlation. The name of the petroleum system included the name of the source rock and major reservoir rock followed by the level of certainty. He classified the systems using certain criteria.

In Magoon (1988, table 1, p. 3), an attempt was made to put the petroleum system into historical perspective using a table that summarized the contribution of Dow (1974), Bois (1975), White (1980), Bois et al. (1982), Demaison (1984), Meissner et al. (1984), Ulmishek (1986), and Magoon (1987). The table specified the geologic parameters and evaluation criteria discussed by each author. Magoon (1988, p. 2) states that

The petroleum system emphasizes the genetic relation between a particular source rock and the resulting petroleum accumulation; basin studies emphasize structural depressions and the included sedimentary rocks regardless of the relation to any petroleum deposits; and the play or prospect approach emphasizes whether the present-day trap is detectable with available technology or tools.

The most recent definition of a petroleum system and classification scheme can be found in Magoon (1989a). The definition incorporates previous contributions and

adds new words where necessary to clarify a petroleum system. The levels of petroleum investigation (Magoon, 1989b) are introduced to distinguish the petroleum system from the sedimentary basin, play, and prospect.

Magoon and Dow's Petroleum System

The petroleum system is predicated on the synthesis of previous work (Table 1.2). The terms *sedimentary basin*, *play*, and *prospect* have been informally used by petroleum geologists prior to the advent of modern-day organic geochemistry to explain the habitat of hydrocarbons. Early work in organic geochemistry by Trask and Wu (1930), Triebs (1936), Hunt and Jamieson (1956), and Phillipi (1957) provided ways to measure and map source rocks and associated products. To understand a petroleum system, a working knowledge of petroleum geochemistry is essential.

Dow (1974) distinguished a play from the oil system based on geochemistry. Ulmishek (1986) recognized the (independent) petroliferous system as a separate unit distinct from the sedimentary basin and play. Magoon (1989b) identified the levels of petroleum investigation as basin studies, petroleum systems, plays, and prospects. The present volume refers to the sedimentary basin, petroleum system, prospect, and play.

The term petroleum system was chosen because petroleum includes all forms of hydrocarbons (solid, liquid, or gaseous) (Levorsen, 1967) and system accounts for the interdependence of the essential elements (source rock, reservoir rock, seal rock, and overburden rock) and processes (trap formation and generation-migration-accumulation of petroleum). The term has been used before by Perrodon (1980, 1983a,b) and Perrodon and Masse (1984) in a way that is consistent with our use. The term *essential elements* originates from Meissner et al. (1984) and Ulmishek (1986), and *processes* are formalized in Meissner et al. (1984) and Ulmishek (1986).

The uniqueness of a petroleum system is based on petroleum-source rock correlation and is named according to Dow (1974), whereas the *level of certainty* is according to Magoon (1987, 1988, 1989a,b). The geographic and stratigraphic distribution as well as the preservation time of the petroleum system is specified by Magoon (1988). The definition of the petroleum system used in this volume is a refinement of previous work.

PETROLEUM SYSTEM DEFINITIONS AND CHARACTERISTICS

A petroleum system is defined here as a natural system that encompasses a pod of active source rock and all related oil and gas and which includes all the geologic elements and processes that are essential if a hydrocarbon accumulation is to exist. This once-active source rock may now be inactive or spent (depleted). *Petroleum* here includes high concentrations of (1) thermal or biogenic gas found in conventional reservoirs or in gas hydrate, tight reservoirs, fractured shale, and coal; or (2) condensates, crude oils, and asphalts found in nature.

Table 1.3. Oil and Gas Fields in the Fictitious Deer–Boar(.) Petroleum System, or the Accumulations Related to One Pod of Active Source Rock

Field Name	Discovery Date	Reservoir Rock	API gravity (°API)	Cumulative Oil Production (million bbl)	Remaining Reserves (million bbl)
Big Oil	1954	Boar Ss	32	310	90
Raven	1956	Boar Ss	31	120	12
Owens	1959	Boar Ss	33	110	19
Just	1966	Boar Ss	34	160	36
Hardy	1989	Boar Ss	29	85	89
Lucky	1990	Boar Ss	15	5	70
Marginal	1990	Boar Ss	18	12	65
Teapot	1992	Boar Ss	21	9	34

The term *system* describes the interdependent elements and processes that form the functional unit that creates hydrocarbon accumulations. The essential elements include a petroleum source rock, reservoir rock, seal rock, and overburden rock, and the processes are trap formation and the generation–migration–accumulation of petroleum. These essential elements and processes must occur in time and space so that organic matter included in a source rock can be converted to a petroleum accumulation. A petroleum system exists wherever the essential elements and processes occur.

Characteristics and Limits

The geographic, stratigraphic, and temporal extent of the petroleum system is specific and is best depicted using a table (Table 1.3) and the following four figures (Figures 1.2–1.5): (1) a burial history chart depicting the critical moment, age, and essential elements at a specified location; (2) a map and (3) a cross section drawn at the critical moment depicting the spatial relationship of the essential elements; and (4) a petroleum system events chart showing the temporal relationship of the essential elements and processes and the preservation time and critical moment for the system. The table lists all the oil and gas fields in the petroleum system.

The critical moment is that point in time selected by the investigator that best depicts the generation–migration–accumulation of most hydrocarbons in a petroleum system. A map or cross section drawn at the critical moment best shows the geographic and stratigraphic extent of the system. If properly constructed, the burial history chart shows that time when most of the petroleum in the system is generated and accumulating in its primary trap. For biogenic gas, the critical moment is related to low temperatures (Whiticar, Chapter 16, this volume). Geologically, generation, migration, and accumulation of petroleum at one location usually occur over a short time span (England, Chapter 12, this volume). When included with the burial history curve, the essential elements show the function of each rock unit and lithology in the petroleum system. In the example of Figure 1.2 (using fictitious rock units), the so-called Deer Shale is the source rock, the Boar Sandstone is the

reservoir rock, the George Shale is the seal rock, and all the rock units above the Deer Shale comprise the overburden rock. The burial history chart is located where the overburden rock is thickest and indicates that the source rock started through the oil window 260 Ma in Permian time (time scale from Palmer, 1983) and was at its maximum burial depth 255 Ma. The critical moment is 250 Ma, and the time of generation, migration, and accumulation ranges from 260 to 240 Ma, which is also the age of the petroleum system.

The *geographic extent* of the petroleum system at the critical moment is defined by a line that circumscribes the pod of active source rock and includes all the discovered petroleum shows, seeps, and accumulations that originated from that pod. A plan map, drawn at the end of Paleozoic time in our example, includes a line that circumscribes the pod of active source rock and all related discovered hydrocarbons. This map best depicts the geographic extent or known extent of the petroleum system (Figure 1.3)

Stratigraphically, the petroleum system includes the following rock units or essential elements within the geographic extent: a petroleum source rock, reservoir rock, seal rock, and overburden rock at the critical moment. The functions of the first three rock units are obvious. However, the function of the overburden rock is more subtle because, in addition to providing the overburden necessary to thermally mature the source rock, it can also have considerable impact on the geometry of the underlying migration path and trap. The cross section of Figure 1.4, drawn to represent the end of the Paleozoic (250 Ma), shows the geometry of the essential elements at the time of hydrocarbon accumulation and best depicts the *stratigraphic extent* of the system.

The petroleum system *events chart* shows eight different events (Figure 1.5). The top four events record the time of deposition from stratigraphic studies of the essential elements, and the next two events record the time the petroleum system processes took place. The formation of traps is investigated using geophysical data and structural geologic analysis. The generation–migration–accumulation of hydrocarbons, or age of the petroleum system, is based on stratigraphic and petroleum geochemical studies and on the burial history

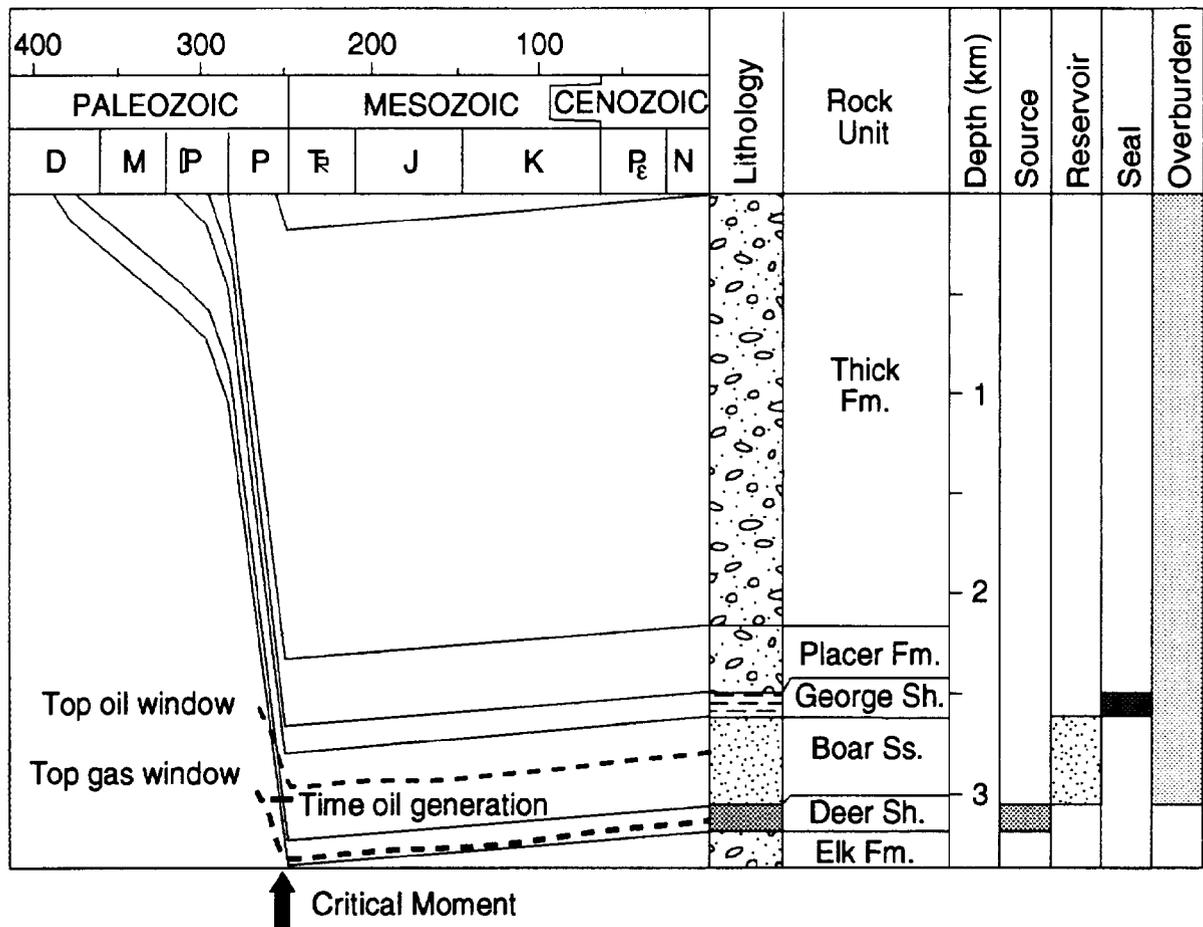


Figure 1.2. Burial history chart showing the critical moment (250 Ma) and the time of oil generation (260–240 Ma) for the fictitious Deer-Boar(.) petroleum system. This information is used on the events chart (Figure 1.5). Neogene (N) includes the Quaternary here. All rock unit names used here are fictitious. Location used for burial history chart is shown on Figures 1.3 and 1.4. (Time scale from Palmer, 1983.)

chart. These two processes are followed by the preservation time, which takes place after the generation–migration–accumulation of hydrocarbons occur, and is the time when hydrocarbons within that petroleum system are preserved, modified, or destroyed. When the generation–migration–accumulation of the petroleum system extends to the present day, there is no preservation time, and it would be expected that most of the petroleum is preserved and that comparatively little has been biodegraded or destroyed. The last event is the critical moment as determined by the investigator from the burial history chart, and it shows the time represented on the map and cross section.

Table 1.3 shows all the discovered accumulations included in the petroleum system, provides a basis for mass balance equations, and is a basis for ranking a system.

Level of Certainty

A petroleum system can be identified at three levels of certainty: known, hypothetical, or speculative. The level

of certainty indicates the confidence for which a particular pod of active source rock has generated the hydrocarbons in an accumulation. In a known petroleum system, a good geochemical match exists between the active source rock and the oil or gas accumulations. In a hypothetical petroleum system, geochemical information identifies a source rock, but no geochemical match exists between the source rock and the petroleum accumulation. In a speculative petroleum system, the existence of either a source rock or petroleum is postulated entirely on the basis of geologic or geophysical evidence. At the end of the system's name, the level of certainty is indicated by (!) for known, (.) for hypothetical, and (?) for speculative (Table 1.4).

Petroleum System Name

The name of the petroleum system includes the source rock, followed by the name of the major reservoir rock, and then the symbol expressing the level of certainty. For example, the Deer-Boar(.) is a hypothetical petroleum system consisting of the Devonian Deer Shale as the oil

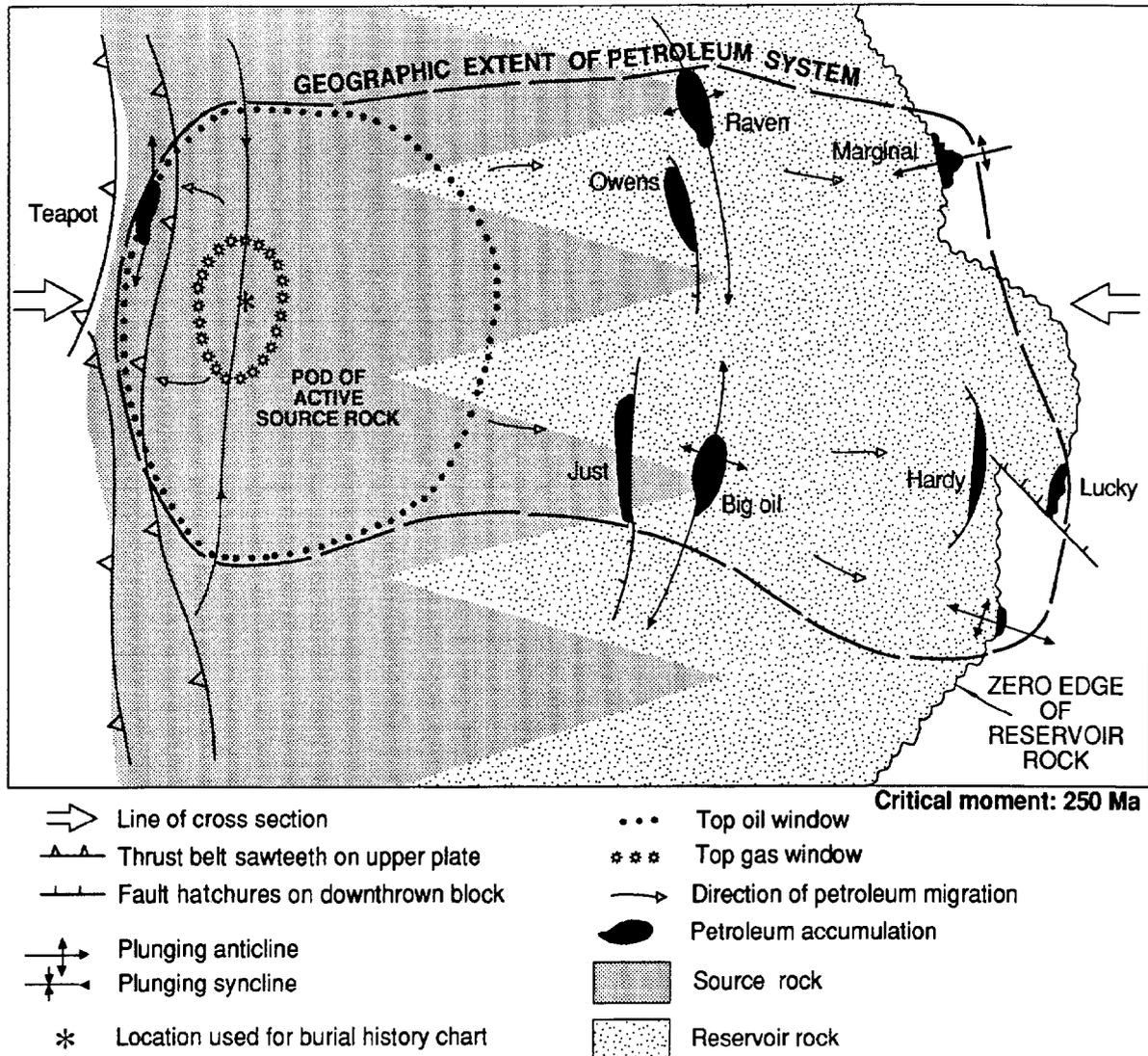


Figure 1.3. Plan map showing the geographic extent of the fictitious Deer-Boar(.) petroleum system at the critical moment (250 Ma). Thermally immature source rock is outside the oil window. The pod of active source rock lies within the oil and gas windows. (Present-day source rock maps and hydrocarbon shows are shown on Figures 5.12 and 5.13, Peters and Cassa, Chapter 5, this volume.)

source rock and the Boar Sandstone as the major reservoir rock. The major reservoir rock contains the largest volume of hydrocarbons in the petroleum system (see, e.g., La Luna-Misoa(!) petroleum system in Talukdar and Marcano, Chapter 29, this volume).

Discussion

Because our description here of a petroleum system attempts to incorporate previous work, it is written in a way that gives some words specific meanings, so that all petroleum types and occurrences are included in the definition. These specific meanings are purposely chosen to address the so-called exceptions in petroleum occurrence, such as biogenic gas and immature oil. The reader is referred to other chapters in this volume and to the

glossary for clarification of terms. Here, terms important to the petroleum system definition are discussed.

Pod of Active Source Rock

A pod of active source rock indicates that a contiguous volume of organic matter is creating petroleum, either through biological activity or temperature, at a specified time. The volume or pod of active source rock is determined by mapping the organic facies (quantity, quality, and thermal maturity) considered to be the presently active, inactive, or spent source rock using organic geochemical data displayed as geochemical logs (Peters and Cassa, Chapter 5, this volume). Organic matter generates petroleum either biologically (Whiticar, Chapter 16, this volume) or thermally (Lewan, Chapter 11). From the time a petroleum phase is created, a

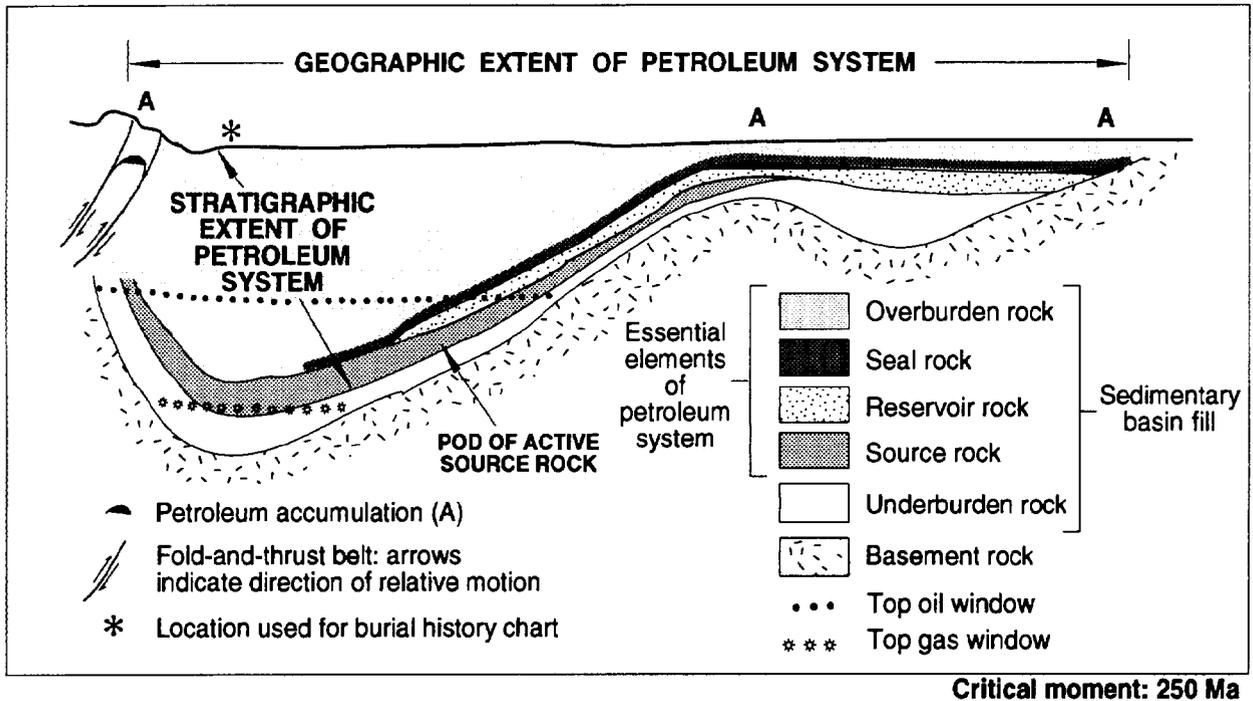


Figure 1.4. Geologic cross section showing the stratigraphic extent of the fictitious Deer-Boar(.) petroleum system at the critical moment (250 Ma). Thermally immature source rock lies updip of the oil window. The pod of active source rock is downdip of the oil window. (The present-day cross section is shown in Figure 5.12F, Peters and Cassa, Chapter 5, this volume.)

petroleum system exists. A source rock is active when it is generating this petroleum, whereas an inactive or spent source rock was at some time in the past an active source rock. For example, the Deer Shale source rock was an active source rock in Late Paleozoic time, but is presently an inactive source rock. The *pod of active source rock* is that contiguous volume of source rock that is generating gas biologically or oil and gas thermally. The active time can be present day or any time in the past.

Petroleum Synonyms

As used in this volume, the terms *petroleum*, *hydrocarbons*, and *oil and gas* are synonyms. Petroleum originally referred to crude oil, but its definition was broadened by Levorsen (1967) to include all naturally occurring hydrocarbons, whether gaseous, liquid, or solid. Geochemically, hydrocarbon compounds are those containing only hydrogen and carbon, such as aromatic or saturated hydrocarbons. Hydrocarbon compounds are in contrast to nonhydrocarbon compounds, or those containing nitrogen, sulfur, and oxygen. Hydrocarbon and nonhydrocarbon compounds are both found in crude oil and natural gas, but hydrocarbon compounds usually predominate. Over the past 10–15 years, whenever the term *hydrocarbons* has been used without modifiers, it is usually meant to be synonymous with petroleum. When *oil and gas* are used together as a term, it collectively refers to crude oil and natural gas in any proportion. *Condensate* is in a gas phase in the accumulation and in a liquid phase at the surface, but either way it is consid-

ered petroleum, as are solid petroleum materials such as natural bitumen, natural asphalt, and bituminous sands.

Major and Minor Reservoir Rocks

Major and minor reservoir rocks are determined from the percentage of in-place petroleum that originated from a particular pod of active source rock. If the volume of in-place petroleum is unavailable, recoverable hydrocarbons are the next best volume. All the discovered oil and gas fields included in a petroleum system are listed and the original in-place (recoverable) hydrocarbons are determined by stratigraphic interval. The volumes of in-place hydrocarbons for each stratigraphic interval are added up, and the percentage for each is determined. Reservoir rocks that contain minor amounts of in-place hydrocarbons are the minor reservoir rocks. Usually one stratigraphic interval contains most of the in-place hydrocarbons, so this interval is the major reservoir rock. The name of this unit is the one used in the second part of the petroleum system name.

The major reservoir rock indicates the optimum migration path for the petroleum between the pod of active source rock and the traps that include the major reservoir rock. The minor reservoir rock indicates the least effective migration path or one that should be studied for overlooked prospects. Major and minor reservoir rocks should be included on the events chart.

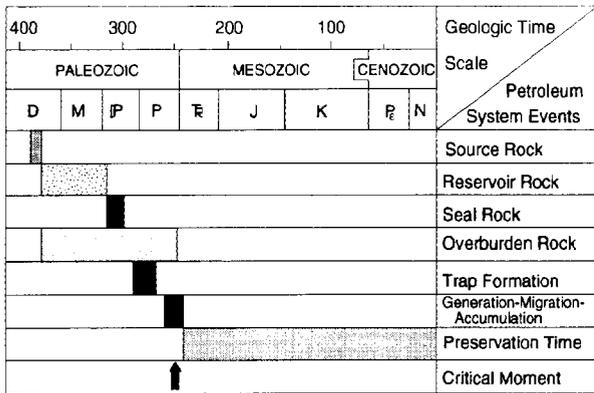


Figure 1.5. The events chart showing the relationship between the essential elements and processes as well as the preservation time and critical moment for the fictitious Deer-Boar(.) petroleum system. Neogene (N) includes the Quaternary here. (Time scale from Palmer, 1983.)

Evolution of a Petroleum System

The time of hydrocarbon generation for a petroleum system can span considerable time and cover a large area. The time span over which petroleum generation occurs can be determined for a series of locations to show how the petroleum system evolves in time and space. At given time increments within this time span, maps and cross sections can be drawn to show the kinematic evolution of the petroleum system. Knowing the age of various horizons within the overburden rock is the key to determining when and where a source rock first starts generating petroleum and when and where it finishes generating petroleum.

For example, for a petroleum system whose overburden rock has been deposited over a broad area (such as a prograding deltaic sequence), the time span over which petroleum generation–migration–accumulation occurs is quite large. If this deltaic sequence, which is the overburden rock, has prograded over a 50-m.y. period from west to east, then the underlying source rock in this petroleum system will generate petroleum first on the west and last on the east. The geologist knows that it is not always practical to show from start to finish the kinematic development of this petroleum system in 5-m.y. increments, as it would require up to 11 maps and cross sections. However, one map and cross section can be drawn to represent the time when the west end of the cross section shows the source rock at maximum burial depth, and another map and cross section can be drawn to represent the time when the east end of the cross section shows the source rock at maximum burial depth. If more detail is required to better understand how the system evolved, then additional maps and cross sections can be drawn. The critical moment is defined as a single moment because, in most instances, the exploration geologist has only enough time to construct and present one map and cross section to depict a petroleum system.

Table 1.4. Definitions of Levels of Certainty

Level of Certainty	Symbol	Criteria
Known	(!)	Oil–source rock or gas–source rock correlation
Hypothetical	(.)	In absence of petroleum–source rock correlation, geochemical evidence indicates the origin of the oil and gas
Speculative	(?)	Geologic or geophysical evidence

Preservation Time

The preservation time of a petroleum system starts after oil and gas generation, migration, and accumulation processes are complete. Processes that occur during the preservation time are remigration, physical or biological degradation, and/or complete destruction of the hydrocarbons (Blanc and Connan, Chapter 14, this volume). During the preservation time, remigrated petroleum can accumulate in traps formed after hydrocarbon generation has ceased in the petroleum system. If insignificant tectonic activity occurs during the preservation time, accumulations will remain in their original position. Remigration occurs during the preservation time only if folding, faulting, uplift, or erosion occurs. If all accumulations and essential elements are destroyed during the preservation time, then the evidence that a petroleum system existed is removed. An actively forming or just completed petroleum system is without a preservation time.

Comparison with Sedimentary Basin and Play

Aspects of the petroleum system can also be compared with the sedimentary basin and the play. If the critical moment of 250 Ma used in our example (Figure 1.4) was instead present-day, then two sedimentary basins, three plays, and one petroleum system would be shown on the map and cross section. The interface between the sedimentary rock and the basement rock on the cross section would show two lenticular bodies of sedimentary rock or two basins. The three plays that would be shown on the map and cross section are (1) a series of suspected traps along an anticlinal trend, (2) a series of suspected traps along a stratigraphic pinch-out trend, or (3) suspected traps within a stratigraphic interval. However, if all these accumulations were discovered, there would be only one petroleum system on the cross section because one pod of active source rock generated all the hydrocarbons in the discovered accumulations.