Note for Petroleum Geology Standard Knowledge System V1.0

I. Background and Objectives

To contribute to geoscience knowledge system development of the Deep-time Digital Earth (DDE) international science program, this document of Petroleum Geology Standard Knowledge System (V1.0) has now completed by the Petroleum Geology Standard Knowledge System Working Group (short for PGKG Working Group) under the Energy & Geothermal Working Group of DDE, with participant experts from SINOPEC Exploration Research Institute, Zhejiang Lab, China University of Petroleum (Beijing), Northeast Petroleum University, and China University of Geosciences (Beijing) by combined traditional way and artificial intelligence (AI) large language model technology. The document has been reviewed by professor Richard Chuchla, James Ogg and professor Mingcai Hou, Liuping Zhang, Zhongxin Cai, Jingong Zhang and Guangdi Liu respectively with revisions made.

This work aims to provide an authoritative terminology framework for scientific research, engineering, and education, and promote global interconnectivity of geological data.

II. Core Data of the Knowledge System

- **Terminology Volume**: Version 1.0 for international experts review includes 1,041 standardized terms covering core concepts of petroleum geology.
- **Terminology Sources**: Built on 287 core terms verified by experts, expanded through three iterative rounds of LLM and refined via expert review.
    - **First Round**: Expanded to 563 terms, optimized to 575 after domestic expert review;
    - **Second Round**: Terminology repository scaled to 909;
    - **Third Round**: Expanded to 1,456 terms and then rigorous manual screening reduced terms to 1,124 (discussion version), which has been reviewed by Richard Chuchla and James Ogg.
    - Following the final review, the version for submission (submitted version) comprises 1,041 terms and introduction section.
- **Quality Control**: Implemented "human-machine collaborative" review mechanisms throughout to ensure terminological accuracy and international consistency.

III. International Impact and Application Prospects

The work plans formal publication through the International Union of Geological Sciences (IUGS) Commission for the Management and Application of Geoscience Information (CGI). This system will serve as a unified global language for petroleum geology research, fostering deep integration of AI technology with traditional geology, accelerating scientific research efficiency, and enhancing interdisciplinary collaboration.

EXPLANATORY NOTES ON TERMINOLOGIES

1. **Black Text**: Terms (e.g., *oil, gas*) are widely used and defined in standard petroleum geology textbooks and numerous professional publications.

2. **Red Text**: Terms (e.g., *alkynes, low wax oil, lithological trap*) appear in only a few petroleum geology textbooks and a limited number of professional publications.

3. **Purple Text**: Terms (e.g., *Grown conventional petroleum endowmen*t) are scarcely used in petroleum geology literatures.

Terminologies defined by the Working Group of Petroleum Geology Knowledge System

For some terms, their formal definitions could not be obtained from the existing available professional publications. Furthermore, GeoGPT could not yield satisfactory definitions. As a result, a definition was given by the working group in the revised version.

Terminology Source Note

Wherever possible, terminologies in PGKS have been derived from authoritative industry sources. The AAPG Wiki, maintained by the American Association of Petroleum Geologists, has been used extensively due to its broad acceptance, expert curation, and alignment with field practice. All such references are explicitly cited.

Petroleum Geology Standard Knowledge System （V1.0）

Petroleum Geology

Petroleum geology is the science that deals with the origin, accumulation, movement, occurrence, as well as the exploration of hydrocarbon. It comprises some specific geological disciplines (source rock analysis, basin analysis, exploration stage) that are of great importance for the search of hydrocarbon.

@ Selley R C. Petroleum Geology in Encyclopedia of Physical Science and Technology (Third Edition), 2003.

1. Petroleum (hydrocarbon or oil and gas)

Petroleum is a compound that includes high concentrations of any of the following substances: (1) crude oils; (2) thermal and biological hydrocarbon gas found in conventional reservoirs as well as in gas hydrates, tight reservoirs, fractured shale, and coal; (3) condensates; (4) natural bitumen in reservoirs, most commonly in siliciclastic and carbonate rocks.
@ Petroleum system - AAPG Wiki: https://wiki.aapg.org/Petroleum_system#What_is_a_petroleum_system.3F, accessed on 11 November 2024

1.1 Oil

Oil, also known as crude oil, is a naturally occurring yellowish to black liquid mixture of mainly hydrocarbons and is found in geological formations.
@ Petroleum - Wikipedia: https://en.wikipedia.org/wiki/Petroleum, accessed on 11 November 2024

1.1.1 Elemental composition

Carbon and hydrogen are the major elements that generally constitute 97%-99% of petroleum; Minor elements include sulfur, nitrogen and oxygen and make up 1-4%; There are dozens of trace elements in oil, which include iron (Fe), calcium (Ca), magnesium (Mg), vanadium (V), and nickel (Ni).
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.1.1.1 Major elements

Major elements refer to the chemical elements which make up the bulk of the crude oil.
@ Defined by the Working Group of Petroleum Geology Knowledge System

1.1.1.1.1 Carbon

Carbon is a chemical element; it has symbol C and atomic number 6. It is nonmetallic and tetravalent—meaning that its atoms are able to form up to four covalent bonds due to its valence shell exhibiting 4 electrons. It belongs to group 14 of the periodic table. Carbon makes up about 0.025 percent of Earth's crust. Three isotopes occur naturally, ^{12}C and ^{13}C being stable, while ^{14}C

is a radionuclide, decaying with a half-life of 5,700 years. Carbon is one of the few elements known since antiquity.
@ Carbon - Wikipedia: https://en.wikipedia.org/wiki/Carbon, accessed on 5 August 2025

1.1.1.1.2 Hydrogen
Hydrogen is a chemical element; it has symbol H and atomic number 1. It is the lightest and most abundant chemical element in the universe, constituting about 75% of all normal matter. Under standard conditions, hydrogen is a gas of diatomic molecules with the formula H_2, called dihydrogen, or sometimes hydrogen gas, molecular hydrogen, or simply hydrogen. Dihydrogen is colorless, odorless, non-toxic, and highly combustible. On Earth, hydrogen is found as the gas H_2 (dihydrogen) and in molecular forms, such as in water and organic compounds. The most common isotope of hydrogen (^1H) consists of one proton, one electron, and no neutrons.
@ Hydrogen - Wikipedia: https://en.wikipedia.org/wiki/Hydrogen, accessed on 5 August 2025

1.1.1.2 Minor elements
Minor elements refer to the chemical elements which constitute a subordinate portion of the crude oil.
@ Defined by the Working Group of Petroleum Geology Knowledge System

1.1.1.2.1 Sulfur
Sulfur is a chemical element; it has symbol S and atomic number 16. It is abundant, multivalent and nonmetallic. Under normal conditions, sulfur atoms form cyclic octatomic molecules with the chemical formula S_8. Elemental sulfur is a bright yellow, crystalline solid at room temperature.
@ Sulfur - Wikipedia: https://en.wikipedia.org/wiki/Sulfur, accessed on 5 August 2025

1.1.1.2.2 Nitrogen
Nitrogen is a chemical element; it has symbol N and atomic number 7. Nitrogen is a nonmetal and the lightest member of group 15 of the periodic table, often called the pnictogens. At standard temperature and pressure, two atoms of the element bond to form N_2, a colourless and odourless diatomic gas. N_2 forms about 78% of Earth's atmosphere, making it the most abundant chemical species in air. Because of the volatility of nitrogen compounds, nitrogen is relatively rare in the solid parts of the Earth.
@ Nitrogen - Wikipedia: https://en.wikipedia.org/wiki/Nitrogen, accessed on 5 August 2025

1.1.1.2.3 Oxygen
Oxygen is a chemical element; it has symbol O and atomic number 8. It is a member of the chalcogen group in the periodic table, a highly reactive nonmetal, and a potent oxidizing agent that readily forms oxides with most elements as well as with other compounds. Oxygen is the most abundant element in Earth's crust, making up almost half of the Earth's crust in the form of various oxides such as water, carbon dioxide, iron oxides and silicates. It is the third-most abundant element in the universe after hydrogen and helium.
@ Oxygen - Wikipedia: https://en.wikipedia.org/wiki/Oxygen, accessed on 5 August 2025

1.1.1.3 Trace elements

A trace element is a chemical element of a minute quantity, a trace amount, especially used in referring to a micronutrient, but is also used to refer to minor elements in the composition of a rock, or other chemical substance.
@ Trace element - Wikipedia: https://en.wikipedia.org/wiki/Trace_element, accessed on 15 August 2025

1.1.1.3.1 Iron

Iron is a chemical element with the symbol Fe and atomic number 26. It is a metal in the first transition series. It is by mass the most common element on Earth, forming much of Earth's outer and inner core. It is the fourth most common element in the Earth's crust.
@ iron - CGI vocabularies: http://resource.geosciml.org/classifier/cgi/commodity-code/iron, accessed on 13 November 2025

1.1.1.3.2 Calcium

Calcium is a chemical element; it has symbol Ca and atomic number 20. As an alkaline earth metal, calcium is a reactive metal that forms a dark oxide-nitride layer when exposed to air. Its physical and chemical properties are most similar to its heavier homologues strontium and barium. It is the fifth most abundant element in Earth's crust, and the third most abundant metal, after iron and aluminum. The most common calcium compound on Earth is calcium carbonate, found in limestone and the fossils of early sea life; gypsum, anhydrite, fluorite, and apatite are also sources of calcium.
@ Calcium - Wikipedia: https://en.wikipedia.org/wiki/Calcium, accessed on 5 August 2025

1.1.1.3.3 Magnesium

Magnesium is a chemical element with the symbol Mg and atomic number 12. Its common oxidation number is +2. It is an alkaline earth metal and the eighth-most-abundant element in the Earth's crust and ninth in the known universe as a whole.
@ magnesium - CGI vocabularies: http://resource.geosciml.org/classifier/cgi/commodity-code/magnesium, accessed on 13 November 2025

1.1.1.3.4 Vanadium

Vanadium is a chemical element with the symbol V and atomic number 23. It is a hard, silvery gray, ductile and malleable transition metal. The element is found only in chemically combined form in nature, but once isolated artificially.
@ vanadium - CGI vocabularies: http://resource.geosciml.org/classifier/cgi/commodity-code/vanadium, accessed on 13 November 2025

1.1.1.3.5 Nickel

Nickel is a chemical element with the chemical symbol Ni and atomic number 28. It is a silvery-white lustrous metal with a slight golden tinge. Nickel belongs to the transition metals and is hard and ductile.
@ nickel - CGI vocabularies: http://resource.geosciml.org/classifier/cgi/commodity-code/nickel, accessed on 13 November 2025
@ Nickel - Wikipedia: https://en.wikipedia.org/wiki/Nickel, accessed on 5 August 2025

1.1.1.3.6 Copper

Copper is a chemical element with the symbol Cu and atomic number 29. It is a ductile metal with very high thermal and electrical conductivity. Pure copper is soft and malleable; a freshly exposed surface has a reddish-orange color. It is used as a conductor of heat and electricity, a building material, and a constituent of various metal alloys.
@ copper - CGI vocabularies: http://resource.geosciml.org/classifier/cgi/commodity-code/copper, accessed on 13 November 2025

1.1.1.3.7 Zinc

Zinc is a metallic chemical element; it has the symbol Zn and atomic number 30. It is the first element of group 12 of the periodic table. In some respects zinc is chemically similar to magnesium: its ion is of similar size and its only common oxidation state is +2. Zinc is the 24th most abundant element in the Earth's crust and has five stable isotopes.
@ zinc - CGI vocabularies: http://resource.geosciml.org/classifier/cgi/commodity-code/zinc, accessed on 13 November 2025

1.1.1.3.8 Molybdenum

Molybdenum is a Group 6 chemical element with the symbol Mo and atomic number 42. The name is from Neo-Latin Molybdaenum, from Ancient Greek Μόλυβδος molybdos, meaning lead, since its ores were confused with lead ores.
@ molybdenum - CGI vocabularies: http://resource.geosciml.org/classifier/cgi/commodity-code/molybdenum, accessed on 13 November 2025

1.1.2 Compound composition

The gross composition of a crude oil can be defined by the content of saturated hydrocarbons, aromatic hydrocarbons, and resins and asphaltenes.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.1 Principal types of hydrocarbons in crude oil

They contain saturated hydrocarbons and unsaturated hydrocarbons.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.1.1 Saturated hydrocarbons

A saturated hydrocarbon is an organic compound that contains only hydrogen and carbon. It contains only single bonds between the carbon atoms and is highly saturated with hydrogen. In a saturated hydrocarbon, all the carbon atoms are bonded to four other atoms, generally to as many hydrogen atoms as possible and hence are ‘saturated’. They include normal and branched alkanes (paraffins), and cycloalkanes (naphthenes).
@ Saturated Hydrocarbons: Definition, Formula, Types, Uses and Sample questions: https://collegedunia.com/exams/saturated-hydrocarbons-science-articleid-809, accessed on 11 November 2024
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.1.1.1 Alkanes (Paraffins)

The paraffins, often called alkanes, are saturated hydrocarbons with a general formula C_nH_{2n+2}. Normal alkanes (n-alkanes) have a straight, continuous chain of carbon atoms, whereas Branched alkanes (iso-alkanes) have a least one carbon atom connected to three or four other carbon atoms to create a branch.

@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego

1.1.2.1.1.1.1 Normal alkanes (n-alkanes)

Straight-chain alkanes are sometimes indicated by the prefix n- (for "normal") where a non-linear isomer exists. Although this is not strictly necessary and is not part of the IUPAC naming system, the usage is still common in cases where one wishes to emphasize or distinguish between the straight-chain and branched-chain isomers, e.g., "n-butane" rather than simply "butane" to differentiate it from isobutane. Alternative names for this group used in the petroleum industry are linear paraffins or n-paraffins.

@ Alkane - Wikipedia: https://en.wikipedia.org/wiki/Alkane, accessed on 13 June 2025

1.1.2.1.1.1.2 Branched alkanes (iso-alkanes)

Simple branched alkanes often have a common name using a prefix to distinguish them from linear alkanes, for example n-pentane, isopentane, and neopentane.

@ Alkane - Wikipedia: https://en.wikipedia.org/wiki/Alkane#Branched_alkanes, accessed on 13 June 2025

1.1.2.1.1.2 Cycloalkanes (Naphthenes)

The second major group of hydrocarbons found in crude oils are the naphthenes or cycloalkanes. The carbon atoms form closed rings with only single bonds between them. This group has a general formula C_nH_{2n}.

@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego

1.1.2.1.2 Unsaturated hydrocarbons

An unsaturated hydrocarbon is an organic compound in which a at least one carbon-carbon bond is double (C=C) or triple. These bonds reduce the number of hydrogen atoms attached to the carbon chain, hence the hydrocarbon is ‘unsaturated’. Unsaturated types include alkenes, aromatics and alkynes.

@ McMurry, J., 2015. Organic Chemistry (9th edition), Cengage Learning.

1.1.2.1.2.1 Alkenes (Olefins)

Alkene: A group of unsaturated hydrocarbons with the chemical formula C_nH_{2n} that contain one or more double bonds, including typical compounds such as ethylene (ethene, C_2H_4) and propylene (propene, C_3H_6). These compounds are not typically found in natural petroleum or crude oil.

@ McMurry, J., 2015. Organic Chemistry (9th edition), Cengage Learning.

1.1.2.1.2.2 Aromatics

Aromatics are defined as cyclic compounds satisfying Huckel’s Rule. Their distinctive features include: typically unreactive, often non polar and hydrophobic, and high carbon-hydrocarbon ratio.

@ Aromatic compound - Wikipedia: https://en.wikipedia.org/wiki/Aromatic_compound, accessed on 5 August 2025

1.1.2.1.2.2.1 Monoaromatics

Any compound having a single aromatic ring, especially such a constituent of petroleum.
@ Monoaromatics - Wikipedia: https://en.wiktionary.org/wiki/monoaromatic, accessed on 13 June 2025
@ Liao J, Lu H, and Sheng G Y, et al., 2015. Monoaromatic, Diaromatic, Triaromatic, and Tetraaromatic Hopanes in Kukersite Shale and Their Stable Carbon Isotopic Composition. Energy Fuels, 29(6), 3573–3583.

1.1.2.1.2.2.2 Diaromatics

Any compound having two aromatic (typically benzene) rings.
@ Diaromatics - Wikipedia: https://en.wiktionary.org/wiki/diaromatic, accessed on 13 June 2025
@ Liao J, Lu H, and Sheng G Y, et al., 2015. Monoaromatic, Diaromatic, Triaromatic, and Tetraaromatic Hopanes in Kukersite Shale and Their Stable Carbon Isotopic Composition. Energy Fuels, 29(6), 3573–3583.

1.1.2.1.2.2.3 Triaromatics

Any compound having three aromatic (typically benzene) rings.
@ Triaromatics - Wikipedia: https://en.wiktionary.org/wiki/triaromatic, accessed on 13 June 2025
@ Liao J, Lu H, and Sheng G Y, et al., 2015. Monoaromatic, Diaromatic, Triaromatic, and Tetraaromatic Hopanes in Kukersite Shale and Their Stable Carbon Isotopic Composition. Energy Fuels, 29(6), 3573–3583.

1.1.2.1.2.2.4 Polyaromatics

A polycyclic aromatic hydrocarbon (PAH) is any member of a class of organic compounds that is composed of multiple fused aromatic rings. PAHs are uncharged, non-polar and planar. Many are colorless. Many of them are also found in fossil fuel deposits such as coal and in petroleum.
@ Polycyclic aromatic hydrocarbon - Wikipedia: https://en.wikipedia.org/wiki/Polycyclic_aromatic_hydrocarbon, accessed on 13 June 2025

1.1.2.1.2.3 Alkynes

In natural science, alkynes are the unsaturated hydrocarbons having something like a triple connection between carbon-carbon particles (- C≡C-). The general formula of this unsaturated hydrocarbon is C_nH_{2n-2}, where n-2, 3, 4, 5…Alkynes are customarily known as acetyls. Like other hydrocarbons, alkynes are additionally hydrophobic.
@ alkynes definition structure preparation properties - geeksforgeeks: https://www.geeksforgeeks.org/alkynes-definition-structure-preparation-properties/, accessed on 8 August 2025

1.1.2.2 Sulfur compounds

The averages sulfur content of crude oils, based on 9347 samples is 0.65% by weight. The distribution is bimodal with a minimum at 1% separating: low sulfur crude oils containing less than 1% sulfur and high sulfur crude oils containing more than 1% sulfur. Sulfur is the third most abundant atomic constituent of crude oils following carbon and hydrogen. It is present in medium as well as in heavy fractions of crude oils. in the low and medium molecular weight range (up to

C_{25}) sulfur is associated only with carbon and hydrogen. In the heavier fractions of crude oils, it is frequently incorporated in large polycyclic molecules comprising N, S O.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.2.1 Thiols (Mercaptans)
Thiols can be thought of as derived from hydrogen sulfide, by substitution of an alkyl or cycloalkyl radical to a hydrogen atom. They are the sulfur equivalent of an alcohol. Mercaptans naturally occur in crude oil and natural gas. Normal and isoalkanethiols, cyclopentanethiol and cyclohexanethiol have been found in petroleum. Aromatic thiols have not been reported. Most thiols have a low molecular weight (less than 8 carbon atoms). The most abundant in Wasson crude oil, Texas, is ethanethiol and amounts only to 0.0053% by weight of the crude.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.2.2 Sulfides
Hydrogen sulfide (H_2S) occurs in the subsurface both as free gas and, because of its high solubility, in solution with oil and brine. It is a poisonous, foul-smelling and explosive gas, whose presence causes operational problems in both oil and gas fields. It is highly corrosive to steel, quickly attacking production pipes, valves, and flowlines. Its presence necessitates the use of metallurgically resistant ("sour service") tubulars and valves.
@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego

1.1.2.2.3 Thiophenes
Thiophene can be described as an unsaturated 5-membered ring, comprising one sulfur and four carbon atoms. In many respects (e.g., chromatography), the thiophene ring behaves like a benzene ring. Thiophene itself is generally very scarce, but benzothiophenes, dibenzothiophenes, and benzonaphthothiophenes (comprising one thiophene ring and 1, 2, or 3 benzene rings, respectively) are important constituents of all high-sulfur crude oils. They are present in small amounts in low-sulfur crude oils.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.3 Nitrogen compounds
Nitrogen content is usually much lower than sulfur content in crude oils: about 90% of the crudes contain less than 0.2% of nitrogen. The main part of nitrogen is found in high molecular weight and high boiling point fraction.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.3.1 Pyridines
Pyridines (C_5H_5N) are a general type of nitrogen compounds frequently found in the distillates of crude oil.
@ Haliburton, 2001. Basic Petroleum Geology, Haliburton

1.1.2.3.2 Quinolines

Quinolines (C_9H_7N) are nitrogen compounds found in the distillates of crude oil.

@ Haliburton, 2001. Basic Petroleum Geology, Haliburton

1.1.2.3.3 Carbazoles

Carbazole is an aromatic heterocyclic organic compound composed of two benzene rings fused on either side of a five-membered nitrogen-containing ring and is commonly found in crude oils. These can as a geochemical migration tracer molecule with the potential to supplement the existing suite of hydrocarbon targets for fine-tuning the source tracking of petroleum spills.

@ Oil spill - Wikipedia: https://en.wikipedia.org/wiki/Oil_spill, accessed on 8 August 2025

@ Terken J M J and Frewin N L, 2020. The Dhahaban Petroleum System of Oman, AAPG Bulletin, V. 84, No. 4, P. 523–544

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

1.1.2.4 Oxygen compounds

The most important groups of oxygen containing compounds are acids, which seem to be a common constituent in young and immature crude oils.

@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.4.1 Phenols

Phenols and alcohols can be thought of as organic derivatives of water in which one of the water's hydrogens is replaced by an organic group: H-O-H versus R-O-H, such as a benzene ring in the case of a simple phenol. Phenols occur widely throughout nature.

@ McMurry, J., 2015. Organic Chemistry (9th edition), Cengage Learning

1.1.2.4.2 Carboxylic acids

Compounds called carboxylic acids, which contain a $-CO_2H$ grouping, occur abundantly in all living organisms and are involved in almost all metabolic pathways. Acetic acid, pyruvic acid, and citric acid are examples.

@ McMurry, J., 2015. Organic Chemistry (9th edition), Cengage Learning

1.1.2.5 High Molecular Weight N. S .O Compounds: resins and asphaltenes

High molecular weight constituents of crude oils usually contain N, S and O compounds. They are referred to as resins and asphaltenes. Asphaltenes and most resins are complex molecular arrangements made of polycyclic aromatic or naphthenoaromatic nuclei with chains and heteroatoms (O, N, S).

@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.5.1 Resins

Resins are made of the high molecular weight polycyclic fraction of crude oils comprising N, S and O atoms. They are more soluble than asphaltenes, but are strongly retained on silica gel when performing liquid chromatography.

@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.5.2 Asphaltenes

Asphaltenes are made of the high molecular weight polycyclic fraction of crude oils comprising N, S and O atoms. They are insoluble in light alkanes and thus precipitate with n-hexane.

@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.6 Organometallic compounds

Crude oils contain metals, particularly nickel and vanadium in variable amounts from less than 1 ppm in some Paleozoic crudes from Algeria and the USA, up to 1200ppm vanadium and 150ppm nickel in Boscan crude from Venezuela.

@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.6.1 Metals in crude oil

Vanadium and nickel seem definitely to be the most abundant metals in crude oil. Other metals such as iron, zinc, copper, lead, arsenic, molybdenum, cobalt, manganese chromium, etc. have also been reported.

@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.2.6.2 Porphyrins

Porphyrins are characterized by a tetrapyrrolic nucleus, probably inherited from chlorophyll or hemin. Besides nitrogen they contain oxygen and a metal which is usually vanadium or nickel; iron and copper are also reported.

@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.3 Physical properties of oils

A physical property is any property that is measurable, characterizing the state of a physical system. Physical properties of oil include color, specific gravity, viscosity, fluorescence, rotary polarization, solubility, electrical conductivity, density, and pour point.

@ Physical property - Wikipedia: https://en.wikipedia.org/wiki/Physical_property, accessed on 10 March 2025

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.1.3.1 Color

In appearance, oils vary from straw yellow, green, and brown to dark brown or black in color.

@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego

1.1.3.2 Specific gravity

It is the ratio of the density of oil at 20℃ to that of water at 4℃. The specific gravity of petroleum typically ranges from 0.76 to 1.0.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.1.3.3 API gravity

API gravity is a convenient scale of the American Petroleum Institute (API) that is inversely related to the density of liquid petroleum. API gravity = 141.5/specific gravity at 60°F (15.6℃) - 131.5. API gravity of petroleum typically ranges from 35 °(Light oil) to 15 °(Heavy oil).

@ Peters, Kenneth E, David J C, et al., 2012. An overview of basin and petroleum system modeling: Definitions and concepts, Basin modeling: New horizons in research and applications: AAPG Hedberg Series, 4, 1-16.

@ API gravity - AAPG Wiki: https://wiki.aapg.org/API_gravity, accessed on 10 November 2024

1.1.3.4 Viscosity

It is a measure of oil's resistance to gradual deformation by shear stress at a given rate. It varies with the abundance of non-hydrocarbons such as nitrogen, oxygen and sulfur and temperature and pressure. The units are centipoise (cP). At 20℃, water has a viscosity of 1 cP; Light oil is typically 20 to 100 cP, Heavy oil is typically 1000 to 10,000 cP, and honey is typically 10,000 cP.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.1.3.5 Fluorescence

Under ultraviolet light, oil emits fluorescence, which results from poly-aromatics and NSO compounds. Saturated HCs do not fluoresce.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.1.3.6 Rotary polarization

It results from presence of compounds with asymmetric molecular structures, such as cholesterol.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.1.3.7 Solubility

Oil is soluble in organic solvents but has a very low solubility in water. Solubility varies as a function of parameters such as temperature and pressure.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.1.3.8 Pour point

It is the temperature at which a liquid becomes semi solid and loses its flow characteristics. The pour points for medium crude oil ranges from -30℃ to +30℃.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.1.3.9 Surface tension

Surface tension is the tendency of liquid surfaces at rest to shrink into the minimum surface area possible. Surface tension is what allows objects with a higher density than water such as razor blades and insects (e.g. water striders) to float on a water surface without becoming even partly submerged. At liquid–air interfaces, surface tension results from the greater attraction of liquid

molecules to each other (due to cohesion) than to the molecules in the air (due to adhesion).
@ Surface tension - Wikipedia, https://en.wikipedia.org/wiki/Surface_tension, accessed on 5 August 2025

1.1.3.10 Thermal conductivity

Thermal conductivity (λ, in units of W/(m K)) is a physical quantity that defines the amount of heat that flows through a specific medium over a certain distance during a given time increment, if there is a temperature gradient. At 20℃, the typical thermal conductivity of medium crude oil of 0.15 to 0.2 W/(m K) makes it a superior insulator to that of that of water with 0.6 W/(m K).
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.3.11 Electrical conductivity

Electrical conductivity (or specific conductance) is the reciprocal of electrical resistivity. It represents a material's ability to conduct electric current. It is commonly signified by the Greek letter σ (sigma), but κ (kappa) (especially in electrical engineering) and γ (gamma) are sometimes used. The SI unit of electrical conductivity is siemens per metre (S/m). Resistivity and conductivity are intensive properties of materials, giving the opposition of a standard cube of material to current. Electrical resistance and conductance are corresponding extensive properties that give the opposition of a specific object to electric current.
@ Electrical conductivity - Wikipedia:
https://en.wikipedia.org/wiki/Electrical_resistivity_and_conductivity, accessed on 6 August 2025

1.1.3.12 Boiling point range

The boiling point of a substance is the temperature at which the vapor pressure of a liquid equals the pressure surrounding the liquid and the liquid changes into a vapor.
@ Boiling point range - Wikipedia: https://en.wikipedia.org/wiki/Boiling_point, accessed on 6 August 2025

1.1.3.13 Flash point

The flash point of a material is the lowest liquid temperature at which, under certain standardized conditions, a liquid gives off vapours in a quantity such as to be capable of forming an ignitable vapour/air mixture.
@ Flash point - Wikipedia: https://en.wikipedia.org/wiki/Flash_point, accessed on 6 August 2025

1.1.3.14 Cloud point

The cloud point corresponds to the appearance of a cloud of wax (paraffin) crystals when the oil is chilled. The cloud point for light crude oil is around 0℃ and heavy oil may exceed 30℃.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.1.3.15 Refractive index

In optics, the refractive index (or refraction index) of an optical medium is the ratio of the apparent speed of light in the air or vacuum to the speed in the medium.

@ Refractive index - Wikipedia: https://en.wikipedia.org/wiki/Refractive_index, accessed on 6 August 2025

1.1.3.16 Interfacial tension

Interfacial tension is the force that acts at the interface between two immiscible phases (liquid-liquid or gas-liquid), resulting from unbalanced attractive forces, and largely determines the flow behavior of a polyphasic fluid system by producing a pressure difference across the interface. Interfacial tension directly affects crude oil's extractability, processing efficiency, environmental behavior, and interaction with geological formations.

@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

@ Haliburton, 2001. Basic Petroleum Geology, Haliburton

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 3 August 2025

1.1.3.17 Compressibility

Compressibility is a measure of the relative volume change (volumetric strain) of a fluid or solid in response to a pressure or mean stress change, taking into account the degree of severity of the formation, the change in volume of oil when lifted from the reservoir to the stock tank, and the effects of time, temperature, and the compressibility of the mineral grains and the bulk material. Crude oil typically expands by ~1–4% when raised from a 3 km depth to the surface.

@ Chapman R E, 1983. Petroleum Geology, Elsevier, Amsterdam.

@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 3 August 2025

1.1.3.18 Heat capacity

Heat capacity or thermal capacity is a physical property of matter, defined as the amount of heat to be supplied to an object to produce a unit change in its temperature. The SI unit of heat capacity is joule per kelvin (J/K). It quantifies the ability of a material or system to store thermal energy.

@ Heat capacity - Wikipedia: https://en.wikipedia.org/wiki/Heat_capacity, accessed on 13 June 2025

1.1.4 Oil types

They refer to how oil is classified into different types based on different criteria.

@ Defined by the Working Group of Petroleum Geology Knowledge System

1.1.4.1 Oil types based on API gravity

Oil is classified into different types on basis of API gravity.

@ Defined by the Working Group of Petroleum Geology Knowledge System

1.1.4.1.1 Heavy/heavy crude oils

Oils with API gravity of less than 25^{o}.

@ Peters, Kenneth E, David J C, et al., 2012. An overview of basin and petroleum system

modeling: Definitions and concepts, Basin modeling: New horizons in research and applications: AAPG Hedberg Series, 4, 1-16.
@ API gravity - AAPG Wiki: https://wiki.aapg.org/API_gravity, accessed on 10 March 2025

1.1.4.1.1.1 Heavy oil
Mobile oils with API gravity of less than 25^o and viscosity of 10-100cP
@ EXTRA HEAVY OILS IN THE WORLD ENERGY SUPPLY: https://oilproduction.net/files/extra-heavy-oils-in-the-world-energy-supply.pdf, accessed on 10 March 2025

1.1.4.1.1.2 Extra-heavy oil
Mobile oils with API gravity of less than 20^o and viscosity of 100-10,000cP
@ EXTRA HEAVY OILS IN THE WORLD ENERGY SUPPLY: https://oilproduction.net/files/extra-heavy-oils-in-the-world-energy-supply.pdf, accessed on 10 March 2025

1.1.4.1.1.3 Oil sand-bitumen
Non-mobile oils with API gravity of 7-12^o and viscosity of more than 10,000cP
@ EXTRA HEAVY OILS IN THE WORLD ENERGY SUPPLY: https://oilproduction.net/files/extra-heavy-oils-in-the-world-energy-supply.pdf, accessed on 10 March 2025

1.1.4.1.2 Medium/medium crude oils
Oils with API gravity of 25 to 35^o.
@ Peters, Kenneth E, David J C, et al., 2012. An overview of basin and petroleum system modeling: Definitions and concepts, Basin modeling: New horizons in research and applications: AAPG Hedberg Series, 4, 1-16.
@ API gravity - AAPG Wiki: https://wiki.aapg.org/API_gravity, accessed on 10 March 2025

1.1.4.1.3 Light/light crude oils
Oils with API gravity of 35 to 45^o.
@ Peters, Kenneth E, David J C, et al., 2012. An overview of basin and petroleum system modeling: Definitions and concepts, Basin modeling: New horizons in research and applications: AAPG Hedberg Series, 4, 1-16.
@ API gravity - AAPG Wiki: https://wiki.aapg.org/API_gravity, accessed on 10 March 2025

1.1.4.2 Oil types based on sulfur content
Oil is classified into different types on basis of abundance of chemical element of sulfur.
@ Defined by the Working Group of Petroleum Geology Knowledge System

1.1.4.2.1 High sulfur oil (Sour crude)
Sour crude oil is crude oil containing a high amount of the impurity sulfur. It is common to find crude oil containing some impurities. When the total sulfur level in the oil is more than 0.5% (by weight), the oil is called "sour".
@Sour crude - Wikipedia: https://en.wikipedia.org/wiki/Sour_crude_oil, accessed on 10 March 2025

1.1.4.2.2 Low sulfur oil (Sweet Crude)
Sweet crude oil is a type of petroleum. The New York Mercantile Exchange designates petroleum with less than 0.5% sulfur as sweet.
@Sweet crude - Wikipedia: https://en.wikipedia.org/wiki/Sweet_crude_oil, accessed on 10 March 2025

1.1.4.3 Oil types based on wax content
Oil is classified into different types on basis of abundance of wax in the crude oil.
@ Defined by the Working Group of Petroleum Geology Knowledge System

1.1.4.3.1 High wax oil
High wax crude oil typically contains more than 10% paraffin wax content. These are most common in terrestrial or lacustrine source rocks and might require heated pipelines or chemical additives for transport.
@ Defined by the Working Group of Petroleum Geology Knowledge System

1.1.4.3.2 Low wax oil
Low wax crude oil typically contains less than 5% paraffin wax content.
@ Defined by the Working Group of Petroleum Geology Knowledge System

1.1.4.4 Oil types based on extraction challenges
Oil is classified into different types on basis of technologies extracting the oil.
@ Defined by the Working Group of Petroleum Geology Knowledge System common sense terms

1.1.4.4.1 Conventional oil
Conventional oil refers to the oil which can be extracted using traditional drilling and pumping methods.
@ Petroleum reservoir - Wikipedia: https://en.wikipedia.org/wiki/Petroleum_reservoir, accessed on 10 March 2025

1.1.4.4.2 Unconventional oil
Unconventional oil is petroleum produced or extracted using techniques other than the conventional methods. It includes tight oil, shale oil, oil sands, extra-heavy oil, oil shale, coal-to-liquid, and gas-to-liquid.
@ Petroleum - Wikipedia: https://en.wikipedia.org/wiki/Petroleum, accessed on May 6 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

1.1.4.4.2.1 Tight oil
Tight oil is a type of unconventional petroleum accumulation in low permeability rocks that occurs throughout a large area and is not significantly affected by hydrodynamic influences (also called "continuous-type deposit"). Such accumulations lack the porosity and permeability of conventional reservoirs which flow without stimulation at economic rates.
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

1.1.4.4.2.2 Shale oil

Shale oil is a sub-type of tight oil where the lithologies are predominantly shales or siltstones.

@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

1.1.4.4.2.3 Oil sands-bitumen

Non-mobile oils with API gravity of 7-12^o and viscosity of more than 10,000cP

@ EXTRA HEAVY OILS IN THE WORLD ENERGY SUPPLY: https://oilproduction.net/files/extra-heavy-oils-in-the-world-energy-supply.pdf, accessed on 10 March 2025

1.1.4.4.2.4 Extra-heavy oils

Mobile oils with API gravity of less than 20^o and viscosity of 100-10,000cP

@ EXTRA HEAVY OILS IN THE WORLD ENERGY SUPPLY: https://oilproduction.net/files/extra-heavy-oils-in-the-world-energy-supply.pdf, accessed on 10 March 2025

1.1.4.4.2.5 Oil shale

An oil shale is defined as a fine-grained sedimentary rock that contains a high proportion of endogenous organic matter (kerogen) mostly insoluble in ordinary petroleum solvents, from which substantial amounts of synthetic oil and/or gas can be extracted by heating it to a sufficiently high temperature, a process called retorting. Oil shales have a low calorific value and high ash and mineral content.

@ Oil shale - AAPG Wiki: https://wiki.aapg.org/Oil_shale, accessed on 8 August 2025

1.1.4.4.2.6 Coal-to-liquid (CTL)

Coal liquefaction is a chemical process that converts solid coal into liquid hydrocarbons, including synthetic fuels and petrochemicals. Often referred to as "coal-to-liquids" (CTL) or more broadly "carbon-to-X" (where X represents various hydrocarbon-based products), coal liquefaction offers an alternative to conventional petroleum-derived fuels. The process can be classified into two main approaches: direct liquefaction (DCL) and indirect liquefaction (ICL).

@ Takao Kaneko, Frank Derbyshire, Eiichiro Makino, David Gray, Masaaki Tamura, Kejian Li (2012). "Coal Liquefaction". Ullmann's Encyclopedia of Industrial Chemistry. Weinheim: Wiley-VCH. doi:10.1002/14356007.a07_197. pub2. ISBN 978-3-527-30673-2

1.1.4.4.2.6.1 Direct liquefaction CTL

Coal is dissolved in solvents under high pressure and temperature, often with hydrogen addition, to break down complex molecules into liquid fuels.

@ Coal liquefaction - Wikipedia: https://en.wikipedia.org/wiki/Coal_liquefaction, accessed on 6 August 2025

1.1.4.4.2.6.2 Indirect liquefaction CTL

Coal is first gasified to produce syngas (a mix of carbon monoxide and hydrogen), which is then catalytically processed into liquid hydrocarbons (e.g., Fischer-Tropsch synthesis).

@ Coal liquefaction - Wikipedia: https://en.wikipedia.org/wiki/Coal_liquefaction, accessed on 9 August 2025

1.1.4.4.2.7 Gas-to-liquid (GTL)
Gas to liquids (GTL) is a refinery process to convert natural gas or other gaseous hydrocarbons into longer-chain hydrocarbons, such as gasoline or diesel fuel. Methane-rich gases are converted into liquid synthetic fuels.
@ Gas to liquids - Wikipedia: https://en.wikipedia.org/wiki/Gas_to_liquids, accessed on 9 August 2025.

1.2 Gas
In a broad sense, natural gas refers to any gas occurring in nature. Natural gas in the vernacular of petroleum geology refers to flammable gas, which is related to oil or gas fields. It is dominated by hydrocarbons but may contain significant amounts of non-hydrocarbon gases such as CO_2, H_2S, nitrogen and helium.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.2.1 Chemical composition
A chemical composition specifies the identity, arrangement, and ratio of the chemical elements making up a compound by way of chemical and atomic bonds.
@ Chemical composition - Wikipedia: https://en.wikipedia.org/wiki/Chemical_composition, accessed on 15 August 2025

1.2.1.1 Methane
Methane is the simplest of all the hydrocarbons and is also the most stable.
@ Haliburton, 2001. Basic Petroleum Geology, Haliburton

1.2.1.2 Ethane
Ethane (C_2H_6) is the second member of the alkane series, consisting of two carbon atoms and six hydrogen atoms. It is a stable hydrocarbon with the maximum permitted number of hydrogen atoms, following the chemical formula C_nH_{2n+2}, where n is the number of carbon atoms. Ethane is typically present in concentrations less than 0.1 percent, with heavier hydrocarbon gases found only in trace amounts.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA
@ Chapman R E, 1983. Petroleum Geology, Elsevier, Amsterdam.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

1.2.1.3 Propane
Propane (C_3H_8) is a natural gas of the methane series
@ Link P K, 1987. Basic Petroleum Geology 2nd edition), OGCI Publications, Oil & Gas Consultants International, Inc., Tulsa

1.2.1.4 Butanes
Butane (C_4H_{10}) is a paraffinic hydrocarbon gas of composition.
@ Link P K, 1987. Basic Petroleum Geology (2nd edition), OGCI Publications, Oil & Gas Consultants International, Inc., Tulsa

1.2.1.5 Pentanes

Pentane (C_5H_{12}) is a straight-chain alkane hydrocarbon gas.
@ McMurry, J., 2015. Organic Chemistry (9th edition), Cengage Learning

1.2.1.6 Heavier hydrocarbons

Hexane, Heptane, Octane, etc. are named after the number of carbon atoms in the straight-chain alkane hydrocarbon gas or liquid.
@ McMurry, J., 2015. Organic Chemistry (9th edition), Cengage Learning

1.2.1.7 Non-hydrocarbon components

Non-hydrocarbon components are those substances associated with the production of natural gas that are not composed of hydrocarbons, such as helium or sulfur. If these components are removed before the reference point and subsequently marketed separately, they are included in the extraction quantities (e.g., raw production) from the reservoir, but are not included in reserves.
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

1.2.1.7.1 Carbon dioxide

Carbon dioxide is a chemical compound with the chemical formula CO_2. It is made up of molecules that each have one carbon atom covalently double bonded to two oxygen atoms. It is found in a gas state at room temperature and at normally-encountered concentrations it is odorless. As the source of carbon in the carbon cycle, atmospheric CO_2 is the primary carbon source for life on Earth. In the air, carbon dioxide is transparent to visible light but absorbs infrared radiation, acting as a greenhouse gas. Carbon dioxide is soluble in water and is found in groundwater, lakes, ice caps, and seawater.
@ Carbon dioxide - Wikipedia: https://en.wikipedia.org/wiki/Carbon_dioxide, accessed on 5 August 2025

1.2.1.7.2 Hydrogen sulfide

Hydrogen sulfide (H_2S) occurs in the subsurface both as free gas and, because of its high solubility, in solution with oil and brine. It is a poisonous, foul-smelling gas, whose presence causes operational problems in both oil and gas fields. It is highly corrosive to steel, quickly attacking production pipes, valves, and flowlines. Gas or oil containing significant traces of hydrogen sulfide is referred to as sour—in contrast to sweet, which refers to oil or gas without hydrogen sulfide.
@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego

1.2.1.7.3 Nitrogen

Nitrogen is a chemical element; it has symbol N and atomic number 7. Nitrogen is a nonmetal and the lightest member of group 15 of the periodic table, often called the pnictogens. At standard temperature and pressure, two atoms of the element bond to form N_2, a colourless and odourless diatomic gas. N_2 forms about 78% of Earth's atmosphere, making it the most abundant chemical species in air. Because of the volatility of nitrogen compounds, nitrogen is relatively rare in the solid parts of the Earth.
@ Nitrogen - Wikipedia: https://en.wikipedia.org/wiki/Nitrogen, accessed on 5 August 2025

1.2.1.7.4 Helium

Helium is a common constituent of natural petroleum accumulations and due to its mobility, chemical inertness, and abiogenic nature, it forms a very good indirect geochemical marker.
@ Surficial geochemistry and hydrocarbon detection methods - AAPG Wiki: https://wiki.aapg.org/Surficial_geochemistry_and_hydrocarbon_detection_methods, accessed on 5 March 2025

1.2.1.7.5 Argon

Argon is a chemical element; it has symbol Ar and atomic number 18. It is in group 18 of the periodic table and is a noble gas.[10] Argon is the third most abundant gas in Earth's atmosphere, at 0.934% (9340 ppmv). It is more than twice as abundant as water vapor (which averages about 4000 ppmv, but varies greatly), 23 times as abundant as carbon dioxide (400 ppmv), and more than 500 times as abundant as neon (18 ppmv). Argon is the most abundant noble gas in Earth's crust, comprising 0.00015% of the crust.
@ Argon - Wikipedia: https://en.wikipedia.org/wiki/Argon, accessed on 5 August 2025

1.2.1.7.6 Hydrogen

Hydrogen is a chemical element; it has symbol H and atomic number 1. It is the lightest and most abundant chemical element in the universe, constituting about 75% of all normal matter. Under standard conditions, hydrogen is a gas of diatomic molecules with the formula H_2, called dihydrogen, or sometimes hydrogen gas, molecular hydrogen, or simply hydrogen. Dihydrogen is colorless, odorless, non-toxic, and highly combustible. On Earth, hydrogen is found as the gas H_2 (dihydrogen) and in molecular forms, such as in water and organic compounds. The most common isotope of hydrogen (^{1}H) consists of one proton, one electron, and no neutrons.
@ Hydrogen - Wikipedia: https://en.wikipedia.org/wiki/Hydrogen, accessed on 5 August 2025

1.2.1.7.7 Oxygen

Oxygen is a chemical element; it has symbol O and atomic number 8. It is a member of the chalcogen group in the periodic table, a highly reactive nonmetal, and a potent oxidizing agent that readily forms oxides with most elements as well as with other compounds. Oxygen is the most abundant element in Earth's crust, making up almost half of the Earth's crust in the form of various oxides such as water, carbon dioxide, iron oxides and silicates. It is the third-most abundant element in the universe after hydrogen and helium.
@ Oxygen - Wikipedia: https://en.wikipedia.org/wiki/Oxygen, accessed on 5 August 2025

1.2.1.7.8 Mercury

Mercury is a chemical element with the symbol Hg and atomic number 80. It is commonly known as quicksilver and was formerly named hydrargyrum. A heavy, silvery d-block element, mercury is the only metallic element that is liquid at standard conditions for temperature and pressure; the only other element that is liquid under these conditions is bromine, though metals such as caesium, gallium, and rubidium melt just above room temperature.
@ mercury - CGI vocabularies: http://resource.geosciml.org/classifier/cgi/commodity-code/mercury, accessed on 13 November 2025

1.2.1.7.9 Radon

Radon is a chemical element; it has symbol Rn and atomic number 86. It is a radioactive noble gas and is colorless and odorless. Of the three naturally occurring radon isotopes, only ^{222}Rn has a sufficiently long half-life (3.825 days) for it to be released from the soil and rock where it is generated. Radon isotopes are the immediate decay products of radium isotopes. The instability of ^{222}Rn, its most stable isotope, makes radon one of the rarest elements. Radon will be present on Earth for several billion more years despite its short half-life, because it is constantly being produced as a step in the decay chains of ^{238}U and ^{232}Th, both of which are abundant radioactive nuclides with half-lives of at least several billion years. ^{220}Rn occurs in minute quantities as an intermediate step in the decay chain of 232Th, also known as the thorium series, which eventually decays into stable ^{208}Pb.

@ Radon - Wikipedia: https://en.wikipedia.org/wiki/Radon, accessed on 5 August 2025

1.2.2 Physical properties of gases

Physical properties of gases include relative density, viscosity, solubility, vapor pressure, and diffusion.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.2.2.1 Relative density

It the ratio of the density of natural gas to the density of the air at standard temperature and pressure conditions. The typical natural gas has 55% to 65% the density of air.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.2.2.2 Viscosity

Dynamic viscosity is a measure of the resistance of the gas to flow. It varies with composition, temperature and pressure. Kinematic viscosity is the dynamic viscosity divided by density. The typical natural gas has a lower dynamic viscosity than air; but a higher kinematic viscosity due to its lower density.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.2.2.3 Solubility

Solubility refers to the degree to which gas dissolves in a liquid solvent.

@ Solubility, https://www.britannica.com/science/solubility-chemistry, accessed on 20 March 2025

1.2.2.4 Vapor pressure

Saturated vapor pressure refers to the pressure required to liquefy gas. It is related to temperature and molecular weight. Typical natural gas (primarily methane) cannot be liquefied at room temperature (e.g., ~20°C) by increasing pressure alone. This is because methane’s critical temperature is −82.6°C, above which no amount of pressure will induce liquefaction.

@ Vapour pressure-science: https://www.britannica.com/science/vapor-pressure, accessed on 5 August 2025

1.2.2.5 Diffusion

It is the net movement of molecules or atoms from a region of high concentration to a region of low concentration. This is also referred to as the movement of a substance down a concentration gradient.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.2.2.6 Heating value

Heating value (or energy value or calorific value) of a substance is the amount of heat released during the combustion of a specified amount of it. The heating value of natural gas depends on its composition. The heating value of natural gas is about 1010 to 1035 ±5% BTU per cubic foot of gas at 1 atmosphere and 60 ℉ (41 MJ ±5% per cubic meter of gas at 1 atmosphere and 15.6 ℃).

@ Natural-gas processing - Wikipedia: https://en.wikipedia.org/wiki/Natural-gas_processing, accessed on 10 June 2025

1.2.2.7 Thermal conductivity

Thermal conductivity (λ) is a physical quantity that defines the amount of heat that flows through a specific medium over a certain distance during a given time increment, if there is a temperature gradient.

@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.2.3 Types of gases

They refer to gases with different compositions.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.2.3.1 Gas types based on methane content

Gas is classified into different types on basis of methane abundance.

@ Defined by the Working Group of Petroleum Geology Knowledge System

1.2.3.1.1 Dry gas

It refers to the gas in which the proportion of heavier gas (C_2-C_4) is less than 5% of the natural gas. Generally near 100% methane. May be biogenic and thermogenic.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

1.2.3.1.2 Wet gas

It refers to any gas with a small amount of liquid present. The term “wet gas” has been used to describe a range of conditions varying from a humic gas which is gas saturated with liquid vapor to a multiphase flow with a 90% volume of gas. There is currently no fully defined quantitative definition of a wet gas flow that is universally accepted.

@ Wet gas - Wikipedia: https://en.wikipedia.org/wiki/Wet_gas, accessed on 20 March 2025

1.2.3.2 Gas types based on association with oil

Gas is classified into different types on basis of presence or abundance of oil in a hydrocarbon accumulation.

@ Defined by the Working Group of Petroleum Geology Knowledge System

1.2.3.2.1 Associated gas

Associated gas is natural gas that originates from crude oil wells and can exist either as a separate gas cap above the crude oil in the underground reservoir or dissolved in the crude oil, coming out of solution as the pressure is reduced during production. This gas may be used in local industries.

@ Natural-gas processing – Wikipedia: https://en.wikipedia.org/wiki/Natural-gas_processing, accessed on 20 March 2025

@ Hasson R C, Mason J F and Moore Q M, 1975. Petroleum Developments in Middle East Countries in 1975. AAPG Bulletin, 60(10), 1865-1899.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 6 August 2025

1.2.3.2.2 Non-associated gas

Raw natural gas along with natural gas liquid with little to no crude oil and are called non-associated gas.

@ Natural-gas processing - Wikipedia: https://en.wikipedia.org/wiki/Natural-gas_processing, accessed on 20 March 2025

1.2.3.3 Gas types based on sulfur content

Gas is classified into different types on basis of abundance of chemical element of sulfur.

@ Defined by the Working Group of Petroleum Geology Knowledge System

1.2.3.3.1 Sour gas

Like sour oil, there is some natural gas naturally high in sulfur, called sour gas (greater than 2% hydrogen sulfide). The sulfur is present in the form of hydrogen sulfide, a toxic gas that must be removed for safety reasons and because of its highly corrosive nature.

@ Sulfur production in the United States - Wikipedia: https://en.wikipedia.org/wiki/Sulfur_production_in_the_United_States, accessed on 20 March 2025

1.2.3.3.2 Sweet gas

Sweet gas is natural gas with little or no sulfur (less than 0.3% hydrogen sulfide).

@ Sulfur production in the United States - Wikipedia: https://en.wikipedia.org/wiki/Sulfur_production_in_the_United_States, accessed on 20 March 2025

1.2.3.4 Gas types based on extraction challenges

Gas is classified into different types on basis of the geological and engineering difficulties involved in its production, primarily distinguishing between reservoirs with natural flow potential and those requiring advanced stimulation or recovery techniques.

@ Defined by the Working Group of Petroleum Geology Knowledge System

1.2.3.4.1 Conventional gas
Conventional gas refers to the natural gas which can be extracted using traditional drilling and pumping methods.
@ Defined by the Working Group of Petroleum Geology Knowledge System

1.2.3.4.2 Unconventional gas
Unconventional gas is natural gas, mainly methane, formed over millions of years from the remains of ancient plants and animals buried underground and transformed by heat and pressure. Unlike conventional gas, which flows easily from porous and permeable reservoirs, unconventional gas is trapped in rock layers with very low permeability–such as shale, tight sandstone, or coal–and does not flow easily to the well. It requires advanced technologies like horizontal drilling and hydraulic fracturing to be produced economically.
@ Unconventional gas - studentenergy: https://studentenergy.org/source/unconventional-gas/, accessed on 15 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

1.2.3.4.2.1 Shale gas
Shale gas is a sub-type of tight gas where the reservoir lithologies are predominantly shales or siltstones.
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

1.2.3.4.2.2 Coalbed methane (Coal bed methane)
Coalbed methane is methane trapped in underground coal seams. This type of methane can be accessed using drilling techniques similar to those used in the collection of shale gas. In these deposits, the methane is attached to the surface of the coal.
@ Energy Education: https://energyeducation.ca/encyclopedia/Coal_bed_methane, accessed on 20 March 2025

1.2.3.4.2.3 Tight gas
Tight gas is natural gas trapped within a rock with extremely low permeability—typically limestone or sandstone. This is not to be confused with shale gas, which is natural gas trapped within shale formations.
@ Energy Education: https://energyeducation.ca/encyclopedia/Tight_gas, accessed on 20 March 2025

1.2.3.4.2.4 Gas hydrates
Gas hydrates (also called gas clathrates) are icelike, crystalline solids composed of natural-gas molecules, principally methane, trapped in rigid crystalline cages formed by frozen water molecules. They are found at relatively shallow depth below the seafloor and have a very conspicuous seismic response (high amplitude).
@ Collett, T S, 2001. Natural-gas hydrates: Resources of the twenty-first century?, in M. W. Downey et al., eds., Petroleum provinces of the twenty-first century: AAPG Memoir 74, 85-108.
@ Gas hydrates - AAPG Wiki: https://wiki.aapg.org/Gas_hydrates, accessed on 20 March 2025

1.2.3.5 Gas types based on origin

Gas is classified into different types on basis of the ways in which gas was generated.
@ Defined by the Working Group of Petroleum Geology Knowledge System

1.2.3.5.1 Biogenic gas

Biogenic gas is only generated at low temperature levels (below 80 ℃) and can be recognized by its very low carbon-isotopic ratios ($\delta^{13}C_1$ from -70% to -55%). Pure biogenic gas does not contain higher hydrocarbons in appreciable proportion.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

1.2.3.5.2 Thermogenic gas

Thermogenic gas is a natural gas resulting from the thermal alteration of kerogen due to an increase in overburden pressure and temperature. Overburden pressure itself is not a major driver of maturation.
@ Haliburton, 2001. Basic Petroleum Geology, Haliburton

1.2.4 Gas processing and treatment (gas treatment and processing)

Natural gas processing consists of separating all of the various hydrocarbons and fluids from the pure natural gas, to produce what is known as 'pipeline quality' dry natural gas.
@ processing-ng - naturalgas: https://naturalgas.org/naturalgas/processing-ng/, accessed on 23 March 2025

1.2.4.1 Dehydration

In addition to separating oil and some condensate from the wet gas stream, it is necessary to remove most of the associated water. The removal of the water vapor that exists in solution in natural gas requires a more complex treatment. This treatment consists of 'dehydrating' the natural gas, which usually involves one of two processes: either absorption, or adsorption. Absorption occurs when the water vapor is taken out by a dehydrating agent, such as glycol. Adsorption occurs when the water vapor is condensed and collected on the surface.
@ processing-ng - naturalgas: https://naturalgas.org/naturalgas/processing-ng/, accessed on 23 March 2025

1.2.4.2 Acid gas removal

Acid Gas Removal (Sweetening): Removing acidic gases like hydrogen sulfide (H_2S) and carbon dioxide (CO_2), which can be corrosive and toxic. Common methods include amine treating or using polymeric membranes,
@ processing-ng - naturalgas: https://naturalgas.org/naturalgas/processing-ng/, accessed on 23 March 2025

1.2.4.3 Nitrogen rejection

Nitrogen is an inert gas that lowers the heating value of natural gas. Nitrogen is typically removed using a Nitrogen Rejection Unit (NRU), often employing cryogenic distillation.
@ Nitrogen rejection unit - Wikipedia: https://en.wikipedia.org/wiki/Nitrogen_rejection_unit, accessed on 23 March 2025

1.2.4.4 Natural gas liquids (NGL) extraction

Natural gas liquids (NGLs) can be very valuable by-products of natural gas processing. NGLs include ethane, propane, butane, iso-butane, and natural gasoline. These NGLs are sold separately and have a variety of different uses; including as sources of energy. The two principle techniques for removing NGLs from the natural gas stream are the absorption method and the cryogenic expander process.

@ processing-ng - naturalgas: https://naturalgas.org/naturalgas/processing-ng/, accessed on 23 March 2025

1.2.4.5 Sulfur recovery

The most common process for removing hydrogen sulfide from sour gas is the 'amine process', or alternatively as the Girdler process. The sour gas is run through a tower containing the amine solution which has an affinity for sulfur, and absorbs it. Sulfur can be sold and used if reduced to its elemental form. Elemental sulfur is a bright yellow powder like material, and can often be seen in large piles near gas treatment plants.

@ Natural-gas processing - Wikipedia: https://en.wikipedia.org/wiki/Natural-gas_processing, accessed on 23 March 2025

1.2.5 Gas storage and transportation

Natural gas, like most other commodities, can be stored for an indefinite period of time.

@ storage - naturalgas: https://naturalgas.org/naturalgas/storage/, accessed on 25 March 2025

1.2.5.1 Underground storage

There are three main types of underground storage: depleted gas reservoirs, aquifers, and salt caverns. The most prominent and common form of underground storage consists of depleted gas reservoirs, which are those formations that have already been tapped of all their recoverable natural gas. Aquifers are the least desirable and most expensive type of natural gas storage facility. Salt caverns are the most common type of peak load storage facility.

@ storage - naturalgas: https://naturalgas.org/naturalgas/storage/, accessed on 25 March 2025

1.2.5.2 LNG (Liquefied Natural Gas)

LNG is natural gas in its liquid form. LNG is produced by purifying natural gas and super-cooling it to -260 ℉ to turn it into a liquid. During the process known as liquefaction, natural gas is cooled below its boiling point, removing most of the extraneous compounds found in the fuel. The remaining natural gas is primarily methane with small amounts of other hydrocarbons.

@ natural gas basics- energy: https://afdc.energy.gov/fuels/natural-gas-basics/, accessed on 25 March 2025

1.2.5.3 CNG (Compressed Natural Gas)

CNG is produced by compressing natural gas to less than 1% of its volume at standard atmospheric pressure. To provide adequate driving range, CNG is stored onboard a vehicle in a compressed gaseous state at a pressure of up to 3,600 pounds per square inch.

@ natural gas basics- energy: https://afdc.energy.gov/fuels/natural-gas-basics/, accessed on 25 March 2025

1.2.5.4 Pipeline transportation

There are three major types of pipelines along the transportation route: the gathering system, the interstate pipeline system, and the distribution system.
@ transport- naturalgas: https://naturalgas.org/naturalgas/transport/, accessed on 25 March 2025

1.2.6 Gas and Environment (Environmental considerations)

It refers how environment is impacted by gas.
@ Defined by the Working Group of Petroleum Geology Knowledge System

1.2.6.1 Greenhouse gas emissions

Natural gas is the cleanest of all the fossil fuels. Because of its high hydrogen content, it emits almost 30 percent less carbon dioxide-per-energy-unit upon combustion than oil, and just under 45 percent less carbon dioxide than coal. However, methane, the principle component of natural gas, is itself a potent greenhouse gas.
@ environment- naturalgas: https://naturalgas.org/environment/naturalgas/, accessed on 25 March 2025

1.2.6.2 Methane leakage

Methane leakage is one hazard associated with hydraulic fracturing natural gas. Methane is a prominent greenhouse gas, 72 times more potent than carbon dioxide over a twenty-year period.
@ Fracking in the United States - Wikipedia:
https://en.wikipedia.org/wiki/Fracking_in_the_United_States, accessed on 25 March 2025

1.2.6.3 Gas venting

Gas venting, more specifically known as natural-gas venting or methane venting, is the intentional and controlled release of gases containing alkane hydrocarbons - predominately methane - into Earth's atmosphere. It is a widely used method for disposal of unwanted gases which are produced during the extraction of coal and crude oil. Such gases may lack value when they are not recyclable into the production process, have no export route to consumer markets, or are surplus to near-term demand. In cases where the gases have value to the producer, substantial amounts may also be vented from the equipment used for gas collection, transport, and distribution.
@ Gas venting - Wikipedia: https://en.wikipedia.org/wiki/Gas_venting, accessed on 8 August 2025

1.3 Natural gas condensate

Also called natural gas liquids, or condensate, or gas condensate, it is a low-density mixture of hydrocarbon liquids that are present as gaseous components in the raw natural gas produced from many natural gas fields. Some gas species within the raw natural gas will condense to a liquid state if the pressure and temperature are reduced to below the hydrocarbon dew point.
@ Natural-gas condensate - Wikipedia: https://en.wikipedia.org/wiki/Natural-gas_condensate, accessed on 25 March 2025

1.3.1 Physical properties

A physical property is any property of a physical that is measurable.

@ Physical property - Wikipedia: https://en.wikipedia.org/wiki/Physical_property, accessed on 15 August 2025

1.3.1.1 API gravity
API gravity ranges between 45º to 75º.
@ Natural-gas condensate - Wikipedia: https://en.wikipedia.org/wiki/Natural-gas_condensate, accessed on 25 March 2025

1.3.1.2 Color
Color varies from clear to yellow or whitish-blue.
@ Natural-gas condensate - Wikipedia: https://en.wikipedia.org/wiki/Natural-gas_condensat, accessed on 25 March 2025

1.3.1.3 Viscosity
Viscosity is a measure of the resistance of a fluid to flow.
@ Viscosity - AAPG Wiki: https://wiki.aapg.org/Viscosit, accessed on 25 March 2025

1.3.2 Source of natural gas for creating condensate
They include crude oil wells, dry gas wells and condensate wells.
@ Defined by the Working Group of Petroleum Geology Knowledge System

1.3.2.1 Crude oil wells (oil wells)
Natural gas that comes from crude oil wells is typically called associated gas. This gas could exist as a separate gas cap above the crude oil in the underground reservoir or could be dissolved in the crude oil, ultimately coming out of solution as the pressure is reduced during production. Condensate produced from oil wells is often referred to as lease condensate.
@ Natural-gas condensate - Wikipedia: https://en.wikipedia.org/wiki/Natural-gas_condensate, accessed on 25 March 2025

1.3.2.2 Dry gas wells (Gas wells)
These wells typically produce only natural gas that contains no condensate with little to no crude oil and are called non-associated gas wells. Condensate from dry gas is extracted at gas processing plants and is often called plant condensate.
@ Natural-gas condensate - Wikipedia: https://en.wikipedia.org/wiki/Natural-gas_condensate, accessed on 25 March 2025

1.3.2.3 Condensate wells
These wells typically produce raw natural gas along with natural gas liquids with little to no crude oil and are called non-associated gas. Such raw natural gas is often referred to as wet gas.
@ Natural-gas condensate - Wikipedia: https://en.wikipedia.org/wiki/Natural-gas_condensate, accessed on 25 March 2025

2. Geological elements

They include source rock, reservoir rock, seal rock and trap, which are required to form a hydrocarbon accumulation.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1 Source rock

A source rock is a fine-grained dark sedimentary rock that contains sufficient organic matter such that when it is buried and heated it will generate petroleum (oil and gas). The quantity and quality of organic matter preserved and modified during diagenesis of a sediment ultimately determine the petroleum potential of the rock.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.1.1 Source rock types

In terms of lithology, there are three major types of potential source rocks: carbonaceous mudstone and shale, carbonates and coal measures. In terms of environment of deposition, there exist marine, terrestrial (lacustrine) and paralic source rocks.
@ Ahlbrandt, T. S., Charpentier, R. R., Klett, T.R., Schmoker, J. W. and Christopher J. Schenk, C. J., 2000. Chapter AR Analysis of assessment results, U.S. Geological Survey World Petroleum Assessment 2000–Description and Results: U.S. Geological Survey Digital Data Series 60.
@ National Energy Administration, 2019. Geochemical method for source rock evaluation SY/T 5735-2019, 10p.

2.1.1.1 Type by lithology

2.1.1.1.1 Carbonaceous mudstone and shale source rock
Carbonaceous mudstone and shale serve as source rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.1.2 Carbonate source rock
Carbonates serve as source rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.1.3 Coal measures or coal source rock
Coal measures or coals serve as source rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.2 Type by Sedimentary Facies

2.1.1.2.1 Marine source rock
It refers to the source rock deposited in marine depositional environment.
@ Ahlbrandt, T S, Charpentier, R. R., Klett, T.R., Schmoker, J. W. and Christopher J. Schenk, C. J., 2000. Chapter AR Analysis of assessment results, U.S. Geological Survey World Petroleum Assessment 2000–Description and Results: U.S. Geological Survey Digital Data Series 60.

2.1.1.2.1.1 Deep marine (pelagic) source rock
It refers to source rocks deposited in deep marine (pelagic) environment.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.2.1.2 Shelf source rock
It refers to source rocks deposited in shelf environment.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.2.1.3 Intra-shelf basin source rock
It refers to source rocks deposited as intra-shelf basinal facies.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.2.1.4 Marine deltaic source rock
It refers to source rocks deposited in marine deltaic environment.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.2.1.5 Lagoon source rock
It refers to source rocks deposited in lagoon environment.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.2.2 Non-marine source rock
Non-marine source rocks are those accumulating in lakes and river basins and usually contain a mixture of fresh-water algae and land plant tissue.
@ Brooks J, Cornford C and Archer R, 1987, The role of hydrocarbon source rocks in petroleum exploration. In Brooks, J. and Fleet, A. J. (eds) Marine Petroleum Source Rocks. Geological Society Special Publication No. 26 p.17-46.

2.1.1.2.2.1 Lacustrine source rock
It refers to the source rock deposited in lacustrine depositional environment.
@ Ahlbrandt, T. S., Charpentier, R. R., Klett, T.R., Schmoker, J. W. and Christopher J. Schenk, C. J., 2000. Chapter AR Analysis of assessment results, U.S. Geological Survey World Petroleum Assessment 2000–Description and Results: U.S. Geological Survey Digital Data Series 60.

2.1.1.2.2.2 Deltaic source rock
It refers to source rocks deposited in lacustrine deltaic environment.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.2.2.3 Floodplain source rock
It refers to source rocks deposited in floodplain environment.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.2.3 Coaly source rock (marine-continental transitional source rock)
It refers to the source rock deposited as coal, which are often from a coastal (paralic) depositional environment.
@ Ahlbrandt, T. S., Charpentier, R. R., Klett, T.R., Schmoker, J. W. and Christopher J. Schenk, C. J., 2000. Chapter AR Analysis of assessment results, U.S. Geological Survey World Petroleum Assessment 2000–Description and Results: U.S. Geological Survey Digital Data Series 60.

2.1.1.3 Type by Age
Source rocks are classified into different types on basis of their age.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.3.1 Precambrian source rocks
It refers to source rocks with a Precambrian age.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.3.2 Paleozoic source rocks
It refers to source rocks with a Paleozoic age.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.3.3 Mesozoic source rocks
It refers to source rocks with a Mesozoic age.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.1.3.4 Cenozoic source rocks
It refers to source rocks with a Cenozoic age.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.2 Organic matter
It refers solely to material comprised of organic molecules in monomeric or polymeric form derived directly or indirectly from the organic part of organisms. Mineral skeletal parts, such as shells, bones and teeth, are not included. Phytoplankton, bacteria, and higher plants make the main contribution to the organic matter in source rocks; zooplankton and benthics make some contribution; and higher animals make little contribution.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.1.2.1 Chemical composition of the biomass
The chemical constituents of the biomass consist of various groups of molecular constituents including lipids, proteins, carbohydrates, and lignin, of which lipids are being the best organic matter for generating oil.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.1.2.1.1 Lipids
They are water insoluble and include waxes, plant or animal oil and fats, oil-soluble pigments, terpenoids, and steroids. With respect to the formation of hydrocarbons, lipids are the most important group.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.1.2.1.2 Proteins

They are highly ordered polymers made from over 20 individual amino acids and account for most of the N2 within an organism. They can be broken down, either by enzymes or by hydrolyzation.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.1.2.1.3 Carbohydrates

They have a generalized formula of $Cn(H_2O)n$ and are essentially the hydrated forms of carbon Sugar. Starch and cellulose are nearly pure carbohydrates. Higher plants contain high amounts of cellulose whereas algae and marine organisms are devoid of cellulose.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.1.2.1.4 Lignin

Lignin is a class of complex organic polymers that form key structural materials in the support tissues of most plants. Lignins are particularly important in the formation of cell walls, especially in wood and bark, because they lend rigidity and do not rot easily. Chemically, lignins are polymers made by cross-linking phenolic precursors.

@ Lignin - Wikipedia: https://en.wikipedia.org/wiki/Lignin, accessed on 5 August 2025

2.1.2.2 Elemental composition of kerogen

Kerogen is a mixture of insoluble organic material, rather than a specific chemical, it does not have a specific chemical formula. Indeed, its chemical composition can vary distinctively from sample to sample. It consists of C, H, O and minor amounts of S and N.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.1.2.2.1 Carbon content common sense terms

common sense terms

2.1.2.2.2 Hydrogen content

common sense terms

2.1.2.2.3 Oxygen content

common sense terms

2.1.2.2.4 Sulfur content

common sense terms

2.1.2.2.5 Nitrogen content

common sense terms

2.1.2.3 Maceral composition of kerogen

Kerogen consists of different groups of macerals: liptinite/exinite, vitrinite and inertinite.

@ Brooks J, Cornford C and Archer R, 1987. The Role of hydrocarbon source rocks in petroleum exploration, in Brooks J and Fleet A J, Marine and Petroleum Source Rocks, Geological Society Special Publication no. 26, p.17-46.

2.1.2.3.1 Liptinite/exinite

Also called exinite, liptinite is derived from spores, pollens, cuticles, and resins in the original plant material. These plant parts are more hydrogen-rich than other macerals. It is characterized by a very dark gray color or a low reflectance in polished section and a bright yellow color, due to their greater transparence, in thin section.
@ Macerals: https://www.uky.edu/KGS/coal/coal-macerals.php, accessed on 5 August 2025

2.1.2.3.1.1 Sporinite

Sporinite, a type of liptinite maceral, has its origin as the outer cell walls of plant spores and pollen. It is an oil-prone hydrogen-rich kerogen that fluoresces under ultraviolet light.
@ Liptinite - AAPG Wiki: https://wiki.aapg.org/Liptinite, accessed on 5 August 2025
@ Macerals: https://www.uky.edu/KGS/coal/coal-macerals.php, accessed on 5 August 2025

2.1.2.3.1.2 Cutinite

Cutinite, a type of liptinite maceral, has its origin as the outer coatings (cuticles) of leaves, roots, stems.
@ Macerals: https://www.uky.edu/KGS/coal/coal-macerals.php, accessed on 5 August 2025

2.1.2.3.1.3 Suberinite

Suberinite, a type of liptinite maceral, has its origin as degrades (suberinized) cell walls of cork in bark and roots.
@ Macerals: https://www.uky.edu/KGS/coal/coal-macerals.php, accessed on 5 August 2025

2.1.2.3.1.4 Resinite

Resinite, a type of liptinite maceral, has its origin as plant resins, balsams, latexes, fats and waxes.
@ Macerals: https://www.uky.edu/KGS/coal/coal-macerals.php, accessed on 5 August 2025

2.1.2.3.1.5 Alginite

Alginite is a type of lipinite maceral, has its origin with algae, is often structureless (amorphous) and, when immature, fluoresces golden yellow in ultraviolet (UV) light. It is a component of kerogen type I, which is predominantly composed of the most hydrogen-rich organic matter preserved in the rock record.
@ Kerogen - AAPG Wiki: https://wiki.aapg.org/Kerogen, accessed on 5 August 2025

2.1.2.3.1.6 Exsudatinite

Exsudatinite, a type of liptinite maceral, has its origin as secondary crack-filling material formed from maturation after oil generation.
@ Macerals: https://www.uky.edu/KGS/coal/coal-macerals.php, accessed on 5 August 2025

2.1.2.3.1.7 Fluorinite

Fluorinite, a type of liptinite maceral, has its origin as secondary crack-filling material formed from maturation after oil generation.
@ Macerals: https://www.uky.edu/KGS/coal/coal-macerals.php, accessed on 5 August 2025

2.1.2.3.1.8 Liptodetrinite
Liptodetrinite, a type of liptinite maceral, has its origin as fragments or degradation residuas of liptinites.
@ Macerals: https://www.uky.edu/KGS/coal/coal-macerals.php, accessed on 5 August 2025

2.1.2.3.2 Vitrinite
Vitrinite is a coaly organic maceral derived from partially "gelled" wood, bark, and roots, and contain less hydrogen than liptinite. The reflectance of vitrinite changes with heat.
@ Brooks J, Cornford C and Archer R, 1987. The Role of hydrocarbon source rocks in petroleum exploration, in Brooks J and Fleet A J, Marine and Petroleum Source Rocks, Geological Society Special Publication no. 26, 17-46.
@ Macerals: https://www.uky.edu/KGS/coal/coal-macerals.php, accessed on 5 August 2025

2.1.2.3.3 Inertinite
Inertinites are mainly oxidation products of other macerals and are consequently richer in carbon than liptinites or vitrinites, because much of the oxygen in the original plant parts or residues has been consumed by oxidation. The inertinite group includes fusinite (most of which is fossil charcoal) derived from ancient fires in the coal-forming peat. Other inertinite macerals (for example, macrinite) owe their origin to biological decomposition and decay of plant material. Still others (for example, micrinite) result from thermal maturation of peat. Inertinites have no potential for conversion to hydrocarbon product.
@ Macerals: https://www.uky.edu/KGS/coal/coal-macerals.php, accessed on 5 August 2025
@ Brooks J, Cornford C and Archer R, 1987. The Role of hydrocarbon source rocks in petroleum exploration, in Brooks J and Fleet A J, Marine and Petroleum Source Rocks, Geological Society Special Publication no. 26, 17-46.

2.1.2.4 Organic matter richness
The parameters used to indicate the quantity and richness of organic matter in sediments include TOC (Total organic carbon), bitumen, hydrocarbons and rock-eval pyrolysis (S_1 and S_2).

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 93-120.

2.1.2.4.1 TOC
The total organic carbon (TOC) present in a rock is expressed in wt.%. The two most common techniques of analyzing a rock for TOC are Rock-Eval pyrolysis with TOC and the LECO method. Conventional well logs can also provide information for evaluating interval richness.
@ Source rock richness - AAPG Wiki: https://wiki.aapg.org/Source_rock_richness, accessed on 5 August 2025

2.1.2.4.2 Rock-Eval pyrolysis
Pyrolysis is the decomposition of organic matter by heating in the absence of oxygen. Organic geochemists use pyrolysis to measure richness and maturity of potential source rocks. In Rock-Eval pyrolysis, a sample is placed in a vessel and is progressively heated to temperature 550 ℃ under an inert atmosphere. During the analysis, the hydrocarbons already present in the sample are volatized at a moderate temperature. The amount of hydrocarbons is measured and recorded

as a peak known as S_1. Next pyrolyzed is the kerogen present in the sample, which generates hydrocarbons and hydrocarbon-like compounds (recorded as the S_2 peak), CO_2, and water. The CO_2 generated is recorded as the S_3 peak. Residual carbon is also measured and is recorded as S_4.
@ Tissot B P, Welte D H, 1984. Petroleum Formation and Occurrence, 2 ed.: New York, Springer-Verlag, 699.
@ Rock-Eval pyrolysis - AAPG Wiki: https://wiki.aapg.org/Rock-Eval_pyrolysis, accessed on 5 August 2025

2.1.2.4.2.1 S_1
It is a measurement of the free hydrocarbons present in the sample and volatized at a moderate temperature during the Rock-Eval analysis in mg HC/g rock.
@ Tissot B P, Welte D H, 1984. Petroleum Formation and Occurrence, 2 ed.: New York, Springer-Verlag, 699.
@ Rock-Eval pyrolysis - AAPG Wiki: https://wiki.aapg.org/Rock-Eval_pyrolysis, accessed on 5 August 2025

2.1.2.4.2.2 S2
Following the release of S_1, next pyrolyzed is the kerogen present in the sample, which generates hydrocarbons and hydrocarbon-like compounds (recorded as the S_2 peak). It is a measurement of the volume of hydrocarbons that formed during thermal pyrolysis of the sample in mg HC/g rock.
@ Tissot B P, Welte D H, 1984. Petroleum Formation and Occurrence, 2 ed.: New York, Springer-Verlag, 699.
@ Rock-Eval pyrolysis - AAPG Wiki: https://wiki.aapg.org/Rock-Eval_pyrolysis, accessed on 5 August 2025

2.1.2.4.2.3 Genetic Potential (S_1+S_2)
It is the sum of S_1 and S_2.
@ Tissot B P, Welte D H, 1984. Petroleum Formation and Occurrence, 2 ed.: New York, Springer-Verlag, 699.
@ Rock-Eval pyrolysis - AAPG Wiki: https://wiki.aapg.org/Rock-Eval_pyrolysis, accessed on 5 August 2025

2.1.2.4.3 Bitumen
Bitumen refers to the organic matter in a source rock, which is soluble in organic solvent, in wt. % or ppm.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

2.1.2.4.4 Total Hydrocarbons
Total Hydrocarbon content (THC) refers to the aggregate amount of hydrocarbons present in a source rock sample. THC is often measured using Flame Ionization Detectors or other analytical techniques like gas chromatography-mass spectrometry.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 93-120.

2.1.2.5 Kerogen type

The type of kerogen present determines source rock quality and the hydrocarbons it generates during maturation. The more oil prone a kerogen, the higher its quality. Four basic types of kerogen are found in sedimentary rocks. A single type or a mixture of types may be present in a source rock. The type of kerogen can be determined by results of elemental analysis, petrological maceral analysis, and pyrolysis analysis (hydrocarbon index and oxygen index).
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.1.2.5.1 Type I

Type I refers to kerogen with a high initial H/C atomic ratio (ca. 1.5 or more) and a low initial O/C ratio (generally less than 0.1). Such kerogen comprises much lipid material, particularly aliphatic chain. The content of polyaromatic nuclei and heteroatomic bonds is low, compared with the other types of kerogen. The high proportion of lipids may result either (l) from a selective accumulation of algal material or (2) from a severe biodegradation of the organic matter (other than lipids and microbial waxes) during deposition. It has the largest oil generation potential. Up to 80% by weight of Type I kerogen could be converted to oil and gas during its pyrolysis. It commonly occurs in lacustrine depositional environments and produces waxy oils.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.1.2.5.2 Type II

Type II is perhaps the most commonly reported type of kerogen. True Type II kerogens possess relatively high initial hydrogen content and a moderate amount of oxygen. Type II kerogens are derived from phytoplankton (dominant), zooplankton, and bacteria deposited in a reducing environment, and some terrestrially derived material as well, although marine-derived Type II kerogen is more common. It has a moderate oil generation potential. Approximately 60 wt % of Type II kerogen could be converted to oil and gas during its pyrolysis.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.1.2.5.3 Type III

Type III refers to kerogen with a relatively low initial H/C ratio (usually less than 1.0) and a high initial O/C atomic ratio (as high as 0.2 or 0.3). Type III kerogens are typically derived from higher plants, i.e., vitrinitic, not liptinitic. This kerogen type releases little in the way of aliphatic material during thermal maturation and, therefore, true Type III kerogens are not usually considered oil prone. It has a low generation potential. Approximately 30 wt % of type III kerogen could be converted to hydrocarbons dominated by gas during its pyrolysis.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.1.2.5.4 Type IV

Kerogen Type IV is composed of hydrogen-poor constituents such as inertinite, which is detrital organic matter oxidized directly by thermal maturation including fire (charcoal) or by biological or sedimentological recycling. It is a term not universally employed by organic geochemists

because it is difficult to distinguish Type IV from Type III using only Rock-Eval pyrolysis. It is an inert (does not generate hydrocarbons) end-member on the hydrocarbon generative spectrum.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.1.2.6 Maturity of organic matter (Thermal maturity indicators)

It represents the extent of thermal conversion of sedimentary organic matter to oil. Two parameters of Ro (vitrinite reflectance) and Tmax are commonly used to quantify maturity of organic matter.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 93-120.

2.1.2.6.1 Vitrinite reflectance (R_o)

Vitrinite reflectance is a measure of the percentage of incident light reflected from the surface of vitrinite particles in a sedimentary rock. It is referred to as %Ro. Results are often presented as a mean Ro value based on all vitrinite particles measured in an individual sample. Vitrinite reflectance (V_r or R_o), the most commonly used thermal indicator, is the benchmark for maturation studies in the petroleum and coal industries. This technique is primarily useful for Devonian and younger clastic sediments and coals.
@ Tissot B P, Welte D H, 1984. Petroleum Formation and Occurrence, 2 ed.: New York, Springer-Verlag, 699.
@ Vitrinite reflectance - AAPG Wiki: https://wiki.aapg.org/Vitrinite_reflectance, accessed on 5 August 2025

2.1.2.6.2 T_{max}

It is the temperature at which the maximum rate of hydrocarbon generation occurs in a kerogen sample during pyrolysis analysis. The S_2 peak represents the rate of hydrocarbon generation (the area under the curve represents the amount). The temperature at the time the S_2 peak is recorded during pyrolysis is Tmax, given in ℃.
@ Tissot B P, Pelet R, Ungerer P, 1987. Thermal history of sedimentary basins, maturation indices, and kinetics of oil and gas generation, AAPG Bulletin, 71, 1445-1466.
@ Tmax - AAPG Wiki: https://wiki.aapg.org/Tmax, accessed on 5 August 2025

2.1.2.6.3 Production Index (PI)

Production Index (PI) is calculated from Rock-Eval data: $PI = S_1/[S_1+S_2]$, where S_1 is the quantity of free hydrocarbons (gas + oil), in mg/g of rock and S_2 is the quantity of thermally generated (cracked) hydrocarbons, in mg/g of rock.
@ Production Index (PI) - AAPG Wiki: https://wiki.aapg.org/Production_Index_(PI), accessed on 5 August 2025

2.1.2.6.4 Thermal Alteration Index (TAI)

Thermal alteration index (TAI) is a numerical scale (typically from 1 to 5) based on thermally induced color changes in spores and pollen. These color changes, which range from yellow to black as temperatures increase, indicate the degree to which the organic matter has been heated and altered over geological time.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 93-120

2.1.2.6.5 Spore Coloration Index (SCI)
The spore coloration index is a semiquantitative measure of thermal maturity, where the spore color (from colorless through yellow, orange, brown, and black) is used to give a semiquantitative measure of thermal maturity.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

2.1.2.6.6 Conodont Alteration Index (CAI)
The color alteration of conodonts is a valuable tool for assessing organic metamorphism because it is a rapid and inexpensive method requiring only standard laboratory techniques and a binocular microscope. Conodont color alteration begins near the upper thermal limit for the preservation of many palynomorphs. The technique does not provide thermal thresholds for oil generation, but does provide thermal cutoffs for oil, condensate, and dry gas generation.
@ Epstein, A.G., Epstein, J.B., and Harris, L.D., 1977. Conodont Color Alteration – an Index to Organic Metamorphism. USGS Prof. Paper 995, USA Govt. Printing Office, Washington, D.C.

2.1.2.6.7 Biomarker ratios
Biomarker ratios are calculated from the sterane and triterpane distributions and reflect maturation and source differences. Sterane and triterpane are derived from the degradation of sterols and triterpenoids, respectively, which are components of living organisms.
@ Duncan A D and Hamilton R F M, 1988. Palaeolimnology and organic geochemistry of the Middle Devonian in the Orcadian Basin. In Fleet A J, Kelts K and Talbot M R (eds), Lacustrine Petroleum Source Rocks, Geological Society Special Publication No. 40, p. 173-201.

2.1.2.7 Organic matter preservation factors
A diverse set of controls on organic matter degradation and preservation in sediments mostly revolve around the relative roles of bottom water and pore water oxygen and the rate of organic matter delivery to the sediments.
@ Hedges, J. I. & Keil, R. G., 1995. Sedimentary organic matter preservation: an assessment and speculative synthesis. Marine Chemistry 49, p. 81–115.
@ Wakeham, S.G., Canuel, E.A., 2005. Degradation and preservation of organic matter in marine sediments. In: Volkman, J.K. (eds) Marine Organic Matter: Biomarkers, Isotopes and DNA. The Handbook of Environmental Chemistry, vol 2N. Springer, Berlin, Heidelberg. https://doi.org/10.1007/698_2_009

2.1.2.7.1 Depositional environment
In geology, depositional environment or sedimentary environment describes the combination of physical, chemical, and biological processes associated with the deposition of a particular type of sediment and, therefore, the rock types that will be formed after lithification, if the sediment is preserved in the rock record. In most cases, the environments associated with particular rock types or associations of rock types can be matched to existing analogues. However, the further back in geological time sediments were deposited, the more likely that direct modern analogues are not available (e.g. banded iron formations).

@ Depositional environment - Wikipedia:
https://en.wikipedia.org/wiki/Depositional_environment, accessed on 5 August 2025

2.1.2.7.2 Sedimentation rate

Moderate to high sedimentation rates rapidly bury organic matter, reducing exposure to oxygenated water. However, excessively high rates may dilute organic content.

@ Al-Shamlan, A.A., El-Sayed, M.I.A. & Khaiwka, M.H. The depositional environment of Mauddud limestone, Greater Burgan oil field, Kuwait. Geol Rundsch 70, 941–955 (1981). https://doi.org/10.1007/BF01820173

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.1.2.7.3 Bottom water circulation

Stagnant or restricted bottom water circulation limits oxygen replenishment, creating anoxic (oxygen-depleted) or euxinic (sulfidic) conditions. These environments inhibit aerobic microbial degradation of organic matter. Water column stratification enables isolation of bottom waters from the more oxygenated surface waters.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.1.2.7.4 Biological productivity

High biological productivity (e.g., algal blooms) increases organic flux to the seafloor. In poorly circulated basins, microbial decomposition of this organic load depletes residual oxygen, reinforcing anoxia.

@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.1.2.7.5 Redox conditions

Organic matter is preserved most effectively in oxygen-depleted (anoxic) or sulfidic (euxinic) environments. These conditions inhibit aerobic microbial degradation. It is not a simple matter to decipher paleo-redox conditions during the formation of organic-carbon-rich fine-grained rocks. A series of geochemical proxies are used to interpret paleo-redox conditions.

@ Potter P E, Maynard J B, Pryor W A, 1980. Sedimentology of shale, Study guide and reference source: Berlin, Springer-Verlag, 303.

@ Tools and techniques for studying mudstones - AAPG Wiki:
https://wiki.aapg.org/Tools_and_techniques_for_studying_mudstones, accessed on 11 August 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 11 August 2025

2.1.2.7.6 Sediment grain size

Interactions between organic matter and mineral matrices through sorption on clay minerals and metal oxides are important factors to the preservation of sediment organic matter.

@ Hedges, J. I. & Keil, R. G., 1995. Sedimentary organic matter preservation: an assessment and speculative synthesis. Marine Chemistry 49, p. 81–115.

__2.1.2.8 Stage of thermal maturity for oil generation__

It refers to the level of thermal maturation of organic matter, which can be quantified by Ro and T_{max}.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.2.8.1 Immature stage

Ro: 0.2-0.6%, T_{max}: <435^{o}C

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.2.8.2 Mature stage

Early Ro: 0.6-0.65%, T_{max}: 435-445^{o}C; Peak Ro: 0.65-0.9%, T_{max}: 445-450^{o}C; Late Ro: 0.9-1.35%, T_{max}: 450-470^{o}C.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.2.8.3 Postmature (Overmature) stage (Gas generation stage)

Ro: >1.35%, T_{max}: >470^{o}C.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.3 Source rock evaluation techniques

Source rock evaluation techniques are designed to assess a rock's ability—past, present, and potential—to generate hydrocarbons by quantifying the key elements and processes controlling source rock development in petroleum exploration and production.

@ Kuchinskiy V, Gentry K, Hill R, 2012. Source Rock Evaluation Technique: A Probabilistic Approach for Determining Hydrocarbon Generation Potential and In-Place Volume for Shale Plays. AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25.

@ Source Rock Evaluation - SEG: https://wiki.seg.org/wiki/Source_Rock_Evaluation, accessed on 15 August 2025

__2.1.3.1 Geochemical analysis__

The mid-twentieth century was when scientists began to seriously study petroleum geochemistry. Geochemistry was originally utilized for surface prospecting for subsurface hydrocarbons. Today geochemistry serves the petroleum industry by helping seek out effective petroleum systems. Once oil to source rock correlation is found, petroleum geologists will use this information to render a 3D model of the basin. Now they can assess the timing of generation, migration, and accumulation relative to the trap formation. This aids in the decision-making process on whether further exploration is necessary. Additionally, this can increase recoveries of the petroleum remaining in reservoirs that were initially deemed unrecoverable.

@ Petroleum geology - Wikipedia: https://en.wikipedia.org/wiki/Petroleum_geology#Geochemical_analysis, accessed on 13 June 2025

2.1.3.1.1 Rock-Eval pyrolysis

Pyrolysis is the decomposition of organic matter by heating in the absence of oxygen. Organic geochemists use pyrolysis to measure richness and maturity of potential source rocks. In Rock-Eval pyrolysis, a sample is placed in a vessel and is progressively heated to temperature 550 ℃ under an inert atmosphere. During the analysis, the hydrocarbons already present in the sample are volatized at a moderate temperature. The amount of hydrocarbons is measured and recorded as a peak known as S_1. Next pyrolyzed is the kerogen present in the sample, which generates hydrocarbons and hydrocarbon-like compounds (recorded as the S_2 peak), CO_2, and water. The CO_2 generated is recorded as the S_3 peak. Residual carbon is also measured and is recorded as S_4.

@ Tissot B P, Welte D H, 1984. Petroleum Formation and Occurrence, 2 ed.: New York, Springer-Verlag, 699.

@ Rock-Eval pyrolysis - AAPG Wiki: https://wiki.aapg.org/Rock-Eval_pyrolysis, accessed on 5 August 2025

2.1.3.1.1.1 S1

It is a measurement of the free hydrocarbons present in the sample and volatized at a moderate temperature during the Rock-Eval analysis in mg HC/g rock.

@ Tissot B P, Welte D H, 1984. Petroleum Formation and Occurrence, 2 ed.: New York, Springer-Verlag, 699.

@ Rock-Eval pyrolysis - AAPG Wiki: https://wiki.aapg.org/Rock-Eval_pyrolysis, accessed on 5 August 2025

2.1.3.1.1.2 S2

Following the release of S_1, next pyrolyzed is the kerogen present in the sample, which generates hydrocarbons and hydrocarbon-like compounds (recorded as the S_2 peak). It is a measurement of the volume of hydrocarbons that formed during thermal pyrolysis of the sample in mg HC/g rock.

@ Tissot B P, Welte D H, 1984. Petroleum Formation and Occurrence, 2 ed.: New York, Springer-Verlag, 699.

@ Rock-Eval pyrolysis - AAPG Wiki: https://wiki.aapg.org/Rock-Eval_pyrolysis, accessed on 5 August 2025

2.1.3.1.1.3 S3

The CO2 generated is recorded as the S3 peak.

@ Tissot B P, Welte D H, 1984. Petroleum Formation and Occurrence, 2 ed.: New York, Springer-Verlag, 699.

@ Rock-Eval pyrolysis - AAPG Wiki: https://wiki.aapg.org/Rock-Eval_pyrolysis

2.1.3.1.1.4 Tmax

It is the temperature at which the maximum rate of hydrocarbon generation occurs in a kerogen sample during pyrolysis analysis. The S_2 peak represents the rate of hydrocarbon generation (the area under the curve represents the amount). The temperature at the time the S_2 peak is recorded during pyrolysis is Tmax, given in ℃.

@ Tissot B P , Pelet R, Ungerer P, 1987. Thermal history of sedimentary basins, maturation indices, and kinetics of oil and gas generation: AAPG Bulletin, vol. 71, 1445–1466.
@ Tmax - AAPG Wiki: https://wiki.aapg.org/Tmax, accessed on 5 August 2025

2.1.3.1.1.5 Hydrogen Index (HI)

The hydrogen index (HI) represents the amount of hydrogen relative to the amount of organic carbon present in a sample. It is defined as (S_2/TOC) x 100, mg HC/g TOC.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.3.1.1.6 Oxygen Index (OI)

It is defined as (S_3/TOC) x 100, mg CO_2/g TOC. It is related to the amount of oxygen in the kerogen.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.3.1.1.7 Production Index (PI)

Production Index (PI) is calculated from Rock-Eval data: PI = $S_1/[S_1+S_2]$, where S_1 is the quantity of free hydrocarbons (gas + oil), in mg/g of rock and S_2 is the quantity of thermally generated (cracked) hydrocarbons, in mg/g of rock.
@ Production Index (PI) - AAPG Wiki: https://wiki.aapg.org/Production_Index_(PI), accessed on 5 August 2025

2.1.3.2 Elemental analysis

Elemental analysis is a process where a sample of some material (e.g., soil, waste or drinking water, bodily fluids, minerals, chemical compounds) is analyzed for its elemental and sometimes isotopic composition. Elemental analysis can be qualitative (determining what elements are present), and it can be quantitative (determining how much of each is present). Elemental analysis falls within the ambit of analytical chemistry, the instruments involved in deciphering the chemical nature of our world.
@ Elemental analysis - Wikipedia: https://en.wikipedia.org/wiki/Elemental_analysis, accessed on 6 August 2025

2.1.3.3 X-ray diffraction (XRD)

The principal advantage of XRD is that a qualitative or semiquantitative evaluation of mineralogy is generated. A fixed wavelength X-ray source such as copper X-ray tubes, which have a 1.54A wavelength, is used to irradiate a powdered sample. The incident angle θ of the diffracted beam and the intensity are recorded with a counter or tube. If parallel planes of atoms of a crystal are struck at the same angle, coherent (additive) intensity is detected and recorded as a peak. Bragg's Law is the basis for determining the characteristic peaks (d spacing) for known minerals and compounds ($n\lambda = 2d \sin \theta$). Tables of standards established by the JCPDS (Joint Council of Powder Diffraction Standards) can be consulted for mineral identification, where θ is the incident angle, λ the X-ray wavelength and d the spacing between planes of atoms in the crystal.
@ Cullity B D, 1959. Elements of X-ray Diffraction: Reading, MA, Addison-Wesley, 514.

@ SEM, XRD, CL, and XF methods - AAPG Wiki:
https://wiki.aapg.org/SEM,_XRD,_CL,_and_XF_methods, accessed on 6 August 2025

2.1.3.4 Microscopic analysis

Microscopy is the technical field of using microscopes to view subjects too small to be seen with the naked eye (objects that are not within the resolution range of the normal eye).
@ Microscopy - Wikipedia: https://en.wikipedia.org/wiki/Microscopy, accessed on 15 August 2025

2.1.3.4.1 Optical microscopy

The optical microscope, also referred to as a light microscope, is a type of microscope that commonly uses visible light and a system of lenses to generate magnified images of small objects. Optical microscopes are the oldest design of microscope and were possibly invented in their present compound form in the 17th century. Basic optical microscopes can be very simple, although many complex designs aim to improve resolution and sample contrast.
@ Optical microscopy - Wikipedia: https://en.wikipedia.org/wiki/Optical_microscope, accessed on 6 August 2025

2.1.3.4.2 Scanning electron microscopy (SEM)

The mechanics of the modern scanning electron microscope (SEM) system allow for various imaging and detecting techniques that can be used to study different aspects of the composition of samples at very high resolution. Scanning electron microscopy, unlike conventional light microscopy, produces images by recording various signals resulting from interactions of an electron beam with the sample as it is scanned in a raster pattern across the sample surface. A fine electron probe, with a spot size from a few angstroms to several hundred nanometers, is generated by focusing electrons emanating from an electron source (conventionally called the electron gun) onto the surface of the specimen using a series of electro-optical lens elements. The combination of the source and the lens elements is called the electron column.
@ Scanning electron microscopy (SEM) - AAPG Wiki:
https://wiki.aapg.org/Scanning_electron_microscopy_(SEM), accessed on 6 August 2025

2.1.3.4.3 Transmission electron microscopy (TEM)

Transmission electron microscopy (TEM) is a microscopy technique in which a beam of electrons is transmitted through a specimen to form an image. The specimen is most often an ultrathin section less than 100 nm thick or a suspension on a grid. An image is formed from the interaction of the electrons with the sample as the beam is transmitted through the specimen. The image is then magnified and focused onto an imaging device, such as a fluorescent screen, a layer of photographic film, or a detector such as a scintillator attached to a charge-coupled device or a direct electron detector.
@ Transmission electron microscopy-Wikipedia:
https://en.wikipedia.org/wiki/Transmission_electron_microscopy, accessed on 6 August 2025

2.1.3.4.4 Fluorescence microscopy

A fluorescence microscope is an optical microscope that uses fluorescence instead of, or in addition to, scattering, reflection, and attenuation or absorption, to study the properties of organic or inorganic substances. A fluorescence microscope is any microscope that uses fluorescence to

generate an image, whether it is a simple setup like an epifluorescence microscope or a more complicated design such as a confocal microscope, which uses optical sectioning to get better resolution of the fluorescence image.
@ Fluorescence microscopy - Wikipedia:
https://en.wikipedia.org/wiki/Fluorescence_microscope, accessed on 6 August 2025

2.1.3.5 Well log analysis

Well logging, also known as borehole logging is the practice of making a detailed record (a well log) of the geologic formations penetrated by a borehole. The log may be based either on visual inspection of samples brought to the surface (geological logs) or on physical measurements made by instruments lowered into the hole (geophysical logs). Some types of geophysical well logs can be done during any phase of a well's history: drilling, completing, producing, or abandoning. Well logging is performed in boreholes drilled for the oil and gas, groundwater, mineral and geothermal exploration, as well as part of environmental, scientific and geotechnical studies.
@ Well logging - Wikipedia: https://en.wikipedia.org/wiki/Well_logging, accessed on 15 August 2025

2.1.3.5.1 Gamma-ray log

Gamma-ray logs measure the natural radioactivity which is produced in the rock. The elements which produce gamma radiation of significance in ordinary sedimentary rocks are potassium, thorium and uranium. Shale normally contains the most of these elements and the gamma reading of shales is almost always higher than that of sandstones.
@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.

2.1.3.5.2 Resistivity log

Resistivity logs are the result of measuring the resistance between 2 and 4 electrodes which are in contact with the rocks in the well wall. Resistivity (in ohms) is measured as a function of the cross-section (m^2) of the rock and the distance (m) between the electrodes. The resistivity R = ohm $\cdot m^2$ /m, and the unit is ohm meter.
@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.

2.1.3.5.3 Density log

The density log records bulk density; hence porous rocks record a lower density than do rocks of similar mineralogy but lower density. The log is created by emitting gamma rays into the formation and measuring the intensity of the returning gamma rays.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA
@ Density logging - Wikipedia: https://en.wikipedia.org/wiki/Density_logging, accessed on 5 August 2025

2.1.3.5.4 Neutron log

Neutron logs (also called neutron porosity logs) determine the hydrogen atom concentration in a formation, and since almost all of the hydrogen occurs in the fluid phase (petroleum and/or water) such measurements can be transposed to porosity data.

@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

2.1.3.5.5 Sonic log
A sonic log measures the time it takes for a sound pulse to travel from a transmitter to a receiver via the formation. Sonic logs can be used for measuring porosity but are more commonly used by the geophysicist as they give velocity information for calibrating seismic data. Velocity data allow the geophysicist to convert the time taken for a seismic wave to travel down and back from a specific seismic reflector into an equivalent subsurface depth.
@ Gerhardt J H, and Haldorsen H H, 1989. On the value of information: Presented at Offshore Europe, Society of Petroleum Engineers, September 5–8, Aberdeen, United Kingdom, SPE Paper 19291, 11.
@ Data: sources - AAPG Wiki: https://wiki.aapg.org/Data:_sources, accessed on 5 August 2025

2.1.3.5.6 Nuclear magnetic resonance (NMR) log
NMR logging, a subcategory of electromagnetic logging, measures the induced magnet moment of hydrogen nuclei (protons) contained within the fluid-filled pore space of porous media (reservoir rocks). Unlike conventional logging measurements (e.g., acoustic, density, neutron, and resistivity), which respond to both the rock matrix and fluid properties and are strongly dependent on mineralogy, NMR-logging measurements respond to the presence of hydrogen protons. Because these protons primarily occur in pore fluids, NMR effectively responds to the volume, composition, viscosity, and distribution of these fluids such as oil, gas and water.
@ Nuclear magnetic resonance (NMR) logging: https://onepetro.org/spe/general-information/1857/Nuclear-magnetic-resonance-NMR-logging, accessed on 5 August 2025

2.1.3.6 Seismic analysis
We can enhance our recognition of stratigraphic features by using seismic data attributes, reflection strength, coherence, and instantaneous phase. These attributes are well suited to stratigraphic interpretation and are an effective interpretive tool when displayed in map view.
@ Seismic data: analyzing individual reflectors: https://wiki.aapg.org/Seismic_data:_analyzing_individual_reflectors, accessed on 15 August 2025

2.1.3.6.1 Seismic facies analysis
Seismic facies analysis is the description and geological interpretation of seismic reflectors between sequence boundaries. It includes the analysis of such parameters as the configuration, continuity, amplitude, phase, frequency, and interval velocity. These variables give an indication of the lithology and sedimentary environment of the facies.
@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego

2.1.3.6.2 Amplitude versus offset (AVO) analysis
The amplitude versus offset (AVO) phenomena on seismic data can provide substantial exploration and development information. Under good conditions the information extracted can be as detailed as an elastic layered model of the earth in the vicinity of the exploration or development target.
@Amplitude versus offset (AVO) analysis - AAPG Wiki: https://wiki.aapg.org/Amplitude_versus_offset_(AVO)_analysis, accessed on 5 August 2025

2.1.3.6.3 Spectral decomposition
Spectral decomposition is a way of breaking down a seismic trace into its discrete component frequencies.
@ Lithofacies maps - AAPG Wiki: https://wiki.aapg.org/Lithofacies_maps, accessed on 5 August 2025

2.1.3.6.4 Seismic inversion
The object of seismic inversion is to convert the seismic interpreter's view of timing between seismic reflections as a function of time to the geologist's view of the velocity as a function of depth.
@ Seismic inversion - AAPG Wiki: https://wiki.aapg.org/Seismic_inversion, accessed on 5 August 2025

2.1.4 Source rock distribution
It describes how source rocks are distributed spatially and stratigraphically.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.1.5 Source rock quality assessment
Source Rock Quality Assessment refers to the evaluation of the potential of a sedimentary rock (typically rich in organic matter) to generate and expel hydrocarbons (oil and gas). It involves analyzing key geochemical and geological properties to determine the quantity, type, and maturity of organic matter, which together define how effective the rock is as a source of petroleum.
@ Source Rock Evaluation - SEG: https://wiki.seg.org/wiki/Source_Rock_Evaluation, accessed on 15 August 2025

2.1.5.1 Quantity of organic matter
Quantity of Organic Matter refers to the amount of organic material present in a sedimentary rock, typically measured as the weight percentage of organic carbon relative to the total rock mass.
@ Amount of organic matter in soils - SARE: https://www.sare.org/publications/building-soils-for-better-crops/amount-of-organic-matter-in-soils/, accessed on 15 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.1.5.1.1 Poor source rock
TOC <0.5 wt. %, S_1 <0.5, S_2<2.5, Bitumen <500 ppm, Hydrocarbons <300 ppm.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.1.2 Fair source rock
TOC 0.5-1.0 wt. %, S_1 0.5-1.0, S_2 2.5-5.0, Bitumen 500-1000 ppm, Hydrocarbons 300-600 ppm.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.1.3 Good source rock
TOC 1.0-2.0 wt. %, S_1 1.0-2.0, S_2 5.0-10.0, Bitumen 1000-2000 ppm, Hydrocarbons 600-1200 ppm.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.1.4 Very good source rock
TOC 2.0-4.0 wt. %, S_1 2.0-4.0, S_2 10.0-20.0, Bitumen 2000-4000 ppm, Hydrocarbons 1200-2400 ppm.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.1.5 Excellent source rock
TOC >4.0 wt. %, S_1 >4.0, S_2 >20.0, Bitumen >4000 ppm, Hydrocarbons >2400 ppm.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.2 Quality of organic matter (Kerogen type)
The quality of organic matter is often assessed by determining the type of kerogen present in a rock. Kerogen is the solid, insoluble organic material found in sedimentary rocks and serves as the precursor to hydrocarbons such as oil and gas. The type of kerogen can significantly influence the potential for hydrocarbon generation.
@ Kerogen - AAPG: https://wiki.aapg.org/Kerogen, accessed on 15 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.1.5.2.1 Type I kerogen
HI (mg HC/g TOC)>600, S_2/S_3>15, Atomic H/C >1.5.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.2.2 Type II kerogen
HI (mg HC/g TOC) 300-600, S_2/S_3 10-15, Atomic H/C 1.2-1.5.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.2.3 Type II/III kerogen
HI (mg HC/g TOC) 200-300, S_2/S_3 5-10, Atomic H/C 1.0-1.2.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.2.4 Type III kerogen

HI (mg HC/g TOC) 50-200, S2/S3 1-5, Atomic H/C 0.7-1.0.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.2.5 Type IV kerogen

HI (mg HC/g TOC) <50, S2/S3 <1, Atomic H/C <0.7.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.3 Thermal maturity (Maturity of organic matter)

In petroleum geology, the maturity of a rock is a measure of its state in terms of hydrocarbon generation. Maturity is established using a combination of geochemical and basin modelling techniques.

@ Maturity (geology)- Wikipedia: https://en.wikipedia.org/wiki/Maturity_(geology), accessed on 15 August 2025

2.1.5.3.1 Immature (Immature stage for oil)

Ro (%) 0.2-0.6, T_{max} (^oC) <435, TAI 1.5-2.6.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.3.2 Mature (Mature stage for oil)

Ro (%) 0.6-1.35, T_{max} (^oC) 435-470, TAI 2.6-3.3.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.3.2.1 Early mature (Early mature stage for oil)

Ro (%) 0.6-0.65, T_{max} (^oC) 435-445, TAI 2.6-2.7.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.3.2.2 Peak mature (Peak mature stage for oil)

Ro (%) 0.65-0.9, T_{max} (^oC) 445-450, TAI 2.7-2.9.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.3.2.3 Late mature (Late mature stage for oil)

Ro (%) 0.9-1.35, T_{max} (^oC) 450-470, TAI 2.9-3.3.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.5.3.3 Postmature/Overmature (Postmature/overmature stage for oil)
Ro (%) >1.35, T_{max} (°C) >470, TAI >3.3.
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

2.1.6 Source rock modeling

Source Rock Modeling is the process of simulating the burial, thermal history, and chemical evolution of organic-rich sedimentary rocks (source rocks) over geological time to predict the timing, quantity, and type of hydrocarbons generated and expelled. It integrates geological, geochemical, and geophysical data into a numerical framework to reconstruct the history of a sedimentary basin and assess the petroleum generation potential of source rocks within it.
@ Bou Daher, S. et al. (2023). Source Rocks Forward Modelling: Significance and Approach. In: El Atfy, H., Ghassal, B.I. (eds) Advances in Petroleum Source Rock Characterizations: Integrated Methods and Case Studies. Advances in Science, Technology & Innovation. Springer, Cham. https://doi.org/10.1007/978-3-031-16396-8_4
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 202

2.1.6.1 Basin modeling

Basin modeling is designed to describe the burial of source rocks, the hydrocarbon generation in those rocks, and the expulsion, migration, trapping, and preservation of those hydrocarbons. The definition of basin modeling as presently used usually corresponds more closely to the concept of a sedimentary basin than to that of a petroleum system. A single basin modeling simulation often includes several petroleum systems, without separating or distinguishing among them.
@ Waples D W, 1994. Thermal modeling: Thermal Indicators, hydrocarbon generation, and oil cracking, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.307-322.

2.1.6.2 Maturity modeling

All maturity modeling should begin with a clear conceptual model of geologic history because modeling based on inadequate geologic concepts is likely to show serious weaknesses under close scrutiny. One important objective of maturity modeling is to test the original geologic model and suggest improvements. The second major objective is to obtain information about the status and history of hydrocarbon generation and thus help to determine whether a petroleum system exists.
@ Waples D W, 1994. Thermal modeling: Thermal Indicators, hydrocarbon generation, and oil racking, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.307-322.

2.1.6.2.1 Time-Temperature Index
TTI modeling (Lopatin, 1971; Waples, 1980) assumes that (l) only time and temperature are important factors in maturation and (2) time and temperature can be substituted for each other (e.g., the lower the temperature, the longer the time required to reach a given level of thermal

maturity). Pressure effects are neglected. The way in which time and temperature are interconverted depends on a gross simplification of basic principles of chemical kinetics.
@ Waples D W, 1994. Thermal modeling: Thermal Indicators, hydrocarbon generation, and oil cracking, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.307-322.

2.1.6.2.2 Kinetic modeling
Kinetic modeling is used both to predict hydrocarbon generation and oil cracking and to model the behavior of some thermal indicators. The theoretical foundation of kinetic modeling is much more solid than that of TTI modeling, but is still imperfect. Kinetic models assume that a given process (such as hydrocarbon generation or vitrinite reflectance change) consists of one or several parallel chemical reactions. Kinetic parameters for each individual reaction are derived from laboratory experiments, empirical data from wells, or both. The maturation of different types of organic matter (including different types of kerogen) can be modeled using different kinetic parameters.
@ Waples D W, 1994. Thermal modeling: Thermal Indicators, hydrocarbon generation, and oil cracking, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.307-322.

2.2 Reservoir rock
A reservoir rock is a porous and permeable rock that has both storage capacity and the ability to allow fluids to flow through it.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.2.1 Reservoir rock type
There are two major types of reservoir rocks in terms of lithology and they are siliciclastic and carbonate reservoir rocks.
@ Magoon, L. B, and W. G. Dow, eels., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60

2.2.1.1 Siliciclastic reservoir
Siliciclastic reservoir rocks are primarily composed of silicate minerals and owe much of their diversity and stratigraphic heterogeneity to the many different depositional environments in which they are deposited. These hydrocarbon reservoirs are formed in settings ranging from continental alluvial sands and gravels to deep submarine fans.
@ Morese, D G, 1994. Siliciclastic reservoir rocks, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.121-139.

2.2.1.1.1 Conglomerate reservoir
It refers to porous conglomerate which acts as the reservoir rock.
@ Morese, D G, 1994. Siliciclastic reservoir rocks, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.121-139.

2.2.1.1.2 Sandstone reservoir

It refers to porous sandstone which acts as the reservoir rock. It the most common siliciclastic reservoir.

@ Morese, D G, 1994. Siliciclastic reservoir rocks, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.121-139.

2.2.1.1.3 Tight sandstone reservoir (tight sand reservoir) (tight reservoir)

A tight sandstone is one in which the permeability to gas flow is less than 0.1 md.

@ Tight gas reservoirs: https://petrowiki.spe.org/Tight_gas_reservoirs, accessed on 5 August 2025

2.2.1.1.4 Shale reservoir (mudstone reservoir)

It refers to shale which acts as both the reservoir rock and source rock in an unconventional petroleum system or as fractured shale which acts as the reservoir rock only.

@ Breyer, J. A., 2012, Shale reservoirs, in J. A. Breyer, ed., Shale reservoirs—Giant resources for the 21st century: AAPG Memoir 97, p. x– xii.

2.2.1.1.4.1 Classification by grain size

Already defined in sedimentary petrology discipline

2.2.1.1.4.1.1 Coarse mudstone reservoir (siltstone reservoir)

Course mudstone serves as the reservoir rock.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.1.1.4.1.2 medium mudstone reservoir (mudstone reservoir)

Medium mudstone serves as the reservoir rock.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.1.1.4.1.3 fine mudstone reservoir (claystone reservoir)

Fine mudstone serves as the reservoir rock.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.1.1.4.2 Classification by composition

Already defined in sedimentary petrology discipline

2.2.1.1.4.2.1 Argillaceous mudstone reservoir

Argillaceous mudstone serves as the reservoir rock.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.1.1.4.2.2 Siliceous mudstone reservoir

Siliceous mudstone serves as the reservoir rock.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.1.1.4.2.3 Calcareous mudstone reservoir

Calcareous mudstone serves as the reservoir rock.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.1.1.4.2.4 Mixed mudstone reservoir
Mixed mudstone serves as the reservoir rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.1.2 Carbonate reservoir
Carbonate reservoirs are comprised of a sedimentary rock having a carbonate mineral fraction exceeding 50%. Dolomites, grainstones, and boundstones are the most common carbonate reservoir rock types. Secondary pore types tend to dominate carbonate reservoir facies, as opposed to primary pore types. The main factors in evaluating carbonate reservoirs are lithofacies, pore types, shelf setting, sequence stratigraphy, and diagenetic overprint. Inner shelf, outer shelf, and slope lithofacies belts are prime exploration fairways that are relatively predictable, with middle shelf prospects being less so.
@ Jordan, C F Jr, and Wilson, J L, 1994. Carbonate reservoir rocks, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 140-158.

2.2.1.2.1 Limestone reservoir
It refers to the porous limestone which acts as the reservoir rock.
@ Gluyas J. & Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

2.2.1.2.2 Dolomite (dolostone) reservoir
It refers to the porous dolomite (dolostone) which acts as the reservoir rock.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

2.2.1.2.3 Chalk reservoir
It refers to the chalk which acts as the reservoir rock.
@ Carbonate reservoir - AAPG Wiki: https://wiki.aapg.org/Carbonate_reservoir, accessed on 5 August 2025

2.2.1.3 Fractured reservoirs
Fractured reservoirs are geological formations where the primary storage and flow of hydrocarbons are facilitated by fractures rather than the matrix porosity. These fractures can cross-cut different lithologies, including hard, nonporous mudstones, and can significantly enhance permeability even in rocks with low porosity. Fractured reservoirs may be in full pressure communication through fractures, allowing for the extraction of oil from one reservoir to affect the oil/water contact in another. The presence of fractures is critical for the production of oil and gas, as their absence would either prevent production or seriously reduce it.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.1.3.1 Natural fractures

Natural fractures are diagenetic fractures and/or tectonic fractures. They are mechanical breaks in rocks, which form in nature, in response to litho-static, tectonic and thermal stress and high fluid pressure. They occur in a variety of scales and with high degree of heterogeneity.

@ Mohaghegh S D, 2013. Reservoir modeling of shale formations, Journal of Natural Gas Science and Engineering, 12, p.22-33.

2.2.1.3.2 Induced fractures

Induced fractures are those induced artificially, e.g., by coring, core handling, drilling, fluid injection (fracking), etc.

@ Ameen M S and Hailwood E A, 2008. A new technology for the characterization of microfractured reservoirs (test case Unayzah reservoir, Wudayhi field, Saudi Arabia), AAPG Bulletin, v.92(01), p.31-52. DOI:10.1306/08200706090

2.2.1.3.3 Fractured shale reservoir

Fractured shale serves as reservoir rock.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.1.3.4 Fractured igneous reservoir

Fractured igneous rock serves as reservoir rock.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.1.3.5 Fractured metamorphic reservoir

Fractured metamorphic rock serves as reservoir rock.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.2 Petrophysical properties

They refer to the properties characterizing the reservoir rocks, which include porosity, permeability, saturation, wettability, and capillary pressure.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.2.1 Porosity

Porosity φ is the ratio of void space within a rock (or sediment) relative to bulk volume. It reflects the fluid storage capacity of the reservoir.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.2.2.1.1 Pore system

Pores consist of relatively large voids, or pores, distributed among smaller passages called pore throats. A pore system is an aggregate of pores and pore throats that share a similar morphology. These elements play a role in determining reservoir and seal petrophysics (the characteristic way that oil, gas, and water move through rocks).

@ Pore system fundamentals - AAPG Wiki: https://wiki.aapg.org/Pore_system_fundamentals, accessed on 5 August 2025

2.2.2.1.1.1 Pore throat size

Pore and pore throat sizes have two defining parameters of absolute size and aspect ratio.

@ Pore and pore throat sizes - AAPG Wiki: https://wiki.aapg.org/Pore_and_pore_throat_sizes, accessed on 5 August 2025

2.2.2.1.1.1.1 Absolute size (size)

Absolute size of a pore throat is the radius of a circle drawn perpendicular to fluid flow and fitting within its narrowest point. Absolute size of a pore is the radius of the largest sphere that will fit inside it. The cross-sectional shape of fluids moving through intergranular porosity is roughly circular. Both pores and pore throats can be divided into petrophysically significant size ranges.
@ Pore and pore throat sizes - AAPG Wiki: https://wiki.aapg.org/Pore_and_pore_throat_sizes, accessed on 5 August 2025

2.2.2.1.1.1.2 Aspect ratio

Aspect ratio is the ratio of pore size to pore throat size. Geometrical reasoning and limited experimental data suggest that aspect ratios have small ranges in intergranular and intercrystalline pore systems (see Reservoir quality). Disparate Archie rock types such as quartz-cemented sandstones, bioturbated sandstones, and sucrosic dolomites have aspect ratios that range between 5:1 and 10:1. Non-Archie rock types have even larger variations in aspect ratios.
@ Pore and pore throat sizes - AAPG Wiki: https://wiki.aapg.org/Pore_and_pore_throat_sizes, accessed on 5 August 2025

2.2.2.1.1.2 Pores in sandstone

Four basic porosity types can be recognized in sandstones: intergranular (primary), microporosity, dissolution (secondary), and fracture.
@ Pittman, E. D., 1979, Porosity, diagenesis and productive capability of sandstone reservoirs. SEPM Spec. Pub. 26, p.159–173.

2.2.2.1.1.2.1 Intergranular porosity

This type of porosity exists as space between detrital grains.
@ Pittman, E. D., 1979, Porosity, diagenesis and productive capability of sandstone reservoirs. SEPM Spec. Pub. 26, p.159–173.

2.2.2.1.1.2.2 Microporosity

This type of porosity exists as small pores (less than 2 μm) commonly associated with detrital and authigenic clay minerals.
@ Pittman, E. D., 1979, Porosity, diagenesis and productive capability of sandstone reservoirs. SEPM Spec. Pub. 26, p.159-173.

2.2.2.1.1.2.3 Dissolution porosity

This type of porosity is the pore space formed from the partial to complete dissolution of framework grains and/or cements.
@ Pittman, E. D., 1979, Porosity, diagenesis and productive capability of sandstone reservoirs. SEPM Spec. Pub. 26, p.159-173.

2.2.2.1.1.2.4 Fracture porosity

This type of porosity is the void space associated with natural fractures.

@ Pittman, E. D., 1979, Porosity, diagenesis and productive capability of sandstone reservoirs. SEPM Spec. Pub. 26, p.159-173.

2.2.2.1.1.3 Pores in carbonates

In comparison to clastic pore systems, pore types in carbonate rocks are more varied. Three basic pore groups can be recognized: fabric selective, not fabric selective, and fabric selective or not. Seven porosity types (interparticle, intraparticle, intercrystal, moldic, fenestral, fracture, and vugs) are common and volumetrically important.
@ Choquette PW, Pray LC (1970) Geological nomenclature and classification of porosity in sedimentary carbonates. AAPG Bull 54, p.207–250

2.2.2.1.1.3.1 Interparticle porosity

It refers to porosity between particles.
@ Choquette PW, Pray LC (1970) Geological nomenclature and classification of porosity in sedimentary carbonates. AAPG Bull 54, p.207–250

2.2.2.1.1.3.2 Intraparticle porosity

It refers to porosity within individual particles or grains.
@ Choquette PW, Pray LC (1970) Geological nomenclature and classification of porosity in sedimentary carbonates. AAPG Bull 54, p.207–250

2.2.2.1.1.3.3 Moldic porosity

It refers to porosity formed by selective removal of an individual constituent of the rock.
@ Choquette PW, Pray LC (1970) Geological nomenclature and classification of porosity in sedimentary carbonates. AAPG Bull 54, p.207–250

2.2.2.1.1.3.4 Fenestral porosity

It refers to pores larger than grain-supported interstices (interparticle). These voids, or fenestrae, are can be formed by various processes, including gas bubbles, dissolution of former evaporite pockets, sediment shrinkage, or the decay of organic matter.
@ Choquette PW, Pray LC (1970) Geological nomenclature and classification of porosity in sedimentary carbonates. AAPG Bull 54, p.207–250

2.2.2.1.1.3.5 Fracture porosity

It refers to porosity formed by fracturing.
@ Choquette PW, Pray LC (1970) Geological nomenclature and classification of porosity in sedimentary carbonates. AAPG Bull 54, p.207–250

2.2.2.1.1.3.6 Vug porosity

It refers to pores larger than 1/16 mm in diameter and somewhat equant in shape.
@ Choquette PW, Pray LC (1970) Geological nomenclature and classification of porosity in sedimentary carbonates. AAPG Bull 54, p.207–250

2.2.2.1.2 Porosity type

Porosities can be classified according to effectiveness and origin.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.2.1.2.1 Type by effectiveness of pores
Porosity is classified into different types on basis of effectiveness of pores hosting hydrocarbons.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.2.1.2.1.1 Total porosity
It is all void space in a rock whether effective or noneffective.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.2.2.1.2.1.2 Effective porosity
It is the interconnected pore volume available to free fluids. It describes the proportion of pore space that is sufficiently connected to yield recoverable hydrocarbons.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.2.2.1.2.1.3 Ineffective porosity
Ineffective porosity refers to isolated or dead-end pores that do not contribute to fluid flow, but it can affect the overall storage capacity of a reservoir.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.2.2.1.2.2 Type by origin of pores
Porosity is classified into different types on the ways in which pores were formed.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.2.1.2.2.1 Primary porosity
Primary porosity represents the original porosity of a sediment due to variations in grain size, packing, grain shape, sorting, and the amount of cement and/or matrix material. It is the amount of pore space present in the sediment at the time of deposition, or formed during sedimentation.
@ Pettijohn F J, 1957, Sedimentary Rocks (2nd edition), Harper and Brothers, New York

2.2.2.1.2.2.2 Secondary porosity
Secondary porosity is the porosity that is formed in response to post-depositional changes or diagenesis.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.2.2.2 Permeability
Permeability (K) is the ability of a rock to transmit fluids, without changing the structure of the rock or a displacement of its components.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.2.2.2.1 Absolute permeability
Reservoirs contain water and oil or gas in varying amounts. Each interferes with and impedes the flow of the others. The aquifer portion of a reservoir system by definition contains water as a single phase (100% S_w). The permeability of that rock to water is absolute permeability (K_{ab}).

@ Relative permeability - AAPG Wiki: https://wiki.aapg.org/Relative_permeability, accessed on 5 August 2025

2.2.2.2.2 Effective permeability
The permeability of a reservoir rock to any one fluid in the presence of others is its effective permeability to that fluid. It depends on the values of fluid saturations.
@ Relative permeability - AAPG Wiki: https://wiki.aapg.org/Relative_permeability, accessed on 5 August 2025

2.2.2.2.3 Relative permeability
Relative permeability to oil (K_{ro}), gas (K_{rg}), or water (K_{rw}) is the ratio of effective permeability of oil, gas, or water to absolute permeability. Relative permeability can be expressed as a number between 0 and 1.0 or as a percent. Pore type and formation wettability affect relative permeability.
@ Relative permeability - AAPG Wiki: https://wiki.aapg.org/Relative_permeability, accessed on 5 August 2025

2.2.2.2.4 Directional permeability
Permeability that varies with direction of flow through the porous medium. Lateral permeability contrast can be particularly important in fractured formations, where effective.
@ directional permeability – Glossary:
https://glossary.slb.com/en/terms/d/directional_permeability, accessed on 13 June 2025

2.2.2.2.4.1 Vertical permeability
Vertical permeability refers to the permeability perpendicular to bedding planes.
@ Permeability - AAPG Wiki: https://wiki.aapg.org/Permeability, accessed on 13 June 2025

2.2.2.2.4.2 Horizontal permeability
Horizontal permeability refers to the permeability parallel to the bedding planes.
@ Permeability - AAPG Wiki: https://wiki.aapg.org/Permeability, accessed on 13 June 2025

2.2.2.2.5 Matrix permeability
Matrix permeability refers to the intrinsic ability of a porous rock or sediment to transmit fluids through its interconnected pore network, independent of fractures, joints, or other macro-scale features. It is a critical parameter in subsurface hydrology, petroleum engineering, and geothermal energy systems, as it governs fluid flow and resource recovery efficiency. It's often measured in millidarcies (mD). Tight formations are those with an inherently low permeability.
@Curtis J B, 2002. Fractured shale-gas systems, AAPG Bulletin, v.86(11), p.1921-1938
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 12 August 2025

2.2.2.2.6 Fracture permeability
Fracture permeability refers to the dependence of production on fracture permeability (either natural or as a result of stimulation) for low-matrix-permeability rocks containing large amounts of hydrocarbons, but with low recovery factors.

@ Jarvie D M, Hill R J, Ruble, T E and Pollastro R M, 2007. Unconventional shale-gas systems: The Mississippian Barnett Shale of north-central Texas as one model for thermogenic shale-gas assessment, AAPG Bulletin, 91(4), 475-499.

2.2.2.2.7 Permeability measurement techniques

Permeability measurement techniques are methods used to quantify a rock's ability to transmit fluids (such as water, oil, or gas) through its pore network. Permeability is a critical property in petroleum engineering, hydrogeology, and reservoir characterization, typically measured in units of millidarcies (mD).
@ NIH: https://www.ncbi.nlm.nih.gov/books/NBK54124/, accessed on 15 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.2.2.7.1 Laboratory methods
Permeability can be measured using various laboratory techniques, including: (1) Steady-state methods which measure flow rate at a constant pressure difference. (2) Transient techniques, such as pulse decay or pressure build-up, which analyze pressure changes over time.
@ *Permeability - AAPG Wiki: https://wiki.aapg.org/Permeability*, accessed on 13 June 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.2.2.7.2 Well testing methods
Well testing methods for permeability involve various techniques to determine the ability of subsurface formations to transmit fluids. These methods include (1) hydraulic well test analysis, (2) Pressure pulse test (Lugeon test), Stonely wave analysis, and impression packer tests.
@ Defining well testing - SLB: https://www.slb.com/resource-library/oilfield-review/defining-series/defining-well-testing/, accessed on 15 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.2.3 Fluid saturation
It is rare in nature to find a reservoir entirely oil- (or gas-) saturated. More commonly, the pore system contains both oil and water. The proportions of each phase are usually expressed as percentages, linked to the abbreviations S_w for water, So for oil, and Sg for gas.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

2.2.2.3.1 Oil saturation
Oil saturation (So) is the percentage of the pore volume in a porous rock that is occupied by oil, expressed as the ratio of the volume of oil to the total pore volume of the rock.
@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.
@ Fluid flow fundamentals - AAPG Wiki: https://wiki.aapg.org/Fluid_flow_fundamentals, accessed on 5 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.2.3.2 Gas saturation
Gas saturation is expressed as a fraction or percentage of the pore space occupied by gas.

@ Chapman R E, 1983. Petroleum Geology, Elsevier, Amsterdam.

2.2.2.3.3 Water saturation

Water saturation is the quantity of water in a petroleum-bearing reservoir, commonly expressed as a fraction or percentage of the pore space.

@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

2.2.2.3.4 Irreducible water saturation

Irreducible water saturation is the value of water saturation at which all of the contained water will be trapped by capillary pressure and/or by adsorption of water on the surface of rock grains (surface tension). At irreducible water saturation, all of the water within the reservoir will be immovable, and hydrocarbon production will be water-free.

@ Haliburton, 2001. Basic Petroleum Geology, Haliburton

2.2.2.3.5 Saturation measurement

Saturation Measurement refers to the determination of the proportion (or fraction) of pore space in a rock that is filled by a specific fluid, such as oil, gas, or water. It is typically expressed as a percentage or fraction between 0 and 1.

@ Ultimate guide to saturation - NumberAnalytics: https://www.numberanalytics.com/blog/ultimate-guide-to-saturation, accessed on 15 August 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.2.4 Wettability

Physically, wettability represents a balance of forces that occur at the interface between three phases, one of which is a solid. In an oil reservoir it controls reservoir quality by affecting the amount of water production. When the reservoir rock is oil-wet, water is located in the central portion of the pores and will flow through the pore system with the oil. Conversely, in a water-wet reservoir, the water is restricted to the perimeter of the pores and will not flow through the pore system until much of the oil has been removed. In addition, the irreducible water saturations of oil-wet reservoirs tend to be much lower than those of water-wet reservoirs.

@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.2.4.1 Wetting fluid

It refers to the fluid which can easily adhere to the solid, also called wetting phase.

@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.2.4.1.1 Water-wet

In a pore system with oil and water, water is the wetting phase if it adheres to the grain surfaces. Oil is the non-wetting phase. The rock is water-wet.

@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.2.4.1.2 Oil-wet

In a pore system with oil and water, oil is the wetting phase if it adheres to the grain surfaces. Oil is the wetting phase. The rock is oil-wet.

@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.2.4.2 Non-wetting fluid

It refers to the fluid which can hardly adhere to the solid, also called nonwetting phase.

@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.2.4.3 Mixed wettability

Following oil migration, sandstone reservoirs can end up as predominantly water wet, predominantly oil wet, or more frequently in a mixed-wettability state, that is, somewhere in between oil wet and water wet. Carbonate reservoirs are commonly described as showing mixed wettability tending to oil wet.

@ Treiber L E, Archer D L, and Owens W W, 1972. A laboratory evaluation of the wettability of fifty oil-producing reservoirs, Society of Petroleum Engineers 46th Annual Fall Meeting, 12(6), 531–540.

@ Chilingar G V, and Yen T F, 1983. Some notes on wettability and relative permeabilities of carbonate reservoir rocks, Energy Sources, 7(1), 67–75.

@ Reservoir fluids - AAPG Wiki: https://wiki.aapg.org/Reservoir_fluids, accessed on 5 August 2025

2.2.3 Non-petrophysical properties

They refer to properties which are not related to petrophysics.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.2.3.1 Capillary pressure

Capillary pressure is defined as the difference in pressure across the meniscus in the capillary tube. Put another way, capillary pressure is the amount of extra pressure required to force the nonwetting phase to displace the wetting phase in the capillary. The capillary pressure of a reservoir affects the magnitude and distribution of water saturation and thus the hydrocarbon volume in a given reservoir area. The capillary pressure is a function of the capillary radius, the interfacial tension, and the contact angle between the water and the solid. In a reservoir, zones with larger pores and pore throats have lower capillary pressure, lower irreducible water saturation, and higher hydrocarbon pore volume.

@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.3.2 Electrical properties

Electrical properties refer to a material's ability to conduct electric current. Electrical properties include electrical resistance, high conductivity, operators of rebellion, dielectric strength, and associated expenses. Electrical resistivity resists the flow of electric current through it. It is a give-and-take of the absorption coefficient—ohm centimetres. As previously stated, resistivity values are merely the absorption coefficient's give and take.
@ Electrical properties - unacademy: https://unacademy.com/content/cbse-class-12/study-material/physics/electrical-properties/, accessed on 15 August 2025

2.2.3.2.1 Formation resistivity factor

The Formation Resistivity Factor (F) is a dimensionless material constant that is used in electrical-log interpretation. It is defined as the ratio of the resistivity of a porous rock that is saturated with an electrolyte to the resistivity of the electrolyte. It is a measure of porosity and is proportional to the square of the tortuosity and inversely proportional to the porosity of the material. It is independent of the resistivity and salinity of the pore fluid.
@ Chapman R E, 1983. Petroleum Geology, Elsevier, Amsterdam

2.2.3.2.2 Cementation factor

The cementation factor (m) is a parameter in the Archie's equation that relates the electrical resistivity of a porous rock to the water saturation. It is used in the formula $S_w^n = (aR_w)/(\phi^m R_t)$, where n is the saturation exponent, a is the tortuosity, Rt is the measured formation resistivity in ohm-m, and S_w is the water saturation.
@ Cross-well electromagnetic tomography monitoring of fluid distribution - AAPG Wiki: https://wiki.aapg.org/Cross-well_electromagnetic_tomography_monitoring_of_fluid_distribution, accessed on 5 August 2025

2.2.3.2.3 Saturation exponent

The saturation exponent describes how the tortuosity of the conductive paths in the formation increases as the water saturation decreases.
@ Standard interpretation - AAPG Wiki: https://wiki.aapg.org/Standard_interpretation, accessed on 5 August 2025

2.2.3.3 Acoustic properties

Acoustical properties are those that govern how materials respond to sound waves, which are what we perceive as sound.
@ Acoustical Properties. In: Food Physics. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-34194-9_12

2.2.3.3.1 P-wave velocity

P-waves (Primary/compression waves) are where rock particles oscillate parallel to the wave direction. They travel through solids, liquids and gasses. P-wave velocities are generally 1.5 to 3 times faster than S-wave velocities.
@ P wave - Wikipedia: https://en.wikipedia.org/wiki/P_wave, accessed on 16 June 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.3.3.2 S-wave velocity
In seismology and other areas involving elastic waves, S waves, secondary waves, or shear waves (sometimes called elastic S waves) are a type of elastic wave and are one of the two main types of elastic body waves, so named because they move through the body of an object, unlike surface waves.
@ S wave - Wikipedia: https://en.wikipedia.org/wiki/S_wave, accessed on 8 August 2025

2.2.3.3.3 Acoustic impedance
Acoustic impedance (AI) is the product of the rock density and the transmission velocity.
@ Data: sources - AAPG Wiki: https://wiki.aapg.org/Data:_sources, accessed on 5 August 2025

2.2.3.4 Compressibility
Compressibility is a measure of the relative volume change (volumetric strain) of a fluid or solid in response to a pressure or mean stress change, taking into account the degree of severity of the formation, the change in volume of oil when lifted from the reservoir to the stock tank, and the effects of time, temperature, and the compressibility of the mineral grains and the bulk material. Crude oil typically expands by ~1–4% when raised from a 3 km depth to the surface.
@ Chapman R E, 1983. Petroleum Geology, Elsevier, Amsterdam.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 3 August 2025

2.2.3.4.1 Rock compressibility
Rock compressibility is a measure of the relative volume change (volumetric strain) of a rock in response to a pressure or mean stress change, taking into account the degree of severity of the formation, the change in volume of oil when lifted from the reservoir to the stock tank, and the effects of time, temperature, and the compressibility of the mineral grains and the bulk material. Crude oil typically expands by ~1–4% when raised from a 3 km depth to the surface.
@ Chapman R E, 1983. Petroleum Geology, Elsevier, Amsterdam.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 3 August 2025

2.2.3.4.2 Fluid compressibility
Fluid compressibility is a measure of the relative volume change (volumetric strain) of a fluid in response to a pressure or mean stress change, taking into account the degree of severity of the formation, the change in volume of oil when lifted from the reservoir to the stock tank, and the effects of time, temperature, and the compressibility of the mineral grains and the bulk material. Crude oil typically expands by ~1–4% when raised from a 3 km depth to the surface.
@ Chapman R E, 1983. Petroleum Geology, Elsevier, Amsterdam.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 3 August 2025

2.2.3.5 Thermal properties

The physical properties of an object that are traditionally defined by classical mechanics are often called mechanical properties. Other broad categories, commonly cited, are electrical properties, optical properties, thermal properties, etc.

@ Physical property - Wikipedia: https://en.wikipedia.org/wiki/Physical_property, accessed on 15 August 2025

2.2.3.5.1 Thermal conductivity

Thermal conductivity (λ) is a physical quantity that defines the amount of heat that flows through a specific medium over a certain distance during a given time increment, if there is a temperature gradient.

@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

2.2.3.5.2 Heat capacity

Heat capacity or thermal capacity is a physical property of matter, defined as the amount of heat to be supplied to an object to produce a unit change in its temperature. The SI unit of heat capacity is joule per kelvin (J/K). It quantifies the ability of a material or system to store thermal energy.

@ Heat capacity - Wikipedia: https://en.wikipedia.org/wiki/Heat_capacity, accessed on 13 June 2025

2.2.3.6 Nuclear Magnetic Resonance (NMR) properties

S In Nuclear Magnetic Resonance (NMR), T_1 (longitudinal/spin-lattice relaxation time) and T_2 (transverse/spin-spin relaxation time) describe how nuclei return to equilibrium after excitation by a radiofrequency pulse. In most cases, as energy dissipation (T_1) is slower than phase decoherence (T_2). T_2 Distributions can be used to estimate pore-size geometry and fluid mobility. Short T_2 indicates small pores/clay-bound water; long T_2 correlates with free hydrocarbons.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.3.6.1 T1 relaxation time

The decay of RF-induced NMR spin polarization is characterized in terms of two separate processes, each with their own time constants. One process, called T_1, is responsible for the loss of resonance intensity following pulse excitation. The other process, called T_2, characterizes the width or broadness of resonances. Stated more formally, T_1 is the time constant for the physical processes responsible for the relaxation of the components of the nuclear spin magnetization vector M parallel to the external magnetic field, B0 (which is conventionally designated as the z-axis). T_2 relaxation affects the coherent components of M perpendicular to B_0. In conventional NMR spectroscopy, T_1 limits the pulse repetition rate and affects the overall time an NMR spectrum can be acquired. Values of T1 range from milliseconds to several seconds, depending on the size of the molecule, the viscosity of the solution, the temperature of the sample, and the possible presence of paramagnetic species (e.g., O_2 or metal ions).

@ Relaxation (NMR) - Wikipedia: https://en.wikipedia.org/wiki/Relaxation_(NMR)#T1_and_T2, accessed on 13 June 2025

2.2.3.6.2 T2 relaxation time
The decay of RF-induced NMR spin polarization is characterized in terms of two separate processes, each with their own time constants. One process, called T_1, is responsible for the loss of resonance intensity following pulse excitation. The other process, called T_2, characterizes the width or broadness of resonances. T_2 relaxation affects the coherent components of M perpendicular to B_0.
@ Relaxation (NMR) - Wikipedia: https://en.wikipedia.org/wiki/Relaxation_(NMR)#T1_and_T2, accessed on 13 June 2025

2.2.4 Controls on reservoir quality
They refer to the main geological factors controlling the reservoir quality, which mainly include depositional environment, depth of burial which controls diagenesis, structural deformation, wettability and capillary pressure.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.4.1 Depositional environment
In geology, depositional environment or sedimentary environment describes the combination of physical, chemical, and biological processes associated with the deposition of a particular type of sediment and, therefore, the rock types that will be formed after lithification, if the sediment is preserved in the rock record. In most cases, the environments associated with particular rock types or associations of rock types can be matched to existing analogues. However, the further back in geological time sediments were deposited, the more likely that direct modern analogues are not available (e.g. banded iron formations).
@ Depositional environment - Wikipedia:
https://en.wikipedia.org/wiki/Depositional_environment, accessed on 5 August 2025

2.2.4.2 Diagenesis
During and following burial, diagenetic events will modify the original pore network of reservoir rocks. Four main diagenetic mechanisms affect reservoir quality: compaction, cementation, dissolution, and recrystallization. These mechanisms are controlled by grain size, the detrital composition of the rock, burial depth, burial time, burial temperature, pore fluids, and pore fluid pressure.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.4.2.1 Compaction
Compaction, a geological process for decreasing the volume of a fixed mass of sediment, reduces the porosity and permeability of a rock by causing the following: (1) grain rotation and rearrangement into a tighter packing configuration, (2) plastic deformation of ductile grains that flow into adjacent pores and pore throats, (3) fracturing and crushing of brittle grains, and (4) pressure solution in the form of grain suturing and stylolitization.

@ McBride E F, 1984. Compaction in sandstones—influence on reservoir quality, AAPG Bulletin, 68, 505.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.4.2.2 Cementation (mineral anthogenesis)
Cementation, the filling of original pore space by cements, may occur early or late in the diagenetic history of a rock. Precipitation of authigenic minerals usually reduces reservoir quality; however, early formation of some authigenic minerals such as grain coating chlorite can preserve the original porosity by protecting the rock from later degradation by cementation.
@ Scholle P A, Schluger P R, 1979. Aspects of Diagenesis, SEPM Special Publication, 26, 443.
@ McDonald D A, Surdam R C, 1984. Clastic Diagenesis, AAPG Memoir, 37, 434.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.4.2.3 Dissolution
It refers to the process of dissolving into a homogenous solution, as when an acidic solution dissolves limestone. In karst, it refers to the process of dissolving rock to produce landforms, in contrast to solution, the chemical product of dissolution.
@ dissolution - CGI vocabularies:
http://resource.geosciml.org/classifier/cgi/eventprocess/dissolution, accessed on 13 November 2025

2.2.4.2.4 Recrystallization
Recrystallization of carbonates and the alteration of grains and cements to clays can have a significant impact on reservoir quality in sandstones and carbonates. Dolomitization of limestones or calcite cement in sandstones typically increases porosity and permeability. Similarly, clay replacement may increase overall porosity of the rock; however, the pores associated with clay minerals tend to be micropores that contain irreducible water. Also, delicate clay flakes may become mobile with flowing pore fluids and migrate to, and clog, pore throats.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.4.2.5 Replacement
Replacement occurs when groundwater action interchanges one mineral in a rock mass for another. In this way, entire minerals are substituted for each other.
@ Link P K, 1987. Basic Petroleum Geology (2nd edition), OGCI Publications, Oil & Gas Consultants International, Inc., Tulsa

2.2.4.3 Structural deformation
Fracturing and brecciation associated with folds, faults, and diapirs generally increase the reservoir quality of well-indurated rocks. Fracture porosity is typically low, usually providing only about 1% porosity; however, fractures in large reservoirs may hold considerable reserves.

Fracture permeability may be as high as tens of darcies and is directional in nature. Conversely, fractures filled by mineralization or with gouge may produce a permeability barrier in the direction perpendicular to the fracture. Brecciation along fracture or fault zones may occur due to shearing or dissolution and collapse. Except where mineralization has occurred in the breccia, brecciation can increase both porosity and permeability considerably. Closely spaced sealing faults can significantly compartmentalize a reservoir.
@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.4.3.1 Fault
It refers to a discrete surface, or zone of discrete surfaces, with some thickness, separating two rock masses across which one mass has slid past the other and characterized by brittle deformation.
@ fault - CGI vocabularies: http://resource.geosciml.org/classifier/cgi/faulttype/fault, accessed on 13 November 2025

2.2.4.3.2 Fold
Folds are bends or flexures of layered rock that form in response to motion along faults, diapirism, compaction, and regional subsidence or uplift. Folds are expressed in seismic reflection profiles as one or more regions of dipping reflections (dip domains) that correspond to inclined stratigraphic contacts.
@ Fold - AAPG Wiki: https://wiki.aapg.org/Fold, accessed on 5 August 2025

2.2.4.3.3 Fracture
Fracture is the appearance of a crack or complete separation of an object or material into two or more pieces under the action of stress. The fracture of a solid usually occurs due to the development of certain displacement discontinuity surfaces within the solid. If a displacement develops perpendicular to the surface, it is called a normal tensile crack or simply a crack; if a displacement develops tangentially, it is called a shear crack, slip band, or dislocation.
@ Fracture - Wikipedia: https://en.wikipedia.org/wiki/Fracture, accessed on 5 August 2025

2.2.5 Methods for assessing reservoir quality
Numerous methods exist for assessing reservoir quality, ranging in scale from the macroscopic to the microscopic.
@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.5.1 Geophysical techniques
They mainly include three techniques: seismic, wireline log and drill stem test (DST).
@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.5.1.1 Seismic technique

Modern three-dimensional seismic data can sometimes assist in predicting reservoir quality away from well control. Careful processing of seismic data allows a conversion of the seismic reflection amplitudes to estimates of acoustic impedance. Because lithology, porosity, and fluid saturations affect the acoustic impedance of a rock, a relationship can then be established between the seismic estimates of impedance and the rock properties determined from the logs or in the laboratory.

@ Brown A R, 1986. Interpretation of three-dimensional seismic data, AAPG Memoir, 42, 194.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.5.1.2 Wireline log technique (Well log technique)

Wireline logs can be classified into three different groups based on the information they provide: (1) lithology indicators—gamma ray, sonic, density, and neutron logs, (2) porosity logs—sonic, density, and neutron logs, and (3) fluid saturation logs—resistivity logs. In addition to lithology, porosity, and fluid saturations, permeability sometimes can be inferred from log responses or a combination of log responses. The spontaneous potential log is most often used as a qualitative indicator of the permeability of a formation.

@ Asquith G, Gibson C, 1982. Basic well log analysis for geologists, AAPG Methods in Exploration Series, 3, 216.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.5.1.2.1 Gamma-ray log

Gamma-ray logs measure the natural radioactivity which is produced in the rock. The elements which produce gamma radiation of significance in ordinary sedimentary rocks are potassium, thorium and uranium. Shale normally contains the most of these elements and the gamma reading of shales is almost always higher than that of sandstones.

@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.

2.2.5.1.2.2 Resistivity log

Resistivity logs are the result of measuring the resistance between 2 and 4 electrodes which are in contact with the rocks in the well wall. Resistivity (in ohms) is measured as a function of the cross-section (m^2) of the rock and the distance (m) between the electrodes. The resistivity R = ohm $\cdot$m^2 /m, and the unit is ohm meter.

@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.

2.2.5.1.2.3 Density log

The density log records bulk density; hence porous rocks record a lower density than do rocks of similar mineralogy but lower density. The log is created by emitting gamma rays into the formation and measuring the intensity of the returning gamma rays.

@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA
@ Density logging - Wikipedia: https://en.wikipedia.org/wiki/Density_logging, accessed on 5 August 2025

2.2.5.1.2.4 Neutron log
Neutron logs (also called neutron porosity logs) determine the hydrogen atom concentration in a formation, and since almost all of the hydrogen occurs in the fluid phase (petroleum and/or water) such measurements can be transposed to porosity data.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

2.2.5.1.2.5 Sonic log
A sonic log measures the time it takes for a sound pulse to travel from a transmitter to a receiver via the formation. Sonic logs can be used for measuring porosity but are more commonly used by the geophysicist as they give velocity information for calibrating seismic data. Velocity data allow the geophysicist to convert the time taken for a seismic wave to travel down and back from a specific seismic reflector into an equivalent subsurface depth.
@ Rider M H, 1996. The geological interpretation of well logs: Caithness, Whittles Publishing, 300.
@ Data: sources - AAPG Wiki: https://wiki.aapg.org/Data:_sources, accessed on 5 August 2025

2.2.5.2 Drill stem test
A drill stem test is generally performed after the well has been conditioned by sealing the zone(s) of interest and allowing the production of fluids (see Drill stem testing). The fluids are tested for hydrocarbon content and the pressures and flow rates are measured. The permeability can be inferred from the pressures measured over time, and the productive capability of the formation is determined from the types of fluid produced and the flow rates.
@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.5.3 Core-based techniques
They mainly include two techniques: core analysis and capillary pressure.
@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.5.3.1 Core analysis
Core analysis measurements performed on representative core samples can more accurately assess reservoir quality and heterogeneities. Core analysis porosities are typically determined using one of three techniques: summation of fluids, resaturation, and Boyle's Law. Permeability on core samples is determined using one of two methods: steady-state or unsteady-state.
@ Keelan D K, 1972. A critical review of core analysis techniques, Journal of Canadian Petroleum Technology, 2, 42–55.

@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.5.3.1.1 Special core analysis (SCAL)

n the petroleum industry, special core analysis, often abbreviated SCAL or SPCAN, is a laboratory procedure for conducting flow experiments on core plugs taken from a petroleum reservoir. Special core analysis is distinguished from "routine (RCAL) or conventional (CCAL) core analysis" by adding more experiments, in particular including measurements of two-phase flow properties, determining relative permeability, capillary pressure, wettability, and electrical properties. Due to the time-consuming and costly character of SCAL measurements, routine core analysis (RCAL) data should be inspected thoroughly to select a representative subset of samples for SCAL.

@ "Oilfield Glossary: Term 'special core analysis (SCAL)'". www.glossary.oilfield.slb.com. Archived from the original on 2006-03-22.

@ Abouzar M P, Asadolahpour S R, Hadi S J, et al., 2020. A new framework for selection of representative samples for special core analysis, Petroleum Research, 5 (3): 210–226.

2.2.5.3.2 Capillary pressure measurement

Capillary pressure can also be measured in the laboratory on core samples. Various techniques are used to determine fluid saturations in the sample at various pressures so that a saturation profile at different pressures is created, which characterizes the irreducible water saturation and hydrocarbon pore volume of the rock.

@ Wardlaw N C, 1976. Pore geometry of carbonate rocks as revealed by pore casts and capillary pressure: AAPG Bulletin, 60, 245–257.

@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.5.4 Laboratory techniques

Microscopic techniques used to assess reservoir quality include thin section analysis, petrographic image analysis, scanning electron microscopy, and X-ray diffraction.

@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.5.4.1 Thin section analysis

Through thin section analysis, the pore types and distribution, the extent of reservoir enhancement or degradation by diagenesis, and the influence.

@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.5.4.2 Scanning electron microscopy (SEM)

Another microscopic method of assessing reservoir quality is through the use of scanning electron microscopy (SEM) with energy-dispersive X-ray. The SEM allows examination of a reservoir

rock at very high magnifications with an excellent depth of field so that the pore network and clay minerals within the pores can be viewed. Energy-dispersive X-ray analysis provides an elemental analysis of the grains, cements, and clays identified by the SEM and is used to aid in determining the mineralogy.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.5.4.3 Petrographic image analysis
Petrographic image analysis is a relatively new technique that provides porosity and permeability values and capillary pressure curves for sandstone samples that are not suitable for conventional core analysis, such as cuttings, percussion sidewall cores, and unconsolidated core samples. Image analysis measures key two-dimensional geometrical characteristics of the pore network in thin section using a research-grade petrographic microscope coupled with an image analysis system. The system generates a binary image representing porosity and rock material from thin section views of undamaged portions of the sample. From this image, pore area, diameter, perimeter, length, width, and aspect ratio can be analyzed and related to the three-dimensional porosity, permeability, and capillary pressure values that have been measured on conventional core samples.
@ Gerard R E, Philipson C A, and Ballentine F M, et al., 1992. Petrographic image analysis—an alternate method for determining petrophysical properties, Automated Pattern Analysis in Petroleum Exploration: New York, Springer-Verlag, 249-263.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.2.5.4.4 X-ray diffraction (XRD) analysis
The principal advantage of XRD is that a qualitative or semiquantitative evaluation of mineralogy is generated. A fixed wavelength X-ray source such as copper X-ray tubes, which have a 1.54A wavelength, is used to irradiate a powdered sample. The incident angle θ of the diffracted beam and the intensity are recorded with a counter or tube. If parallel planes of atoms of a crystal are struck at the same angle, coherent (additive) intensity is detected and recorded as a peak. Bragg's Law is the basis for determining the characteristic peaks (d spacing) for known minerals and compounds ($n\lambda = 2d \sin \theta$). Tables of standards established by the JCPDS (Joint Council of Powder Diffraction Standards) can be consulted for mineral identification, where θ is the incident angle, λ the X-ray wavelength and d the spacing between planes of atoms in the crystal.
@ SEM, XRD, CL, and XF methods - AAPG Wiki:
https://wiki.aapg.org/SEM,_XRD,_CL,_and_XF_methods, accessed on 6 August 2025

2.2.6 Reservoir heterogeneity
The term reservoir heterogeneity is used here to describe the geological complexity of a reservoir and the relationship of that complexity to the flow of fluids through it.
@ Alpay O A, 1972. A practical approach to defining reservoir heterogeneity: Journal of Petroleum Technology, 24, 841–848.

@ Geological heterogeneities - AAPG Wiki: https://wiki.aapg.org/Geological_heterogeneities, accessed on 5 August 2025

2.2.7 Petrophysical (Rock physics) modeling

Petrophysical modeling provides direct reservoir property measurements, while rock physics modeling bridges these properties to seismic data, enabling spatial prediction of reservoir quality. This integrated approach optimizes drilling targets and production strategies by identifying high-permeability zones, diagenetic risks, and fluid contacts.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.8 Reservoir quality prediction

Reservoir quality prediction is the process of estimating the physical and chemical properties of a subsurface reservoir, such as porosity, permeability, fluid saturation, and mineral composition, before drilling or during the exploration phase. This prediction is crucial for assessing the potential productivity and economic viability of hydrocarbon (oil and gas) reservoirs.

@ Rashid M, Luo M, and Ashraf U, et al., 2023. Reservoir Quality Prediction of Gas-Bearing Carbonate Sediments in the Qadirpur Field: Insights from Advanced Machine Learning Approaches of SOM and Cluster Analysis. Minerals. 13(1), 29.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.8.1 Diagenetic modeling (simulation of diagenesis)(numerical modeling of diagenesis)

Diagenetic modeling is a scientific approach used to understand and predict the physical, chemical, and biological processes that occur in sediments after their deposition but before they become fully lithified (turned into rock). These processes, collectively known as diagenesis, can significantly alter the properties of sediments and rocks, affecting their porosity, permeability, mineral composition, and other characteristics.

@ Brenner R L. Modeling diagenetic styles--an integral part of basin analysis. Kansas Geological Survey. Subsurface Geology, 12, 57-58.

@ Boudreau B P, 2003. Diagenetic Models and Their Implementation: Modelling Transport and Reactions in Aquatic Sediments. Springer.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.8.2 Artificial intelligence

Artificial Intelligence (AI) is a branch of computer science that aims to create systems capable of performing tasks that typically require human intelligence. These tasks include, but are not limited to, visual perception, speech recognition, decision-making, and language translation.

@ artificial-intelligence-vs-machine-learning – Google: https://cloud.google.com/learn/artificial-intelligence-vs-machine-learning, accessed on 13 June 2025

2.2.8.3 Machine learning

Machine Learning (ML) is a subset of AI that focuses on building systems that can learn from and make predictions or decisions based on data, without being explicitly programmed for each task. ML involves developing algorithms that enable computers to identify patterns and relationships in data, and then use these insights to make informed decisions or predictions.

@ artificial-intelligence-vs-machine-learning – Google: https://cloud.google.com/learn/artificial-intelligence-vs-machine-learning, accessed on 13 June 2025

2.2.9 Reservoir rock geomechanics

Reservoir rock geomechanics is the branch of geomechanics that studies the mechanical behavior of reservoir rocks and their interaction with pore fluids under changing stress, pressure, and temperature conditions during hydrocarbon production or fluid injection. It integrates principles from rock mechanics, geology, and reservoir engineering to understand and predict how reservoir rocks deform, fail, or alter their physical properties (such as porosity, permeability, and fracture conductivity) in response to changes in the in-situ stress field caused by fluid withdrawal or injection.

@ soeees-ygeoresgeo202-reservoir-geomechanics - Stanford: https://online.stanford.edu/courses/soeees-ygeoresgeo202-reservoir-geomechanics, accessed on 13 June 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.9.1 In-situ stress state

The in-situ stress state refers to the natural state of stress existing within the Earth's crust at a given location and depth, prior to any human-induced disturbance (such as drilling or fluid injection). It is characterized by the magnitude, orientation, and principal directions of the three mutually perpendicular principal stresses acting on a rock mass in its natural environment.

@ Cheng Y, Yan C, Han Z， 2023. In: Foundations of Rock Mechanics in Oil and Gas Engineering. Springer, Singapore.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.9.2 Rock strength and deformation properties

Rock strength and deformation properties refer to the intrinsic mechanical characteristics of a rock that determine its ability to resist failure (strength) and its response to applied stresses in terms of shape or volume change (deformation) under various loading conditions. These properties are fundamental for assessing rock behavior during drilling, production, excavation, or natural geologic processes.

@ Kulhawy F H, 1975. Stress deformation properties of rock and rock discontinuities. Engineering Geology, 9(4), 327-350.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.9.3 Pore pressure and effective stress

The concepts of pore pressure and effective stress are fundamental in rock mechanics, geomechanics, and reservoir engineering. They describe how stress is distributed within a porous rock and control rock deformation, strength, and fluid flow behavior. Pore pressure is the pressure exerted by the fluids (such as water, oil, or gas) contained within the pore spaces of a subsurface rock formation. Effective stress is the portion of the total external stress applied to a rock that is actually carried by the mineral skeleton (solid framework) of the rock. It represents the stress responsible for rock deformation, compaction, shear failure, and changes in porosity and permeability.

@ fluid porepress – Itascacg: https://docs.itascacg.com/flac3d700/3dec/docproject/source/theory/fluid/fluid_porepress.html, accessed on 13 June 2025

@ Boitnott G N, Miller T W, and Shafer J L, 2009. Pore-Pressure Depletion and Effective Stress Issues in the Gulf of Mexico's Lower Tertiary Play. the SPE Annual Technical Conference and Exhibition.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.9.4 Geomechanical modeling
A geomechanical model is defined as a three-dimensional representation that estimates the geomechanical effects related to reservoir behavior, integrating various data such as well logs and production history to inform well drilling campaigns and optimize oil field project management.
@ Geomechanical model - Sciencedirect: https://www.sciencedirect.com/topics/engineering/geomechanica-model, accessed on 13 June 2025

2.2.9.5 Wellbore stability analysis
Wellbore Stability Analysis is the geomechanical assessment of the ability of a drilled hole (wellbore) in the subsurface to maintain its structural integrity without collapsing, fracturing, or undergoing excessive deformation during or after drilling. It involves evaluating the balance between the mechanical stresses acting on the wellbore wall, the strength of the surrounding rock, the pore pressure within the formation, and the stabilizing influence of the drilling fluid (mud) pressure. The primary goal is to determine the safe operating window for mud weight—i.e., the lower and upper pressure limits that prevent wellbore failure.
@ Mostafa Mansourizadeh, Majid Jamshidian, and Pouya Bazargan, et al., 2016. Wellbore stability analysis and breakout pressure prediction in vertical and deviated boreholes using failure criteria – A case study. Journal of Petroleum Science and Engineering. 145, 482-492.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.10 Reservoir rock geochemistry
Reservoir Rock Geochemistry is the study of the chemical composition, reactions, and processes occurring within reservoir rocks and their contained fluids (such as oil, gas, and formation water), and how these influence reservoir properties, hydrocarbon quality, diagenesis, and fluid-rock interactions over geological time.
@ England W A, 2007. Reservoir geochemistry — A reservoir engineering perspective. Journal of Petroleum Science and Engineering. 58(3-4), 344-354.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.10.1 Mineral reactivity
Mineral Reactivity refers to the tendency or capacity of a mineral to undergo chemical reactions with fluids (such as water, acids, or formation brines) or other minerals under specific physical and chemical conditions—such as temperature, pressure, pH, redox potential, and fluid composition.
@ Encarnación R A, Christine V P, 2019. Preface: Mineral reactivity: from biomineralization and Earth’s climate evolution, to CO2 capture and monument conservation. European Journal of Mineralogy. 31(2), 205–207.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.10.2 Fluid-rock interactions (Diagenetic reactions)
Fluid-Rock Interactions (Diagenetic Reactions) refer to the physical, chemical, and biological processes that occur between fluids (such as formation water, hydrocarbons, or injected fluids) and the mineral matrix of a rock during and after sediment burial, primarily under subsurface temperature and pressure conditions.
@ Tian, B., Yuan, Y., Tang, J. et al., 2023. Fluid evolution and related fluid–rock interactions of the Oligocene Zhuhai sandstones in the Baiyun Sag, northern margin of the South China Sea. Scientific Report, 13, 14067.
@ Yang, L., Xu, T., Liu, K., et al., 2016. Fluid–rock interactions during continuous diagenesis of sandstone reservoirs and their effects on reservoir porosity. Sedimentology, 64(5), 1303-1321.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.10.3 Diagenetic products
Diagenetic products are secondary materials generated within sedimentary rocks during diagenesis through precipitation, mineral transformation, or authigenic growth. They include newly formed minerals, pore-filling cements, replacement minerals, and reaction by-products that modify the original composition and fabric of the sediment.
@ COUDRAY J. and MONTAGGIONI L., 1986. The diagenetic products of marine carbonates as sea-level indicators. In van de Plassche, O (edior). Sea-level Research: a manual for the collection and evaluation of data, 311-360..
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.2.10.4 Isotope geochemistry
Isotope geochemistry is an aspect of geology based upon the study of natural variations in the relative abundances of isotopes of various elements. Variations in isotopic abundance are measured by isotope-ratio mass spectrometry, and can reveal information about the ages and origins of rock, air or water bodies, or processes of mixing between them.
@ Isotope geochemistry - wikipedia: https://en.wikipedia.org/wiki/Isotope_geochemistry, accessed on 13 June 2025

2.3 Seal rock
A seal (cap) rock is a relatively impermeable rock such as shale, anhydrite, or salt, that forms a barrier above around or below a reservoir rock within a trap so that entrapped petroleum fluids cannot migrate beyond the reservoir.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.3.1 Seal rock types
They refer to how seal rocks are classified into different types based on different criteria.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.1 Classification by lithology
Any lithology can serve as a seal for a hydrocarbon accumulation. The only requirement is that the minimum displacement pressure (capillary entry pressure) of the lithologic unit comprising the sealing rock be greater than the buoyancy pressure of the hydrocarbon column in the accumulation.

@ Downey M W, 1994. Hydrocarbon seal rocks, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 159-164.

2.3.1.1.1 Evaporite seal
Evaporites such as halite, gypsum, anhydrite act as the seal rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.1.1.1 Halite seal
Halite acts as the seal rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.1.1.2 Anhydrite seal
Anhydrite acts as the seal rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.1.1.3 Gypsum seal
Gypsum acts as the seal rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.1.2 Carbonate seal
Carbonates, usually marls or argillaceous limestone, can act as the seal rock. Micritic limestones and dolomites are typically too brittle and chalks tend to be reservoirs more than provide sealing lithologies.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.1.2.1 Micritic limestone seal
Micritic limestone serves as the seal rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.1.2.2 Dolomite seal
Dolomite serves as the seal rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.1.2.3 Chalk seal
Chalk serves as the seal rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.1.2.4 Marl seal
Marl serves as the seal rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.1.2.5 Argillaceous limestone seal
Argillaceous limestone serves as the seal rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.1.3 Mudstone/shale seal
Mudstones/shales act as the seal rock.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.2 Classification by extent
It refers to the classification on basis of areal extent of the seal rock in a sedimentary basin.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.2.1 Regional seal
It is a seal that creates a widespread "roof" (barrier) to migrating hydrocarbons.
@ Downey M W, 1994. Hydrocarbon seal rocks, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 159-164.

2.3.1.2.2 Local seal
It is a seal that confines a hydrocarbon accumulation in a discrete trap.
@ Downey M W, 1994. Hydrocarbon seal rocks, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.159-164.

2.3.1.2.3 Intraformational seal
An intraformational seal is a layer within a geological formation, typically provided by dense materials such as clay or carbonate that acts as a barrier to fluid flow. It is not typically regional in extent.
@ Defined by the Working Group of Petroleum Geology Knowledge System
@ Richard Chuchla, written communication, 15 July 2025

2.3.1.3 Classification by sealing mechanism
It refers to the classification on basis of the mechanism by which hydrocarbons are sealed.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.1.3.1 Capillary seals
A capillary seal is formed when the capillary pressure across the pore throats is greater than or equal to the buoyancy pressure of the migrating hydrocarbons. Capillary seals do not allow fluids to migrate across them until the buoyancy of the hydrocarbon column exceeds the capillary entry pressure of the seal or until their integrity is disrupted (e.g. fractured), at which point they cease to be capillary seals. An example is a shale overlying a sandstone reservoir, where the shale's tiny pore throats block upward migration of oil or gas.
@ Petroleum reservoir - Wikipedia: https://en.wikipedia.org/wiki/Petroleum_reservoir
@ Richard Chuchla, written communication, 15 July 2025
@ GeoGPT: https://geogpt.zero2x.org, accessed on 7 Auguest 2025

2.3.1.3.2 Hydraulic seals
Hydraulic seal is a relatively soft, non-metallic ring, captured in a groove or fixed in a combination of rings, forming a seal assembly, to block or separate fluid in reciprocating motion applications. Hydraulic seals are vital in machinery. Their use is critical in providing a way for fluid power to be converted to linear motion. For example, they are widely used in hydraulic cylinders of excavators, bulldozers, cranes, and many other types of heavy equipment.
@ Hydraulic seal - Wikipedia: https://en.wikipedia.org/wiki/Hydraulic_seal, accessed on 5 August 2025

2.3.1.3.3 Membrane seals
Membrane seal: A rock-sealing surface that holds back hydrocarbons until the capillary pressure created by the height of an underlying petroleum column exceeds the seal's capillary displacement pressure. This type of seal does not fracture during deformation and fails due to the buoyancy pressure of the hydrocarbons passing through the water-wet rock pores. An example is an evaporite layer (e.g., salt or anhydrite) sealing a carbonate reservoir, as salt's plasticity and lack of permeability create an unbreachable seal.
@ Watts, N. 1., 1987, Theoretical aspects of cap-rock and fault seals for single- and two-phase hydrocarbon columns: Marine and Petroleum Geology, v. 4, p. 274-307.
@ Intact membrane seal leakage - AAPG Wiki:
https://wiki.aapg.org/Intact_membrane_seal_leakage
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.3.2 Seal characteristics
Ductility, thickness, uniformity, capillary pressure, permeability, porosity, sealing capability, mineralogy, pore throat size, wettability, fractures, brittleness index, elastic properties (mechanical properties, Young's modulus, Poisson's ratio), and thermal conductivity are the main characteristics that influence the effectiveness of hydrocarbon seal rocks.
@ Downey M W, 1994. Hydrocarbon seal rocks, in Magoon, L. B, and W. G. Dow, eds., 1994, *The Petroleum System-from Source to Trap*: AAPG Memoir 60, p.159-164.

2.3.2.1 Ductility
Ductility is a rock property that varies with pressure and temperature (burial depth) and water content as well as with lithology. Evaporite rocks makes extraordinarily good ductile seals when overburden rocks exceed several thousand feet, but they can be brittle at shallow depths.
@ Downey M W, 1994. Hydrocarbon seal rocks, in Magoon, L. B, and W. G. Dow, eds., 1994, ***The Petroleum System-from Source to Trap***: AAPG Memoir 60, p.159-164.

2.3.2.2 Thickness
Several centimeters of ordinary clay shale are theoretically adequate to trap a large vertical column of hydrocarbons. Unfortunately, there is a low probability that a zone only a few centimeters thick could be continuous, unbroken, and unbreached and also maintain uniform lithologic character over a sizable accumulation. The benefits of a thick seal are that it provides many layers of sealing lithologies and a larger probability that a sealing surface will actually be distributed over an entire prospect.
@ Downey M W, 1994. Hydrocarbon seal rocks, in Magoon, L. B, and W. G. Dow, eds., 1994, ***The Petroleum System-from Source to Trap***: AAPG Memoir 60, p.159-164.

2.3.2.3 Uniformity
Identifiable stratigraphic units may vary greatly in their capillary properties with only modest changes in lithology. A stratigraphic cross section of the potential seal unit, using electric log character and lithology, is an excellent start toward establishing whether the seal unit is uniform over the geographic extent of the petroleum system.
@ Downey M W, 1994. Hydrocarbon seal rocks, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.159-164.

2.3.2.4 Capillary entry pressure (Displacement pressure) (Pd)

Capillary entry pressure (Pd) of a water-filled rock is a function of the hydrocarbon-water interfacial tension, wettability, and radius of largest pore throats. Capillary entry pressure (sealing capacity) of the seal rock increases as (1) the throat radius of the largest connected pores decreases, (2) the wettability decreases, and (3) the hydrocarbon-water interfacial tension increases.

@ Downey M W, 1994. Hydrocarbon seal rocks, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 159-164.

2.3.2.5 Permeability

Permeability (K) is the ability of a rock to transmit fluids, without changing the structure of the rock or a displacement of its components.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahom

2.3.2.6 Porosity

Porosity φ is the ratio of void space within a rock (or sediment) relative to bulk volume. It reflects the fluid storage capacity of the reservoir.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.3.2.7 Fault seal behavior

The two basic types of fault seal behavior are (1) cross sealing or cross leaking and (2) dip sealing or dip leaking. Cross seal and leak refers to the lateral communication across the fault between juxtaposed sands. Dip seal and leak refers to the vertical communication along the fault between stacked sands. The type of seal behavior is important in controlling the type of fault-dependent leak points. Fault-dependent leak points limit the volume of trapped hydrocarbons. The ability to identify these fault-dependent leak points is a fundamental tool for prospect assessment.

@ Fault seal behavior – AAPG wiki:
https://wiki.aapg.org/Fault_seal_behavior#Finite_seal_capacity, accessed on 5 August 2025

2.3.2.8 Mineralogy

Mineralogy is a subject of geology specializing in the scientific study of the chemistry, crystal structure, and physical (including optical) properties of minerals and mineralized artifacts. Specific studies within mineralogy include the processes of mineral origin and formation, classification of minerals, their geographical distribution, as well as their utilization.

@ Mineralogy - Wikipedia: https://en.wikipedia.org/wiki/Mineralogy, accessed on 5 August 2025

2.3.2.9 Pore throat size

Pore and pore throat sizes have two defining parameters of absolute size and aspect ratio.

@ Pore and pore throat sizes - AAPG Wiki: https://wiki.aapg.org/Pore_and_pore_throat_sizes, accessed on 5 August 2025

2.3.2.10 Wettability

Physically, wettability represents a balance of forces that occur at the interface between three phases, one of which is a solid. In an oil reservoir it controls reservoir quality by affecting the

amount of water production. When the reservoir rock is oil-wet, water is located in the central portion of the pores and will flow through the pore system with the oil. Conversely, in a water-wet reservoir, the water is restricted to the perimeter of the pores and will not flow through the pore system until much of the oil has been removed. In addition, the irreducible water saturations of oil-wet reservoirs tend to be much lower than those of water-wet reservoirs.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.3.2.11 Fracture

Fracture is the appearance of a crack or complete separation of an object or material into two or more pieces under the action of stress. The fracture of a solid usually occurs due to the development of certain displacement discontinuity surfaces within the solid. If a displacement develops perpendicular to the surface, it is called a normal tensile crack or simply a crack; if a displacement develops tangentially, it is called a shear crack, slip band, or dislocation.
@ Fracture - Wikipedia: https://en.wikipedia.org/wiki/Fracture, accessed on 5 August 2025

2.3.2.12 Elastic properties (mechanical properties, Young's modulus, Poisson's ratio)

Elastic properties describe the reversible deformation (elastic response) of a material to an applied stress. They are a subset of the material properties that provide a quantitative description of the characteristics of a material, like its strength.
Material properties are most often characterized by a set of numerical parameters called moduli. The elastic properties can be well-characterized by the Young's modulus, Poisson's ratio, Bulk modulus, and Shear modulus or they may be described by the Lamé parameters.
@ Elastic properties of the elements (data page) - Wikipedia:
https://en.wikipedia.org/wiki/Elastic_properties_of_the_elements_(data_page), accessed on 5 August 2025

2.3.2.13 Thermal conductivity

Thermal conductivity (λ, in units of W/(m K)) is a physical quantity that defines the amount of heat that flows through a specific medium over a certain distance during a given time increment, if there is a temperature gradient. At 20℃, the typical thermal conductivity of medium crude oil of 0.15 to 0.2 W/(m K) makes it a superior insulator to that of that of water with 0.6 W/(m K).
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

2.3.3 Seal failure mechanism

It documents how a seal fails in its effectiveness.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.3.3.1 Capillary failure

Capillary failure is the normal mode of seal failure under hydrostatic and moderate overpressure conditions, where the fluid pressure exceeds the seal's capillary entry pressure.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

2.3.3.2 Hydraulic fracturing

Hydraulic fracturing ("fracking") is a method used to stimulate hydrocarbon production by inducing fractures in a reservoir rock. This is achieved by injecting fluids (such as water or other fluids) and granular materials (such as sand or ceramic proppant) into the rock formation at pressures that exceed the natural formation pressure, causing the rock to fracture. The fractures are then propped open by the granular materials to allow the hydrocarbons to flow more freely into the well. This technique is commonly used in wells to improve economic recovery of gas, oil and condensate. It can also be applied to stimulate water injectors or to fracture seal rock under certain conditions.

@ Halliburton, 2001. Basic Petroleum Geology and Log Analysis[M]. Houston: Halliburton.
@ White paper: Hydraulic fracturing - AAPG Wiki:
https://wiki.aapg.org/White_paper:_Hydraulic_fracturing, accessed on 25 May 2025.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 7 August 2025

2.3.3.3 Fault reactivation

Fault reactivation refers to the process of a fault becoming active again after stress rebuilds or under a new stress field.

@ Parnaud, F., Y. Gou, J.-C. Pascual, I. Truskowski, O. Gallango, H. Passalacqua, and F. Roure, 1995, Petroleum geology of the central part of the Eastern Venezuela basin, in A. J. Tankard, R. Suárez S., and H. J. Welsink, Petroleum basins of South America: AAPG Memoir 62, p. 741–756.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 7 August 2025

2.3.3.4 Diffusion

Hydrocarbon transport by diffusion is very slow. Rates depend on the concentration at the location from which diffusion proceeds.

@ Migration rate - AAPG Wiki: https://wiki.aapg.org/Migration_rate, accessed on 5 August 2025

2.3.3.5 Overpressure

Overpressure is a term used for subsurface pressures that significantly exceed the hydrostatic pressure. This situation implies that the flow of porewater to the surface during compaction is resisted to a considerable degree, so that the pressure gradients are increased in the least permeable part of the sediments. This process is referred to as compaction disequilibrium.

@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.

2.3.4 Seal evaluation techniques

Seal evaluation techniques are methods used in petroleum geoscience to assess the ability of a rock layer (the seal or cap rock) to prevent the upward or lateral migration of hydrocarbons from a reservoir. A good seal is essential for trapping oil and gas in a reservoir and maintaining a viable petroleum system.

@ Seven seal testing methods for flexible packaging - Greener: https://greenercorp.com/resource-blog/seven-seal-testing-methods-for-flexible-packaging/, accessed on 15 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.3.4.***1*** Petrophysical analysis
The seal quality of a rock is established soon after deposition. It is strongly influenced by its environment of deposition. Diagenesis can alter or completely change the original pore space of a rock, especially for carbonates. However, if the original pore space is not altered too much, then a relationship exists between lithofacies and seal-quality rocks that we can use when prospecting for stratigraphic traps. A petrophysical analysis of the lithofacies of a rock section in a target area can help determine if such a relationship exists.
@ Petrophysical analysis of lithofacies - AAPG Wiki:
https://wiki.aapg.org/Petrophysical_analysis_of_lithofacies, accessed on 5 August 2025

2.3.4.***2*** Seismic interpretation
Simply defined, seismic interpretation is the science (and art) of inferring the geology at some depth from the processed seismic record. While modern multichannel data have increased the quantity and quality of interpretable data, proper interpretation still requires that the interpreter draw upon his or her geological understanding to pick the most likely interpretation from the many “valid” interpretations that the data allow.
@ Seismic interpretation - AAPG Wiki: https://wiki.aapg.org/Seismic_interpretation, accessed on 5 August 2025

2.3.4.***3*** X-ray diffraction (XRD) analysis
The principal advantage of XRD is that a qualitative or semiquantitative evaluation of mineralogy is generated. A fixed wavelength X-ray source such as copper X-ray tubes, which have a 1.54A wavelength, is used to irradiate a powdered sample. The incident angle θ of the diffracted beam and the intensity are recorded with a counter or tube. If parallel planes of atoms of a crystal are struck at the same angle, coherent (additive) intensity is detected and recorded as a peak. Bragg's Law is the basis for determining the characteristic peaks (d spacing) for known minerals and compounds ($n\lambda = 2d \sin \theta$). Tables of standards established by the JCPDS (Joint Council of Powder Diffraction Standards) can be consulted for mineral identification, where θ is the incident angle, λ the X-ray wavelength and d the spacing between planes of atoms in the crystal.
@ SEM, XRD, CL, and XF methods - AAPG Wiki: :
https://wiki.aapg.org/SEM,_XRD,_CL,_and_XF_methods, accessed on 6 August 2025

2.3.4.***4*** Scanning electron microscopy (SEM)
Another microscopic method of assessing reservoir quality is through the use of scanning electron microscopy (SEM) with energy-dispersive X-ray. The SEM allows examination of a reservoir rock at very high magnifications with an excellent depth of field so that the pore network and clay minerals within the pores can be viewed. Energy-dispersive X-ray analysis provides an elemental analysis of the grains, cements, and clays identified by the SEM and is used to aid in determining the mineralogy.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.3.4.***5*** Nuclear magnetic resonance (NMR) spectroscopy

Nuclear magnetic resonance spectroscopy, most commonly known as NMR spectroscopy or magnetic resonance spectroscopy (MRS), is a spectroscopic technique based on re-orientation of atomic nuclei with non-zero nuclear spins in an external magnetic field. This re-orientation occurs with absorption of electromagnetic radiation in the radio frequency region from roughly 4 to 900 MHz, which depends on the isotopic nature of the nucleus and increases proportionally to the strength of the external magnetic field. Notably, the resonance frequency of each NMR-active nucleus depends on its chemical environment. As a result, NMR spectra provide information about individual functional groups present in the sample, as well as about connections between nearby nuclei in the same molecule. As the NMR spectra are unique or highly characteristic to individual compounds and functional groups, NMR spectroscopy is one of the most important methods to identify molecular structures, particularly of organic compounds.

@ Nuclear magnetic resonance spectroscopy - Wikipedia: https://en.wikipedia.org/wiki/Nuclear_magnetic_resonance_spectroscopy, accessed on 5 August 2025

2.3.5 Seal diagenesis

Seal diagenesis refers to the physical, chemical, and mineralogical changes that occur in a seal rock (such as shale, mudstone, or evaporite) after its initial deposition, during burial, compaction, and exposure to fluids, temperature, and pressure over geological time.

@ Diagenesis - Fiveable: https://library.fiveable.me/geochemistry/unit-7/diagenesis/study-guide/fJKrnTUZrnuuMyVR, accessed on 15 August 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.3.5.1 Compaction

Compaction, a geological process for decreasing the volume of a fixed mass of sediment, reduces the porosity and permeability of a rock by causing the following: (1) grain rotation and rearrangement into a tighter packing configuration, (2) plastic deformation of ductile grains that flow into adjacent pores and pore throats, (3) fracturing and crushing of brittle grains, and (4) pressure solution in the form of grain suturing and stylolitization.

@ McBride E F, 1984. Compaction in sandstones—influence on reservoir quality: AAPG Bulletin, 68, 505.

@ Reservoir quality - AAPG Wiki: https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.3.5.2 Cementation (mineral anthogenesis)

Cementation, the filling of original pore space by cements, may occur early or late in the diagenetic history of a rock. Precipitation of authigenic minerals usually reduces reservoir quality; however, early formation of some authigenic minerals such as grain coating chlorite can preserve the original porosity by protecting the rock from later degradation by cementation.

@ Wilson M D, Pittman E D, 1977. Authigenic clays in sandstones—recognition and influence on reservoir properties and paleoenvironmental analysis: Journal of Sedimentary Petrology, 47, 3–31.

@ Scholle P A, Schluger P R, 1979. Aspects of Diagenesis: SEPM Special Publication, 26, 443.

@ McDonald D A, Surdam R C, 1984, Clastic Diagenesis: AAPG Memoir, 37, 434.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

2.3.5.3 Dissolution

It refers to the process of dissolving into a homogenous solution, as when an acidic solution dissolves limestone. In karst, it refers to the process of dissolving rock to produce landforms, in contrast to solution, the chemical product of dissolution.
@ dissolution - CGI vocabularies:
http://resource.geosciml.org/classifier/cgi/eventprocess/dissolution, accessed on 13 November 2025

2.3.6 **Fault seal analysis**

Fault seal analysis is used to determine the level of connectivity of a separate reservoir due to fault segments. This is controlled by the permeability and porosity parameters of rocks that are in the fault section. Fault segment that becomes insulating if it has high porosity and permeability values will channel hydrocarbon fluid to the surface. So that the fault is one of the traps that are good for hydrocarbons.
@ Watts N, 1987. Theoretical aspects of cap-rock and fault seals for single- and two-phase hydrocarbon columns: Marine and Petroleum Geology, 4, 274–307.
@ Knipe R J, 1992. Faulting processes and fault seal, Structural and tectonic modelling and its application to petroleum geology: Proceedings of Norwegian Petroleum Society Workshop, 325-342.
@ Fault seal analysis for reservoir development - AAPG Wiki:
https://wiki.aapg.org/Fault_seal_analysis_for_reservoir_development, accessed on 5 August 2025

2.4 Trap

A trap consists of a trapping geometry of permeable (reservoir) and less-permeable (seal) rocks, which when combined with the physical and chemical properties of subsurface fluids, can allow hydrocarbons to accumulate.
@ Trap - AAPG Wiki: https://wiki.aapg.org/Trap, accessed on 5 August 2025

2.4.1 Trapping elements

Three main trapping elements of reservoir, seal and fluids comprise every subsurface hydrocarbon accumulation.
@ Trap - AAPG Wiki: https://wiki.aapg.org/Trap, accessed on 5 August 2025

2.4.1.1 Trap reservoir

The reservoir acts as the storage for accumulating hydrocarbons and can transmit hydrocarbons.
@ Trap - AAPG Wiki: https://wiki.aapg.org/Trap, accessed on 5 August 2025

2.4.1.2 Trap seal

The seal acts as an impediment or barrier that impedes hydrocarbon migration from the reservoir.
@ Trap - AAPG Wiki: https://wiki.aapg.org/Trap, accessed on 5 August 2025

2.4.1.3 Trap fluids
They refer to the fluids contained in a trap. Their physical and chemical contrasts, especially differences in miscibility, solubility, and density between the common reservoir fluids (primarily water, gas, and oil) allow hydrocarbons to migrate, segregate, and concentrate in the sealed reservoir.
@ Trap - AAPG Wiki: https://wiki.aapg.org/Trap, accessed on 5 August 2025

2.4.2 Trap classification
A meaningful trap classification scheme must consider structural, stratigraphic and unconformity, reservoir, seal, and fluid properties and how these properties relate to one another to form closure.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.2.1 Structural trap
Structural traps are those traps whose geometry was formed by deformation after the deposition of the beds involved.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.2.1.1 Anticlinal trap
The anticline with 4-way closure acts as the trap. It includes compressional anticline, anticline resulting from basement uplifting, diapiric anticline, drape anticline, roll-over anticline and other anticlines related to the underlying fault geometry.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.2.1.1.1 Simple anticline
It is a 4-way closure anticline.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.4.2.1.1.2 Compressional anticline
It is an anticline formed by compressional stress.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.4.2.1.1.3 Drape anticline
It is an anticline formed by stratigraphic draping over a structural high.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.4.2.1.1.4 Roll-over anticline
It is an anticline formed by formation bending against the growth fault.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.4.2.1.1.5 Thrust-related anticline
It is an anticline resulting from thrust faulting.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.4.2.1.2 Fault trap

Traps associated with faults may only be formed when faulting can juxtapose impermeable (e.g. shales) rocks over or adjacent to more permeable ones (e.g. sandstones) or the fault behaves as a sealing fault. They include normal fault trap, reverse fault trap, strike slip fault trap and growth fault traps. Fault trap are also related to the geometry of the underlying fault (for example fault bend folds, fault propagation folds).

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.2.1.2.1 Normal fault trap

It is a trap associated with normal faults.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.4.2.1.2.2 Reverse fault trap

It is a trap associated with reverse faults.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.4.2.1.2.3 Strike-slip fault trap

It is a trap associated with strike-slip faults.

@ Defined by the Working Group of Petroleum Geology Knowledge System

2.4.2.1.3 Diapiric trap

It refers to the trap formed by local upward movement of salt or mud/shale which has domed the overlying strata. In addition, many traps can occur along the flanks or overhangs of the diapir.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.2.1.3.1 Salt dome

Salt dome-A circular or elliptical, salt-cored structure which deforms the surrounding sediments into a domal shape.

@ Link P K, 1987. Basic Petroleum Geology (2nd edition), OGCI Publications, Oil & Gas Consultants International, Inc., Tulsa

2.4.2.1.3.2 Shale diapir

During the late Pliocene, the sedimentation was most rapid. The shale diapirs grew into the section, which is generally thought to be caused by the rapid deposition and resultant increase in over pressuring.

@ Yinggehai basin - Wikipedia: https://en.wikipedia.org/wiki/Yinggehai_basin#Shale_diapir, accessed on 5 August 2025

2.4.2.1.3.3 Mud volcano

Mud volcano: A mudstone diapir driven by rapid deposition and insufficient dewatering (a state of compaction disequilibrium) that has reached the surface, and continues to be active until sufficient fluid has been expelled to halt the upward flow of the mud tendency.

@ Chapman R E, 1983. Petroleum Geology, Elsevier, Amsterdam.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.4.2.2 Stratigraphic trap

Stratigraphic traps are those whose geometry is due to changes in lithology. Such changes may be caused by the original deposition of the rock, as with a reef or channel. Alternatively, the change in lithology may be postdepositional, as with a truncation or diagenetic trap.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.2.2.1 Stratigraphic trap unrelated to an unconformity

It includes stratigraphic trap due to deposition and stratigraphic trap due to diagenesis. The former includes channel trap, barrier bar trap, pinchout trap, and reef trap. The latter is referred as diagenetic trap resulting from porosity and permeability changes caused by solution and cementation.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.2.2.1.1 Pinch-out trap

Pinch-out traps are stratigraphic traps in which the petroleum reservoir thins around impermeable rock strata and eventually 'pinches out' with impermeable rock strata on either side, creating a trap.
@ Petroleum trap - Wikipedia: https://en.wikipedia.org/wiki/Petroleum_trap#Pinch-out_trap, accessed on 5 August 2025

2.4.2.2.1.2 Reef trap

A reef trap is a petroleum accumulation retained by the permeability of a reef, which is characterized by a rigid stony framework with high primary porosity, and surrounded by adjacent impermeable rocks. Reefs often develop as domal (pinnacle) or elongated (barrier) antiforms and can be transgressed by marine shales, which may act as hydrocarbon source rocks.
@ Link P K, 1987. Basic Petroleum Geology (2nd edition), OGCI Publications, Oil & Gas Consultants International, Inc., Tulsa
@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.4.2.2.2 Lithological trap

It is a trap type corresponding to stratigraphic trap unrelated to an unconformity. It is commonly listed a trap type parallel with the structural trap type in Chinese literatures.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.4.2.2.3 Stratigraphic trap related to an unconformity

It refers to stratigraphic trap in which the unconformity facilitates the juxtaposition of the porous reservoir rock and impermeable seal rock. It comprises the supraunconformity trap such as stratigraphic onlap trap and subunconformity trap such as buried hill trap and buried structural trap.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.2.3 Combination trap
Combination traps refer to those formed by at least two of the three factors controlling trap formation, which include structural, stratigraphic and unconformity elements. It includes structural-stratigraphic, structural-unconformity, unconformity-stratigraphic traps and so on.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.2.4 Hydrodynamic trap
Hydrodynamic oil traps occur where hydrocarbons are entrapped by a flowing aquifer. They are typically characterized by tilted hydrocarbon/water contacts.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.2.4.1 Tilted oil-water contacts
A tilted oil-water contact is an oil-water interface that is inclined due to variations in aquifer pressure caused by the movement of water in the subsurface, such as from a mobile artesian aquifer or basin dewatering. The tilt is generally less than 2 degrees and is directed towards the area of lower pressure.
@ Link P K, 1987. Basic Petroleum Geology (2nd edition), OGCI Publications, Oil & Gas Consultants International, Inc., Tulsa
@ Reservoir fluids - AAPG Wiki: https://wiki.aapg.org/Reservoir_fluids, accessed on 5 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.4.3 Trap description
The parameters describing a trap include its boundaries, spill point, closure, percent-fill, geometry, depth and capacity.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.3.1 Trap boundaries
They define the limits of the trap and usually consist of (1) boundaries between solids, such as the contact between reservoir and seal, or (2) boundaries between fluids, such as oil–water or gas–water contacts.
@ Trap - AAPG Wiki: https://wiki.aapg.org/Trap, accessed on 5 August 2025

2.4.3.1.1 Structural boundaries
Structural boundaries refer to the physical limits or interfaces within the Earth's crust that are formed by tectonic and structural deformation processes, such as folding, faulting, fracturing, and uplift. These boundaries separate different geological units or domains and play a critical role in shaping subsurface architecture, particularly in petroleum geology, structural geology, and reservoir characterization.
@ Trap systems: structural, stratigraphic, and fluidic - AAPG: https://wiki.aapg.org/index.php?title=Trap_systems:_structural,_stratigraphic,_and_fluidic&mobileaction=toggle_view_desktop, accessed on 15 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.4.3.1.2 Stratigraphic boundaries
Stratigraphic boundaries are surfaces that separate distinct layers (strata) of sedimentary rock based on differences in lithology, fossil content, depositional environment, age, or other sedimentological characteristics. These boundaries represent changes in the conditions of deposition over time and are fundamental to understanding the geological history of sedimentary basins.
@ Trap systems: structural, stratigraphic, and fluidic - AAPG: https://wiki.aapg.org/index.php?title=Trap_systems:_structural,_stratigraphic,_and_fluidic&mobileaction=toggle_view_desktop, accessed on 15 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.4.3.1.3 Fluid contact boundaries
Fluid contact boundaries are surfaces within a reservoir that separate different fluid phases, such as oil, gas, and water, based on their density differences. These boundaries are critical in petroleum engineering and reservoir geology for defining the distribution of hydrocarbons and water in a trap.
@ Trap systems: structural, stratigraphic, and fluidic - AAPG: https://wiki.aapg.org/index.php?title=Trap_systems:_structural,_stratigraphic,_and_fluidic&mobileaction=toggle_view_desktop, accessed on 15 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.4.3.2 Spill point
It is the lowest point at which hydrocarbons may be contained in the trap; this lies on a horizontal contour, the spill plane.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.3.3 Trap closure
It is a measure of the potential storage capacity or size of the trap defined by the trap boundaries.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.3.3.1 Vertical closure
It is a measure of the maximum potential hydrocarbon column of the trap. It is the vertical distance from crest (the highest point of the trap) to spill plane.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.3.3.2 Areal closure
It is a measure of the maximum area of the potential hydrocarbon accumulation within the trap boundaries. It is the area within the intersection between the spill plane and top of the reservoir bed.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.3.3.3 Volumetric closure
It integrates vertical and areal closure with pay thickness, porosity, and hydrocarbon saturation to provide the in-place volume of the potential hydrocarbon accumulation within the trap boundaries. The volume of hydrocarbons which can be produced from the hydrocarbon accumulation is called the recoverable volume and is calculated by multiplying the in-place volume by the recovery factor and adjusting it by the formation volume factor.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

2.4.3.4 Percent fill of a trap
The percent fill of a trap is the percentage of the trap volume filled with hydrocarbons compared with its total volume. It can be controlled by a number of factors, including top seal capacity/integrity, synclinal spill points, charge, fault seal capacity and fault-dependent leak points.
@ Percent fill: controlling factors - AAPG Wiki:
https://wiki.aapg.org/Percent_fill:_controlling_factors, accessed on 5 August 2025

2.4.3.5 Trap geometry
We often assume that a structure remains static when charged by petroleum. Traps may be charged during structural growth, and accumulations can be partially or completely spilled by later structural deformation.
@ Trap geometry: changes - AAPG Wiki: https://wiki.aapg.org/Trap_geometry:_changes, accessed on 5 August 2025

2.4.4 Trap evaluation techniques
They refer to the techniques used to evaluate traps.
@ Defined by the Working Group of Petroleum Geology Knowledge System

2.4.4.1 Seismic interpretation
Simply defined, seismic interpretation is the science (and art) of inferring the geology at some depth from the processed seismic record. While modern multichannel data have increased the quantity and quality of interpretable data, proper interpretation still requires that the interpreter draw upon his or her geological understanding to pick the most likely interpretation from the many “valid” interpretations that the data allow.
@ Seismic interpretation - AAPG Wiki: https://wiki.aapg.org/Seismic_interpretation, accessed on 5 August 2025

2.4.4.2 Well log analysis
Well log is one of the most fundamental methods for reservoir characterization, in oil and gas industry, it is an essential method for geoscientist to acquire more knowledge about the condition below the surface by using physical properties of rocks. This method is very useful to detect hydrocarbon bearing zone, calculate the hydrocarbon volume, and many others.
@ Well log analysis for reservoir characterization - AAPG Wiki:
https://wiki.aapg.org/Well_log_analysis_for_reservoir_characterization, accessed on 5 August 2025

2.4.5 Trap risk assessment

Trap risk assessment is the systematic evaluation of the likelihood that a geological trap can effectively contain hydrocarbons without leakage or failure. It is a critical component of petroleum exploration that quantifies the uncertainty associated with the presence, integrity, and sealing capacity of a potential hydrocarbon trap.

@ The risk assessment trap - ankerandmarsh: https://ankerandmarsh.co.uk/the-risk-assessment-trap/, accessed on 15 August 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.4.5.1 Seal integrity

Seal integrity refers to the capability of a geological barrier to prevent fluid migration, which can be compromised by tectonic stress and related fracturing or high pore pressure leading to fracturing or by variations in fluid boundaries related to capillary pressure, lithologic properties, or relative permeability.

@ Law B E, 2002. Basin-Centered Gas Systems, AAPG Bulletin, 86 (11): 1891–1919

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

@ Natural hydraulic fracturing of top seals - AAPG Wiki: https://wiki.aapg.org/Natural_hydraulic_fracturing_of_top_seals, accessed on 5 August 2025

2.4.5.2 Reservoir quality

Reservoir quality is defined as the ability of a reservoir to store and transmit oil or gas.

@ Predicting carbonate reservoir location and quality - AAPG Wiki: https://wiki.aapg.org/Predicting_carbonate_reservoir_location_and_quality, accessed on 5 August 2025

2.4.6 Trap preservation

Trap preservation refers to the ability of a hydrocarbon trap to retain accumulated hydrocarbons over geological time without being compromised by later geological processes. It is a critical factor in petroleum system analysis and exploration risk assessment, focusing on whether a trap that once held hydrocarbons has remained intact and sealed since the time of charge.

@ Bruckner A, Ott C, 2024. Attraction of pitfall trap preservation fluids complicates the estimation of Collembola density. Pedobiologia, 107(151001).

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

2.4.6.1 Tectonic stability

Tectonic stability is critical for maintaining seal integrity.

@ Petroleum system concept: examples of application - AAPG Wiki: https://wiki.aapg.org/Petroleum_system_concept:_examples_of_application, accessed on 5 August 2025

2.4.6.2 Burial history

A burial history curve is a graph on which burial depth is plotted against geological time for a particular region.

@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego

2.4.6.3 Uplift and erosion

Uplift and erosion describe the process where crustal shortening, thermal doming, and tectonic movements cause the elevation and subsequent wearing away of the rock mass, resulting in the formation of topographic highs, regional unconformities, and the exposure of underlying strata.
@ Talukdar, S C, and Marcano F, 1994. Petroleum Systems of the Maracaibo
@Basin, Venezuela, in Magoon, L. B, and W. G. Dow, eds., 1994, The petroleum system-from source to trap: AAPG Memoir 60, p.463-48.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3. Geological processes in formation of oil and gas accumulations

Geological processes required to form a hydrocarbon accumulation include petroleum generation, migration, accumulation and preservation.
@ Defined by the Working Group of Petroleum Geology Knowledge System
@ James Ogg, written communication, 7 July 2025.

3.1 Petroleum generation

It is the process by which kerogen present in source rocks is transformed into liquid or gaseous hydrocarbons. Petroleum generation starts in natural conditions at temperatures around 70-80 ℃, which frequently corresponds to burial depth of 2.5-3 km, depending on the geothermal gradient.
@ Burrus, J, 1998. Petroleum: Primary migration (generation and expulsion). In: Geochemistry. Encyclopedia of Earth Science. Springer, Dordrecht. https://doi.org/10.1007/1-4020-4496-8_249

3.1.1 Kinetics of petroleum generation

Reaction kinetics characterize the rate of chemical reactions. The rate at which molecular bonds in kerogen are broken drives the rate of formation of hydrocarbons. Bond breaking is mainly controlled by temperature and time, which play a dominant role in the maturation of kerogen. The breaking process can be described by a first-order reaction, so hydrocarbon generation is said to be characterized by first-order kinetics.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin
@ Atwah I & Sweet S, 2023. Petroleum generation kinetics of unconventional Mississippian mudrocks in central Oklahoma, United States: Frontiers in Earth Science, DOI 10.3389/feart.2023.1146251

3.1.1.1 Roles of time and temperature

During the hydrocarbon generation from kerogens, the extent of kerogen conversion has an exponential relationship with temperature and a linear relationship with time. Temperature has a more significant impact on hydrocarbon generation than time.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

3.1.1.2 Relationship between time and temperature

Time and temperature can compensate for each other. The same extent of reaction can be reached either by a higher temperature and a shorter period of time or by a lower temperature and a longer period of time assuming conditions achieve the activation energy for the reaction.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

3.1.1.3 Activation energy and frequency factor

Kinetic parameters that describe chemical reaction rates include the activation energy (E_a), which is the energy barrier that reactions must overcome, and the frequency factor (A), which determines how often collisions occur to attempt overcoming this barrier.

@ Peters, Kenneth E, David J C, et al., 2012. An overview of basin and petroleum system modeling: Definitions and concepts, Basin modeling: New horizons in research and applications: AAPG Hedberg Series, 4, 1-16.

@ Kinetics - AAPG Wiki: https://wiki.aapg.org/Kinetics, accessed on 5 August 2025

3.1.1.4 Arrhenius equation in petroleum generation

In physical chemistry, the Arrhenius equation is a formula for the temperature dependence of reaction rates.

@ Arrhenius equation - Wikipedia: https://en.wikipedia.org/wiki/Arrhenius_equation, accessed on 10 March 2025

3.1.1.5 Time-Temperature Index (TTI)

The Time-Temperature Index (TTI) is a quantitative measure developed by N. V. Lopatin in 1971 to evaluate the thermal maturity of organic material in sediments, integrating both the time and temperature conditions experienced by the source rock. It is calculated using a formula that sums the products of time spent in each 10℃ temperature increment and the corresponding temperature, as determined from the burial curve.

@ Waples D W, 1994. Thermal modeling: Thermal Indicators, hydrocarbon generation, and oil cracking, in Magoon, L. B, and W. G. Dow, eds., 1994, The petroleum system-from source to trap: AAPG Memoir 60, p.307-322.

3.1.1.6 Vitrinite reflectance (Ro)

Vitrinite reflectance is a measure of the percentage of incident light reflected from the surface of vitrinite particles in a sedimentary rock. It is referred to as %Ro. Results are often presented as a mean Ro value based on all vitrinite particles measured in an individual sample. Vitrinite reflectance (Vr or Ro), the most commonly used thermal indicator, is the benchmark for maturation studies in the petroleum and coal industries. This technique is primarily useful for Devonian and younger clastic sediments and coals.

@ Vitrinite reflectance - AAPG Wiki: https://wiki.aapg.org/Vitrinite_reflectance, accessed on 5 August 2025

3.1.1.7 EASY%Ro model (EASY%Ro)

EASY%Ro is a simplified model that treats vitrinite transformation as a series of temperature-de pendent reactions, significantly improving predictions over simple empirical relationships. However, the EASY%Ro model tends to overestimate the thermal history of a basin, therefore later enhancements adjust the frequency factor of the reaction equations to yield more consistent results over a range of heating rates.

@ Rajman, D., 2025. A cool vitrinite reflectance model. GeoExPro: https://geoexpro.com/a-cool-vitrinite-reflectance-model/

3.1.2 Generation model

It describes the ways in which oil and/or gas are generated by reactive kerogens as well as initial petroleum in the source rock. It should also consider post initial generation changes such as a heating event which leads to the cracking of hydrocarbons in the trap.
@ Brooks J, Cornford C and Archer R, 1987. The role of hydrocarbon source rocks in petroleum exploration, in Brooks J and Fleet A J, Marine and Petroleum Source Rocks, Geological Society Special Publication no. 26, 17-46.

3.1.2.1 Tissot and Welte model

Firstly, the model by Tissot and Welte documents the stages of petroleum formation which are diagenesis, catagenesis and metagenesis. Diagenesis corresponds to the immature zone, catatagenesis the oil zone and wet gas zone, and metagenesis the dry gas zone. Secondly, it sets up the threshold concept for oil generation. Thirdly, it proposes the oil window concept.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

3.1.2.1.1 Oil generation threshold

The oil generation threshold refers to the temperature or corresponding depth below which intense oil generation occurs.
@ Pigott J D, 1985. Assessing Source Rock Maturity in Frontier Basins: Importance of Time, Temperature, and Tectonics: AAPG Bulletin, 69(8), 1269-1274.

3.1.2.1.2 Oil window

The oil window refers to the depth or maturity range within which a source rock generates and expels liquid petroleum.
@ Petersen H I, 2006. The petroleum generation potential and effective oil window of humic coals related to coal composition and age: International Journal of Coal Geology, 67(4), 221-248.

3.1.2.1.3 Gas window

The gas window corresponds to the interval from the top of the wet gas zone (<98% methane, with significant amounts of ethane, propane, and heavier hydrocarbons) downward to the base of the dry gas zone (98% or more of methane).
@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 93-120.

3.1.2.2 Evolution stages of petroleum generation

It refers to the changes of organic matter from deposition to the beginning of metamorphism.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

3.1.2.2.1 Diagenesis

Diagenesis refers to all chemical, biological, and physical changes to organic matter during and after deposition of sediments but prior to reaching burial temperatures greater than about 60 °-80 ℃. The quantity and quality of organic matter preserved and modified during diagenesis of a sediment ultimately determine the petroleum potential of the rock.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

3.1.2.2.2 Catagenesis

Catagenesis can be divided into the oil zone (~0.6-1.35% Ro), which corresponds to the oil window, where liquid oil generation is accompanied by gas formation, and the more mature wet gas zone (1.35-2.0% Ro), where light hydrocarbons are generated through cracking and their proportion increases rapidly. Wet gas (<98% methane) contains methane and significant amounts of ethane, propane, and heavier hydrocarbons. The gas window corresponds to the interval from the top of the wet gas zone downward to the base of the dry gas zone.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.93-120.

3.1.2.2.3 Metagenesis

It corresponds to the dry gas zone where dry gas is generated (2.0-4.0% Ro). Dry gas consists of 98% or more of methane. Dry gas is also found as deposits of bacteriogenic (microbial) gas generated during diagenesis of organic matter by methanogenic bacteria under anoxic conditions but has a very different isotopic signature.

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p. 93-120.

3.1.2.3 Basin modeling

Basin modeling is designed to describe the burial of source rocks, the hydrocarbon generation in those rocks, and the expulsion, migration, trapping, and preservation of those hydrocarbons. The definition of basin modeling as presently used usually corresponds more closely to the concept of a sedimentary basin than to that of a petroleum system. A single basin modeling simulation often includes several petroleum systems, without separating or distinguishing among them.

@ Waples D W, 1994. Thermal modeling: Thermal Indicators, hydrocarbon generation, and oil cracking, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.307-322.

3.2 Petroleum migration

Petroleum migration is a geological process describing the movement of oil and gas from the source rock, to the reservoirs, and eventually to the trap. Secondary migration which accounts for the bulk of migration is driven by the buoyancy of the hydrocarbon and flow is always perpendicular to the structural contour of the carrier bed.

@ Peters, Kenneth E, David J C, et al., 2012. An overview of basin and petroleum system modeling: Definitions and concepts, Basin modeling: New horizons in research and applications: AAPG Hedberg Series, 4, 1-16.

@ Hydrocarbon migration – AAPG Wiki: https://wiki.aapg.org/Hydrocarbon_migration. accessed on 5 August 2025

3.2.1 Primary migration

Primary migration is the process by which hydrocarbons are expelled from the source rock into an adjacent permeable carrier bed.
@ Hydrocarbon migration – PetroWiki (spe.org):
https://petrowiki.spe.org/Hydrocarbon_migration#Secondary_Migration

3.2.1.1 Primary migration mechanisms assisted by water

They refer to mechanisms in which petroleum or precursor petroleum products are assisted in their escape from the source rock by water. They could include the following mechanisms: solution of oil in water, solution of gas in water, solution of nonoil organic molecules in water, micellar formation, and emulsion of oil in water. Movement of the solution/emulsion would then occur through one or more of the following: diffusion, convection, meteoric water movement, compaction-induced water movement, and release of water during clay dehydration.
@ Gluyas J. & Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

3.2.1.2 Primary mechanisms by a discrete petroleum phase

They refer to the ways in which primary migration occurs as a discrete petroleum phase, and can be explained by a variety of mechanisms. The petroleum could occur in several forms: as oil as a single phase, as a solution of oil in gas, or as a solution of gas in oil. The transport mechanisms could then include migration within the kerogen network of the source rock or migration within the mineral network of the source rock. The driving force for discrete petroleum-phase migration would be the pressure differential between the source and carrier bed caused by hydrocarbon generation from kerogen, acting with or without capillary imbibition at the source rock/carrier bed boundary.
@ Gluyas J. & Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA
@ Richard Chuchla, written communication, 15 July 2025.

3.2.1.2.1 Microfracture

Microfractures are produced as a direct result of the increase in fluid volume, and hence pressure, increase associated with petroleum formation.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

3.2.1.2.2 Pressure-driven expulsion

Pressure-driven expulsion will occur either through the existing pore network or through induced fractures.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

3.2.1.2.3 Kerogen network expulsion

The transport mechanisms could include migration within the kerogen network of the source rock.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

3.2.1.3 Expulsion efficiency

The efficiency of primary migration (expulsion efficiency) is the percentage of the originally generated hydrocarbons that are expelled from a source rock. It ranges for *n*-alkanes between about 10% and 80% depending on carbon number.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

3.2.2 Secondary migration

Secondary migration is the movement of hydrocarbons along a "carrier bed" from the source area to the trap. Migration mostly takes place as one or more separate hydrocarbons phases (gas or liquid depending on pressure and temperature conditions). There is also minor dissolution in water of methane and short-chain hydrocarbons.
@ Hydrocarbon migration - PetroWiki (spe.org):
https://petrowiki.spe.org/Hydrocarbon_migration#Secondary_Migration

3.2.2.1 Driving force in secondary migration

Under hydrostatic conditions, buoyancy is the main driving force for continuous-phase secondary hydrocarbon migration. When two immiscible fluids (hydrocarbon and water) occur in a rock, a buoyant force is created owing to the density difference between the less-dense hydrocarbon phase and the water phase. Under conditions of water flow (hydrodynamic) through a secondary migration route, the movement of petroleum will be modified. The interaction between the buoyancy driving the petroleum and the flowing water may retard or enhance migration.
@ Gluyas J. & Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

3.2.2.1.1 Buoyancy

Buoyancy is the tendency for a body (or a drop of immiscible fluid) to float or rise when submerged in a fluid of greater density, driven by the vertical buoyancy force due to the lower density of the less-dense fluid compared to the surrounding denser fluid.
@ England W.A., 1994. Secondary Migration and Accumulation of Hydrocarbons: in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.211-218.
@ Buoyancy pressure - AAPG Wiki: https://wiki.aapg.org/Buoyancy_pressure, accessed on 5 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, Accessed on 10 August 2025

3.2.2.1.2 Capillary pressure

Capillary pressure is defined as the difference in pressure across the meniscus in the capillary tube. Put another way, capillary pressure is the amount of extra pressure required to force the nonwetting phase to displace the wetting phase in the capillary. The capillary pressure of a reservoir affects the magnitude and distribution of water saturation and thus the hydrocarbon volume in a given reservoir area. The capillary pressure is a function of the capillary radius, the interfacial tension, and the contact angle between the water and the solid. In a reservoir, zones with larger pores and pore throats have lower capillary pressure, lower irreducible water saturation, and higher hydrocarbon pore volume.

@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

3.2.2.1.3 Hydrodynamic flow

Pressure gradients and the resulting buoyant pressures are not always static. Both hydrodynamic flow and pressure transients change seal capacity.
@ Hydrodynamic flow and pressure transients - AAPG:
https://wiki.aapg.org/Hydrodynamic_flow_and_pressure_transients/, Accessed on 25 June 2025

3.2.2.2 Retarding force in secondary migration

A restricting force to petroleum migration is the capillary injection pressure also known as capillary entry pressure. The force required to move petroleum through a pore throat is a function of the radius of the pore throat, the interfacial tension between the petroleum and the water, and the wettability of the rock-petroleum-water system.
@ Gluyas J. & Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

3.2.2.2.1 Capillary resistance

Capillary resistance is the force that opposes the movement of petroleum through small pore throats in a rock, where smaller and narrower pore throats are more effective at sealing because they require a higher capillary displacement pressure to be breached. Vertical migration of petroleum ceases when the pressure in the oil is insufficient to overcome this capillary resistance.
@ Gluyas J. & Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA
@ Chapman R E, 1983. Petroleum Geology, Elsevier, Amsterdam.
@ GeoGPT: https://geogpt.zero2x.org/, Accessed on 10 August 2025.

3.2.2.2.2 Hydrodynamic flow

Pressure gradients and the resulting buoyant pressures are not always static. Both hydrodynamic flow and pressure transients change seal capacity.
@ Hydrodynamic flow and pressure transients - AAPG:
https://wiki.aapg.org/Hydrodynamic_flow_and_pressure_transients/, Accessed on 25 June 2025

3.2.2.3 Migration rate

The rate at which petroleum migrates can be calculated using Darcy's Law. The calculated migration rate for petroleum in sandstone ranges from 1 to 1000 km per million years, and in limestone 0.01-10 km per million years.
@ England, WA., Mann, A.L., & Mann, D.M. 1991, Migration from source to trap. In Merrill, R.K. (ed.) Source and Migration Processes and Evaluation Techniques. Treatise of Petroleum Geology Handbook of Petroleum Geology, American Association of Petroleum Geologists, Tulsa, Oklahoma, Chapter 3,23-46.

3.2.2.4 Migration direction

Buoyancy drives oil/gas to migrate upwards or updip. Hydrodynamic pressure drives oil/gas to migrate laterally from a higher potentiometric level to a lower one.

@ Feng Z Q, Zhang S, Feng Z H. 2011. Discovery of "Enveloping Surface of Oil and Gas Overpressure Migration" in the Songliao Basin and its bearings on hydrocarbon migration and accumulation mechanisms. Science China Earth Science, v.41(12), p.1872-1883.

3.2.2.5 Migration distance

Lateral migration distances, established by oil-source geochemical fingerprinting, could reach hundreds of kilometers; vertical migration distances could reach a few kilometers.
@ Migration distance: vertical and lateral - AAPG Wiki:
https://wiki.aapg.org/Migration_distance:_vertical_and_lateral, accessed on 5 August 2025

3.2.2.6 Migration pathway

Migration pathways are the conduits provided by features such as faults, fractures, unconformities, and laterally continuous reservoirs that facilitate the movement of hydrocarbons from source rocks to reservoirs and traps. These pathways can include short lateral and vertical migration through or along faults into juxtaposed and interfingering reservoirs, significant lateral migration along pre-salt clastic carrier beds, upward migration through salt windows and along faults into post-rift reservoirs, and direct migration from source rocks to reservoirs in the absence of salt seals.
@Mello M.R., 1994. Selected Petroleum Systems in Brazil: in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.499-512.
@ Beglinger S E, Doust H, Cloetingh S. Relating petroleum system and play development to basin evolution: West African South Atlantic basins[J]. Marine and Petroleum Geology, 2012, 30(1): 1-25.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.2.2.6.1 Carrier bed

Carrier bed describes a permeable and porous rock formation that serves as a migration pathway for petroleum compounds, facilitating their movement from source rocks to traps. These beds are typically more permeable and porous than the source rocks, enabling the efficient transport of hydrocarbons through fractures, faults, and interconnected pore spaces. Examples include weathered zones, sandstones, and other regionally continuous permeable zones.
@ Walters R F. Differential entrapment of oil and gas in Arbuckle dolomite of central Kansas. AAPG Bulletin, 1958, 42(9): 2133-2173.
@ Murris R J .Middle East, Stratigraphic evolution and oil habitat.AAPG Bulletin, 1980, 64(5):597-618
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.2.2.6.2 Fault and fracture

Faults and fractures in a particular tectonic setting have acted as conduits with respect to the migration of subsurface fluids.
@ Fault seal-conduit studies-AAPG Wiki: https://wiki.aapg.org/Fault_seal-conduit_studies, accessed on 5 August 2025

3.2.2.6.3 Unconformity
In an ideal sequence of rocks, all the strata would stack up like the pages in a book in a conformable relationship. Where they don't, the plane between the mismatched strata—representing some sort of gap—is an unconformity.
@ Unconformities: Gaps in the Geological Record: https://www.thoughtco.com/unconformities-gaps-in-the-record-1440771, accessed on 6 August 2025.

3.2.3 Other concepts related to migration

3.2.3.1 Migration driven by overpressure
It refers to hydrocarbon migration due to the difference of pressure potential within the source rock and tight non-source rocks where the capillary pressure is greater than the buoyancy. It could lead to the formation of continuous tight oil and gas (unconventional) accumulations.
@ Feng Z Q, Zhang S, Feng Z H. 2011. Discovery of "Enveloping Surface of Oil and Gas Overpressure Migration" in the Songliao Basin and its bearings on hydrocarbon migration and accumulation mechanisms. Science China Earth Science, 41(12), 1872-1883.

3.2.3.2 Envelope depicting the extent of overpressure migration
It refers to the stratigraphic extent to which migrating hydrocarbons driven by overpressure could reach. Within the envelope, continuous shale oil/gas and tight oil/gas accumulations could be formed.
@ Feng Z Q, Zhang S, Feng Z H. 2011. Discovery of "Enveloping Surface of Oil and Gas Overpressure Migration" in the Songliao Basin and its bearings on hydrocarbon migration and accumulation mechanisms. Science China Earth Science, 41(12), 1872-1883.

3.2.3.3 Remigration
Remigration refers to migration from one reservoir position through an intervening section into another reservoir position in the same or a different reservoir.
@ Hydrocarbon migration-AAPG wiki: https://wiki.aapg.org/Hydrocarbon_migration, accessed on 6 August 2025.

3.2.3.4 Lateral migration
Lateral migration refers to the significant movement of petroleum along relatively permeable, intercalated beds, which can occur over large distances and through specific carrier beds. This process is driven by buoyancy and confined by the tilt of permeable sandstone and carbonate formations with low structural dip. It can also involve migration through stratigraphically younger units, and is essential for the charging of reservoirs in areas without adjacent source rocks.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA
@ Chapman R E, 1983. Petroleum Geology, Elsevier, Amsterdam.
@ Richard Chuchla, written communication, 15 July 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.2.3.5 Vertical migration

Vertical migration describes the movement of hydrocarbons from their source rock to reservoir rocks in a direction perpendicular to the structural contour of the carrier bed(s). This process can be driven by overpressure, buoyant forces, and the presence of fractures or conduits such as faults and salt diapirs. Vertical migration ceases when the pressure of the hydrocarbon column is insufficient to overcome the capillary resistance of the cap rock. The migration pathways can vary, including pressure-induced vertical migration through overpressure fractures, migration along unconformities, and movement through dense limestone intervals when the buoyant pressure exceeds the capillary pressure of the seal.

@ Cornford C and Mandal-Ekofisk, 1994.Petroleum system in the Central Graben of the North Sea: in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.537-571.

@ Ulmishek G F, Klemme H D. Depositional controls, distribution, and effectiveness of world's petroleum source rocks[J].U.S.geological Survey Bulletin, 1991, 73:3.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 11 August 2025

3.2.3.6 Migration efficiency

Migration efficiency is the percentage of expelled oil in the fetch area that reaches the trap, which can be influenced by factors such as the structural dip, focusing features like “noses”, reservoir rock type, distance between the source kitchens and the trap, and whether spilled oil is included in the calculation.

@ England W A , 1994. Secondary migration and accumulation of hydrocarbons: in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.211-217.

@ Richard Chuchla, written communication, 15 July 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.2.4 Modeling migration (simulation of migration)

Migration modeling is defined as a predictive tool used to forecast hydrocarbon presence during the exploration and development stages, utilizing various mechanisms such as hybrid, flowpath, and invasion percolation to establish migration pathways.

@ migration modeling - Sciencedirect: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/migration-modeling, accessed on 15 August 2025

3.2.4.1 Darcy's law applications

Darcy's law is an equation that describes the flow of a fluid through a porous medium and through a Hele-Shaw cell. The law was formulated by Henry Darcy based on results of experiments on the flow of water through beds of sand, forming the basis of hydrogeology, a branch of earth sciences. It is analogous to Ohm's law in electrostatics, linearly relating the volume flow rate of the fluid to the hydraulic head difference (which is often just proportional to the pressure difference) via the hydraulic conductivity. In fact, the Darcy's law is a special case of the Stokes equation for the momentum flux, in turn deriving from the momentum Navier–Stokes equation.

@ Darcy’s law - Wikipedia: https://en.wikipedia.org/wiki/Darcy%27s_law#Background, accessed on 10 March 2025

3.2.4.2 Invasion percolation models

Invasion percolation is a mathematical model of realistic fluid distributions for slow immiscible fluid invasion in porous media, in percolation theory. It "explicitly takes into account the transport process taking place". A wetting fluid such as water takes over from a non-wetting fluid such as oil, and capillary forces are taken into account.
@ Invasion percolation - Wikipedia: https://en.wikipedia.org/wiki/Invasion_percolation, accessed on 10 March 2025

3.2.4.3 Ray tracing methods

Ray tracing is a method for calculating the path of waves or particles through a system. The method is practiced in two distinct forms: Ray tracing (physics), which is used for analyzing optical and other systems; Ray tracing (graphics), which is used for 3D image generation.
@ Ray tracing - Wikipedia: https://en.wikipedia.org/wiki/Ray_tracing, accessed on 10 March 2025

3.2.5 Migration indicators and tools

They are the indicators and tools used for investigating hydrocarbon migration.
@ Defined by the Working Group of Petroleum Geology Knowledge System

3.2.5.1 Biomarker indicators

The identification and correlation of petroleum accumulations rely heavily on biomarkers—organic compounds derived from biological precursors—that retain structural information about their origins. Biomarkers are quantified via GC-MS targeting mass fragments (e.g., m/z 191 for terpanes, m/z 217 for steranes). Statistical tools like Pearson correlation coefficients (PCC) and principal component analysis (PCA) enhance pattern recognition across datasets. Matching biomarker fingerprints (e.g., sterane profiles) ties oils to specific formations.
@ Richard Chuchla, written communication, 15 July 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 11 August 2025

3.2.5.2 Seismic indicators

Seismic indicators are specific features or patterns observed in seismic data that provide information about the subsurface geology, tectonic activity, and potential hazards. These indicators can be used to infer various geological phenomena such as faulting, folding, sedimentary structures, and the presence of hydrocarbons.
@ Sinvhal A, Khattri K N, Sinvhal H, Awasthi A K ,1984. Seismic indicators of stratigraphy. GEOPHYSICS, 49(8), 1140-1395.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.2.5.2.1 Direct Hydrocarbon Indicators (DHI)

Gas, and on occasion oil, in situ in the reservoir may generate a "direct hydrocarbon indicator" (DHI) that is visible on seismic as a flat spot, bright spot or a dim spot. Just as sharp changes in the acoustic properties of rocks are responsible for generating seismic reflections, so too can abrupt changes in the acoustic properties of the formation fluids also create reflections. Where such reflections do occur, they are most commonly generated at gas/water or gas/oil contacts. More rarely, DHIs can be generated at oil/water contacts. Such effects should be flat in the depth domain and can crosscut seismic reflectors generated from contrasting lithologies.

@ Gluyas J. & Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

3.2.5.2.2 Amplitude Variation with Offset (AVO)
AVO has been a prominent technique in detecting hydrocarbons and reducing drilling risk. AVO can detect hydrocarbons because AVO shows the variation of the amplitude of the offset, which represents the amplitude of the wave energy as it passes through the layer which is influenced by the parameters of the speed and density of the coating, so that the density of the layer can be analyzed by analyzing the reflection coefficient. AVO means that amplitude change with offset caused by lithology of fluid. AVO is also known as AVA (amplitude variation with angle) because this phenomenon is based on the relationship between the reflection coefficient and the angle of incidence. But since the angle of incidence affecting the offset and the offset itself can be varied in order to change the angle of incidence, so it is commonly known as AVO.
@ Amplitude variations with offset (AVO) -AAPG Wiki:
https://wiki.aapg.org/Amplitude_variations_with_offset_(AVO), accessed on 16 June 2025

3.2.6 Migration efficiency
Migration efficiency can be estimated by mapping flowlines from the effective source to the trap. Where flowlines are focused due to the structural geometry within the drainage area (such as the presence of structural "noses"), efficiency is generally high. This analysis allows determination of trap fill multiples which is one way of derisking the likelihood of trap charge.
@ Defined by the Working Group of Petroleum Geology Knowledge System
@ Richard Chuchla, written communication, 15 July 2025

3.3 Petroleum accumulation
It is a geological process describing the entrapment of oil and gas. A hydrocarbon accumulation forms when migrating hydrocarbon filaments encounter a zone (the seal), either laterally or vertically, with pore throat sizes smaller than the carrier bed. The seal pore throat breakthrough pressure (also known as the capillary entry pressure) or the distance to the spill point of the trap, whichever is less, determines the hydrocarbon accumulation column height.
@ Hydrocarbon expulsion, migration, and accumulation - AAPG Wiki:
https://wiki.aapg.org/Hydrocarbon_expulsion,_migration,_and_accumulation#Accumulation, accessed on 16 June 2025

3.3.1 Hydrocarbon accumulation process in traps
Hydrocarbons can accumulate in a single trap and a series of traps.
@ Levorsen A L, 2001. Geology of Petroleum, AAPG Special Publication, The AAPG Foundation, Tulsa, Oklahoma

3.3.1.1 Hydrocarbon accumulation process in a single trap
It comprises 3 stages. In Stage I, oil migrates into the trap and displaces water. In Stage II, with further maturation, gas is generated from the source rock. It moves to the crest of the trap and displaces the oil downward. In Stage III, with further gas generation, oil can be completely displaced from the trap (displaced below the spill plane) and migrates to the next trap up dip. This is commonly described as a "fill and spill" sequence.

@ Levorsen A L, 2001. Geology of Petroleum, AAPG Special Publication, The AAPG Foundation, Tulsa, Oklahoma

3.3.1.2 Differential entrapment in a series of traps

It is the process of oil and gas entrapment in a number of traps.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

3.3.1.2.1 Differential entrapment
In a multitude of traps whose spill points are gradually raised upwards, the traps with spill points at lower elevations are filled with gas, those with spill points at intermediate elevations are filled with oil and those with spill points at higher elevations are filled with water.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

3.3.1.2.2 Results of oil and gas differential entrapment
(1) From traps with lower spill points to those with higher spill points, the sequential hydrocarbon pools are gas pools, oil and gas pools, oil pools and traps with water only. (2) Traps fully filled with oil can be refilled with gas, but traps filled with gas cannot be refilled with oil. (3) The number of oil, oil and gas, and gas pools formed by differential entrapment is controlled by the amount of hydrocarbons available for entrapment, the number of traps, the size of traps and the migration pathway.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

3.3.2 Accumulation model

It is a model to indicate how a hydrocarbon accumulation is formed. It generally describes the ways in which oil and/or gas migrate from the source rock and accumulate in the trap. The model is usually shown both in geological cross sections, on a structure map of the base of the seal at the top of the carrier bed and in 3D models with the source rock, reservoir rock, seal rock, migration pathway and directions being shown. The structure map of the base of the seal at the top of the carrier bed allows definition of the drainage area feeding the trap. Migration is perpendicular to the structural contour of the top of the carrier bed (or the base of the overlying seal).
@ Defined by the Working Group of Petroleum Geology Knowledge System
@ Richard Chuchla, written communication, 15 July 2025

3.3.2.1 Buoyancy-driven accumulation

Buoyancy-driven accumulation refers to the process by which fluids, such as oil and gas, migrate and accumulate in subsurface reservoirs due to differences in density between the fluids and the surrounding rock or water. This process is a fundamental concept in petroleum geology and plays a critical role in the formation of hydrocarbon reservoirs.
@ Pang X, 2023. Buoyancy-Driven Hydrocarbon Accumulation Depth in the WPS. In: Quantitative Evaluation of the Whole Petroleum System.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.3.2.1.1 Buoyancy forces (Buoyancy)
Buoyancy is the tendency for a body (or a drop of immiscible fluid) to float or rise when submerged in a fluid of greater density, driven by the vertical buoyancy force due to the lower density of the less-dense fluid compared to the surrounding denser fluid.
@ England W.A., 1994. Secondary Migration and Accumulation of Hydrocarbons: in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.211-218.
@ Buoyancy pressure - AAPG Wiki: https://wiki.aapg.org/Buoyancy_pressure, accessed on 5 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, Accessed on 10 August 2025

3.3.2.1.2 Capillary resistance
Capillary resistance is the force that opposes the movement of petroleum through small pore throats in a rock, where smaller and narrower pore throats are more effective at sealing because they require a higher capillary displacement pressure to be breached. Vertical migration of petroleum ceases when the pressure in the oil is insufficient to overcome this capillary resistance.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA
@ Chapman R E, 1983. Petroleum Geology, Elsevier, Amsterdam
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.3.2.2 Hydrodynamic trapping
It refers to the trapping resulting from true hydrodynamic flow.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

3.3.2.2.1 Tilted oil-water contacts
A tilted oil-water contact is an oil-water interface that is inclined due to variations in aquifer pressure caused by the movement of water in the subsurface, such as from a mobile artesian aquifer or basin dewatering. The tilt is generally less than 2 degrees and is directed towards the area of lower pressure.
@ Link P K, 1987. Basic Petroleum Geology (2nd edition), OGCI Publications, Oil & Gas Consultants International, Inc., Tulsa
@ Reservoir fluids - AAPG Wiki: https://wiki.aapg.org/Reservoir_fluids, accessed on 5 August 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.3.2.2.2 Hydrodynamic flow patterns
Pressure gradients and the resulting buoyant pressures are not always static. Both hydrodynamic flow and pressure transients change seal capacity.
@ Hydrodynamic flow and pressure transients - AAPG: https://wiki.aapg.org/Hydrodynamic_flow_and_pressure_transients/, Accessed on 25 June 2025

3.3.2.3 Charge-limited vs. trap-limited accumulation
Charge-limited accumulation occurs when the amount of hydrocarbons generated and available for migration is insufficient to fill the available traps.

Trap-limited accumulation occurs when the amount of hydrocarbons generated and available for migration exceeds the capacity of the available traps to hold them.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.4 Petroleum Preservation

Preservation of petroleum accumulation is a function of tectonic setting, trap type, depth of burial, and seal type. Some petroleum accumulations are likely to persist for hundreds of millions of years with relatively little alteration or dilution. Other hydrocarbon accumulations, however, may be destroyed or depleted through later leakage or other processes. In many prospects it is not enough just to know that a trap is present in a basin where hydrocarbons were generated and migrated. We also must know that the trap was preserved over time. It is imperative that explorationists know destructive processes and how to determine the age of an accumulation.
@ Predicting preservation and destruction of accumulations - AAPG Wiki: https://wiki.aapg.org/Predicting_preservation_and_destruction_of_accumulations, accessed on 16 June 2025

3.4.1 Destructive processes

Petroleum accumulations can be destroyed as a result of spillage, leakage or destruction.

3.4.1.1 Spillage

Trapping geometry changes (for example, the trap is tilted) so that the petroleum spills below the sealing lithology.

3.4.1.1.1 Structural spillage

Structural spillage is avoided if trapping geometry is maintained during deformation after charging. Structural closure must be maintained at all times during subsequent deformation. Throws on faults likely to cut the trap seal at the accumulation should be less than the seal thickness to avoid spillage by juxtaposition across the fault plane.
@ Trap geometry: changes - AAPG Wiki: https://wiki.aapg.org/Trap_geometry:_changes, accessed on 16 June 2025

3.4.1.1.2 Stratigraphic spillage

Stratigraphic Spillage refers to the leakage or escape of hydrocarbons from a trap due to a lateral or vertical discontinuity in the reservoir or seal caused by stratigraphic features, rather than by structural deformation (such as faulting or folding).
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.4.1.2 Leakage

Lack of integrity of sealing lithology allows petroleum to leak through the seal. This may be due to faulting or if the trap undergoes later exhumation.

3.4.1.2.1 Capillary leakage

Cap-rock seals can be divided genetically into those that fail by capillary leakage (*membrane seals*) and those whose capillary entry pressures are so high that seal failure preferentially occurs by fracturing and/or wedging open of faults (*hydraulic seals*).

An intact membrane seal fails when the capillary pressure (created by the height of an underlying petroleum column) exceeds the seal capillary displacement pressure. This type of seal does not fracture during deformation.
@ Watts N L, 1987. Theoretical aspects of cap-rock and fault seals for single- and two-phase hydrocarbon columns, Marine and Petroleum Geology, 4(4), 274-307.
@ Intact membrane seal leakage - AAPG Wiki: https://wiki.aapg.org/Intact_membrane_seal_leakage, accessed on 13 June 2025

3.4.1.2.2 Fault-related leakage
Fault-related leakage is the process by which fluids escape from a reservoir or containment zone along a fault plane due to either the intrinsic permeability of the fault zone, fault reactivation under stress changes, or geomechanical failure (e.g., shear slip or dilation), thereby compromising the integrity of the seal and enabling vertical or lateral fluid migration.
@ Seyyed A H, 2019. Fault leakage detection and characterization using pressure transient analysis. Journal of Petroleum Science and Engineering. 176, 880-886.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.4.1.2.3 Fracture-related leakage
In settings with extreme overpressure, pore-water pressure approaches the pressure required for natural hydraulic fracturing. If the petroleum column is thick enough, the sum of the capillary pressure and fluid pressure can equal or exceed the pressure needed to fracture the rock. The result is natural hydraulic fracturing: the seal becomes hydrofractured and the petroleum leaks.
@ Hydrofractured seal leakage - AAPG Wiki: https://wiki.aapg.org/Hydrofractured_seal_leakage, accessed on 13 June 2025

3.4.1.2.4 Diffusion through seals
Natural gas can dissolve in water to a significant enough degree that diffusion through water in the seal rock can result in substantial loss of gas, given geological time. Because of their very low solubility in water, black oils and high molecular-weight components of oil cannot leak by this mechanism, even at high temperatures. Leakage rates determined in various published studies demonstrate the likelihood of gas accumulations lasting for tens to hundreds of million years.
@ McAuliffe C D, 1980. Oil and gas migration: chemical and physical constraints, Problems of Petroleum Migration: AAPG Studies in Geology, 10, 89–108.
@ Montel F, Caillet G, Pucheu A, and Caltagirone J, 1993. Diffusion model for predicting reservoir gas losses: Marine and Petroleum Geology, 10, 51–57.
@ Diffusive seal leakage - AAPG Wiki: https://wiki.aapg.org/Diffusive_seal_leakage, accessed on 13 June 2025

3.4.1.2.5 Exhumation
In geology, exhumation is the process by which a parcel of buried rock approaches Earth's surface.
@ Exhumation (geology) - Wikipedia:
https://en.wikipedia.org/wiki/Exhumation_(geology)#cite_note-:6-1, accessed on 13 June 2025

3.4.1.3 Destruction
Petroleum is destroyed, altered, or diluted with nonhydrocarbon gases.

@ Blanc P and Connan J, 1994. Preservation, Degradation, and Destruction of Trapped Oil: in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Ssource to Trap: AAPG Memoir 60, p.237-247.

3.4.1.3.1 Bacterial degradation (Biodegradation)
Biodegradation is the microbial oxidation of crude oil. It usually takes place at a shallow depth where the oil is in contact with flowing oxic water.
@ Blanc P and Connan J, 1994. Preservation, Degradation, and Destruction of Trapped Oil: in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Ssource to Trap: AAPG Memoir 60, p.237-247.

3.4.1.3.2 Water washing
Water washing is the removal of the more water-soluble compounds from crude oil, which often occurs simultaneously with biodegradation as both processes require contact with flowing meteoric water.
@ Blanc P and Connan J, 1994. Preservation, Degradation, and Destruction of Trapped Oil: in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.237-247.

3.4.1.3.3 Thermal cracking
Thermal cracking is the molecularly dissociative process that alters kerogen and other organic constituents, leading to the breakdown of liquid hydrocarbons and the generation of dry gas, typically at temperatures around 180 ℃. More extensive thermal cracking in the deep subsurface can also result in the formation of isotopically heavier condensates as residual liquids.
@ Terken J M J, Frewin N L, Indrelid S L. Petroleum systems of Oman: charge timing and risks. AAPG bulletin, 2001, 85(10): 1817-1845.
@ Law B E. Basin-centered gas systems. AAPG bulletin, 2002, 86(11): 1891-1919.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025.

3.4.2 Determining the age of accumulations
Accumulations should be dated to evaluate the potential importance of accumulation destruction in an area of interest. Leakage, spillage, petroleum destruction, and cementation are more likely to alter the size and quality of old accumulations than young accumulations. Young accumulations with active petroleum charge are more likely to be affected by displacement of oil by later gas charge.
@ Mcgregor D S, 1996. Factors controlling the destruction or preservation of giant light oilfields: Petroleum Geoscience, 2, 197–217.
@ Predicting preservation and destruction of accumulations - AAPG Wiki: https://wiki.aapg.org/Predicting_preservation_and_destruction_of_accumulations#Determining_age_of_accumulations, accessed on 16 June 2025

3.4.2.1 Dating the generation of the trapped hydrocarbons
In dating the generation of the trapped hydrocarbons, we use geohistory models to determine when the oil or gas charged an accumulation. If the migration distance is short, this date is an estimate of the age of the accumulation. Oil and gas may remigrate later due to structural growth, so these dates may overestimate the true age of the accumulation. For example, by this approach,

the Sho-Vel-Tum trend oil fields in southern Oklahoma accumulated from the Atokan (early Pennsylvanian), when generation began in the Ardmore basin, to Permian, when oil generation ended in the Ardmore and Anadarko basins. Because no significant tectonic events have changed the structure of these fields since trapping, these accumulations are at least 250 m.y. old—maybe as old as 300 m.y.
@ Predicting preservation and destruction of accumulations - AAPG Wiki: https://wiki.aapg.org/Predicting_preservation_and_destruction_of_accumulations#Determining_age_of_accumulations, accessed on 16 June 2025

3.4.2.1.1 Biomarker analysis
he identification and correlation of petroleum accumulations rely heavily on biomarkers—organic compounds derived from biological precursors—that retain structural information about their origins. Biomarkers are quantified via GC-MS targeting mass fragments (e.g., m/z 191 for terpanes, m/z 217 for steranes). Statistical tools like Pearson correlation coefficients (PCC) and principal component analysis (PCA) enhance pattern recognition across datasets. Matching biomarker fingerprints (e.g., sterane profiles) ties oils to specific formations.
@ Richard Chuchla, written communication, 15 July 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 11 August 2025

3.4.2.1.2 Isotope geochemistry
Isotope geochemistry is an aspect of geology based upon the study of natural variations in the relative abundances of isotopes of various elements. Variations in isotopic abundance are measured by isotope-ratio mass spectrometry, and can reveal information about the ages and origins of rock, air or water bodies, or processes of mixing between them.
@ Isotope geochemistry - wikipedia: https://en.wikipedia.org/wiki/Isotope_geochemistry, accessed on 13 June 2025

3.4.2.1.3 Basin modeling
Basin modeling is designed to describe the burial of source rocks, the hydrocarbon generation in those rocks, and the expulsion, migration, trapping, and preservation of those hydrocarbons. The definition of basin modeling as presently used usually corresponds more closely to the concept of a sedimentary basin than to that of a petroleum system. A single basin modeling simulation often includes several petroleum systems, without separating or distinguishing among them.
@ Waples D W, 1994. Thermal modeling: Thermal Indicators, hydrocarbon generation, and oil cracking, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.307-322.

3.4.2.2 Dating the formation of the reservoir, seal, and trap
Dating the formation of the reservoir, seal, and trap, sets a lower (oldest) limit on the age of a petroleum accumulation. For example, offshore Gulf of Mexico accumulations in Pleistocene reservoirs cannot be older than the Pleistocene.
@ Predicting preservation and destruction of accumulations - AAPG Wiki: https://wiki.aapg.org/Predicting_preservation_and_destruction_of_accumulations#Determining_age_of_accumulations, accessed on 16 June 2025
@ James Ogg, written communication, 7 July 2025.

3.4.2.2.1 Stratigraphic dating

The main method for stratigraphic dating is the widely used application of biostratigraphy for determining the relative age of geologic formations. This biostratigraphic dating is based on the interception, overlap, and/or absence of different index fossils, which have short and non-repeatable life spans. In operational use, that uses cutting returned to the surface as drilling progresses, dating is done through the first (highest) downhole occurrence (FDO) of these index fossils, while the last (lowest) downhole occurrence (LDO) can be inaccurate due to mechanical caving of higher rocks.

@ Biostratigraphic applications in hydrocarbon exploration - AAPG Wiki: https://wiki.aapg.org/Biostratigraphic_applications_in_hydrocarbon_exploration, accessed on 16 June 2025

3.4.2.2.2 Structural dating

Structural dating refers to the methodology of assigning a time (either relative or absolute) to structural features (e.g., faults, folds, joints, foliations) or deformation phases by combining field-based structural analysis with geochronological techniques, stratigraphic relationships, or cross-cutting relationships.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.4.2.3 Directly measuring entrapment by radiometric means

Direct radiometric measurements are difficult to perform because most reservoirs do not have datable material that formed during charging. The Groningen gas field (Permian, the Netherlands) has been dated as pre-Late Jurassic by the retardation effect of gas on radiometrically datable illite cements in the reservoir.

@ Lee M, Aronson J L, and Savin S M, 1985. K/Ar dating of time of gas emplacement in Rotliegendes sandstone, Netherlands: AAPG Bulletin, 69, 1381–1385.

@ Predicting preservation and destruction of accumulations - AAPG Wiki: https://wiki.aapg.org/Predicting_preservation_and_destruction_of_accumulations#Determining_age_of_accumulations, accessed on 16 June 2025

3.4.2.4 Biomarker analysis

The identification and correlation of petroleum accumulations rely heavily on biomarkers—organic compounds derived from biological precursors—that retain structural information about their origins. Biomarkers are quantified via GC-MS targeting mass fragments (e.g., m/z 191 for terpanes, m/z 217 for steranes). Statistical tools like Pearson correlation coefficients (PCC) and principal component analysis (PCA) enhance pattern recognition across datasets. Matching biomarker fingerprints (e.g., sterane profiles) ties oils to specific formations.

@ Richard Chuchla, written communication, 15 July 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 11 August 2025

3.4.3 Overpressure and its impact on preservation

It deals with terminologies related to overpressure and its impact on preservation of hydrocarbons.

@ Defined by the Working Group of Petroleum Geology Knowledge System

3.4.3.1 Overpressure

Overpressure is a term used for subsurface pressures that significantly exceed the hydrostatic pressure. This situation implies that the flow of porewater to the surface during compaction is resisted to a considerable degree, so that the pressure gradients are increased in the least permeable part of the sediments. This process is referred to as compaction disequilibrium.

@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.

3.4.3.1.1 Mechanisms of overpressure generation

It documents how overpressure is created in the subsurface formations.

@ Defined by the Working Group of Petroleum Geology Knowledge System

3.4.3.1.1.1 Compaction Disequilibrium

The term compaction disequilibrium has been used to describe the development of overpressure because the permeability is too low for the water to be expelled at lower pressure gradients. A disequilibrium is always required for compaction to take place, but if the permeabilities are not very low, only a slight overpressure is required for the expulsion of porewater during compaction.

@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.

3.4.3.1.1.2 Fluid expansion

Fluid expansion refers to the mechanism, such as gas generation, that displaces matrix oil into the fracture system.

@ Al Salhi, M., Al Maimani, and Makel, G.H., 2001, A switch from verticals to dual lateral producers accelerate oil production and reduces UTC for Natih Field: SPE Paper 68217, 10 p.

Devonian E, Devonian L .1997 AAPG International Conference and Exhibition Abstracts. AAPG Bulletin, 1997, 81(8): 1359-1422.

@ GeoGPT: https://geogpt.zero2x.org/ , accessed on 8 August 2025.

3.4.3.2 Hydrodynamics

Hydrodynamics describes lateral fluid movement through aquifers that have generally low dip. The fluids can have a vertical component to their movement but, on a basinwide scale, the lateral flow component is of major concern.

@ Hydrodynamics - AAPG: https://wiki.aapg.org/Hydrodynamics, accessed on 16 June 2025

3.4.4 Role of tectonics in preservation

The role of tectonics in preservation is the control exerted by tectonic activity on the long-term stability and integrity of subsurface geological systems—particularly sedimentary basins, hydrocarbon accumulations, and stratigraphic records—by influencing burial history, trap formation, seal integrity, and exposure to erosion or fluid migration.

@ Dilce D F R, 2006. The Role of Tectonics on the Preservation of Incised-Valley Estuaries in Areas with Low Accommodation Rates: Examples From Upper Scretaceous and Miocene Successions in Northern Brazil. SEPM.

3.4.4.1 Uplift and erosion

Uplift and erosion describe the process where crustal shortening, thermal doming, and tectonic

movements cause the elevation and subsequent wearing away of the rock mass, resulting in the formation of topographic highs, regional unconformities, and the exposure of underlying strata.
@ Talukdar, S C, and Marcano F, 1994. Petroleum Systems of the Maracaibo
@ Basin, Venezuela, in Magoon, L. B, and W. G. Dow, eds., 1994, The petroleum system-from source to trap: AAPG Memoir 60, p.463-48.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

3.4.4.2 Fault reactivation

Fault reactivation refers to the process of a fault becoming active again after stress rebuilds or under a new stress field.
@ Parnaud, F., Y. Gou, J.-C. Pascual, I. Truskowski, O. Gallango, H. Passalacqua, and F. Roure, 1995, Petroleum geology of the central part of the Eastern Venezuela basin, in A. J. Tankard, R. Suárez S., and H. J. Welsink, Petroleum basins of South America: AAPG Memoir 62, p. 741–756.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 7 August 2025

4. Petroleum occurrence

Petroleum occurrence is the distribution of oil and gas in different geological entities including pool, field, play, system and basin.
@ Modified from Levorsen A L, 2001. Geology of Petroleum, AAPG Special Publication, The AAPG Foundation, Tulsa, Oklahoma

4.1 Pool

A pool is a hydrocarbon accumulation in a single trap. It has its own pressure system and fluid contacts. In general, the term “pool” is synonymous with the term “reservoir”; however, in certain situations, a pool may consist of more than one reservoir.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

4.1.1 Pool type

Pool is classified into different types on basis of the primary hydrocarbon phase and fluid composition present in the reservoir.
@ Defined by the Working Group of Petroleum Geology Knowledge System

4.1.1.1 Oil and gas pool

It is a pool with gas in the upper portion, oil in the middle and water in the bottom portion.
@ Levorsen A L, 2001. Geology of Petroleum, AAPG Special Publication, The AAPG Foundation, Tulsa, Oklahoma

4.1.1.2 Oil pool

It is a pool with oil in the upper portion and water in the bottom portion.
@ Levorsen A L, 2001. Geology of Petroleum, AAPG Special Publication, The AAPG Foundation, Tulsa, Oklahoma

4.1.1.3 Gas pool

It is a pool with gas in the upper portion and in the bottom portion.

@ Levorsen A L, 2001. Geology of Petroleum, AAPG Special Publication, The AAPG Foundation, Tulsa, Oklahoma

4.1.1.4 Condensate pool

It is a pool of gases which condense to condensate when brought to the surface.
@ Defined by the Working Group of Petroleum Geology Knowledge System

4.1.2 Pool attributes

Pool attributes refer to parameters for describing the oil and gas occurrence in a trap.
@ Defined by the Working Group of Petroleum Geology Knowledge System

4.1.2.1 Fluid contacts

Fluid contact refers to the boundaries between gas, oil, and water within a petroleum pool, which develop due to differences in specific gravity between these fluids. These contacts are generally horizontal unless influenced by fluid movement or other factors within the reservoir. The nature of these boundaries can be sharp or transitional, with abrupt contacts indicating high permeability and gradational ones suggesting low permeability and high capillary pressure. Pressure within the reservoir plays a crucial role in determining the predominant hydrocarbon phases, such as gas, dissolved gas, or condensate. A flowing aquifer can also cause tilted fluid contacts.
@ Link P K. 1988. Basic Petroleum Geology, OGCI Publications, Oil & Gas Consultants International, Inc., Tulsa
@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025.

4.1.2.1.1 GOC (Gas-Oil Contact)
It is the gas-oil contact separating the gas cap from the underlying oil column.
@ Levorsen A L, 2001. Geology of Petroleum, AAPG Special Publication, The AAPG Foundation, Tulsa, Oklahoma

4.1.2.1.2 OWC (Oil-Water Contact)
It is the oil-water contact separating the oil column from the underlying water.
@ Levorsen A L, 2001. Geology of Petroleum, AAPG Special Publication, The AAPG Foundation, Tulsa, Oklahoma

4.1.2.1.3 GWC (Gas-Water Contact)
GWC (Gas-Water Contact) is the subsurface boundary where gas and water are in direct contact, typically occurring at a specific depth.
@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

4.1.2.1.4 Free Water Level (FWL)
The free water level (FWL) occurs where buoyancy pressure is zero in the reservoir-aquifer system. It defines the downdip limits of an accumulation.
@ Free water level determination using pressure - AAPG Wiki: https://wiki.aapg.org/Free_water_level_determination_using_pressure, accessed on 16 June 2025

4.1.2.1.5 Oil and gas column (hydrocarbon column)
It is the vertical distance between the OWC and the trap crest.
@ Levorsen A L, 2001. Geology of Petroleum, AAPG Special Publication, The AAPG Foundation, Tulsa, Oklahoma

4.1.2.2 Volumetrics
It is a term related to the measuring of volume.
@ volumetric - Cambridge: https://dictionary.cambridge.org/zhs/%E8%AF%8D%E5%85%B8/%E8%8B%B1%E8%AF%AD-%E6%B1%89%E8%AF%AD-%E7%AE%80%E4%BD%93/volumetric, accessed on 13 June 2025

4.1.2.2.1 Area
It is the area bounded by the outer margin, which is the intersection line of the oil-water contact and the top of the reservoir bed.
@ Levorsen A L, 2001. Geology of Petroleum, AAPG Special Publication, The AAPG Foundation, Tulsa, Oklahoma

4.1.2.2.2 Pay
Pay is defined as that part of a reservoir unit from which hydrocarbons can be produced at economic rates given a specific production method. This concept of pay links the physical characteristics of the reservoir (rock properties, fluid saturations, and capillary behavior) to the economic aspects of production (completion method, recovery techniques, and volumetric estimates of reserves).
@ Pay determination - AAPG Wiki: https://wiki.aapg.org/Pay_determination, accessed on 16 June 2025

4.1.2.2.3 Nonpay
Nonpay is defined as the part of a reservoir unit that will not produce hydrocarbons at economic rates and includes intrareservoir barriers.
@ Pay determination - AAPG Wiki: https://wiki.aapg.org/Pay_determination, accessed on 16 June 2025

4.1.2.2.4 Net-to-gross ratio
The net-to-gross ratio, typically estimated from analogues and wireline logs, is used to calculate the proportion of the sedimentary interval that contains reservoir rocks.
@ Petroleum exploration - AAPG Wiki: https://wiki.aapg.org/Petroleum_exploration, accessed on 16 June 2025

4.1.2.2.5 Porosity
Porosity φ is the ratio of void space within a rock (or sediment) relative to bulk volume. It reflects the fluid storage capacity of the reservoir.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

4.1.2.2.6 Fluid saturation

It is rare in nature to find a reservoir entirely oil- (or gas-) saturated. More commonly, the pore system contains both oil and water. The proportions of each phase are usually expressed as percentages, linked to the abbreviations Sw for water, So for oil, and Sg for gas.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

4.1.2.2.7 Formation volume factor

A formation volume factor represents the change in volume of the oil or gas that will take place when it is lifted from the high pressure and temperature of the reservoir and placed in the "stock tank". The formation volume factor for oil is represented as Bo and the formation volume factor for gas is represented as Bg.
@ Gluyas J. & Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

4.1.2.2.8 Recovery factor

The recovery factor is the ratio of the volume of oil or gas that can be recovered by present technology at present prices to the total volume of oil or gas in place, typically ranging from 20-30% but potentially up to 40-60% for oil and up to 80% for gas, and is influenced by the type of reservoir and the drive mechanism.
@ Chapman R E, 1983. Petroleum Geology, Elsevier, Amsterdam.
@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

4.1.3 Reservoir

The term “reservoir” creates confusion between different disciplines. Explorationists apply the term to mean a porous and permeable rock regardless of the fluid it contains. Reservoir engineers apply the term to mean a rock that contains hydrocarbons and associated fluids. This difference in meanings can cause problems for multidisciplinary teams unless the terminology is clear.
@ Reservoir system - AAPG Wiki: https://wiki.aapg.org/Reservoir_system, accessed on 16 June 2025

4.1.3.1 Reservoir temperature

Reservoir temperature is the temperature at which the reservoir is found, which can influence the properties of the crude oil it contains and the presence of light hydrocarbons and gases.
@ Tissot B T & Welte D H, 1984. Petroleum Formation and Occurrence (2nd edition), Springer-Verlag, Berlin

4.1.3.2 Reservoir pressure

Hydrocarbon reservoir pressure refers to the pressure exerted by the fluids (oil, gas, and water) within a hydrocarbon reservoir. This pressure is crucial for understanding the behavior of the reservoir and its ability to produce hydrocarbons.
@ Petroleum – Wikipedia: https://en.wikipedia.org/wiki/Petroleum, accessed on 10 March 2025
@ Richard Chuchla, written communication, 15 July 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

4.1.3.3 Pressure transient analysis

Pressure transient analysis is a technique used to assess the properties of the reservoir and the reservoir fluid around the wellbore by analyzing pressure data obtained from induced pressure variations in a well over time.

@ Data: sources - AAPG Wiki: https://wiki.aapg.org/Data:_sources, accessed on 16 June 2025

4.1.3.4 Microseismic monitoring

Microseismic monitoring is a technique that uses sensitive geophones to detect and map the location of small seismic events associated with the growth of fractures in the target formation. This monitoring can be performed in real time using a surface array or, if a nearby offset well is available, using downhole microphones. The data collected helps infer the size, orientation, and geometry of the induced fractures.

@ Fracking in the United Kingdom – Wikipedia:
https://en.wikipedia.org/wiki/Fracking_in_the_United_Kingdom, accessed on 5 May 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

4.1.3.5 Reservoir characterization

Reservoir characterization involves the integration of a vast amount of data from seismic surveys, from geophysical well logs, and from geological samples. The main aim of reservoir characterization is to produce a geological model that honors the available data and can be used to predict the distribution of porosity, permeability, and fluids throughout the field.

@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego

4.1.3.5.1 Compartmentalization

Compartmentalization in a petroleum reservoir refers to the division of the reservoir into separate pressure compartments. This can occur due to various geological processes, such as the presence of laterally discontinuous lithologies, tectonic activity, or the formation of seals that isolate compartments. These processes can develop over geologic or production time frames and often result in different fluid flow rates within each compartment. The identification of these compartments is frequently made during the production phase of the field by observing different fluid pressure in the compartments. Additionally, compartmentalization can be influenced by the deformation of source rock kitchens, leading to localized deposition and migration of hydrocarbons.

@ Devonian E, Devonian L .1997 AAPG International Conference and Exhibition Abstracts[J]. AAPG Bulletin, 1997, 81(8): 1359-1422.

@ Yowlumne field - AAPG Wiki: https://wiki.aapg.org/Yowlumne_field, accessed on 16 June 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 10 August 2025.

4.1.3.5.2 Flow units

A flow unit is a specific volume of a reservoir, which is composed of one or more reservoir quality lithologies and any nonreservoir-quality features, such as shales and cemented layers, within that same volume, as well as the fluids they contain. Flow units are internally consistent, but not necessarily homogeneous, in terms of either geological or petrophysical properties.

@ Flow units for reservoir characterization - AAPG Wiki: https://wiki.aapg.org/Flow_units_for_reservoir_characterization, accessed on 16 June 2025

4.1.3.5.3 Reservoir simulation
A simulation study requires description of the reservoir's rock and fluid properties, validation of completion and production history, and extensive history matching to validate and modify this input data. When history matching is complete, numerous predictions of field and well performance characteristics are calculated for various development scenarios.
@ Reservoir simulation study - AAPG: https://wiki.aapg.org/Reservoir_simulation_study, accessed on 16 June 2025

4.2 Prospect

A prospect is a potential hydrocarbon trap that has not yet been evaluated by drilling to determine whether it contains commercial quantities of petroleum. Once drilling is completed, the term “prospect” is dropped; the site becomes either a dry hole or a discovery. With further appraisal, the discovery may become a commercially viable producing field.
@ Province, basin, system, play, and prospect - AAPG Wiki: https://wiki.aapg.org/Province,_basin,_system,_play,_and_prospect#Play_and_prospect, accessed on 16 June 2025

4.2.1 Prospect evaluation

The exploration prospect evaluation process incorporates specification of geologic play concept, assessment of geologic risk, estimation of hydrocarbon volumes, conceptual engineering, and a development plan for economic analysis. The process includes a feedback loop for process improvement based on results of comparisons between predrill and postdrill results.
@ Otis R M and Schneidermann N, 1997. A Process for evaluating exploration prospects: AAPG Bulletin, v. 81(7), p.1087–1109

4.2.1.1 Seismic interpretation

Simply defined, seismic interpretation is the science (and art) of inferring the geology at some depth from the processed seismic record. While modern multichannel data have increased the quantity and quality of interpretable data, proper interpretation still requires that the interpreter draw upon his or her geological understanding to pick the most likely interpretation from the many “valid” interpretations that the data allow.
@ Seismic interpretation - AAPG Wiki: https://wiki.aapg.org/Seismic_interpretation, accessed on 5 August 2025

4.2.1.1.1 Structural interpretation
Structural seismic interpretation is directed toward the creation of structural maps of the subsurface from the observed three-dimensional configuration of arrival times.
@ Seismic interpretation - AAPG Wiki: https://wiki.aapg.org/Seismic_interpretation, accessed on 16 June 2025

4.2.1.1.2 Sequence stratigraphic interpretation
Seismic sequence stratigraphic interpretation relates the pattern of reflections observed to a model of cyclic episodes of deposition. The aim is to develop a chronostratigraphic framework of cyclic, genetically related strata.
@ Seismic interpretation - AAPG Wiki: https://wiki.aapg.org/Seismic_interpretation, accessed on 16 June 2025

4.2.1.1.3 Attribute analysis
This is concerned with the study of wave shape, polarity, continuity, and amplitude. Such analysis may give an indication of the thickness and of the nature of the upper and lower contacts of a reservoir. Comparison of observed seismic waves with synthetic traces computed from a geological model may give some insight into the lithological characteristics of the sand, and hence help to predict its geometry, internal reservoir characteristics and production behavior.
@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego

4.2.1.2 Well log analysis
ell log is one of the most fundamental methods for reservoir characterization, in oil and gas industry, it is an essential method for geoscientist to acquire more knowledge about the condition below the surface by using physical properties of rocks. This method is very useful to detect hydrocarbon bearing zone, calculate the hydrocarbon volume, and many others.
@ Well log analysis for reservoir characterization - AAPG Wiki: https://wiki.aapg.org/Well_log_analysis_for_reservoir_characterization, accessed on 5 August 2025

4.2.1.2.1 Petrophysical analysis
The seal quality of a rock is established soon after deposition. It is strongly influenced by its environment of deposition. Diagenesis can alter or completely change the original pore space of a rock, especially for carbonates. However, if the original pore space is not altered too much, then a relationship exists between lithofacies and seal-quality rocks that we can use when prospecting for stratigraphic traps. A petrophysical analysis of the lithofacies of a rock section in a target area can help determine if such a relationship exists.
@ Petrophysical analysis of lithofacies - AAPG Wiki: https://wiki.aapg.org/Petrophysical_analysis_of_lithofacies, accessed on 5 August 2025

4.2.1.2.2 Formation evaluation
Formation Evaluation in Petroleum Engineering is the process of assessing subsurface rock formations to determine their ability to produce oil and gas. It helps identify hydrocarbon-bearing zones, understand reservoir properties, and make decisions about well completion, production, and reservoir management.
@ Formation evaluation - Wikipedia: https://en.wikipedia.org/wiki/Formation_evaluation, accessed on 5 May 2025

4.2.1.3 Geological mapping
Digital geological mapping is the process by which geological features are observed, analyzed, and recorded in the field and displayed in real-time on a computer or personal digital assistant

(PDA). The primary function of this technology is to produce spatially referenced geological maps that can be utilized and updated while conducting field work.
@ Geological map - Wikipedia: https://en.wikipedia.org/wiki/Geological_map, accessed on 5 May 2025

4.2.1.3.1 Structural mapping
It leads to identifying the locations of major rock units and the faults and folds that led to their placement there.
@ Geology - Wikipedia: https://en.wikipedia.org/wiki/Geology#Structural_geology, accessed on 5 May 2025

4.2.1.3.2 Isopach mapping
An isopach map illustrates thickness variations within a tabular unit, layer or stratum. Isopachs are contour lines of equal thickness over an area. Isopach maps are utilized in hydrographic survey, stratigraphy, sedimentology, structural geology, petroleum geology and volcanology.
@ Isopach map - Wikipedia: https://en.wikipedia.org/wiki/Isopach_map, accessed on 5 May 2025

4.2.1.4 Basin modeling
Basin modeling is designed to describe the burial of source rocks, the hydrocarbon generation in those rocks, and the expulsion, migration, trapping, and preservation of those hydrocarbons. The definition of basin modeling as presently used usually corresponds more closely to the concept of a sedimentary basin than to that of a petroleum system. A single basin modeling simulation often includes several petroleum systems, without separating or distinguishing among them.
@ Waples D W, 1994. Thermal modeling: Thermal Indicators, hydrocarbon generation, and oil cracking, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.307-322.

4.2.1.4.1 Thermal history
Thermal history describes the thermal evolution of the source rock within a basin, which drives the generation, expulsion, and migration of liquid and gaseous hydrocarbons. This history is corrected using observed bottom-hole temperatures.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 10 May 2025;
@ James Ogg, written communication, 7 July 2025

4.2.1.4.2 Burial history
A burial history curve is a graph on which burial depth is plotted against geological time for a particular region.
@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego

4.2.1.4.3 Hydrocarbon generation
It is the process by which kerogen present in source rocks is transformed into liquid or gaseous hydrocarbons. Petroleum generation starts in natural conditions at temperatures around 70-80 ℃, which frequently corresponds to burial depth of 2.5-3 km, depending on the geothermal gradient.
@ Burrus, J, 1998. Petroleum: Primary migration (generation and expulsion). In: Geochemistry. Encyclopedia of Earth Science. Springer, Dordrecht. https://doi.org/10.1007/1-4020-4496-8_249

4.2.1.4.4 Hydrocarbon migration

Petroleum migration is a geological process describing the movement of oil and gas from the source rock, to the reservoirs, and eventually to the trap. Secondary migration which accounts for the bulk of migration is driven by the buoyancy of the hydrocarbon and flow is always perpendicular to the structural contour of the carrier bed.

@ Peters, Kenneth E, David J C, et al., 2012. An overview of basin and petroleum system modeling: Definitions and concepts, Basin modeling: New horizons in research and applications: AAPG Hedberg Series, 4, 1-16.

@ Hydrocarbon migration – AAPG Wiki: https://wiki.aapg.org/Hydrocarbon_migration, accessed on 5 August 2025

4.2.2 Prospect risking

It gives a quantitative assessment of the chances of geological success when the prospect is drilled.

@ Defined by the Working Group of Petroleum Geology Knowledge System

4.2.2.1 Geological risk factors

Geological risk factors are elements that can influence the success or failure of a geological project, such as oil and gas exploration, mining, or construction.

@ Miguel A S, Alberto F, and Carmen T, et al., 2007. Geological risk assessment of the area surrounding Altamira Cave: A proposed Natural Risk Index and Safety Factor for protection of prehistoric caves. Engineering Geology. 94(3-4), 180-200.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

4.2.2.1.1 Source rock

A source rock is a fine-grained dark sedimentary rock that contains sufficient organic matter such that when it is buried and heated it will generate petroleum (oil and gas). The quantity and quality of organic matter preserved and modified during diagenesis of a sediment ultimately determine the petroleum potential of the rock.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

4.2.2.1.2 Reservoir rock

A reservoir rock is a porous and permeable rock that has both storage capacity and the ability to allow fluids to flow through it.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

4.2.2.1.3 Seal rock

A seal (cap) rock is a relatively impermeable rock such as shale, anhydrite, or salt, that forms a barrier above around or below a reservoir rock within a trap so that entrapped petroleum fluids cannot migrate beyond the reservoir.

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

4.2.2.1.4 Trap
A trap consists of a trapping geometry of permeable (reservoir) and less-permeable (seal) rocks, which when combined with the physical and chemical properties of subsurface fluids, can allow hydrocarbons to accumulate.
@ Trap - AAPG Wiki: https://wiki.aapg.org/Trap, accessed on 5 August 2025

4.2.2.1.5 Timing and migration
It refers to the relative timing of trap formation and hydrocarbon migration.
@ Defined by the Working Group of Petroleum Geology Knowledge System

4.2.2.2 Probability of geological success (POS)
The probability of geological success is the chance of a well finding petroleum.
@ Selley, R C, 1998. Elements of Petroleum Geology (2nd edition), Academic Press, San Diego

4.2.3 Volume estimate
A volume estimate is a calculated approximation of the quantity or size of a resource, such as oil, gas, minerals, or water, within a specific geological formation or reservoir. This estimation is crucial for assessing the economic viability and potential value of a project in industries like petroleum exploration, mining, and groundwater management.
@ Manxgeology: https://manxgeology.com/wp-content/uploads/2019/06/Quirk-Schmid-Method-for-estimating-exploration-prospect-size-AAPG-RU-Forum-Abz-18-Jun-19.pdf, accessed on 13 June 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

4.2.3.1 Deterministic approach
A deterministic approach is when there is no stochastic variable involved and the forecasts depend on the selected functions and parameters.
@ Forecasting - Wikipedia: https://en.wikipedia.org/wiki/Forecasting#Deterministic_approach, accessed on 5 May 2025

4.2.3.2 Probabilistic (stochastic) approach (Monte Carlo simulation)
The Monte Carlo technique consists of generating many different joint outcomes of random processes and then observing the behavior of response values that are functions of these outcomes. Such behavior can be characterized by probability density functions (pdf) of the response variables.
@ Monte Carlo and stochastic simulation methods - AAPG: https://wiki.aapg.org/Monte_Carlo_and_stochastic_simulation_methods, accessed on 16 June 2025

4.2.4 Prospect economics
Prospect economics refers to the financial analysis and evaluation of a potential oil, gas, or mineral prospect to determine its economic viability. This involves assessing various factors such as costs, revenues, risks, and returns to decide whether the project is worth pursuing.
@ Prospect_theory - Wikipedia: https://en.wikipedia.org/wiki/Prospect_theory, accessed on 13 June 2025

4.2.4.1 Net Present Value (NPV) (net present value)
The net present value is equivalent to the future cash flows at an assumed discount rate. It is the fundamental parameter to express value of a project assuming success, and it measures the cumulative value of the venture above the corporate discount rate.
@ Economics: key parameters - AAPG Wiki: https://wiki.aapg.org/Economics:_key_parameters, accessed on 16 June 2025

4.2.4.2 Decision tree analysis
A decision tree is a decision support recursive partitioning structure that uses a tree-like model of decisions and their possible consequences, including chance event outcomes, resource costs, and utility. It is one way to display an algorithm that only contains conditional control statements.
@ Decision tree - Wikipedia: https://en.wikipedia.org/wiki/Decision_tree, accessed on 5 May 2025

4.2.4.3 Sensitivity analysis
Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be divided and allocated to different sources of uncertainty in its inputs. This involves estimating sensitivity indices that quantify the influence of an input or group of inputs on the output. A related practice is uncertainty analysis, which has a greater focus on uncertainty quantification and propagation of uncertainty; ideally, uncertainty and sensitivity analysis should be run in tandem.
@ Saltelli, A.; Tarantola, S.; Campolongo, F.; Ratto, M. (2004). Sensitivity analysis in practice: a guide to assessing scientific models. Vol. 1. doi:10.1002/0470870958. ISBN 978-0-470-87093-8.
@ Sensitivity analysis - Wikipedia: https://en.wikipedia.org/wiki/Sensitivity_analysis, accessed on 5 May 2025

4.2.4.4 Economic chance of success
The economic chance of success is the chance of a well finding a commercial quantity of petroleum.
@ Defined by the Working Group of Petroleum Geology Knowledge System

4.3 Play
A play is a group of related hydrocarbon accumulations and/or prospects, characterized by combinations of similar geologic parameters such as reservoir-seal couple with or without trap style, essential to the processes of petroleum generation, migration, accumulation, and retention. It should have a clear geographic distribution that can be defined by polygons on the ground and/or be confined to limited stratigraphic intervals.
@ Doust H, 2010. The exploration play: What do we mean by it? AAPG Bulletin, 94(11), 1657–1672

4.3.1 Structural play
It refers to a play in which structural trap is the dominant trap type.
@ Defined by the Working Group of Petroleum Geology Knowledge System

4.3.2 Stratigraphic play
It refers to a play in which stratigraphic trap is the dominant trap type.

@ Defined by the Working Group of Petroleum Geology Knowledge System

4.3.2.1 Pinch-out play
It refers to a play in which pinch-out trap is the dominant trap type.
@ Defined by the Working Group of Petroleum Geology Knowledge System

4.3.2.2 Reef play
It refers to a play in which reef trap is the dominant trap type.
@ Defined by the Working Group of Petroleum Geology Knowledge System

4.3.3 Unconformity play
It refers to a play in which a sharp lithologic change related to an unconformity is the dominant trap type.
@ Defined by the Working Group of Petroleum Geology Knowledge System

4.3.4 Combination play
It refers to a play in which combination of at least two of the three factors controlling trap formation, which include structural, stratigraphic and unconformity elements, is the dominant trap type.
@ Defined by the Working Group of Petroleum Geology Knowledge System

4.3.5 Play fairway analysis
It refers the analysis of source, reservoir, seal and traps associated with a particular play.
@ Defined by the Working Group of Petroleum Geology Knowledge System

4.3.6 Play risk assessment
It assesses the change of geological success of a particular play and its undiscovered petroleum resources.
@ Defined by the Working Group of Petroleum Geology Knowledge System

4.4 Petroleum system
A petroleum system encompasses a pod of active source rock and all genetically related oil and gas accumulations. It includes all the geologic elements and processes that are essential if an oil and gas accumulation is to exist.
@ Petroleum system - AAPG Wiki:
https://wiki.aapg.org/Petroleum_system#What_is_a_petroleum_system.3F, accessed on 16 June 2025

4.4.1 Essential elements
Essential elements include source rock, reservoir rock, seal rock, and overburden rock, which refers to rocks (mostly sedimentary) overlying the source rock.
@ Petroleum system - AAPG Wiki:
https://wiki.aapg.org/Petroleum_system#What_is_a_petroleum_system.3F, accessed on 16 June 2025

4.4.1.1 Source rock

A source rock is a fine-grained dark sedimentary rock that contains sufficient organic matter such that when it is buried and heated it will generate petroleum (oil and gas). The quantity and quality of organic matter preserved and modified during diagenesis of a sediment ultimately determine the petroleum potential of the rock.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

4.4.1.2 Reservoir rock

A reservoir rock is a porous and permeable rock that has both storage capacity and the ability to allow fluids to flow through it.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

4.4.1.3 Seal rock

A seal (cap) rock is a relatively impermeable rock such as shale, anhydrite, or salt, that forms a barrier above around or below a reservoir rock within a trap so that entrapped petroleum fluids cannot migrate beyond the reservoir.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

4.4.1.4 Overburden rock

Overburden rock is the total stratigraphic section of mostly sedimentary rock that overlies the source rock, seal rock, and reservoir rock. It provides a history of the rate of burial of a source rock and determines the depth and temperature necessary for hydrocarbon generation from the source rock. As an essential, mappable geologic element of the petroleum system, overburden rock controls the fundamental processes of generation, expulsion, migration, entrapment, and preservation of petroleum.
@ Deming D., 1994. Overburden Rock, Temperature, and Heat flow: in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.165-184.
@ Wandrey C J. Eocene to Miocene Composite Total Petroleum System, Irrawaddy-Andaman and North Burma Geologic Provinces, Myanmar, Chapter E in Wandrey, CJ, ed., Petroleum systems and related geologic studies in Region 8. South Asia: US Geological Survey Bulletin, 2006.
@ GeoGPT: https://geogpt.zero2x.org, accessed on 11 August 2025

4.4.2 Processes

Petroleum systems have two processes, which are trap formation the generation–expulsion–migration-accumulation of hydrocarbons.
@ Petroleum system - AAPG Wiki:
https://wiki.aapg.org/Petroleum_system#What_is_a_petroleum_system.3F, accessed on 16 June 2025

4.4.2.1 Trap formation

It is the geological process depicting the formation of traps.

@ Magoon, L. B, and W. G. Dow, 1994. The Petroleum system, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 1-24.

4.4.2.2 Generation–expulsion–migration–accumulation of hydrocarbons

It refers to the entire process from petroleum expulsion from source rocks to accumulation in traps.
@ Magoon, L. B, and W. G. Dow, 1994. The Petroleum system, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 1-24.

4.4.2.2.1 Petroleum (hydrocarbon) generation

It is the process by which kerogen present in source rocks is transformed into liquid or gaseous hydrocarbons. Petroleum generation starts in natural conditions at temperatures around 70-80 ℃, which frequently corresponds to burial depth of 2.5-3 km, depending on the geothermal gradient.
@ Burrus, J, 1998. Petroleum: Primary migration (generation and expulsion). In: Geochemistry. Encyclopedia of Earth Science. Springer, Dordrecht. https://doi.org/10.1007/1-4020-4496-8_249

4.4.2.2.2 Petroleum (hydrocarbon) expulsion

Expulsion describes the process by which hydrocarbons, generated within a source rock, are forced out of the rock and into a migration pathway, facilitated by the saturation of pore space, compaction, and diagenesis. This process can be influenced by factors such as the amount of hydrocarbon generated, the porosity and permeability of the source rock, pressure, and structural activity or faulting. Expulsion is a critical step in the overall sequence of petroleum generation, migration, entrapment, and preservation. This is also called primary migration.
@ Hydrocarbon expulsion, migration, and accumulation - AAPG Wiki: https://wiki.aapg.org/Hydrocarbon_expulsion,_migration,_and_accumulation, accessed on 16 June 2025

4.4.2.2.3 Petroleum (hydrocarbon) migration

Petroleum migration is a geological process describing the movement of oil and gas from the source rock, to the reservoirs, and eventually to the trap. Secondary migration which accounts for the bulk of migration is driven by the buoyancy of the hydrocarbon and flow is always perpendicular to the structural contour of the carrier bed.
@ Hydrocarbon migration – AAPG Wiki: https://wiki.aapg.org/Hydrocarbon_migration

4.4.2.2.4 Petroleum (hydrocarbon) Accumulation

It is a geological process describing the entrapment of oil and gas. A hydrocarbon accumulation forms when migrating hydrocarbon filaments encounter a zone (the seal), either laterally or vertically, with pore throat sizes smaller than the carrier bed. The seal pore throat breakthrough pressure (also known as the capillary entry pressure) or the distance to the spill point of the trap, whichever is less, determines the hydrocarbon accumulation column height.
@ Hydrocarbon expulsion, migration, and accumulation - AAPG Wiki: https://wiki.aapg.org/Hydrocarbon_expulsion,_migration,_and_accumulation#Accumulation, accessed on 16 June 2025

4.4.2.3 Petroleum (hydrocarbon) preservation

Preservation of petroleum accumulation is a function of tectonic setting, trap type, depth of burial, and seal type. Some petroleum accumulations are likely to persist for hundreds of millions of years with relatively little alteration or dilution. Other hydrocarbon accumulations, however, may be destroyed or depleted through later leakage or other processes. In many prospects it is not enough just to know that a trap is present in a basin where hydrocarbons were generated and migrated. We also must know that the trap was preserved over time. It is imperative that explorationists know destructive processes and how to determine the age of an accumulation.
@ Predicting preservation and destruction of accumulations - AAPG Wiki:
https://wiki.aapg.org/Predicting_preservation_and_destruction_of_accumulations, accessed on 16 June 2025

4.4.2.4 Critical moment (timing)

The critical moment in a petroleum system refers to the specific geological time period when hydrocarbons are generated, migrated, and accumulated within traps. This is a pivotal point in the evolution of a petroleum system because it marks the timing when all essential elements (source rock, reservoir rock, seal, trap, and overburden) are present and functioning together to form an effective hydrocarbon accumulation. A map and cross section drawn at the critical moment best show the geographic and stratigraphic extent of the system.
@ Petroleum system: geographic, stratigraphic and temporal extent - AAPG Wiki:
https://wiki.aapg.org/Petroleum_system:_geographic,_stratigraphic,_and_temporal_extent#What_is_an_events_chart.3F, accessed on 16 June 2025

4.4.3 Petroleum system investigation

A petroleum system investigation identifies, names, determines the level of certainty, and maps the geographic, stratigraphic, and temporal extent of a petroleum system.
@ Petroleum system - AAPG Wiki:
https://wiki.aapg.org/Petroleum_system#Petroleum_system_investigation, accessed on 16 June 2025

4.4.3.1 Identification

To identify a petroleum system, the explorationist must find some petroleum. Any quantity of petroleum, no matter how small, is proof of a petroleum system. An oil or gas seep, a show of oil or gas in a well, or an oil or gas accumulation demonstrates the presence of a petroleum system.
@ Petroleum system identification - AAPG Wiki:
https://wiki.aapg.org/Petroleum_system_identification#Petroleum_system_identification, accessed on 16 June 2025

4.4.3.1.1 Petroleum–petroleum geochemical correlation

Correlations are comparisons of oils with other oils to classify oils into genetic families. Correlations are accomplished by comparing elemental, molecular, and isotopic parameters using techniques such as gas chromatography (GC), gas chromatography with mass spectrometry (GC/MS), and carbon isotope ratio determination. This is most commonly done through biomarker analysis.

@ Oil-oil and oil-source rock correlation - AAPG Wiki: https://wiki.aapg.org/Oil-oil_and_oil-source_rock_correlation, accessed on 16 June 2025

4.4.3.1.1.1 Physical features (Physical properties)
A physical property is any property of a physical that is measurable.
@ Physical property - Wikipedia: https://en.wikipedia.org/wiki/Physical_property, accessed on 15 August 2025

4.4.3.1.1.2 Biomarker analysis (GS-MS)
The identification and correlation of petroleum accumulations rely heavily on biomarkers—organic compounds derived from biological precursors—that retain structural information about their origins. Biomarkers are quantified via GC-MS targeting mass fragments (e.g., m/z 191 for terpanes, m/z 217 for steranes). Statistical tools like Pearson correlation coefficients (PCC) and principal component analysis (PCA) enhance pattern recognition across datasets. Matching biomarker fingerprints (e.g., sterane profiles) ties oils to specific formations.
@ Richard Chuchla, written communication, 15 July 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 11 August 2025

4.4.3.1.1.2.1 Hopanes
A hopane biomarker is a type of organic compound derived from bacterial membrane lipids, specifically bacteriohopanepolyols, which are synthesized by various aerobic bacteria, including cyanobacteria. These compounds undergo diagenetic and catagenetic transformations in sedimentary environments, forming stable terpane hydrocarbons known as hopanes.
@ Richard Chuchla, written communication, 15 July 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

4.4.3.1.1.2.2 Steranes
Steranes are biological marker compounds whose features are indicative of the sources of organic matter, with specific structures uniquely attributable to specific classes of organisms, and in certain oil families. Patterns in Regular Steranes (C_{27}, C_{28}, C_{29}) reveal organic matter type (e.g., C_{29} dominance suggests land plants; C_{27} links to algae). Steranes are characterized by C_{27}-dominated distributions.
@ Brooks J, Cornford C, Archer R, 1987. The role of hydrocarbon source rocks in petroleum exploration, Geological Society of London Special Publications, 26(1), 17-46.
@ Frewi J M J T L, 2000. The Dhahaban Petroleum System of Oman[J], Aapg Bulletin.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

4.4.3.1.1.2.3 Pristane/Phytane ratio
The ratio (Pr/Ph) of acyclic isoprenoids Pristane (C_{19}) and Phytane (C_{20}) distinguishes oxic (high Pr/Ph) vs. anoxic (low Pr/Ph) depositional environments.
@ Rashid M A, 1979. Pristane-phytane ratios in relation to source and diagenesis of ancient sediments from the Labrador Shelf, Chemical Geology, 25(1-2:)109-122
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 10 August 2025

4.4.3.1.1.2.4 Tricyclic terpanes

Tricyclic Terpanes are used to infer depositional environments (e.g., high C_{23}/C_{21} ratios indicate deeper aquatic settings).

@ Wang A, Li C, Li L, et al., 2023. C_{20}-C_{21}-C_{23} tricyclic terpanes abundance patterns: Origin and application to depositional environment identification. Frontiers Earth Science, 11.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 10 August 2025

4.4.3.1.1.2.5 Isotope analysis (MS)

Isotope analysis is a highly versatile technique that uses the ratio of two non-radioactive isotopes of an element within a sample to provide insights about the conditions under which it formed. This is possible because certain biochemical and geochemical processes favor one isotope, usually the lighter one, over the other. This results in measurable differences between the isotopic composition of the initial reactants and the resulting products

@ Malainey, M.E., 2011. Isotope Analysis. In: A Consumer's Guide to Archaeological Science. Manuals in Archaeological Method, Theory and Technique. Springer, New York, NY. https://doi.org/10.1007/978-1-4419-5704-7_13, accessed on 17 September 2025

4.4.3.1.1.2.5.1 Carbon isotopes

Carbon isotope ratios are used to discern the composition of petroleum deposits by examining the ratio of carbon isotopes and comparing this ratio to known values for carbon-based structures of which the petroleum could be composed.

@ Organicgeochemistry - Wikipedia: https://en.wikipedia.org/wiki/Organic_geochemistry, accessed on 12 May 2025

4.4.3.1.1.2.5.2 Hydrogen isotopes

Hydrogen has three naturally occurring isotopes: ^{1}H, ^{2}H, and ^{3}H. ^{1}H and ^{2}H are stable, while ^{3}H has a half-life of 12.32 years. Heavier isotopes also exist; all are synthetic and have a half-life of less than 1 zeptosecond (10^{-21} s).

@ Isotopes of hydrogen - Wikipedia: https://en.wikipedia.org/wiki/Isotopes_of_hydrogen, accessed on 12 May 2025

4.4.3.1.1.2.5.3 Sulfur isotopes

Sulfur ($_{16}S$) has 23 known isotopes with mass numbers ranging from 27 to 49, four of which are stable: ^{32}S (94.85%), ^{33}S (0.76%), ^{34}S (4.37%), and ^{36}S (0.016%). The preponderance of sulfur-32 is explained by its production from carbon-12 plus successive fusion capture of five helium-4 nuclei in the alpha process of nucleosynthesis.

@ Isotopes of sulfur - Wikipedia: https://en.wikipedia.org/wiki/Isotopes_of_sulfur, accessed on 12 May 2025

4.4.3.1.2 Petroleum–source rock geochemical correlation

Correlations are comparisons of oils with source rock extracts to determine whether a genetic relationship exists. Correlations are accomplished by comparing elemental, molecular, and isotopic parameters using techniques such as gas chromatography (GC), gas chromatography with mass spectrometry (GC/MS), and carbon isotope ratio determination. This is most commonly done through biomarker analysis.

@ Oil-oil and oil-source rock correlation - AAPG Wiki: https://wiki.aapg.org/Oil-oil_and_oil-source_rock_correlation, accessed on 16 June 2025

4.4.3.2 Naming

The name for a specific petroleum system separates it from other petroleum systems and other geologic names.
@ Petroleum system naming - AAPG Wiki: https://wiki.aapg.org/Petroleum_system_naming, accessed on 16 June 2025

4.4.3.2.1 Parts of a petroleum system name (Components of a petroleum system name)

The name of a petroleum system contains several parts that name the hydrocarbon fluid system: (1) The source rock in the pod of active source rock; (2) The name of the reservoir rock that contains the largest volume of in-place petroleum; (3) The symbol expressing the level of certainty.
@ Petroleum system naming - AAPG Wiki: https://wiki.aapg.org/Petroleum_system_naming, accessed on 16 June 2025

4.4.3.2.2 Level of certainty

A petroleum system can be identified at three levels of certainty: known, hypothetical, and speculative. The level of certainty indicates the confidence for which a particular pod of mature source rock has generated the hydrocarbons in an accumulation. At the end of the system's name, the level of certainty is indicated by (!) for known, (.) for hypothetical, and (?) for speculative.
@ Petroleum system naming - AAPG Wiki: https://wiki.aapg.org/Petroleum_system_naming, accessed on 16 June 2025

4.4.3.2.2.1 Known

It is a system supported by a positive oil-source rock or gas-source rock correlation.
@ Petroleum system naming - AAPG Wiki: https://wiki.aapg.org/Petroleum_system_naming, accessed on 16 June 2025

4.4.3.2.2.2 Hypothetical

It is a system supported by geochemical evidence in the absence of a positive petroleum-source rock correlation.
@ Petroleum system naming - AAPG Wiki: https://wiki.aapg.org/Petroleum_system_naming, accessed on 16 June 2025

4.4.3.2.2.3 Speculative

It is a system supported by geological or geophysical evidence.
@ Petroleum system naming - AAPG Wiki: https://wiki.aapg.org/Petroleum_system_naming, accessed on 16 June 2025

4.4.3.3 Extents

Petroleum systems are limited by time and space. Each system can be described in terms of its own unique temporal and spatial elements and processes.

@ Petroleum system: geographic, stratigraphic, and temporal extent - AAPG Wiki: https://wiki.aapg.org/Petroleum_system:_geographic,_stratigraphic,_and_temporal_extent, accessed on 16 June 2025

4.4.3.3.1 Temporal extent

The temporal extent of the petroleum system is shown on the events chart and includes the age of the essential elements and processes, the preservation time, and the critical moment. By displaying together the time over which these separate events took place, the relation between forming and charging the traps containing the accumulations is easily evaluated.
@ Petroleum system: geographic, stratigraphic, and temporal extent - AAPG Wiki: https://wiki.aapg.org/Petroleum_system:_geographic,_stratigraphic,_and_temporal_extent, accessed on 16 June 2025

4.4.3.3.2 Geographic extent

Geographic extent is the area over which the petroleum system is known to occur and shown by the petroleum system map.
@ Petroleum system: geographic, stratigraphic, and temporal extent - AAPG Wiki: https://wiki.aapg.org/Petroleum_system:_geographic,_stratigraphic,_and_temporal_extent, accessed on 16 June 2025

4.4.3.3.3 Stratigraphic extent

Stratigraphic extent is the span of lithological units which encompasses the essential elements within the geographic extent of a petroleum system.
@ Petroleum system: geographic, stratigraphic, and temporal extent - AAPG Wiki: https://wiki.aapg.org/Petroleum_system:_geographic,_stratigraphic,_and_temporal_extent, accessed on 16 June 2025

4.4.3.4 Size (volume)

The size of a petroleum system includes the total volume of all recoverable hydrocarbons that originated from a single pod of active source rock. This total volume is used to compare against other petroleum systems and to determine the generation–accumulation efficiency.
@ Petroleum system size - AAPG Wiki: https://wiki.aapg.org/Petroleum_system_size, accessed on 16 June 2025

4.4.4 Petroleum system diagrams

They refer to the diagrams and table constructed from petroleum system investigations.
@ Magoon, L. B, and W. G. Dow, 1994. The Petroleum system, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 1-24.

4.4.4.1 Burial history chart

A burial history chart is a diagram that shows the depth of burial corrected for compaction of each rock unit (subsidence curve) versus the timing of the essential elements in a petroleum system, including the time interval and critical moment for petroleum generation. The calculated temperature history and the timing of petroleum generation based on calculated vitrinite reflectance or other maturity parameters are commonly overlain on the burial history diagram.

@ Peters, Kenneth E, David J C, et al., 2012. An overview of basin and petroleum system modeling: Definitions and concepts, Basin modeling: New horizons in research and applications: AAPG Hedberg Series, 4, 1-16.
@ Burial history chart - AAPG Wiki: https://wiki.aapg.org/Burial_history_chart, accessed on 16 June 2025

4.4.4.2 Petroleum system map
It is defined by a line that circumscribes the pod of active source rock and all oil and gas seeps, shows, and accumulations originating from that pod.
@ Petroleum system: geographic, stratigraphic, and temporal extent - AAPG Wiki: https://wiki.aapg.org/Petroleum_system:_geographic,_stratigraphic,_and_temporal_extent, accessed on 16 June 2025

4.4.4.3 Cross section
A cross section is a graphical representation of vertical slices through the earth used to clarify or interpret geological relationships with or without companying maps. It shows the stratigraphic extent of the petroleum system at the critical moment.
@ Cross section - AAPG Wiki: https://wiki.aapg.org/Cross_section, accessed on 16 June 2025

4.4.4.4 Events chart
An events chart shows the temporal relation of the essential elements and processes of a petroleum system. It also shows the preservation time and the critical moment for the system. An events chart can be used to compare the times that the processes occurred with the times that the elements formed.
@ Petroleum system: geographic, stratigraphic, and temporal extent - AAPG Wiki: https://wiki.aapg.org/Petroleum_system:_geographic,_stratigraphic,_and_temporal_extent#What_is_an_events_chart.3F, accessed on 16 June 2025

4.4.5 Petroleum system table
It is a table listing the names, discovery dates, reserves and other relevant data of the accumulations with hydrocarbons originated from the source rocks of the petroleum system.
@ Magoon, L. B, and W. G. Dow, 1994. The Petroleum system, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 1-24.

4.4.6 Petroleum system modeling
It is a technique used to represent the history of a sedimentary basin, including the processes and components necessary to form petroleum: petroleum source rock, reservoir, trapping mechanism, seal, and appropriate relative timing of formation of these.
@ slb Energy Glossary: https://glossary.slb.com/terms/p/petroleum_systems_modeling, accessed on 17 September 2025

4.4.6.1 2D modeling
Basin modeling and petroleum system analysis brings together several dynamic processes, including sediment deposition, faulting, burial, kerogen maturation kinetics and multiphase fluid flow. These processes may be examined at several levels and complexity which are typically increases with spatial dimensionality. Briefly, 1D modeling examines burial history at a point

location, and 2D modeling, either in map or cross section, can be used to reconstruct oil and gas generation, migration and accumulation along a cross section.
@ Basin Modeling and Petroleum System Analysis, https://en.energyariana.com/products-and-services/basin-modeling-and-petroleum-system-analysis/#:~:text=Briefly%2C%201D%20modeling%20examines%20burial%20history%20at%20a,in%201D%2C%202D%20or%203D%2C%20and%20through%20time, accessed on 17 September 2025

4.4.6.2 3D modeling
Basin modeling and petroleum system analysis brings together several dynamic processes, including sediment deposition, faulting, burial, kerogen maturation kinetics and multiphase fluid flow. These processes may be examined at several levels and complexity which are typically increases with spatial dimensionality. Briefly, 1D modeling examines burial history at a point location, and 2D modeling, either in map or cross section, can be used to reconstruct oil and gas generation, migration and accumulation along a cross section. 3D modeling reconstructs petroleum systems at reservoir and basin scales and has the ability to display the output in 1D, 2D or 3D, and through time.
@ Basin Modeling and Petroleum System Analysis: https://en.energyariana.com/products-and-services/basin-modeling-and-petroleum-system-analysis/#:~:text=Briefly%2C%201D%20modeling%20examines%20burial%20history%20at%20a,in%201D%2C%202D%20or%203D%2C%20and%20through%20time, accessed on 17 September 2025

4.5 Sedimentary basin
A sedimentary basin is a depression filled with sedimentary rocks. The presence of sedimentary rocks is proof that a basin existed.
@ Province, basin, system, play, and prospect - AAPG Wiki: https://wiki.aapg.org/Province,_basin,_system,_play,_and_prospect#Petroleum_province, accessed on 16 June 2025

4.5.1 Petroleum province
Petroleum province, a geographic term, is an area where petroleum occurs in commercial quantities. Basin is sometimes used geographically to mean petroleum province, such as the Williston Basin or Paris Basin. The Zagros fold belt could be a structural province or a petroleum province, but technically it not a sedimentary basin.
@ Province, basin, system, play, and prospect - AAPG Wiki: https://wiki.aapg.org/Province,_basin,_system,_play,_and_prospect, accessed on 16 June 2025

4.5.2 Defining the basin framework
To define a basin, the following steps are followed. (1) define the outline of the basin and important regional structural features, (2) map total sediment thickness, (3) identify subbasins (depocenters and minibasins), (4) map age and location of oil and gas fields, (5) map age and location of source rocks.
@ Basin framework - AAPG Wiki: https://wiki.aapg.org/Basin_framework, accessed on 16 June 2025

4.5.2.1 Basement

Basement is the rock below a sedimentary cover, often igneous or metamorphic. It is generally not of interest in exploration for oil and gas, but in some places fractured basement has proven to be a commercial reservoir.

@ Basement - AAPG Wiki: https://wiki.aapg.org/Basement, accessed on 16 June 2025

4.5.2.2 Sedimentary cover/basin fill

It refers to the stratified sedimentary rocks of Proterozoic and Phanerozoic age that rest upon the largely crystalline basement rocks.

@ Modified from Sloss, L. L. 1998. Sedimentary Cover-North American Craton: Geological Society of America Volume D-2

4.5.2.3 Structural elements

Structural elements refer to the geological features that control the distribution, migration, and accumulation of hydrocarbons. These elements are crucial for understanding how oil and gas form, move through the subsurface, and accumulate in traps.

@ Richard Chuchla, written communication, 15 July 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 10 August 2025

4.5.2.3.1 Faults

In geology, a fault is a planar fracture or discontinuity in a volume of rock across which there has been significant displacement as a result of rock-mass movements. Large faults within Earth's crust result from the action of plate tectonic forces, with the largest forming the boundaries between the plates, such as the megathrust faults of subduction zones or transform faults. Energy release associated with rapid movement on active faults is the cause of most earthquakes. Faults may also displace slowly, by aseismic creep.

@ Lutgens, Frederick K.; Tarbuck, E.J.; Tasa, D. (illustrator) (2012). Essentials of geology (11th ed.). Boston: Prentice Hall. p. 32. ISBN 978-0321714725.

4.5.2.3.2 Folds

Folds are bends or flexures of layered rock that form in response to motion along faults, diapirism, compaction, and regional subsidence or uplift. Folds are expressed in seismic reflection profiles as one or more regions of dipping reflections (dip domains) that correspond to inclined stratigraphic contacts.

@ Fold - AAPG Wiki: https://wiki.aapg.org/Fold, accessed on 5 August 2025

4.5.2.4 Stratigraphic units

A stratigraphic unit is a recognizable and mappable body of rock that is distinguished from adjacent units based on its lithological, organic, or genetic properties, and often bounded by unconformities or their correlative conformities. These units can be subdivided into smaller units or aggregated into larger units, such as formations, groups, and sequences, and are used for mapping, correlation, and description. In the vernacular of sequence, stratigraphy units are grouped as sequences and parasequences.

@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.

@ Organic facies - AAPG Wiki: https://wiki.aapg.org/Organic_facies, accessed on 16 June 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 11 August 2025.

4.5.2.4.1 Lithostratigraphy
Lithostratigraphy: Classification of sedimentary rock types on the basis of their composition, appearance and sedimentary structures.
@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.

4.5.2.4.2 Chronostratigraphy
Chronostratigraphy is an attempt to correlate rocks deposited at the same time, across larger areas. The accuracy achievable with chronostratigraphic correlation depends on whether the sediments contain evidence of well-defined geological events which were simultaneous across the region. A related goal is to correlate the basin chronostratigraphy to the international scale of geological stages and systems.
@ James Ogg, written communication, 7 July 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 5 August 2025.

4.5.3 Basin classification
Basin classification refers to the categorization of sedimentary basins based on their tectonic settings and evolutionary stages. This includes their positions relative to major geotectonic areas such as cratons, accreted zones, and convergent and divergent margins, as well as the sequence of structural elements that reflect their tectonic evolution. Classification systems may also consider geodynamic regimes, basin structural profiles, and positions on continents, but fundamentally, they are based on the locations in which basins occur and their tectonic histories.
@ Link P K, 1987. Basic Petroleum Geology (2nd edition), OGCI Publications, Oil & Gas Consultants International, Inc., Tulsa
@ Richard Chuchla, written communication, 15 July 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

4.5.3.1 Tectonic setting
A tectonic setting refers to the geological environment in which tectonic processes occur, including the arrangement and movement of Earth's lithospheric plates. It encompasses features like plate boundaries, subduction zones, and rift valleys, influencing the formation of geological structures such as mountains and earthquakes. Understanding the tectonic setting helps explain how metamorphic processes develop under specific conditions.
@ tectonic setting - Fiveable: https://library.fiveable.me/key-terms/introduction-geology/tectonic-setting, accessed on 13 June 2025

4.5.3.2 Basin types
Basin type: Refers to the range of different basin types, including rift and sag basins, passive margin basins, and collision-related basins, which often evolve from one type to another. Foredeep is a specific basin type created by subsidence related to compressional deformation.
@ GeoGPT: https://geogpt.zero2x.org/,accessed on 20 May 2025.
@ Richard Chuchla, written communication, 15 July 2025

4.5.3.2.1 Rift basins

A Rift basin is a type of basin that forms due to rifting, which is typically associated with extensional tectonics and can occur in both continental and marine settings. Rift basins in arid environments are characterized by evaporite deposits, while those in more humid settings may contain lacustrine or marine sediments.

@ Allen, P A and Allen J R, 2013. Basin Analysis: Principles and Application to Petroleum Play Assessment, 3rd Edition, Wiley-Blackwell,

@ Roeder D, Chamberlain R L, 1995. Eastern Cordillera of Colombia: Jurassic–Neogene crustal evolution. Petroleum basins of South America: AAPG Memoir 62: 633-645.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

4.5.3.2.2 Passive margin basins

Already defined in Tectonics and Basin Analysis disciplines.

4.5.3.2.3 Strike-slip basins (pull-apart basins or wrench basins)

Already defined in Tectonics and Basin Analysis disciplines

4.5.3.2.4 Foreland basins

Foreland basins are asymmetric, wedge-shaped accumulations of sedimentary rock that form adjacent to fold-thrust belts. Migration of the fold-thrust sheet loads the lithosphere, causing isostatic subsidence underneath the core of the orogen and flexural downwarping in the adjacent foreland. The foredeep that forms as a depression next to the orogenic belt rapidly fills with sediment eroded from the adjacent orogenic mountains. Sedimentation amplifies flexural subsidence, and a foreland basin is formed.

@ Deming D, 1994. Overburden rock, temperature, and heat flow, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 165-186.

4.5.3.2.5 Intracratonic basins (cratonic basins or platform basins)

Intracratonic, or platform, basins form on continental interiors (e.g., the Michigan, Illinois, and Williston basins of North America). They are typically a few hundred kilometers wide and contain a few kilometers of flat-lying sedimentary rocks recording continuous subsidence and sediment deposition over periods of time greater than 100 m.y.

@ Deming D, 1994. Overburden rock, temperature, and heat flow, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 165-186.

4.5.3.2.6 Fore-arc basins

Fore-arc basin (relatively shallow basin in front of island arcs). Fore-arc basins form between the actual island arcs with volcanoes, and the subduction trench. They are not subjected to the intense tectonic deformation which occurs in trench basins. Fore-arc basins often transgress onto the island arcs as the belt of volcanic activity gradually withdraws towards the continent. These basins will contain fluvial and deltaic sediments closest to the island arcs, then shallow marine continental shelf sediments. In the outer parts, sediments are deposited in deeper water towards the oceanic slope. There is good potential here for organic-rich sediments to accumulate, but the geothermal gradient may be low despite the proximity to a volcanic island chain, and consequently the maturation is slow. With a few prominent exceptions (e.g. LA basin), these basins rarely form good habitats for hydrocarbon accumulations.

@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.

4.5.3.2.7 Back-arc basins

Back-arc basin is a sedimentary basin that develops due to seafloor spreading behind the island arcs. There is likely to be an abundant supply of sediment from the continent, and back-arc basins may also fill with deltaic and shallow marine sediments.

@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.

4.5.4 Depositional evolution

Already defined in Sedimentology and Facies and Paleogeography disciplines

4.5.5 Tectonic evolution

Tectonic evolution refers to the processes and events that shape the Earth's crust over geological time, including orogeny, rifting, magmatism, and basin formation. These processes can lead to the development of major structural features such as mountain ranges, rift basins, and continental margins. Tectonic evolution involves the transformation of continental and oceanic lithosphere through crustal accretion, orogenic collapse, and the opening and closing of ocean basins, resulting in the formation and modification of various geological structures and sedimentary basins.

@ North_German_basin - Wikipedia：https://en.wikipedia.org/wiki/North_German_basin, accessed on 12 May 2025

@ Biswas S K, Rangaraju M K, Thomas J, and Bhattacharya S K, 1994. Cambay-Hazad(!) Petroleum System in the South Cambay Basin, India: in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p. 615-624.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 10 August 2025.

4.5.5.1 Subsidence history

Subsidence history refers to the plot of tectonic subsidence against time for each section studied, calculated by subtracting subsidence caused by the isostatic loading of sediment and the water column, as per the simplified technique outlined by Matthews (1984). Corrections for estimated compaction are minor and do not affect the general shape of the subsidence curves.

@ Pratt, B R and Smewing J D, 1993. Early Cretaceous platform-margin configuration and evolution in the central Oman mountains, Arabian Peninsula: AAPG Bulletin, v. 77(2), p.225-244

4.5.5.1.1 Tectonic subsidence

Tectonic subsidence is the subsidence of the Earth's crust resulting from tectonic processes, which can include stretching, cooling of the ocean floor, and the creation of basins. This subsidence can accommodate the deposition and accumulation of sediments, leading to the formation of sedimentary rocks. It is characterized by periods of active tectonic activity and periods of relative quiescence, often associated with thermal cooling and can result in widespread marine transgressions and the deposition of thick sedimentary sequences.

@ Subsidence - Wikipedia：https://en.wikipedia.org/wiki/Subsidence, accessed on 10 April, 2025

@ Deming D., 1994. Overburden Rock, Temperature, and Heat flow: in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.165-184.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

4.5.5.1.2 Thermal subsidence

Thermal subsidence is the process by which the lithosphere cools and contracts, leading to the subsidence of the crust and the formation of basins. This can occur due to various factors such as the cessation of crustal stretching, the decay of thermal anomalies created during the stretching phase, and the movement of oceanic crust away from mid-ocean ridges. Thermal subsidence can also follow uplift due to a thermal plume or sheet and is influenced by the progressive cooling and thickening of the lithosphere.
@ Thermal_subsidence – Wikipedia: https://en.wikipedia.org/wiki/Thermal_subsidence, accessed on 10 April, 2025
@ Beglinger S E, Doust H, Cloetingh S. Relating petroleum system and play development to basin evolution: West African South Atlantic basins[J]. Marine and Petroleum Geology, 2012, 30(1): 1-25.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025.

4.5.5.1.3 Sedimentation subsidence

Sedimentation subsidence is the downward movement of the basement rock-sedimentary rock contact in response to loading by later sedimentation and compaction.
@ Deming D, 1994. Overburden rock, temperature, and heat flow, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 165-186.

4.5.5.2 Thermal history

Thermal history describes the thermal evolution of the source rock within a basin, which drives the generation, expulsion, and migration of liquid and gaseous hydrocarbons. This history is corrected using observed bottom-hole temperatures.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 10 May 2025
@ James Ogg, written communication, 7 July 2025.

4.5.5.2.1 Heat flow

The temperature increases downwards in the crust; therefore, there is a transport of heat upwards, referred to as the heat flow. Most of the flow is by conduction (thermal diffusion). Flow of porewater will also transport heat in the subsurface but the flow rates in sedimentary basins are normally so small that we can ignore the contribution from fluid flow (advection).
@ Bjørlykke K, 2010. Petroleum Geoscience: From Sedimentary Environments to Rock Physics, Springer, Heidelberg.

4.5.5.2.2 Geothermal gradient

The geothermal gradient is the rate of temperature increase with depth in the Earth, typically measured in degrees Celsius per kilometer or degrees Fahrenheit per 100 feet. It varies globally, with a common range of 25 to 40 ℃/km (1.4 to 2.2 ℉/100 ft), though it can be as low as 15 ℃/km (0.8 ℉/100 ft) or as high as 50 ℃/km (2.7 ℉/100 ft) in some areas. The gradient is influenced by factors such as basal heat flow, lithology, groundwater circulation, and drilling fluid cooling. It is mathematically expressed as $G = dT/dz$, where T is temperature and z is depth.

@ Geothermal gradient - AAPG Wiki: https://wiki.aapg.org/Geothermal_gradient, accessed on 10 April, 2025
@ Magma – Wikipedia: https://en.wikipedia.org/wiki/Magma, accessed on 10 April 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 10 April 2025

4.5.6 Basin analysis techniques
Already defined in Basin Analysis discipline

4.5.6.1 Seismic interpretation
Simply defined, seismic interpretation is the science (and art) of inferring the geology at some depth from the processed seismic record. While modern multichannel data have increased the quantity and quality of interpretable data, proper interpretation still requires that the interpreter draw upon his or her geological understanding to pick the most likely interpretation from the many "valid" interpretations that the data allow.
@ Seismic interpretation - AAPG Wiki: https://wiki.aapg.org/Seismic_interpretation, accessed on 5 August 2025

4.5.6.1.1 2D seismic
Seismic data are of critical importance for trap detection. They are the only widely used data that give a complete, albeit fuzzy, picture of the whole area of study, be it basin, play fairway, prospect, trap or reservoir. 2D seismic data are regional two-dimensional (2D) lines across the basin. Individual lines are commonly tens of kilometers long, and may be hundreds of kilometers long. Such lines will be interpreted in terms of gross structural and stratigraphic geometries. They are used in frontier exploration and basin exploitation.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA

4.5.6.1.2 3D seismic
The 3-D seismic technique yields much more information than an equivalent amount of 2-D seismic and can reduce risk. A 3-D seismic data set is a cube or volume of data; a 2-D seismic data set is a panel of data. To interpret the 3-D data we need to investigate the interior of the cube. This is done almost universally on a computer to process the massive amounts of data involved. A 3-D data set can range in size from a few tens of megabytes to several gigabytes — the equivalent of a library of information.
@ 3-D seismic data: the data cube: https://wiki.aapg.org/3-D_seismic_data:_the_data_cube, accessed on 17 September 2025

4.5.6.2 Well log analysis
Well log is one of the most fundamental methods for reservoir characterization, in oil and gas industry, it is an essential method for geoscientist to acquire more knowledge about the condition below the surface by using physical properties of rocks. This method is very useful to detect hydrocarbon bearing zone, calculate the hydrocarbon volume, and many others.
@ Well log analysis for reservoir characterization - AAPG Wiki: https://wiki.aapg.org/Well_log_analysis_for_reservoir_characterization, accessed on 5 August 2025

4.5.6.3 Core analysis

Core analysis measurements performed on representative core samples can more accurately assess reservoir quality and heterogeneities. Core analysis porosities are typically determined using one of three techniques: summation of fluids, resaturation, and Boyle's Law. Permeability on core samples is determined using one of two methods: steady-state or unsteady-state.
@ Reservoir quality - AAPG Wiki:
https://wiki.aapg.org/Reservoir_quality#Controls_on_reservoir_quality, accessed on 5 August 2025

4.5.6.4 Field mapping

Already defined in Structural Geology discipline.

4.5.6.5 Biostratigraphy

Biostratigraphy is the branch of stratigraphy that focuses on correlating and assigning relative ages of rock strata by using the fossil assemblages contained within them. The primary objective of biostratigraphy is "correlation", demonstrating that a particular horizon in one geological section represents the same period of time as another horizon at a different section.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 15 May 2025
@ James Ogg, written communication, 7 July 2025.

4.5.6.6 Geochemical analysis

The mid-twentieth century was when scientists began to seriously study petroleum geochemistry. Geochemistry was originally utilized for surface prospecting for subsurface hydrocarbons. Today geochemistry serves the petroleum industry by helping seek out effective petroleum systems. Once oil to source rock correlation is found, petroleum geologists will use this information to render a 3D model of the basin. Now they can assess the timing of generation, migration, and accumulation relative to the trap formation. This aids in the decision-making process on whether further exploration is necessary. Additionally, this can increase recoveries of the petroleum remaining in reservoirs that were initially deemed unrecoverable.
@ Petroleum geology - Wikipedia:
https://en.wikipedia.org/wiki/Petroleum_geology#Geochemical_analysis, accessed on 13 June 2025

4.5.6.7 Sequence stratigraphy

Sequence stratigraphy is the study of the sequential organization of sedimentary units within a chronostratigraphic framework, focusing on genetically related strata bounded by surfaces of erosion or nondeposition, or their correlative unconformities. It was developed from seismic stratigraphy in the 1970s and is based on the principle that seismic reflectors are time surfaces and that unconformities are bounding surfaces that separate strata into time-coherent packages. Sequence stratigraphy provides a predictive tool for understanding the distribution of source rocks, reservoirs, and seals by correlating time-equivalent sediment packages across and among marine basins. The basic unit in sequence stratigraphy is the sequence, which is a relatively conformable, genetically related succession of strata bounded by unconformities or their correlative conformities. Sequences are composed of parasequences and parasequence sets, which are smaller units of genetically linked strata. The key property of the bounding surfaces is that

they are chronostratigraphically significant, allowing for accurate correlation of sedimentary units.
@ Gluyas J and Swarbrick R, 2004. Petroleum Geoscience, Blackwell Science Ltd, Maiden, Massachusetts, USA
@ Sequence stratigraphy - AAPG Wiki: https://wiki.aapg.org/Sequence_stratigraphy, accessed on 20 April, 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 15 May 2025.

4.5.6.8 Numerical modeling

Numerical modeling is the running of a mathematical model on a computer, the model being designed to represent the behaviour of, or the outcome of, a real-world or physical system. The reliability of some mathematical models can be determined by comparing their results to the real-world outcomes they aim to predict. Computer simulations have become a useful tool for the mathematical modeling of many natural systems in physics (computational physics), astrophysics, climatology, chemistry, biology and manufacturing, as well as human systems in economics, psychology, social science, health care and engineering. Simulation of a system is represented as the running of the system's model. It can be used to explore and gain new insights into new technology and to estimate the performance of systems too complex for analytical solutions.
@ Computer simulation - Wikipedia: https://en.wikipedia.org/wiki/Computer_simulation, accessed on 12 May 2025

5. Petroleum resources

Petroleum resources are the quantities of hydrocarbons naturally occurring on or within the Earth's crust. Resources assessments estimate quantities in known and yet-to-be-discovered accumulations. Resources evaluations are focused on those quantities that can potentially be recovered and marketed by commercial projects.
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.1 Conventional resources

Conventional gas refers to the natural gas which can be extracted using traditional drilling and pumping methods.
@ Defined by the Working Group of Petroleum Geology Knowledge System

5.2 Unconventional resources

Unconventional resources are petroleum accumulations that are pervasive throughout a large area (also called "continuous-type deposits"), not driven by buoyancy and lack well-defined hydrocarbon-water contacts of OWC or GWC. Such resources cannot be recovered using traditional recovery projects owing to fluid viscosity (e.g., oil sands) and/or reservoir permeability (e.g., tight gas/oil/CBM) that impede natural mobility. Moreover, the extracted petroleum may require significant processing before sale (e.g., bitumen upgraders).
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.2.1 Shale oil and gas

Shale oil is a sub-type of tight oil where the lithologies are predominantly shales or siltstones. Shale gas is a sub-type of tight gas where the reservoir lithologies are predominantly shales or siltstones.

@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.2.1.1 Geological characteristics

Geological characteristics refer to physical characteristics of the Earth's surface and subsurface, including the depth of sedimentation over bedrock, groundwater table depth, and the thermal properties of soil and rock, which can impact the cost and efficiency of geothermal systems.

@ Geological feature - Sciencedirect: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/geological-feature, accessed on 13 June 2025

5.2.1.1.1 Stratigraphic framework

A stratigraphic framework is a systematic arrangement of rock units that defines the geological history of a basin or region. It is characterized by distinct depositional sequences, each bounded by erosive events or depositional hiatuses, and serves as a basis for dating and correlating source rock formations. This framework can be lithostratigraphic, chronostratigraphic, or based on sequence stratigraphy, and it is used to understand the depositional environments and geological processes that shaped the area.

@ Paraná Basin – Wikipedia: https://en.wikipedia.org/wiki/Paraná_Basin, accessed on 22 April 2025

@ Baby, P., I. Moretti, B. Guillier, R. Limachi, E. Mendez, J. Oller, and M. Specht, 1995, Petroleum system of the northern and central Bolivian sub-Andean zone, in A. J. Tankard, R. Suárez S., and H. J. Welsink, Petroleum basins of South America: AAPG Memoir 62, p. 445–458.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 11 August 2025

5.2.1.1.2 Depositional setting

Depositional setting refers to the environment in which sediments are deposited, characterized by factors such as water depth, energy levels, and the types of sediments and organisms present. It can range from low-turbulence settings like restricted shallow marine bays or shelf-lagoonal complexes to high-turbulence areas with beach sands or corals. Depositional settings can be inferred from sedimentary structures, fossil content, and isotopic trends, and include environments such as deep lagoonal, shelf-margin, platform-interior, slope and open-marine, and basinal settings. These settings can be distinguished by the presence of specific organisms or sediment types, sedimentary structures, sequence architectures, and facies stacking patterns, and can also be influenced by relative sea level fluctuations.

@ Williams, K. E., 1995, Tectonic subsidence analysis and Paleozoic paleogeography of Gondwana, *in* A. J. Tankard, R. Suárez S., and H. J. Welsink, Petroleum basins of South America: AAPG Memoir 62, p. 79–100.

@ Al-Ghamdi N, Pope M, 2014. Integrated high-resolution chemostratigraphy and facies-based stratigraphic architecture of the Lower Cretaceous (Aptian), Shuaiba Formation, Saudi Arabia. AAPG Bulletin, 98(8): 1521–1549.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025.

5.2.1.1.3 Lithofacies

Lithofacies is the rock record of any particular sedimentary environment, including both physical and organic characteristics.

@ Lithofacie - Wikipedia: https://en.wikipedia.org/wiki/Lithofacie, accessed on 12 May 2025

5.2.1.1.4 Mineralogy

Mineralogy is a subject of geology specializing in the scientific study of the chemistry, crystal structure, and physical (including optical) properties of minerals and mineralized artifacts. Specific studies within mineralogy include the processes of mineral origin and formation, classification of minerals, their geographical distribution, as well as their utilization.

@ Mineralogy - wikipedia: https://en.wikipedia.org/wiki/Mineralogy, accessed on 12 May 2025

5.2.1.2 Geochemical characteristics

Geochemical characteristics refer to the chemical properties and compositions of rocks, minerals, fluids, and gases in the Earth's crust and mantle. These characteristics are studied using geochemistry, a branch of geology that focuses on the distribution and movement of chemical elements and isotopes within the Earth.

@ Beckford H O, Chu H, Song C, et al., 2021. Geochemical characteristics and behaviour of elements during weathering and pedogenesis over karst area in Yunnan–Guizhou Plateau, southwestern China. Environ Earth Sci, 80(61).

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

5.2.1.2.1 Organic matter richness

The parameters used to indicate the quantity and richness of organic matter in sediments include TOC (Total organic carbon), bitumen, hydrocarbons and rock-eval pyrolysis (S_1 and S_2).

@ Peters, K E and Cassa M R, 1994. Applied source rock geochemistry, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, 93-120.

5.2.1.2.2 Kerogen type

The type of kerogen present determines source rock quality and the hydrocarbons it generates during maturation. The more oil prone a kerogen, the higher its quality. Four basic types of kerogen are found in sedimentary rocks. A single type or a mixture of types may be present in a source rock. The type of kerogen can be determined by results of elemental analysis, petrological maceral analysis, and pyrolysis analysis (hydrocarbon index and oxygen index).

@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

5.2.1.2.3 Thermal maturity

In petroleum geology, the maturity of a rock is a measure of its state in terms of hydrocarbon generation. Maturity is established using a combination of geochemical and basin modelling techniques.

@ Maturity (geology)- Wikipedia: https://en.wikipedia.org/wiki/Maturity_(geology), accessed on 15 August 2025

5.2.1.3 Production techniques

Production techniques refer to the methods and technologies used to extract, process, and manage resources such as oil, gas, minerals, and water from their natural reservoirs. These techniques are crucial for maximizing efficiency, minimizing environmental impact, and ensuring the economic viability of resource extraction projects.

@ James S, 2019. Shale Oil and Gas Production Processes. Gulf Professional Publishing.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

5.2.1.3.1 Horizontal drilling

Horizontal drilling refers to any method employed to hit a predetermined subsurface target. At a predetermined depth, the well is kicked off and the angle is shallowed to a 90 °(horizontal) inclination. The major reasons for horizontal drilling are increasing the wellbore's exposure to the pay interval, intersecting many vertical fractures in a single wellbore, reducing water and gas coning problems, increasing ultimate recovery, and faster payout.

@ Wellbore trajectory - AAPG Wiki: https://wiki.aapg.org/Wellbore_trajectory, accessed on 16 June 2025

5.2.1.3.2 Hydraulic fracturing ("fracking")

Hydraulic fracturing ("fracking") is a method used to stimulate hydrocarbon production by inducing fractures in a reservoir rock. This is achieved by injecting fluids (such as water or other fluids) and granular materials (such as sand or ceramic proppant) into the rock formation at pressures that exceed the natural formation pressure, causing the rock to fracture. The fractures are then propped open by the granular materials to allow the hydrocarbons to flow more freely into the well. This technique is commonly used in wells to improve economic recovery of gas, oil and condensate. It can also be applied to stimulate water injectors or to fracture seal rock under certain conditions.

@ Halliburton, 2001. Basic Petroleum Geology and Log Analysis[M]. Houston: Halliburton.

@ White paper: Hydraulic fracturing - AAPG Wiki: https://wiki.aapg.org/White_paper:_Hydraulic_fracturing, accessed on 25 May 2025.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 7 August 2025

5.2.1.3.3 Microseismic monitoring

Microseismic monitoring is a technique that uses sensitive geophones to detect and map the location of small seismic events associated with the growth of fractures in the target formation. This monitoring can be performed in real time using a surface array or, if a nearby offset well is available, using downhole microphones. The data collected helps infer the size, orientation, and geometry of the induced fractures.

@ Fracking in the United Kingdom – Wikipedia: https://en.wikipedia.org/wiki/Fracking_in_the_United_Kingdom, accessed on 5 May 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

5.2.2 Tight oil and gas

Tight oil is a type of unconventional petroleum accumulation in low permeability rocks that occurs throughout a large area and is not significantly affected by hydrodynamic influences (also called "continuous-type deposit"). Such accumulations lack the porosity and permeability of

conventional reservoirs which flow without stimulation at economic rates. Tight gas is natural gas trapped within a rock with extremely low permeability—typically limestone or sandstone. This is not to be confused with shale gas, which is natural gas trapped within shale formations.
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7
@ Energy Education: https://energyeducation.ca/encyclopedia/Tight_gas, accessed on 20 March 2025

5.2.2.1 Geological characteristics
Geological characteristics refer to physical characteristics of the Earth's surface and subsurface, including the depth of sedimentation over bedrock, groundwater table depth, and the thermal properties of soil and rock, which can impact the cost and efficiency of geothermal systems.
@ Geological feature - Sciencedirect: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/geological-feature, accessed on 13 June 2025

5.2.2.1.1 Reservoir rock
A reservoir rock is a porous and permeable rock that has both storage capacity and the ability to allow fluids to flow through it.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

5.2.2.1.2 Porosity and permeability
Porosity φ is the ratio of void space within a rock (or sediment) relative to bulk volume. It reflects the fluid storage capacity of the reservoir. Permeability (K) is the ability of a rock to transmit fluids, without changing the structure of the rock or a displacement of its components.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

5.2.2.1.3 Natural fracture systems
Natural fractures are diagenetic fractures and/or tectonic fractures. They are mechanical breaks in rocks, which form in nature, in response to litho-static, tectonic and thermal stress and high fluid pressure. They occur in a variety of scales and with high degree of heterogeneity.
@ Mohaghegh S D, 2013. Reservoir modeling of shale formations, Journal of Natural Gas Science and Engineering, 12, 22-33.

5.2.2.2 Production techniques
Production techniques refer to the methods and technologies used to extract, process, and manage resources such as oil, gas, minerals, and water from their natural reservoirs. These techniques are crucial for maximizing efficiency, minimizing environmental impact, and ensuring the economic viability of resource extraction projects.
@ James S, 2019. Shale Oil and Gas Production Processes. Gulf Professional Publishing.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

5.2.2.2.1 Horizontal drilling

A horizontal well is a directional well, usually exceeding 80 ° of departure from vertical, which is designed and steered to maximize the productive interval of exposure in the wellbore. The horizontal lateral(s) can go beyond true 90 ° horizontal and actually drill upward.

@ Horizontal well-AAPG wiki: https://wiki.aapg.org/Horizontal_well, accessed on 8 August 2025

5.2.2.2.2 Hydraulic fracturing

"Hydraulic fracturing" is a general term for the technique used to "fracture" rock in an oil or gas reservoir by pumping water (or other fluid) and sand (or other granular material) into a sedimentary rock layer at a pressure that is greater than the earth's natural pressure at that depth. The oil or natural gas that producers are looking to extract consists of hydrocarbon molecules trapped in the tiny spaces between the grains of sand or tiny clay particles that comprise the rock. By creating artificial cracks in the rock through hydraulic fracturing, these molecules are able to flow out along these cracks to the well, where they are brought to the surface. In nature, there is much more hydrocarbon in the rock than historically has been produced. Hydraulic fracturing as a technology provides a more efficient method of producing the additional oil and gas.

@ White paper: Hydraulic fracturing-AAPG wiki: https://wiki.aapg.org/White_paper:_Hydraulic_fracturing#The_evolution_of_hydraulic_fracturing_in_the_United_States, accessed on 8 August 2025

5.2.2.2.3 Acidizing

Acidizing can be divided into three types of operations:

- Acid fracturing, which involves injecting acid at rates above those that will be accepted by the matrix, fracturing the formation, and etching the face of the fracture to develop a permeable flow path.
- Matrix acidizing, which involves injecting acid at low rates to permit the uniform penetration of the formation without fracturing it.
- Acid washing, which involves using acid to dissolve scales and precipitates within the wellbore by moving acid across the encrusted surfaces. The acid used in acid washing seldom enters the formation and for that reason is not discussed further.

@ Stimulation – AAPG Wiki: https://wiki.aapg.org/Stimulation#Acidizing, accessed on 16 June 2025

5.2.3 Coalbed methane

Coalbed methane is methane trapped in underground coal seams. This type of methane can be accessed using drilling techniques similar to those used in the collection of shale gas. In these deposits, the methane is attached to the surface of the coal.

@ Energy Education: https://energyeducation.ca/encyclopedia/Coal_bed_methane, accessed on 20 March 2025

5.2.3.1 Geological characteristics

Geological characteristics refer to physical characteristics of the Earth's surface and subsurface, including the depth of sedimentation over bedrock, groundwater table depth, and the thermal properties of soil and rock, which can impact the cost and efficiency of geothermal systems.

@ Geological feature - Sciencedirect: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/geological-feature, accessed on 13 June 2025

5.2.3.2 Production techniques
They refer the techniques used to extract coalbed methane.
@ Defined by the Working Group of Petroleum Geology Knowledge System

5.2.3.2.1 Dewatering
Dewatering is the removal of water from a location. This may be done by wet classification, centrifugation, filtration, or similar solid-liquid separation processes, such as removal of residual liquid from a filter cake by a filter press as part of various industrial processes.
@ Dewatering - Wikipedia: https://en.wikipedia.org/wiki/Dewatering, accessed on 12 May 2025

5.2.3.2.2 Enhanced coalbed methane recovery
Enhanced coal bed methane recovery is a method of producing additional coalbed methane from a source rock, similar to enhanced oil recovery applied to oil fields. Carbon dioxide (CO_2) injected into a bituminous coal bed would occupy pore space and also adsorb onto the carbon in the coal at approximately twice the rate of methane (CH_4), allowing for potential enhanced gas recovery. This technique may be used in conjunction with carbon capture and storage in mitigation of global warming where the carbon dioxide that is sequestered is captured from the output of fossil fuel power plants.
@ Defined by the Working Group of Petroleum Geology Knowledge System common sense terms

5.2.4 Oil sands
Non-mobile oils with API gravity of 7-12^{o} and viscosity of more than 10,000cP
@ EXTRA HEAVY OILS IN THE WORLD ENERGY SUPPLY:
https://oilproduction.net/files/extra-heavy-oils-in-the-world-energy-supply.pdf, accessed on 10 March 2025

5.2.4.1 Geological characteristics
Geological characteristics refer to physical characteristics of the Earth's surface and subsurface, including the depth of sedimentation over bedrock, groundwater table depth, and the thermal properties of soil and rock, which can impact the cost and efficiency of geothermal systems.
@ Geological feature - Sciencedirect: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/geological-feature, accessed on 13 June 2025

5.2.4.1.1 Bitumen properties
They are the physical properties of bitumen which include gravity and viscosity.
@ Defined by the Working Group of Petroleum Geology Knowledge System

5.2.4.1.2 Reservoir quality
The quality of a reservoir is defined by its hydrocarbon storage capacity and deliverability. The hydrocarbon storage capacity is characterized by the effective porosity and the size of the reservoir, whereas the deliverability is a function of the permeability. Effective porosity is the volume percentage of interconnected pores in a rock. The remaining space in the rock is occupied by the framework or matrix of the rock and, if present, nonconnected pore space.
@ Reservoir quality – AAPG Wiki: https://wiki.aapg.org/Reservoir_quality, accessed on 16 June 2025

5.2.4.1.3 Overburden thickness
It refers to the thickness of the overburden rocks overlying the oil sand.
@ Defined by the Working Group of Petroleum Geology Knowledge System

5.2.4.2 Production techniques
They refer the techniques used to extract coalbed methane.
@ Defined by the Working Group of Petroleum Geology Knowledge System

5.2.4.2.1 Surface mining
An economic means of producing very large volumes of bitumen or highly degraded oil which occurs at or very near the surface and has very little or no overburden. In Athabasca bitumen has been extracted on a commercial scale from the Athabasca Oil Sands by surface mining.
@ Athabasca oil sands - Wikipedia: https://en.wikipedia.org/wiki/Athabasca_oil_sands, accessed on 12 May 2025
@ Richard Chuchla, written communication, 6 July 2025.

5.2.4.2.2 In-situ methods (SAGD, CSS)
In situ methods like steam-assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS) have been developed to extract bitumen from the subsurface by injecting steam to heat the sands and reduce the bitumen viscosity so that it can be pumped out like conventional crude oil.
@ Athabasca oil sands - Wikipedia: https://en.wikipedia.org/wiki/Athabasca_oil_sands, accessed on 12 May 2025

5.2.5 Extra-heavy oils
Mobile oils with API gravity of less than 20^{o} and viscosity of 100-10,000cP
@ EXTRA HEAVY OILS IN THE WORLD ENERGY SUPPLY: https://oilproduction.net/files/extra-heavy-oils-in-the-world-energy-supply.pdf, accessed on 10 March 2025

5.2.5.1 Oil viscosity
It is a measure of oil's resistance to gradual deformation by shear stress at a given rate. It varies with the abundance of non-hydrocarbons such as nitrogen, oxygen and sulfur and temperature and pressure. The units are centipoise (cP). At 20℃, water has a viscosity of 1 cP; Light oil is typically 20 to 100 cP, Heavy oil is typically 1000 to 10,000 cP, and honey is typically 10,000 cP.
@ Bend S L, 2007. Petroleum Geology eTextbook, An AAPG Special Publication on CD-ROM, Tulsa, Oklahoma

5.2.5.1.1 API gravity
API gravity ranges between 45^{o} to 75^{o}.
@ Natural-gas condensate - Wikipedia: https://en.wikipedia.org/wiki/Natural-gas_condensate, accessed on 25 March 2025

5.2.5.1.2 Depth and temperature
The depth and temperature at which extra-heavy oils are found play significant roles in their behavior and the methods used for their extraction.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

5.2.5.2 Production techniques

They refer the techniques used to extract coalbed methane.

@ Defined by the Working Group of Petroleum Geology Knowledge System

5.2.5.2.1 Cold production

Cold production is a method used to extract extra-heavy oils without the need for thermal or other external energy inputs. This technique leverages the natural properties of the reservoir and the oil itself to enhance recovery, making it a cost-effective and environmentally friendly approach.

@ Bernard Tremblay, 2013. Cold Production of Heavy Oil, Enhanced Oil Recovery Field Case Studies. Gulf Professional Publishing, 615-666.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

5.2.5.2.2 Thermal recovery

All thermal recovery processes involve the use of heat to accelerate the oil recovery process. The heat can be generated at the surface and injected into the reservoir, as in the case of steam injection, or generated in the reservoir by injecting a fluid such as air that is combustible with the in-place oil. The choice of which technique to use to add thermal energy to the reservoir depends on an analysis of the oil reservoir and the economics of generating the energy. However, a major goal of all thermal methods is to reduce the viscosity of the in-place oil.

@ Enhanced oil recovery - AAPG Wiki: https://wiki.aapg.org/Enhanced_oil_recovery, accessed on 16 June 2025

5.2.6 Gas hydrates

Gas hydrates (also called gas clathrates) are icelike, crystalline solids composed of natural-gas molecules, principally methane, trapped in rigid crystalline cages formed by frozen water molecules. They are found at relatively shallow depth below the seafloor and have a very conspicuous seismic response (high amplitude).

@ Collett T S, 2001. Natural-gas hydrates: Resources of the twenty-first century?, Petroleum provinces of the twenty-first century: AAPG Memoir,74, 85-108.

@ Collett T S, 2002. Energy resource potential of natural gas hydrates, AAPG Bulletin, 86(11), 1971-1992.

@ Gas hydrates - AAPG Wiki: https://wiki.aapg.org/Gas_hydrates, accessed on 20 March 2025

5.3 Petroleum resources

Petroleum resources refer to hydrocarbon deposits predominantly occurring in subsurface geologic formations, which include both discovered and undiscovered reserves, as well as unrecoverable quantities of petroleum. They encompass the total accumulations of oil and gas, with estimates of the recoverable fraction influenced by technical, economic, and geopolitical factors.

@ Petroleum resource - Sciencedirect: https://www.sciencedirect.com/topics/engineering/petroleum-resource, accessed on 13 June 2025

5.3.1 USGS classification

The U.S. Geological Survey Library classification system has been designed for earth science libraries. It is a tool for assigning call numbers to earth science and allied pure science materials in order to collect these materials into related subject groups on the library shelves and arrange them alphabetically by

author and title. The classification can be used as a retrieval system to access materials through the subject and geographic numbers.
@ us geological survey library classification system - Usgs: https://www.usgs.gov/publications/us-geological-survey-library-classification-system, accessed on 13 June 2025

5.3.1.1 Cumulative production
Cumulative production refers to the total volume of hydrocarbons that have been extracted and produced from a particular geological or judicial entity up to a specified point in time.
@ Books-PRMgmtSystem_V1.01 Nov 27
@ Klett, T.R., Schmoker, J. W., Charpentier, R. R., Ahlbrandt, T. S., and Ulmishek, 2000. Chapter GL GLOSSARY, U.S. Geological Survey World Petroleum Assessment 2000– Description and Results: U.S. Geological Survey Digital Data Series 60.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

5.3.1.2 Remaining reserves (reserves)
Reserves are those quantities of petroleum anticipated to be commercially recoverable by application of development projects to known accumulations from a given date forward under defined conditions. Reserves must satisfy four criteria: discovered, recoverable, commercial, and remaining (as of the evaluation's effective date) based on the development project(s) applied.
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.3.1.3 Reserve growth (field growth***)***
Reserve growth refers to the increases in known petroleum volume that commonly occur as oil and gas fields are developed and produced.
@ Klett, T.R., Schmoker, J. W., Charpentier, R. R., Ahlbrandt, T. S., and Ulmishek, 2000. Chapter GL GLOSSARY, U.S. Geological Survey World Petroleum Assessment 2000– Description and Results: U.S. Geological Survey Digital Data Series 60.

5.3.1.4 Undiscovered resources
They refer to resources postulated from geologic information and theory to exist outside of known oil and gas fields.
@ Klett, T.R., Schmoker, J. W., Charpentier, R. R., Ahlbrandt, T. S., and Ulmishek, 2000. Chapter GL GLOSSARY, U.S. Geological Survey World Petroleum Assessment 2000– Description and Results: U.S. Geological Survey Digital Data Series 60.

5.3.1.5 Conventional petroleum endowment
The sum of the known petroleum volume (cumulative production plus remaining reserves) and the mean of the undiscovered volume. Oil endowment and gas endowment are sometimes used as abbreviated forms of this term.
@ Klett, T.R., Schmoker, J. W., Charpentier, R. R., Ahlbrandt, T. S., and Ulmishek, 2000. Chapter GL GLOSSARY, U.S. Geological Survey World Petroleum Assessment 2000– Description and Results: U.S. Geological Survey Digital Data Series 60.

5.3.1.6 Grown conventional petroleum endowment
The sum of the known petroleum volume (cumulative production plus remaining reserves), the mean of the undiscovered volume, and additions to reserves by reserve growth.

@ Klett, T.R., Schmoker, J. W., Charpentier, R. R., Ahlbrandt, T. S., and Ulmishek, 2000. Chapter GL GLOSSARY, U.S. Geological Survey World Petroleum Assessment 2000–Description and Results: U.S. Geological Survey Digital Data Series 60.

5.3.2 BGR (Federal Institute for Geosciences and Natural Resources) classification
The BGR Classification refers to the standardized system(s) used or developed by the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) to categorize geological resources—especially fossil fuels (coal, oil, gas) and mineral raw materials—based on geological knowledge, technical feasibility, and economic viability, in accordance with international standards such as the UNFC.
@ Federal Institute for Geosciences and Natural Resources - Wikipedia: https://en.wikipedia.org/wiki/Federal_Institute_for_Geosciences_and_Natural_Resources, accessed on 13 June 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

5.3.2.1 Cumulative production
Cumulative production refers to the total volume of hydrocarbons that have been extracted and produced from a particular geological or judicial entity up to a specified point in time.
@ Books-PRMgmtSystem_V1.01 Nov 27
@ Klett, T.R., Schmoker, J. W., Charpentier, R. R., Ahlbrandt, T. S., and Ulmishek, 2000. Chapter GL GLOSSARY, U.S. Geological Survey World Petroleum Assessment 2000–Description and Results: U.S. Geological Survey Digital Data Series 60.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

5.3.2.2 Reserves
Reserves are those quantities of petroleum anticipated to be commercially recoverable by application of development projects to known accumulations from a given date forward under defined conditions. Reserves must satisfy four criteria: discovered, recoverable, commercial, and remaining (as of the evaluation's effective date) based on the development project(s) applied.
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.3.2.3 Resources
Resources refer to known of hydrocarbon resources which cannot currently be exploited for technical and/or economic reasons, as well as unproven but geologically possible energy resources which may be exploitable in future.
@ BGR-Bundesanstalt Für Geowissenschaften und Rohstoffe. BGR Energy Study 2023 – Data and Developments Concerning German and Global Supplies (Edition 25).
https://www.bgr.bund.de/EN/Themen/Energie/Downloads/energiestudie_2023_en.html;jsessionid=1475223B8BEBE0027152F7978936E00E.internet961?nn=1547192

5.3.2.4 Estimated ultimate recovery (EUR)
The estimated total amount of an hydrocarbons that can be extracted from a deposit.
@ BGR-Bundesanstalt Für Geowissenschaften und Rohstoffe. BGR Energy Study 2023 – Data and Developments Concerning German and Global Supplies (Edition 25).
https://www.bgr.bund.de/EN/Themen/Energie/Downloads/energiestudie_2023_en.html;jsessionid=1475223B8BEBE0027152F7978936E00E.internet961?nn=1547192

5.3.2.5 Potential

The potential of petroleum resources refers to the estimated quantity of oil and natural gas that is believed to exist in a given area, including both discovered and undiscovered resources. This concept encompasses the total hydrocarbon endowment of a region or basin, taking into account geological, technical, and economic factors.
@ Tong X G, Zhang G Y, and Wang Z M, et al., 2018. Distribution and potential of global oil and gas resources. Petroleum Exploration and Development, 45(4), 779-789.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

5.3.2.5.1 Total potential
It is the sum of cumulative production, reserves and resources.
@ BGR-Bundesanstalt Für Geowissenschaften und Rohstoffe. BGR Energy Study 2023 – Data and Developments Concerning German and Global Supplies (Edition 25).
https://www.bgr.bund.de/EN/Themen/Energie/Downloads/energiestudie_2023_en.html;jsessionid=1475223B8BEBE0027152F7978936E00E.internet961?nn=1547192

5.3.2.5.2 Remaining potential (remaining resources)
It is the sum of reserves and resources.
@ BGR-Bundesanstalt Für Geowissenschaften und Rohstoffe. BGR Energy Study 2023 – Data and Developments Concerning German and Global Supplies (Edition 25).
https://www.bgr.bund.de/EN/Themen/Energie/Downloads/energiestudie_2023_en.html;jsessionid=1475223B8BEBE0027152F7978936E00E.internet961?nn=1547192

5.3.3 Petroleum Resources Management System (PRMS)

The most widely accepted classification and reporting methodology is the 2018 petroleum resources management system (PRMS), which summarizes a consistent approach to estimating oil and gas quantities within a comprehensive classification framework, jointly developed by the Society of Petroleum Engineers (SPE), the World Petroleum Council (WPC), the American Association of Petroleum Geologists (AAPG), the Society of Petroleum Evaluation Engineers (SPEE) and the Society of Economic Geologists (SEG).
@ Oil and gas reserves and resource quantification - Wikipedia: https://en.wikipedia.org/wiki/Oil_and_gas_reserves_and_resource_quantification, accessed on 12 May 2025

5.3.3.1 Total petroleum initially-in-place

Total Petroleum Initially-In-Place (PIIP) is all quantities of petroleum that are estimated to exist originally in naturally occurring accumulations, discovered and undiscovered, before production.
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.3.3.2 Discovered petroleum initially-in-place

Discovered Petroleum-initially-in-place is that quantity of petroleum which is estimated, on a given date, to be contained in known accumulations, plus those quantities already produced therefrom.
@ Petroleum Resources Classification System and Definitions - SPE: https://www.spe.org/media/filer_public/58/a2/58a24952-4f2c-4c2c-9eca-038299cb2ceb/petroleum_resources_classification_system_and_definitions.pdf, accessed on 13 June 2025

5.3.3.2.1 Production (cumulative production)
Cumulative production refers to the total volume of hydrocarbons that have been extracted and produced from a particular geological or judicial entity up to a specified point in time.
@ Books-PRMgmtSystem_V1.01 Nov 27
@ Klett, T.R., Schmoker, J. W., Charpentier, R. R., Ahlbrandt, T. S., and Ulmishek, 2000. Chapter GL GLOSSARY, U.S. Geological Survey World Petroleum Assessment 2000– Description and Results: U.S. Geological Survey Digital Data Series 60.
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

5.3.3.2.2 Reserves
Reserves are those quantities of petroleum anticipated to be commercially recoverable by application of development projects to known accumulations from a given date forward under defined conditions. Reserves must satisfy four criteria: discovered, recoverable, commercial, and remaining (as of the evaluation's effective date) based on the development project(s) applied.
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.3.3.2.2.1 Proved Reserves
Proved reserves are those quantities of petroleum that, by analysis of geoscience and engineering data, can be estimated with reasonable certainty to be commercially recoverable from known reservoirs and under defined technical and commercial conditions. If deterministic methods are used, the term "reasonable certainty" is intended to express a high degree of confidence that the quantities will be recovered. If probabilistic methods are used, there should be at least a 90% probability that the quantities actually recovered will equal or exceed the estimate.
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.3.3.2.2.2 Probable Reserves
Probable reserves are those additional reserves which analysis of geoscience and engineering data indicate are less likely to be recovered than Proved Reserves but more certain to be recovered than Possible Reserves. It is equally likely that actual remaining quantities recovered will be greater than or less than the sum of the estimated Proved plus Probable Reserves (2P). In this context, when probabilistic methods are used, there should be at least a 50% probability that the actual quantities recovered will equal or exceed the 2P estimate.
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.3.3.2.2.3 Possible Reserves
Possible Reserves are those additional reserves that analysis of geoscience and engineering data suggest are less likely to be recoverable than Probable Reserves. The total quantities ultimately recovered from the project have a low probability to exceed the sum of Proved plus Probable plus Possible (3P) Reserves, which is equivalent to the high-estimate scenario. When probabilistic methods are used, there should be at least a 10% probability that the actual quantities recovered will equal or exceed the 3P estimate.
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.3.3.2.3 Contingent Resources

Contingent Resources are those quantities of petroleum estimated, as of a given date, to be potentially recoverable from known accumulations, by the application of development project(s) not currently considered to be commercial owing to one or more contingencies.

@ SPE, 2018. Petroleum resources5.3.3.3 Undiscovered petroleum initially-in-place management system (version1.01), ISBN 978-1-61399-660-7

5.3.3.3 Undiscovered petroleum initially-in-place

Undiscovered Petroleum-initially-in-place is that quantity of petroleum which is estimated, on a given date, to be contained in accumulations yet to be discovered.

@ Petroleum Resources Classification System and Definitions - SPE: https://www.spe.org/media/filer_public/58/a2/58a24952-4f2c-4c2c-9eca-038299cb2ceb/petroleum_resources_classification_system_and_definitions.pdf, accessed on 13 June 2025

5.3.3.3.1 Prospective resources

Prospective Resources are those quantities of petroleum estimated, as of a given date, to be potentially recoverable from undiscovered accumulations by application of future development projects. Prospective Resources have both an associated chance of geologic discovery and a chance of development. Prospective Resources are further categorized in accordance with the range of uncertainty associated with recoverable estimates, assuming discovery and development, and may be sub-classified based on project maturity.

@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.3.3.3.2 Unrecoverable prospective resources

They are the unrecoverable portion of the undiscovered petroleum initially-in-place.

@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.3.3.4 UNFC classification

United Nations Framework Classification for Resources (UNFC) is an international scheme for the classification, management and reporting of energy, mineral, and raw material resources. United Nations Economic Commission for Europe's (UNECE) Expert Group on Resource Management (EGRM) is responsible for the development promotion and further development of UNFC.

@ United Nations Framework Classification for Resources -Wikipedia: https://en.wikipedia.org/wiki/United_Nations_Framework_Classification_for_Resources, accessed on 12 May 2025

5.4 Petroleum resource assessment

Petroleum resource assessment is the process of estimating the quantity and quality of oil and natural gas resources in a specific area or region. This assessment involves a combination of geological, geophysical, and engineering techniques to evaluate the potential for hydrocarbon reserves and their economic viability.

@ world oil and gas resource assessments - Usgs: https://www.usgs.gov/centers/central-energy-resources-science-center/science/world-oil-and-gas-resource-assessments, accessed on 13 June 2025

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

5.4.1 Conventional petroleum

Conventional oil refers to the oil which can be extracted using traditional drilling and pumping methods. Conventional gas refers to the natural gas which can be extracted using traditional drilling and pumping methods.

@ Petroleum reservoir - Wikipedia: https://en.wikipedia.org/wiki/Petroleum_reservoir, accessed on 10 March 2025

@ Defined by the Working Group of Petroleum Geology Knowledge System

5.4.1.1 Analogy approach (Analog methodology)

Analogy method for estimating reserves directly compares a newly discovered or poorly defined reservoir to a known reservoir thought to have similar geological or petrophysical properties (depth, lithology, porosity, and so on). While analogy is the least accurate of the methods presented, it is often used early in the life of a reservoir to establish an order-of-magnitude recovery estimate. As the field matures and data become available to make volumetric OOIP or OGIP estimates, analogy is often used to establish a range of recovery factors to apply to the in-place volumes. Evaluating recovery in this fashion is particularly useful when some performance history is available but a decline rate has yet to be established. Analogy should always be used in conjunction with other techniques to ensure that the results of the more computationally intensive methods make sense within the geological framework.

@ Reserves estimation - AAPG: https://wiki.aapg.org/Reserves_estimation, accessed on 16 June 2025

5.4.1.2 Basin modelling approach (Basin modeling methodology)

Basin modeling is designed to describe the burial of source rocks, the hydrocarbon generation in those rocks, and the expulsion, migration, trapping, and preservation of those hydrocarbons. The definition of basin modeling as presently used usually corresponds more closely to the concept of a sedimentary basin than to that of a petroleum system. A single basin modeling simulation often includes several petroleum systems, without separating or distinguishing among them.

@ Waples D W, 1994. Thermal modeling: Thermal Indicators, hydrocarbon generation, and oil cracking, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.307-322.

5.4.1.3 Probabilistic approach (Seventh approximation assessment model (USGS method))

It is the methodology used for resources assessment by USGS.

@ Klett, T.R., Schmoker, J. W., Charpentier, R. R., Ahlbrandt, T. S., and Ulmishek, 2000. Chapter GL GLOSSARY, U.S. Geological Survey World Petroleum Assessment 2000–Description and Results: U.S. Geological Survey Digital Data Series 60.

5.4.2 Unconventional petroleum

Unconventional resources are petroleum accumulations that are pervasive throughout a large area (also called "continuous-type deposits"), not driven by buoyancy and lack well-defined hydrocarbon-water contacts of OWC or GWC. Such resources cannot be recovered using traditional recovery projects owing to fluid viscosity (e.g., oil sands) and/or reservoir permeability (e.g., tight gas/oil/CBM) that impede natural mobility. Moreover, the extracted

petroleum may require significant processing before sale (e.g., bitumen upgraders).
@ SPE, 2018. Petroleum resources management system (version1.01), ISBN 978-1-61399-660-7

5.4.2.1 Volumetric methods

Oil & gas volumes in a conventional reservoir can be calculated using a volume equation.
@ Oil and gas reserves and resource quantification -Wikipedia: https://en.wikipedia.org/wiki/Oil_and_gas_reserves_and_resource_quantification#Volumetric_method, accessed on 12 May 2025

5.4.2.2 Analogue methods

Analogy method for estimating reserves directly compares a newly discovered or poorly defined reservoir to a known reservoir thought to have similar geological or petrophysical properties (depth, lithology, porosity, and so on). While analogy is the least accurate of the methods presented, it is often used early in the life of a reservoir to establish an order-of-magnitude recovery estimate. As the field matures and data become available to make volumetric OOIP or OGIP estimates, analogy is often used to establish a range of recovery factors to apply to the in-place volumes. Evaluating recovery in this fashion is particularly useful when some performance history is available but a decline rate has yet to be established. Analogy should always be used in conjunction with other techniques to ensure that the results of the more computationally intensive methods make sense within the geological framework.
@ Reserves estimation - AAPG: https://wiki.aapg.org/Reserves_estimation, accessed on 16 June 2025

5.4.2.3 Probabilistic method

It is the methodology used for resources assessment by USGS.
@ Klett, T.R., Schmoker, J. W., Charpentier, R. R., Ahlbrandt, T. S., and Ulmishek, 2000. Chapter GL GLOSSARY, U.S. Geological Survey World Petroleum Assessment 2000–Description and Results: U.S. Geological Survey Digital Data Series 60.

5.4.2.4 Basin modeling method

Basin modeling is designed to describe the burial of source rocks, the hydrocarbon generation in those rocks, and the expulsion, migration, trapping, and preservation of those hydrocarbons. The definition of basin modeling as presently used usually corresponds more closely to the concept of a sedimentary basin than to that of a petroleum system. A single basin modeling simulation often includes several petroleum systems, without separating or distinguishing among them.
@ Waples D W, 1994. Thermal modeling: Thermal Indicators, hydrocarbon generation, and oil cracking, in Magoon, L. B, and W. G. Dow, eds., 1994, The Petroleum System-from Source to Trap: AAPG Memoir 60, p.307-322.

5.4.3 Integrated assessment approaches

They refer to methodologies involving different approaches for resources assessment.
@ Defined by the Working Group of Petroleum Geology Knowledge System

6. Global petroleum distribution

Global petroleum distribution refers to the geographical and geological patterns of oil and natural gas deposits around the world. It encompasses the locations, sizes, and types of hydrocarbon reservoirs, as well as the factors that influence their formation and accumulation.
@ World distribution of oil - Britannica: https://www.britannica.com/science/petroleum/World-distribution-of-oil, accessed on 13 June 2025
@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025

6.1 Middle Eas

The Middle East is a large area of land in the eastern hemisphere. The lands of the Arabian Peninsula and some of the lands of the eastern Mediterranean are part of the Middle East. The Middle East's population is mostly Muslim. The name of the Middle East comes from its position to the east of Europe and to the west of the Far East.
@ Middle East - Simple English Wikipedia, the free encyclopedia:
https://simple.wikipedia.org/wiki/Middle_East, accessed on 13 June 2025

6.1.1 Arabian Basin

The greatest proportion of the Middle East oil and gas reserves and resources are found in the Arabian Basin, which, according to Klemme (1980), constitutes a type 4 basin. Other oil and gas deposits are linked to rift-type basins (e.g., Red Sea). The Paleozoic to Middle Miocene sequence in the Arabian Basin is the world's richest hydrocarbon province. Large volumes of non-associated gas also are housed in the Paleozoic sequence of central and eastern Arabia.
@ Alsharhan, A.S. and Nairn, A.E.M., 1997. Sedimentary Basins and Petroleum Geology of the Middle East, Elsevier, Amsterdam, 843pp

6.1.2 Zagros Basin

The Zagros Basin is located in the Middle East, the majority of the basin being in Iraq, Syria, and Turkey. This basin covers a large amount of land, in fact covering an area of 500,000 km^2 . The Zagros Basin is bar far one of the most prolific and important basins in the Middle East regarding how many oil and gas fields have been discovered. For this reason, this basin has been a focal point of oil and gas production in the Middle East finding over 400 oil and gas fields, as well as large amounts of hydrocarbon accumulation. Drilling began in the early years of the 1900's and with continued success, the Zagros Basin will continue to be a sought after explorative area.
@ Zagros Basin- SEG: https://wiki.seg.org/wiki/Zagros_Basin, accessed on 16 June 2025

6.1.3 South Oman Salt Basin

The South Oman Salt Basin is a sedimentary basin in Oman, at the southeastern edge of the Arabian Peninsula. It is one of the oldest commercial deposits in the world. Its oil is associated with source rocks of the Neoproterozoic to Cambrian age Huqf Supergroup.
@ South Oman Salt Basin - Wikipedia: https://en.wikipedia.org/wiki/South_Oman_Salt_Basin, accessed on 12 May 2025

6.2 North America

North America is a large continent in the Northern and Western Hemispheres of Earth. It is to the east of the Pacific Ocean, the west of the Atlantic Ocean, the south of the Arctic Ocean, and it is the northern

part of the Americas. The southernmost part is Central America. It is the third largest continent in the world after Asia and Africa. North America has a population of around 528 million, and is the 4th most populous continent in the world.
@ North America - Simple English Wikipedia, the free encyclopedia: https://simple.wikipedia.org/wiki/North_America, accessed on 13 June 2025

6.2.1 Gulf of Mexico Basin

The formation of the Gulf of Mexico, an oceanic rift basin located between North America and the Yucatan Block, was preceded by the breakup of the Supercontinent Pangaea in the Late-Triassic, weakening the lithosphere. Rifting between the North and South American plates continued in the Early-Jurassic, approximately 160 million years ago, and formation of the Gulf of Mexico, including subsidence due to crustal thinning, was complete by 140 Ma. Stratigraphy of the basin, which can be split into several regions, includes sediments deposited from the Jurassic through the Holocene, currently totaling a thickness between 15 and 20 kilometers.
@ Sternbach, C.A., 2020. Super basin thinking: Methods to explore and revitalize the world's greatest petroleum basins. AAPG Bulletin 104 (12): 2463-2506.

6.2.2 Western Canadian Sedimentary Basin

The Western Canada Sedimentary Basin (WCSB) underlies 1.4 million square kilometres (540,000 sq mi) of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. This vast sedimentary basin consists of a massive wedge of sedimentary rock extending from the Rocky Mountains in the west to the Canadian Shield in the east. This wedge is about 6 kilometres (3.7 mi) thick under the Rocky Mountains, but thins to zero at its eastern margins. The WCSB contains one of the world's largest reserves of petroleum and natural gas and supplies much of the North American market, producing more than 450 million cubic metres (16 billion cubic feet) per day of gas in 2000. It also has huge reserves of coal. Of the provinces and territories within the WCSB, Alberta has most of the oil and gas reserves and almost all of the oil sands.
@ Sternbach, C.A., 2020. Super basin thinking: Methods to explore and revitalize the world's greatest petroleum basins. AAPG Bulletin 104 (12): 2463-2506.
@ Western Canada Sedimentary Basin -Wikipedia: https://en.wikipedia.org/wiki/Western_Canada_Sedimentary_Basin, accessed on 12 May 2025

6.2.3 Permian Basin

Permian Basin is in geology the name of two large intercontinental basins that were formed in the Permian period: (1) Permian Basin (North America), a basin in the subsurface of the south of the United States, in west Texas and southeast New Mexico. (2) Permian Basin (Europe), a basin in the subsurface of northern Europe, centred on the North Sea.
@ Sternbach, C.A., 2020. Super basin thinking: Methods to explore and revitalize the world's greatest petroleum basins. AAPG Bulletin 104 (12): 2463-2506.
@ Permian Basin - Wikipedia: https://en.wikipedia.org/wiki/Permian_Basin, accessed on 12 May 2025

6.3 Russia and Central Asia

Russia, or the Russian Federation, is a country spanning Eastern Europe and North Asia. It is the largest country in the world, and extends across eleven time zones, sharing land borders with

fourteen countries. Central Asia, central region of Asia, extending from the Caspian Sea in the west to the border of western China in the east. It is bounded on the north by Russia and on the south by Iran, Afghanistan, and China. The region consists of the former Soviet republics of Kazakhstan, Uzbekistan, Tajikistan, Kyrgyzstan, and Turkmenistan.
@ Russia – Wikipedia: https://en.wikipedia.org/wiki/Russia, accessed on 15 August 2025
@ Central Asia | History, Geography & Culture | Britannica: https://www.britannica.com/place/Central-Asia, accessed on 15 August 2025

6.3.1 West Siberian Basin

The West Siberian petroleum basin (also known as the West Siberian hydrocarbon province or Western Siberian oil basin) is the largest hydrocarbon (petroleum and natural gas) basin in the world covering an area of about 2.2 million km2, and is also the largest oil and gas producing region in Russia. Geographically it corresponds to the West Siberian plain in North Asia. From continental West Siberia, it extends into the Kara Sea as the East-Prinovozemelsky field. Beneath lie remnants of the Siberian Traps, thought to be responsible for the Great Dying 250 million years ago.
@ Sternbach, C.A., 2020. Super basin thinking: Methods to explore and revitalize the world's greatest petroleum basins. AAPG Bulletin 104 (12): 2463-2506.
@ West Siberian petroleum basin -Wikipedia: https://en.wikipedia.org/wiki/West_Siberian_petroleum_basin, accessed on 12 May 2025

6.3.2 Pre-Caspian Basin

The Pre-Caspian Basin is one of the oldest basins in the world, and is located in Russia, Kazakhstan, and the Northern part of the Caspian Sea. The basin spans about 500,000 km2, and reaches depths of 20 km below the Earth's surface. The Pre-Caspian Basin is one of the largest hydrocarbon provinces in the world and exploration of the hydrocarbon-rich basin began in the early twentieth century.
@ Pre-Caspian Basin - SEG: https://wiki.seg.org/wiki/Pre-Caspian_Basin, accessed on 12 May 2025

6.3.3 Amu-Darya Basin

The Amu Darya, also shortened to Amu and historically known as the Oxus, is a major river in Central Asia which flows through Tajikistan, Turkmenistan, Uzbekistan, and Afghanistan. Rising in the Pamir Mountains, north of the Hindu Kush, the Amu Darya is formed by the confluence of the Vakhsh and Panj rivers, in the Tigrovaya Balka Nature Reserve on the border between Afghanistan and Tajikistan, and flows from there north-westwards into the southern remnants of the Aral Sea. In its upper course, the river forms part of Afghanistan's northern border with Tajikistan, Uzbekistan, and Turkmenistan. In ancient history, the river was regarded as the boundary of Greater Iran with Turan, which roughly corresponded to present-day Central Asia.
@ Amu Darya - Wikipedia: https://en.wikipedia.org/wiki/Amu_Darya, accessed on 12 May 2025

6.4 South America

South America, fourth largest of the world's continents. It is the southern portion of the landmass generally referred to as the New World, the Western Hemisphere, or simply the Americas. The continent is compact and roughly triangular in shape, being broad in the north and tapering to a point—Cape Horn, Chile—in the south.
@ South America - Britannica: https://www.britannica.com/place/South-America, accessed on 13 June 2025

6.4.1 Maracaibo Basin

The Maracaibo Basin, also known as Lake Maracaibo natural region, Lake Maracaibo depression or Lake Maracaibo Lowlands, is a foreland basin and one of the eight natural regions of Venezuela, found in the northwestern corner of Venezuela in South America. Covering over 36,657 square km, it is a hydrocarbon-rich region that has produced over 30 billion bbl of oil with an estimated 44 billion bbl yet to be recovered. The basin is characterized by a large shallow tidal estuary, Lake Maracaibo, located near its center. The Maracaibo basin has a complex tectonic history that dates back to the Jurassic period with multiple evolution stages. Despite its complexity, these major tectonic stages are well preserved within its stratigraphy. This makes The Maracaibo basin one of the most valuable basins for reconstructing South America's early tectonic history.

@ Sternbach, C.A., 2020. Super basin thinking: Methods to explore and revitalize the world's greatest petroleum basins. AAPG Bulletin 104 (12): 2463-2506.

@ Maracaibo Basin - Wikipedia: https://en.wikipedia.org/wiki/Maracaibo_Basin, accessed on 12 May 2025

6.4.2 Santos Basin

The Santos Basin (Portuguese: Bacia de Santos) is an approximately 352,000 square kilometres (136,000 sq mi) large mostly offshore sedimentary basin. It is located in the south Atlantic Ocean, some 300 kilometres (190 mi) southeast of Santos, Brazil. The basin is one of the Brazilian basins to have resulted from the break-up of Gondwana since the Early Cretaceous, where a sequence of rift basins formed on both sides of the South Atlantic; the Pelotas, Santos, Campos and Esp ŕito Santo Basins in Brazil, and the Namibia, Kwanza and Congo Basins in southwestern Africa.

@ Santos Basin - Wikipedia: https://en.wikipedia.org/wiki/Santos_Basin, accessed on 12 May 2025

6.4.3 East Venezuela Basin

The Eastern Venezuela Basin is major sedimentary basin in northeastern Venezuela that contains copious petroleum reserves. The basin lies between several geological structures. To the south it bounds Guiana Shield, to the north metamorphic rocks of the easternmost Andes, to the west the Espino Graben, to the northeast the Barbados accretionary complex and to the east it bounds to the oceanic crust of the Atlantic Ocean.

@ Eastern Venezuela Basin - Wikipedia: https://en.wikipedia.org/wiki/Eastern_Venezuela_Basin, accessed on 12 May 2025

6.5 Africa

Africa, the second largest continent (after Asia), covering about one-fifth of the total land surface of Earth. The continent is bounded on the west by the Atlantic Ocean, on the north by the Mediterranean Sea, on the east by the Red Sea and the Indian Ocean, and on the south by the mingling waters of the Atlantic and Indian oceans.

@ Africa - Britannica: https://www.britannica.com/place/Africa, accessed on 13 June 2025

6.5.1 Sirte Basin

The Sirte Basin is a late Mesozoic and Cenozoic triple junction continental rift (extensional basin) along northern Africa that was initiated during the late Jurassic Period. It borders a relatively

stable Paleozoic craton and cratonic sag basins along its southern margins. The province extends offshore into the Mediterranean Sea, with the northern boundary drawn at the 2,000 meter (m) bathymetric contour. It borders in the north on the Gulf of Sidra and extends south into northern Chad.
@ Sternbach, C.A., 2020. Super basin thinking: Methods to explore and revitalize the world's greatest petroleum basins. AAPG Bulletin 104 (12): 2463-2506.
@ Sirte Basin - Wikipedia: https://en.wikipedia.org/wiki/Sirte_Basin, accessed on 12 May 2025

6.5.2 Niger Delta Basin

The Niger Delta Basin, also referred to as the Niger Delta province, is an extensional rift basin located in the Niger Delta and the Gulf of Guinea on the passive continental margin near the western coast of Nigeria with suspected or proven access to Cameroon, Equatorial Guinea and São Tomé and Príncipe. This basin is very complex, and it carries high economic value as it contains a very productive petroleum system. The Niger delta basin is one of the largest subaerial basins in Africa. It has a subaerial area of about 75,000 km^2, a total area of 300,000 km^2, and a sediment fill of 500,000 km^3. The sediment fill has a depth between 9–12 km. It is composed of several different geologic formations that indicate how this basin could have formed, as well as the regional and large scale tectonics of the area. The Niger Delta Basin is an extensional basin surrounded by many other basins in the area that all formed from similar processes. The Niger Delta Basin lies in the south westernmost part of a larger tectonic structure, the Benue Trough. The other side of the basin is bounded by the Cameroon Volcanic Line and the transform passive continental margin.
@ Niger Delta Basin (geology) - Wikipedia:
https://en.wikipedia.org/wiki/Niger_Delta_Basin_(geology), accessed on 12 May 2025

6.5.3 Angola Basin

The Angola Basin is located along the West African South Atlantic Margin which extends from Cameroon to Angola. It is characterized as a passive margin that began spreading in the south and then continued upwards throughout the basin. This basin formed during the initial breakup of the supercontinent Pangaea during the early Cretaceous, creating the Atlantic Ocean and causing the formation of the Angola, Cape, and Argentine basins. It is often separated into two units: the Lower Congo Basin, which lies in the northern region and the Kwanza Basin which is in the southern part of the Angola margin. The Angola Basin is famous for its "Aptian Salt Basins," a thick layer of evaporites that has influenced topography of the basin since its deposition and acts as an important petroleum reservoir.
@ Angola Basin - Wikipedia: https://en.wikipedia.org/wiki/Angola_Basin, accessed on 12 May 2025

6.6 Europe

Europe, second smallest of the world's continents, composed of the westward-projecting peninsulas of Eurasia (the great landmass that it shares with Asia) and occupying nearly one-fifteenth of the world's total land area. It is bordered on the north by the Arctic Ocean, on the west by the Atlantic Ocean, and on the south (west to east) by the Mediterranean Sea, the Black Sea, the Kuma-Manych Depression, and the Caspian Sea. The continent's eastern boundary (north to south) runs along the Ural Mountains and then roughly southwest along the Emba (Zhem) River, terminating at the northern Caspian coast.

@ Europe - Britannica: https://www.britannica.com/place/Europe, accessed on 13 June 2025

6.6.1 North Sea Basin

The North Sea lies between Great Britain, Denmark, Norway, Germany, the Netherlands, Belgium, and France. A sea on the European continental shelf, it connects to the Atlantic Ocean through the English Channel in the south and the Norwegian Sea in the north. It is more than 970 kilometres (600 mi) long and 580 kilometres (360 mi) wide, covering 570,000 square kilometres (220,000 sq mi).
@ Sternbach, C.A., 2020. Super basin thinking: Methods to explore and revitalize the world's greatest petroleum basins. AAPG Bulletin 104 (12): 2463-2506.
@ North Sea - Wikipedia: https://en.wikipedia.org/wiki/North_Sea, accessed on 12 May 2025

6.6.2 Northwest Germanic-Poland Basin

The Germanic Basin (German: Germanisches Becken) is a large region of sedimentation in Western and Central Europe that, during the Permian and Triassic periods, extended from England in the west to the eastern border of Poland in the east. To the south it is bounded by the Vindelician Ridge (Vindelizische Schwelle) and, to the west and northwest, by the Armorican and London-Brabant Massifs. To the north the basin is bordered by the highlands of Ireland and Scotland, which were then still connected to the North American continent. To the east the basin was defined by the East European Platform, to the northeast by the Fennoscandian Shield (Scandinavia and Finland). The sedimentation began in the Rotliegendes with continental depositions. Later, during the Zechstein and Muschelkalk the region was largely flooded by the sea. Bunter sandstone and Keuper are again largely of continental origin. But even in these rocks the perimeter regions have marine influences, short incursions of the sea also reached the centre of the basin in northern Germany.
@ Germanic Basin - Wikipedia: https://en.wikipedia.org/wiki/Germanic_Basin, accessed on 12 May 2025
@ Sternbach, C.A., 2020. Super basin thinking: Methods to explore and revitalize the world's greatest petroleum basins. AAPG Bulletin 104 (12): 2463-2506.

6.7 Asia

Asia is the largest continent on Earth by area and number of people. It is mainly in the northern hemisphere. Asia is connected to Europe in the west and Africa on the south. Sometimes Asia and Europe are combined to form a larger continent called Eurasia.
@ Asia - Simple English Wikipedia, the free encyclopedia: https://simple.wikipedia.org/wiki/Asia6.7.1 Songliao Basin, accessed on 13 June 2025

6.7.1 Songliao Basin

The Songliao Basin is located in Northeastern China surrounded by the Greater Khingan, Lesser Khingan, and Changbai mountains. The Songliao basin originated between the late phase of Indonesian movement and the early stage of Yanshan movement. The development stage took place between mid-late Yanshan movement and early Himalayan movement. It is a sedimentary basin characterized with high surroundings and a low center. The low center is comprised of Cretaceous strata distributed under Cenozoic strata.
@ Songliao Basin - SEG Wiki: https://wiki.seg.org/wiki/Songliao_Basin, accessed on 13 June 2025

6.7.2 Bohai Bay Basin

The Bohai Bay Basin is defined as a geological region located east of the Craton in northern China, characterized by 14 depressions influenced by Pacific plate movement and crustal expansion, with significant hydrocarbon sources found in early dark shale and reservoirs in delta rivers and turbidite formations.

@ Bohai Bay Basin - an overview | ScienceDirect Topics: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/bohai-bay-basin, accessed on 15 August 2025

6.7.3 Central Sumatra Basin

The Central Sumatra Basin is one of three important oil- and gas-producing basins on Sumatra Island, Republic of Indonesia. Central Sumatra is the largest oil-enriched area in Indonesia, with approximately 849 exploration wells drilled in this area. Oil and gas in the Central Sumatra Basin are generally produced from shale rich in organic matter originating from lacustrine in the Pematang Group, a freshwater lake system that developed during the Paleogene period in a structurally controlled rift graben.

@ Applying random forest to oil and gas exploration in Central Sumatra basin Indonesia based on surface and subsurface data - ScienceDirect:
https://www.sciencedirect.com/science/article/pii/S2352938523001210, accessed on 13 June 2025

6.7.4 Malay Basin

The Malay Basin is located offshore West Malaysia in the South China Sea, within north central region of 1st order Sunda Block. The basin developed partly as a result of tectonic collisions and strike-slip shear of the Southeast Asia continental slabs, as the Indian Plate collided into Eurasia, and subsequent extrusion of lithospheric blocks towards Indochina.

@ Structural evolution of Malay Basin, its link to Sunda Block tectonics - ScienceDirect:
https://www.sciencedirect.com/science/article/pii/S0264817214001603, accessed on 13 June 2025

6.7.5 Gulf of Thailand Basin

The Gulf of Thailand Basin is a significant geological and hydrocarbon-rich region located in the western part of the South China Sea, encompassing the waters and coastal areas of Thailand, Cambodia, Vietnam, and Malaysia. This basin is characterized by its complex tectonic history, diverse sedimentary environments, and substantial petroleum resources.

@ GeoGPT: https://geogpt.zero2x.org/, accessed on 8 August 2025