Project 11029

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Updated definitions of concepts and terms

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This memo describe technical terms and concepts used in relation to CO_2 storage. This text is included in the Nordic CO_2 Storage Atlas availeble at :

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Updated definition of CO_2 storage concepts and terms

Introduction

Within the NORDICCS competence centre it is important that all project participants get a common understanding of the technical terms and concepts used in relation to CO_2 storage in order to harmonise the work. This paper reflexes how the NORDICCS storage working group comprehend the included CO_2 storage concepts and terms.

Preparation of the updated dictionary covering CO_2 storage concepts has been extended with several technical geological terms and will be published together with the Nordic CO_2 storage atlas. This will give the users of the atlas an opportunity to get a better understanding of the geological storage site descriptions.

Highlighted text means that the concept or term is defined in this paper.

CO_2 storage concepts and terms

Anticline
An anticline is a convex fold in rocks or sediments where the oldest layers are in the core of the fold (figure 6B), compare syncline.

Aquifer
An **aquifer** is an underground water-bearing **porous** and **permeable** layer often of sedimentary origin, such as sandstone or limestone (sedimentary rocks) or gravel or sand (sediments). **Volcanic rocks** or crystalline rocks with fractures may also form aquifers. See also **saline aquifer**. The aquifer can be either open or closed to some degree in terms of confining **faults** or **stratigraphy** (figure 1).

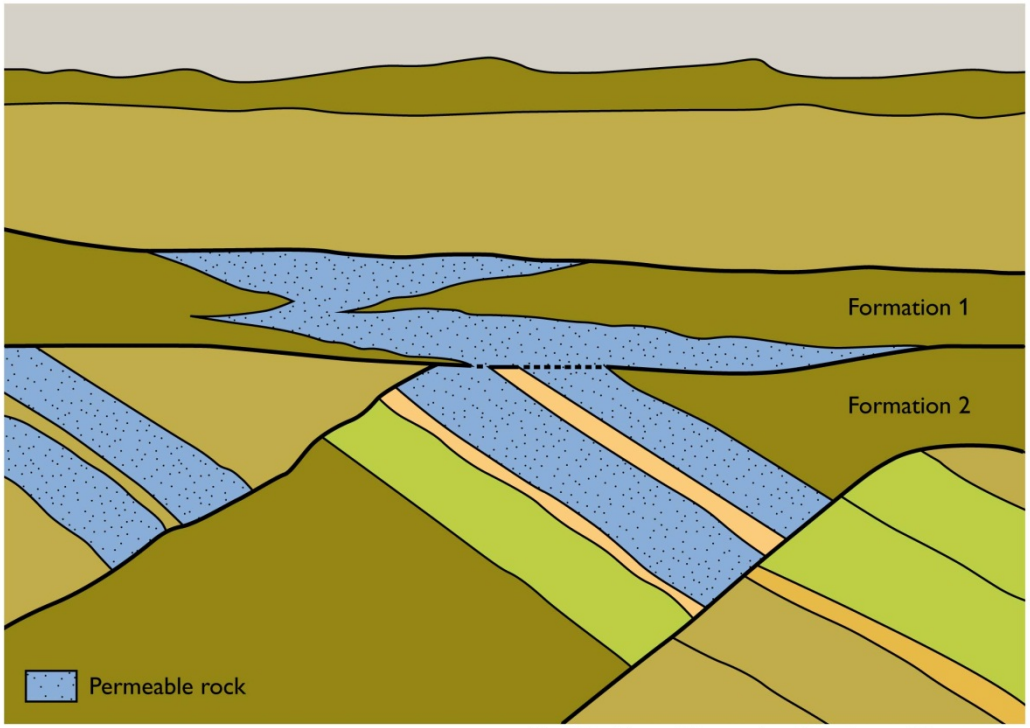

Figure 1. Example of an aquifer, which in this case consists of porous layers from two formations with connectivity.

Bentonitic
A bentonitic rock is rich in absorbent bentonite clay minerals, such as smectites, which have good properties for sealing, due to swelling properties.

Caprock
See **Seal.**

Carbonates
Carbonates are rocks (limestone) or minerals containing carbonic acid (CO_3) together with a base. For example calcium (Ca), forming calcium carbonate, $CaCO_3$. Most carbonate rocks form from biogenic processes.

CO_2 plume
The dispersing volume of CO_2 in the geological **formation**.
Definition from the EU CCS Directive, 2009.

CO_2 storage maturity
Maturity in connection with CO_2 storage is used as an informal term to indicate how close a potential site is to utilisation. This is a combination of certainty in storage capacity, site integrity and safety aspects, which all depend on the available knowledge.

CO_2 stream
A flow of substances that results from CO_2 capture processes.
Definition from the EU CCS Directive, 2009.

CO_2 trapping
When CO_2 is injected into a **reservoir** rock various trapping mechanismes can take place (figure 2 and 3).

1. **Structural and stratigraphic trapping** (see **Trap**, figure 6) occurs when the buoyant CO_2 is prevented from moving to the surface, because the CO_2 is caught below low permeable rock layers.
2. **Residual trapping,** is a physical trapping of CO_2 within the pore space of the rock due to capillary forces.
3. **Solubility trapping** describes CO_2 dissolved into the **formation fluids**.
4. **Mineral trapping** occurs where CO_2 reacts with the **reservoir** rock and/or formation fluids to form **carbonate minerals**.

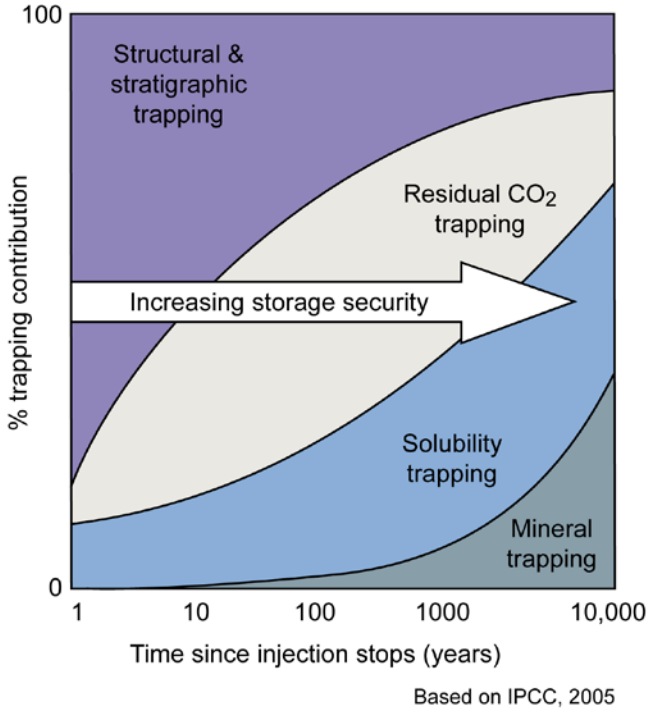

Figure 2. A possible relationship between different trapping mechanisms and time. The relative importance of the different trapping mechanisms can change depending on type of aquifer (closure, open dipping, homogenous/heterogeneous etc.).

Depression
In geological terms, a depression is a sunken landform with a lower position than surrounding areas.

Diagenesis
Diagenesis is the sum of changes in a sediment after deposition. Porosity is reduced due to compaction (weight of overlying sediments), dissolution of instable minerals and precipitation of new, stable minerals in the pore spaces. The transition from sand to sandstone involves diagenetic processes.

Exploration
The assessment of potential storage complexes for the purposes of geologically storing CO_2 by means of activities intruding into the subsurface, such as drilling and **seismic surveys**, to obtain geological information about **strata** in the potential storage complex and, as appropriate, carrying out injection tests in order to characterise the storage site.
Definition from the EU CCS Directive, 2009.

Facies
A facies is the sum of features characterising a specific rock. Sedimentary facies reflect specific depositional processes in a certain environment. Facies are also defined for metamorphic and volcanic rocks.

Fault
A fault is a fracture, or fracture zone, in a body of rock along which block-movement and displacement has taken place (figure 6A and C). Faults may subdivide a reservoir.

Fault confined
A body of rock confined by faults resulting in a complete or partly isolated rock unit (figure 6C).

Formation
A **formation,** or geological formation, is the fundamental unit of lithostratigraphy. A formation consists of a number of rock layers with a distinct **lithology** or **facies** sequence and must be mappable within a region. Formations can vary in thickness from a few meters to several thousand meters. Formations can form part of a group, or may be subdivided into members.

Formation fluids
The naturally occurring fluids in a subsurface rock. These will in most cases be saline water (also termed pore water or brine, Fig. 3), but the term also covers the occurrence of oil and gas.

Geological setting
A geological setting is a physical and environmental frame for deposition.

Geological storage of CO_2
Injection accompanied by storage of CO_2 streams in underground geological formations (figure 3).
Definition from the EU CCS Directive, 2009.

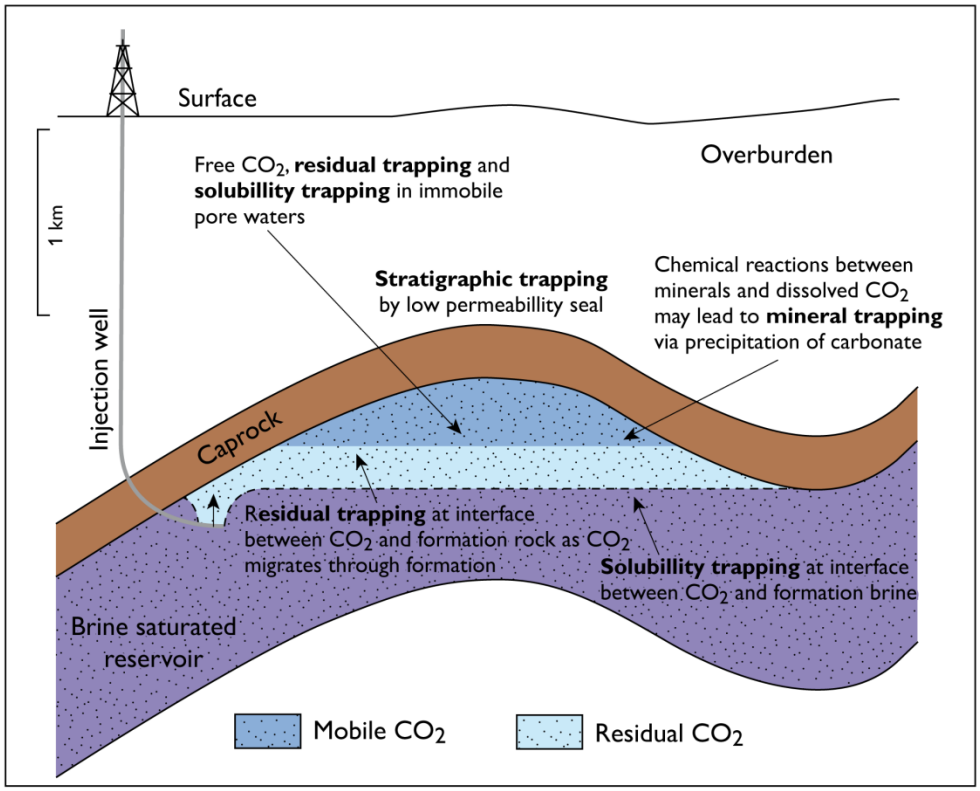

Figure 3. Overview of a conceptual storage site and different trapping mechanisms. The buoyant CO_2 will move towards lower pressure (the surface).

Geological structure

A geological structure, is a physical subsurface feature that has been defined geologically or geophysically, and contains physically trapped fluids. Examples include **anticlines**, fault blocks and **stratigraphic traps** (figure 10).
Definition from the EU CCS Guidance Document, 2009.

Geological time scale

Please see website for the International Commission on Stratigraphy. The time scale is revised following decisions by the Commission.
http://www.stratigraphy.org/index.php/ics-chart-timescale

Geothermal gradient

The heat gradient measured from the surface and downwards through the subsurface. Average value is 25-30 ˚C per km, but can be higher in volcanic areas.

Graben/Halfgraben

A graben is a structural term describing a downthrown block bounded by two parallel faults.
A halfgraben has an asymmetric subsidence, and the strata dip toward the longest of the bounding faults.

Heterogeneous rock sequence

A heterogeneous rock succession consisting of alternating layers of rocks with different composition and/or grain size. Depending on the scale (cm to tens of metres) and mode of formation (depositional environment for sedimentary rocks) the heterogeneous succession may belong to one **facies** or one **formation**.

Homogeneous rock sequence
A homogeneous rock sequence has only minor differences in composition and/or grain size throughout the sequence.

Hydraulic connection
Connected pore spaces, which allow flow of fluids (see also permeability).

Hydraulic unit
A hydraulically connected pore space where pressure communication can be measured by technical means and which is bordered by flow barriers, such as faults, salt domes, lithological boundaries, or by the wedging out or outcropping of the formation.
Definition from the EU CCS Directive, 2009.

Injectivity
A measure of the CO_2 injection rate into a reservoir and thus how fast the CO_2 migrates away from the well. It is defined as the product of the reservoir permeability and thickness, unites in Darcy metre (Dm). (See also **well injectivity index**)

Lithology
Lithology is the physical characteristic of a rock, i.e. mineral composition, grain size, structure, texture, colour etc.

Lithostatic pressure
The pressure due to the weight of the entire overburden (fluid plus matrix). The lithostatic pressure gradient is 22-26 MPa (220-260 bars) per km.

Leakage
Any release of CO_2 from the **storage complex**.
Definition from the EU CCS Directive, 2009.

Migration
The movement of CO_2 within the **storage complex**.
Definition from the EU CCS Directive, 2009.

Net/Gross ratio (N/G)
Is an estimate of the storage capacity of a formation, i.e. the volume of reservoir rock suitable for CO_2 storage relative to the bulk volume of the **storage formation**. The ratio is found by analysing well log curves and apply cut-off values separating the **reservoir** part (net) from the bulk volume (gross).

Platform
A platform is a coherent area covered with relatively flat sedimentary strata directly overlying the crystalline basement.

Porosity
Porosity is a measure of how much of a rock is open space (filled by air or formation fluids). This space can be between grains or within cracks or cavities of the rock. Values are given as a percentage or fraction.

Permeability
Permeability is a measure of the ability of a fluid to flow through a porous rock. Measured in milli-Darcy (mD) or Darcy (D).

Reservoir
A reservoir is a large subsurface porous layer containing fluid or gas, in many cases this will be porous sandstone or limestone.

Saline Aquifer
An **aquifer** where the salinity of the formation water is above 3% making it unsuitable as potable water.

Seal (Caprock)
A seal is a layer with low **permeability,** which prevents the fluid or gas from migrating towards the surface. This is often called the caprock, and is often a claystone.

Sedimentary basin
A sedimentary basin is an area at the earth's surface, which accumulated and preserved **sediments** due to a higher subsidence. A sedimentary basin has definable margins and the scale of basins varies greatly (from tens to thousands of km).

Sediment
Sediments are divided into clastic -, biogenic, and chemical sediments. Clastic sediments consist of particles formed by weathering and erosion of older rock material. The particles are subsequently transported by wind, water or ice to be deposited and form sediments (such as sand) or sedimentary rock (sandstone). In biogenic sediments the particles form by biological processes, fragments of shells, tests, and plant remains. Limestone is the most important group of biogenic sediments. Chemical sediments, such as evaporites, form by chemical processes. Classification of sedimentary rocks can be based on mineralogy and grain size.

Clay	Silt	Fine sand	Medium sand	Coarse sand	Gravel
< 0.002 mm	0.06─0.002 mm	0.2─0.06 mm	0.6─0.2 mm	2.0─0.6 mm	> 2 mm

Seismic survey
A seismic survey is a method of investigating the geometry of subsurface layers by the use of acoustic signals.

Spill point
In relation to traps a spill point is the location were the **trap** content will leak from, when the **trap** is filled up.

Storage capacity
The available pore volume for CO_2 storage in a storage **formation**, **storage unit** or **trap**.

Storage capacity calculation – static
Static CO_2 storage capacity assessments can be evaluated on different levels from basin scale and down to a single trap. Several CO_2 storage projects have attempted to assess the geological storage potential and no standard methodology exist yet, but most projects agree on calculations based on volume of the storage formation, storage unit or trap, porosity, volume of the CO_2 at reservoir conditions and a **storage efficiency factor**. The current status for harmonisation and recommendations of CO_2 storage

assessments are summarised in the International Energy Agency workshop report from 2013 "Methods to assess geological CO_2 storage capacity: status and best practice".
http://www.iea.org/publications/freepublications/publication/workshop_report_methodstoassessgeologicCO2storagecapacity.pdf

The CO_2 storage capacity calculations in the Nordic CO_2 Storage Atlas follow the EU GeoCapacity methodology (Vangkilde-Pedersen 2009). The calculation methodology is valid for sedimentary storage aquifers, storage units and traps.

Theoretical CO_2 storage capacity:

$$TH\_MCO2 = V \times N/G \times \phi \times \rho CO2r$$

TH_MCO2	theoretical storage capacity
V	volume of trap or regional aquifer
N/G	average net/gross ratio
ϕ	average reservoir porosity
ρCO2r	CO2 density at reservoir conditions

Effective CO_2 storage capacity:

$$EFF\_MCO2 = V \times N/G \times \phi \times \rho CO2r \times S_{eff}$$

EFF_MCO2	effective storage capacity
V	volume of trap or regional aquifer
N/G	average net/gross ratio
ϕ	average reservoir porosity
ρCO2r	CO2 density at reservoir conditions
S_{eff}	storage efficiency

For the Danish and Swedish storage sites S_{eff} is based on GeoCapacity "Rule-of-thumb" approach (Figure 4).

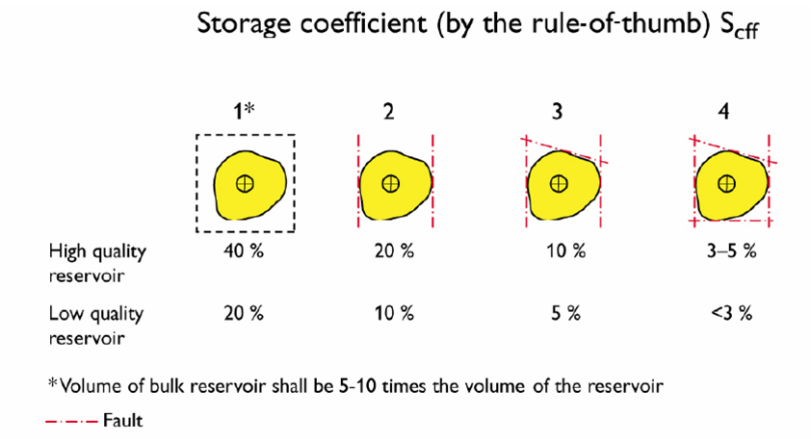

Figure 4. Illustration of the "Rule-of-thumb" used in EU GeoCapacity (Vangkilde-Pedersen 2009).

The Norwegian S_{eff} values are taken from "CO_2 Storage Atlas – Norwegian Continental Shelf" by the Norwegian Petroleum directorate, 2014 (Halland et al. 2014).

Storage capacity calculation – dynamic
Dynamic capacity calculations are based on **reservoir** simulations of CO_2 injection.

Storage efficiency factor
Is the fraction of the accessible pore volume that can be occupied by CO_2.

Storage site
A defined volume within a geological **formation** used for the geological storage of CO_2 and associated surface and injection facilities.
Definition from the EU CCS Directive, 2009.

Storage unit
A part of a formation where CO_2 can be stored (the porous and permeable parts). A **formation** can have several storage units and a storage unit can have several traps. Storage units are without **hydraulic connection** and can be separated by **faults**, **facies** variations, **diagenesis** etc. See also **hydraulic unit**. The term is also used for a defined national part of a storage aquifer e.g. for Sweden.

Strata
Strata are the latin word for layers. The layers within a sedimentary succession are distinguished from other layers by specific characteristics.

Stratigraphic trap
A stratigraphic trap is formed as a result of lateral and vertical variations in the porosity/permeability of the reservoir rock with respect to the surrounding bedrocks. See **Trap** and figure 6.

Stratigraphy
In geology, stratigraphy is the study of rock layers (**strata**) and their mutual relationships with respect to age, fossil content, lithology and depositional environment. Subfields in stratigraphy are lithostratigraphy, based on **lithology**, and biostratigraphy, based on flora and fauna, chronostratigraphy and sequence stratigraphy.

Structural trap
A structural trap is formed as a result of deformation of the rock layers. See **Traps** and figure 6.

Super critical CO_2
CO_2 becomes supercritical at a pressure around 73 bar and a temperature of approximatly 31 ˚C where the volume of CO_2 will have decreased to about 0.3% of the volume at surface temperature and pressure conditions. Depending on the **geothermal gradient** and **lithostatic pressure** these temperature and pressure conditions are present at about 800 meter depth. In supercritical state CO_2 will be a fluid behaving like a gas (figure 5).

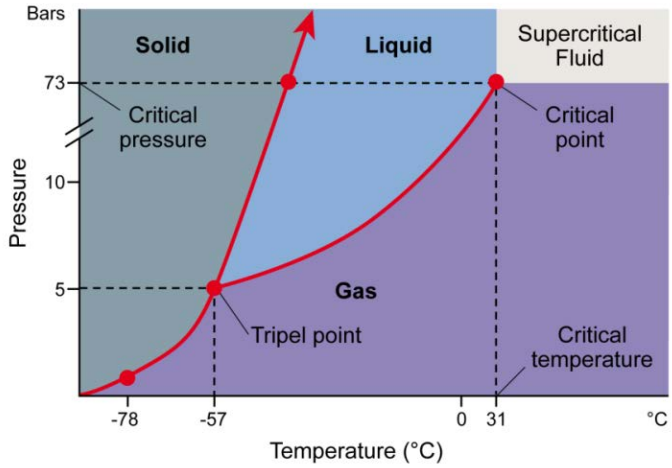

Figure 5. Phase diagram for CO_2.

Syneclise

A syneclise is a large depression formed by slow and steady subsidence on a continental **platform**.

Trap

A trap is a geometric arrangement of rocks that permits significant accumulation of fluid or gas in the subsurface. A trap includes a reservoir rock and a **seal** that impede or prevent migration out of the **reservoir**. Traps are divided into **structural traps** and **stratigraphic traps** or a combination of both (figure 6).

Volcanic rocks

Volcanic rocks are formed in a magma chamber underground and erupted to the surface from a volcano. Usually volcanic rocks are very fine-grained crystalline or glassy igneous rock resulting from volcanic action at or near the Earth's surface either ejected explosively or extruded as lava (e.g. basalt).

Well injectivity index

Well injectivity index is defined as the injection rate divided by pressure drop from the well into the reservoir, i.e. $II = q/(Pw-Pr) = (2\pi kh)/(\mu B(\ln(re/rw))$.

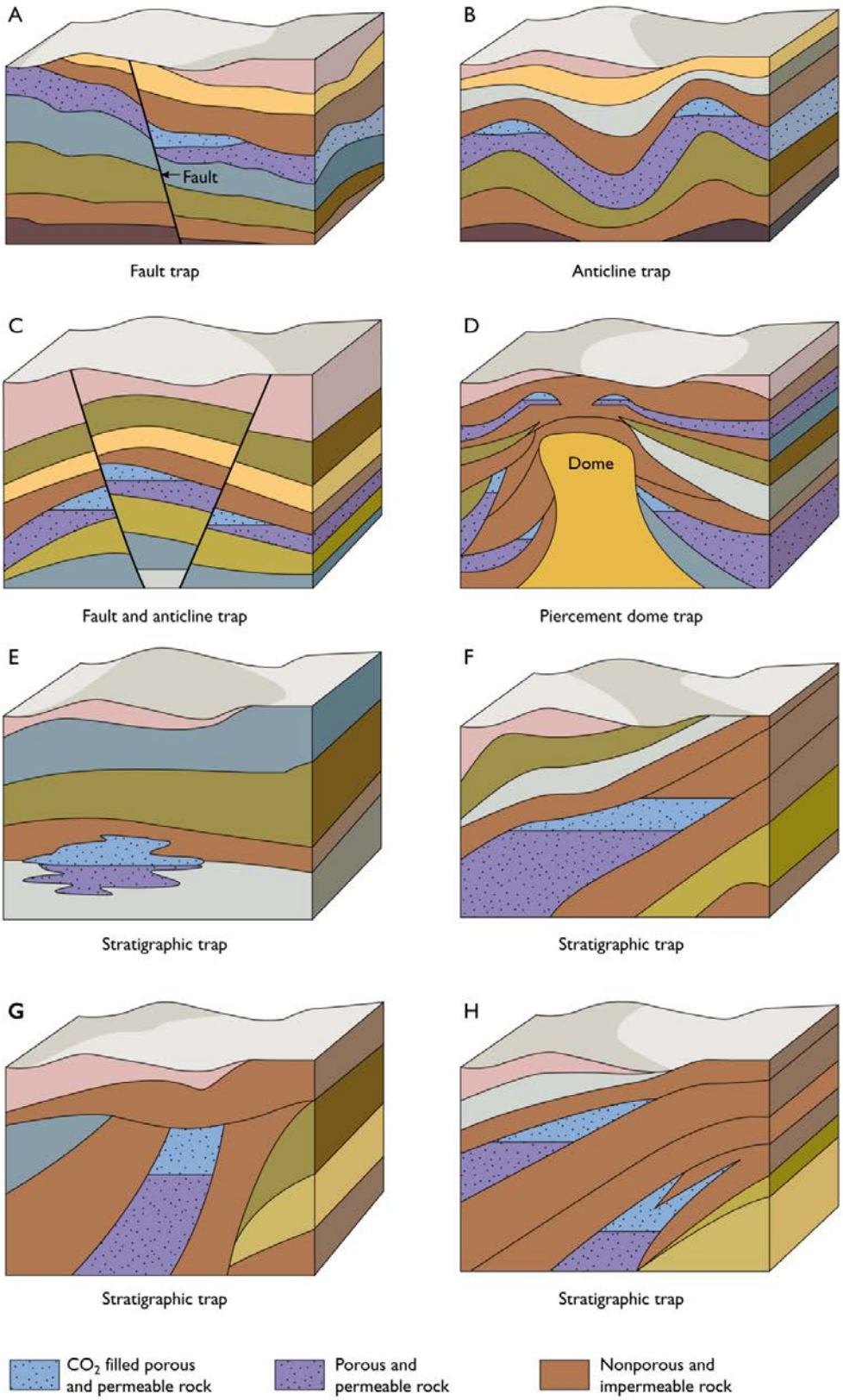

Figure 6. Illustrating structural (A – D) and stratigraphic traps (E – H).

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