Environmental Geology Lab 10 – Fossil Fuel Resources

Fossil fuels are naturally occurring, organically derived fuel materials (i.e., they can be burned for fuel) that were produced by geologic processes in the geologic past. The three most important kinds of fossil fuels are crude oil, natural gas, and coal. The less well known unconventional fossil fuels, which are generally not cost competitive in the present market but are likely to be important in future because of large resource base, include oil shale and tar sands. Oil shales are fine-grained rocks which contain significant amounts of an insoluble hydrocarbon called kerogen, which can be converted to liquid oil by combustion at 500^{o}C or higher temperature. Tar sands contain viscous to semisolid hydrocarbon material called bitumen, which can be liquefied to oil by heating. Although, the various fossil fuels differ in appearance and chemical composition, have different energy contents per unit weight, and are processed differently for utilization, they all are composed of hydrocarbon compounds (compounds of hydrogen and carbon) and owe their origin to bacterial decay and “cooking” of organic debris from dead terrestrial (land) plants (for coal) and marine organisms (for oil and natural gas) at elevated temperatures and pressures after they were buried in sediments by younger sediments.

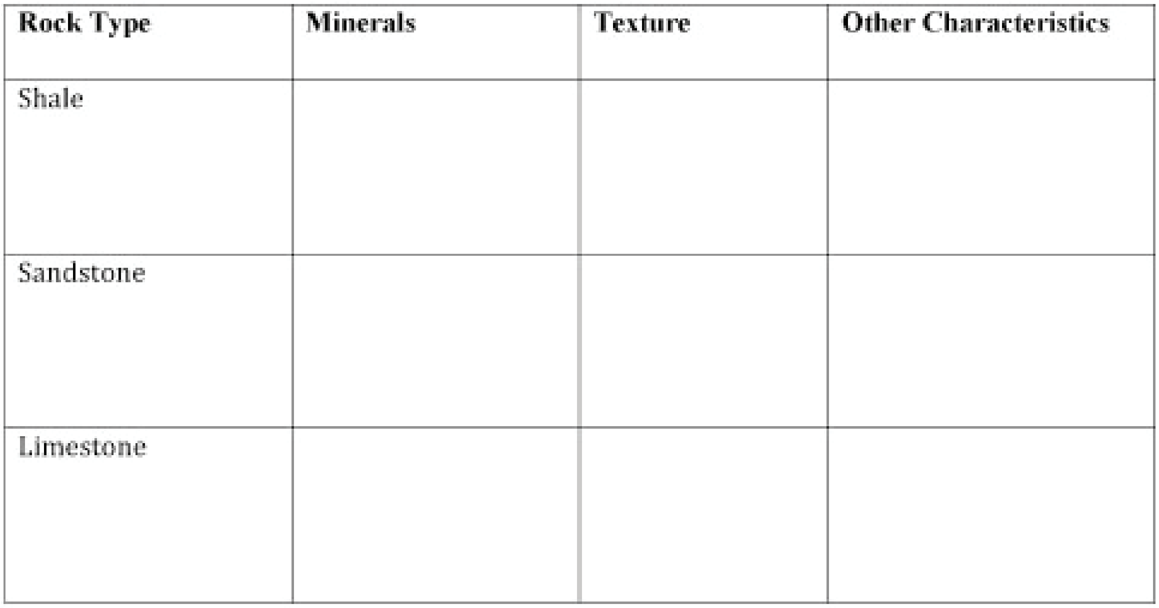
Sedimentary rocks are the only rock type associated with fossil fuels. Sediments can be divided based on whether they consist of weathered pieces of preexisting rocks (**detrital** sediment: gravel, sand, silt, and clay) or the hard parts of preexisting animal or plant life (**nondetrital** sediment; limestone or coal). A series of chemical and physical processes collectively known as weathering will begin to slowly break these rocks down into their constituent minerals. All silicate minerals, except for quartz, will eventually break down into a very fined-grained material known as clay. Clays that are deposited along floodplains or swamps or lagoons by rivers may dry up and harden over time to produce a detrital sedimentary rock called a **shale**.

Sand that is deposited by rivers in their channels, at deltas or along beeches may also be converted into a sedimentary rock. Most sand is made up of quartz, but is not pure. Along with the sand are loose chemical ions that formed as unstable silicate minerals are converted to clay by various weathering processes. If this mixture of sand and loose ions is deposited at a place where they can accumulate, groundwater may eventually percolate through pore spaces in the material and selectively dissolve and reprecipitate the loose ions that are mixed with the quartz sand. This will fill the pores in between the sand grains with minerals they can act as a natural cementing agent, thus binding the quartz sand grains into a detrital sedimentary rock called a **sandstone**.

Nondetrital sediment consists of parts of preexisting animal or plant life. The largest concentration of animal life on our planet lives just offshore in the shallow water of the earth’s oceans. Here, animals such as clams, snails, oysters. etc., extract chemicals (mostly the mineral calcite) from sea water to build their hard shells. These shells are washed up onto beaches in vast quantities and, over time, may be compacted and cemented together to form a sedimentary rock called a **limestone**. Swamps, lagoons and river deltas are environments that can support vast amounts of plant life. In these quiet, often stagnant areas plants live, die and accumulate in vast quantities. Over geologic time this accumulated plant material may become slowly compacted and converted into a soft, black material called carbon. A sedimentary rock that consists of the ‘carbonized’ remains of ancient plants is called **coal**.

PETROLEUM SECTION
QUESTIONS:

1. Examine the three sedimentary rock samples and provide a description of each rock. Examine page 1 carefully for clues in terms of how to fill out the table below. For texture indicate if the rock is detrital or non-detrital.



Rock Type	**Minerals**	**Texture**	**Other Characteristics**
Shale			
Sandstone			
Limestone			

2. Describe the ancient depositional environment that can potentially produce coal. Again read the bottom paragraph on pg. 1 carefully.

3. Would you look for crude oil or fossil fuel deposits in igneous volcanic rocks? Fully justify your answer. Hint: Are volcanic rocks mentioned on pg. 1 associated with petroleum formation.

4. Describe some potential unconventionals types of fossil fuels that are not economic today (they can not be considered reserves) but may become so in the future.

Fossil fuels consist of mainly a type of compound referred to as hydrocarbons. Hydrocarbons are molecules that consist of hydrogen and carbon atoms. Hydrocarbons are classified based on the number of carbon atoms in a molecule (Figure 1). Simple hydrocarbons have few carbon atoms and tend to exist in a gaseous state. Complex hydrocarbons can form long chains with tens of carbon atoms and tend to exist in a liquid or even a semi-solid state (i.e. tar). Natural gas consists of over 99% methane (CH_4) gas, which is the simplest hydrocabon molecule (Figure 1). The remanding 1% is comprised of other hydrocarbon gases and impurities such as carbon dioxide and hydrogen sulfide).

Crude oil is composed essentially of a mixture of hydrocarbon compounds of different molecular weights and number of carbon atoms. The conversion of marine organic matter to crude oil, referred to as maturation, takes place at temperatures between 50° and 200°C with optimum conversion between 100° and 120°C commonly referred to as the “oil window,” corresponding to burial depths of 2,000-3,000 meters (Figure 2). The temperature increases an average of 27 °C / km within the crust, which is referred to as the geothermal gradient. At greater depths of burial (i.e., at higher temperatures of up to 200°C), the remaining hydrocarbon is almost wholly methane (natural gas). Thus the oil:gas ratio in an oil field is largely a function of the burial depth of the precursor organic matter At great depths the temperature (> is 200°C) too high for hydrocarbon compounds to survive.

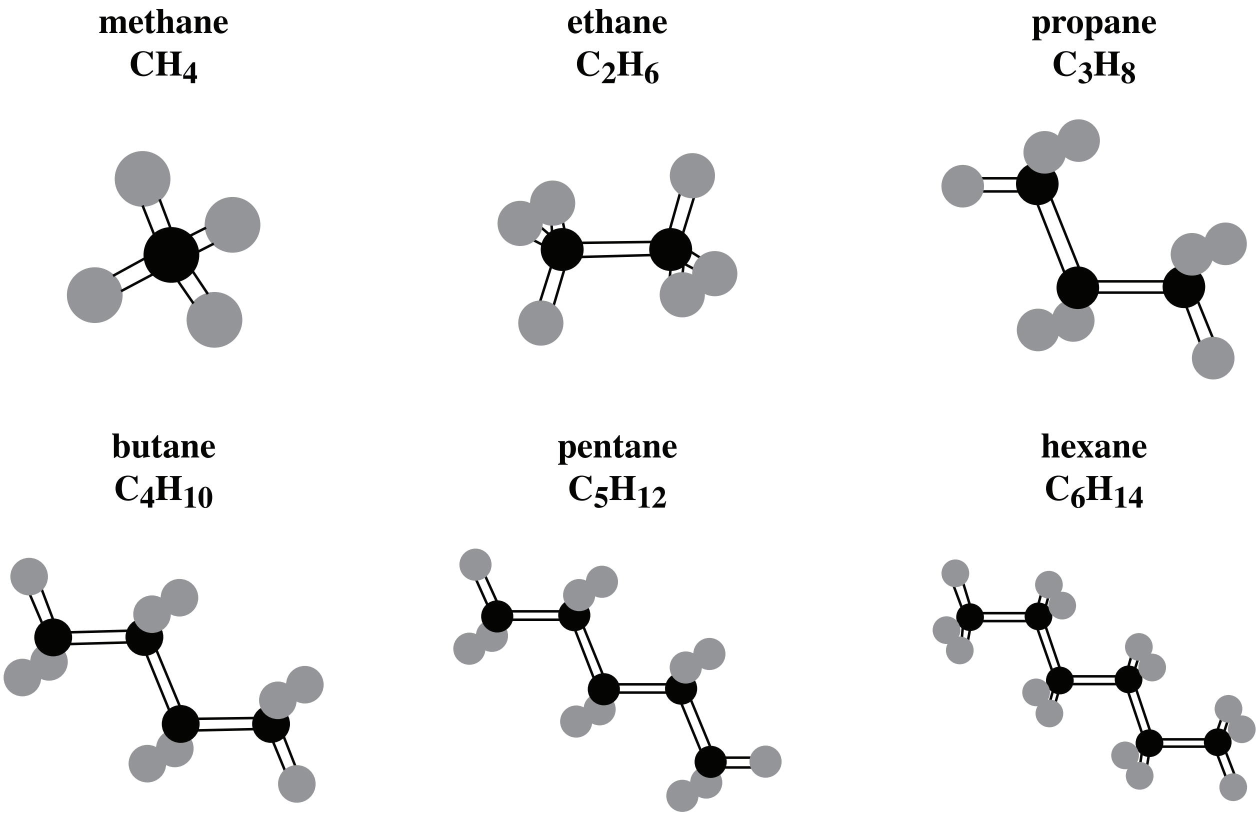


Figure 1. Representative hydrocarbon molecules present in fossil fuels (black circles are carbon atoms and gray circles are hydrogen atoms).

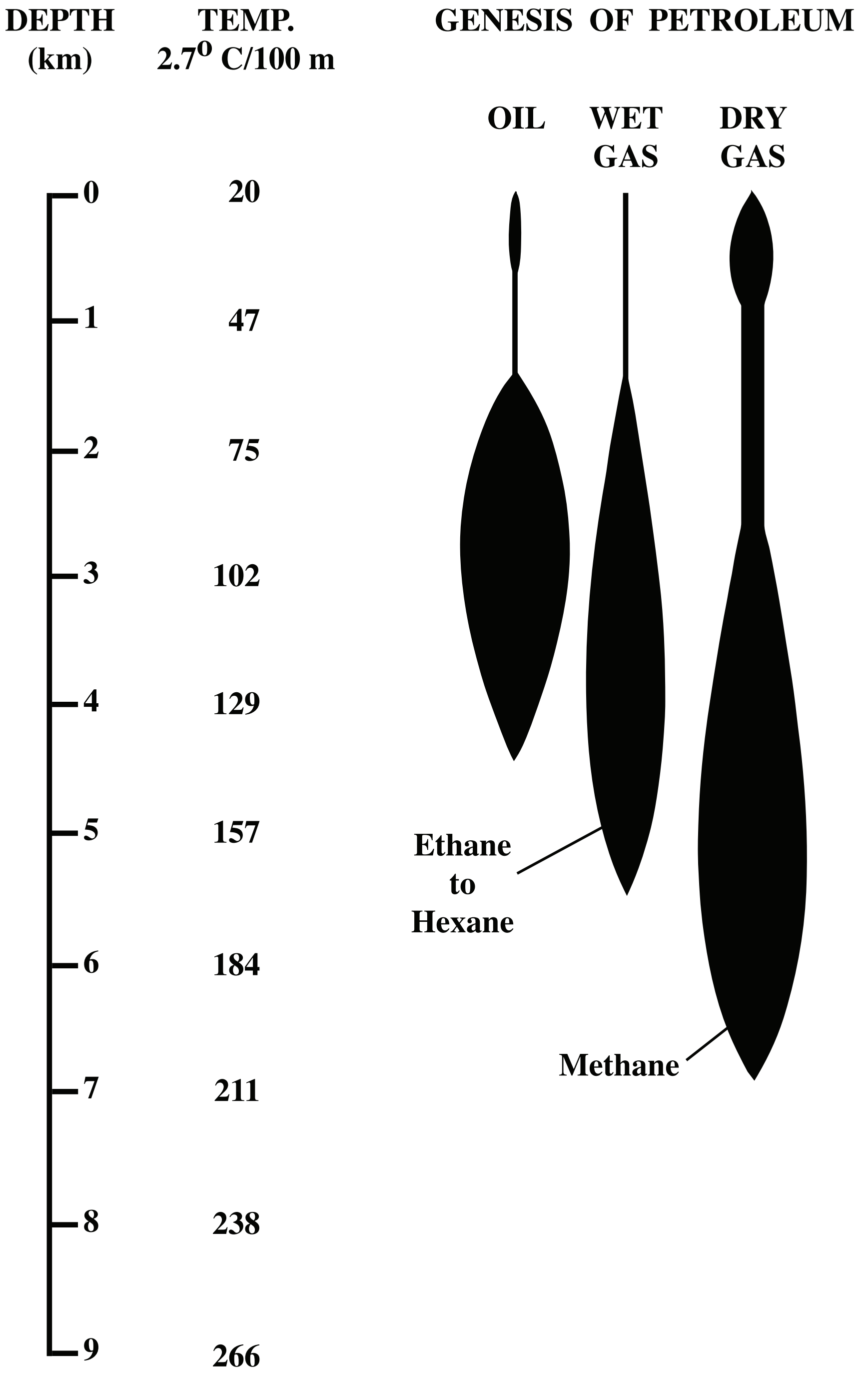


Figure 2. Products of organic maturation and their distribution with respect to buurial depth and temperature.

The initial amounts of organic matter in nearly all sediments are too low and dispersed to form commercial quantities of oil or gas in the source rocks. Significant deposits occur only when migration of the oil and gas leads to accumulation in a smaller volume of reservoir rock (commonly porous sandstones or limestones) and further migration is prevented by a structural (e.g.,a fold or a fault) or stratigraphic (e.g., an impermeable bed made of shale or rock salt referred to as a trap rock) trap (Figures 3 to 5). Reservoir rocks typically have significant porosity and permeability that can be filled with hydrocarbons. Within a petroleum reservoir there is a predictable stratification of materials filling available porosity based on the density of the geofluids present in the reservoir (Figure 3). Natural gas will be present at the top of the reservoir, crude oil, if present, will be in the middle of the reservoir, with water at the bottom of the reservoir.

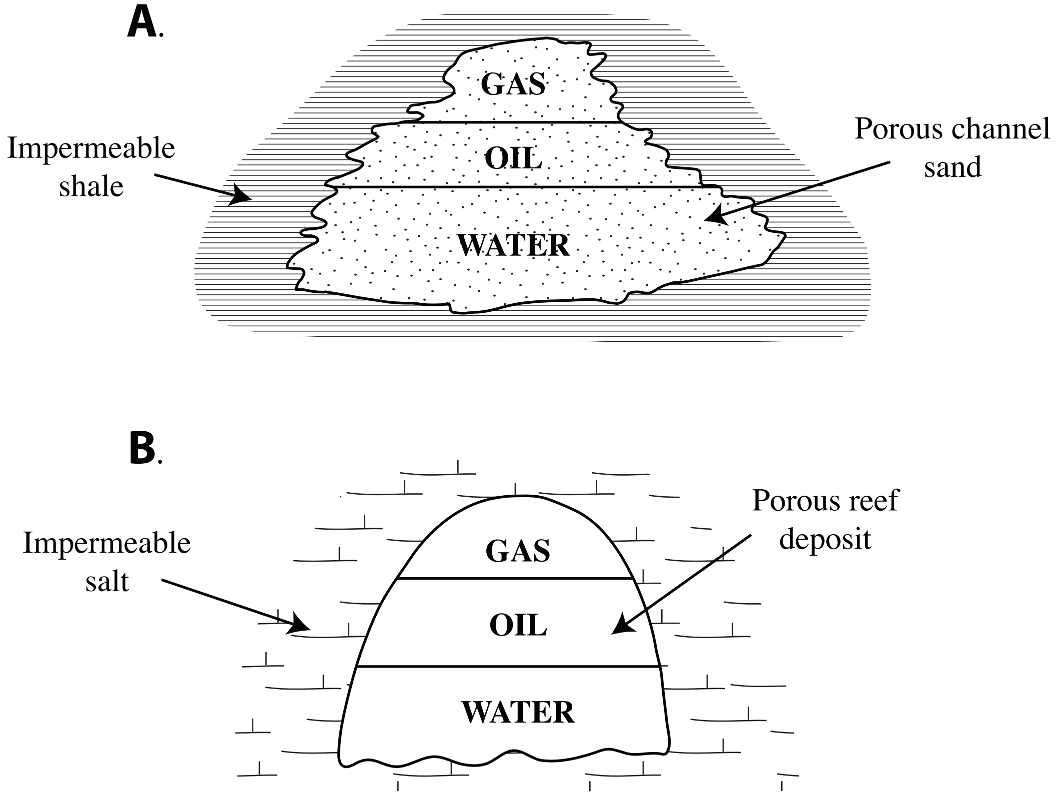


Figure 3. Stratigraphic petroleum traps. (a) Impermeable shale. (b) Impermeable salt.

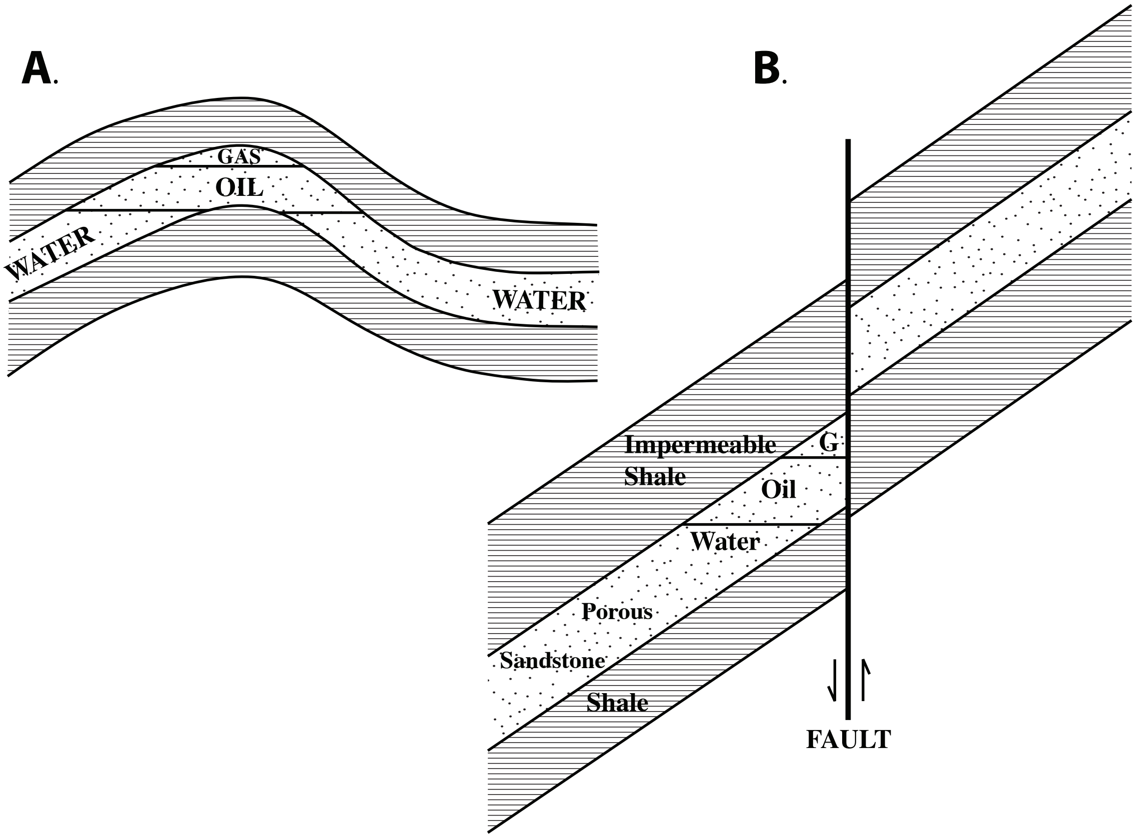


Figure 4. Structural petroleum traps. (a)Anticline fold. (b) Fault.

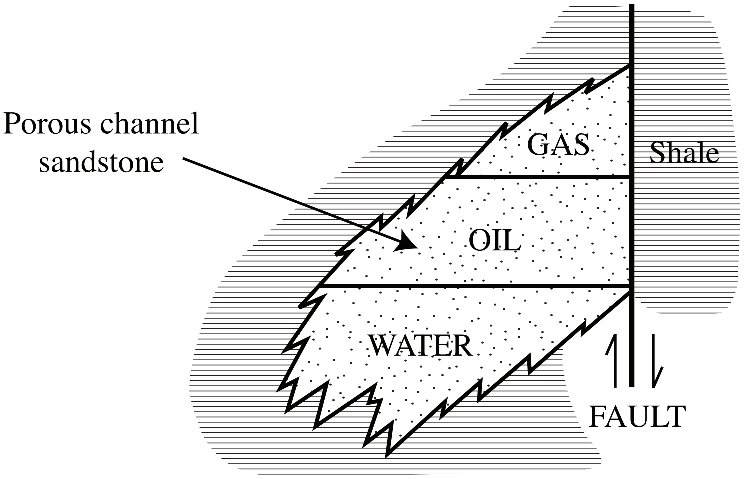


Figure 5. Combination traps with the features of both a stratigraphic and structural traps.

QUESTIONS:

5. Based on the above description comment on what role these rocks play in the formation of oil or gas. Check off the box when appropriate. A rock can be checked more than once.

Rock Type	Source Rock	Reservoir Rock	Trap Rock
Shale			
Sandstone			
Limestone			

6. Describe a situation when a reservoir is filled with only natural gas and water but there is no crude oil.

7. Under average circumstances would it make sense to look for crude oil at a depth of 10 km below the surface. Explain in detail. Hint: think about the geothermal gradient and the location where natural gas and oil normally form.

8. Within a reservoir why is the crude oil separated from the natural gas.

9. Describe the relationship between the complexity of hydrocarbon atoms in petroleum and the state of matter (gas versus liquid) in which the petroleum exists.

10. In Figure 6 well-temperature versus depth is plotted for the Pan-Am/Gilbert well near Port Arthur, Texas. Calculate the geothermal gradient (^{o}C / km). Addtionally, sketch in the depths most likely to produce crude oil and natural gas as horizontal zones on Figure 6. Refer to Figure 3.

Measure Temperature at 0 km _______

1 km _______

Geothermal gradient = (Temperature at 1 km) - (Temperature at 0 km) = _______ °C / km

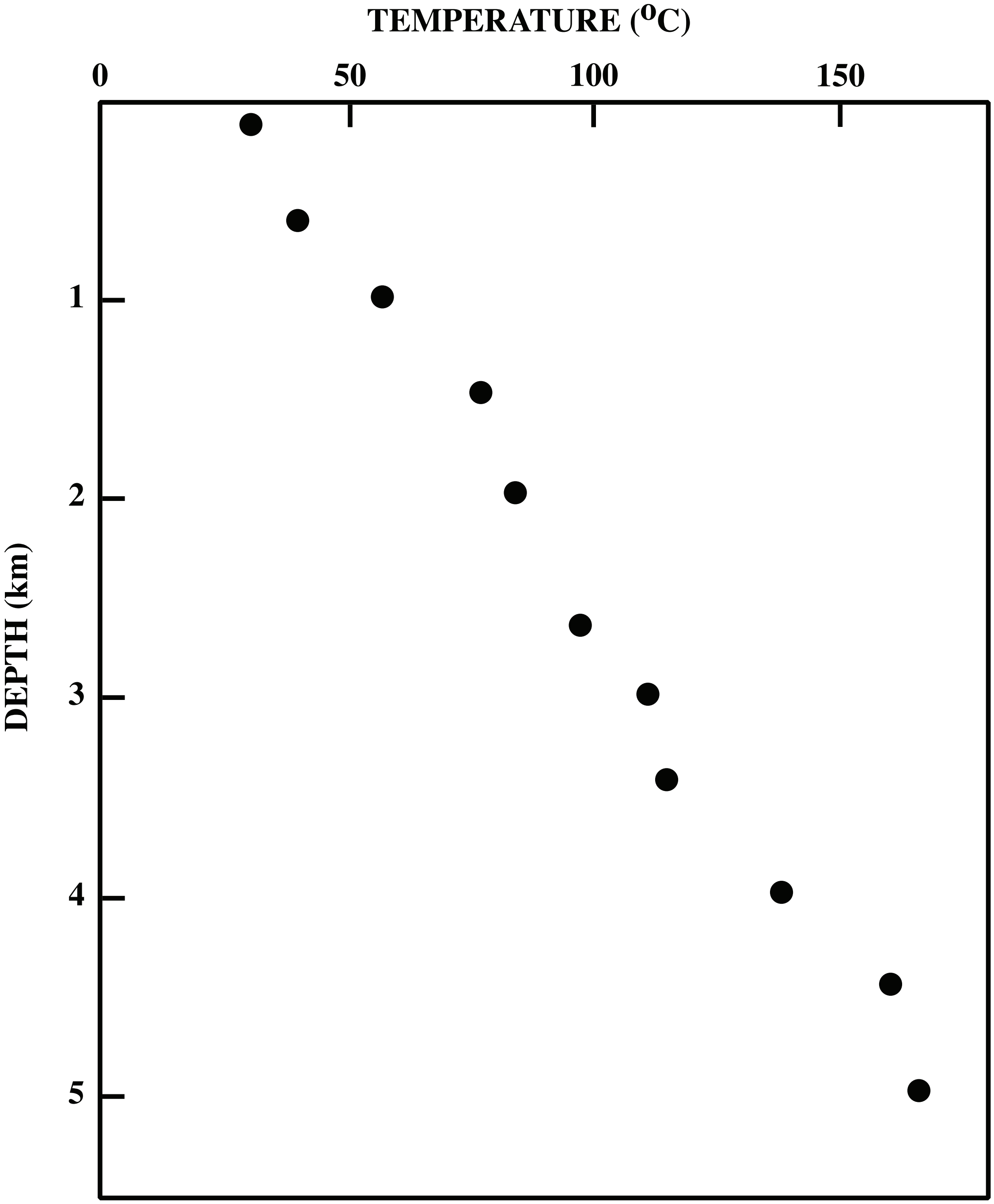


Figure 6. Temperature versus depth for the Pan-Am/Gilbert well.

11. Classify each of the following traps in Figure 7.

A. ______________________________________

B. ______________________________________

C. ______________________________________

D. ______________________________________

E. ______________________________________

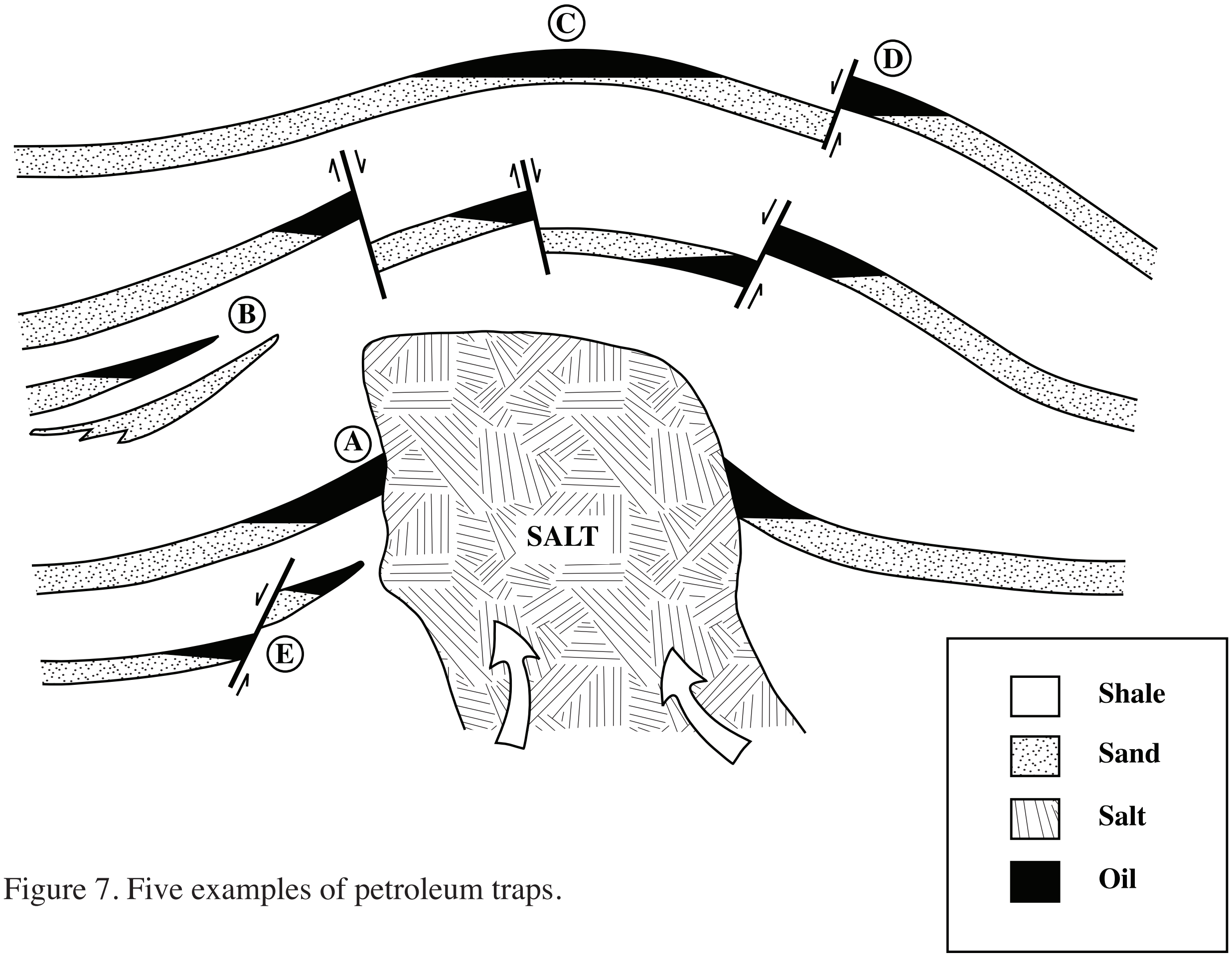


Figure 7. Five examples of petroleum traps.

Petroluem Recovery

The recovery of oil or natural gas from a well can be classified into three caterogies.

Primary Recovery

During the primary recovery stage, reservoir drive comes from a number of natural mechanisms. These include: natural water displacing oil downward into the well, expansion of the natural gas at the top of the reservoir, expansion of gas initially dissolved in the crude oil, and gravity drainage resulting from the movement of oil within the reservoir from the upper to the lower parts where the wells are located. Recovery factor during the primary recovery stage is typically 5-15%.

Secondary Recovery

Over the lifetime of the well the pressure will fall, and at some point there will be insufficient underground pressure to force the oil to the surface. After natural reservoir drive diminishes, secondary recovery methods are applied. They rely on the supply of external energy into the reservoir in the form of injecting fluids to increase reservoir pressure, hence replacing or increasing the natural reservoir drive with an artificial drive. Secondary recovery techniques increase the reservoir's pressure by water injection, natural gas reinjection and gas lift, which injects air, carbon dioxide or some other gas into the bottom of an active well, reducing the overall density of fluid in the wellbore. Typical recovery factor from water-flood operations is about 30%, depending on the properties of oil and the characteristics of the reservoir rock.

Enhanced Recovery

Thermally enhanced oil recovery methods heat the oil, mainly from stream injection, thus reducing its viscosity and making it easier to extract. Other enhanced recovery methods use surfactants (detergents) are injected to alter the surface tension between the water and oil in the reservoir, mobilizing oil which would otherwise remain in the reservoir as residual oil. Another method to reduce viscosity is carbon dioxide flooding.

A finally recovery method involves hydraulic fracturing (also hydrofracturing or fracking). Some hydraulic fractures form naturally—certain veins or dikes are examples. A high-pressure fluid (usually chemicals and sand suspended in water) is injected into a wellbore to create cracks in the deep-rock formations through which natural gas, petroleum, and brine will flow more freely. When the hydraulic pressure is removed from the well, small grains of hydraulic fracturing proppants (either sand or aluminium oxide) hold the fractures open once the deep rock achieves geologic equilibrium.

Hydraulic fracturing is highly controversial, proponents advocating economic benefits of readily accessible hydrocarbons, and opponents concerned for the environmental impact of hydraulic fracturing including contamination of ground water, depletion of fresh water, degradation of the air quality, the triggering of earthquakes, noise pollution, surface pollution, and the consequential risks to health and the environment. Increases in seismic activity following hydraulic fracturing are usually caused by the deep-injection disposal of flowback and brine (which is produced from hydraulically fractured wells).

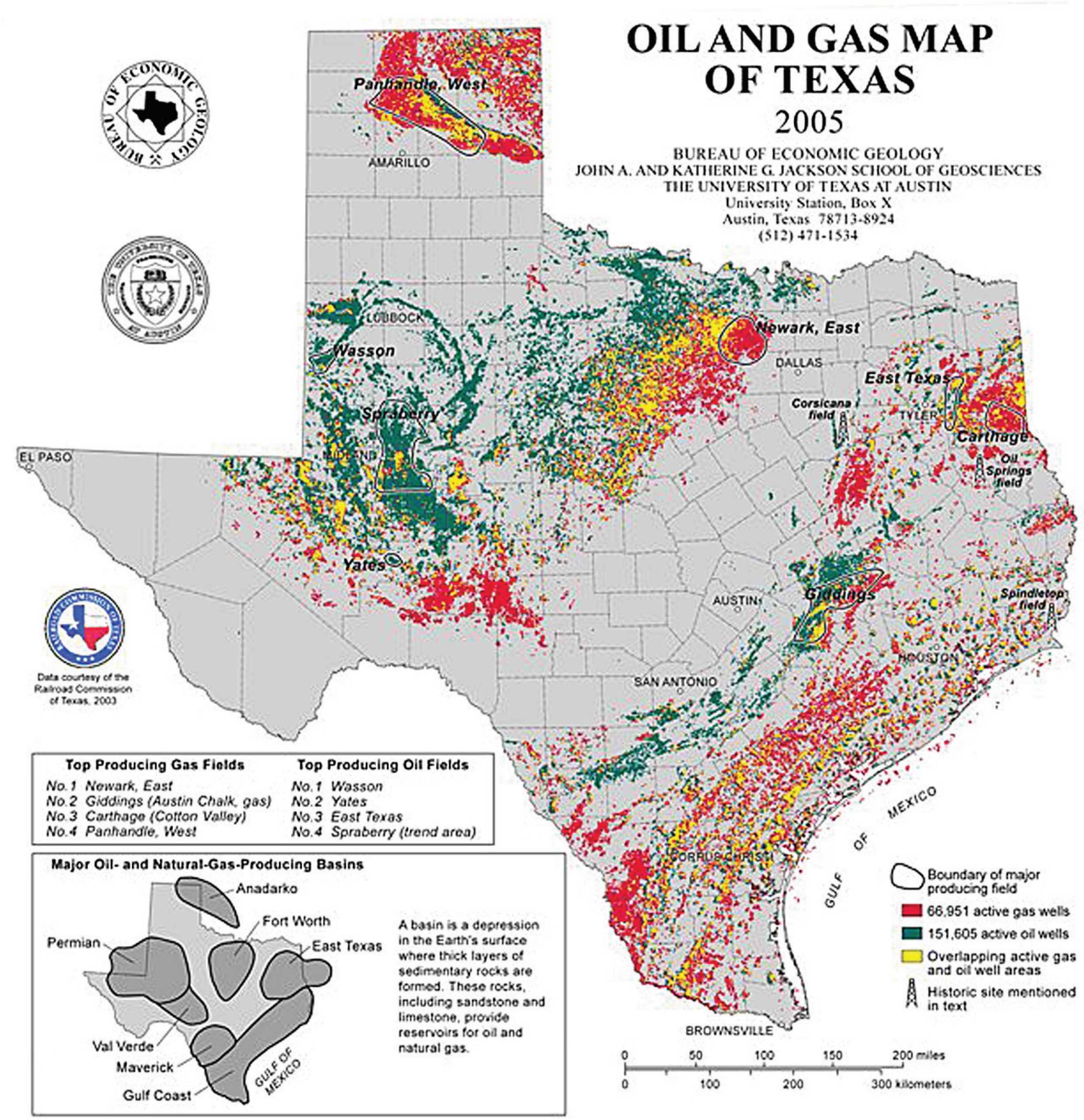


Figure 8. Oil and gas resources of Texas.

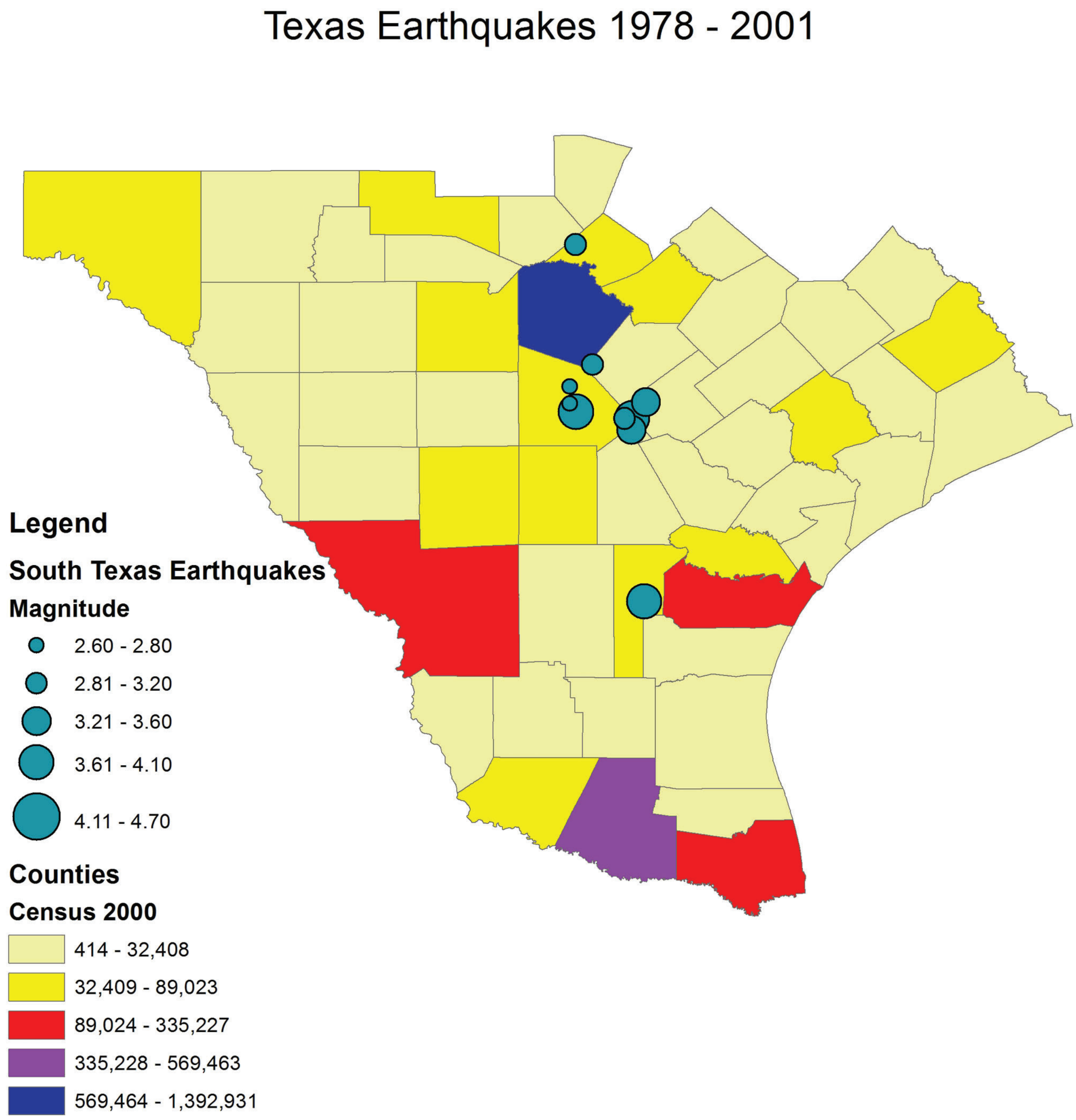


Figure 9. South Texas earthquake epicenters from 1978 to 2004.

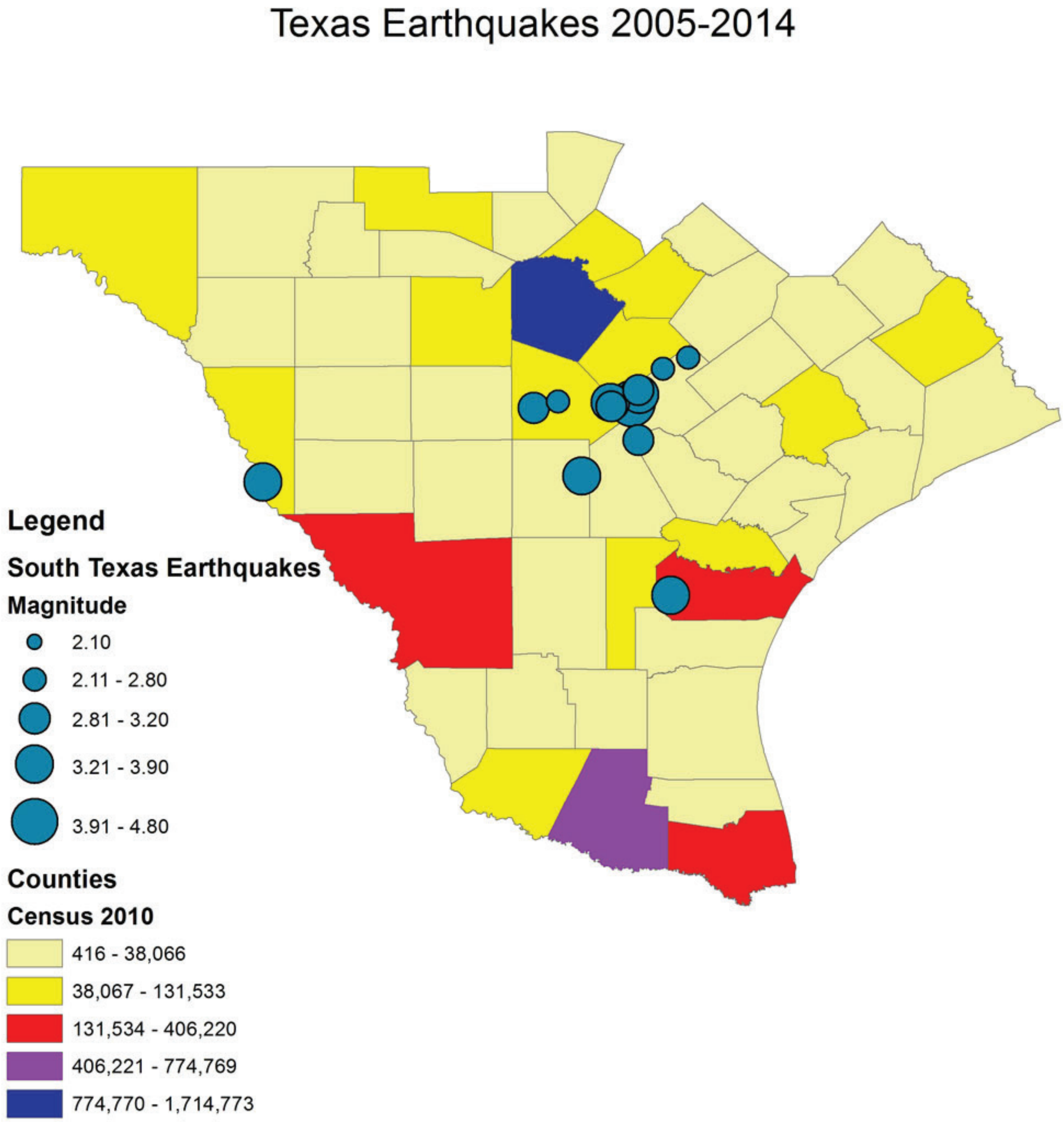


Figure 10. South Texas earthquake epicenters from 2005 to 2014.

QUESTIONS:

12. How many major oil and natural gas basins are there in Texas. Look in the small inset on Figure 8.

13. Around which major Texas city is there no production of oil and gas within a distance of 100 miles?

14. What type of petroleum is most abundant in Webb County. Oil or Natural gas

15. An investor (Mr. Neeks Bill) approaches you and wants to sell you a contract for partial ownership of an oil well for a cost of $10,000 per month. He tells you that the well is located 50 miles west of Austin. Would this be a wise investment - would you sign the contract with him or even call him back? Justify your answer.

16. Describe the difference between primary, secondary, and enhanced petroluem recovery.

17. Describe some of the environmental issues that can result from fracking.

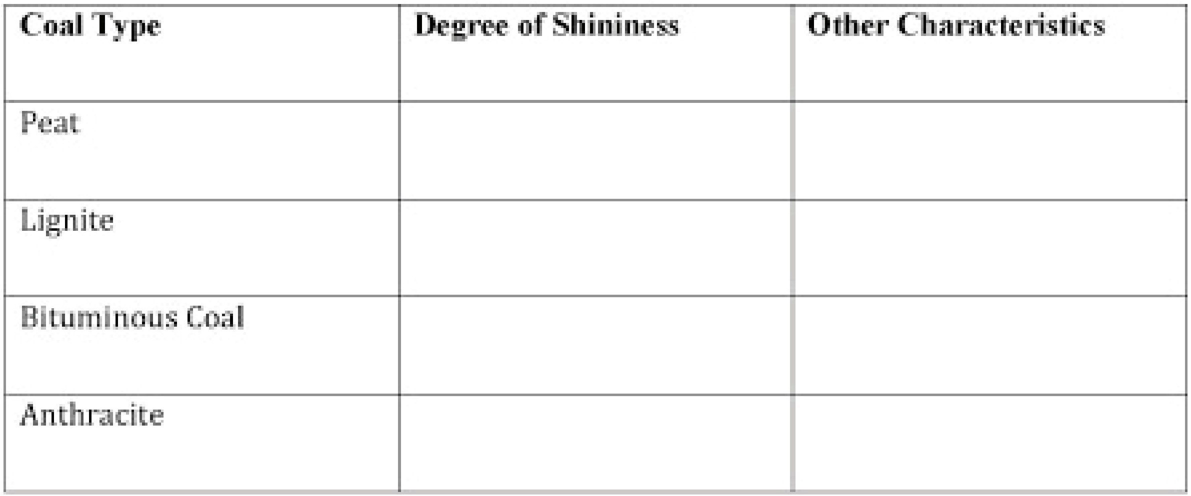
18. Examine the two earthquake maps of South Texas on the previous page (Figure 9). Using these maps comment on the pausibility that there is a connection between the recent increase in fracking and seismic activity in the region.

COAL SECTION

Coal is composed of carbon. The formation of coal requires the quick burial of large amounts of terrestial plant debris by younger sediments, before they are completely decomposed by oxidation. The process of coalification (conversion of planrt material to coal, in response to increased temperature and pressure) involves the progressive loss of moisture and volatiles, resulting in a corresponding increase in the carbon content and, therefore, in the calorific value (heat given off during burning) of the coal. The degree of coalification is denoted by the **rank** of the coal which comprises the sequence (from the lowest to the highest rank): peat, lignite (brown coal), bituminous coal, and anthracite. In the commercial realm, a much more detailed rank classification is used, based on the carbon content, the calorific value, the moisture and volatile matter contents. As a rough guide, the carbon content increases from a low of 15% in peat to 35% in lignite, to 55-75% in bituminous coal, to more than 95% in anthracite. The calorific value ranges from <5,000 Btu/lb for peat to 6,000 - 10,000 Btu/lb for lignites to 10,000 - 14,000 Btu/lb for bituminous coals, to more than 15,000 Btu/lb for anthracites.

QUESTIONS:

19. Describe the appearance of the four types of coal.



Coal Type	**Degree of Shininess**	**Other Characteristics**
Peat		
Lignite		
Bituminous Coal		
Anthracite		

20. From page one, describe the depositional environment associated with the formation of coal.

21. How do the different attributes of coal listed below vary with the coal rank? Indicate an increasing tend by adding one arrowhead (< or >) at one end of end of each line.

	Peat	***Lignite***	***Bituminoucs Coal***	***Anthracite***
Carbon content				
Calorific Value				
Moisture Content				
Volatiles Content				

FOR THE REMAINDING QUESTIONS EXAMINE FIGURE 11 on the next page.

22. What type of coal resources exist at the near surface in Texas?

23. What type of coal resources exist in the subsurface (Deep Basin) in Texas?

24. In Webb County, relative to Laredo, where are there surface and subsurface coal resources?

25. In Webb County, can the near surface coal resources be characterized as high quality coal. Comment in detail.

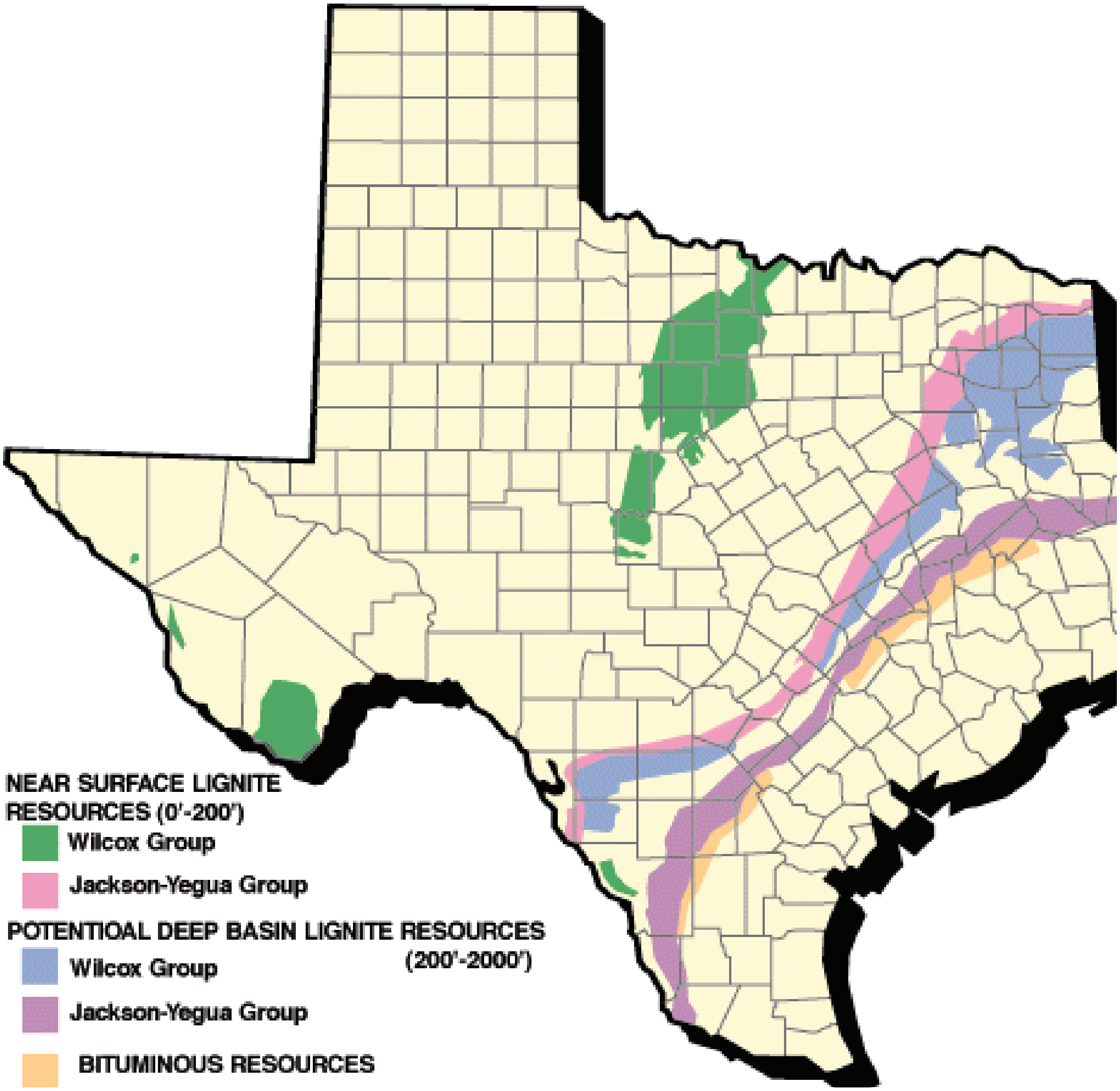


Figure 11. Coal resources of Texas.