Chapter 6

Understanding what geologists do: how geologists use investigational skills in their work today

6.1 What geologists do

If you were employed as a geologist, what would you do? The answer would probably depend on where you live. In developing countries, most geologists are employed in prospecting for and extracting raw materials. These include fuels such as oil, gas and coal, the materials needed for construction and industry (provided by mining and quarrying), and groundwater supplies. In more developed countries, the balance is different, and most geologists are employed in environmental protection, helping to clear up environments damaged by the extraction of raw materials in the past, while ensuring that extraction and waste disposal today minimise environmental damage; environmental geologists also contribute to the climate change debate. Meanwhile, geologists are widely employed in geotechnical work, ensuring buildings have proper foundations and roads and railways are safely-built.

Figure 6.1: Geologists at work, examining cores from a borehole.

Many countries also have their own government-run Geological Surveys, employing geologists to build up national databases of geological information and providing expertise to industries involved in geologically-related activity. Geological Surveys across the world provide maps, geological publications and other data to inform government, industry and the public and many also provide educational support. The 'One geology' initiative, launched during the 'International Year of Planet Earth' in 2008, is combining the geological maps produced by Geological Surveys around the world into one global geological map, see http://www.onegeology.org/; you should be able to find the geology of your country shown there. Meanwhile many universities across the world have departments of Geology, Geoscience or Earth Science, where geologists carry out academic research and teach future geologists.

If you want to become a geologist, you will need a university degree in a geoscience subject. You may also need extra training or a higher degree. Although many people with geoscience degrees work as geologists, others are employed in a wide range of activities, from business to journalism, to teaching. There are also technical opportunities in geologically-related industries for people with non-university qualifications. Worldwide, geological employment tends to fluctuate, with large numbers of geologists being employed in global 'boom' periods and fewer geological jobs when global industry slows down. Nevertheless, there will always be a need for geologists, to find the raw materials we need, to contribute to safe building, to record global geological data and to safeguard the environment for the future.

6.2 Oil/gas exploration

Geoscientists who explore for oil and gas need to understand how these hydrocarbons are formed and trapped and how to find the buried **reserves**. Oil and gas provide well over half the global fuel supply today and will be providing major contributions to global power supplies for many years to come. Meanwhile, global oil/gas supplies are dwindling, so the world will need geologists in the oil and gas industries well into the future.

For oil and gas to be trapped underground, five things must happen:

- there must be a **source rock** - most oil comes from mudstones that were laid down as mud in ancient seas, containing lots of organic material, usually from the microscopic plants in dead plankton; these muds also produce some natural gas, but most natural gas comes from the source rock coal (which formed from plant debris preserved in ancient swamp deposits);

- the source rock must have been **heated enough** for the organic material to be broken down to release the oil and gas, and compressed to squeeze out the hydrocarbons;

- there must be a **reservoir rock** - reservoir rocks contain the tiny pore spaces that can collect the oil or gas, they are porous (with maybe 10% - 20% pore space) and permeable (so that the fluids can flow through);

- the reservoir rock must have a **cap rock** that seals the hydrocarbons in - the cap rock is often an impermeable clay, but may be a salt deposit or an impermeable clay seal along a fault;

Figure 6.2: A drilling rig used for oil/gas exploration in the North Sea.

- the rocks must form a **trap** that seals in the oil/gas like a bubble (spread through the pore spaces in the reservoir rock); examples of common traps are shown in Figure 1.3.

When an oil or gas reservoir has formed, an organic-rich source rock will have been deposited and will have been heated and compressed, possibly during a mountain-building episode. Oil/gas is less dense than the water that most sedimentary rocks contain, and so flows upwards from the source rock through the water in the pore spaces into a porous and permeable reservoir rock (sometimes though, the oil/gas is squeezed sideways or even downwards). If the reservoir rock has been sealed by a cap rock and formed into the right trap shape, the oil and gas will be trapped. We can then find and extract the oil/gas by drilling boreholes into the reservoir rock. Try modeling your own oil and gas field and borehole through, 'Trapped: why can't oil and gas escape from their underground prison', at `http://www.earthlearningidea.com`.

In oil and gasfield areas, the rock sequence of the region is usually well known from other nearby boreholes, so geologists will already think that there is likely to be a source rock in the area, with a reservoir rock above, possibly capped by a cap rock. The hydrocarbon exploration team must therefore find a trap and drill into it to see if it contains oil/gas.

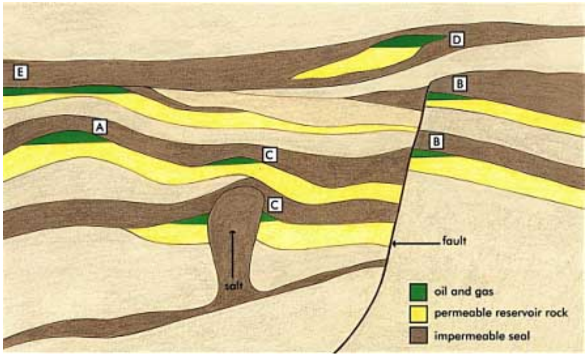

Figure 6.3: Different types of oil and gas traps: A - an upfold (anticlinal) trap; B - fault traps; C - traps caused by a rising salt dome; D - a trap caused by a body of coarser porous sediment in finer impermeable sediment; E - an unconformity trap.

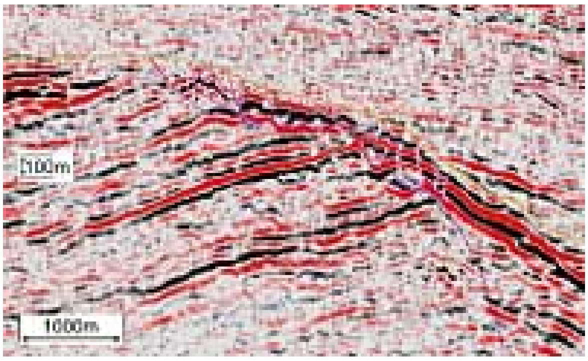

Figure 6.4: A seismic cross section, showing sedimentary beds that dip to the left cut by an unconformity surface; if the dipping sedimentary rocks have alternating reservoir and cap rocks, and if the rock above the unconformity is a cap rock, oil/gas may be trapped in the reservoir rocks.

First, geophysicists will run a series of **geophysical surveys**, such as gravity and magnetic surveys which might suggest areas where a trap may have been formed, as in Figure 1.3. In likely areas they then run **seismic surveys** where shock waves are reflected from the rock layers below the surface, showing a cross section of the geology, as in Figure 1.4. Modern geophysical surveys using the latest technology can reveal the shape and character of the geology beneath the surface very clearly, but they cannot show if a trap contains hydrocarbons. The only way to test whether a potential trap contains oil/gas is to drill a **well** (Figure 1.2).

During the drilling of an **exploration well**, the job of the geologist is crucial, since drilling is vastly expensive and needs to be run as efficiently as possible. Most drilling is done using drill bits that 'chew up' the rock into tiny chips, so that the geologist has to interpret the geology from these chips. However, if the geologist needs more information about the rock sequence, a hollow drill bit is used, producing cylindrical **cores** of rock (although this is even more expensive). The geologist will examine the microfossils from the chips and cores to find out where in the geological sequence the drill bit is drilling. If the borehole has not yet reached, or is drilling in, the reservoir rock sequence, it should keep drilling. If it is below the likely sequence, the borehole should be abandoned as the well is 'dry' and oil/gas has not been found. The rock chips are used to give other details of the rock as well, such as its permeability, whilst other sensors test for oil or gas.

When the borehole has been completed, it is geophysically surveyed by lowering sensors down the hole in '**downhole logging**'. Even if the hole is a dry one, it may give details helpful to interpreting the geology in the next hole to be drilled. Since geologists decide where holes are to be drilled and when they should be abandoned, their decisions are vital to successful hydrocarbon prospecting.

When an oil/gas field has been found, a series of **production wells** is drilled to extract the hydrocarbons. The hydrocarbons are then pumped to oil terminals to be refined, before being sold to provide power or for use in the chemical industry.

During the exploration and production processes, great care must be taken to prevent leaks. While leaks of oil can devastate the environment, gas leaks can cause highly dangerous explosions. If the oil leaking from an oil well catches fire, it can cause enormous environmental problems and is very difficult, dangerous and expensive to put out. This means that there has to be very careful monitoring during borehole drilling, which has to continue right through the production life of a well.

6.3 Mineral prospecting and mining

All the mineral deposits that were easy to find have already been found, so geologists hunting for minerals today have to use a wide range of prospecting techniques in their search for **anomalies**. A mineral anomaly is something that is different from the background data, so if the background copper content of rocks and soils in a region is less than ten parts per million copper, and a soil anomaly of 35 parts per million copper is found, there may be a copper deposit nearby.

Different techniques are used in searching for different minerals, but the principles are similar. First a survey is carried out across a large area. When an anomaly is found, much more detailed surveys are carried out to pinpoint the origin of the anomaly and outline its size and shape. Then a series of trenches or boreholes is used to find the source of the minerals producing the anomaly. At this stage, the prospecting geologist will probably hand over to a mining geologist, who will then excavate pits for evaluating the ore while carrying out a programme of borehole-drilling to outline the three-dimensional size, shape and richness of the ore body. If the deposit is economically viable, and so could give a profit to the mining company, a commercial mine will be excavated to exploit the **ore** (an ore being an economic concentration of metal minerals).

Geologists working for mining companies prospect either greenfield regions, where no ore deposits have previously been found, or brownfield areas, near known deposits, where other similar deposits may be found. If you were prospecting a greenfield area of country with unknown geology, you might first examine any remote sensing data for the region for unusual features, including satellite data using visible light or other parts of the spectrum, and aerial photographs. The next stage might be to fly a geophysical survey, during which variations in gravity and geomagnetism are mapped. This would be followed up by work on the ground, where more detailed geophysical surveys may be carried out. Geomagnetic ground surveys would provide more detail on magnetic anomalies, whilst electrical surveying might find highly conducting (low **resistivity**) ore deposits. Geiger counter surveys would be used to find radioactive uranium-bearing deposits.

Geochemical surveying would be carried out to find, for example, copper, lead, zinc and uranium anomalies but also anomalies of 'pathfinder' elements that are often associated with other ore deposits, such as molybdenum for copper, mercury for lead and zinc,

Figure 6.5: Electrical resistivity surveying.

and arsenic and silver for gold deposits. **Heavy mineral surveys** could find titanium ores, diamonds and gold. Geochemical and heavy mineral surveys begin by sampling the stream sediments of a region and sending the samples to labs for analysis. Any anomalies are followed up, upstream, by more intense stream sampling and later by soil sampling, normally on a grid pattern, to pinpoint the source of the anomaly.

Mineral exploration geologists spend most of their time in the field, often in large and developing countries where the geological potential is least well known. Mining geologists are based in mines, which may often be in remote areas. They explore rock sequences and ore deposits ahead of the miners, using evidence from surface or underground drilling but sometimes with geophysical methods as well. This is important rock detective work, since the work of the miners and the profit of the mining company is based on the decisions of the mining geologist.

Geological work with the mining industry fluctuates with world and local economies, but there will always be need for natural resources and the expertise of mineral exploration and mining geologists (Figure 1.1).

6.4 Hydrogeology

Hydrologists study the whole of the water cycle, both above and below ground, but **hydrogeologists** focus particularly on subsurface water, called **groundwater**. When it rains, water **infiltrates** into the ground and percolates down into the rocks beneath.

Figure 6.6: Groundwater flowing out of the bedrock in a spring.

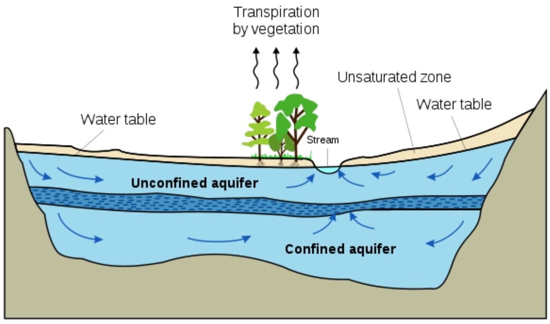

Figure 6.7: Water flows down through the unsaturated zone to the water table and then flows sideways as groundwater, emerging naturally in springs or rivers.

If these rocks are permeable the water will continue to run down until it reaches the **saturated zone**, where all the pore spaces are full of water. The top of this zone is called the **water table** and you can often see the top of the water table by looking down a well. The water table is not flat but is higher under hills and lower beneath valleys, so the groundwater flows slowly downhill, towards the valleys. Where the water table reaches the ground surface, water flows out of the ground, in a **spring**, marsh or bog, or directly into rivers, lakes or the sea.

A permeable rock containing water is called an **aquifer**. If part of the aquifer is beneath an impermeable layer, this is a **confined aquifer** (Figure 1.7). Boreholes drilled into aquifers to extract water are called wells and if wells are drilled into confined aquifers, water may flow naturally out of the well under pressure.

The job of the hydrogeologist is to find aquifers in places where there is not enough surface water from rivers or reservoirs to supply the population. When the hydrogeologist has examined the regional geology and found areas where there are likely to be permeable rocks containing groundwater, an exploratory well is drilled. If the well hits water, the water may naturally flow out of the ground, if the aquifer was confined, but normally, the water will need to be pumped from the well.

When a possible aquifer is found, the hydrogeologist will investigate if the well can produce a reliable water supply by carrying out **pumping tests**. A series of test wells is drilled in a line on either side of the first borehole. Then water is pumped from the central borehole. This causes the water table to be drawn down to form a '**cone of depression**' around the pumping borehole and the shape of the cone of depression can be found by measuring the height of the water in the test wells. If the sides of the cone of depression are steep, the rock is not very permeable, water flows only slowly into the pumping well and will not produce enough reliable water. However, if the cone of depression is broad, water flows easily into the pumping well from the surrounding rock and a reliable water source has been found.

Figure 6.8: A wind pump extracting groundwater to be used by agriculture.

Since many parts of the world will always be short of surface water, the job of the hydrogeologist is vital. In many regions, groundwater is the main source of water for agriculture, industry and the population. A major global problem is that in many of these places the groundwater is being extracted at a greater rate than it is being replaced by rainwater. This water will eventually run out and cannot be replaced. As the world requires more and more water, this will probably become one of the most critical environmental issues on Earth in the future.

Hydrogeologists also play an important part in planning new surface reservoir sites. They examine the reservoir and dam sites to ensure that the rock is not so permeable that water ponded behind the dam will either seep away into the rocks beneath, or flow through the rocks under the dam, and be lost. These studies examine the permeability of the rocks and their direction of dip, since permeable rocks that dip towards the site will tend to bring water into the reservoir, but those that dip away will drain the reservoir water. Where rocks are too permeable then plastic membranes can be laid and rock fractures can be filled, but these measures are very expensive. Hydrologists also work with geotechnical engineers to monitor groundwater flow in the rocks surrounding reservoirs, since if the pore water pressures in unstable rocks become too great during storms, the material can slump into the reservoir causing a disastrous flood. This happened in the 1963 Vajont

Dam disaster in Italy, when the wave of water flooding over the dam killed 2,500 people in the valley below.

Hydrogeologists also monitor groundwater flows and pollution near waste disposal sites, contributing to environmental geological studies. Try modeling groundwater flow and pollution yourself, using the 'From rain to spring: water from the ground' activity at http://www.earthlearningidea.com.

6.5 Environmental geology

Environmental geologists have a wide variety of geoscience-related work, ranging from planning for and monitoring modern raw-material extraction and waste disposal sites, to helping to clear up (or **remediate**) old extraction sites and other polluted areas. Environmental geological work overlaps the work of hydrogeologists but is broader, focusing on all the environmental issues concerning a geological site. Environmental geologists manage the environmental concerns of working quarries and mines, advising on where banks and reservoirs should be sited, where landscaping should take place and vegetation planted. Similarly they contribute to the planning of waste disposal sites, monitoring them during their working lives, and ensuring that they are properly remediated and monitored afterwards. Environmental geologists often work with other scientists such as environmental biologists and geographers, ensuring that after sites have closed, they are made suitable for their later use, in agriculture or for public amenity.

A major environmental problem in old mining areas is **acid mine drainage** (Figure 1.9). While the mines were working, water was being pumped out and minerals became exposed to the air and oxidised. When the pumping stopped, the mines filled with water, dissolving the oxidised minerals to make a highly acid solution. When the mine fills up, the water overflows into nearby streams, polluting them and killing all life in the river downstream. This is just one of the many water pollution problems that environmental geologists tackle.

Disused heavy industrial sites, including gasworks, often have badly polluted soils beneath them caused by nasty fluids that leaked from them while they were working, including oil products, solvents, pesticides and heavy metals. Before these industrial brownfield sites can be used for any other purpose such as house-building, the soils have to be remediated. The polluted soils must be extracted, treated and disposed of in new, carefully controlled sites. This too is the work of the environmental geologist, enabling old industrial sites to be reused.

It is not surprising that most environmental geologists today are employed in developed countries where extractive and other industries were not carefully controlled in the past, and where building space is precious and polluted brownfield sites have to be re-used. As other countries develop in the future, they should be able to learn from past mistakes and preserve their own environments more effectively as extraction and industrialisation develop.

Figure 6.9: Acid mine drainage from an abandoned mine in Spain.

6.6 Geotechnical engineering

Geotechnical engineers study building foundations and the earth materials in which other constructions, such as dams, bridges, roads, railways and waterways are sited, as well as landfill and coastal protection sites. The earth materials involved include soil, surface deposits from rivers and glaciation, and the bedrock beneath. A new geotechnical project will begin by researching the information already available from maps and other publications. Geotechnical engineers will assess the likely strength of the earth materials involved, and will be looking out for faults, fractures and other weaknesses in the bedrock. They will also be looking for particular problems such as natural features, like caves and potholes, or features caused by past human activity, such as mining, quarrying, waste disposal or poor foundations of previous constructions. They will research potential problems from natural hazards too, like danger from landslides, or sediments which might 'liquefy' and collapse in earthquakes.

The geotechnical engineer will visit the site, assess any exposures of earth materials and then carry out an investigation, usually involving a pattern of soil samples or boreholes and the testing of the materials found; sometimes geophysical investigations are also used. The next stage is the planning of suitable foundations and other constructions to cope with the findings of the investigation. Then as construction continues, the geotechnical engineer will continue to monitor the site to ensure that everything works as planned.

Building work uses a range of foundation types, from simple foundations for smaller buildings on stable materials to deep foundations for tall buildings, or buildings on less

Figure 6.10: A slab foundation, built to spread the load of a smaller building.

Figure 6.11: Deep foundations being constructed in Spain.

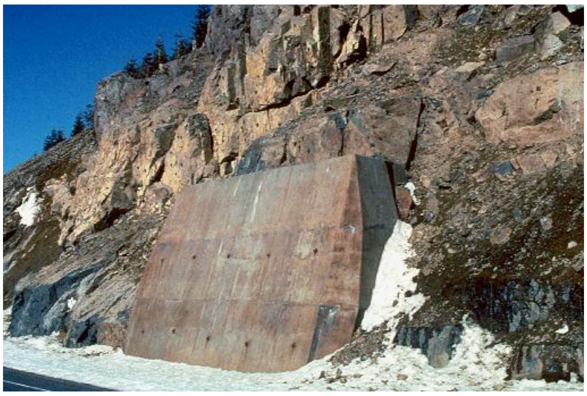

Figure 6.12: A retaining wall supporting weaker materials in a cutting.

Figure 6.13: Stone-filled gabions, stabilising a river bank.

stable material. These may need vertical columns of steel-reinforced concrete called **piles** to be hammered into the ground, or other specialised structures.

Dams need particular sorts of foundations, depending on their design, whilst transport routes need well-constructed embankments, **cuttings** and tunnels, and bridges with well-engineered foundations. Where cuttings and tunnels are excavated into weaker materials, these are dealt with in different ways, from removing material to make more stable shallow slopes, to supporting it with walls or stone-filled **gabion cages**. Similar methods are used to stabilise river banks and coastlines. Meanwhile, rivers prone to flooding have artificial banks called levées or dykes constructed on their banks, built of rock, concrete or gabions.

While building continues across the world, geotechnical engineers will always be in demand.

Figure 6.14: Did an asteroid impact cause dinosaurs to become extinct?....

Figure 6.15: ... or did huge volcanic eruptions cause the dinosaurs to die out?

6.7 Academic research geologists

Academic research geologists are usually based at universities but may also be employed in government agencies such as Geological Surveys. Wherever they operate from, the scientific research process is similar, and is also similar to the investigational work carried out in science courses at schools and colleges. First the geoscientist has to become familiar with the area of study, usually by reading published materials, consulting maps and photographs and conducting fieldwork. The next stage is to develop a research question or questions (a hypothesis or hypotheses) that need to be answered - this will usually involve further reading and data-collection. Then the project swings into action, evidence is collected and recorded in a variety of different ways including: field notes, field diagrams, photographs, measurements, samples and specimens, maps, logs of strata and technological data. Then the geoscientist assembles all the data to provide an answer to the research question posed. Finally the results are written up for publication, but before they can be published, they are '**peer-reviewed**' by other scientists who check that the work done and the report written, are up to the standards expected of scientific publications.

This might sound a simple and straightforward process, but the reality is usually rather different. Often the research question set in the first place turns out not to be quite the right question, and needs modifying. Meanwhile the research usually throws up a whole range of new research questions that need answering. Nowadays research questions are frequently addressed by research teams, involving much discussion, debate and sometimes disagreement during the research. This research work is often at the 'cutting edge' of science, discovering new scientific information that has never been known before. Most researchers work on topics that are vital to human existence, such as 'climate change' whilst a few others work on 'blue skies' research, studying things that have no known value (but which often turn out later to provide new scientific insights).

An example of this is investigations into the extinction of the dinosaurs and other major extinctions of the past. At the moment, there are two main competing theories to account for mass extinctions. Some scientists argue for an 'impact theory', where an asteroid hit the Earth, causing a massive impact, tsunamis, wildfires, and thick clouds of dust that hid the sun, killing the vegetation and most of the animals that lived on the vegetation. Other geoscientists argue that the extinctions are connected with massive outpourings of lava, producing volcanic gases and ash, that transformed the climate of the Earth, affecting all life. Still others argue that the extinctions might have been caused by a combination of events, including these, or that some extinctions had one cause while others had different causes. The only way of deciding which of these ideas is the most likely, is to collect more evidence, similar to that already collected from many parts of the Earth including, geological evidence of lavas and impacts, geophysical evidence of impact craters, geochemical evidence from sediments, fossil evidence of species present before and after extinctions, and detailed logging of geological sequences at the times of the Earth's major extinction events. What will the answer(s) be? If you become a geologist, you might help to find out.

Some people might complain that it is not worth researching major extinctions in the distant geological past, but whatever we find out about ancient extinctions, might help us to understand how species become extinct today, together with the impacts that climate change might have on future extinctions. So geologists contribute not only to debates about the past, but also to discussions on what is happening on our planet today, and what might happen in the future.

The world of academic research is changing because most of the funding for research comes from large national organisations such as government councils or charities. Research scientists have to put in bids for funds to run their research programmes, these are 'peer reviewed' and the successful bids get funding. Most successful bids are submitted by research groups of several scientists and much of the actual work is done by research students. Even though quite a lot of the work involves high technology, using expensive machines and computers, geoscience information still needs to be collected from the ground, with fieldwork and field data collection being key parts of the job. The result of all this is that few research scientists now work alone and good team work is vital (Figure 1.16). It is also vital that research scientists communicate their work to their colleagues and to the public, showing that today's research scientists need to play a wide range of different roles if they are to be successful.

Since university geologists not only carry out research, but also teach on university courses, new students learn how to become future geologists and also how to become research scientists. With the past, present and future to investigate, research geoscientists will always play a crucial role in studying and contributing to how our planet evolves in the future.

Studying geoscience can offer a wealth of opportunities, both in the commercial and research fields. It also provides a sound foundation for people to move into lots of different jobs, with geologists playing important roles in government, law, education, media and a wide range of commercial positions. A number of websites contain more details of

Figure 6.16: A team of geologists measuring the magnetic field on the flanks of the Mt St. Helens volcano.

geoscience opportunities and the career paths of different geoscientists from a wide range of backgrounds. Geoscientists clearly play a vital role on our planet today and their investigations are critical to the future of the Earth.