Fun with Thin Sections

By Jonathan Slack

For the last five years, my wife and I have been walking the Southwest coastal path. We do this very slowly, making a trip a few times a year and have so far made our way from Poole Harbour to Land's End. Every so often she would point and ask me "what sort of rock is that?" Once we had got past the chalk and the Kimmeridge clay, I found it quite hard to answer. In theory I knew about sandstones, shales and limestones and about the different types of igneous rock, but the colour of rocks so often depends on lichens or iron staining or general dirt, so you need to look up close at a freshly exposed surface. Even then I still had some trouble and decided that I really needed to improve my identification skills.

As a retired biology professor I have spent a whole career looking at sections of animal tissues down the microscope. I knew that rocks become transparent in thin section and wondered if I could make my own rock sections to aid with identification. Having found out what equipment and skills are required to do this, I decided it would not be possible, but I did find someone willing to make them. Robert Gill of GEOSEQ will make you a slide from your sample for £14, including postage, and will also help you interpret it.

So, I bought some slides of igneous rocks from him and set about learning how to distinguish the different mineral crystals. I have an old Zeiss microscope (vintage 1977), which, although designed for biology, does have the rotating stage and polarising attachment which are essential for petrological work. Compared with biology, the "thin" sections of petrology are actually rather thick. A biological section would be 6-10µm thick, while the standard thickness of a rock section is 30µm. With sections this thick it is fortunate that the magnification used tends to be rather low, otherwise a lot of the section would be out of focus. The most useful objective lenses are the lowest powers: x2.5 and x6.3. For even lower power, I use a dissecting microscope with a transmitted light base and simply place the polaroid filters on either side of the slide.

To take photographs I needed a camera. So I bought an old Canon SLR, without the lens, from eBay, and I had an adapter made for my microscope by GT Vision Ltd. This setup has worked reasonably well, although it is not as slick as the professional imaging setups I used to work with.

Identifying minerals

I have focused most attention on igneous rocks. By the time we got to South Devon, we were encountering some of these in the field. The first thing I had to get used to looking at thin sections was that there are numerous tiny crystals at every possible orientation. The optical properties of a crystal differ depending on the orientation and so you have to look at several crystals of the same mineral to decide what it is. How do you know it is the same mineral? This is very much an art but you do get used to it after a while. The identification of minerals in thin section depends on a variety of features: colour, crystal shape including twinned structures, "relief" (i.e. refractive index), cleavages, and, especially, the colour when viewed between crossed polaroids.

Most minerals are colourless in thin section but some are coloured. Moreover for some of these the colour changes in plane polarised light (i.e. using just the lower polarising filter) as the crystal is rotated. This colour change is called pleochroism and can be very useful for identification. To illustrate this, a crystal of biotite, a dark form of mica is shown in Fig.1. The two views are taken in plane polarised light but with the specimen rotated 90°. The first view shows a dark brown colour while the second is almost colourless. This indicates a high degree of pleochroism, which, together with the characteristic cleavage pattern definitively identifies this crystal as biotite. The dark patches in the crystal are common in biotite and are halos of radioactive transformation around small inclusions of zircon. Zircon is a complex silicate of zirconium, often containing radioactive elements such as uranium and thorium, and the halos represent the effect of the emitted particles on the surrounding mineral.

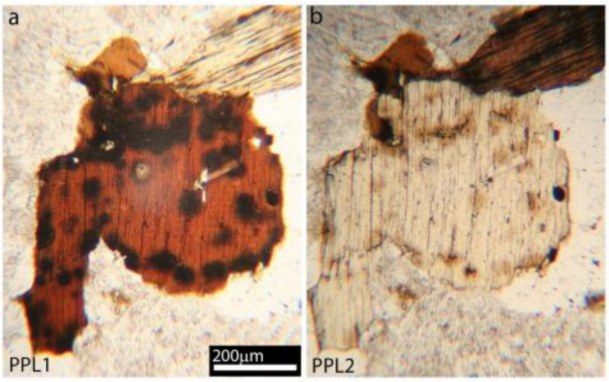

Fig. 1 Pleochroism of biotite in plane polarised light (PPL). a) Maximum colour orientation: the crystal is dark brown. It also shows prominent dark patches due to the effect of radioactive elements in minute zircon inclusions. b) Rotated 90°. The brown colour is almost gone. The second crystal at the top is now brown.

The appearance of mineral crystals between crossed polaroids is a real joy to observe, as the colours and patterns are often strikingly beautiful, arguably as beautiful as the frog embryos I used to look at. Most mineral crystals are anisotropic, which means that the refractive index differs depending on the path taken through the crystal by the light ray. When plane polarised light enters an anisotropic crystal, it is divided into two rays with their vibrations at right angles. Because of the different refractive indices of the crystal in different directions, one ray will be a little faster than the other so they emerge from the crystal out of phase. If a second polariser, at 90° to the first, is placed above the specimen, it captures just one vibration plane of both rays. If there is no phase shift between them no light will be transmitted and the specimen will appear black. If there is a phase shift then the interference of the two rays will generate a colour.

This effect is known as birefringence. As the specimen is rotated the birefringence changes from none (black, or extinction) to maximum (a specific colour) every 90 degrees. This does not occur for minerals of the cubic crystal system, such as garnet, which are isotropic and so appear black in all orientations. For anisotropic minerals, the difference of refractive index, and thus the resultant colour, does differ depending on the orientation of the crystal. Each type of mineral has a maximum birefringence colour which is characteristic of the largest possible difference, assuming that the section thickness is the standard 30µm.

The birefringence colour is one of the most valuable diagnostic features for identification. As the degree of birefringence increases so the colours recur, so we speak of first order yellow, second order yellow and so on. The first three cycles are apparent in Fig.2a which shows a wedge-shaped piece of olivine. Because the degree of birefringence is proportional to the thickness of the crystal, in a wedge you see the full succession of colours in order. The sequence of colours is known as Newton's scale, and is presented as the Michal-Lévy chart in all books on optical mineralogy. Usually it is not difficult to decide to which order a particular colour belongs, partly because you can often see the adjacent colours due to variations in thickness, and partly because they become pearlier in appearance after the third cycle. In Fig.2 three minerals are shown in addition to the olivine wedge. Quartz has a maximum birefringence of a creamy white colour. Augite, a complex silicate belonging to the pyroxene group, appears blue but has a maximum birefringence of second order pink. Muscovite, or white mica, which is a sheet silicate, has a maximum of third order pink.

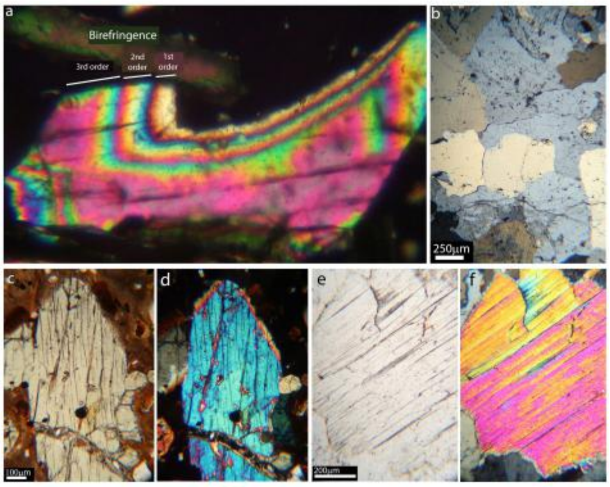

Fig. 2 Birefringence in crossed polarised light (XPL). a) A wedge of olivine showing a progression through three cycles of interference colours with increasing thickness. b) Quartz crystals in a granite. These occupy the central part of the image and vary from grey to buff to a cream colour (maximum birefringence) depending on orientation. c,d) Augite from an andesite, viewed in PPL and XPL. This appears blue but the maximum birefringence of augite is higher. e,f) Muscovite from a granite, viewed in PPL and XPL. This is second order pink, but again, can be higher.

The most common mineral in most igneous rock samples is feldspar. There are several types of feldspar and to understand them it is helpful to consider first the chemical structure of quartz. Quartz consists of an endless three-dimensional arrangement of silicon atoms each surrounded by four oxygens in a tetrahedral arrangement. Because each oxygen is shared between two silicons, the overall ratio of silicon to oxygen in quartz is 1:2, hence the conventional chemical formula SiO_2. The structure of the feldspars is like quartz except that about one in four silicons is replaced by aluminium. Aluminium is trivalent while silicon is tetravalent, so in the feldspars some additional cations (positive ions) are needed to ensure electrical neutrality. If the cation is potassium ion we have an orthoclase feldspar, if it is some mixture of sodium and potassium ions, we have an alkali feldspar, and if it is some mixture of sodium and calcium ions we have a plagioclase feldspar. Mixtures of potassium and calcium ions are not found.

It is possible by optical methods to be quite discriminating about identification of which particular subclass of feldspar is being observed, but in Fig.3 I show just two common appearances typical of alkali and plagioclase feldspar. Both show a low level of maximum birefringence which is first order white. The most characteristic difference between them is the twinning behaviour. Twinning of crystals occur when they grow on either side of a mirror plane giving multiple crystals related by mirror symmetry. Alkali feldspars tend to show simple twinning, while plagioclase tends to show lamellar twinning, visible between crossed polaroids as multiple stripes of black and white. For both types of twinning, as the microscope stage is rotated, the black areas change to white and the white to black, because their orientation relative to the light beam is changing. Feldspars in igneous rocks are often "altered", meaning that they have suffered some chemical degradation or transformation over the millions of years since the crystals were formed. This is apparent in Fig.3 as the buff-coloured or grey opacity seen as irregular patches.

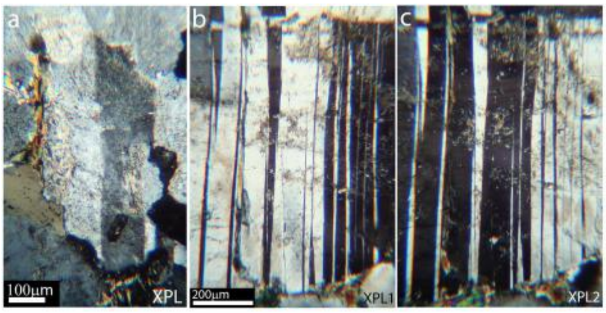

Fig. 3 Feldspars viewed in crossed polarised light. a) Alkali feldspar from a granite showing simple twinning. b,c) Plagioclase feldspar from a gabbro showing lamellar twinning. There are two crossed polaroid views, 90 degrees rotated. Both these specimens are slightly "altered", or degraded, which is common for feldspars.

In some areas of Cornwall the alteration of feldspars in granite has progressed so far that a large proportion of the rock has become kaolin, or China clay.

Rocks

Having learned to identify some minerals down the microscope I was beginning to be able to identify some rocks from their mineral composition. One of the most characteristic igneous rocks, familiar to those of us living in the South West, is granite (Fig.4). This forms the moorlands of Devon and Cornwall and outcrops along much of the Cornish Coast. Granite is actually pretty easy to identify without a microscope because of its characteristic jointed structure and the fact that the crystals are large and visible to the naked eye or a hand lens but it looks much nicer down the microscope. Granite is classified as an “acidic” rock i.e. high in silica, and plutonic, i.e. cools slowly below the ground so crystals have time to grow large. It is normally composed of quartz, feldspars and micas. The South West granite outcrops also often contain tourmaline.

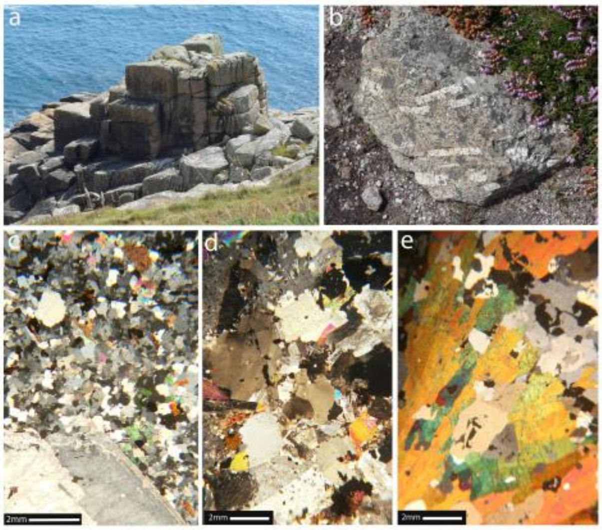

Fig. 4 Granites. a) A granite outcrop on the Cornish sea coast. Note the vertical and horizontal jointing. b) A granite near Land’s End containing huge feldspar crystals (phenocrysts). c-e) Low power sections of three different granites from the South West. c) From Dartmoor. At the bottom, there is a large alkali feldspar phenocryst showing simple twinning. Most of the small crystals are quartz, appearing black grey or white, there is also some green tourmaline and brown biotite. d) From Bodmin moor. Here the crystals are larger. They are mostly quartz and feldspar with a few brightly coloured crystals of muscovite. e) From Penwith. This granite has an unusually high content of tourmaline, which appears as the yellow, green and orange crystals.

Geology textbooks all contain a classification of igneous rocks based on the silica content and grain size. Among the plutonic rocks, diorite contains less silica and more plagioclase than granite together with some pyroxene and amphibole. Gabbro has a lot of plagioclase and pyroxene, and maybe a little olivine. Peridotite, characteristic of the mantle region below the Earth’s crust, consists largely of olivine and pyroxene. The minerals dominating the low silica, or “basic”, rocks: pyroxenes, amphiboles and olivine, are referred to as mafic minerals because of the high content of magnesium and iron (Fe). These minerals are intrinsically dark coloured and because of them basic igneous rocks are dark in colour or contain a preponderance of dark to light coloured crystals. The mafic minerals are all silicates. Olivine consists of isolated SiO_4 groups with Mg and Fe ions to balance the electric charge. Pyroxenes have chains of linked SiO_4 groups, and amphiboles have double chains. Fig.5 shows samples of diorite, gabbro and peridotite

Igneous rocks that solidify at the surface, otherwise known as volcanic rocks, usually have a very small grain size because the crystals do not have much time to grow while the lava is cooling. However, often volcanic rocks show a porphyritic structure in which small crystals are embedded in an amorphous matrix. In such cases the crystals represent those minerals of higher melting point that can start to crystallise while the lava is still molten. Tuffs, formed by ejection of material from volcanos, can be identified because they contain pumice fragments as well as the usual components of the lava.

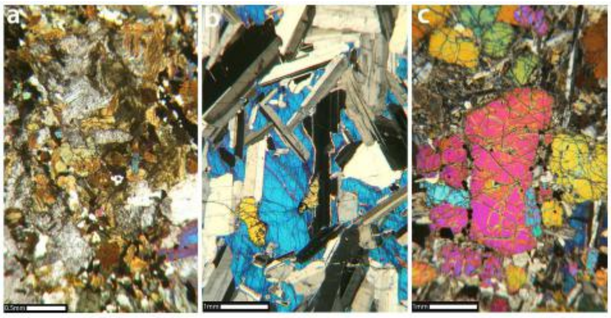

Fig. 5 Some other igneous rocks. a) Diorite from the Malvern Hills, containing plagioclase (stripy), pyroxene (blue), some quartz, and some opaque material, probably magnetite. b) A gabbro from Ardnamurchan, Scotland, containing plagioclase and pyroxene (blue). c) A peridotite from the Isle of Rhum, mostly consisting of olivine. b) and c) are not my own collection, but were purchased from GEOSEC.

If the crystals in a tuff are oriented this indicates that the material was moving fast just before solidification, so it is probably a rock formed from a pyroclastic flow, called an ignimbrite. We often go to the Bodrum peninsula in Turkey (Fig.6a,b). This picturesque area suffered extensive volcanism about 10 million years ago and most of the scenery is formed from lavas and tuffs. The rocks are classified as andesites, which means an intermediate silica content, similar to diorite, and a small grain size. Fig.6c shows a porphyritic andesite from a volcanic plug near the town of Turgutreis, which contains crystals of augite and biotite. In the village of

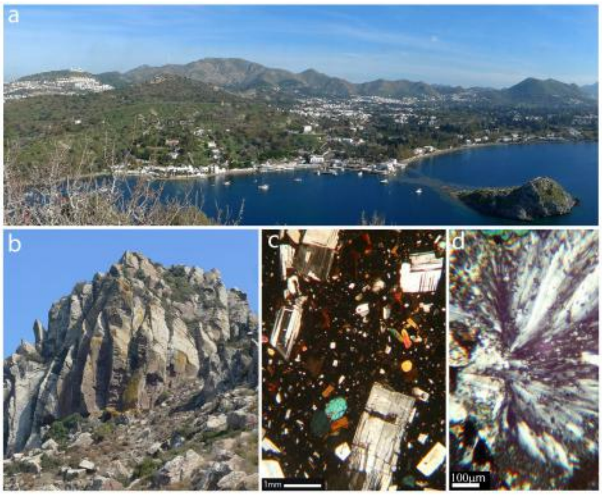

Fig. 6 a) Gümüşlük bay on the Bodrum Peninsula, Turkey, showing the volcanic scenery. b) A striking volcanic plug above Turgutreis, Bodrum Peninsula. c) Low power section of andesite from near the plug. Crystals are embedded in a black matrix, and include plagioclase (stripy), biotite (dark brown) and augite (blue). d) A spherulite, formed of radiating crystals, in a green tuff commonly used for building in the ancient world.

Gümüşlük, where we stay, there are many masonry blocks left over from Roman and Byzantine times still lying on the surface. A popular stone used in those days was a greenish tuff which is relatively soft and easy to work. This contains radiating spherulites probably composed of quartz and feldspar (Fig.6d).

Metamorphic rocks

Having become moderately familiar with igneous rocks I have tried to extend my attention to metamorphic rocks. These contain many more different minerals and are very complex indeed. The composition of a specific metamorphic rock depends on what it was before metamorphosis (the protolith), and on the degree of pressure and temperature to which it has been subjected. For a particular protolith, a plot of pressure against temperature can be divided into zones of different composition called facies. Metamorphic rocks often have a layered structure arising from the compression they have suffered. This layering is clearly apparent in Fig.7a showing a mica schist from South Devon which has distinct layers dominated by quartz and muscovite. It arose from a Devonian shale which was metamorphosed in the late Carboniferous when the granite intrusions of the area were formed. Igneous rocks can also undergo metamorphism, and Fig.7b shows a hornblende schist from Cornwall which arose from a basaltic protolith and is largely composed of hornblende, which is a type of amphibole, and pyroxene. A mineral often found in metamorphic rocks is chlorite. Contrary to its name, this does not include chlorine, but is a complex sheet silicate formed from various mafic minerals by chemical alteration. Chlorite and another metamorphic mineral, zoisite, are unusual in that they show an anomalous birefringence colour, not part of the normal Newton's scale. This appears as a strong Prussian blue colour (Fig.7c) which is very characteristic and aids identification.

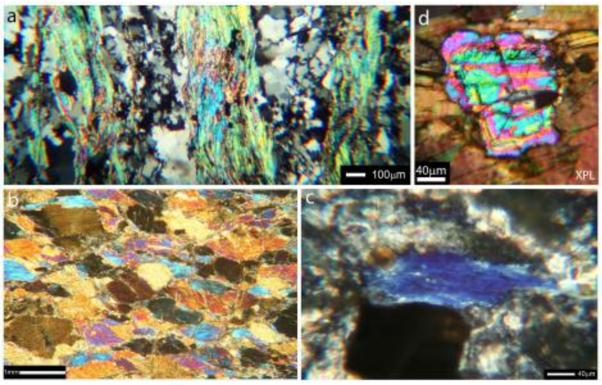

Fig. 7 Metamorphic rocks. a) A mica schist, showing alternating bands of quartz crystals (black, grey or white), and muscovite (multicoloured, and at this magnification appearing as fibrous swirls). b) A hornblende schist, with brown crystals of hornblende and blue augite. c) A clump of chlorite in an altered basaltic rock, appearing a "Prussian Blue" colour due to anomalous birefringence. d) A crystal of epidote in a biotite gneiss.

Gneisses are rocks of high metamorphic grade, also with a layered structure, usually arising from granites or diorites. Fig.7d shows an epidote crystal from a granitic gneiss rich in biotite. Although found in Devon close to the mica schist, this was a beach cobble, so its exact location of origin is unknown.

I still find the identification of metamorphic rocks difficult, as the appearance of the rocks can be very diverse and the minerals present in a specimen often don't seem to correspond to any particular facies! However, as always, the specimens are very beautiful and can show an infinite variety of shapes and colours.
In the last few years I have had a lot of fun collecting samples and making a provisional decision about what they are from their hand lens appearance. I then have some of them sectioned and attempt to identify the constituent minerals to see if I was correct in the preliminary identification. I have improved my skills to some extent but also learned to be cautious as the range of rock types is very large and the superficial appearances can be very varied. In the future I will aim to explore the metamorphic rocks in more detail and try to become familiar with the range of minerals they contain and the various facies they display. I also feel I should try to understand more about the crystallography of minerals, as this is the real key to making sense of what you see down the microscope. If any member of the Society would like to help me with interpretation of the sections I should be most grateful. Please get in touch at j.m.w.slack@bath.ac.uk.

Sources

As a complete newcomer to this area I have needed all the help I could get. In terms of books, I have found "Minerals and the Microscope" by H.G.Smith to be the most useful. This is old (4th edn 1956) and out of print, but second-hand copies are available. It explains the principles of optical mineralogy pretty clearly and describes the appearance of a wide range of mineral. Because of its antiquity it does not have colour illustrations. For these I have turned to "A Colour Atlas of Rocks and Minerals in Thin Section" by MacKenzie and Adams, which provides a basic set of pictures taken in plane polarised and crossed polarised light. Useful illustrations are also to be found in "A Key for Identification of Rock-forming Minerals in Thin Section" by Barker. This presents a dichotomous key for identification of minerals similar to those used for identifying plant or animal species in biology. I find the key quite hard to use as it depends a lot on identifying cleavage patterns, which of course vary with orientation, but the pictures are good and show a wider range of minerals than MacKenzie and Adams. As far as websites are concerned, Robert Gill of GEOSEQ has a useful site with descriptions of several common minerals. There is also a remarkably comprehensive set of sections presented by Alex Strekeisen, an Italian geologist who has compiled a very extensive website illustrating almost everything.

Websites:

http://www.alexstrekeisen.it/english/index.php
http://www.geosecslides.co.uk/

Books:

Smith, H.G.(revised Wells, M.K.), *Minerals and the Microscope*. London: George, Allen and Unwin. 4th edn.1956.

MacKenzie, W.S. and Adams, A.E. *A Colour Atlas of Rocks and Minerals in Thin Section*. London: Manson Publishing. 1994.

Barker, A. *A Key for the Identification of Rock-Forming Minerals in Thin-Section*. London: CRC Press. 2014.

Quiz:

By Sam Medworth

We live on the southern slopes of Bath, roughly halfway between Combe Down (of Oolite fame) and the river Avon. Sheet 265 of the BGS 1:50000 maps shows this as "Lower and Middle Jurassic in a foundered area", and I can confirm this from my own experience, having dug up pieces of chalky white limestone as well as clay from the Fuller's Earth formation; rubbly limestone, Midford Sandstone, and Oolitic limestone which may be builders' rubble or may have slipped down from higher up the hill. Over the 35 years that we have lived here, I have collected a number of fossils and thought members might like to see some pictures. I decided to present them as a quiz. The winner will be the first person to email the Chairman with the correct genus name for each.

1.

2. Split in half lengthways

3.

4.

5.