BON APATITE!

Apatite is a familiar, friendly little mineral that turns up all over the place. It's useful for teaching students that minerals can have both high relief and low birefringence and for demonstrating the relationship between hexagonal symmetry and the interference figure. I have often encountered it within the alkali feldspars in many of the alkaline rocks I have worked on but, seduced by the feldspar microtextures, have never analysed one. However, right at the start of my career, I serendipitously became involved with rocks with so much apatite that they were seriously considered as a commercial source of phosphate.

I started my PhD studies in 1960, right at the beginning of what became a golden decade for mineralogy and petrology. Perhaps all of us oldies think of our early careers as part of a golden age, but it is hard to argue with a decade that gave us plate tectonics, outstanding work in experimental petrology, the introduction of the electron microprobe and XRF analysis, the first routine use of computers, and the appearance of the first desktop calculators. And, of course, the Beatles.

The subject of my PhD – at Durham University (UK), under the supervision of Henry Emeleus, a truly great field geologist and petrologist, and still active – was a small syenite pluton, the Loch Ailsh intrusion, on the eastern edge of the Assynt district in the extreme north-west of Scotland. Assynt is genuinely world famous because of the classic maps made by Ben Peach and John Horne at the end of the 19^{th} century. They showed that Assynt was a window into a stacked pile of thrust sheets, the highest and most famous plane of movement being the Moine Thrust. American exchange students sometimes took our courses and I remember one such young lady putting her hand reverently on the thrust plane and commenting, "Wow … I had to write an essay about that!" The top of the Loch Ailsh intrusion is truncated by this great thrust.

Assynt is a wild and sparsely populated region of great beauty (Fig. 1). Geological exposure, however, is dreadful (Fig. 2). It is too boggy even for modern off-roaders, and Peach and Horne did much of their mapping on horseback. When interpolation between the rare exposures became too much even for their fertile (but usually correct) imaginations, they would resort to marking an area as 'peat', until the exposure improved. Most of the Loch Ailsh intrusion is made of alkali feldspar syenite, and it is the type locality of perthosite, a mono-mineralic feldspar rock. About a third of my thesis was concerned with single-crystal X-ray diffraction work on the feldspars and applications of a new-fangled device called a powder diffractometer. Fifty-five years later, I'm still going on about feldspars!

Figure 1 The mountains of western Assynt (Scotland). The photographer is standing in the Moine Thrust Belt and most of the rocks surrounding the loch are imbricated Cambrian limestones. The mountains are part of the belt's foreland zone, below the lowermost thrust, and are unmetamorphosed Proterozoic sandstones resting on Archaean gneiss, a fragment of Laurentia left behind when the North Atlantic opened.

Figure 2 Typical terrain at the western end of the Loch Borralan Complex (Scotland). The boggy peat, sometimes 3 m thick and much of it covered in thick grass and heather, provides only rare glimpses of the nepheline syenite complex and its associated apatite-rich pyroxenites.

At several places in the intrusion there are clusters of xenoliths of more basic varieties of syenite. On the eastern side, close to a contact with some Cambrian limestones, are a few tiny exposures of apatite-rich magnetite pyroxenite in a small stream. A Geological Survey memoir published in 1926 boldly drew an analogy with the Shonkin Sag laccolith in Montana and proposed that the Loch Ailsh intrusion was a stratified laccolith with an upward transition from pyroxenite through shonkinite and pulaskite to an upper body of perthosite. Clearly, this laccolith model stood or fell on the attitude and extent of the pyroxenites under the peat.

Encouraged by geophysicists at Durham University, I found a field assistant and we headed north with another new-fangled device, a proton precession magnetometer. I remember the excitement as we started a traverse at right angles to the little stream, recording the total magnetic intensity every few paced yards. The intensity just went up and up and up! We had discovered one of the largest magnetic anomalies in the UK: 5000 γ, in the units of the time. We made numerous profiles, constructed a contour map which showed the anomaly dying out as the pyroxenites passed under the Moine Thrust, and headed triumphantly home.

The geophysics group was fired up by this discovery. I measured the magnetic properties of orientated samples of pyroxenite and teamed up with Roger Stacey, a geophysics post-grad. He wrote a programme for the Ferranti Pegasus computer in Newcastle University (UK) that would enable us to calculate the subsurface shape of the pyroxenite body. Pegasus was big: think minibus, but narrower. A restored Pegasus in the Computing Gallery of the Science Museum in London is currently the oldest working electronic computer in the world! Each morning it took engineers two hours to warm up its vacuum tubes. Because we had to travel some distance, Roger and I were given special permission to switch it off when it had finished its number crunching. This was not difficult – we just pressed a big red button and closed the windows!

Our calculations clearly showed that the pyroxenites formed a near vertical mass and that a zone of large vertical screens of pyroxenite occurred within the syenites. The stratified laccolith was no more. My first paper (1965) was in geophysics. But the story does not end there. A few kilometers west-southwest of the Loch Ailsh intrusion is a much larger pluton, the Loch Borralan Complex. The little rock that is actually exposed is a riot of exotic nepheline syenites and quartz syenites, some of which were given names by the early workers that are used to this day. There are also some tiny exposures of pyroxenite, including one hidden in the vegetation of Figure 2. Encouraged by our success at Loch Ailsh, we made a single traverse across a large area of totally unexposed ground in the south-west of the intrusion where the contact had to be. Again, we found a very strong magnetic anomaly and evidence for screens of pyroxenite in other less magnetic rocks of unknown type.

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Commercial interests arrived in 1969 when, encouraged by the high vanadium content (0.3%) of the magnetite in the pyroxenites, Robertson Research International made a detailed magnetic survey of the Loch Borralan Complex and diamond-drilled four holes through our anomaly. Further drilling was carried out by Consolidated Goldfields in 1975, and in 1981 the British Geological Survey completed a detailed gravity survey and drilled 37 boreholes over an area of about 3 km^2, their interest being sparked by the high apatite content (up to 10%) of the pyroxenites and its potential as a source of phosphate. Further drilling followed in the 1980s, funded by the UK Department of Trade and Industry, because of the discovery that some pyroxenites contained up to 328 ppb Pt and 550 ppb Pd. Rather similar platinum group element (PGE) values were found in the Loch Ailsh pyroxenites.

So, from little acorns do mighty oak trees grow. Two lads with a magnetometer, driven only by curiosity, and helped by one of the earliest computers, discover a potential source of PGE and a source of phosphate in the form of apatite. I hope it is never mined. In the UK, we need to preserve our limited wild country.

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