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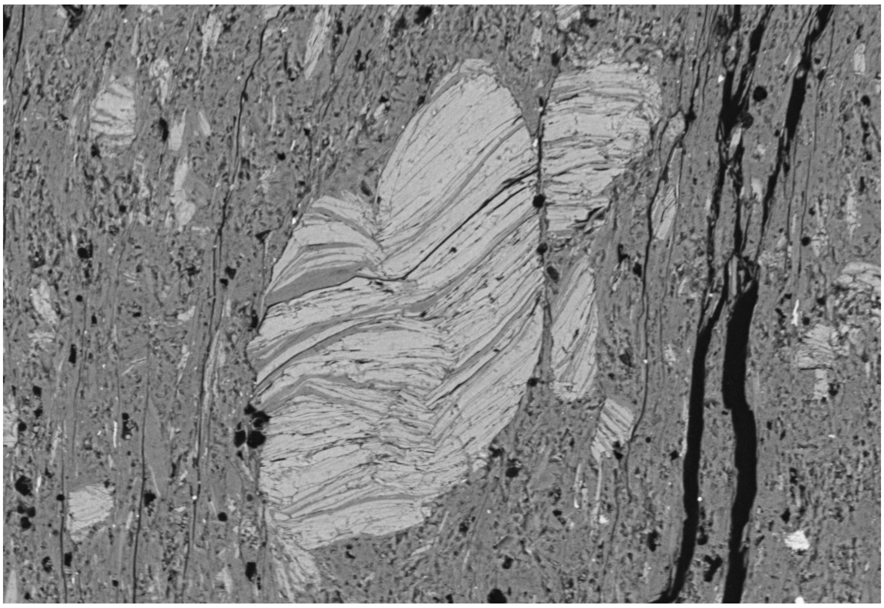
Petrography and low grade metamorphism of an Ordovician pelite from the Fishguard district, Wales, 1:50k sheet 210

Geology & Landscape Southern Britain Programme

Internal Report IR/06/038



BRITISH GEOLOGICAL SURVEY

GEOLOGY & LANDSCAPE SOUTHERN BRITAIN PROGRAMME

INTERNAL REPORT IR/06/038

Petrography and low grade metamorphism of an Ordovician pelite from the Fishguard district, Wales, 1:50k sheet 210

S J Kemp and R J Merriman

Keywords

pelite, petrography, XRD, illite crystallinity, Wales.

Front cover

Backscattered scanning electron photomicrograph showing a deformed chlorite-mica stack.

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Summary

This report describes the results of a petrographic and X-ray diffraction study of a single pelite sample collected as part of the geological survey of the Fishguard, Wales 1:50k sheet 210. A Kubler Index of 0.41 from XRD analysis indicates that the pelite has just reached the low anchizone grade of low grade metamorphism. Backscattered scanning electron microscopy of a polished thin section of the pelite reveals evidence of sedimentary lamination, a penetrative cleavage and later Fe-oxide veining. Such findings are in keeping with previous illite crystallinity surveys of the Welsh Basin.

1 Introduction and techniques

Systematic studies of metapelitic grade linked with the geological re-survey of Wales (e.g. Kemp & Merriman, 2002), the Scottish Southern Uplands (e.g. Kemp & Merriman, 2004) and south-west England (e.g. Merriman & Kemp, 2001) have been used to generate a series of contoured metamorphic maps covering much of the UK's Lower Palaeozoic terranes. These studies have used X-ray diffraction (XRD) measurements of clay mineral reaction progress, particularly *white mica (illite) crystallinity (IC)*, to delineate zones of diagenesis and low-grade metamorphism in the Ordovician, Silurian and Devonian strata.

Burial of unconsolidated clays in basinal sequences causes progressive compaction and lithification resulting in typical shale and mudstone lithologies. The clay mineral reactions that accompany lithification transform authigenic and detrital minerals, such as smectite and kaolinite, to assemblages dominated by illite and chlorite. Tectonic deformation of these pelitic lithologies results in further progressive changes in clay mineral assemblages and the development of metapelites with a *slaty cleavage microfabric*. Progress of late diagenetic and very low-grade metamorphic reactions in buried and tectonized pelitic sequences can be monitored by measuring changes in the illite–muscovite (white mica) reaction series as thicker crystallites develop in response to progressive recrystallisation (Merriman *et al.*, 1990, 1995). The *Kubler index (KI in $\Delta°2\theta$)* measures small reductions in the half-height width of the mica ~10 Å X-ray diffraction (XRD) peak which occur when the crystallite population thickens. In pelitic rock sequences the Kubler index is used to define the limits of a series of metapelitic zones of very low– and low-grade metamorphism: late diagenetic zone KI>0.42; lower anchizone KI 0.30–0.42; upper anchizone KI 0.25–0.30; epizone KI<0.25 (Merriman & Peacor, 1999).

For this study, a single cleaved Ordovician pelite from the Penmaen Dewi Formation (mineralogy and petrology laboratory number, MPLL754) was collected from a cutting at the side of a forestry track at Allt Llyn-dyfrion [SN 1084 2453], some 20 km south-east of Fishguard and 18 km north-east of Haverfordwest, Dyfed, Wales.

The aims of this brief investigation were to establish the grade of the sample and provide evidence for its burial and deformation history. The sample was therefore prepared and analysed by XRD techniques in order to determine the Kubler Index (KI) of white mica (illite) crystallinity. In addition, a polished thin section was prepared for examination under the scanning electron microscope to determine the nature of its texture and fabric.

2 Laboratory methods

2.1 X-RAY DIFFRACTION

2.1.1 Sample preparation

Initial sample crushing was carried out by the BGS Sample Preparation Facility, Keyworth. After removing any surface contaminants with a wire brush, a representative 50 g portion of each sample was stage-ground, using a Cr-steel tema-mill in 5 second bursts, to pass a 1 mm sieve. Care was taken to subject the sample to short bursts of milling in order to reduce the chance of over-grinding delicate *phyllosilicate* grains.

A representative 4 g portion of the crushed sample was then placed in a boiling tube and distilled water added to a predetermined level. Each sample was then shaken thoroughly, subjected to ultrasound for 5 minutes and allowed to stand for 3 hours. Where flocculation occurred, 0.5 ml of 0.1M sodium hexametaphosphate was added and the dispersion process repeated. After 3 hours, a nominal <2 µm fraction was removed and centrifuged at maximum speed for 20 minutes. The clear supernatant was then removed and the <2 µm fraction re-dispersed in ~1 ml distilled water with a glass rod and minimal ultrasound. The <2 µm fraction slurry was then pipetted onto the surface of a frosted glass slip and allowed to dry overnight at room temperature.

2.1.2 Analysis

Each glass slip was analysed using a Philips PW1700 series diffractometer equipped with Ni-filtered Cu-Kα radiation and operating at 45kV and 40mA. The KI of the sample was calculated from the mean of five scans over the range 7.5-10.5 °2θ at a speed of 0.5 °2θ/minute using the machine conditions recommended by Kisch (1991). The width of the ~10 Å peak at half-height was measured using the graphics package within PANalytical's X'Pert software suite and values were corrected using the standards of Warr & Rice (1994).

2.2 SCANNING ELECTRON MICROSCOPY

2.2.1 Polished thin-section preparation.

A polished thin-section was prepared from the sample in BGS's in-house thin-section preparation facility. The sample was impregnated with blue-dyed resin to highlight porosity.

2.2.2 Analysis

The polished section was coated with carbon approximately 25 nm thick using an EMITECH 950L carbon evaporation-coating unit to provide an electrically conductive surface prior to examination.

The section was examined using a LEO 435VP variable pressure digital scanning electron microscope, fitted with a backscattered electron detector and an Oxford Instruments ISIS 300 digital EDXA system. An accelerating voltage of 20 kV and a probe current of 400 nA was used throughtout the study.

3 Results

3.1 X-RAY DIFFRACTION ANALYSIS

XRD analysis indicates the KI of the sample to be 0.41 (Figure 1) which suggests that it has just reached a low anchizonal grade of low-grade metamorphism.

3.2 SCANNING ELECTRON MICROSCOPY

Brief examination of the sample under the scanning electron microscope show it to be a mica- and chlorite-rich, fine-grained silty mudstone with abundant chlorite-mica stacks and authigenic Fe- and Ti-oxides.

Three fabrics are discernable in the pelite from scanning electron microscopy. Firstly, a sedimentary lamination is indicated by a general alignment of the chlorite-mica 00*l* stacking planes (shown ~south-east to north-east in Figures 2, 3, 4 and 5). Chlorite-mica stacks developed during burial of mudrock sequences in the Welsh Basin, and represent the deep diagenetic reaction products of argillised mafic detritus, such as biotite, ferromagnesian minerals and mafic lava particles. The stacking planes in these clay mineral aggregates represent a microfabric with an overall bedding-parallel orientation (Merriman, 2002). Secondly and more obviously due to the orientation of the section, the slaty cleavage is indicated by profuse cracking (oriented ~north-south in Figures 2, 3, 4, 5 and 7), some of which are likely to be an artefact of thin section production. The chlorite-mica stacks show deformation, kinking and fracturing induced by rotation to the direction of cleavage (Figures 3 and 4). During deformation mainly white mica crystallized between the stacking planes.

The pelite is also characterised by a late set of fractures occupied by Fe-oxide veins that post-date cleavage formation (Figures 2, 5 and 6). The veins are characterised by the extensive, surrounding development of Mg, Fe-chlorite (Figures 2, 5 and 6).

4 Discussion

The pelite sample from the Fishguard district shows typical features of many others examined during the course of the Welsh regional survey (Merriman & Frey, 1999).

The low anchizonal grade indicated by a KI of 0.41 is characteristic of large tracts of central Wales that extend through the Fishguard area (cf. Fig 3.7, Merriman & Frey, 1999). This relatively low-grade is predominantly the result of burial metamorphism (Robinson & Bevins, 1986). The bedding-parallel microfabric in the chlorite-mica stacks developed during burial metamorphism, and is essentially a response to overburden stresses associated with static burial (Merriman & Peacor, 1999). Strain-related growth of white mica and chlorite subsequently took place during the development of the Acadian slaty cleavage (Roberts & Merriman, 1985; Merriman, 2002). The age of the post-cleavage fracturing is unknown.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

KEMP, S J and MERRIMAN, R J. 2002. Metamorphism of the Lower Palaeozoic rocks of the Builth Wells district, Wales, 1:50K Sheets 196. *British Geological Survey Technical Report*, IR/02/025.

KEMP, S J and MERRIMAN, R J. 2004. Metamorphism of the Lower Palaeozoic rocks of the Moffat district, southern Scotland, 1:50K Sheet 16W. *British Geological Survey Technical Report*, IR/04/120.

KISCH, H J. 1991. Illite crystallinity: recommendations on sample preparation, X-ray diffraction settings and interlaboratory standards. *Journal of Metamorphic Geology*, 9, 665-670.

MERRIMAN, R J. 2002. Contrasting clay mineral assemblages in British Lower Palaeozoic slate belts: the influence of geotectonic setting. *Clay Minerals*, 37, 207-219.

MERRIMAN, R J and FREY, M. 1999. Patterns of low-grade metamorphism in metapelitic rocks. 61-107 in *Low–grade Metamorphism.* FREY, M and ROBINSON, D. (editors). Blackwell Science.

MERRIMAN, R J and PEACOR, D R. 1999. Very low–grade metapelites: mineralogy, microfabrics and measuring reaction progress. 10-60 in *Low–grade Metamorphism.* FREY, M and ROBINSON, D. (editors). Blackwell Science.

MERRIMAN, R J. and KEMP, S J. 2001. Metamorphism of the Palaeozoic rocks of the Torquay district, Devon, 1:50K Sheet 350. *British Geological Survey Technical Report*, IR/01/184.

MERRIMAN, R J and ROBERTS, B. 2001 (for 2000). Low-grade metamorphism in the Scottish Southern Uplands terrane: deciphering the patterns of accretionary burial, shearing and cryptic aureoles. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, 91, 521-537.

MERRIMAN, R J, ROBERTS, B. and PEACOR, D R. 1990. A transmission electron microscope study of white mica crystallite size distribution in a mudstone to slate transitional sequence, North Wales, U K. *Contributions to Mineralogy and Petrology*, 10**,** 27-40.

MERRIMAN, R J, ROBERTS, B, PEACOR, D R and HIRONS, S R. 1995. Strain–related differences in the crystal growth of white mica and chlorite: a TEM and XRD study of the development of metapelitic microfabrics in the Southern Uplands thrust terrane, Scotland. *Journal of Metamorphic Geology*, 13, 559–576.

ROBERTS, B and MERRIMAN, R J. 1985. The distinction between Caledonian burial and regional metamorphism in metapelites from North Wales: an analysis of isocryst patterns. Journal of the *Geological Society*, 142**,** 615-624.

ROBINSON, D, and BEVINS, R E. 1986. Incipient metamorphism in the Lower Palaeozoic marginal basin of Wales. *Journal of Metamorphic Geology*, 4, 101-113.

WARR, L and RICE, A H N. 1994. Interlaboratory standardization and calibration of clay mineral crystallinity and crystallite size data. *Journal of Metamorphic Geology*, 12, 141–152.

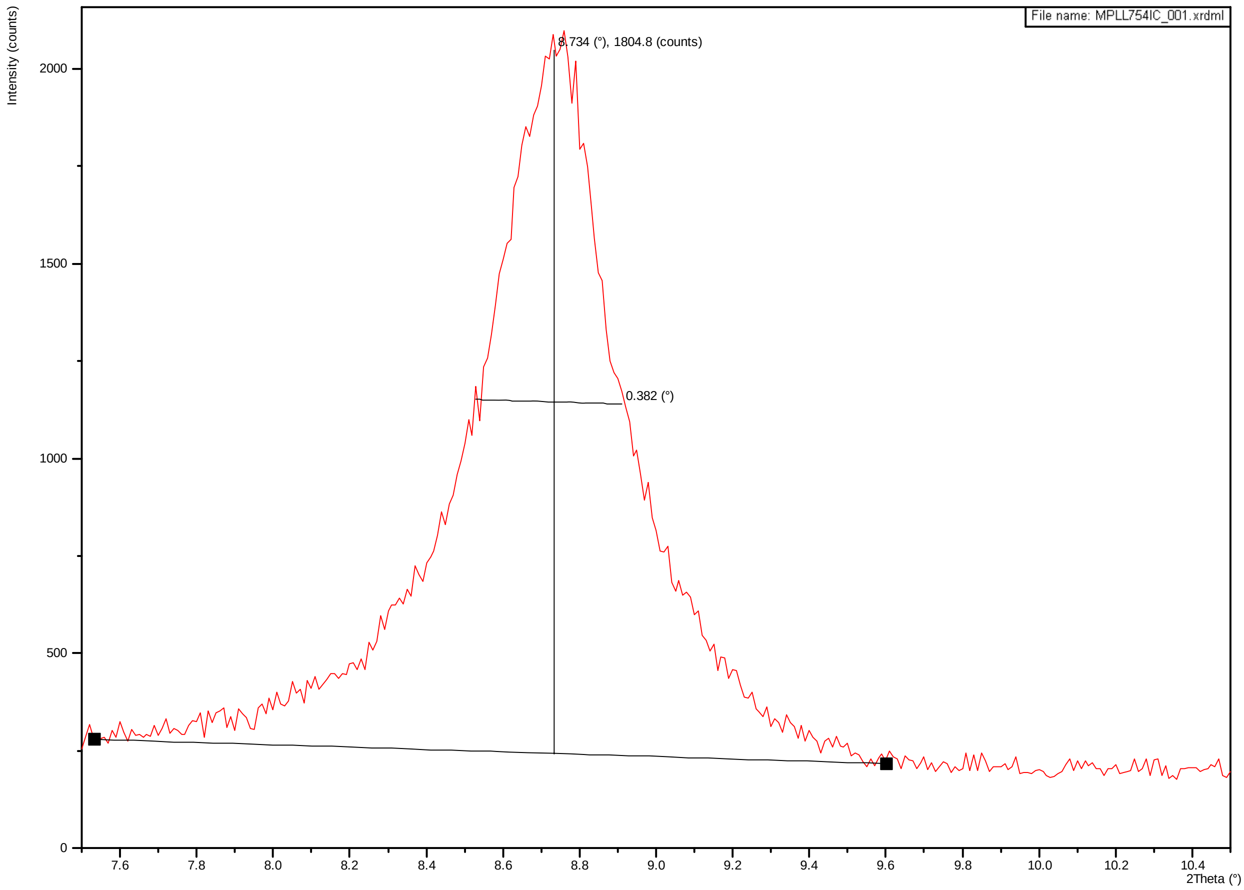

Figure 1. Illite crystallinity XRD scan with marked full width at half maximum (FWHM). Note the FWHM measurement shown on this figure is not the IC value reported as it has not, at this stage, been adjusted to the CIS standard measurements.

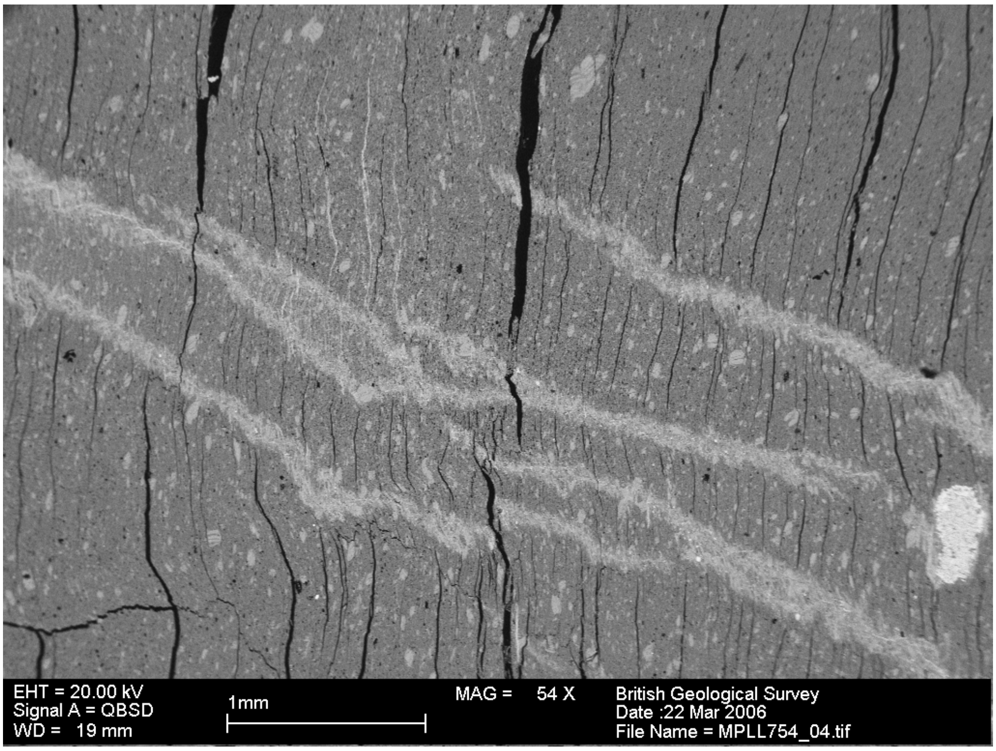

Figure 2. Low magnification backscattered scanning electron photomicrograph illustrating the three main textures in the pelite. Sedimentary lamination is indicated by the approximate alignment (~SW-NE) of the stacking planes of chlorite-mica stacks. Slaty cleavage is indicated by the abundant ~N-S cracking. Both lamination and cleavage are cross-cut by Fe-oxide veining (~WNW-ESE)

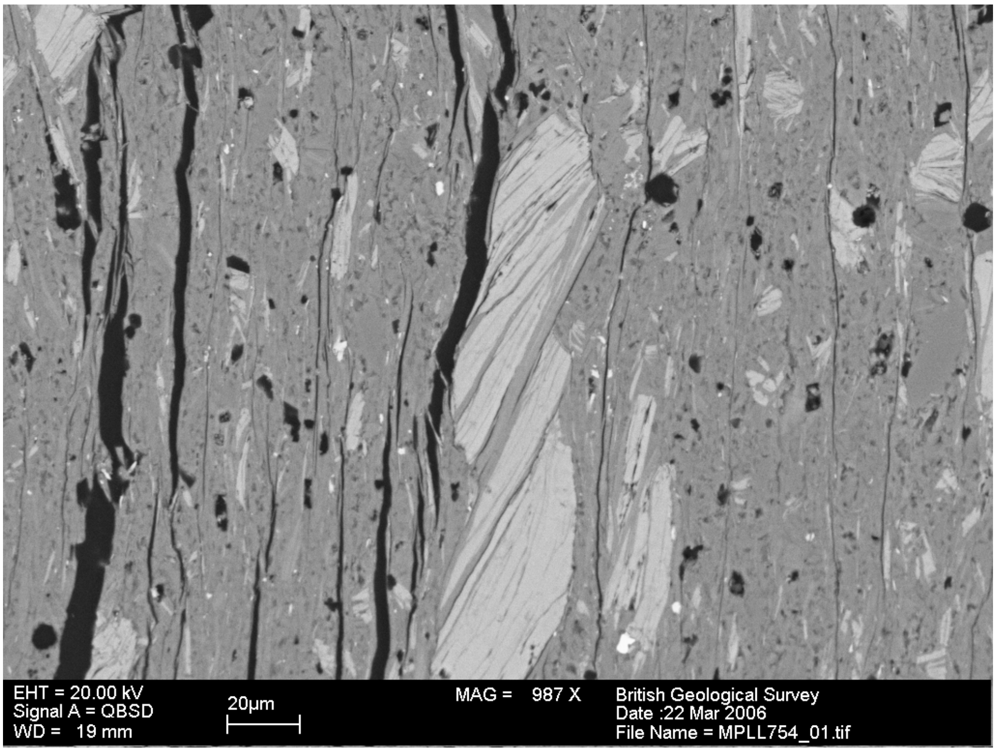

Figure 3. Backscattered scanning electron photomicrograph showing a typical chlorite-mica stack (centre). Note the original sedimentary lamination orientation (~SW-NE) and partial rotation of stack to the near-vertical cleavage direction.

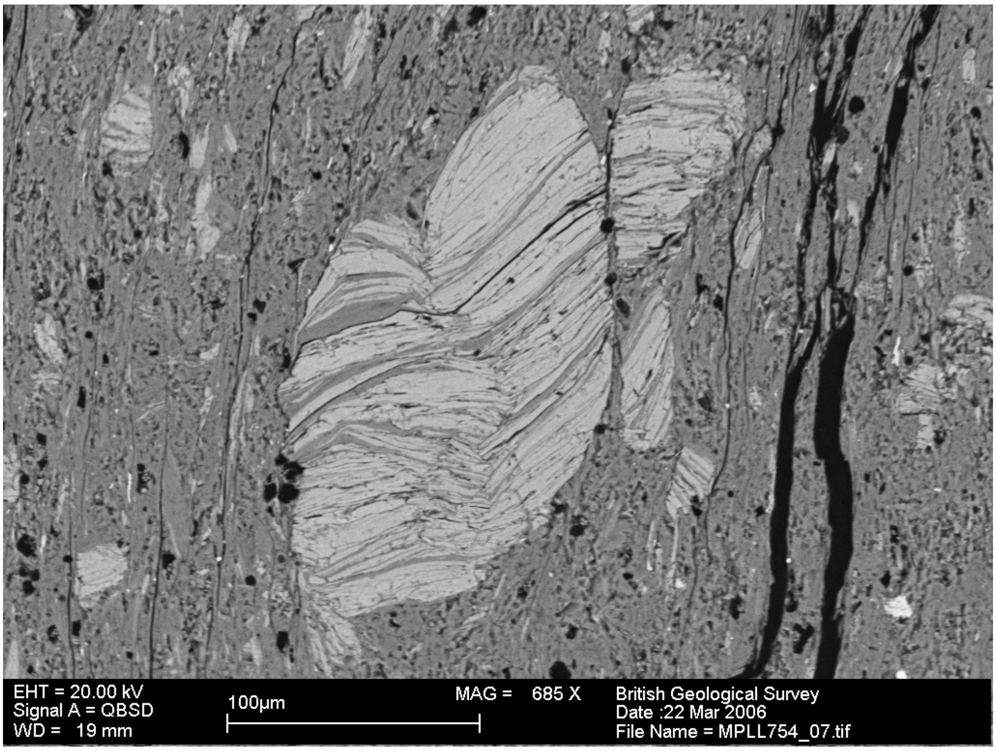

Figure 4. Backscattered scanning electron photomicrograph showing a deformed chlorite-mica stack. Darker layers indicate K-white mica, brighter layers are Mg-rich chlorite. Note how the stacking planes have been deformed, kinked and fractured after rotation during cleavage formation.

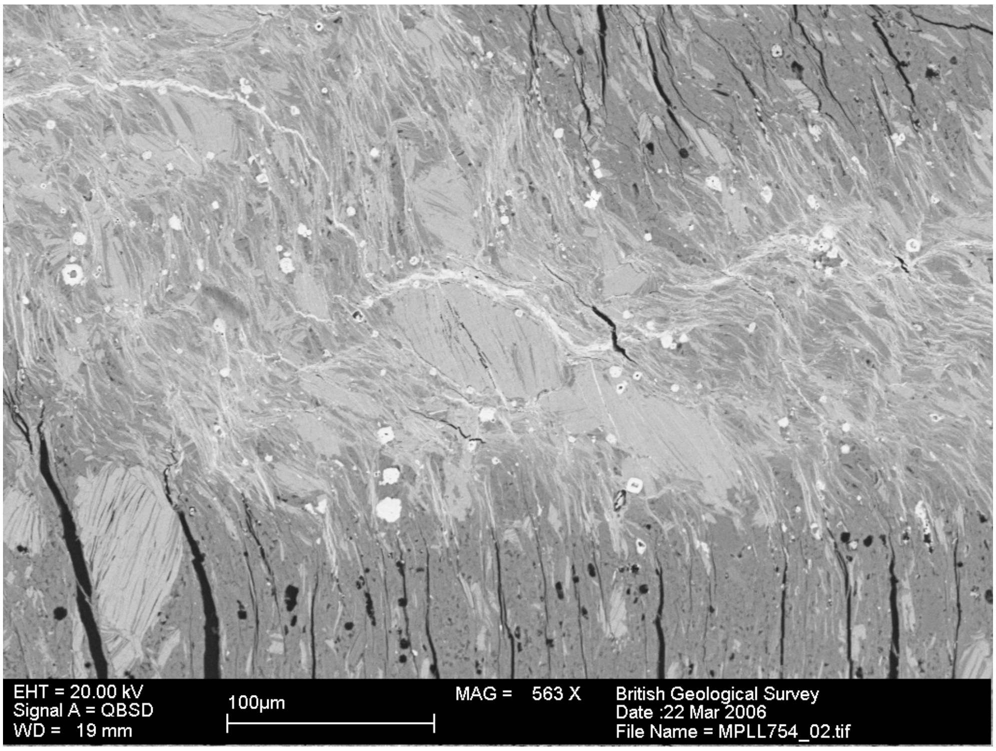

Figure 5. Backscattered scanning electron photomicrograph showing an Fe-oxide vein (bright) cross-cutting the ~N-S cleavage. Note the extensive development of Mg, Fe-chlorite around the Fe-oxide vein. The small bright rounded grains are Ti-oxides (rutile/anatase) and Fe-oxide.

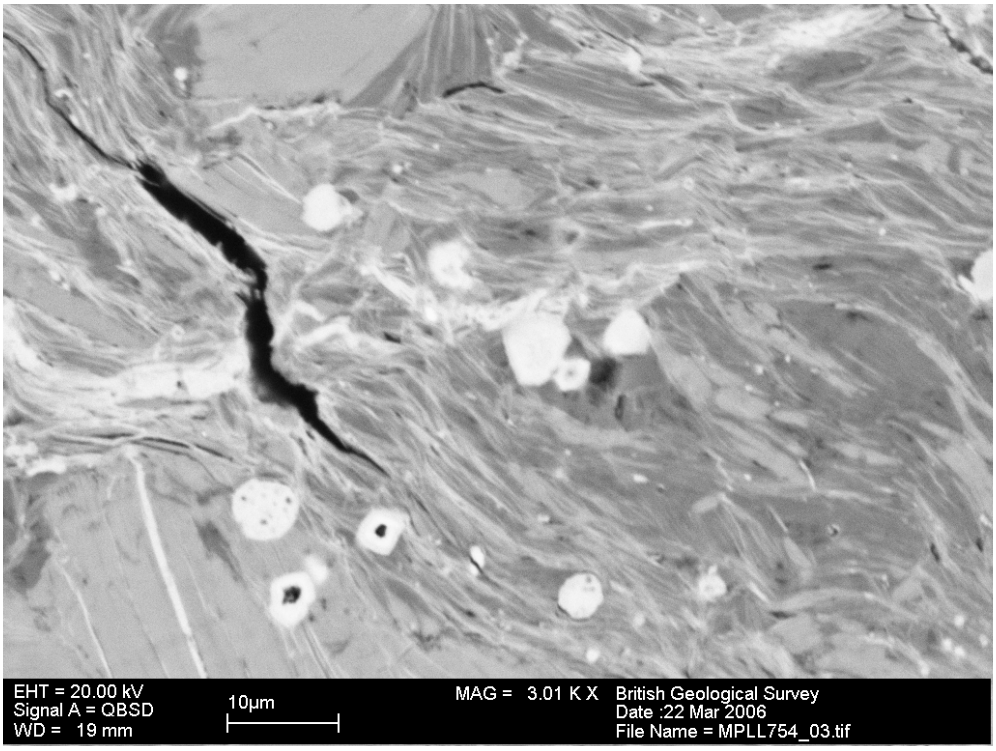

Figure 6. Higher magnification backscattered scanning electron photomicrograph of an Fe-oxide vein (bright) surrounding Mg, Fe-chlorite development. Some of the Fe-oxide grains show corroded cores, perhaps suggesting alteration of primary volcanogenic magnetite to hematite.

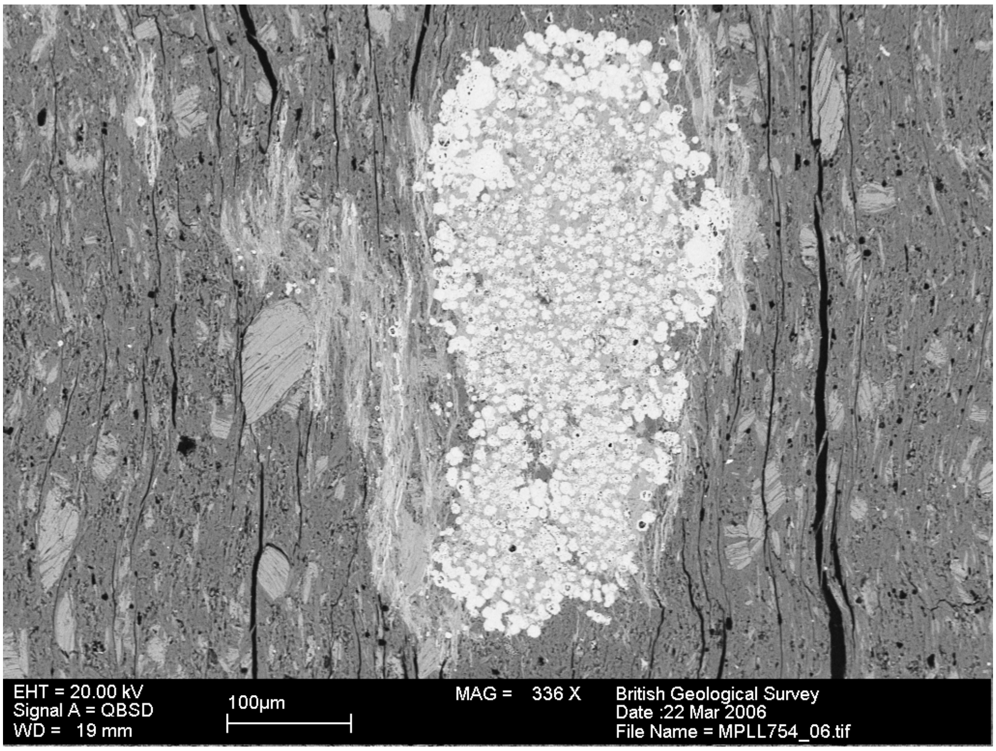

Figure 7. Backscattered scanning electron photomicrograph showing a zone of intense Fe-oxide development, perhaps suggesting alteration of an original large, ferromagnesian-rich grain.

Glossary

Illite crystallinity (IC) Variations in the crystallite size and lattice strain in dioctahedral potassium mica produced in the smectite-I/S-illite-muscovite reaction series, as indicated by the Kubler index.

Kubler index (KI) The width of the X-ray diffraction c.10Å peak at half-height above background, measured as small changes in the Bragg angle $\Delta°2\theta$.

Metapelitic grade The grade of diagenesis and low-grade metamorphism indicated by reaction progress in clay minerals and other phyllosilicates.

Slaty cleavage microfabric A pervasive planar fabric consisting of submicron-spaced domains of phyllosilicates. Strain-related crystal growth of the phyllosilicates has resulted in their (00l) crystallographic planes being orientated approximately parallel to the fabric. Although the mineral constituents of the microfabric cannot be resolved with the naked eye, their parallel orientation gives rise to a fissility that dominates all other fabric elements of the mudrock and can be exploited to cleave the rock into thin (<10 mm) parallel-sided slates.

Strain-related crystal growth The crystal growth of minerals induced by rock deformation. Strain-related crystal growth is response to several interactive processes, including mechanical grain rotation of existing minerals, pressure-solution (dissolution) recrystallization and grain-boundary migration (dislocation creep) in newly-formed minerals.

Phyllosilicates A group of silicate minerals, including the micas and clay minerals, which consist of SiO_4 tetrahedra linked into flat sheets with an Si:O ratio of 1:5. Cations and water are accommodated between the sheets and such minerals are characterised by a very prominent cleavage parallel to the sheet structure.