Undergraduate (BSc) Dissertation

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C2050580

Linking and characterising Lithologies surrounding the Dolaucothi Gold Mine using petrological and mineralogical analyses

Abstract

After being abandoned for 20 years, interest in gold exploration around the Dolaucothi gold mine was reawakened by Sarn Helen Gold in 2020. From August to September 2022, the author worked for Sarn Helen Gold as part of Cardiff University's undergraduate dissertation project. This involved working in a team during a field season of exploration in the area. The data collected during this field season is the foundation for this report, with the focus surrounding studying lithologies using rock samples collected, various analysis methods and field observations. From the samples studied it appears that the mineralogical composition of the host rock follows patterns which are closely linked with what lithology they belong to according to Annels and Roberts (1989) parameters. The Lithologies described by the BGS appear to be based primarily on age and no patterns of mineralogy were observed. From the samples studied in this paper none of the gold sources described by Annels and Roberts (1989) were found, however the high carbon content (causing the black colour) of the shales and the permeability of the siltstone within certain lithologies could affect the ability of gold to be exsolved.

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1. Introduction

1.1 Project background

Welsh Gold is typically associated with mining in the Dolgellau area which has historically provided gold for the British royal family, however the lesser known Dolaucothi mine has also produced gold dating back to the Roman era. The Dolaucothi mine was rediscovered in the Victorian period and mining was operational from the 1890s until closure in the 1930s due to economic struggles, after which it was acquired by the national trust who still own the mine to this day. At the current time the national Trust show no interest in exploration or mining on their land. Sarn Helen Gold (SHG) acquired the exploration licence for the region from the Crown Estate in 2020. The company had an Interest in gold exploration in the area due to the historic mine site as well as the belief that gold mining in Wales mustn't be limited to just the Dolgellau mine. Previous studies conducted in the 1980s by Cardiff University and Anglo-Canadian Exploration have also shown that there is potential for gold to be found in the geological structures extending from the Dolaucothi mine site.

1.2 Details on the placement partner

The placement partner for this project is Sarn Helen Gold Ltd (SHG), a small exploration company focusing on sources of Welsh gold with exploration licences in central and northern Pembrokeshire as well as around the Dolaucothi gold mine in Carmarthenshire. Mike Armitage, former MD of SRK Consulting and a team of geologists and mining engineers founded the company in 2020. SHG provided funding for the thin sections used in this project

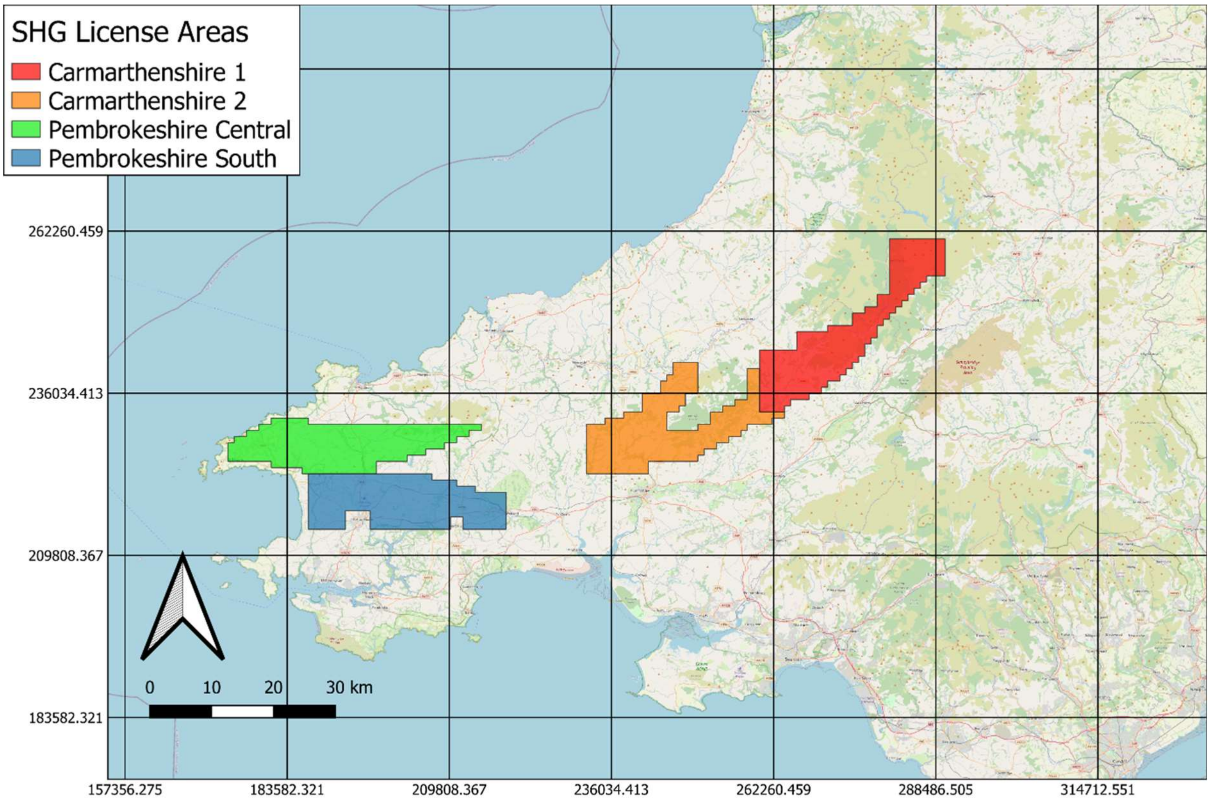


Figure 1: Map of South-West Wales, SHG's license areas represented as coloured polygons

1.4 Role of the student

The author spent 6 weeks on placement with Sarn Helen during the second half of their 2022 field season between 22/08/22 and 30/09/22 working within the Carmarthenshire 1 license area (fig. 1). Accommodation was provided by SHG in Lampeter. Roles on placement involved soil sampling, stream sediment sampling and panning for gold within the licence area around the Dolaucothi gold mine. During the field season the author also spent time mapping the structure of the area and collected relevant data for this dissertation including field observations of outcrop and rock samples.

1.5 Project Aims and Objectives

The Aim of the project is to advance the knowledge of the lithology of the gold host rocks surrounding the Dolaucothi mine and create links with previous studies of the lithology. This will be achieved by the author using petrology, field observations and geochemical/mineralogical analysis methods (XRD, pXRF).

Objectives:

- Create petrological descriptions of rock samples using thin sections.
- Compare optical observations with XRD and XRF data to scrutinise the mineralogy of the samples.
- Compare results and create links with lithologies identified by BGS mapping and in Annels' and Roberts' (1989) paper.
- Compare lithologies with modes of gold exsolution.

2. Geology

2.1 Regional Geology

During the lower Paleozoic Wales was located at the southern continental margin of the Iapetus Ocean and contained a basin known as the Welsh Basin. This Basin accumulated shallow and deep-water sediments into a sequence up to 15km deep (Annels & Roberts, 1989). According to Howells (2007) the size of the basin was controlled by major fractures in the Precambrian basement rock and its evolution over time was caused by uplift and subduction due to tectonic activity along these fractures. During the Ordovician Volcanic activity was prominent in Wales leading to the accumulation of thick layers of volcanic rocks. By the late Ordovician and early Silurian volcanic activity had ended and sequences of fine silts and mud were deposited by processes such as turbidity flows within the Welsh Basin. These lithified to form the rocks currently found within the study area. During the Caledonian orogeny (390-410 Ma) these sediments were folded and uplifted, forming structures such as the Harlech and Berwyn domes (Howells, 2007). Most relevant for this paper is the North-Easterly domeshaped fold structure known as the Cothi Anticline on which the study area is located. The geology of the area as mapped by the BGS is represented in fig.2.

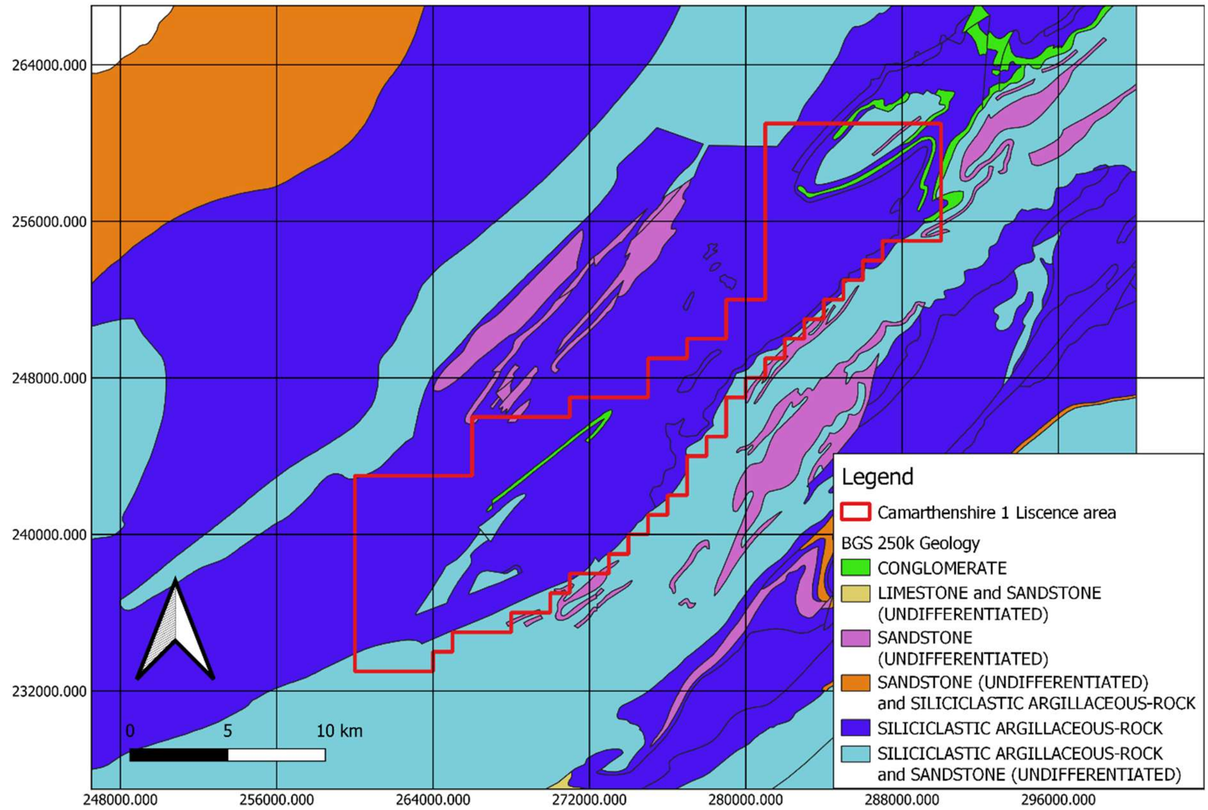


Figure 2: BGS 250k map of regional geology, coloured polygons represent different lithologies, red outline represents SHG's Camarthanshire 1 license area (basemap from Edina Digimap).

2.2 Local Geology

The geology of the study area is comprised of a repetitive sequence of thinly bedded shales and siltstones deposited by turbidity currents during the late Ordovician and early Silurian at the southern margin of the Welsh basin. From previous work by Annels & Roberts (1989) analysing exposures and drill core, five main lithologies have been identified, each representing a section of this sequence transitioning from higher concentrations of silt to black shales. These Lithologies summarised as follows: *black shales* (BS) are close to homogenous, bedding and colour banding is rare and hard to distinguish, a dominant cleavage is present with which a strong fissility is associated, <1mm thick silt bands are locally found. *Banded black shales* (BBS) contain colour banding which is the result of variations of silt content within the shale, they are also differentiated from BS by fissility associated with bedding caused by the presence of 1mm thick silt bands, laminated siltstone bands 5-10mm thick can sometimes be found. *Banded black shales and siltstones* (BBSS) contain similar banding to BBS however 5-10mm thick siltstone bands can make up 20% of the rock, bedding is typically laminar however ripple-drift bedding can occasionally be found, contacts with other lithologies are sharp. *Shale and siltstone* (SS) contain 10-20mm thick siltstone bands, with siltstone making up at least 40% of the rock, the siltstone bands can be lensoid or discontinuous and can contain sharp basal and upper contacts with sudden transitions into shale. *Shales and quartzites* (QS) is the coarsest grained lithology identified and has a very flaggy appearance, quartzite bands 20-100mm thick make up as much as 60% of the rock and crossbedded slump structures, load casts, and other bottom structures are common. Lenticular bedding is usually observed but planar bedding can also be found, Cleavage is rare. Work conducted by the BGS concluded that 4 Lithologies were present in the study area. The contacts of these lithologies follows the Silurian/Ordovician boundary. These lithologies consists of the following: Silurian interbedded mudstone and laminated hemipelagic mudstone, burrow-mottled mudstone (thin bed at the Silurian/Ordovician boundary), Ordovician silty mudstone, Ordovician sandstone. These lithologies are represented in fig.3.

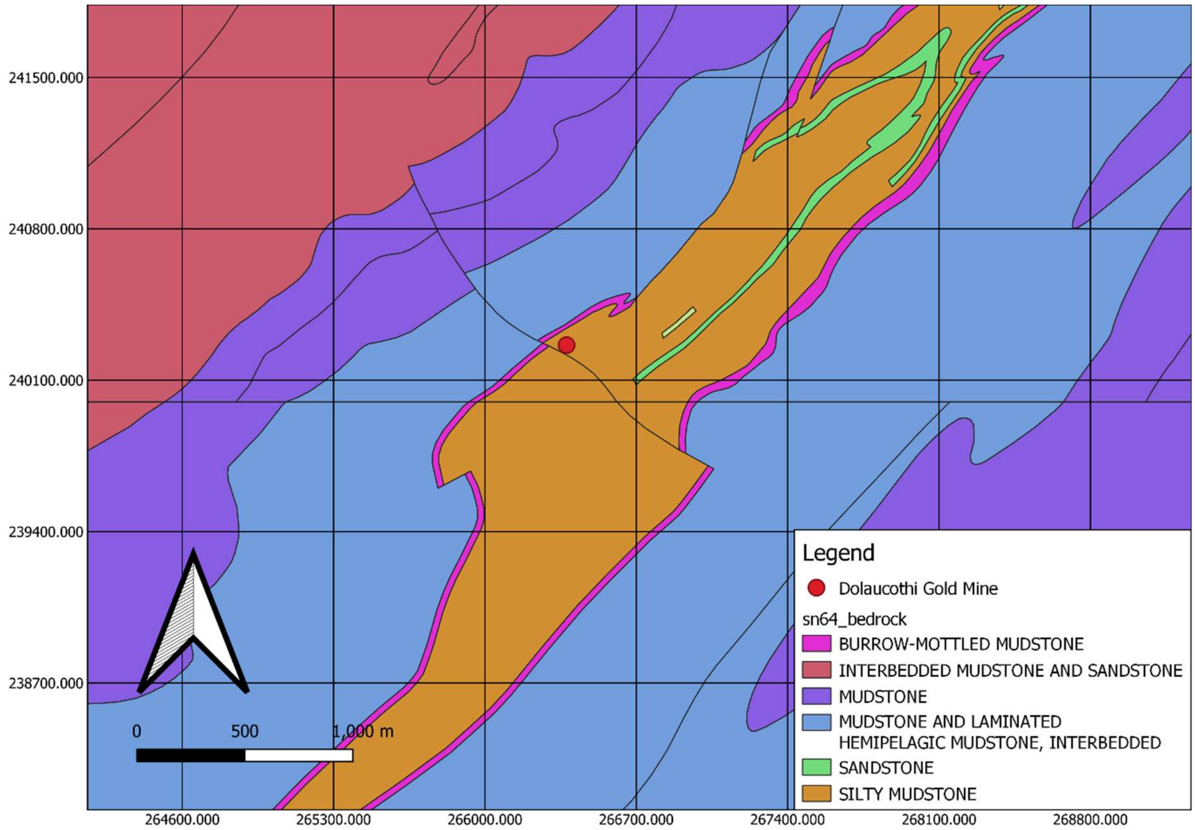


Figure 3: BGS 25k map of geology within study area, coloured polygons represent different lithologies, red dot represents the location of Dolaucothi Gold Mine (basemap from Edina Digimap).

suggested that mineralization in the region is controlled by structures within the Cothi anticline, with particular interest shown in a thrust fault host to the 'Roman lode', a flat-lying auriferous quartz reef. Within the region gold occurs in a variety of host rocks including pyritic shales, quartz-carbonate stringer veins, in steeply or gently inclined veins associated with shear zones and in planar quartz veins associated with the Roman lode. Pyrite and arsenopyrite are described as the dominant sulfides in the region, with ankeritic carbonates, hydro muscovite, and the lithium silicate, cookeite, also present. Their research also suggests that during metamorphism associated with the Caledonian orogeny, fluids circulated through the basement rock and leached gold and associated metals from igneous or volcanic sources. These fluids travelled upwards through the crust during later orogenic events. The host rocks then underwent upper anchizone facies metamorphism whilst the temperature of the mineralizing fluids was approximately 345 to 450^{0}C (Annels and Roberts 1989).

3. Methodology and Data Collection

3.1 Land Access

During the field season data collection took place over an area owned by several private landowners. Contact with these landowners was initially made using information from HM Land Registry, however information was often limited using this method. If permission was given by the landowner, exploration on their land could commence. Once exploration had started supply contact details for neighbouring landowners for often shared. Unfortunately, in some parts of the licence area permission was not granted, most notably on land belonging to the National Trust who are the largest landowners in the area.

3.2 Rock Samples

Before any studies on the characteristics of the host rocks (thin sections, XRD, XRF) could take place samples had to be collected. Fifteen Rock samples were selected based on their location, characteristics visible in the outcrop and in hand specimen and availability (Parts of the study area had a lower concentration of outcrop). This was done to create a data set as representative of the lithologies in the area as possible with the limited budget. At each outcrop from which samples were collected location was recorded using a GPS and field notes were taken. The locations of these outcrops are represented in fig. 4. The first five samples were then labelled as NOS-1-5 (Non-Orientated Sample – 1-5), the other ten were labelled based on the farm in which the outcrops were located. Each sample was then placed in a sample bag.

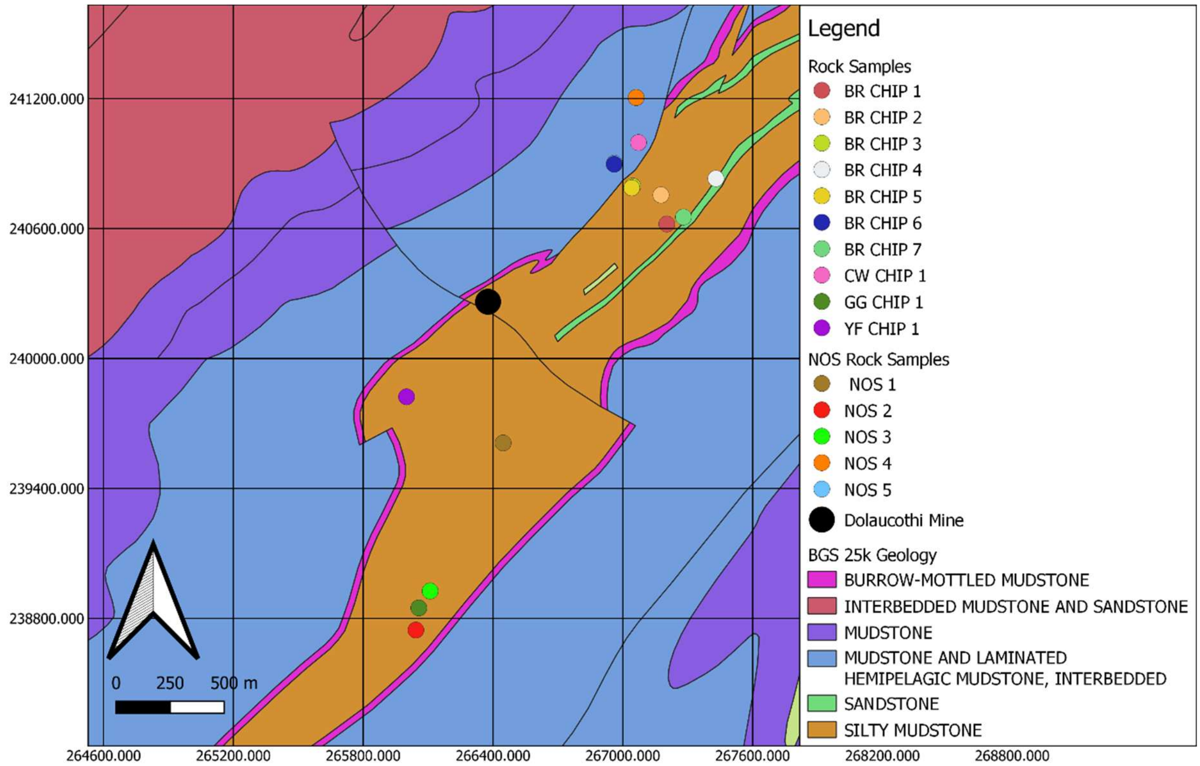


Figure 4: Map showing Rock sample loactions, coloured polygons represent different lithologies from BGS 25k , coloured dots represents the location of the outcrops from which samples were taken and the location of the Dolaucothi Gold Mine (basemap from Edina Digimap).

3.3 Thin Sections

Thin sections were chosen to be made as they allow for the mineral phases of a sample to be studied using microscopes and other analytical instruments. Samples labelled as NOS 1-5 were finished as covered sections whilst the other ten samples were polished as they were also used in another student project where further analysis required a polished surface. These thin sections were produced by Tony Oldroyd at Cardiff University with assistance from the author so that a better understanding of the process was gained. Funding was provided by SHG at a cost of £30 per sample. Samples were analysed and photographed using a Leica DM750P with the LAS version 1.12.0 software.

This method used to produce the thin sections is as follows. Rock samples were Assessed for being soft, fragile, or friable. As they were all these each sample was impregnated with epoxy resin under vacuum so that they were more competent and could withstand the following steps. if competent then the sample is left as is. Next a slice of the sample is cut approximately 10-15mm thick using a diamond saw. The slice is further trimmed, so that rock chip fits onto a glass slide. The sizes used were 76 x 26mm for Covered thin sections and 48 x 28mm for polished thin sections. The side of the sample being attached to the slide was then lapped using a Logitech LP50 machine to create a smooth surface, the other side was labelled prior to this. The samples were then cleaned with water. The slides used were then lapped using the same machine so that the glass was frosted and a better bonding surface was achieved.


Figure 5: Author using the Logitech LP50 lapping michine in the preperation of samples for bonding with slides.

After the samples and slides were prepared, they were bonded with epoxy resin using a mounting jig on a hotplate set to 60^{0}C. This removed any air bubbles from the resin and created a zero bond (gap is less than 1µm thick). The resin used for this and to impregnate the samples has a refractive index of 1.54, the same or close to glass. After the appropriate amount of time the samples were removed from the jig and let cool. Excess rock was then removed from slide using a smaller diamond trim saw with a vacuum holding the slide in place so that approximately 500µm thick of rock was left bonded to the slide. The Slides were then returned to the lapping jig until around 80µm thick before being ground by hand by hand using a glass plate and a slurry of silicon carbide grit. Covered samples were ground down to 30µm thick before a thin piece of glass was placed over the sample and fixed in place using Canada balsam. Polished samples were ground down to 38µm thick before using a Logitech PM5 automatic polisher to finish.

3.4 X-Ray Diffraction

X-ray diffraction (XRD) is a semi-quantitative method which allows for the identification and quantification of minerals within solid, crystalline compounds (notably crystalline rocks). Solid or powdered samples can be analysed and are matched against a database of known mineral phases. The method is based on the principal of crystal structure, in which each pure rock, mineral or compound has a unique diffraction pattern based on its structure. Information previously gathered on the diffraction patterns of minerals is used by software to compare to those of an unknown sample. This allows for the identification of mineralogy. The diffraction pattern of each crystal structure is represented as a set of peaks (d-values) at different intensities on graphs known as diffractograms (Cook et al. 1975).

The XRD analyses was undertaken by Anthony Oldroyd at Cardiff University for this paper, with assistance from the author. The cost of the analyses was £20 per sample. Seven samples were selected before being powdered and packed into an aluminium holder. Using a diffractometer (Philips PW1710 Automated Powder Diffractometer) the samples were then bombarded with X-Rays (Copper (CuKa) Radiation at 35kV 40mA). The diffracted rays were then measured and inputted into a computer (computer software: PW1877 APD version 3.6, Identification Software: PW1876 PC-Identify version 1.0b) where they were converted to d-values of specific intensities using the Bragg equation. Estimations of clay mineral concentrations were undertaken using a paper written by Johns et al. (1954).

3.5 Portable X-Ray Fluorescence

In Brouwer's paper (2006), XRF (X-Ray Fluorescence) is described as a non-destructive, fast, and accurate method of determining the chemical composition of almost any solid or liquid. This is useful for the purposes of this paper as the chemical composition of samples can be used in the identification of mineralogy. XRF machines work by producing X-rays which irradiate the sample. The elements in the sample will then emit fluorescent X-ray radiation with discrete energies characteristic of these elements. These energies can then be measured to determine the elements that are present within the sample. The intensities of the emitted energies are then measured to find the concentrations of each element present within the sample.

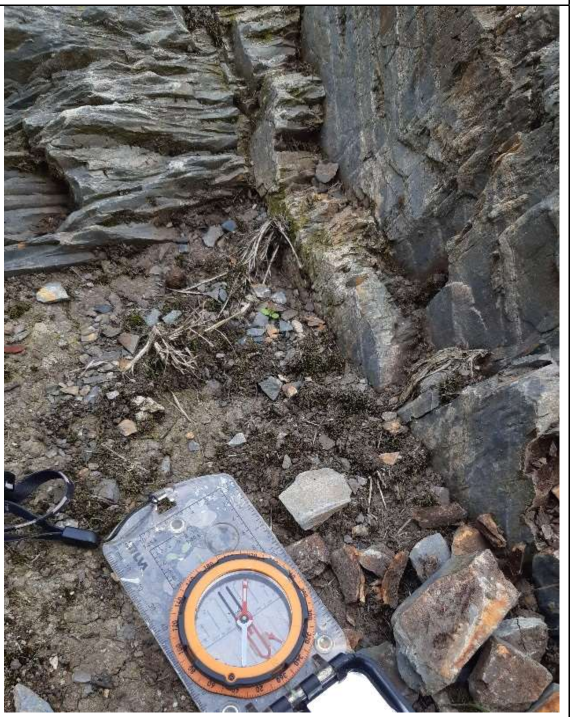
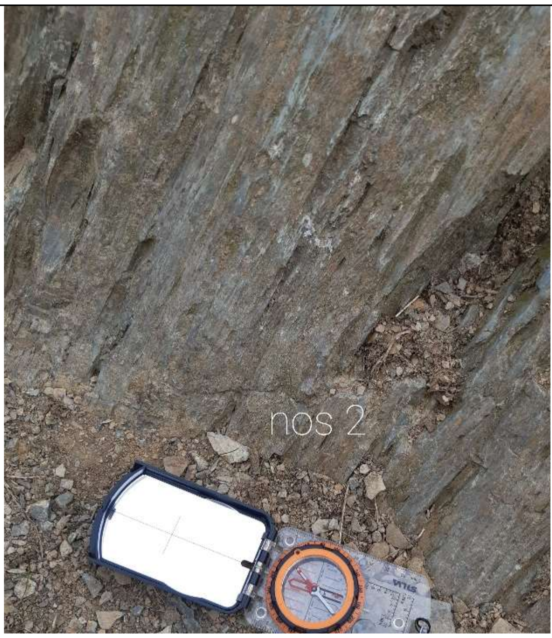
The author sliced each rock sample with a diamond saw in the thin section making process and was left with a fresh surface on the offcut material. Using the pXRF (portable X-Ray Fluorescence) owned by Cardiff University, Dr Iain McDonald analysed the fresh surfaces of 5 samples (NOS-1-5). Scanning fresh surfaces meant that chances of any anomalous results caused by contaminants was minimised. Before analysing the samples, the pXRF was calibrated using a standardised sample of known composition.

4. Results

For the entire project fifteen rock samples were collected, with thin sections being made from all fifteen samples and analysed. XRD analyses was carried out on seven of the samples and pXRF analyses was carried out on five. Field observations of outcrops were also made across the study area.

4.1 Rock Samples & Field Observations

Table 1: Table containing data for each sample location. Observations, coordinates, and photos are presented. Unfortunately photos of some outcrops were corrupted

Sample ID	Field Observations	Outcrop Photo
NOS-1	Bedding and Cleavage visible, thin siltstone banding, stratigraphically bellow banded black shale also seen in outcrop.	
NOS-2	Strong cleavage visible, no bedding observed, extremely homogenous.	

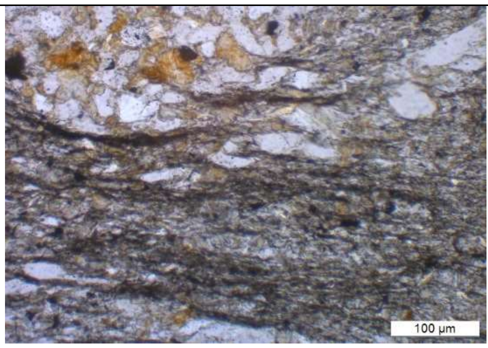
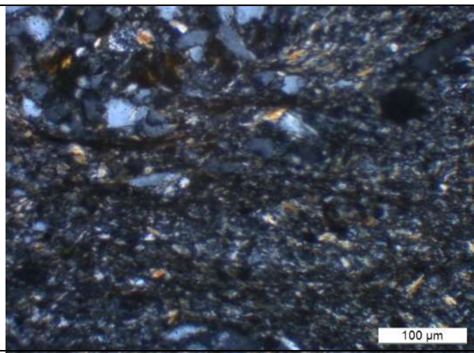
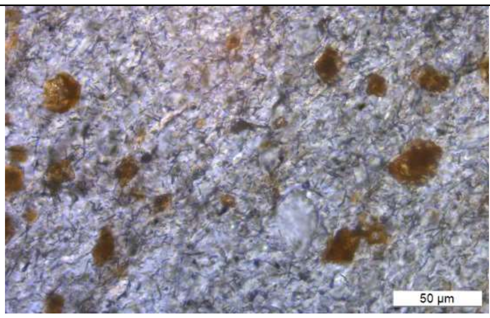
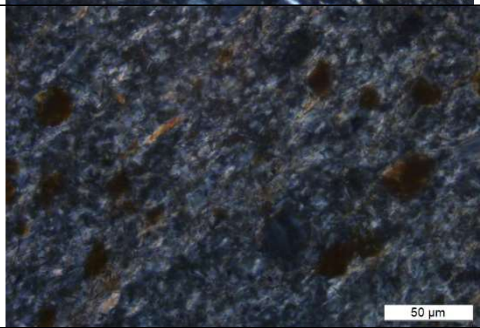
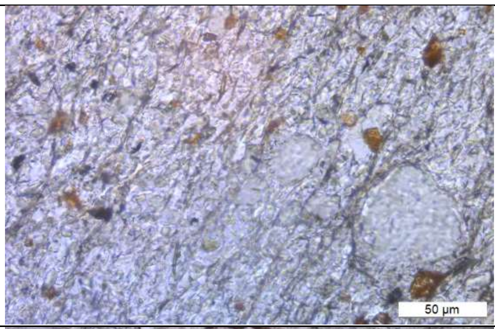
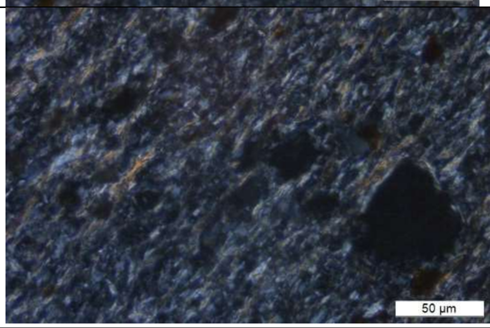
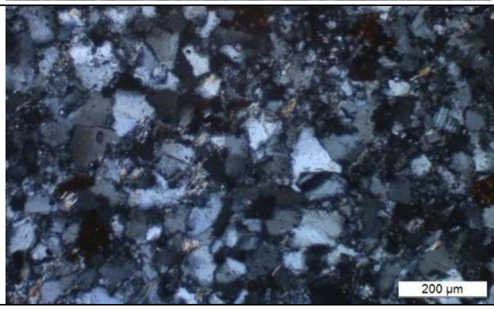
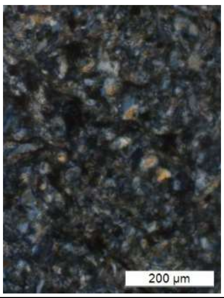
NOS-3	Cleavage visible, no bedding observed, extremely homogenous.	
NOS-4	Bedding and Cleavage visible, Siltstone, coarser grained than surrounding shales.	
NOS-5	Bedding visible, no cleavage observed, siltstone banding, located on road surface so structure could have been affected.	

BR-1	Strong cleavage visible, no bedding observed, extremely homogenous.	
BR-4	Strong cleavage visible, no bedding observed, extremely homogenous.	

CW-1	Appears altered, bedding and cleavage visible	

4.2 Thin sections

Table 2: Table containing microphotographs of each thin section. Photos in cross-polarised and plain polarised light are presented in separate columns, samples containing banding have multiple photos showing different bands.

Sample ID	PPL (plain polarised light)	XPL (cross polarised light)
NOS-1		
NOS-2		
NOS-3		
NOS-4		
NOS-5	 	 

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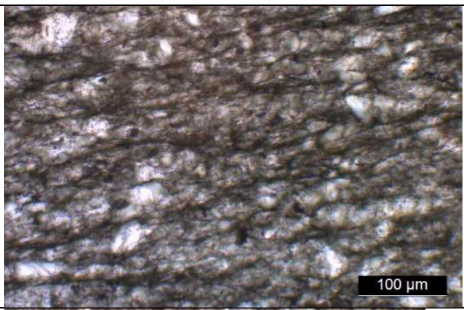
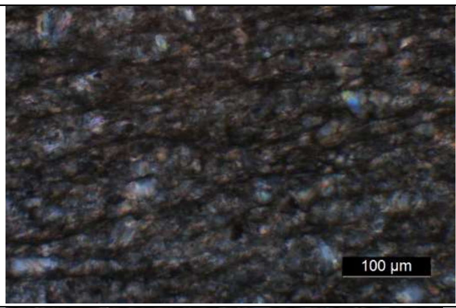
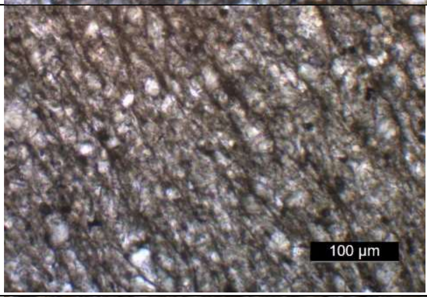
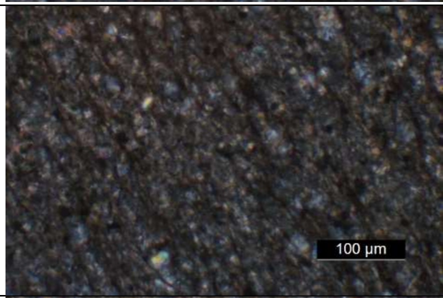
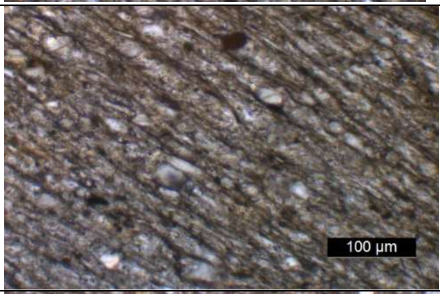
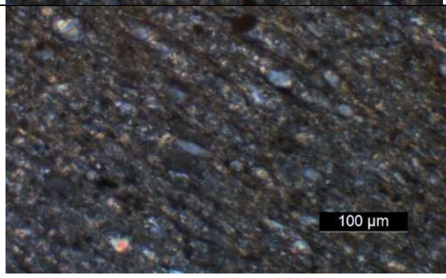
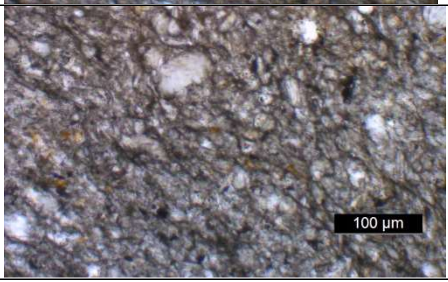
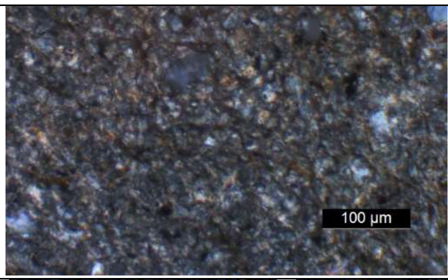
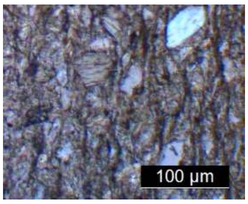
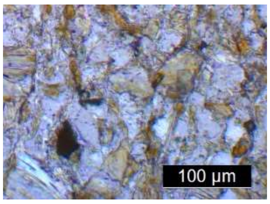
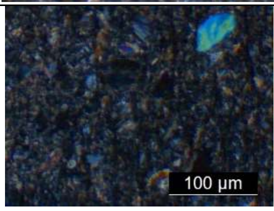
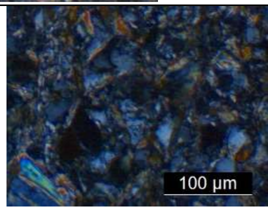
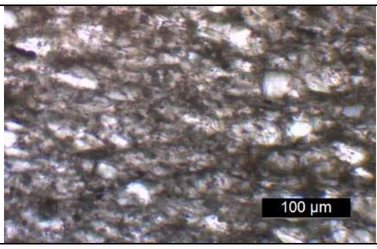
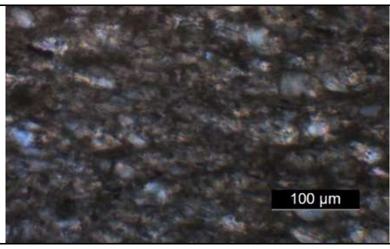
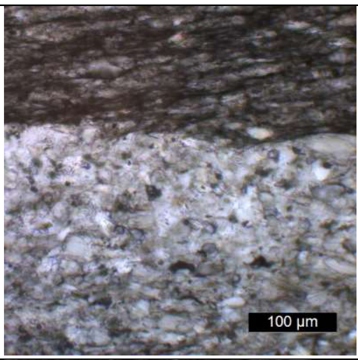
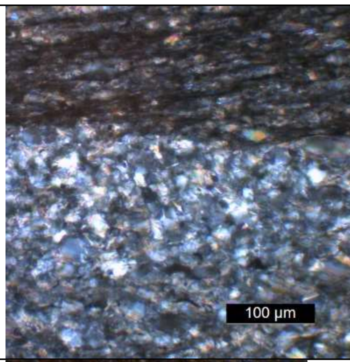
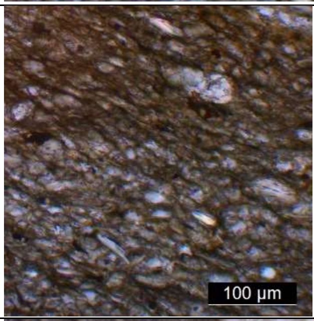
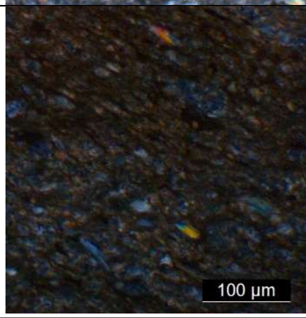
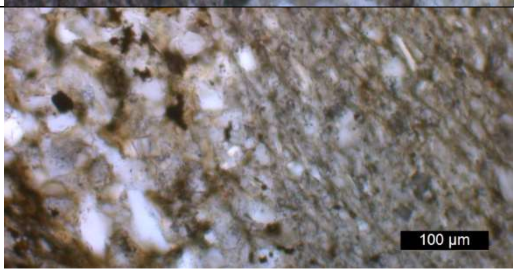
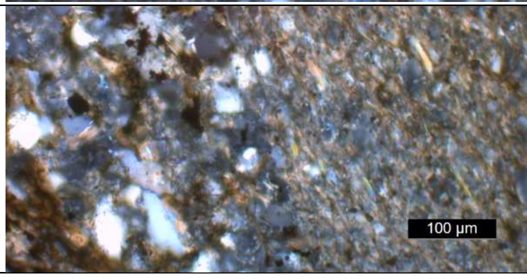
BR-1		
BR-2		
BR-3		
BR-4		
BR-5	 	 
BR-6		

BR-7		
CW-1		
GG-1		
YF-1		

4.3 XRD data

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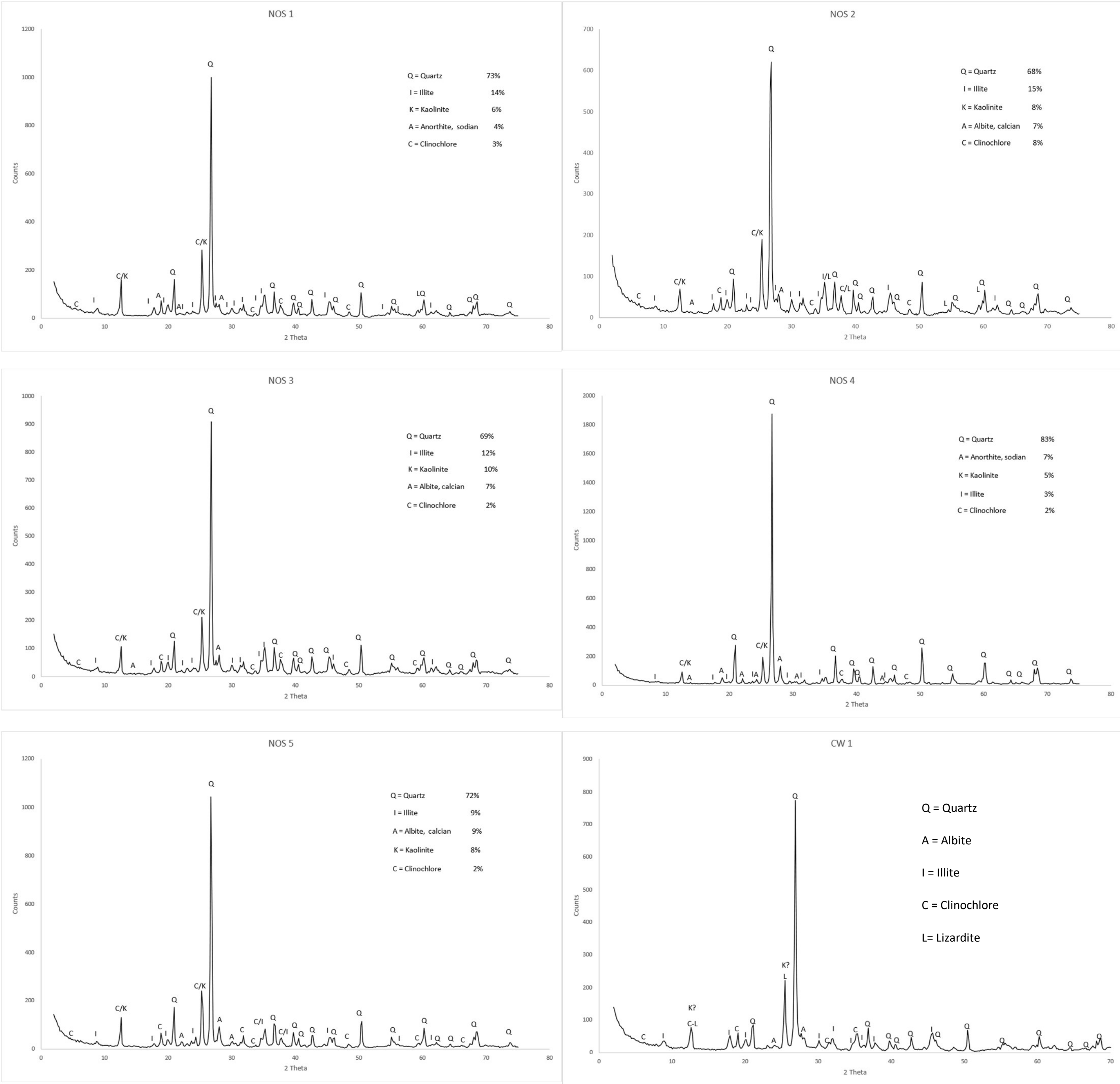

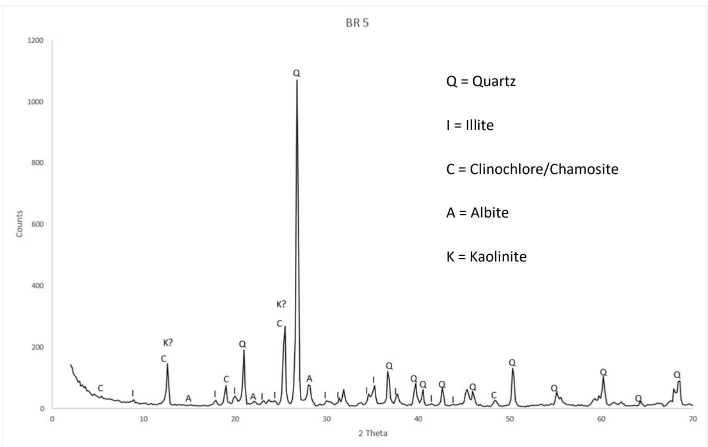

Figure 6: Diffractograms for each of the samples analysed. The diffraction pattern of each mineral is represented as a set of peaks (d-values) at different intensities, shows mineralogy of each sample.

4.4 pXRF data

Table 3: Table containing key pXRF data for each sample analysed. Elements with concentrations too low to detect or not relevant have been removed.

Sample ID	Al%	Al% +/-	Si%	Si% +/-	K%	K% +/-	Fe%	Fe% +/-	As%	As% +/-
NOS1a	8.94	0.18	23.63	0.19	2.6091	0.0246	7.82	0.07	0.0022	0.0004
NOS1b	9.32	0.18	23.37	0.19	2.6526	0.0246	7.2	0.06	0.0026	0.0004
NOS2a	9.4	0.19	23.68	0.2	2.7816	0.0259	7.81	0.07	0.002	0.0004
NOS2b	9.47	0.19	23.22	0.19	2.6989	0.0252	7.83	0.07	0.0023	0.0004
NOS3a	9.08	0.18	23.94	0.2	2.7033	0.0252	7.78	0.06	0.0048	0.0004
NOS3b	9.27	0.19	24.15	0.2	2.7078	0.0252	7.74	0.06	0.0052	0.0004
NOS4a rock	2.58	0.13	31.81	0.25	0.2732	0.0098	4.8964	0.0467	0.0018	0.0004
NOS4b vein	3.23	0.12	32.66	0.23	0.3264	0.0093	5.7161	0.0482	0.0012	0.0004
NOS5a fine	8.27	0.19	22.34	0.2	2.8698	0.0286	6.11	0.06	0.0023	0.0004
NOS5b coarse	5.28	0.14	32.37	0.22	1.073	0.0142	4.2052	0.0379	0.0011	0.0003

5. Data Analysis

5.1 Descriptions of thin sections:

Rock descriptions of each sample have been completed using a combination of optical analyses using thin sections, XRD analyses and XRF analyses. These three analysis methods were used due to the difficulty in identifying mineralogy from optical methods alone. This is caused by the fine-grained, altered nature of the samples. Looking at samples in thin section It was noted that mineralogy appeared to follow patterns based upon which lithology the sample belonged to under Annels and Roberts (1989) definitions. For samples on which XRD and XRF analysis was not undertaken, mineralogical data was extrapolated from other samples of the same lithology to aid optical analysis. All samples were likely deposited in a deep ocean setting (turbidity currents) and have undergone greenschist/anchizone facies metamorphism. Descriptions are as follows:

NOS-1:

Siltstone beds- approx. 1mm thick, yellow, grain size approx. 40µm, well sorted, angular. Shale beds- black, grain size approx. 5µm, angular, moderately sorted, larger quartz grains approx. 10µm, mineralogy- quartz, illite, kaolinite, anorthite, chlinochore.

NOS-2:

Black, grain size approx. 5µm, angular, moderately sorted, mineralogy- larger quartz grains approx. 10µm, illite, kaolinite, albite, chlinochore.

NOS-3:

Black, grain size approx. 5µm, angular, moderately sorted, mineralogy- larger quartz grains approx. 10µm, illite, kaolinite, albite, chlinochore.

NOS-4:

Yellow, grain size approx. 50µm, angular, moderately sorted, mineralogy- quartz, groundmass anorthite, kaolinite, illite, chlinochore.

NOS-5:

Siltstone beds- approx. 5-10mm thick, yellow, grain size approx. 30µm, well sorted, angular. Shale beds- black, grain size approx. 5µm, angular, moderately sorted, larger quartz grains approx. 10µm, mineralogy- quartz, illite, albite, kaolinite, chlinochore.

BR-1:

Black, grain size approx. 5µm, angular, moderately sorted, mineralogy- larger quartz grains approx. 10µm, illite, kaolinite, albite, chlinochore.

BR-2:

Black, grain size approx. 5µm, angular, moderately sorted, mineralogy- larger quartz grains approx. 10µm, illite, kaolinite, albite, chlinochore.

BR-3:

Siltstone beds- approx. 1mm thick, yellow, grain size approx. 40µm, well sorted, angular. Shale beds- black, grain size approx. 5µm, angular, moderately sorted, larger quartz grains approx. 10µm, mineralogy- quartz, illite, kaolinite, anorthite, chlinochore.

BR-4:

Black, grain size approx. 5µm, angular, moderately sorted, mineralogy- larger quartz grains approx. 10µm, illite, kaolinite, albite, chlinochore.

BR-5:

Siltstone beds- approx. 5-10mm thick, yellow, grain size approx. 30µm, well sorted, angular. Shale beds- black, grain size approx. 5µm, angular, moderately sorted, larger quartz grains approx. 10µm, mineralogy- quartz, illite, albite, kaolinite, chlinochore.

BR-6:

Black, grain size approx. 5µm, angular, moderately sorted, mineralogy- larger quartz grains approx. 10µm, illite, kaolinite, albite, chlinochore.

BR-7:

Siltstone beds- approx. 1mm thick, yellow, grain size approx. 40µm, well sorted, angular. Shale beds- black, grain size approx. 5µm, angular, moderately sorted, larger quartz grains approx. 10µm, mineralogy- quartz, illite, kaolinite, anorthite, chlinochore.

CW-1:

Siltstone beds- lensoid, approx. 10-20mm thick, yellow, grain size approx. 40µm, poorly sorted, angular. Shale beds- black, grain size approx. 5µm, angular, moderately sorted, mineralogy- larger quartz grains approx. 10µm, albite, illite, chlinochore. Lizardite was detected in XRD, but none was identified optically.

GG-1:

Siltstone beds- approx. 5-10mm thick, yellow, grain size approx. 30µm, well sorted, angular. Shale beds- black, grain size approx. 5µm, angular, moderately sorted, larger quartz grains approx. 10µm, mineralogy- quartz, illite, albite, kaolinite, chlinochore.

YF-1:

Siltstone beds- approx. 1mm thick, yellow, grain size approx. 40µm, well sorted, angular. Shale beds- black, grain size approx. 5µm, angular, moderately sorted, larger quartz grains approx. 10µm, mineralogy- quartz, illite, kaolinite, anorthite, chlinochore.

6. Interpretation

6.1 Lithological Categorisation

Samples were first categorised into lithologies using the characteristics by which lithologies were separated in the paper by Annels and Roberts (1989). Field observations of outcrops (table 1) and observations of rock slices were compared with these characteristics to identify which lithology each sample belonged to. The results are as follows.

Samples NOS-2, NOS-3, BR-1, BR-2, BR 4 and BR 6 were close to homogenous with very little discernible banding or evidence for bedding so belonged to the black shale lithology. Samples NOS-1, YF-1, BR-7 and BR-3 were similar to black shales however the presence of ~1-mm thick siltstone beds meant they belonged to the banded black shale (BBS) lithology. Samples NOS-5, BR-5, and GG-1 were similar to the banded black shales however they contained close to 20% siltstone bands 5-10mm thick so belonged to the banded black shales and siltstones (BBSS) lithology. Sample CW-1 was the most deformed rock out of those sampled and had siltstone bands constituting above 40% of the rock. Due to the siltstone content this sample it belonged to the shale and siltstone (SS) lithology. Sample NOS 5 was the coarsest grained, being 100% siltstone so belonged to the shales and quartzite (SQ) lithology. From analyses of the mineralogy of these samples there appears to be links between these lithologies and certain mineralogical compositions.

Samples were also categorized spatially based on the BGS 25k geological mapping. Samples belonging to the Silurian interbedded mudstone and laminated hemipelagic mudstone lithology include NOS-4, CW-1, and BR-6. Samples belonging to the Ordovician silty mudstone lithology include BR-1, BR2, BR-3, BR-4, BR-5, BR-7, NOS-1, NOS-2, NOS-3, NOS-5, GG-1, YF-1. From analyses of the mineralogy of samples there appears to be no links between these lithologies and mineralogy. This indicates that the BGS mapping of the geology was based on age rather than observations and composition.

6.2 Effect of lithologies on modes of gold exsolution

According to Annels and Roberts (1989) gold in the area is found in three main sources. In shales containing massive to banded aggregates of mixed sulfides with minor amounts of quartz-carbonate gangue, in heavily pyritized shales containing arsenopyrite porphyroblasts, and in sulfidite bands. Thin quartz, sulfide, carbonate veins can also contain gold. It is suggested that the gold was exsolved from hydrothermally precipitated arsenopyrite. From the samples studies in this paper none of these sources are found, however the high carbon content (causing the black colour) of the shales and the permeability of the siltstone could affect the ability of gold to be exsolved within certain lithologies.

7. Discussion

7.1 Exploration Overview and limitations

In one aspect gold exploration in the UK is a lot easier than exploration for other minerals. This is due to the Crown Estate owning the mineral rights to all gold and silver within the UK. To explore for these resources a license must be obtained by going through the due process in communications with the crown rather than having to obtain mineral rights from various private stakeholders, as is the case with other minerals which can be a lengthy and costly process.

Although SHG has obtained the license to explore within the Carmarthenshire region, landowners still hold the right to choose to whom they grant access onto their land. This has meant that although most landowners have permitted SHG to undertake initial exploration, a large portion of the exploration region has been inaccessible. The National Trust are the largest landowners in the area with an estate covering over 10 square kilometres, most notably including the Dolaucothi mine site, and although negotiations are ongoing, access onto their land has not yet been permitted. Because of this some of the most promising areas within the license area have been out of reach for research and has meant resorting to exploring parts so far thought to be less prospective.

The National Trust's Dolaucothi Estate is a site of special scientific interest (SSSI), meaning protected species of wildlife inhabit the land. This could affect the likelihood of exploration and eventually mining being permitted due to the perception of mining having an adverse effect on wildlife, however using modern exploration and mining methods, harm to ecosystems can be greatly minimised. This along with the fact that the site is brownfield and has previously been used for the same purpose could be used to argue with the National Trust as to why exploration should be permitted. The opening of the mine would also have a positive effect on the local economy.

Another factor which may cause issues with mining in the area is 'Nimbyism' (not in my back yard). This is the effect in which people may be supportive of an idea (mining) in theory, however as soon they perceive it as having a negative on the area close to their homes, local opposition becomes widespread. This is often especially the case in places renowned for their natural beauty, such as Carmarthenshire. Most landowners encountered during the field season were interested in the project, with some being extremely supportive, Likely because of the history of mining in the area and the potential for economic gains. Only a single landowner over the entire field season denied SHG's request to explore on their land. It is hard to know how the people not contacted during the season but who live locally would respond, however there would likely be a portion opposed to the project which could pose an issue in the future. This is a problem almost all exploration projects face however, and there are standard methods of dealing with this such as maintaining good relationships with the community and displaying the benefits of the project.

7.2 XRD, XRF and thin section analysis limitations

Due to the small budget for the project the quantity of analyses which could be undertaken was extremely limited. This means that any interpretations drawn from the data used in this paper may not be accurate as anomalous results were much harder to detect and data could be skewed or unreliable. Another limitation was way that the rock samples were collected from available outcrop rather than systematically being collected across the study area. This means that the data will likely be skewed to represent certain rocks less prone to weathering (perhaps due to higher quartz content) as these are the rocks which are more likely to outcrop. To be more confident about the soundness of the conclusions drawn in this paper further studies would have to be undertaken. In particular the effect of lithologies on gold exsolution. This could involve systematic sampling across a wider area and taking a much greater quantity of samples.

7.3 Wider relevance

The interpretations of the data within this report can be used in future exploration to better understand lithologies so that they can more easily be identified and so that links can be made to the Dolaucothi Mine. In future studies with larger datasets, lithologies can be analysed so that it can be better understood whether certain modes of gold exsolution occur within certain lithologies.

8. Conclusions

The aim of this dissertation was to advance the knowledge of the lithology of the gold host rocks surrounding the Dolaucothi mine and create links with previous studies of the lithology.

Firstly, links between samples and lithologies were analysed. From the samples studied it appears that the mineralogical composition of the host rock follows patterns which are closely linked with what lithology they belong to according to Annels and Roberts (1989) parameters. The Lithologies described by the BGS appear to be based primarily on age and no patterns of mineralogy were observed. These observations are based on a very small dataset so further studies with larger datasets would have to be conducted to confirm any apparent links.

Secondly samples were studied to analyse if certain lithologies were conducive to certain modes of gold exsolution. From the samples studied in this paper none of the gold sources described by Annels and Roberts (1989) were found, however the high carbon content (causing the black colour) of the shales and the permeability of the siltstone within certain lithologies could affect the ability of gold to be exsolved. Further studies with larger datasets would have to be conducted to better understand this.

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