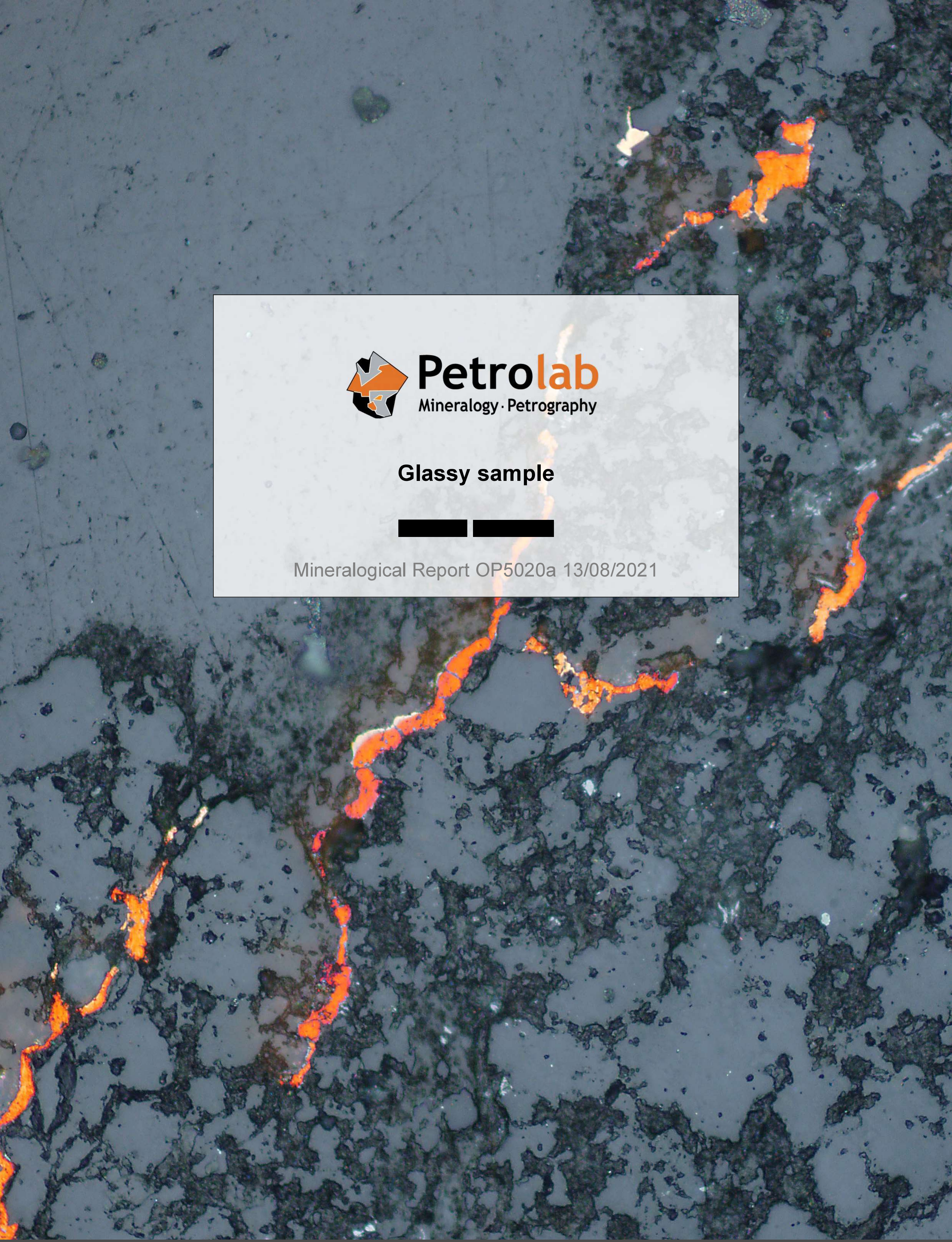

Petrolab
Mineralogy · Petrography

Glassy sample

[redacted]

Mineralogical Report OP5020a 13/08/2021

Petrolab Ltd | www.petrolab.co.uk
tel +44 (0)1209 219 541 **email** petrolab@petrolab.co.uk

C Edwards Offices, Gweal Pawl, Redruth, Cornwall TR15 3AE
Registered in England & Wales · Company No. 4777735

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Petrolab document control			
Client	[redacted]		
Report title	Glassy sample		
Analysis required	Simplified petrography and manual SEM analysis		
Client reference	Meteorite	**Client contact**	[redacted]
Report ID (issue date)	OP5020a 13/08/2021	**Version note**	Report Initial Issue
Prepared by	[redacted] MSci	**Checked by**	[redacted] PhD CGeol [redacted] BSc MSc

Limitations
This report relates only to those samples submitted and specimens examined and to any materials properly represented by those samples and specimens. This report is issued to the Client named above for the benefit of the Client for the purposes for which it was prepared. It does not confer or purport to confer on any third party any benefit or right pursuant to the Contracts (Rights of Third Parties) Act 1999.

Report key findings

This is a mineralogical report for [redacted] to investigate one sample. It was suggested to be a meteorite and Petrolab was requested to undertake a simplified petrographic investigation with ancillary SEM point and ID analysis.

The analysed ('Glassy') sample shows carbonaceous laminated clinker and hypohaline slag as major components, with additions from iron metal and quartz. Iron metal is seen as small blebs in the slag, or more rarely between the cleaving laminations of the clinker.

Multiple properties of the sample suggest that it is not of extraterrestrial origin. These are listed below:

1. The additional unmelted sample contains a texture that is suggestive of chondrules fixed within a laminated carbonaceous matrix. However, these potential chondrules are empty where it would be expected to be filled with olivine, serpentine and other Mg-Fe silicates consistent with carbonaceous chondrite samples. There is no good reason why these potential chondrules would have been selectively dissolved during transit through the atmosphere or comprehensively lost from such a texture during sample preparation. Similarly, no ultramafic Mg/Fe minerals were observed in the glassy sample.
2. Analysis of the hand specimen confirms a highly vesicular nature. Rare achondrites can be vesicular, from other planetary bodies, such as the Moon and Mars. However they contain fewer vesicles than the sample in question and would show a volcanic groundmass.
3. Bulk chemistry (provided by the client) is inconsistent with a primitive carbonaceous chondrite. This is shown in the table below but the key facts are that the C content of carbonaceous chondrites reaches up to 5 wt%[1], whereas the bulk chemistry suggests 45%. Three other elements of key interest are here referenced. Mg and Fe in carbonaceous chondrites are much higher (typically 9 - 13 wt% for Mg and 18 - 23 wt% for Fe[2,3]). The values from the bulk chemistry were <1 wt% for Mg and 2 wt% for Fe. There was also no Ni observed within the bulk chemistry.
4. Blebs of metal seen under SEM, suggest nearly pure Fe, with only trace impurities of silicates or sulphur. Pure metal phases are usually alloys in meteorites, namely Fe/Ni alloys.
5. The major components, dubbed clinker and slag, contain aluminium which is rare in meteorites as a major component (typically ~1 wt%). Significant impurities of Ca within the aluminosilicate slag would provide a composition equivalent to plagioclase feldspar at irregular intervals, a mineral found in chondrites. However, the presence of plagioclase is not consistent with the isotropic nature of slag under transmitted light. Therefore, a slag impurity is more likely.

1 Gilmour, I., Treatise in Geochemistry, 2003.
2 Braukmuller, N., Wombacher, F., Hezel, D.C., Escoube, R. & Munker., C. (2018): The chemical composition of carbonaceous chondrites: Implications for volatile element depletion, complementarity and alteration. *Geochimica et Cosmochimica Acta,* **239,** pp 17-48
3 Expected values are assumed from CI and CM chondrites, due to their higher carbon content.

Table 1: Bulk chemistry of the sample and expected values

Composition	%[4]	Expected %[1,2,3]
C	45.28	<5
O	34.27	10 – 18% H_2O (wt%)
SiO_2	9.62	10-13
Al_2O_3	4.19	0.8-1.1
Fe_2O_3	2.37	18-23
CaO	1.34	0.8-1.5
MgO	0.83	9-13
K2O	0.72	<0.2
P_2O_5	0.41	<0.2
SO_3	0.37	1.5-4
TiO_2	0.25	<0.1
NaO	0.188	<0.6
MnO_2	0.16	<0.2

4 Bulk chemistry data provided by the client.

Introduction

Scope

This is a mineralogical report for [redacted] to ascertain the origin of a suspected meteorite fragment. Two samples were provided and made into polished thin section and block by Thin Section Lab, France. Of these, the 'Glassy' sample was picked for mineralogical analysis. Petrolab was requested to undertake a simplified petrographic investigation with ancillary SEM point and ID analysis.

This report relates only to the sample examined (and any materials properly represented by those samples). It presents the findings of a mineralogical investigation by optical microscopy on thin sections received from the client.

List of samples

Samples received		
No.	**Sample reference**	**Work**
1	Glassy	Petrography and ancillary SEM
2	Unmelted	Not analysed

Methods of investigation

The sections were examined by conventional transmitted and reflected light polarising microscopy using a Nikon research polarising microscope. Digital photomicrographs were taken using a high resolution digital camera attached to the trinocular head of the microscope.

Qualitative mineralogical analysis using scanning electron microscope was requested. Polished thin sections were carbon coated to a thickness of 30 nm. Each chip was analysed using a ZEISS EVO MA 25 scanning electron microscope (SEM)[1] fitted with two Bruker xFlash 6|60 x-ray detectors for energy-dispersive X-ray spectroscopy (EDX) analysis.

Sample description

A simplified mineralogical description of the sample received (which includes annotated photomicrographs), based on a high-power microscopical examination of prepared thin and polished sections, is found below.

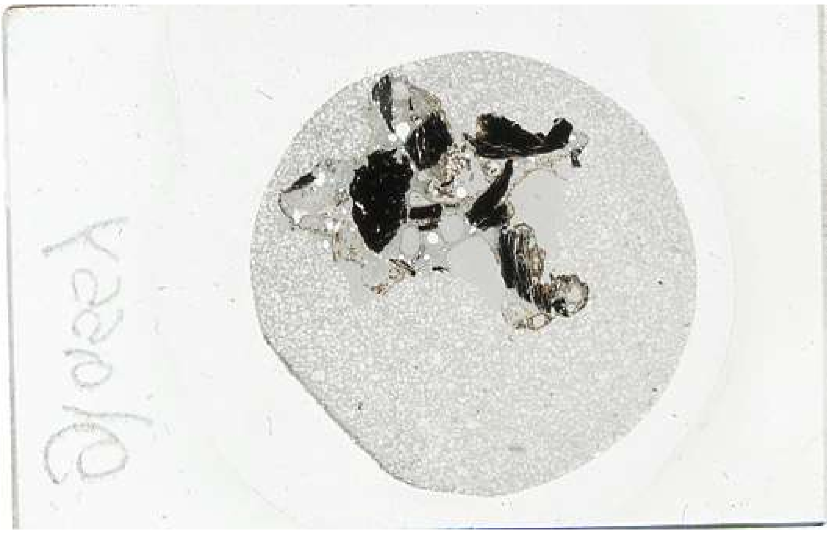
1 SEM system located at Petrolab Ltd, Redruth, UK.

Sample Glassy

Sample as received

Sample Glassy			
Petrolab ID	**Date received**	**Sample type**	**Sample**
#29623	29/07/2021	Thin section	Glassy

Section(s)



A **Sample Glassy**

Low magnification view of sample thin section.

Image AM
Epson scanner
White cold cathode light

Mineral abundance

Sample Glassy		
Mineral / Phase	**Chemical composition**	**Abundance**
Carbonaceous Laminated Clinker, clc	Aluminosilicate with carbon	Major+
Hypohaline Slag, hys	Aluminosilicate, common impurities of Mg, Fe, Ca, K and Ti	Major
Iron Metal, Fe	Fe, FeO	Trace
Quartz, qtz	SiO_2	Trace

Sample summary

Sample Glassy

- The sample is composed of carbonaceous laminated clinker locked by hypohaline slag. The clinker is finely laminated and shows cleaving along the laminations which are not the result of sample preparation. Iron metal is found in the cleavage, alongside possible iron oxides. Some more massive grains of clinker include fine, angular quartz.

- The surrounding slag contains needle like crystals which are likely cooling textures in the slag. Needles are concentrated around clinker grains, possibly suggesting the clinker allowed the slag to cool more slowly, or vice versa. The base composition of the slag is consistent, as an aluminosilicate. However, metal impurities vary throughout and can be noticed by sub spherical areas of higher brightness in the BSE images.

- The two main phases, suggested as slag and clinker are both shown to contain significant aluminium. This is not consistent with the Fe/Mg silicates of olivine and pyroxene associated with

Sample Glassy

meteorites. Aluminium can be observed in CAIs (calcium aluminium inclusions) however the morphology does not fit for classification as CAI. The typical aluminium content of a carbonaceous chondrite is ~1 wt%, and the levels recorded from bulk chemistry for this sample are nearer 4 wt%. Further discrepancies between the expected chemistry of a primitive chondrite and the received bulk chemistry are outlined in the summary table in the report key findings.

- The high abundance of vesicles (air pockets) and presence of fine quartz in a clinker grain are not consistent with a meteorite. A brief investigation of the 'Unmelted' sample suggested the vesicles had a potentially chondrule like morphology. However, these were all empty and no evidence was found in either of the two samples for ultramafic silicates that would be expected to be present (e.g. olivine, orthopyroxene, serpentine)

- Fine blebs of iron metal are found throughout the slag, and are concentrated adjacent to clinker grains. the metal blebs contain pure iron, with some impurities of silicate or rarer sulphur. Fe/Ni alloys, or Fe alloys with other metals are not observed, as expected in a meteorite

Photomicrographs

B **Sample Glassy**

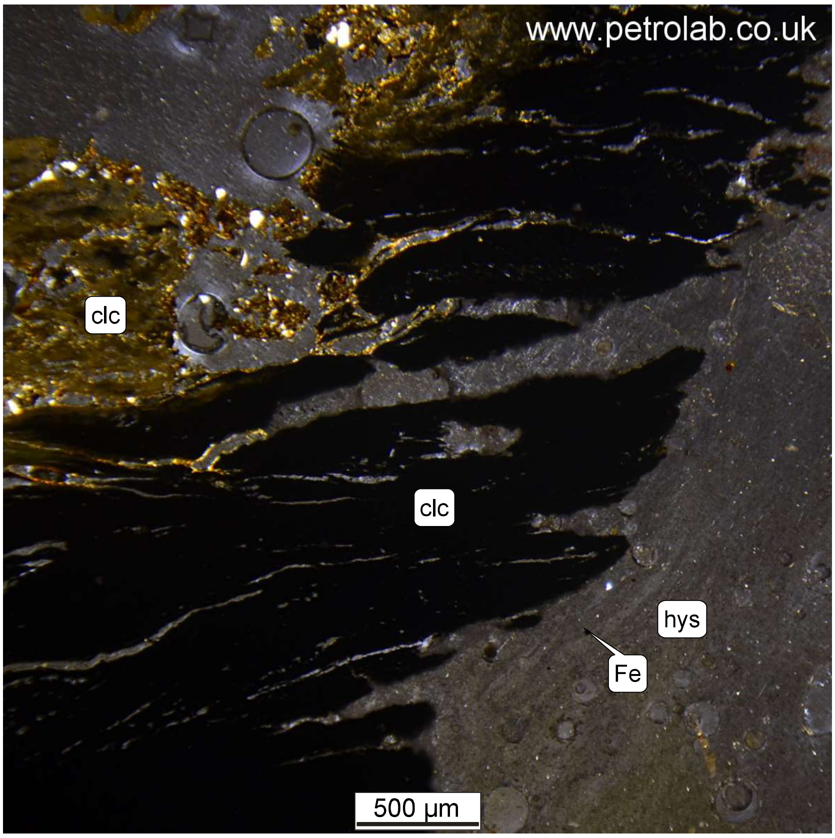
Photomicrograph showing the main components of the sample in plane polarised light, including carbonaceous laminated clinker (clc) and hypohaline slag (hys). Fine blebs of iron metal (Fe) are found in the slag and more rarely between the laminations of the clinker.

Image B

Nikon Microphot-FXA petrological microscope

Plane polarised transmitted light

x40



C **Sample Glassy**

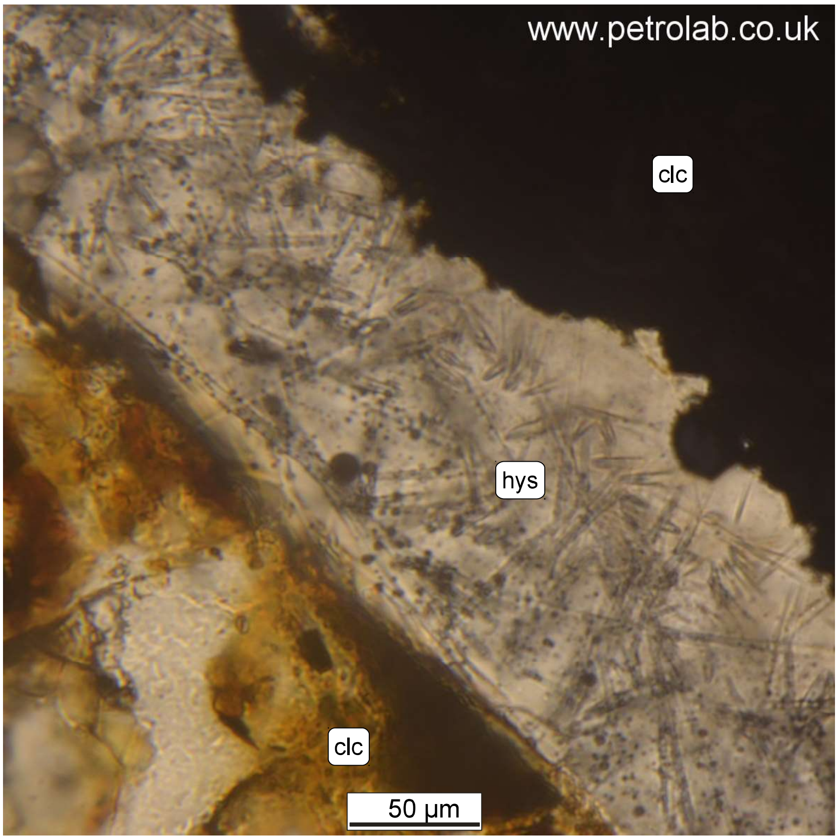
Photomicrograph showing the main components of the sample in cross polarised light, including carbonaceous laminated clinker (clc) and hypohaline slag (hys). Fine blebs of iron metal (Fe) are found in the slag and more rarely between the laminations of the clinker.

Image C

Nikon Microphot-FXA petrological microscope

Cross polarised transmitted light

x40



D Sample Glassy

Photomicrograph showing the components of the sample in plane polarised light. Cooling textures are present in hyposaline slag (hys).

Image D

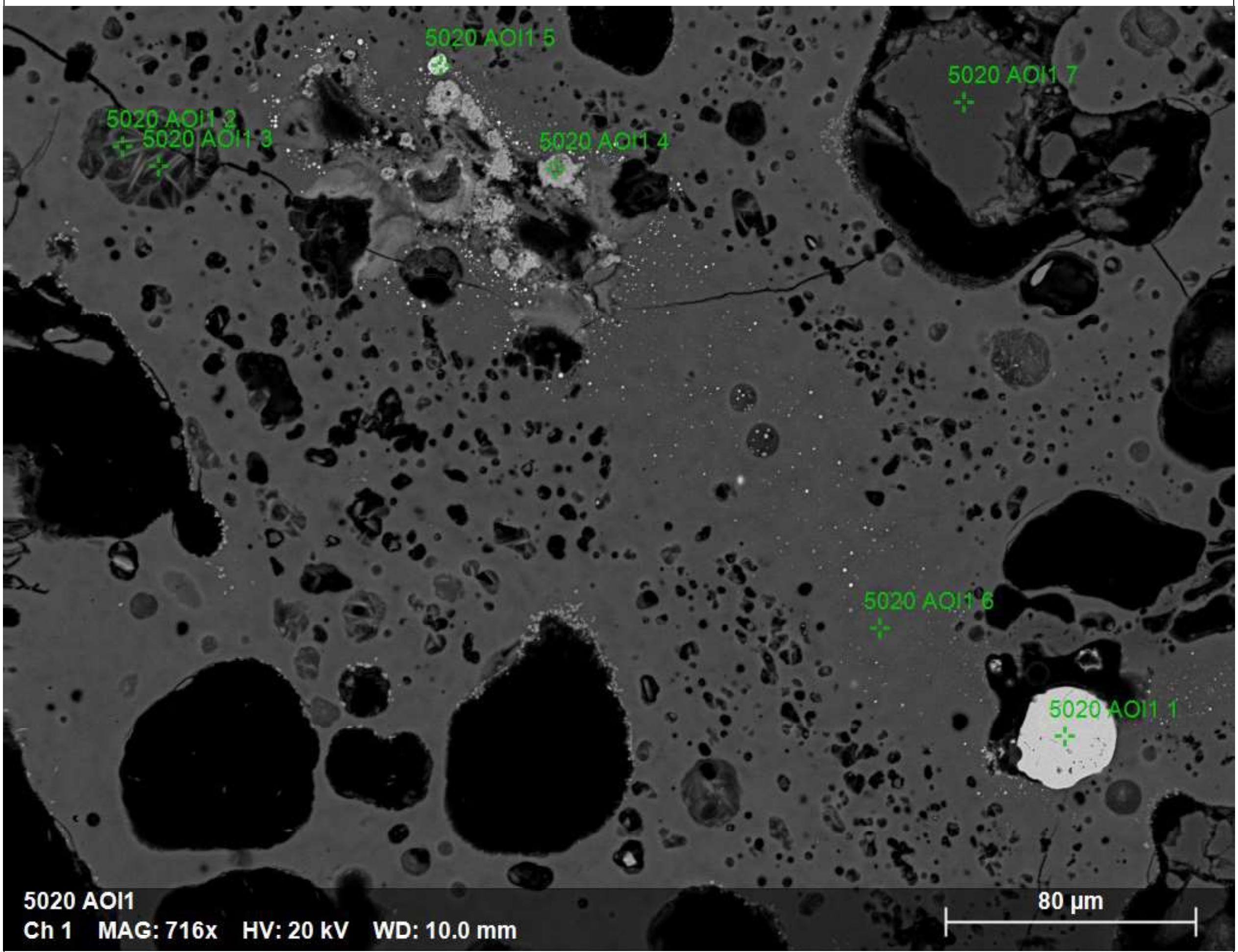
Nikon Microphot-FXA petrological microscope

Plane polarised transmitted light

x800

Manual SEM analysis

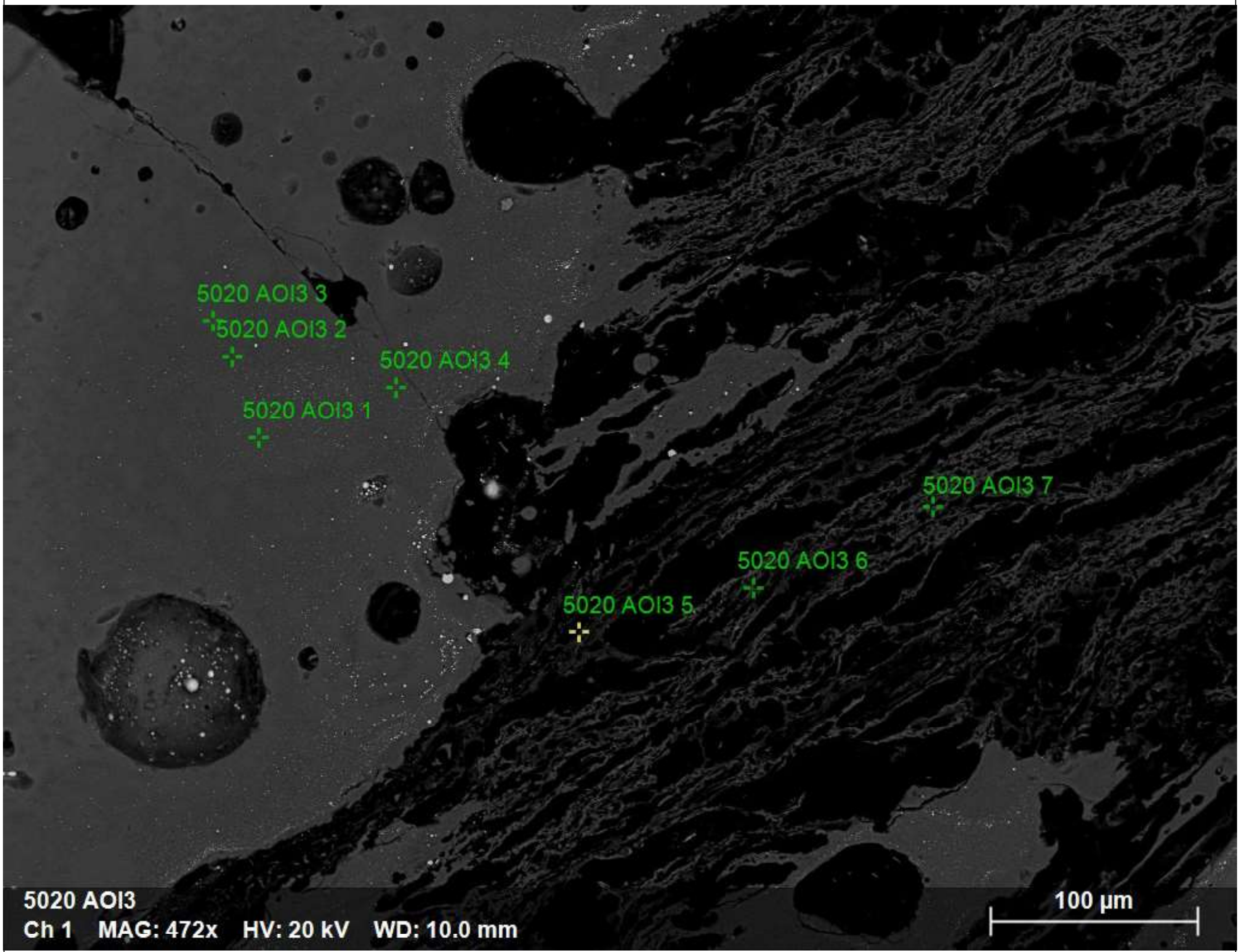
Table 1: **BSE image and selected spectra ID for AOI1**



BSE image of hypohaline slag with blebs of iron metal. The slag is very vesicular and they are usually unlined or lined with very fine blebs of iron metal. The iron metal is usually rounded and rarely exceeds 50 µm.

Spectrum	Mineral
5020 AOI1 1	Iron metal
5020 AOI1 2	Hypohaline slag
5020 AOI1 3	Hypohaline slag
5020 AOI1 4	Iron metal
5020 AOI1 5	Iron metal
5020 AOI1 6	Hypohaline slag
5020 AOI1 7	Quartz

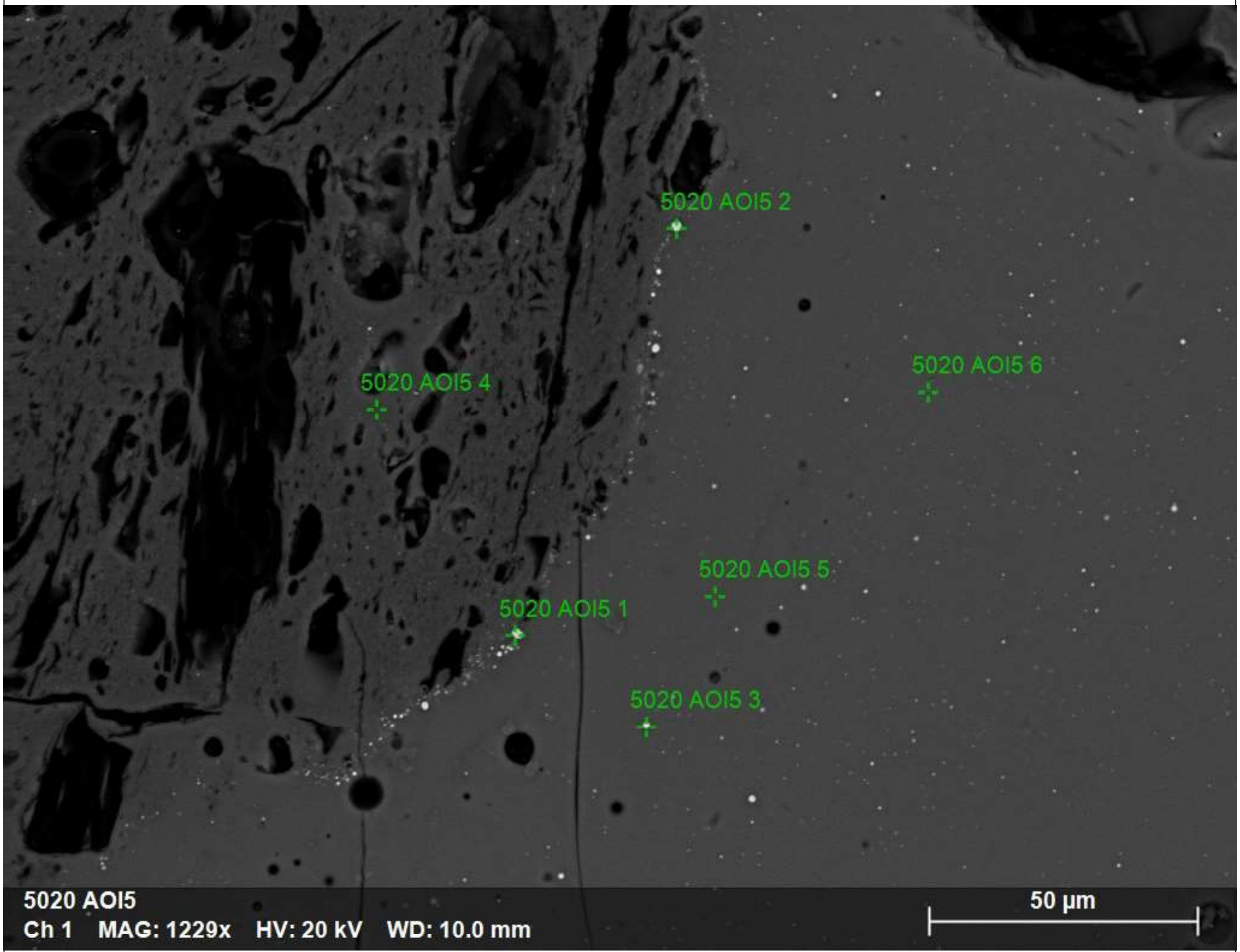
Table 2: BSE image and selected spectra ID for AOI3



BSE image of a grain of carbonaceous laminated clinker within hypohaline slag. Clinker grains are relatively pure, composed of semi-equal quantities of Al, Si and O. The slag is also primarily composed of Al, Si and O, however there are varying quantities of metal impurities. Common impurities include Ca, Fe, Mg, Ti, K and Ti.

Spectrum	Mineral
5020 AOI3 1	Hypohaline slag
5020 AOI3 2	Hypohaline slag
5020 AOI3 3	Hypohaline slag
5020 AOI3 4	Hypohaline slag
5020 AOI3 5	Carbonaceous laminated clinker
5020 AOI3 6	Carbonaceous laminated clinker
5020 AOI3 7	Carbonaceous laminated clinker

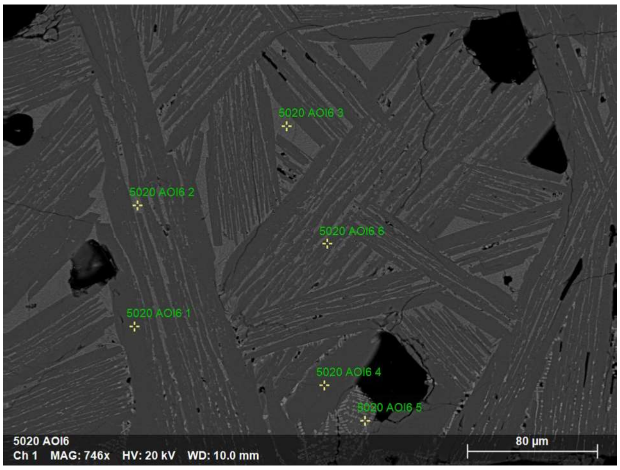
Table 3: **BSE image and selected spectra ID for AOI5**

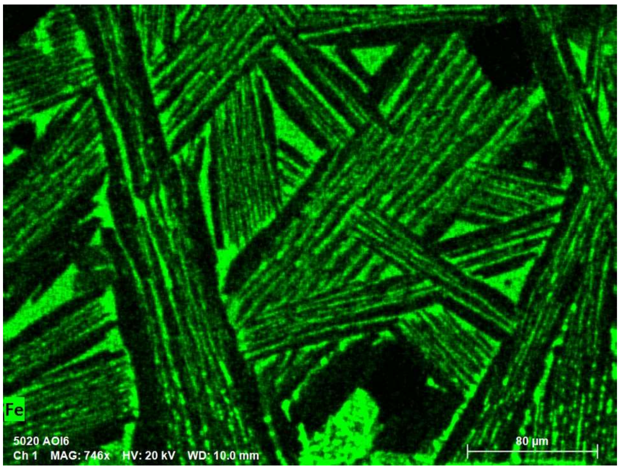


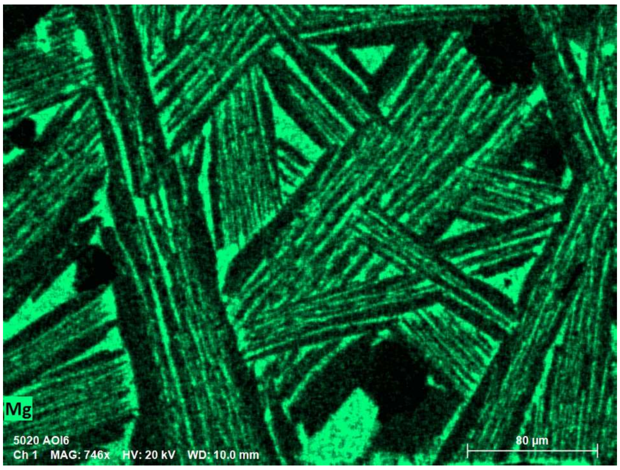
BSE image of a grain of carbonaceous laminated clinker within hypohaline slag. Blebs of iron metal are present in the slag, concentrated as rims on clinker grains.

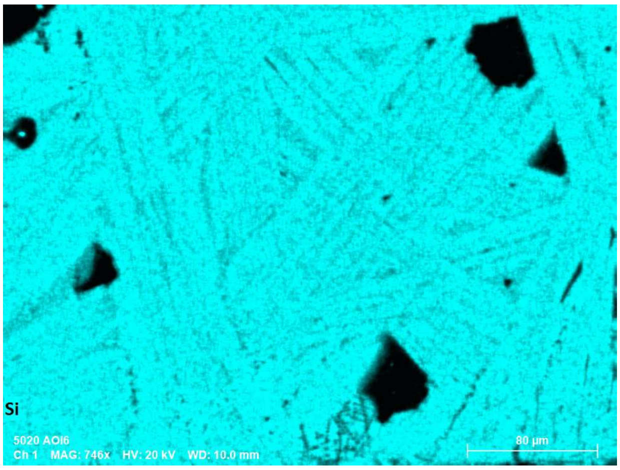
Spectrum	Mineral
5020 AOI5 1	Iron metal
5020 AOI5 2	Iron metal
5020 AOI5 3	Iron metal
5020 AOI5 4	Carbonaceous laminated clinker
5020 AOI5 5	Hypohaline slag
5020 AOI5 6	Hypohaline slag

Table 4: BSE image and selected elemental maps for AOI6









BSE image (top left) and elemental maps of the same area. The imaged area is composed of hypohaline slag showing a cooling texture from the dissolution of metal. Brighter areas in the BSE (5020 AOI6 2, 3 and 5) show a higher metal (HM) content, as evidenced by the elemental maps for Fe and Mg. However, Si is relatively consistent throughout the slag. Cooling textures like these are observed in meteorites. however, they are formed in metal alloys, rather than silicates.

Spectrum	Mineral
5020 AOI6 1	Hypohaline slag
5020 AOI6 2	Hypohaline slag (HM)
5020 AOI6 3	Hypohaline slag (HM)
5020 AOI6 4	Hypohaline slag
5020 AOI6 5	Hypohaline slag (HM)
5020 AOI6 6	Hypohaline slag