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The Scott Simpson Lecture

Understanding the Early Jurassic timescale and Earth System and timescale (the JET project): Initial results from the Prees-2 borehole, Cheshire Basin.

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Drilling for the Early Jurassic Earth System and Timescale ICDP project (JET) was undertaken in 2020/2021. The site is situated in a small-scale latest Triassic to Jurassic sag basin formed above the major Permian–Triassic half graben comprising the Cheshire Basin. The borehole was located to recover an expanded and complete marine succession to complement legacy core from the Llanbedr (Mochras) Farm borehole drilled 1967–1969 in N. Wales; the overall aim is to construct an astronomically-calibrated integrated timescale for the Early Jurassic and to provide insights into the operation of the Early Jurassic Earth System, taking advantage of the proximity of relevant stratotypes in SW and NE England. Initial datasets compiled from core include radiography, natural gamma, density, magnetic susceptibility and XRF. A full suite of downhole logs was also run. Carbon-isotope values from bulk organic matter have also been determined at a resolution of 0.2 m, and these provide the basis for detailed correlation between the Prees-2 succession and adjacent boreholes and GSSP outcrops. Multiple complementary studies are currently underway and preliminary results very promising for the combined Prees and Mochras successions, providing insights into the dynamics of background processes and major palaeoenvironmental change events. Ultimately, we aim to constrain major unknowns regarding solar system orbital history and create a template for correlations and dating of other successions at very high resolution. The results also add value to the already internationally significant Lower Jurassic successions of SW England.

Partitioning of fluid flow along faults and fractures in the Bristol Channel Basin

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This study addresses the topic of fluid flow along pre-existing faults and other fractures in the Bristol Channel Basin and the interplay between fluid flow and fault reactivation. U-Pb-t Thermochronology utilising LA-ICP-MS on fault related veins is used for the first time in this well studied basin to constrain the timing of initial fault development and subsequent reactivation in the region.

Age data show that faulting has occurred in two significant stages. There is a period of extension from 150–120 Ma, followed by inversion from 50–20 Ma. Some structures such as the EastQuantoxhead Fault (EQHF) have veins that record more complex opening and mineral growth histories, suggesting that they have acted as conduits to fluid flow over repeated, discrete, episodes. Veins from the main EQHF yield ages ranging from ~150 Ma – ~29 Ma. Microtextural analysis, including EBSD shows evidence for multiple mineral growth and recrystallization (crystal plastic) events along the fault. Celestine is developed along the fault and represents one of the latest phases of mineral growth, including fibrous growth with reverse-sense kinematics.

Age data supported by other analysis has been able to confirm the timing of the main faulting events in the BCB, and detailed analysis of individual veins in the EQHF documents how this structure has evolved in the context of the wider basin. Changes to mineral phases, microstructure and the apparent mode of failure together indicate that the nature and extent of reactivation is strongly controlled by discrete fluids permeating along the fault core over a protracted period of time. Such changes suggest that the EQHF accesses different fluid sources over time, possibly through downward propagation of the fault through various units within the pre-Lias stratigraphy of the BCB.

Geological Overview of Eden Geothermal

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Background

Eden Geothermal is the second recent deep geothermal project in the United Kingdom and is focussed on utilisation of the geothermal resources associated with the Early Permian Cornubian Batholith in SW England. It is a two-stage project. During the first stage a preliminary well (EG-1) has been drilled to 4.9 km to demonstrate the resource and provide heat to the Eden Project's famous biomes. During the second stage, another well will be completed to enable electricity production. The first stage of the project has been co-funded by the European Regional Development Fund, Cornwall Council and institutional investors.

Geological setting

Eden Geothermal has targeted a fault zone within the southern part of the composite St Austell pluton that comprises biotite, tourmaline and topaz granites (Simons *et al.*, 2016). Elevated U, Th and K contents have resulted in some of the

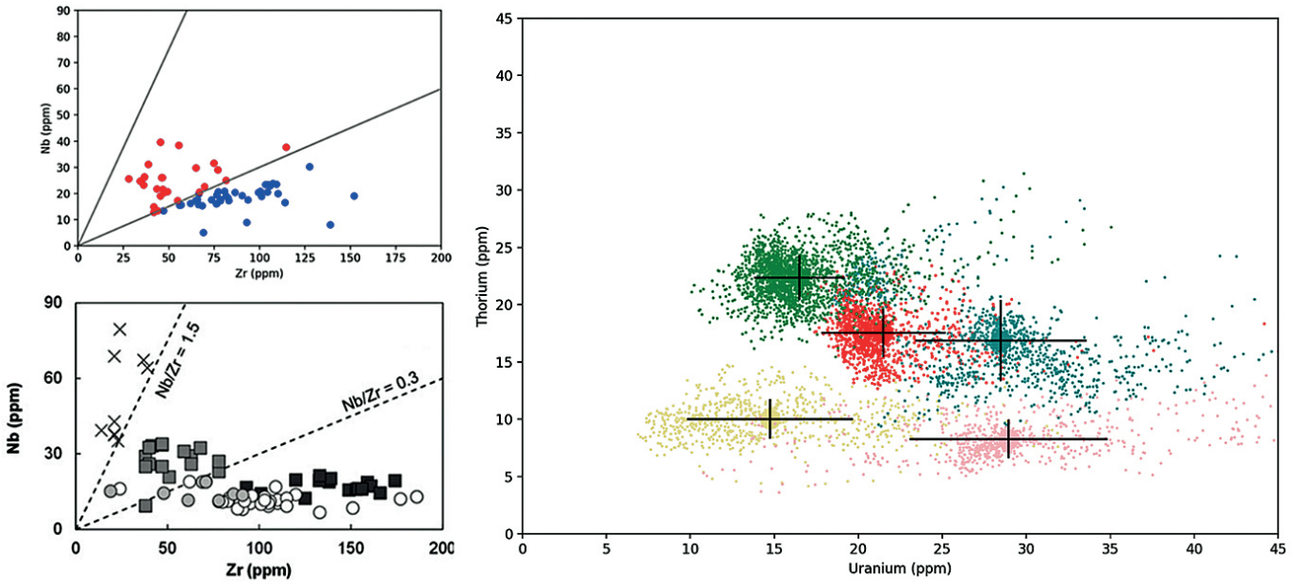

Figure 1. *Example of granite type classification using whole rock geochemistry and spectral gamma responses in EG-1. (a) Nb/Zr plot of EG-1 cuttings. Blue markers interpreted as biotite granite, red markers interpreted as tourmaline granites. (b) SW England granite classification from Simons et al. (2016); unfilled circles (G1 two-mica granite), filled circles (G2 muscovite granite), black squares (G3 biotite granite), grey squares (G4 tourmaline granite), crosses (G5 topaz granite). (c) Example of spectral gamma groupings from EG-1 wireline data with 1σ error bars.*

highest heat flow values in SW England with the temperatures at depths of 5 km estimated at up to 221°C (Beamish and Busby, 2016). It was predicted, prior to drilling, that temperatures between 190° and 200° C would be encountered at the bottom of the well.

The Great Crosscourse target fault zone

The target 'Great Crosscourse' is a major NNW–SSE striking, steeply inclined, fault zone that was initially identified almost 200 years ago within tin and copper mines to the south of the drill site. Its northward continuation through the Bodelva open pit china clay workings, that became the Eden Project, corresponds to a 50-70 m wide network of NW–SE striking steeply inclined quartz-haematite veins and intense kaolinisation (Mueller *et al.*, 1999). Electrical Resistivity Tomography (ERT) investigations were undertaken in the vicinity of the drill site to constrain the near-surface position and geometry of the fault system.

EG-1 drilling history

Drilling of EG-1 commenced on 17th May 2021 and was completed on 26th October 2021, reaching a depth of 5277 m MD (4871 m TVD) with a final azimuth of 061° and inclination of 40°. This makes it the UK's longest and second deepest onshore geothermal well (Table 1).

Table 1. EG -1 configuration

BIT SIZE (IN)	CASING SIZE (IN)	SHOE DEPTH (MD M)	SECTION COMPLETION DATE
Conductor 34 - 36		32	Prior to drilling
26	20	240	03/06/2021
17½	13⅜	1508	16/07/2021
12¼	9⅝	3870	28/08/2021
8½	Open Hole	NA	26/10/2021

Granites

Onsite optical analysis of the drill cuttings was supported by mineralogical (QEMSCAN, XRD), whole rock geochemical (XRF, ICP-OES, ICP-MS) and wireline log data to provide an integrated classification of granite types and formation top boundaries.From surface the well proves biotite granite to be the dominant lithology, with tourmaline granite encountered at greater depths. The granites have been divided into twelve distinct facies (A – L) based on the spectral gamma wireline log (U, Th, K) and the whole rock geochemistry (Zr/Nb) characteristics. These changes show large scale variations within EG-1 that are the result of magmatic and alteration processes and have the potential to be correlated with future wells in the area (Figure 1).

The upper 1 km of EG-1 is classified primarily on K and subtle Th variations. Below 1 km, the granite types show more substantial and defined changes in the U/Th ratio. Granites G and H show gradual increases in Th and Zr/Nb between the two types that suggests these granites are related, with variations potentially arising from in-situ magmatic processes. Other secondary criteria used to define the granite boundaries includes washouts in the caliper log and Th spikes.

Structural geology and mineralisation

Structural data obtained from the kaolinised granites of the Bodelva china clay pit in the late 1990s (Mueller *et al.*, 1999) indicated two dominant vein types/sets: (1) ENE–WSW and subordinate NW–SE striking quartz-tourmaline veins hosted by extensional fault / tensile fracture networks and transfer faults, developed during Early Permian NNW-SSE extension that controlled magmatic-hydrothermal mineralisation accompanying pluton construction, and (2) NW–SE and subordinate ENE–WSW-striking epithermal quartz-hematite veins hosted by extensional fault / tensile fracture networks and transfer faults , developed during mid-to Late Triassic ENE–WNW extension that controlled epithermal mineralisation associated with basinal brine migration. These two major palaeogeothermal episodes recorded in the granites of SW England are typically associated with mineral precipitation and the reduction of fracture permeability.

Image log interpretation to 3958 m MD within the 12¼" section indicated fracture intensity to be greatest in the top half of the well decreasing with depth (Figure 2). A range of fracture and vein orientations are recognised that are broadly consistent with the regional framework. However potentially open or partially open fractures tend to strike between NW-SE and NE-SW and so seldom correspond to the ENE-WSW set. The orientation of these dominant open fracture sets is consistent with minor Cenozoic intraplate strike-slip reactivation of 'cross course' fault zones that has resulted in the fracturing of earlier vein infills and so enhanced permeability.

The most complexity within the 12¼" section was encountered over a 550 m interval between 1950–2500 m. It included numerous fault surfaces, intense damage zones, potentially open fractures and secondary alteration associated with "lode" orientated features; nevertheless, no losses were recorded. Multiple reactivation episodes are inferred from cuttings that included rare early mylonitic granite and later vein calcite.

An approximately 6 m intersection with a fault zone towards the base of the 12¼" section was associated with losses that were controlled by a combination of LCM and cement prior to running the casing. The fault zone is bounded by an upper surface 182°/71° (dip direction / dip) and a lower surface 335°/65° and is broadly consistent with oppositely dipping conjugate elements of an E–W to ENE–WNW striking 'lode'.

Two main fracture zones were identified through optical analysis of the cuttings within the 8½" open hole section. Geochemical and mineralogical analysis revealed that both were associated with wall rock albitisation. These could represent one or more elements of the 'Great Crosscourse' but image logs in in the open hole section are required to validate this correlation.

σH, inferred from the analysis of wellbore axial tensile fractures <2400 m MD, was 133° ± 10°. Significant local rotation of σH, to 038°, was observed from 1960–2004 m MD adjacent to a fault dipping 68°SW.

Further geophysical logs in the 8½" section of EG-1 will confirm the fracture behaviour in the open hole; establish the orientation and extent of the loss zone below 9⅝" casing shoe; determine the nature of features identified by cuttings analysis and allow for a better understanding of the regional stress regime at depth. Open hole logs will be run in the summer of 2022 and subsequent results will be presented as part of this paper.

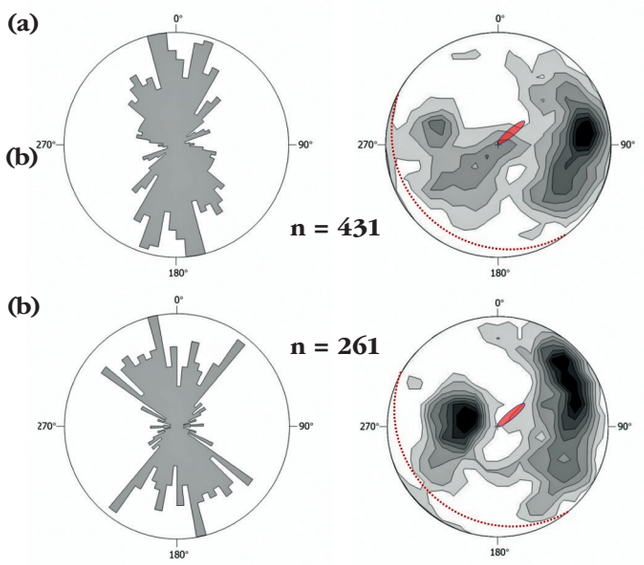

Figure 2. *Summary of FMI-derived open fracture orientations, for the interval 1526–3958 m MD in the EG-1 12¼" section, plotted on strike rose diagrams and lower hemisphere equal area stereograms (red ellipses shows variation in borehole orientation and red dashed great circles show associated loci of borehole censoring for poles to features. (a) Zone of higher fracture intensity, 1526–2700 m MD. (b) Zone of lower fracture intensity, 2700–3958 m.*

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Microfossil analysis of cave sediments: Corbridge Cave, Berry Head, Devon.

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The importance of the South Devon caves has been recognized since the early nineteenth century. Investigation of their archaeology and palaeontology was placed on a scientific footing by William Pengelly (1812–1894). He developed sophisticated recording techniques at his excavations in Kent's Cavern, notably the adoption of a

three-dimensional grid system of recording. Continued excavations in the South Devon Caves to the present day have shown that Quaternary deposits spanning at least the last 500,000 years exist in the region's caves (Proctor, 2018). Long sediment records extending well back into the Middle Pleistocene preserve evidence of regional climate change at Kents Cavern and sea level change at Berry Head. In the Berry Head Limestone Member of Berry Head (Torbay), there are a number of solution caves, of which Corbridge Cave is the largest known. Nearly twenty years' ago,

Corbridge Cave and its cave sediments were described by Proctor and Smart (1991), and this included a series of comments on the foraminifera provided by the late Professor Brian Funnell (University of East Anglia). All of our current suite of samples, collected in 2018, contain foraminifera, thin-valved ostracods and macrofaunal debris (*e.g.*, echinoderm spines). The majority of the diverse assemblages of foraminifera are of small size (maximum 150–250 µm) and this suggests that they may have been transported into the cave system by storm or wave action. All of the recorded species are well-known in Tor Bay, including the sea grass meadows, a large area of which is known from near the Brixham Breakwater. With few evolutionary changes during the late Pleistocene, the foraminifera can only provide limited stratigraphical information, except by using stable isotopes derived from a suite of closely-spaced samples. The present suite of samples may not be able to provide this degree of resolution but still provide useful palaeoclimatological information.

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First evidence of vampyromorph cephalopod jaw structures from the Sinemurian, Lower Jurassic of Dorset

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A new specimen of the Coleoidea from the Charmouth Mudstone Formation of the Dorset Coast has been identified as *Loligosepia bucklandi*. The specimen includes the gladius and some jaw fragments, which represent the first record of its kind, but the head area, arms and suckers are not discernible. It can be favourably compared to other *L. bucklandi* fossils in the Natural History Museum in London and the J. F. Jackson Collection in the National Museum Wales in Cardiff. The range of *L. bucklandi* is likely to be from the *Microderoceras birchi* Subzone to the *Asteroceras stellare* Subzone of the lower Sinemurian, with the new specimen stratigraphically a little older than the precisely located specimens in the J.F. Jackson Collection.

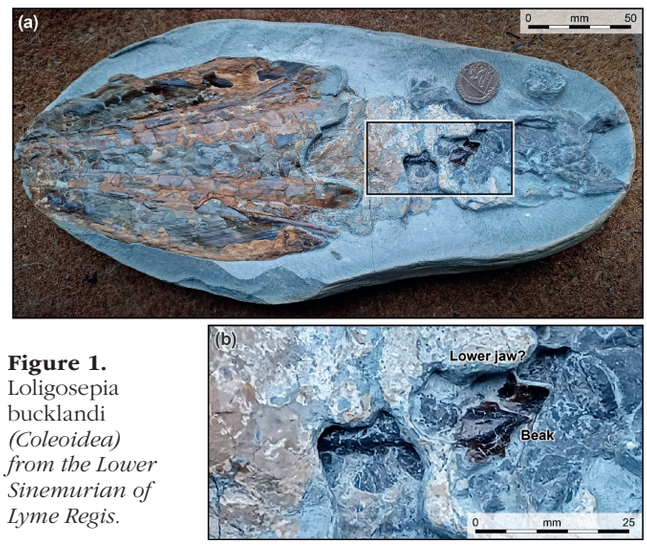

Figure 1. Loligosepia bucklandi *(Coleoidea) from the Lower Sinemurian of Lyme Regis.*

Cornish Tin - The Great Wheal Vor Project - Phase 1 drilling update.

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Cornish Tin Limited is a new exploration company focussed around the famous Great Wheal Vor Tin mine. Having just completed a 22–hole drilling programme, we now have some exciting results which we are looking forward to following up next year.

Lithium In Cornwall, Building A Sustainable Lithium Supply for the UK

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Demand for lithium is expected to rise 965% by 2050 from 2017 production levels (The World Bank, 2019). Cornwall hosts one of the largest lithium-enriched granite batholiths in the world (USGS, 2017). Geothermal waters containing elevated lithium values from hot springs in Cornwall have been recognised in many mines across the county from as early as 1864. Cornish Lithium are focussed on the environmentally sustainable extraction of lithium in the historic mining district of Cornwall and now have a lithium in geothermal waters and hard rock lithium project. Cornish Lithium drilled two ~1 km deep research boreholes at United Downs, Redruth to test the lithium content of geothermal waters contained within permeable structures. Results confirmed the historic occurrences of lithium in the area. A third borehole is currently being drilled to 2 km to test deeper permeable structures. The company are also working with partners to evaluate Direct Lithium Extraction (DLE) technologies to extract the lithium from these geothermal waters. Cornish Lithium's hard rock project is based around a non-operational kaolin pit at Trelavour, St Austell. In December 2021, a JORC compliant Maiden Inferred Resource Estimate was announced with 51.7 Mt at 0.11% Li. This is expected to support a mine life of 15 to 20 years. Scoping study results were published in 2022. The

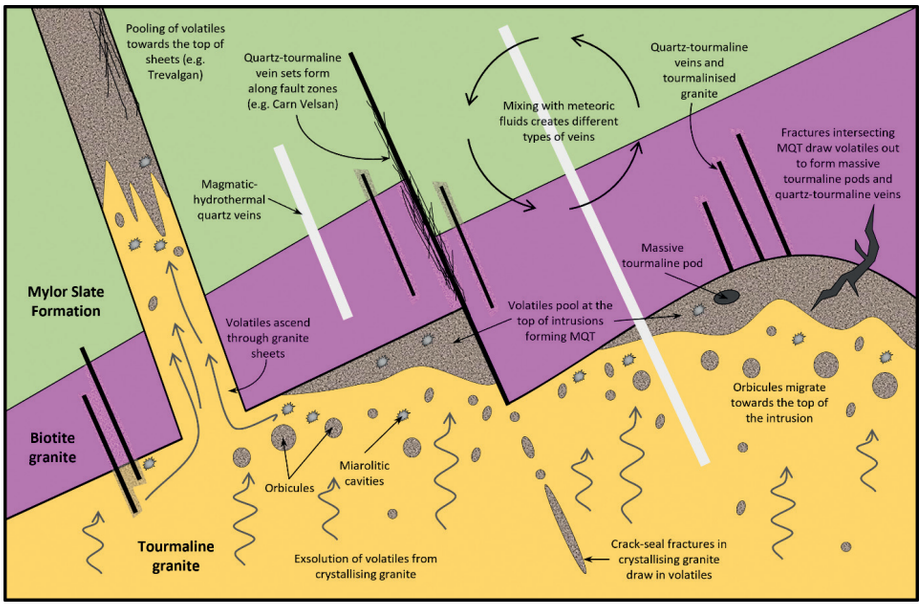

Figure 1. *A model for the exsolution and amalgamation of fluids during crystallisation of late-stage granites, and association with magmatic-hydrothermal mineralisation.*

company have an exclusive licence with Lepidico to use their L-MAX®/LOH-MAX® hydrometallurgical process, which does not use a high temperature roast and is considered to have a reduced environmental impact.

Magmatic-hydrothermal evolution of the Land's End Granite, Cornwall

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Mapping the magmatic-hydrothermal evolution of granitic systems is vital in understanding the causes, styles and distribution of associated mineralisation. There have been several such studies of the Cornubian Batholith; however, the link between regional tectonics and the magmatic-hydrothermal transition remains poorly understood. To address this, a detailed study was carried out across the northern roof zone complex of the Land's End Granite where there are a number of vein tin and copper deposits. Field observations, and mineral-chemical and geochronological studies were undertaken to characterise the magmatic-hydrothermal evolution and evaluate the role of regional tectonics on the distribution of late-stage granites and mineralisation. Emplacement of late-stage granites in the roof zone were controlled by ENE–WSW-striking fractures; however, their distribution also appears to be proximal to large-scale NW–SE-striking structures. Evolved magmas from which the late-stage granites formed were the primary source of the fluids and ore metals that produced the economic magmatic-hydrothermal mineralisation. The majority of granite-related mineralised veins associated with the Land's End Granite predominantly strike ENE–WSW with a subordinate set striking NE–SW and preserve kinematic evidence for formation during NNW–SSE extension. The change in orientation from ENE–WSE to NW–SE in the St Just area could be due to a regional change in tectonic regime, or strain partitioning around pre-existing structures. Fluid exsolution from magmas during crystallisation is recorded by the presence of quartz-tourmaline orbicules, miarolitic cavities and replacement of the granite within the roof zone by massive quartz-tourmaline rock (MQT). Contemporaneous brittle deformation, and pre-existing fractures, controlled fluid migration and variable mixing with meteoric waters, resulting in a wide variety of paragenetically distinct mineralised veins across the pluton.

Elvans: links to lamprophyres and pegmatites. The whole story?

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The origin of the elvan dykes of Cornwall and Devon have been an enigma with very little work in the last 40 years. They are clearly closely related to granite intrusion, cutting all but the latest granites, and even more closely related to mineralisation. The limited published analyses suggest enrichment in K_2O and derivation from G1/G2 granites.

Systematic new sampling and multi-element analyses of ~150 individual samples, throughout Cornwall and W Devon, shows considerable variation both between and within outcrop districts. Many are drastically different from published analyses.

Plots of Nb/Zr shows affinity with both G1/2 and G4/5 granites of Simons et al 2016. The high Nb elvans are chemically similar to ongonites (high level F-rich intrusives) of the Trans-Baikal and Mongolia and are the first reports in the UK. These ongonitic elvans are significantly enriched in Li, F, Ta, resembling the Meldon Aplite in chemistry, and in Sn. Tin is also particularly enriched in low-Li elvans in the area west of Camborne where some elvans are tourmaline-rich. Enrichment in K_2O also appears district specific, indicating sericitization possibly as overprints.

In several areas elvans are spatially related with lamprophyres, notably near St Kew, where lamprophyre fragments are contained in elvans. What is not clear is whether lamprophyres have driven elvan intrusion or used the same structures. Lamprophyric input can be recognized through high MgO, Ni and REE in elvans. Elvans, in a number of cases, are also intruded in the same locations as high Zr acid intrusives of projected Devonian age. An example is the Kingsand area where intrusive elvans cut red beds and are close to interbedded rhyolite.

Variation in chemistry suggests that within districts, individual elvans were intruded over time but with differing sources. Intrusion is controlled by NW-SE faults indicating these structures tapped magmas or hydrothermal systems at depth and may reveal the location of major hydrothermal activity.

A tree or not a tree – a bizarre log-like fossil from the Upper Devonian of Saltern Cove, Torbay, Devon.

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In Late 2020, as part of a geoconservation survey, a large cylindrical fossil around 50 cm long by around 17 cm in diameter was encountered by KNP *in-situ* in marine Frasnian (Upper Devonian) deposits of the Saltern Cove Formation at Saltern Cove in Torbay, Devon. A surface structure covered in rounded pits gave the cylinder an appearance similar to some Mid to Late lycopsid plant fossils from Svalbard, which appeared to confirm that the cylinder was indeed a 'log'. In addition, the association of the specimen with clastic-rich, hard bands with broken corals, a short distance above a contact with a lava apparently capped with a broken-coral-rich band, appeared to provide evidence of a potential source for plant material (i.e. volcanic islands) in a region with no other evidence of Mid to Late Devonian terrestrial input. The specimen was immediately reported to the English Riviera UNESCO Global Geopark, within which Saltern Cove lies, and contact was established with CB as a specialist in early forests in the Devonian. There followed a series of Zoom meetings and site meetings through 2021 – as complicated by the global Covid pandemic – and discussions as to the nature of the fossil. Although the overall shape of the cylinder suggested 'tree', doubt remained about the surface pattern of pits – were these genuinely leaf scars, or did they represent some other structure? It was certainly noted that colonial rugose corals, such as *Marisastreum* were present in the area, and hence the surface pits could conceivably represent individual corallites - but the overall cylindrical structure was very un-coral-like and could not be explained by tectonic distortion. However, in mid-2022 it was agreed to saw a section through part of the specimen, to finally try and answer the ongoing questions about its true identity. The results will be presented at the meeting…

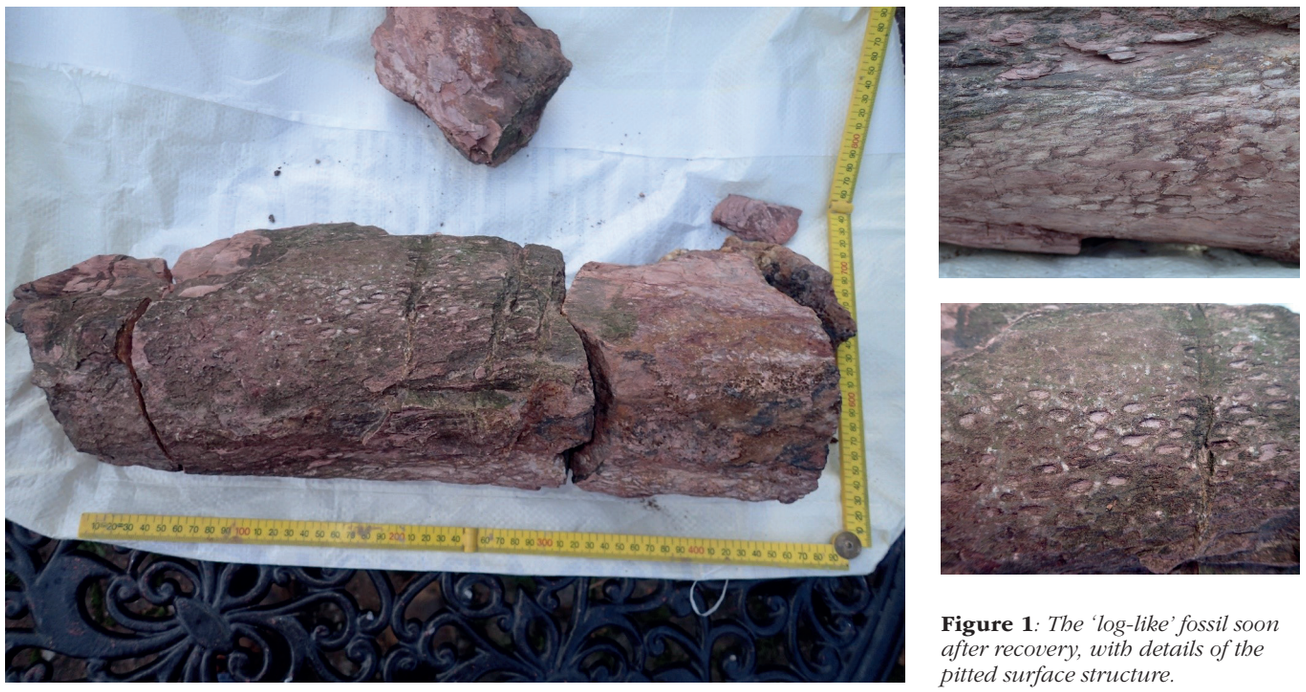

Figure 1: *The 'log-like' fossil soon after recovery, with details of the pitted surface structure.*

An assessment of the spatial distribution and possible source of arsenic, copper, tin, lead and zinc within the surface sediments of the Fowey Estuary, Cornwall.

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Estuarine sediments commonly form major sinks for contaminants released as a result of mining activity. There are a number of contaminant pathways: metals and metalloids discharged in solution via mine drainage; weathering of spoil tips and particulate grains of ore-forming or related minerals released during and after ore processing and transport. In this study, we have mapped the distribution of arsenic, copper, tin, lead and zinc within the surficial sediments of the Fowey Estuary, Cornwall, UK, an area that drains an area that was extensively mined in the 19th Century. The area examined is also within an Area of Outstanding Natural Beauty. The geochemical maps presented here show a clear spatial variation in As, Cu, Pb, Zn and Sn throughout the surface sediments in the Fowey Estuary. We interpret the main source of these contaminants to be from the historical mining activity. Observed values for certain metals exceed sediment quality guidelines. The continued impact of the mining legacy is potentially having an impact on this estuarine ecosystem.

The work of the Cornwall Geoconservation Group

Peter Scott* and Sue Hocking
Cornwall Geoconservation Group

Cornwall is one of the most geologically diverse counties in the UK. It has hundreds of geological sites of international, national or local importance which collectively illustrate a huge range of geological features. Lots were, and still are designated as SSSIs, most having been identified via the Geological Conservation Review, now several decades ago. These sites have statutory protection, managed by Natural England. Other sites, which are arguably just as important for their geodiversity features as the SSSIs, are identified as County Geology Sites (CGS). These are monitored by the Cornwall Geoconservation Group. Additional CGS are added as an ongoing activity, where the geodiversity becomes recognised for either its scientific, educational, or historical importance, or having an aesthetic value or economic significance. The Cornwall Geoconservation Group's other activities include improving the CGS, providing advice to planning authorities, undertaking research, and providing information on Cornwall's geodiversity and keeping an awareness of mineral developments within the county. The Group is keen to have additional members who can offer their expertise and complement the geographical coverage within the county.

Maximum extent and readvance dynamics of the Irish Sea Ice Stream since the Last Glacial Maximum

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In reconstructing the last British-Irish Ice Sheet (BIIS), the BRITICE-CHRONO Project (2012–2018) generated the most detailed observations of the collapse of any former ice sheet on Earth (Clark *et al.*, 2022). The Irish Sea Ice Stream (ISIS), which extended into the Celtic Sea, was the largest ice stream draining the BIIS (Scourse *et al.*, 2021). For ISIS, a suite of new radiocarbon ages from deglacial sequences offshore in the Celtic and Irish seas and terrestrial cosmogenic nuclide and optically-stimulated luminescence ages from ice-marginal sites in the Isles of Scilly, Ireland, Wales and NW England have been generated (Smedley *et al.*, 2017; Scourse *et al.*, 2019). The ISIS was unusual within the former BIIS in that it was a compound ice stream with two outlets, one marine-terminating that flowed through the Irish Sea Basin into the Celtic Sea and a terrestrial terminus that flowed southwards through Cheshire-Shropshire lowlands into the English Midlands (Chiverrell *et al.*, 2021). The ISIS is now recognised to have extended as far as the continental shelf break to the SW of Britain and Ireland between 24 and 27 ka; this advance was synchronous with independently-dated ice-rafted detritus from ISIS in adjacent

deep-sea cores (Scourse *et al.*, 2009; Haapaniemi *et al.*, 2010;). The ice stream then retreated rapidly northwards through the Celtic Sea, with evidence for readvance phases, deglaciating the Isles of Scilly at 25.5 ka, reaching St Georges Channel by 24.3 ka and the Llyn Peninsula by 23.9 ka. Post-project assessment of multi-beam swath bathymetry from the Celtic Sea provides evidence of the extent and behaviour of ISIS with implications for the glaciation of north Cornwall and Devon.

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