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Mobile carvers and mobile monuments: A geochemical study of early medieval cross-slabs from Clonmacnoise and outlying sites, Ireland

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ABSTRACT

Clonmacnoise has one of the largest collections of early medieval (c. 400–1200 CE) carved stone monuments in northwest Europe. The presence of Clonmacnoise-style cross-slabs at outlying church sites within and beyond the immediate hinterland of the site provides an unmatched opportunity to investigate how stone-carving could be used to shape relationships with subsidiaries and affiliates. Geochemical analysis of a dataset collected using p-XRF demonstrates that craftspeople sometimes travelled considerable distances to carve cross-slabs at outlying sites using local stone. It also found evidence to suggest that some Clonmacnoise-style cross-slabs were carved at or near the site itself before being transported upstream via the Shannon to islands in Lough Ree and to a site immediately beyond the lake. This provides new insights into the complexity and variety of the relationships within early ecclesiastical networks, the organisation of the craft of stone-carving, and the mobility of carvers.

1. Introduction

This paper presents geochemical analysis of a dataset collected using p-XRF that reveals new evidence for mobility within early medieval (c. 400–1200 CE) ecclesiastical networks, specifically that centred on Clonmacnoise, Ireland. In a society characterised by small-scale kingdoms in which most of the population lived and worked locally (Kelly 1988, 4), the development of ecclesiastical networks, sometimes spanning several kingdoms, provided certain individuals with greater opportunities for mobility, both spatial and social. While this is evident in textual sources, these are often idealised and selective, so material evidence is also important for uncovering instances of mobility, whether from isotopic analysis of human remains (e.g. Carver et al. 2016, 120–22; Cahill-Wilson et al. 2014; cf. Alonzi et al. 2019), or analysis of artefacts or monuments like that presented here. Using XRF readings on 37 cross-slabs and 17 glacial boulders, we demonstrate that craftspeople sometimes travelled considerable distances to carve cross-slabs at outlying sites using local stone. We also present evidence suggesting that other cross-slabs may have been carved at or near Clonmacnoise and transported to outlying sites.

Established on the east bank of the Shannon in the sixth century CE, Clonmacnoise developed into the most important monastery in the Irish

midlands, benefiting from the patronage of kings on both sides of the river (e.g. Kehnel 1997; King 1998; 2003). It has one of the largest collections of early medieval carved stone monuments in northwest Europe, including six high crosses and c. 720 smaller monuments, mainly cross-slabs (Ó Carragáin et al. 2025). Most of Clonmacnoise's cross-slabs are largely unshaped slabs, 0.4–1.2 m long, retrieved from surface glacial deposits rather than quarried from bedrock, and carved with a prominent cross belonging to a small number of distinct Clonmacnoise types (Types A–D), usually accompanied by an inscription requesting prayers for the deceased. Most were recumbent grave-markers of revered members of the community along with some royal benefactors. The workshop producing these monuments seems to have operated more or less continuously from at least the eighth century to the twelfth (Ó Riain and Ó Carragáin 2024, 102–4).

Its prestige is clear from the many carved stone monuments at sites across Ireland that emulate those at Clonmacnoise (Ó Carragáin et al. 2024, Fig. 6). While most of these are by local carvers, there is also a substantial number of monuments (>20) that are clearly by carvers trained at Clonmacnoise and probably based there given that most of the outlying sites have just one or two examples (Ó Carragáin et al. 2024, Table 1; see also Ó Floinn 1995, 254–55). These sites usually have historical links to Clonmacnoise, and most are subsidiary churches less than

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Table 1

Monuments included in the dataset.

Site	Monument No.	Clonmacnoise Type	Date-range	Clonmacnoise carver?
Clonmacnoise	OF005-023024-	n/a	c. 786 (?)	yes
Clonmacnoise	OF005-023109-	n/a	800–1100	yes
Clonmacnoise	OF005-023138-	A	700–900	yes
Clonmacnoise	OF005-023188-	C	700–1100	yes
Clonmacnoise	OF005-023201-	C	700–1100	yes
Clonmacnoise	OF005-023212-	A	700–900	yes
Clonmacnoise	OF005-023291-	B	800–1100	yes
Clonmacnoise	OF005-023330-	B	1000–1100 (?)	yes
Clonmacnoise	OF005-023357-	B	1000–1100 (?)	yes
Clonmacnoise	OF005-023363-	B	800–1000 (?)	yes
Clonmacnoise (Athlone)	WM029-042095-	A	c. 764	yes
Clonmacnoise (Athlone)	WM029-042096-	B	950–1100 (?)	yes
Clonmacnoise (Athlone)	WM029-042097-	C	800–1000 (?)	yes
Gallen	OF014-029047-	B	800–1000 (?)	probable
Gallen	OF014-029045-	C	800–1100	unlikely
Gallen	OF014-029049-	C	700–1100	unlikely
Gallen	OF014-029051-	n/a	800–1000	unlikely
Gallen	OF014-029056-	A	700–900	possible
Fuerty	RO039-063004-	B	800–1000 (?)	probable
Fuerty	RO039-063003-	C	800–1100	probable
Ballynakill	LF013-045004-	B/C hybrid	800–1100	probable
Ballynakill	LF013-045012-	B	800–1100	probable
Inchcleraun	LF021-048009-	B	800–1100	probable
Taghshinny	LF023-097003-	B	800–1100	possible
Inchbofin	WM015-001007-	C	800–1100	probable
Inchbofin	WM015-001008-	C	700–1100	probable
Inchbofin	WM015-001009-	B	1000–1100 (?)	probable
Inchbofin	WM015-001011-	B	800–1100	probable
Inchbofin	WM015-001016-	n/a	700–1200	possible
Iniscealtra	CL029-009032-	n/a	700–900	unlikely
Iniscealtra	CL029-009033-	n/a	1000–1200	no
Iniscealtra	CL029-009035-	n/a	1000–1200	no
Iniscealtra	CL029-009059-	A (approx.)	700–900	possible
Iniscealtra	CL029-009066-	B	800–1000	probable
Iniscealtra	CL029-009198-	A	700–900	possible
Coolcashin	KK009-019009-	B	800–1100	probable
Coolcashin	KK009-019010-	B	800–1100	probable

40 km away, upstream around Lough Ree, but they include some more distant outliers, up to 120 km or even 180 km away (Ó Carragáin et al. 2024, 281). This is an internationally important example of an early medieval monastery using stone-carving to shape its relationships with subsidiaries and affiliates. The presence of such a slab perhaps meant that those buried at these outlying sites were believed to benefit at a distance from the special qualities of the cemetery at Clonmacnoise (ibid., 299). Important aspects of this phenomenon remain unclear, however. Sometimes the slabs at outlying sites diverge in subtle ways from typical examples at Clonmacnoise itself, hinting that they are special commissions carved with specific sites in mind (ibid., 294), but it remained to be determined whether finished cross-slabs were dispersed from Clonmacnoise, or if the carvers themselves travelled to the outlying sites. Here we use geochemical analysis to address these and related issues, providing new insights about mobility within ecclesiastical networks and the organisation of the craft of stone-carving.

While cross-slabs have been relatively neglected, somewhat more research on these issues has been carried out in relation to Irish high crosses and churches. High crosses, which are precisely and elaborately carved and usually > 3 m tall, represent far more investment, and several schools of carvers have been identified and mapped (e.g., Harbison 1993; Hamlin 1995). For example, the early tenth-century Cross of the Scriptures at Clonmacnoise was one of the outputs of a workshop that operated at at least six major monasteries patronised by the kings of Mide, including Monasterboice, c.120 km away (Stalley 2020, 169–83). While the Clonmacnoise cross is of locally sourced stone, most of the others were probably carved from fine Carricleck sandstone transported more than 20 km in some cases, the basic shape of the crosses probably roughed out at the quarry (ibid. 25–28; Sevastopulo and Stalley 2023). Turning to church buildings, masonry analysis suggests

that clusters of plain pre-Romanesque churches of eleventh- to early twelfth-century date are primarily by locally based masons (Ó Carragáin 2005), but carvers travelled considerably greater distances with the advent of Romanesque architectural sculpture from around 1100 (e.g., Gem 2006; 2021). Of its nature, fine ecclesiastical metalwork presents a different picture, with for example the outputs of the early twelfth-century ‘Cross of Cong’ workshop, based at Roscommon, quite widely dispersed, often as gifts to important sites in different kingdoms (Murray 2014). While cross-slabs are not as precious, they would have been quite easy to transport, especially considering that many of the sites in this study are linked by the Shannon and its tributaries. It cannot, therefore, be assumed that it was always a case of mobile carvers.

To date, the only study to address this question using p-XRF is Goodale et al. (2018), which identified ten small monuments (cross-slabs and crosses) of non-local stone on island monasteries off the west coast, including seven within the large (>60) collection on High Island, Co. Galway. A possible motivation is the fact that the local schist, with its penetrative tectonic fabric, was challenging to carve, but not impossible as shown by the bulk of the monuments there. Clearly other factors were at play. For example, in some cases the stone might have been selected to express a link between the commemorated individual and a home territory or monastery (ibid. 901). The authors conclude that movement of lithic resources ‘was one aspect of exchange and interaction that linked ecclesiastical settlements along the Irish

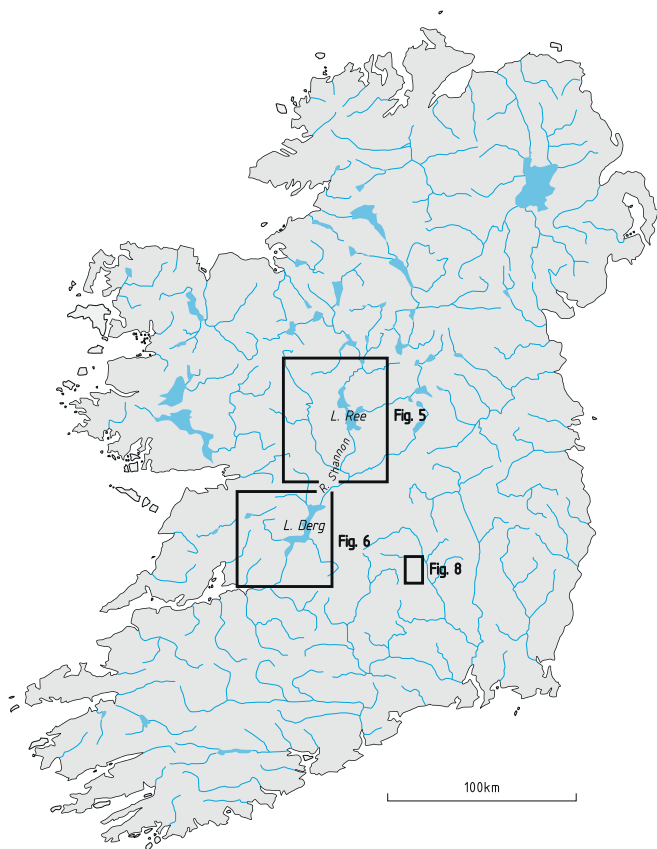


Fig. 1. Map of Ireland showing the location of the monuments and the extents of the detailed geological maps (Figs. 5, 6 & 8).

Connemara coast' (ibid, 902). In most cases, if not all, these monuments are by local carvers, so what is being transported is probably unworked stone.¹ In contrast, the design and execution of the Clonmacnoise-style cross-slabs considered here leave no doubt that we are dealing with mobile carvers and/or mobile monuments. Indeed, this appears to be the only substantial example of this phenomenon in Ireland, certainly the only one involving multiple sites and cross-slabs. Previous research has distinguished between cross-slabs carved by Clonmacnoise-trained carvers and those by local carvers emulating Clonmacnoise designs (Ó Carragáin et al. 2024). As detailed in Table 1, most of the slabs considered here are examples of the former. They cannot be the work of local carvers using pattern books or inspired by designs in other media. They are distinguished, not only by design details, but also by the character and practiced quality of the carving, which sets them apart from the work of local carvers. Where present, the latter is often more rudimentary, while in some cases (e.g., Coolcashin, Fuerty) there is little or no local tradition of carving in the vicinity of the site.

Data were gathered on monuments from nine sites: Clonmacnoise (thirteen including three now in Athlone Castle Museum), Gallen, a subsidiary site to the southeast (five), five sites in the Lough Ree catchment area north of Clonmacnoise (eleven in total), and two sites outside the hinterland of Clonmacnoise (Figs. 1-3). These are Iniscealtra an island on Lough Derg, Co. Clare (six) and Coolcashin, Co. Kilkenny

¹ One of them, a slab on Caher Island, Co. Mayo, of High Island schist (MA094-003044-), is somewhat similar to one of the High Island monuments (GA021-026032-) but is better paralleled at Caher (MA094-003031-). Pace Goodale et al. (2018), while the figure on GA021-026038-, a limestone monument on High Island, is unusual, otherwise its form and design details strongly suggest it is by a High Island carver (cf. e.g., the form of GA021-026033- and GA021-026036- and the roundels of GA021-026037-).

(two; Table 1; Fig. 4). Stylistically, most of these slabs are likely to be the work of Clonmacnoise-trained carvers, but a few of those at Gallen (OF014-029045-, OF014-029049-, OF014-029051-, perhaps OF014-029056-) and Iniscealtra (especially CL029-009033-, CL029-009035-) are more likely to be by locally-trained carvers (Table 1).

2. Geological Setting

The bedrock sandstone geology of the Lough Ree (Irish midlands) and Lough Derg (east Clare) areas predominantly consists of Upper Devonian/Lower Carboniferous Upper Old Red Sandstone (UORS) clastic terrestrial sedimentary rocks preserved in the cores of Variscan fold inliers (Figs. 5, 6). These lithologies typically consist of basal breccias and conglomerates that are followed by fining-upward sequences of well bedded feldspathic sandstones that can vary from purplish red to buffish-white in colour. Compositionally these sandstones consist of poorly sorted and highly angular quartz and plagioclase feldspar (15–20%) clasts with minor amounts of white mica, anatase, rutile and brookite (Fig. 7). There is marked petrological similarity between UORS lithologies from the Irish Midlands inliers and those from the east Clare inliers. This makes distinguishing these lithologies very difficult by simply relying on visual inspection. In contrast, the sandstones in the around Coolcashin, Co. Kilkenny, are part of the wider Upper Carboniferous Castlecomer Plateau and typically consist of dull grey fine to medium grained marine sandstones, again quite flaggy in nature (Fig. 8). The flaggy nature of these sandstones, with sharply defined planar bedding planes, especially seen in the finer grained sandstones from both the UORS and Upper Carboniferous stratigraphic intervals, make them ideal raw material for cross-slab production. This bedrock was subsequently covered by significant Quaternary glacial and fluvio-glacial deposits. These deposits mostly consist of glacial diamicton tills whose cobble/boulder clasts are predominantly derived from the local underlying bedrock (Richards, 2002; Geological Survey of Ireland, 2017; Peltonen et al., 2024). For the Lough Ree sites, the closest sources of potential cross-slab sandstones are a series of structural inliers that are cored by UORS lithologies (Fig. 5). In the case of Iniscealtra there are significant suitable UORS bedrock and associated till units onshore to the immediate west of the island. Finally, Coolcashin is located in an area of Upper Carboniferous sandstones with till boulders derived from same that are a very good initial visual match to the cross-slabs associated with this site.

3. Methodology

X-ray fluorescence (XRF) data were acquired using Thermo Fisher Scientific™ Niton™ XL2 handheld analyser with a built-in, rechargeable battery. It is equipped with multiple excitation filters to optimize sensitivity across different elemental ranges and is capable of determining a range of elements in geological materials from S to U. Specifically, the instrument's "Main Range" filter provides optimum sensitivity for elements ranging from manganese (Mn) to bismuth (Bi), while the "Low Range" filter enhances detection of lighter elements from titanium (Ti) through chromium (Cr). Although the main range filter can also detect Ti, V, and Cr, its sensitivity for these elements is lower than that of the low filter. During our measurements, the instrument operated under default filter settings, wherein it automatically alternates between filters until either the user-defined maximum analysis time is reached, or the measurement is manually terminated.

The instrument uses an Ag anode X-ray tube which can operate at 45 kV and 80 uA maxima. A beam diameter of 8 mm was used for our analysis. Compositional spectra were acquired on a Si-PIN detector which are processed and calibrated according to the manufacturer's specifications using the manufacturer's installed software. The instrument was used to analyse both cross-slabs from the archaeological sites and boulder samples from the associated sandstone lithology under the same instrumental settings. At the start of each analysis session a



Fig. 2. Ten of the thirteen analysed slabs from Clonmacnoise. The first six shown are stored at the site while the lowermost three are now in Athlone Castle Museum.

calibration was carried out using the Systems Check function of the detector verifying it is fully operating to specifications.

For each individual analysis a minimum acquisition time of 12 s was used, and a minimum of 12 analyses were acquired from each individual boulder and slab. It was decided to adopt this multiple analysis relatively short duration acquisition approach to capture any intra-sample geochemical variability. We initially verified that the 2σ % analytical error was consistently below 20% for 12 s or greater for the elements used in this study, while the intra-sample variation between different

points on the same sandstone was significantly larger than this error threshold. This means that the analytical uncertainty is small relative to the true spatial variability in the material (see supplementary file). These measurements were distributed across the exposed surface to account for textural and compositional heterogeneity. For the purposes of this study data were collected for the following heavier elements, Fe, Zn, Rb, Sr, Zr, Ag, Cd, Sn, Sb, and Ba. The XRF analyses were conducted over a period of four days. All samples were clean and dry when measured. Although some studies have reported discrepancies in

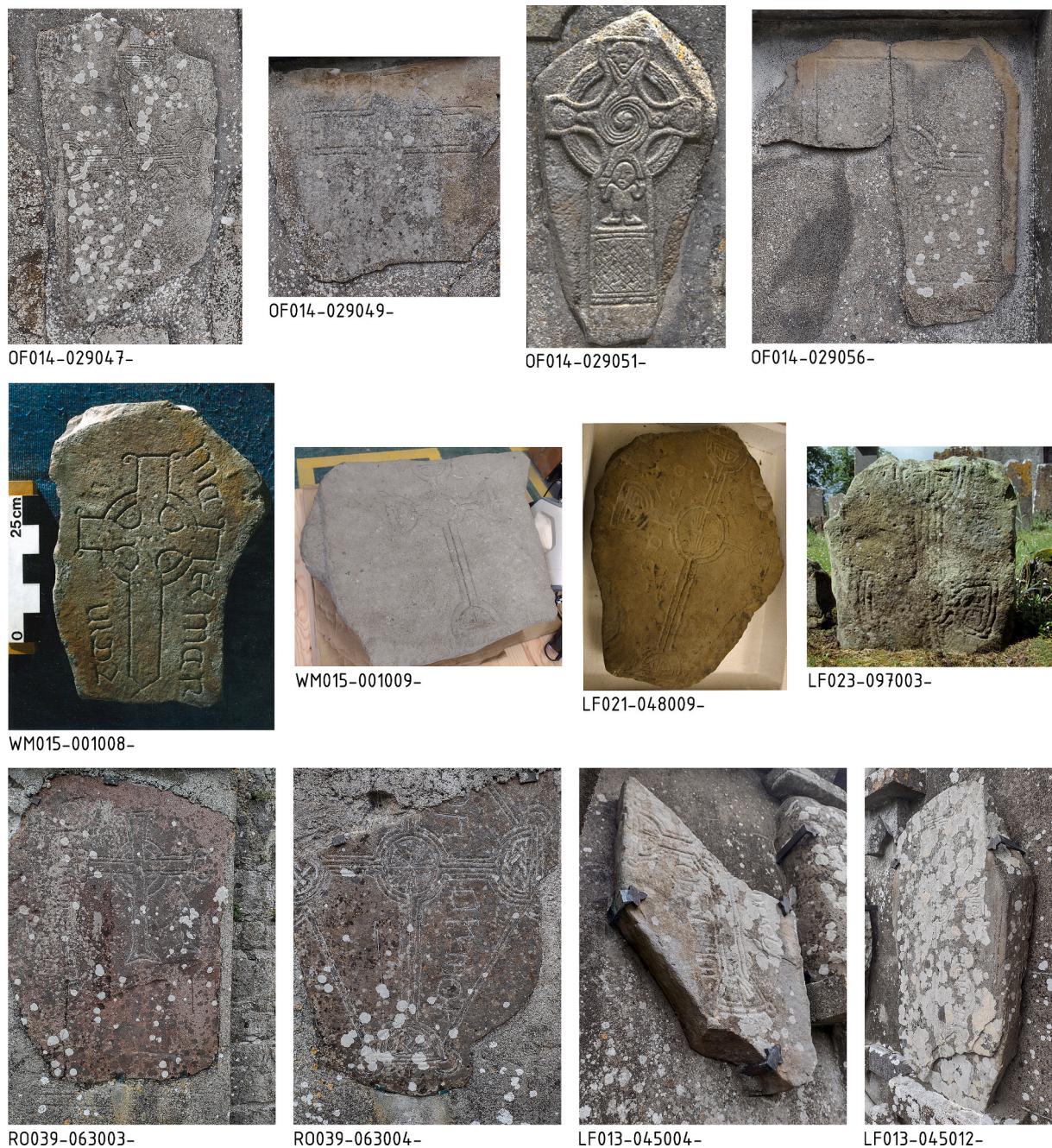


Fig. 3. Slabs in the hinterland of Clonmacnoise: Gallen (OF014-029047-, OF014-029049-, OF014-029051-, OF014-029056-), Inchbofin (WM015-001008-, WM015-001009-), Inchcleraun (LF021-048009-), Taghshinny (LF023-097003-), Fuerty (RO039-063003-, RO039-063004-), and Ballynakill (LF013-045004-, LF013-045012-).

elemental concentrations between wet and dry samples (Bevins et al., 2023), these differences are typically most pronounced in the lighter elements. Since our focus is primarily on heavier elements, the influence of sample moisture is considered minimal. Nonetheless, the dry condition of the samples is noted here for transparency and reproducibility.

The carvers did not use freshly quarried stone, which was not available in the vicinity of the studied sites, but instead used readily available weathered field slabs. The carving must have revealed 'fresher' surfaces in places, but this was not evident when examining the cross-slabs, which now appear uniformly weathered. Interpretations of the results are therefore based on bulk surface geochemistry. Given the random nature of handheld XRF beam placement, some analyses may have intersected trace mineral phases that do not represent the bulk

composition of the rock. As a result, a robust data-cleaning protocol was applied to minimize the impact of such outliers. The quality of each analysis was assessed using the associated 2σ (two sigma) error values generated during XRF data processing. Data points exhibiting high relative uncertainty, specifically those with error values exceeding 30%, were excluded from further analysis. Each element dataset was examined for variability, and outliers were identified using a ± 2 standard deviation (2SD) threshold from the mean. In cases where the relative deviation of an analysis exceeded 20–33% for a given element, the data point was also excluded as an outlier. These criteria were applied in a flexible, element-specific manner rather than using a fixed cutoff across all elements. Despite this filtering process, the number of valid measurements per sample always remained ≥ 8 , ensuring sufficient data for



Fig. 4. Slabs outside the immediate hinterland of Clonmacnoise: Iniscealtra, Co. Clare (CL029-009059-, CL029-009066-, CL029-009198-) and Coolcashin, Co. Kilkenny (KK009-019009-, KK009-019010-).

statistical analysis. Elements in the final filtered dataset included Rb, Sr, Zr, Sn, Sb, and Ba. The cleaned dataset was subsequently used to construct bivariate plots based on elemental ratios, aiding in the geochemical comparison of samples.

It was decided in this study to focus on four elements, Rb, Sr, Ba and Zr, because they consistently yielded robust XRF results across most samples and are comparatively stable in sandstones. In clastic sedimentary rocks, Rb, Sr and Ba is present mainly in feldspars, mica and clay minerals. Variations in their absolute concentrations and ratios (e.g. Rb/Sr) are interpreted as reflecting differences in bulk mineral proportions and mineral chemistry. In particular, the Rb/Sr ratio provides a proxy for the relative contribution of K-rich versus Ca-rich components within the sandstone matrix. Zr in clastic sedimentary rocks is directly related to the presence of detrital heavy minerals, principally zircon and sphene. All of these mineral phases are present in the feldspathic arenites that typically make up ORS and Upper Carboniferous sandstone lithologies.

Ogburn et al. (2013) compared fresh and weathered surfaces of andesite samples and showed that there is no observed effect of weathering on these elements (Rb, Sr, Zr and Ba). We also confirmed this by analysing unweathered and weathered surfaces of a representative sandstone field boulder (25-6-23-3) from Ferbane, County Offaly, near Clonmacnoise (see supplementary file). Sn and Sb are metallogenic and trace indicators of ore-related fluids or specific source rocks and can be useful if only present in sufficient concentration. Therefore, we chose the two ratios Ba/Zr and Rb/Sr for comparing the chemical composition of the slabs and the boulders. Rb/Sr ratio have been used to discriminate sandstone sources and are useful indicators of the depositional conditions, sediment recycling (Ullah et al., 2015; Huang et al., 2018; Meng et al., 2024; Singtuen et al., 2025). Ba/Zr ratio has been useful for identifying sandstone source (Kutterolf et al., 2011). Sr/Ba, Zr/Rb has

also been often used as geochemical indicators of paleosedimentary environment (Liu et al., 2020; Bilobé et al., 2022; Zeng et al., 2021; Li et al., 2021; Chen et al., 2023).

To explore the structure of the dataset in a multivariate context, principal component analysis (PCA) was conducted using R (prcomp). PCA helped identify the elements contributing most to the variance among samples and provided a multidimensional visualization of chemical composition patterns and were helpful in supporting the observations made in the bivariate plots. PCA is a [multivariate statistical analysis](#) technique used for dimension reduction of any dataset (Pawlowsky-Glahn et al., 2015). For PCA analysis, as in most statistical methods, a complete dataset is required, as missing values introduce limitations to the application of the statistical methods. The elements with a high number of missing data have been deleted altogether. For the elements with lower number of missing values the missing values are imputed. Mostly the missing values correspond to data below detection limit (b.d.l.); the common approach is to replace the missing values by the detection limit (DL)/ $\sqrt{2}$ or zero (e.g., Verbóvšek, 2011). After data imputation, the data were transformed using the isometric log-ratio (ILR) method (Filzmoser et al., 2009). Because the units are the same for all the variables, standardization (whitening) of the data is not necessary (Lipp et al., 2020). It is important to remember that PCA doesn't help identify the source, it only shows similarity structure. We are considering six elements in this study and therefore it is easy to overinterpret. Therefore, to exercise caution, we are crosschecking the PCA clusters with bivariate plots and vice versa.²

² The filtered dataset and supplementary files are available here: <https://doi.org/10.5281/zenodo.18980646>.

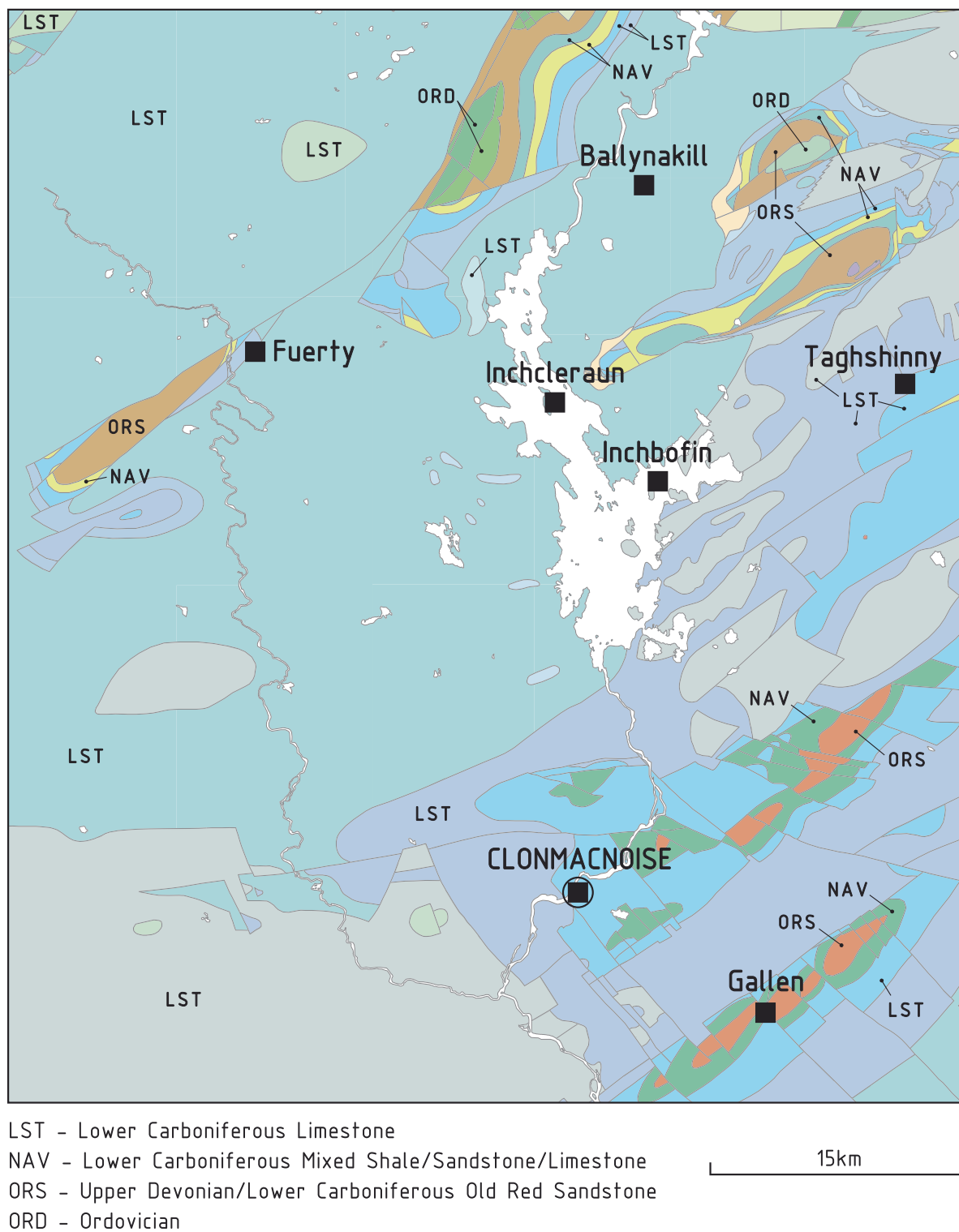


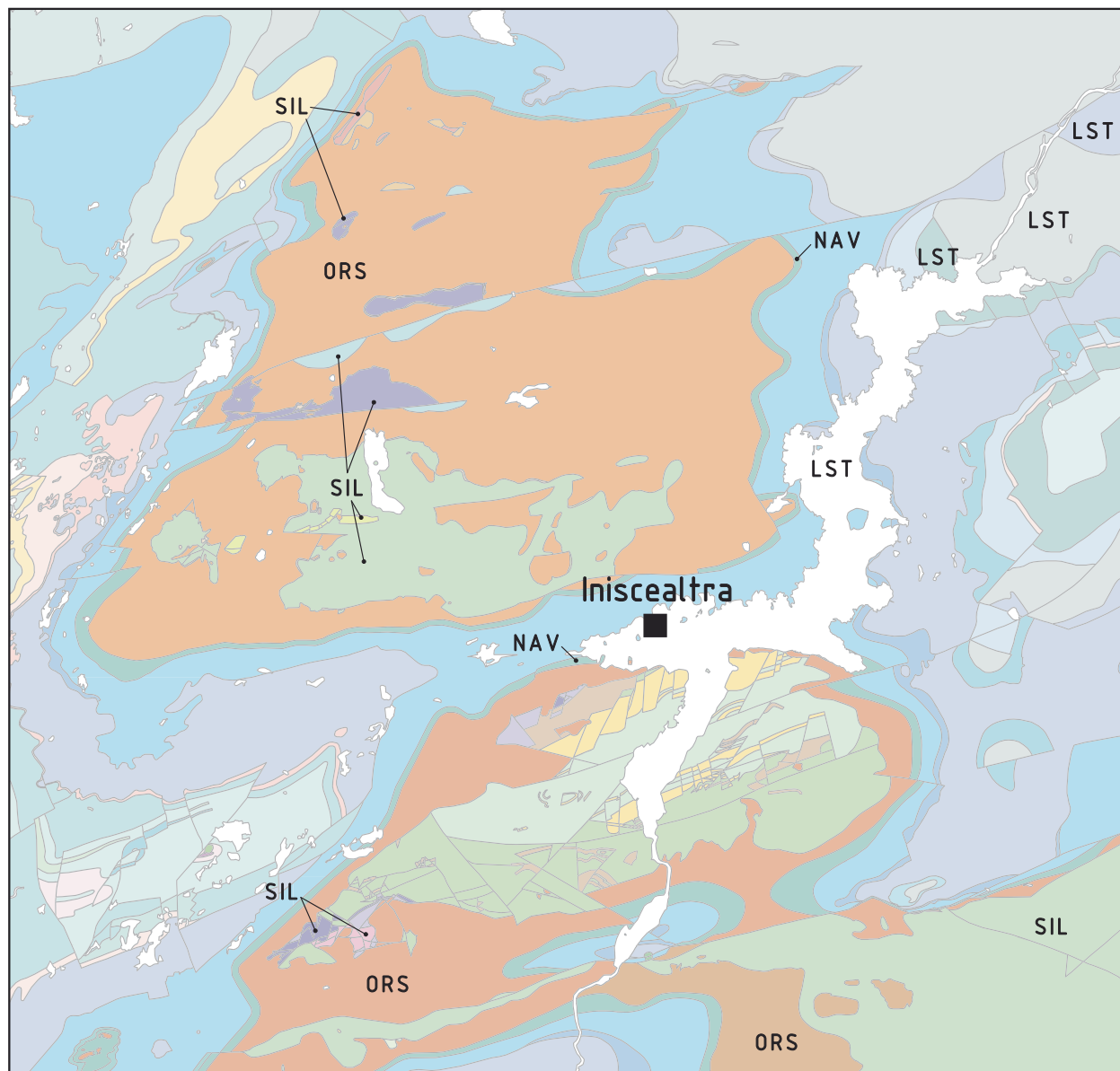
Fig. 5. Geological map showing Clonmacnoise and the outlying sites around Lough Ree illustrating the proximity Old Red Sandstone (ORS) structural inliers to these sites.

4. Results

4.1. Clonmacnoise, County Offaly

Thirteen slabs from Clonmacnoise, including three slabs currently on display in Athlone, were analysed using pXRF (Fig. 9). With the exception of OF005-023291- which has a dark grey colour (and atypical

composition), these slabs are typically pale pink to buff coloured medium to coarse grained flaggy sandstones. On the Ba/Zr v Rb/Sr bivariate plot all but three slabs (OF005-023138-, OF005-023291-, OF005-023363-) plot within a very restricted field with very low (<0.4) Ba/Zr ratios. These low Ba/Zr ratios are primarily due to slabs with consistently higher Zr values when compared to other UORS lithologies from the Irish midlands. The three slabs outside this field plot in a wider field



LST - Lower Carboniferous Limestone
 NAV - Lower Carboniferous Mixed Shale/Sandstone/Limestone
 ORS - Upper Devonian/Lower Carboniferous Old Red Sandstone
 SIL - Silurian Shale

15km

Fig. 6. Geological map centred on Inisceiltra, Lough Derg, east Co. Clare illustrating the proximity of the two east Clare ORS structural inliers to the site.

that broadly corresponds to field boulders derived from local (Ballynahown, Moate) UORS inliers. Their compositions are not clustered but they have compositional overlaps with local boulders from Moate and Bloomhill. This observation is cross verified with the PCA results. Otherwise, using six element concentration (Rb, Sr, Zr, Ba, Sn, Sb), we can see that ten of the Clonmacnoise slabs overlap with each other. The slabs in this cluster do not overlap with any boulder composition that we have analysed.

4.2. Gallen, County Offaly

All of the pXRF analysed Gallen slabs, with the exception of Gallen OF014-029045, which are typically pale buff medium grained sandstones, show a close correspondence on the Ba/Zr v Rb/Sr bivariate plot

to the low Ba/Zr field we see in the majority of Clonmacnoise slabs (Fig. 10).

4.3. Inchbofin, Lough Ree, County Westmeath

The slabs from Inchbofin, an island in Lough Ree, are typically medium to coarse grained sandstones with pale buff to pale pink colouration. Of the five slabs analysed using pXRF, four show a very close correspondence to the 'typical' Ba/Zr v Rb/Sr field (Fig. 11a) we see in Clonmacnoise slabs (Fig. 9). The exception, WM015-001007-, plots in a high Ba/Zr field that broadly corresponds to OF005-023138- and OF005-023363- from Clonmacnoise. This observation corroborates the patterns seen in the PCA plots (Fig. 11c).

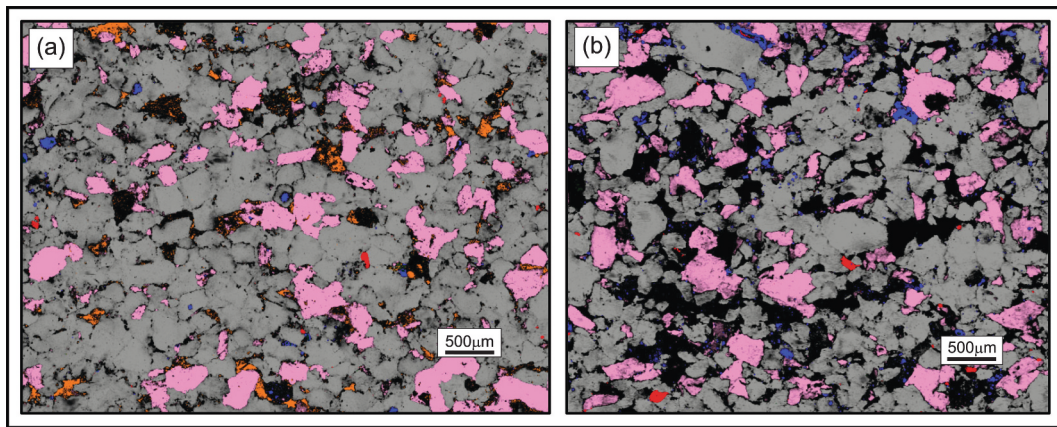


Fig. 7. Raman spectrographic map of Upper Devonian feldspathic sandstones from (a) the Ferbane Inlier, County Offaly and (b) the east Clare Inlier. Grey-quartz, pink-plagioclase feldspar, orange-white mica.

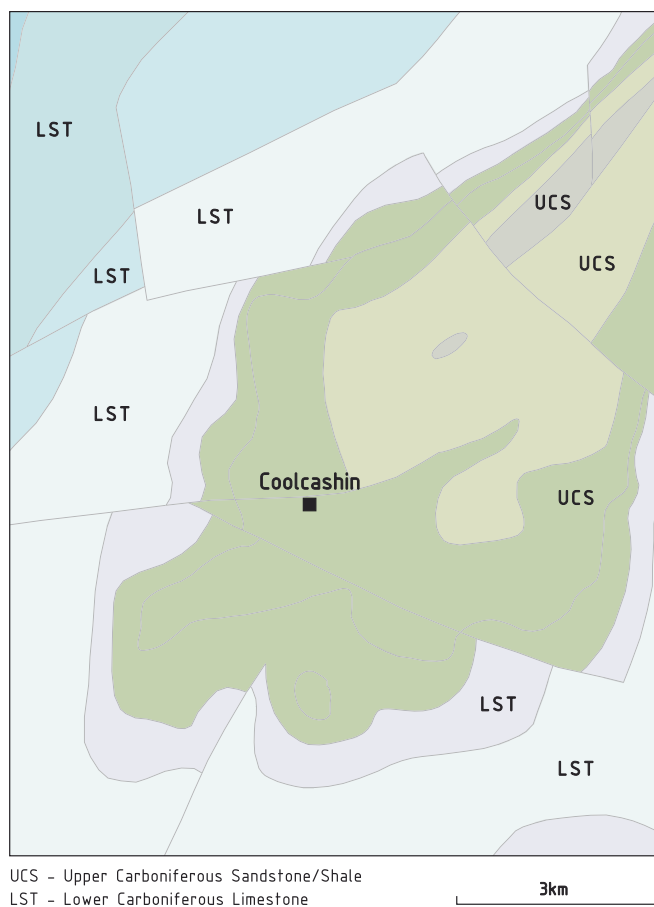


Fig. 8. Geological map centred on Coolcashin, Co. Kilkenny illustrating the proximity of the site to Upper Carboniferous sandstones (UCS).

4.4. Inchcleraun, Lough Ree, County Longford

The single cross-slab analysed from Inchcleraun, an island to the north of Inchbofin, is composed of a pale buff coarse grained sandstone which again plots in the distinct low Ba/Zr field we see dominate in the Clonmacnoise slab lithologies (Fig. 12). This is also reflected in the PCA plot, where the cross-slab sample from Inchcleraun overlap with the Clonmacnoise field (Fig. 12c).

4.5. Taghshinny, County Longford

The single cross-slab analysed from Taghshinny is a coarse-grained sandstone that plots in a Ba/Zr v Rb/Sr field that shows good correspondence to field boulders derived from the local Bawn Mountain UORS Inlier (Fig. 12).

4.6. Ballynakill, County Longford

From the pXRF analyses of two cross-slabs both consisting of medium grained buff flaggy sandstone from the Ballynakill graveyard site, LF013-045012- shows a good correspondence to the Clonmacnoise Ba/Zr v Rb/Sr field, while LF013-045004- is a closer match to material derived from the local Bawn Mountain UORS Inlier (Fig. 12).

4.7. Fuerty, County Roscommon

The two slabs analysed from Fuerty consist of coarse-grained sandstones with a distinct brick red colouration. Lithologically they are a good match to the red and purple micaceous sandstone of the UORS Fearnaght Formation (Morris et al, 2002) which is exposed in the core of the Cregg Inlier to the immediate southwest of the Fuerty site. There is also a good match between both slabs and a red sandstone field boulder derived from the Cregg Inlier on the Ba/Zr v Rb/Sr bivariate plot (Fig. 13). These slabs are distinct from the Clonmacnoise slabs, as seen in the PCA plot.

4.8. Iniscealtra, Lough Derg, County Clare

The cross-slabs from Iniscealtra, an island on Lough Derg, Co. Clare, consist of pale red and flaggy coarse-grained sandstones typical of the lithologies seen in the UORS inliers onshore to the immediate north and south of the site (Fig. 6). On the Ba/Zr v Rb/Sr bivariate plot, as well as the PCA diagram, there is very good overlap between the cross-slab data and data from boulders derived from the adjacent UORS inliers (Fig. 14). The compositional range of these slabs are not within the major Clonmacnoise cluster.

4.9. Coolcashin, County Kilkenny

The two cross-slabs from Coolcashin consist of pale grey/dark green medium sandstones typical of the Upper Carboniferous Bregaun Flagstone Formation which outcrops < 1 km to the east of the site (Fig. 8). On the Ba/Zr v Rb/Sr bivariate plot there is an excellent match between the cross-slab data fields and the local boulder data (Fig. 15). The PCA plot supports this observation. Additionally, the cross-slabs from

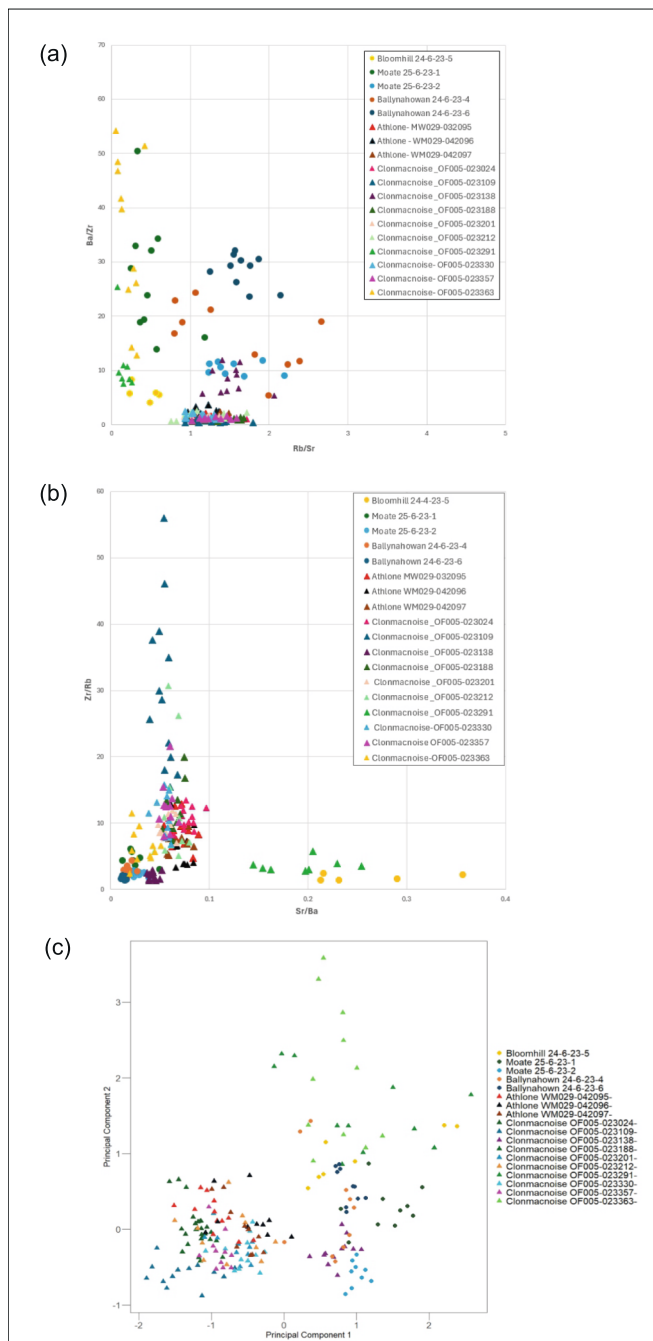


Fig. 9. XRF data plots for the Clonmacnoise cross-slabs (triangles) and boulders (circles) derived from surrounding UORS inliers: (a) Rb/Sr v Ba/Zr, (b) Sr/Ba v Zr/Rb and (c) PCA plot using the six elements Rb, Sr, Ba, Zr, Sn and Sb.

Coolcashin do not overlap with the Clonmacnoise slabs.

5. Discussion

5.1. Clonmacnoise and Gallen

These data provide new insights into the practice of stone-carving both at Clonmacnoise and within its ecclesiastical network. While other factors, to do with its identity as a prestigious place of burial were also important, ready availability of suitable stone must have been a prerequisite for the unparalleled scale of cross-slab production at Clonmacnoise. The profusion of suitable sandstone glacial till slabs on or close to the surface within a short distance of the site, negating the need

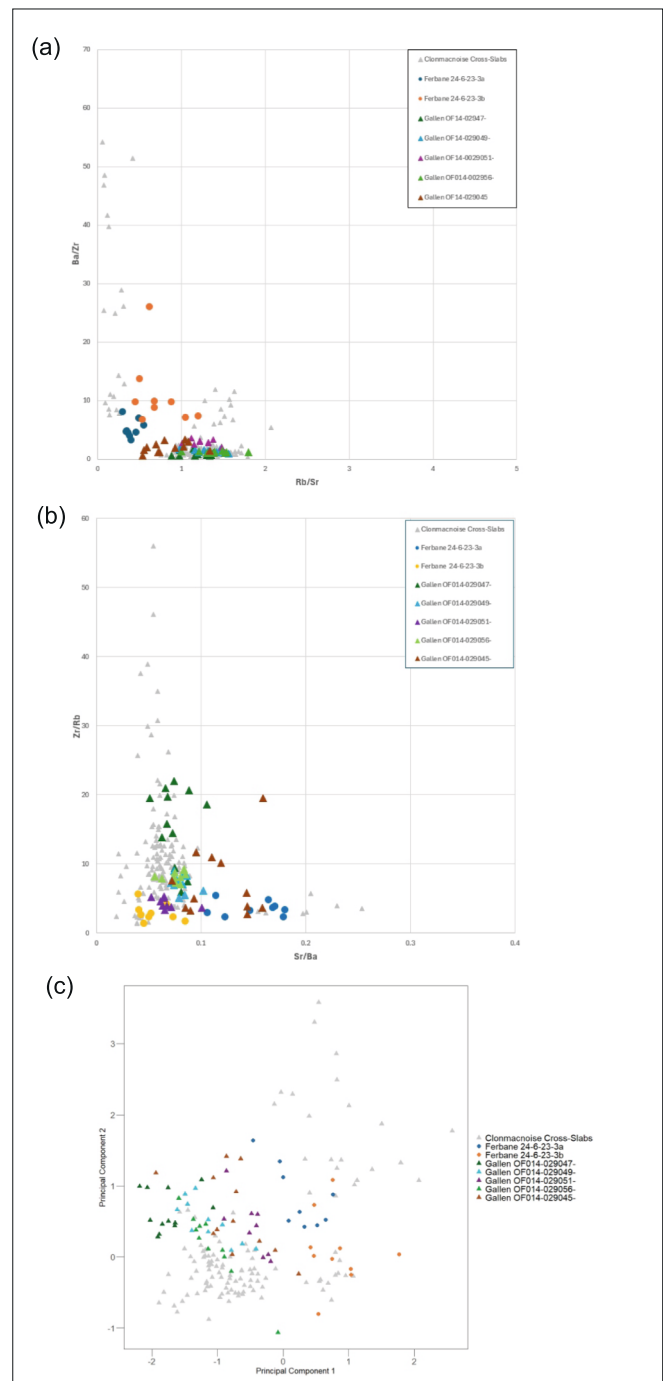


Fig. 10. XRF data plots for the Gallen cross-slabs (triangles) and boulders (circles) derived from surrounding UORS inliers: (a) Rb/Sr v Ba/Zr, (b) Sr/Ba v Zr/Rb and (c) PCA plot using the six elements Rb, Sr, Ba, Zr, Sn and Sb.

for bedrock quarrying, is notable. In stark contrast, the handful of ecclesiastical sites in Ireland of equal or higher status – notably Armagh, Kildare, Kells and Clonard, both in Co. Meath, and Emly, Co. Tipperary – have few or no cross-slabs (Ó Carragáin et al. 2024, 295–96). They might of course have invested in wooden grave-markers but if so these were relatively short-lived monuments, that would not have accumulated over centuries contributing to the character of these complexes in a manner comparable to what we see at Clonmacnoise. Several factors may have contributed to these contrasting strategies of commemoration. In some cases, the close association of this monument type with Clonmacnoise may have been a factor. While the association of specific

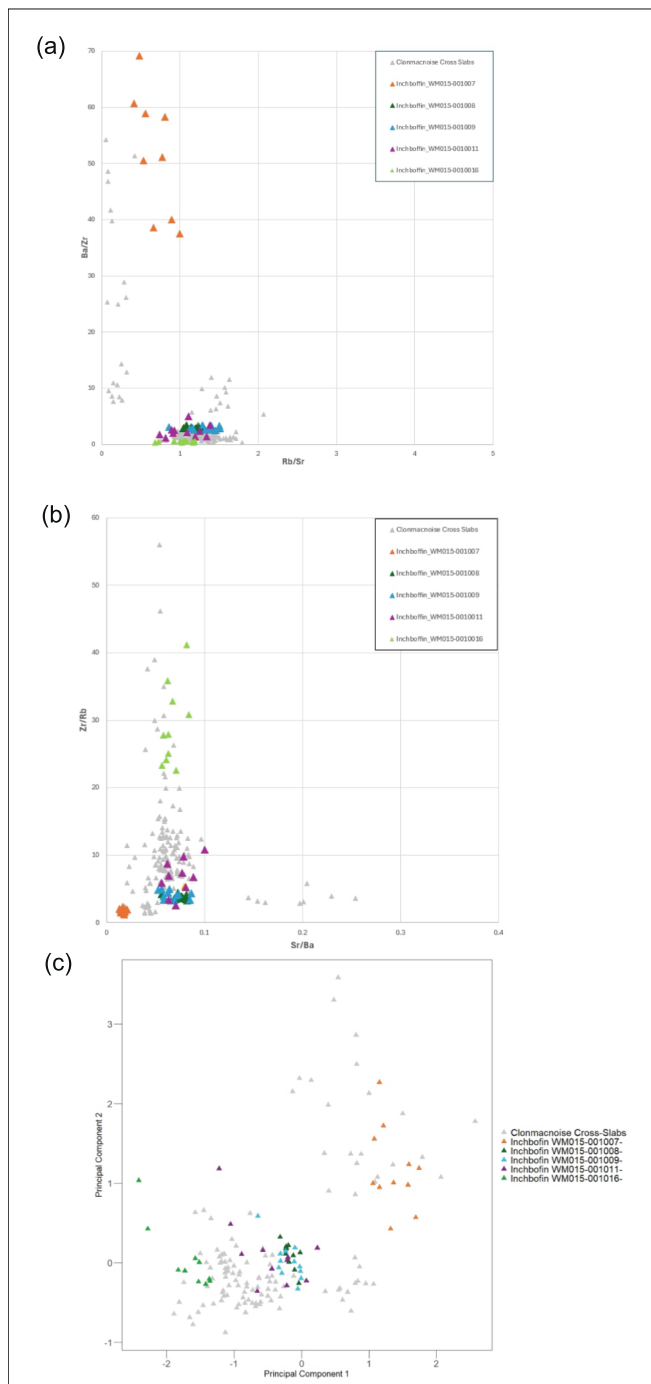


Fig. 11. XRF data plots for the Inchbofin cross-slabs: (a) Rb/Sr v Ba/Zr, (b) Sr/Ba v Zr/Rb and (c) PCA plot using the six elements Rb, Sr, Ba, Zr, Sn and Sb.

designs with Clonmacnoise is well known, the possibility that the large-scale proliferation of recumbent cross-slabs was in itself associated with Clonmacnoise should be considered, given that most of the other substantial collections are relatively late and/or at sites affiliated with Clonmacnoise (ibid; Ó Carragáin et al. 2025). In the case of some sites, notably Armagh and Kells, less ready access to suitable sandstone slabs may have been another factor, though this requires further study.

A large majority (10/13) of the Clonmacnoise slabs analysed have a distinct geochemical signature with relatively high Zr values. This suggests that the carvers of Clonmacnoise had a favoured source. Given that the slabs in question range in date from the eighth century to the eleventh (Table 1) it appears to have been exploited for a considerable

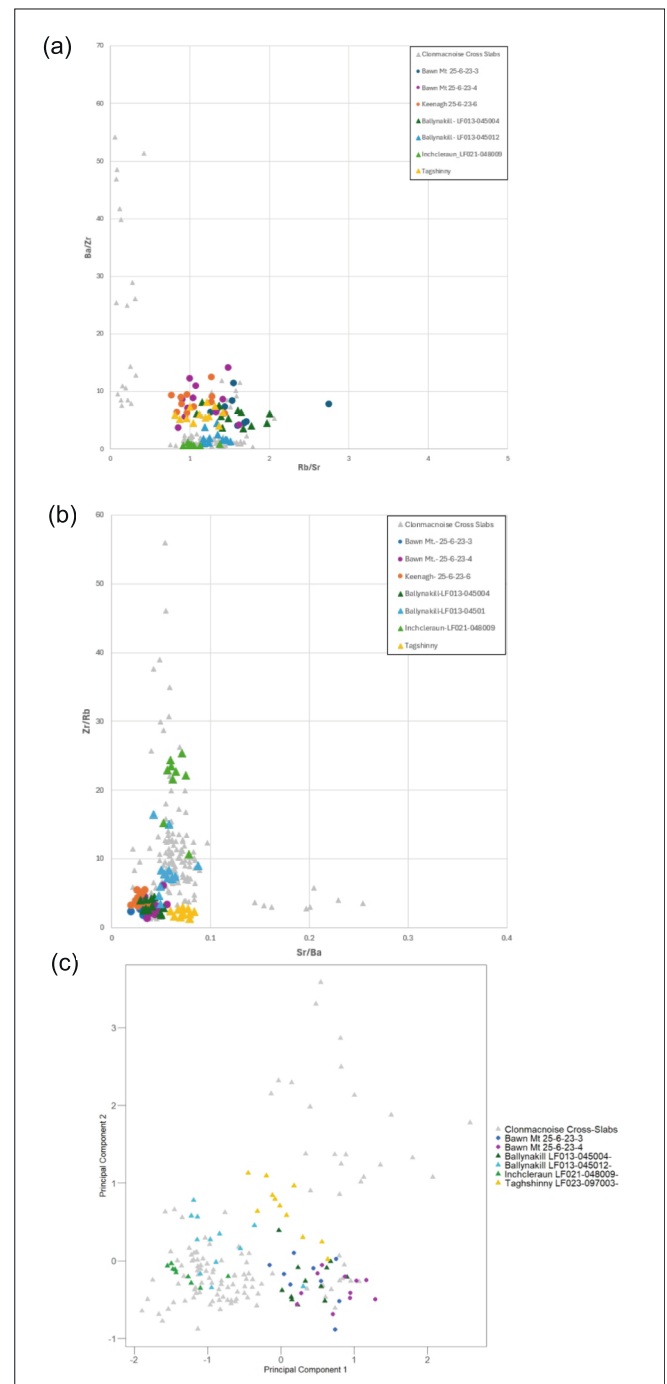


Fig. 12. XRF data plots for the Inchcleraun, Taghshinnny and Ballynakill cross-slabs (triangles) and boulders (circles) derived from surrounding UORS inliers: (a) Rb/Sr v Ba/Zr, (b) Sr/Ba v Zr/Rb and (c) PCA plot using the six elements Rb, Sr, Ba, Zr, Sn and Sb.

period and must have been substantial. In modern times, the greatest profusion of slabs in the vicinity of Clonmacnoise was around Bloom Hill (c. 5 km to the northeast) and Ballynahown (c. 9 km to the northeast), which have been identified as likely sources for both its high crosses and cross-slabs (Feehan 2014, 11–12; 2013, 317, 327). In our data there is not a good match between the bulk of the Clonmacnoise slabs and boulders from Bloomhill or Ballynahown. However, while further work would be needed to identify it, there can be little doubt that the favoured source was local (*contra* Lionard, 1961, 145).

With c. 166 examples, Gallen, one of the most significant of

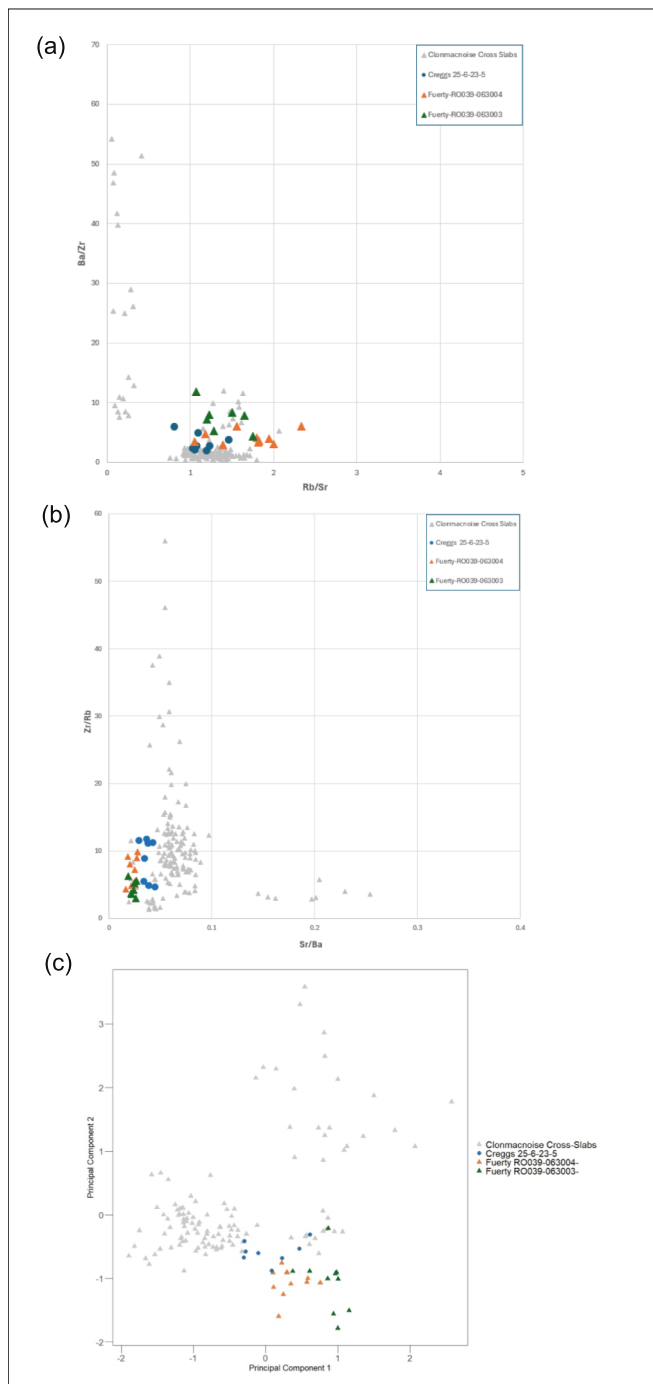


Fig. 13. XRF data plots for the Fuerty cross-slabs (triangles) and boulders (circles) derived from surrounding UORS inliers: (a) Rb/Sr v Ba/Zr, (b) Sr/Ba v Zr/Rb and (c) PCA plot using the six elements Rb, Sr, Ba, Zr, Sn and Sb.

Clonmacnoise's subsidiaries, 13 km to the southeast, has the second largest collection of cross-slabs in Ireland (Ó Carragáin et al 2025). The relationship between the two sites, as expressed in stone-carving, is complex. While Clonmacnoise influence is clear, along with its scale, the distinctive designs of a substantial proportion of Gallen's collection leave no doubt that it had its own workshop. For example, within Ireland slabs with so-called 'thistle crosses' (i.e., in a circular frame and with small hollow angles) are almost exclusively found at Gallen, with not a

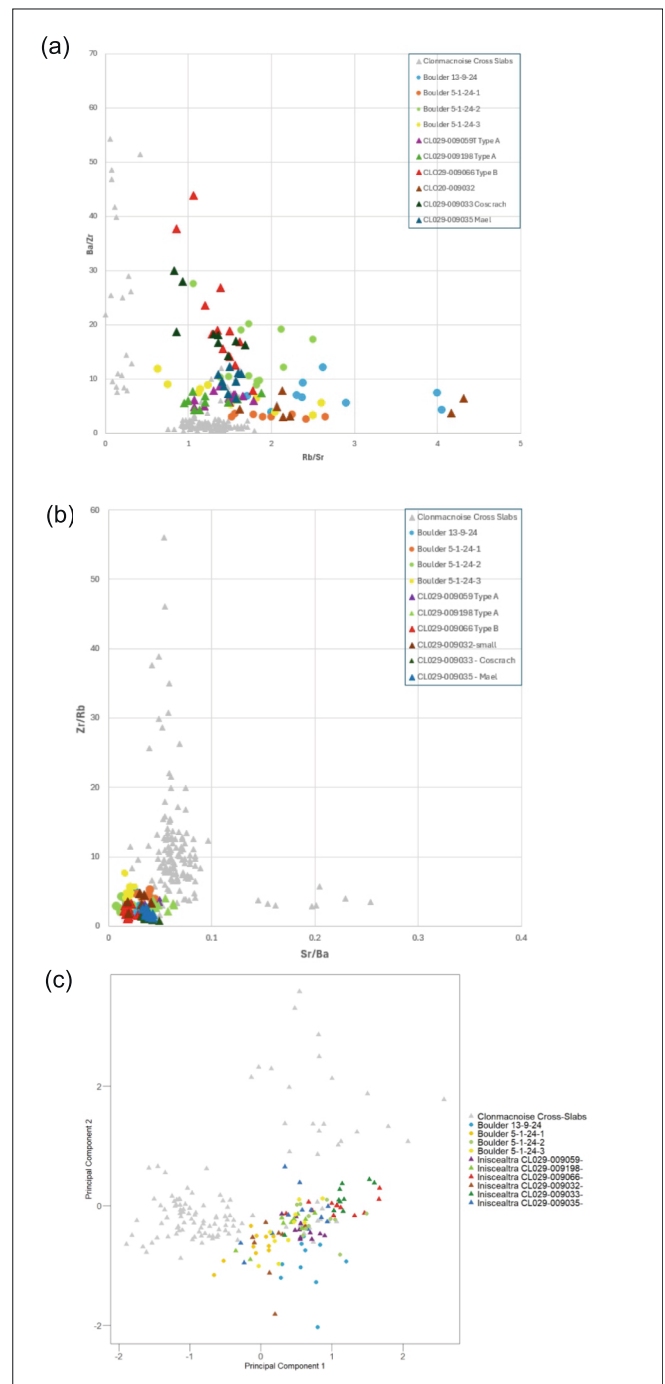


Fig. 14. XRF data plots for the Iniscealtra cross-slabs (triangles) and boulders (circles) derived from surrounding UORS inliers: (a) Rb/Sr v Ba/Zr, (b) Sr/Ba v Zr/Rb and (c) PCA plot using the six elements Rb, Sr, Ba, Zr, Sn and Sb.

single example at Clonmacnoise, suggesting a conscious choice not to import the house style of this subsidiary site (Ó Carragáin and Colbert, in prep). There are similar contrasts in the formulae used in inscriptions at the two sites: though not common, the 'LEC' formula (meaning, 'the {grave}-stone of...') is found exclusively at Gallen (Ó Riain and Ó Carragáin 2024, 99–100), whereas 'OR DO' ('a prayer for'), the formula most commonly used at Clonmacnoise (>100 examples), is surprisingly rare at Gallen with only four possible examples, two of which may be

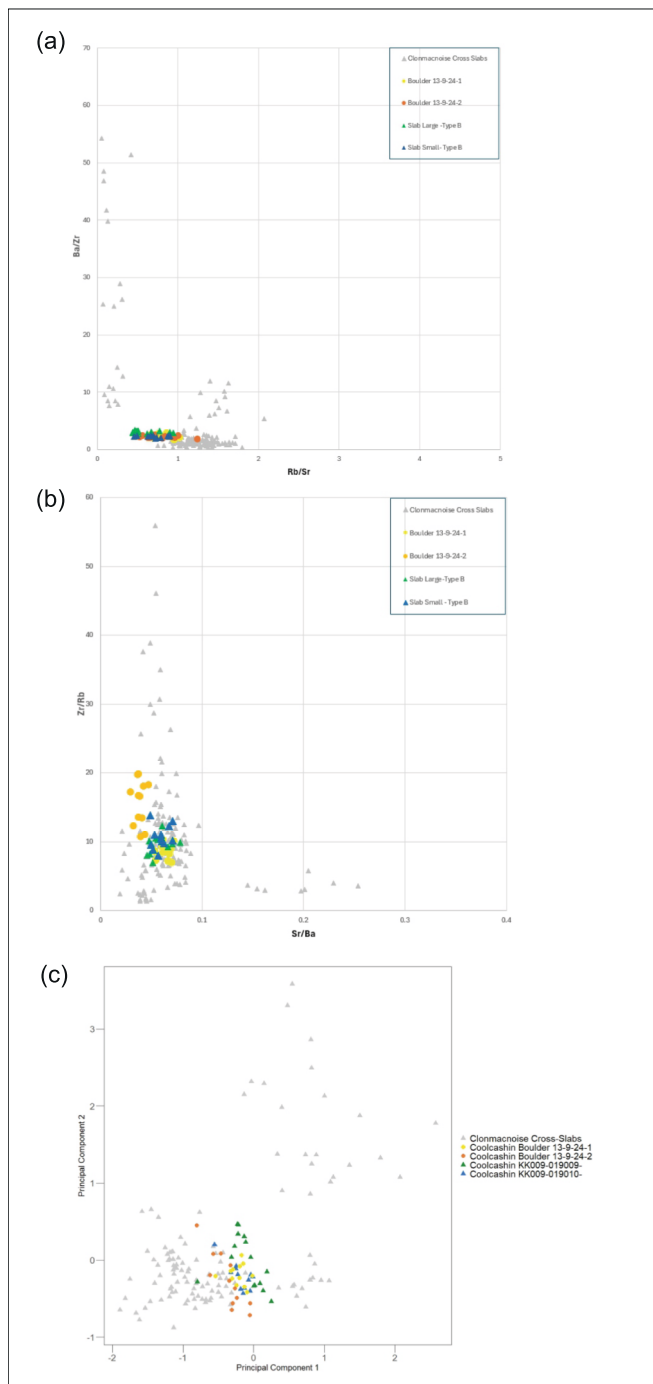


Fig. 15. XRF data plots for the Coolcashion cross-slabs (triangles) and boulders (circles) derived from surrounding UORS inliers: (a) Rb/Sr v Ba/Zr, (b) Sr/Ba v Zr/Rb and (c) PCA plot using the six elements Rb, Sr, Ba, Zr, Sn and Sb.

Type B imports from Clonmacnoise (OF014-029047-, OF014-029025-; the other two are OF014-029057-, OF014-029011-).

These include one of the five Gallen monuments analysed for the present study: OF014-029047-, a classic Type B slab, probably by a Clonmacnoise carver. Another of them, a Type A slab (OF014-029056-) could also be from Clonmacnoise, but it should be noted that at least some of the Type A slabs at Gallen may have been locally produced, for a few of them (albeit not including the present example) have features not found at Clonmacnoise (Ó Carragáin et al. 2024, 271). While they do not include any thistle crosses, the other three analysed monuments are probably products of the Gallen workshop. Two of them (OF014-

029045-, OF014-029049-) have ringed Latin crosses similar to Clonmacnoise Type C but each has several features not paralleled at Clonmacnoise.³ The third, OF014-029051-, is an accomplished piece with a ringed cross in relief decorated with human and animal ornament. The best parallel for it (albeit not quite as well-executed) is at Kildare (KD022-029023-) rather than Clonmacnoise. Thus, we seem to have a mix of monuments by Clonmacnoise (OF014-029047-, possibly OF014-029056-) and Gallen (OF014-029045-, OF014-029049-, OF014-029051-) carvers. However, all five have geochemical signatures very similar to the bulk of the Clonmacnoise slabs, and do not match the local Ferbane boulders we analysed. This raises the possibility that the Gallen carvers were permitted to use the same source as their Clonmacnoise counterparts. If so, this would have been a strong signal of the privileged position enjoyed by the Gallen community within the *familia* of Clonmacnoise. This in turn would make it all the more notable that the Gallen community chose to cultivate and maintain a distinct sculptural identity.

5.2. Mobile carvers

The results presented above clearly indicate that some Clonmacnoise-style slabs at outlying sites were the work of carvers who had travelled there and used local sources of stone. In the vicinity of Lough Ree, the clearest evidence for a mobile carver is at Fuerty, whose two slabs are undoubtedly by Clonmacnoise-trained carver(s) (Ó Carragáin et al. 2024, 279) and carved of local sandstone boulders derived from the Creggs Devonian inlier to the immediate west of the site. Another possible example is LF013-045004- at Ballynakill. In this regard, it is interesting to note that these three slabs had previously been identified as diverging ‘in subtle but similar ways from their Clonmacnoise equivalents, hinting that they are the work of the same [Clonmacnoise-trained] carver’ (Ó Carragáin et al. 2024, 294). In particular, the small ring of LF013-045004- is similar to that of RO039-063003- at Fuerty. In contrast, given that the geochemical signature of the other slab analysed at Ballynakill (LF013-045012-) suggests it might possibly have been brought from Clonmacnoise (below), it may be significant that (apart from a partial frame) it is a more typical Type B slab. Another quite likely instance of a mobile carver in the Lough Ree catchment is LF023-097003- at Taghshinny, though it is not quite as well executed so the possibility that it is the work of a local carver cannot be entirely ruled out. The more distant Clonmacnoise-style slabs, outside its hinterland, provide clear-cut evidence for mobile carvers. All the Iniscealtra slabs are of local stone. They include two related to Clonmacnoise Type A (probably c. 700–850 CE), but sufficiently distinct to suggest they may be by one or more local carvers emulating monuments there. In contrast, we are confident that CL029-009066-, a Type B slab (probably c. 850–1000 CE), is by a Clonmacnoise-trained carver (Ó Carragáin et al. 2024, 281). While some of the pXRF readings for this slab fall outside the main distribution for local material, its geochemical signature is a much better match for CL029-009033-, which is undoubtedly a local slab, than for the Clonmacnoise slabs. Clearer still is the case of Coolcashion, whose two slabs are undoubtedly the work of a Clonmacnoise-trained carver (Ó Carragáin et al. 2024, 285) using local Carboniferous sandstone boulders.

5.3. Mobile Monuments?

Several outlying slabs share the distinctive signature of the bulk of the Clonmacnoise slabs we analysed, raising the possibility that they

³ In the case of OF014-029045- these features are a third line defining the ring, a pair of roundels flanking the shaft and a large rectangular base. OF014-029049- also has a third line defining the ring and two other features not readily paralleled at Clonmacnoise: a dimpled roundel at the crossing and unusually long arms.

were carved near there and transported to outlying sites as finished monuments. It must be emphasised that the evidence is not as clear-cut as we have not as yet identified the source of this stone in the vicinity of Clonmacnoise (see above). The monuments in question include four of the five on Inchbofin, while the fifth is quite a good match for two of the Clonmacnoise slabs with 'atypical' signatures. While textual evidence for links between the two sites is limited, and a few of its slabs are not diagnostically of Clonmacnoise type (notably WM015-001016-), at least some are very likely to be by Clonmacnoise-trained carvers (Ó Carragáin et al. 2024, 277). These data suggest that some of the monuments were transported upstream to the island by boat. The same may be true of LF021-048009-, a Type B slab on Inchlerraun, a site with strong Clonmacnoise links (ibid.). In contrast, most of the other slabs on the island are of local limestone and not of Clonmacnoise type. Finally, as noted already, one of the two slabs analysed at Ballynakill is another classic Clonmacnoise Type B slab with a similar signature to the bulk of the slabs there. All possible instances are at sites readily accessible from, if not indeed on, the Shannon, whereas some of the monuments carved using local stone are further inland, perhaps inhibiting transport of carved slabs (e.g. Fuerty, Taghshinny, Coolcashin). In the case of the two island sites, Inchbofin and Inchlerraun, the fact that they are relatively far from alternative sources of suitable sandstone may have been another consideration. While in some cases transporting complete monuments may have required more labour, this should not be overstated, for it was very modest compared to transport of large blocks of stone for high crosses or large timbers for churches. Furthermore, this option presumably had less of an impact on the output of the Clonmacnoise workshop, given that the carver did not need to travel. From a symbolic perspective, it may also have been appealing to link the outlying sites to Clonmacnoise (or at least its immediate vicinity) not only through the design of the monument but also through the very material of which it was carved. To have a slab from the same source as the bulk of those at the motherhouse may have reinforced the spiritual connection to Clonmacnoise and its cemetery that these slabs were intended to create (cf. Ó Carragáin et al. 2024, 299).

Importantly, the clear-cut evidence that many of the other slabs were carved of local stone demonstrates that the pattern of Clonmacnoise-style slabs at outlying sites is ancient, at least to a large extent. This is necessary because of a reference by antiquarian Robert Graves (1855, 302) to cross-slabs being taken from Clonmacnoise to churchyards on the opposite bank of the Shannon in modern times. He does not claim to have witnessed this practice himself, and it is possible that he invoked it to explain his failure to identify some slabs recorded previously by other antiquarians. A small minority of slabs do indeed seem to have been transported in modern times, notably the four fine slabs at Athlone which are almost certainly part of an antiquarian collection (Ó Floinn 1995, 252), and which we have treated as Clonmacnoise slabs, and a fragment incorporated into a Station of the Cross at a modern monastery outside Athenry, Co. Galway, but not analysed here (OF005-023698-).⁴ However, we concur with the other antiquarians and more recent scholars that most of the outlying slabs have been at their respective sites since the early medieval period (for discussion see Ó Carragáin et al. 2024, 266).⁵ This is confirmed, not only by the geochemical evidence presented here, but also by the fact that most of these sites have early historical links to Clonmacnoise (ibid.); it is implausible to suggest that modern souvenir hunters would by chance have replicated this pattern of ancient dependencies. While it cannot be ruled out entirely,

we think it unlikely that the possible instances of 'mobile monuments' identified here were transported in modern times. Rather than churchyards on the opposite bank of the Shannon, most of them are on islands in Lough Ree that were not heavily settled in modern times but have prominent early monastic establishments, while the remaining example, at Ballynakill, belongs to a small but well-executed collection at a well-documented dependency of Clonmacnoise.

6. Conclusion

This study has found strong evidence that Clonmacnoise-trained carvers travelled to outlying sites, both within and beyond Clonmacnoise's hinterland, to carve slabs using local stone. It also found evidence suggesting that some Clonmacnoise-style cross-slabs were carved in the vicinity of the site before being transported upstream via the Shannon to islands in Lough Ree and to a site immediately beyond the lake. It is interesting to find evidence for both practices, but perhaps not too surprising. As we have seen, the location of outlying sites, their distance from Clonmacnoise, and position in relation to transport networks, especially the River Shannon, may have been one factor. Most of the slabs in question are Type B, which were carved at Clonmacnoise itself over a considerable period (c. 850–1100 CE), perhaps increasing the potential for variation in how they were acquired by outlying sites. Another factor in this regard was surely the varied, and potentially evolving, relationships between the sites. While a few instances of the transportation of unworked stone for carving cross-slabs had previously been recognised (Goodale et al. 2018), this is the only instance in Ireland where multiple sites are linked by the presence of cross-slabs produced by craftspeople belonging to a single workshop. The geochemical analysis reported here provides important new insights into the varied strategies employed to create this visual and material expression of Clonmacnoise's ecclesiastical network. This study also demonstrates the effectiveness of geochemically characterising and distinguishing petrologically very similar sandstone monuments *in situ* using portable XRF analysis.

CRedit authorship contribution statement

Patrick Meere: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tomás Ó Carragáin:** Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Data curation, Conceptualization. **Urmi Ghosh:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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⁴ In addition, there is circumstantial evidence that a Type B slab fragment from Banagher, Co. Offaly, now in the National Museum of Ireland (Reg. No.: 1994:74), may have been brought from Clonmacnoise in modern times.

⁵ For example, in his comprehensive study Macalister (1909, vii) mentions that some slabs were placed within modern graves at the site but thought it unlikely that many were taken from it. We are grateful to Rachel Moss for bringing the reference in Graves to our attention.

Data availability

The filtered dataset and supplementary files are available here: <https://doi.org/10.5281/zenodo.18980646>.

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