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A study of the construction and building materials of Howth Harbour, Co. Dublin.

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ABSTRACT: Howth harbour, completed in 1813, is now over two hundred years old (except for the fishing harbour and yacht marina dating from 1979). Howth harbour was built with durable materials and methods which were advanced for its time, with the first use of the diving-bell in Ireland and pier building *à pierre perdue,* which was deemed to best break and disperse oncoming waves. However, despite the use of durable materials and advanced technology, it was the position of the harbour that lead to its abandonment, as a mail packet station, in 1826.
The composition, some physical properties and current condition of the original masonry including Leinster granite quarried at Dalkey; Howth quartzite from the nearby Kilrock quarry; Howth schist and grouting/pointing mortars reportedly made with eminently-hydraulic, Blue Lias lime are studied. Petrographic analysis evidenced that mortar is largely carbonated and includes abundant remnants of unhydrated clinkers in clusters as well as partially hydrated single clinker grains evidencing the use of an eminently hydraulic binder and a low water:binder ratio. The granite and schist are more weathered than the quartzite with distinct oxide staining, scaling, flaking, fracturing, granular disintegration, salt and biological degradation. The microstructures determined with Scanning Electron Microscopy (SEM) agree with the physical properties measured evidencing dense materials of low open porosity and water absorption. The durability and superficial weathering determined with SEM also agree with these features. Elemental chemical analyses by energy dispersive X-ray analysis consistently disclosed high quantities of calcium (Ca) and significant chlorine (Cl), sulphur (S) and sodium (Na), indicating the presence of salts on the outer surface of the quartzite, granite and schist. However these analyses evidenced that the damage is superficial.

KEY WORDS: Howth Harbour; Blue Lias lime; Leinster granite; Howth quartzite; schist.

1 INTRODUCTION

Howth harbour is located north of the Howth peninsula, the northern point of Dublin bay. It is protected from northern winds by the island of Irelands Eye, approximately two kilometres off the town of Howth. According to Rennie [1], in the late 1700's, a number of factors were creating difficulties for the sea trade from London to Dublin: With no other nearer places of refuge other than Waterford to the south and Carlingford Lough to the north, vessels were forced to remain in the openness of Dublin Bay. In addition, the scant water depths at low spring tides and the limited number of berths in Dublin Port, forced vessels to wait for adequate wind and tide conditions to approach the Pigeon House Station.
According to the author, in 1800, a number of influential people campaigned for a harbour to be constructed in Howth. This campaign was opened with a pamphlet which proposed a harbour on the northern side of Howth, with a canal to transport vessels to the Liffey via Clontarf. In 1802, Captain Bligh surveyed and created maps of Dublin Bay, nominating Howth over Dun Laoghaire as a location for a packet station harbour [2]. Several proposals to convert the sound (sheltered by the mainland and Ireland's Eye Island) were examined however, no work was carried out until 1807, when an Act of Parliament was passed and a start was made upon the construction of Howth harbour [2,3]. The adopted plan was prepared by an engineer (Captain George Taylor) who was to oversee the early stages of construction. The East Pier was build first however in 1809, some 240 feet of the pier end collapsed. Subsequently, Capt. Taylor resigned and John Aird took over under the direction of John Rennie [3]. The East and North piers were completed with the angled section being constructed on the collapsed rubble. Rennie added plans for a second (West) pier. The harbour was completed in 1813 and formally established as a package station in 1818, when a three-storey lighthouse of ashlar granite was constructed at the end of the east pier. The light keeper's dwelling adjoining the tower dates from 1821 and was converted into two storeys in 1856 [2,3,4].
Difficulties arising from problems with depth, siltation and easterly gales causing swell at the entrance resulted in the mail packet ships being transferred to Dun Laoghaire in 1826; and Howth then became a major fishery harbour and leisure sailing centre [5,6].
In 1979, work was undertaken by the Office of Public Works to develop a major fishery harbour and yacht marina at Howth harbour. A new breakwater was added to form an extension to the existing east pier as a breakwater for the marina, and a trawler pier was built between the east and the west piers. The piers were built in situ with Portland cement concrete shuttered with plywood panels mounted on a steel frame [6].

2 CONSTRUCTION OF HOWTH HARBOUR

2.1 *Origin of materials*

The Earl of Howth supplied over 91,000 tonnes of local quartzite and schist from his nearby quarry at Kilrock.

However, later problems with bills and contracts lead to work being halted until sufficient quantities of granite were sourced from Dalkey and sandstone from Runcorn near Liverpool [1]. As documented by Rennie [1], a mortar comprising of one part Aberthaw lime (from Wales), one part pozzolan and two parts sand was used.

2.2 Construction methods

Two main methods were used to build the piers [1], initially, construction involved depositing large rubble stones onto the sea floor 'à pierre perdue', allowing the stone to achieve its natural slope by consolidation and wave action (Figure 1). The stones, transported by railway and inclined planes from the nearby Kilrock quarry above Balscadden Rd, adjust themselves to the natural slope by the motion of the waves. When consolidated in their position, the surface of the slope was paved with large stones wedged and cemented together.
The inner faces of the piers were finished in ashlar granite, quarried at Dalkey and ferried across the bay to Howth.

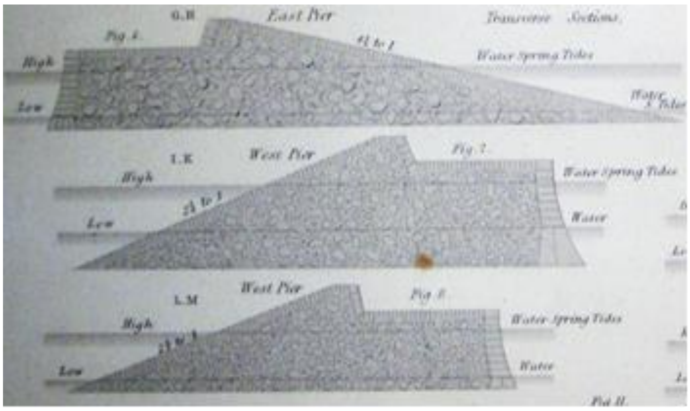


Figure 1. Rennie's sections through the slant piers (East and West), built à pierre perdue before the introduction of the bell.

As construction using Rennie's diving-bell had not yet commenced, the underwater foundations were built with four tonne blocks of Runcorn sandstone from Cheshire, England (Figure 2). A predominantly red-brown sandstone belonging to the Helsby Sandstone Formation (Sherwood sandstone group, aged Triassic) which had been exploited since Roman times and formed a huge area of quarrying in the 19th century [7]. Blocks were laid, inclined sideways, in front of each other (Figure 2); on top, horizontal header and stretcher courses were laid in a mortar composed of one part Aberthaw lime, one part pozzolan and two parts of sand. The backing was grouted with a similar mortar.

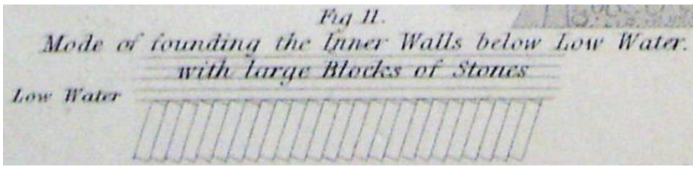


Figure 2. Underwater foundations of East and West piers consisting of English Runcorn sandstone blocks laid at c.80°angle with header and stretcher courses laid on top and grouted with Aberthaw (Blue Lias) lime mortar [1].

Later, the diving-bell (first used in Ireland for the construction of Howth harbour) was used to build the pier head foundations and (together with sub-aqueous blasting) increase the depth of the harbour [1]. It was an adapted design by Rennie, constructed of cast iron and weighing approximately 5 tonnes (Figure 3). A double air pump supplied the bell with air, this was connected to a hose and placed on a platform above or in a boat which attended the bell. The bell was fixed to a circular framework of timber, strengthened by iron, assembled above the intended pier head to be constructed. A fixed pivot near the centre of the bell permitted the bell to easily traverse its outer limits and so that every part of the wall could be approached [2].

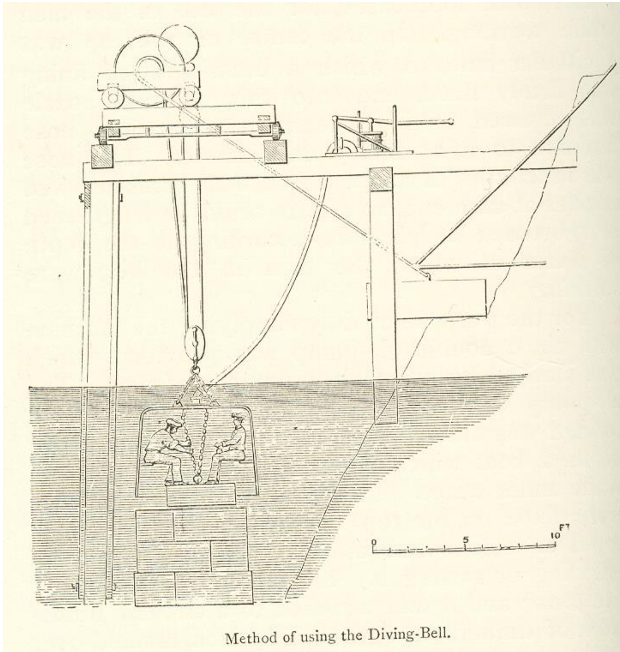


Figure 3. Section of Rennie´s diving-bell building the base of a (vertical section) pier.

Rennie noted that the slant piers, build *à pierre perdue* before the introduction of the diving-bell, improved the breaking of the swell when compared to the vertical walls built with the bell. However, he also concluded that the pier heads, circular in plan and nearly vertical in section, along with the articulation of the harbour entrance and jetties provided better accessibility for vessels arriving and departing the harbour.

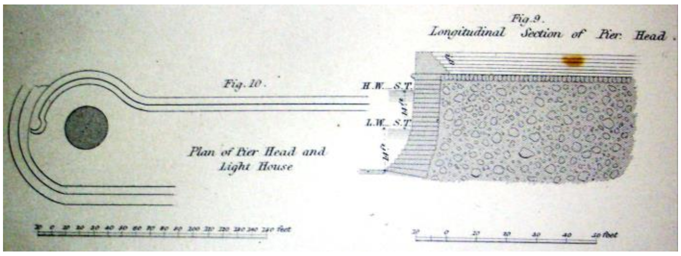


Figure 4. Rennie's section and plan of the East pier, constructed with the diving-bell.

3 ANALYSIS OF MATERIALS AND CURRENT CONDITION

3.1 Methods

Microstructures and chemical composition were determined with a scanning electron microscope (SEM). The analytical system employed was a Zeiss DSM-950 SEM equipped with a backscattered electron detector and a LINK-QX 2000 energy dispersive X-ray analysis attachment (EDX). Spectra were taken with a voltage of 20 kV through a beryllium window. The open porosity (P) and bulk density (ṗ) were tested according to RILEM recommendations [8]. The specimens were immersed in water for 28 days. The saturated (Ms) and hydrostatic weights (Mi) were measured (kg). The samples were then dried and their dry weight (Md) measured. The bulk density and open porosity were calculated according to equations 1 and 2. The water absorption was measured according to UNE 67-027-84 [9] by measuring the water intake at saturation at atmospheric pressure as a percentage by weight.

$$\rho = Md / (Ms - Mi) \quad (1)$$

$$P = (Ms - Md)/(Ms - Mi) \quad (2)$$

The original mortar was analysed with a petrographic microscope. Two samples of pointing mortar from the ashlar granite inner faces of the East pier were studied. Thin sections polished to the standard thickness of c.20 microns and covered with a glass slip were examined with a petrographic microscope with eye pieces of 2, 10, 20 and 40 magnifications, using both natural and polarised light.

3.2 Mortar

As aforementioned, historic records state that 1:1:2 (Aberthaw lime:pozzolan:sand) mortars were used to lay the pier foundations. The Aberthaw lime is a Blue Lias lime from Wales which became famous when it was selected by John Smeaton for the construction of the Eddystone Lighthouse [10]. The Blue Lias limes were made with some of the limestones of the lower Lias formations in England and South Wales. The typical rock formation that produced this lime consisted of thin bedded, blue/grey limestones interbedded with thin layers of shale. This combination of calcareous and argillaceous deposits is similar to the Dublin Calp, each bed containing varying proportions of silica and alumina resulting in a certain variation in the composition of the lime (Table 1). Calcination under the typical conditions of hydraulic lime manufacture, mainly causes the combination of silica and lime to form calcium silicates leaving a certain amount of uncombined silica and much uncombined lime [11]. Table 2 includes typical compositions of Blue Lias limes compared to PC. The significant alumina and iron, act as fluxes facilitating the combination of the silica and lime; and also combine themselves with lime forming aluminates and ferrites which on hydration do not contribute to strength but dispose of some of the free lime excess.

Table 1. Chemical composition of Blue Lias limestone at Monmouthshire [Redgrave & Spackman1905-Millar1897-10].

$CaCO_3$	SiO_2	Al_2O_3	Fe_2O_3	MgO
83.09	7.31	2.31	0.53	0.49

According to Eckel [11], the limestones used to produce hydraulic limes carry 70-80% $CaCO_3$ and, in the best types of hydraulic limestones, the silica varies between 13 and 17% while the iron and alumina together amount to approximately 3%. As seen from its composition (Table 2), the Blue Lias is an eminently hydraulic lime. It was used extensively in engineering works in the UK in the 19th century. According to Donaldson 1860 [in 10], the foundations for the 19th c. Westminster bridge across the Thames in London were prepared with Blue Lias (1:3 - lime: clean, sharp river sand); and a 1:4 (Blue Lias lime: clean gravel) mortar was used for the piers below the low water mark. According to the same authors, the railway bridge at Newcastle 1847 specified Blue Lias mortar for the base piers to a height of 6' above the high water mark; and the quay at Newcastle, Dorset, used Blue Lias lime, burned on site and mixed in proportions 1:1 (with clean sharp river sand) with 1 part of ground iron slag.

Table 2. Chemical composition of Blue Lias limes from Leicestershire [Redgrave & Spackman 1905, Millar 1897 in 10] compared to PC - average of 300 PCs [12].

	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO
Ground	57.39	17.49	5.12	8.97	0.61
Lump	72.98	12.23	4.64	2.90	2.47
PC	64.00	21.00	5.04	2.85	1.67

As aforementioned, the mortar pointing the Dalkey granite ashlar at the inner face of the East pier was studied. The mortar is largely carbonated (Figure 5) and includes abundant remnants of unhydrated clinkers in clusters as well as partially-hydrated, single clinker grains (Figure 6). These, together with the calcium silicates and CSHs in the binder (Figures 7 and 8) prove the use of an eminently hydraulic binder. The common occurrence of unhydrated and partly hydrated clinker grains in the binder (Figure 6) indicates a high binder content i.e. a low water:binder ratio.

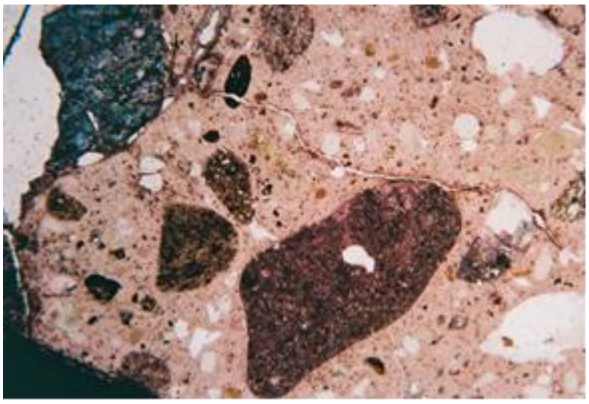


Figure 5. Petrographic micrograph of Howth Harbour mortar with coarse dolomite (left) and limestone aggregate, in a fractured, largely carbonated binder. 2X polarised light.

The presence of CSH and calcium silicates such as the pyroxene diopside also agree with the use of hydraulic lime. It is likely that the aggregate was locally sourced as it comprises dolomitic, shaley, chert and calcium limestone very similar to the Carboniferous limestone bedrock in the Dublin area (Figure 5).

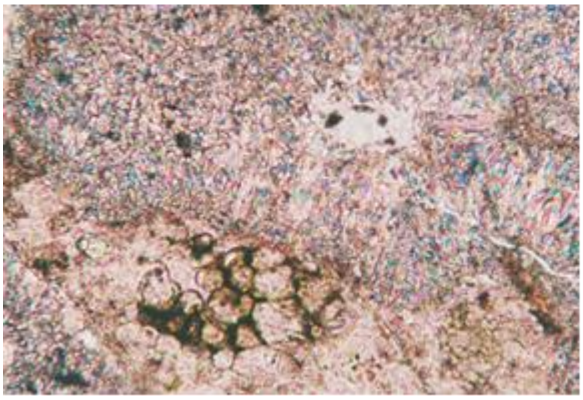


Figure 6. Petrographic micrograph of Howth Harbour mortar with remnants of unhydrated clinker (cluster of alite, belite and dark interstitial phases) and secondary $CaCO_3$ filling fracture (top) 40X polarized light.

The percentage by volume determined on thin section is c. 2:1 (aggregate: binder) which agrees with the 1:1:2 (hydraulic lime: pozzolan: aggregate reported by Rennie to have been used to lay the Runcorn sandstone foundations of the piers.

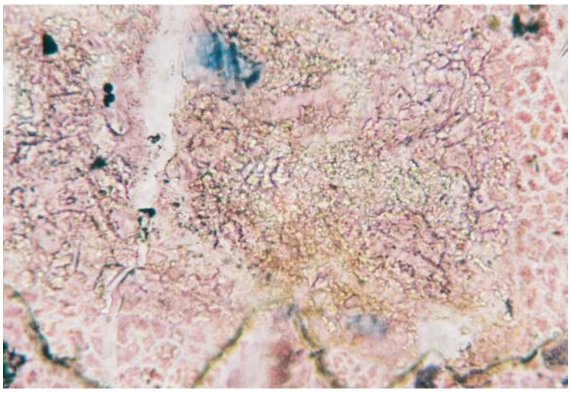


Figure 7. Calcium silicates and CSHs in a Harbour mortar 40X natural light.

No pozzolans were found probably due to the restricted sampling. However, the pozzolans could have been limited to the foundations and masonry below the high water mark.

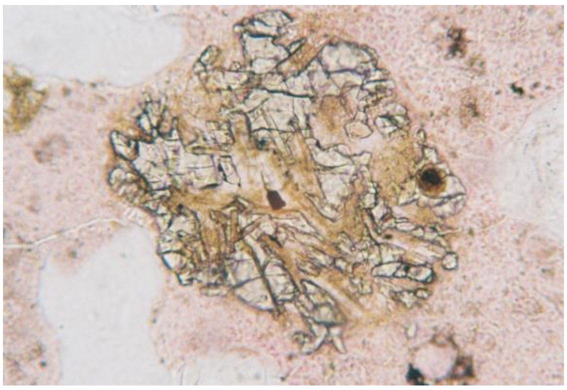


Figure 8. Diopside in harbour mortar.10X natural light

3.3 *Stone*

As aforementioned, Leinster granite from Dalkey; Howth quartzite from the nearby Kilrock quarry and smaller amounts of Howth schist are the main rocks used in the construction of the harbour. The rocks studied below came for the East pier. The properties measured evidence dense materials with very low open porosities and reduced water absorption (Table 1).

Table 2. Physical properties of rocks in Howth Harbour.

Stone type	Open porosity %	Water Absorption %	Bulk Density, [kg/m3]	Real Density, [kg/m3]
Schist	2.00	0.73	27111.75	27667.15
Quartzite	0.68	0.25	26440.75	26622.08
Granite	1.96	0.74	26028.11	26551.79

The local quartzite remains in good condition despite years of exposure. The dense nature and pure composition of the un-weathered quartzite are shown in figure 9.

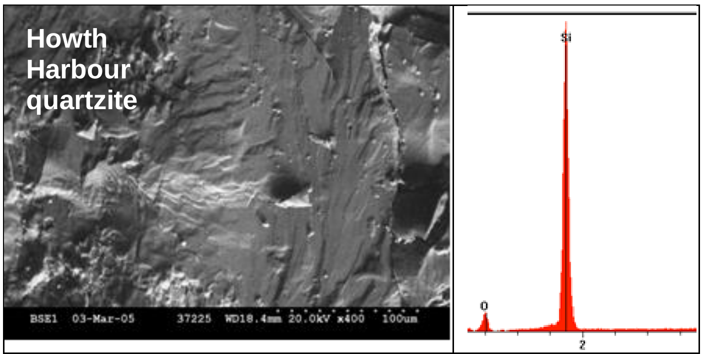
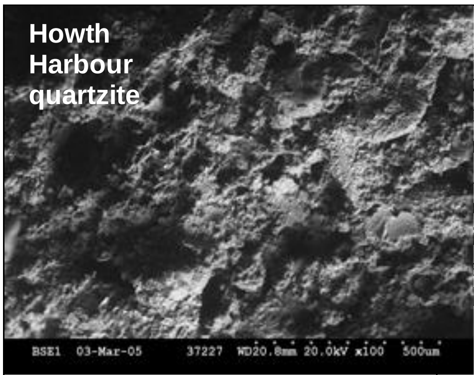
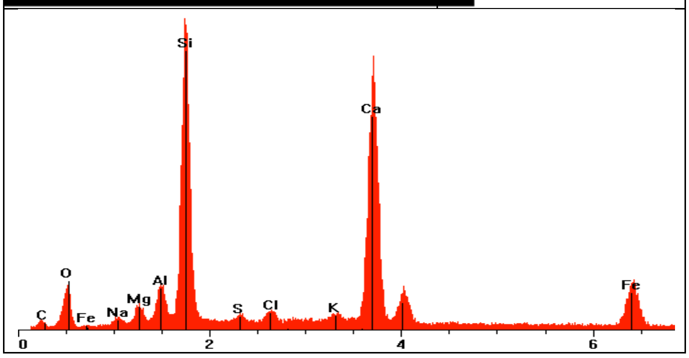


Figure 9. SEM micrograph and EDX analysis of quartzite at c. 10mm depth consisting of unweathered pure quartz.

Figure 9 illustrates the smooth surface of the quartz grains in the quartzite with no sign of weathering; and the elemental analysis yielding pure silica (SiO_2). In contrast, the exposed quartzite surface (Figure 10) displays a rough granular appearance not generally associated with quartzite, containing loose particles evidenced by EDX to consist of iron oxides and salts (carbonates, sulphates and chlorides) .



gure 10. SEM icrograph of posed surface of artzite with salt d oxides (left). emental chemical mposition (EDX) ith secondary Ca, and S, Cl and kalis evidencing lt and weathering.



The schist shows the strongest weathering of all rocks in the harbour owing to its clayey composition and its cleavage. Mineral alteration and splitting along cleavage planes were evident and, similarly to the quartzite, the exposed surface included chlorine (Cl), sulphur (S) and alkalis indicating the presence of salts (Figure 11). The elemental analysis discloses a high quantity of Fe in accordance with its original composition. As expected from the red/yellow surface colour similar to the quartzite, secondary iron is also recorded as a result of the oxidation of iron compounds.

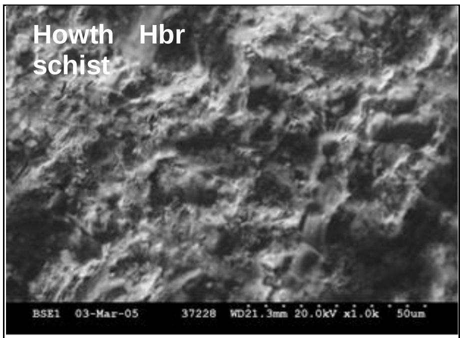
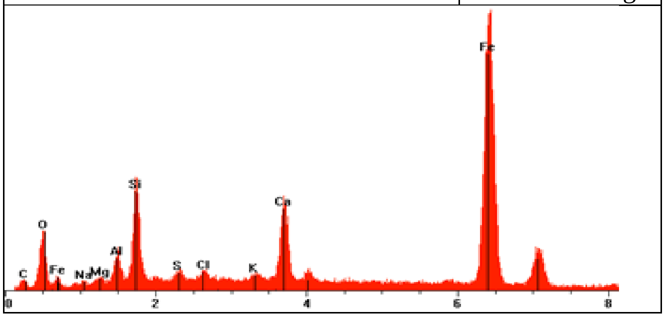


Figure 11. Surface of weathered schist. The analysis reveals high iron content. The chlorine (Cl), sulphur (S) and alkalis indicate salt weathering.



On visual inspection, the granite surface is weathered showing scaling, flaking and staining; with the presence of clay-like material and biological growth. However, the elemental chemical composition of a sample of granite at 5-10mm depth analysed with EDX illustrates the general composition of the Leinster Granite (Figure 12) suggesting that the weathering is superficial.

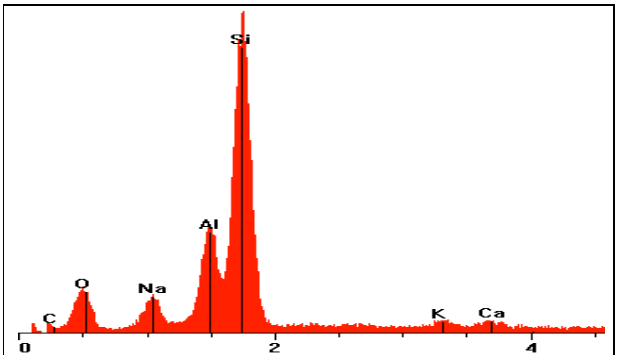


Figure 12. Elemental composition of the granite at c. 10mm depth showing no signs of weathering. The analysis illustrates the general composition of the Leinster granite namely; Quartz (SiO_2), Feldspar: ($KAl.Si_3.O_8$); Albite ($Na.Al.Si_3.O_8$) and micas Muscovite ($H_2K.Al_3(SiO_4)_3$) and Biotite ($K(MgFe)_3Al.Si_3O_{10}(OH,F)_2$).

In contrast, with the sound granite in figure 12, the elemental composition of the weathered granite surface analysed with EDX evidenced abundant chlorine, sulphur and biodegradation (figure 13).

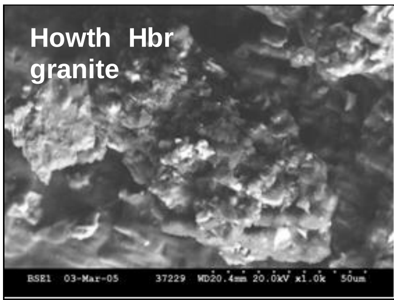
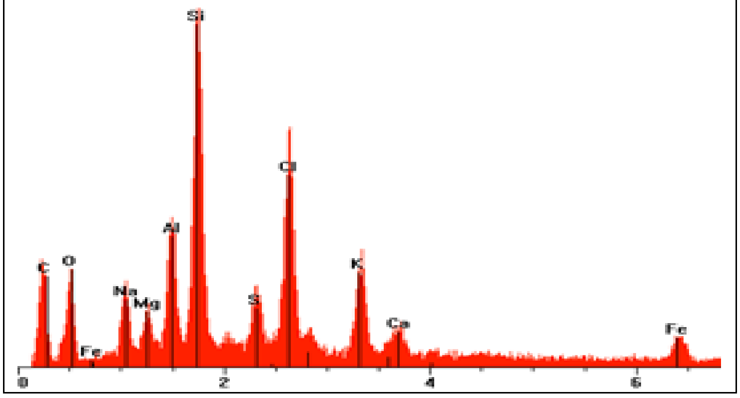


Figure 13. SEM image of weathered granite surface containing salts and organic growth. The chemical analysis (below) revealed abundant chlorine, alkalis and sulphur. The significant carbon represents the strong presence of lichens and algae along the harbour walls.



4 CONCLUSION

Howth harbour completed in 1813 was one of the earliest examples of its kind with respect to construction technology and innovative design; using slant-section piers built *à pierre perdue* and vertical-section piers built with the diving bell. The construction of Howth harbour used local durable materials and was advanced for its time, with the first use of the diving-bell in Ireland. However, despite the advanced materials and technology, it was the position of Howth harbour that lead to its abandonment, as a mail packet station in 1826. A position further to the east of the present harbour and an entrance in a more suitable direction would have provided more desirable conditions lessening the effects of siltation and the swell at the entrance brought on by easterly gales.

The main original construction materials used in the pier walls were Leinster granite, quarried at Dalkey and Howth quartzite, from the nearby Kilrock quarry. The surface of the materials is weathered with evident salts and oxidation however, weathering is superficial and the materials were mostly sound at less than 5 mm in depth. An eminently hydraulic mortar made with Blue Lias lime, local limestone aggregate and low water:binder ratios was used below and above the high water mark. The mortar largely remains in good condition above the high water mark.

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