THE GEOLOGY OF PENLEE QUARRY, CORNWALL, ITS IMPACT ON PREVIOUS QUARRYING AND FUTURE USE

P.W. SCOTT[1] AND G. WALTON[2]

[1] *Camborne School of Mines, University of Exeter, Cornwall Campus, Tremough, Penryn, Cornwall TR10 9EZ.*

[2] *PGW&A LLP, Griffin House, Market Street, Charlbury, Oxon, OX7 3PJ and University of Leeds*

ABSTRACT

Penlee is a large coastal quarry. It comprises mainly a dolerite altered by low grade metamorphism with minor Upper Devonian Mylor Slates, all within the aureole of the Lands End Granite. It contains also two distinct phases of later base metal mineralisation. The quarry is designated as a Site of Special Scientific Interest for its mineralisation and several of these features are suitable for conservation.

Quarry development started in the late 1880s at the northern end as a hillside operation advancing to the west and subsequently south. The impact of geological features and related geotechnical constraints have had a significant affect on subsequent quarry development. The rock has a high density and for England, an exceptionally high compressive strength. Workings ceased in the early 1990s due to a combination of problems relating to access and transport and to its unsuitability for road surfacing owing to its low PSV. In 1999, planning permission was obtained for revised conditions that permitted the further extraction of 28Mt of rock extending to a depth of 100m below sea level. In practice, constraints arising from meeting the requirements of the Quarry Regulations 1999, mean that little of this tonnage is recoverable.

The intended after-use of the quarry is as a marina with housing and commercial development following the production of armourstone for nearby coastal works, during which further development benches would be formed.

Scott, P.W. and Walton, G. 2010.
The geology of Penlee Quarry, Cornwall, its impact on previous quarrying and future use.
Pp. 170-176 in Scott, P.W. and Walton, G. (Eds) Proceedings of the 15th Extractive Industry Geology Conference, EIG Conferences Ltd, 186pp.
E-mail: admin@pgwassoc.co.uk

INTRODUCTION

Penlee, just south of Newlyn, Cornwall, is a large coastal quarry (SW 468278). It comprises mainly a dolerite altered by low grade metamorphism with minor Upper Devonian Mylor Slates, all within the aureole of the Lands End Granite (Figure 1). It contains two distinct phases of later base metal mineralisation, and for this reason is designated as a Site of Special Scientific Interest (SSSI). The quarry has a long history of development providing aggregates mostly for roadstone before quarry workings ceased in the early 1990s. In recent years work has taken place to secure certain quarry faces so that investigations can take place and armourstone can be recovered. The intended development of armourstone workings prepares the quarry for its after-use as a marina with housing and commercial activities. This paper explains the geology of the quarry, its geoconservation significance, and it discusses the influence that the geology and development history of the quarry has had on its potential for future extraction of stone and its after-use.

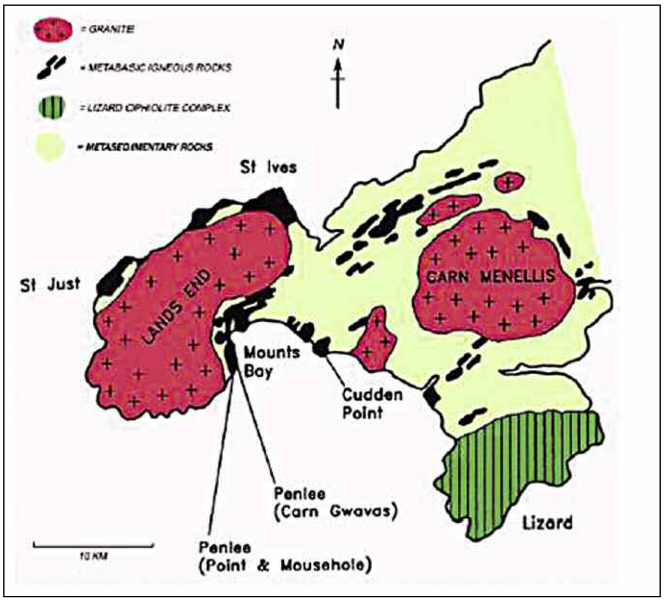


Figure 1. *Simplified geological map of West Cornwall showing location of Penlee Quarry near Carn Gwavas (after Markham and Floyd, 1998 and Denby, 2004).*

Geology and Geoconservation

West Cornwall contains several variably metamorphosed basic igneous or metabasite bodies (Figure 1) (Goode and Taylor, 1988). At Penlee it is a dolerite sill, which intrudes the surrounding Upper Devonian Mylor Slate Formation. It has been metamorphosed by its proximity to the contact with the Land's End Granite (Floyd *et al.*, 1993). The dolerite, strictly a metadolerite, is exposed through much of the quarry, but an upper contact and other possibly faulted contacts with Mylor Slate metasediments are seen in higher benches. Further exposures of the dolerite are found on the foreshore immediately adjacent to the quarry.

The dolerite is mostly fine grained and made up mainly of amphibole and plagioclase (probably albite), along with chlorite. Disseminated sulphides and iron oxides, and late veinlets of actinolite are seen in thin sections. Floyd *et al.* (1993) states that the foreshore exposures, and adjacent small quarries to the south, illustrate features of the albite-epidote hornfels facies of contact metamorphism imposed on a variably textured and differentiated basic intrusive. Minor textural variations in grain size are seen in the main Penlee Quarry.

There is extensive hydrothermal mineralisation in the quarry represented by two distinct sets of veins (Figure 2) along with associated wall-rock alteration. A vertical to sub-vertical ENE-WSW set is represented by thin, up to around 20cm veins hosting a considerable variety of single and polymetallic sulphides and associated minerals with quartz. Pyrite and arsenopyrite are common. Figure 3 shows the detail of a typical vein and Figure 4 shows details of the mineralogy in several veins. A second subvertical set of veins is found with a NW – SE orientation, often called cross-courses, including a major quartz rich multiple vein locally 10-15m across with extensive associated wall rock alteration. This vein crosses the whole quarry (Figure 5). It is presently represented by a promontory on the NW side of the quarry. It contains no sulphide minerals, being made up of several generations of quartz and chalcedony. It splits up on the SE face to form a wider zone and is associated with extensive kaolinisation of the wall rock. A complete list of the minerals found in Penlee Quarry is listed below (excluding those as essential minerals to the metadolerite and Mylor Slates):-

Actinolite	Chlorite	Pyrite
Adularia	Covellite	Pyrrhotite
Arsenopyrite	Fluorite	Quartz
Arsenic(native)	Galena	Siderite
Bismuth (native)	Goethite	Sphalerite
Bornite	Kaolinite	Stannite
Cassiterite	Lollingite	Tellurobismuthite
Chalcedony	Marcasite	
Chalcotite	Molybdenite	
Chalcopyrite	Niccolite	

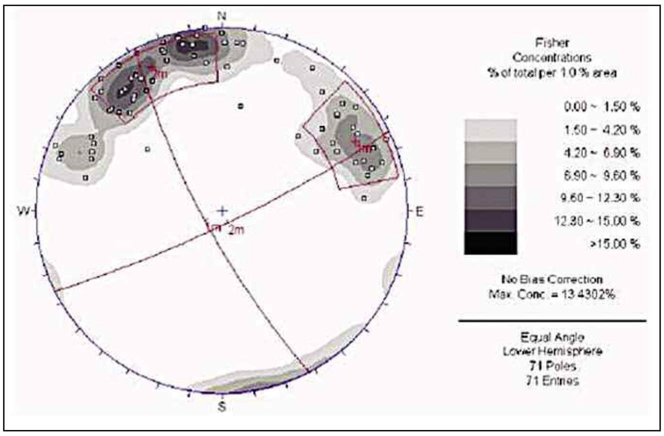


Figure 2. Stereographic plot showing vein orientations at Penlee Quarry and adjacent foreshore (after Denby, 2004).

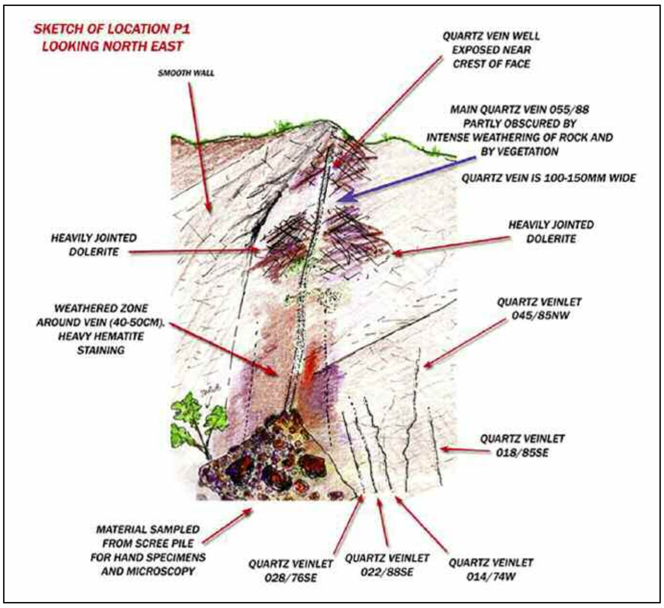
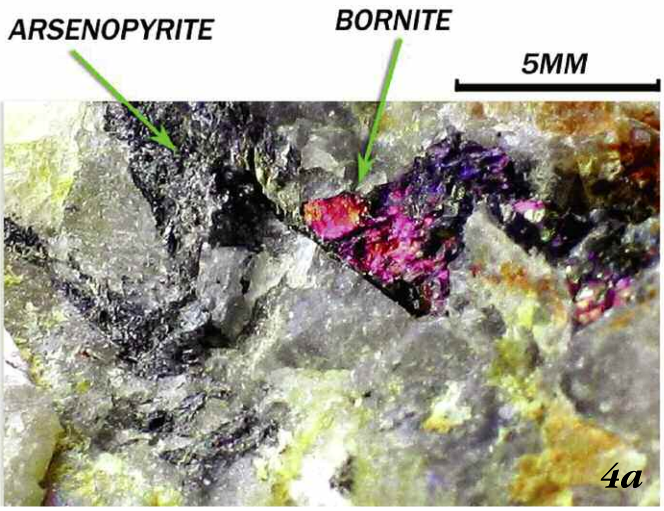
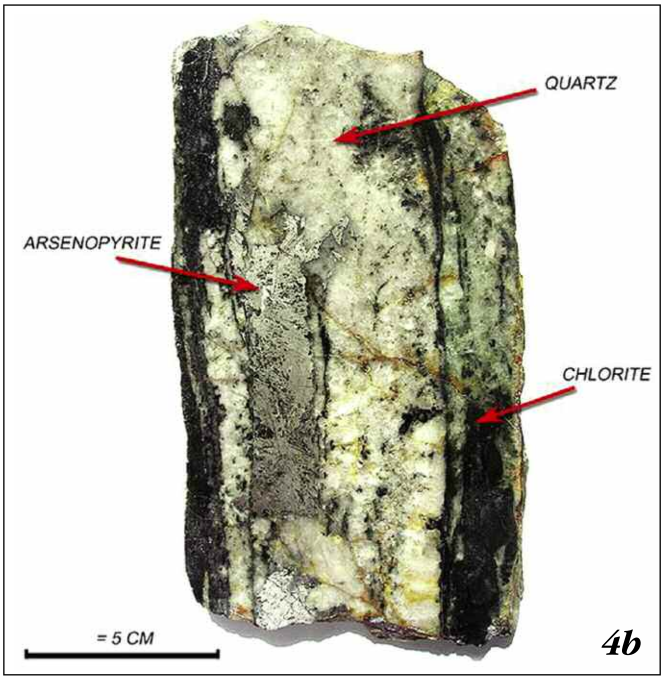


Figure 3. Annotated sketch of the key features found in a typical ENE-WSW vein (from Denby, 2004). The bench height is approximately 10m.

Part of the foreshore exposure of the dolerite is designated an SSSI for its petrological interest (Floyd *et al.* 1993). Although not documented, other than in its citaton by English Nature, the quarry is an SSSI for its mineralisation (more than 25 hectares in area). The citation states the site is important for the diversity of the mineralisation types and gives an opportunity to study the effects of host rock chemistry on this mineralisation over a wide temperature range. Several, but not all parts of the quarry, illustrate the mineralisation to good effect. These areas, particularly the large cross-course vein, will be considered for conservation as part of the after-use plans for the quarry. The NNE – SSW vein set containing abundant sulphide minerals is also well developed on the foreshore adjacent to the quarry, where the continuous washing and abrasion by wave action in the intertidal zone provides a rare opportunity to see unweathered sulphides at the surface. This area is outside the designated SSSI for the igneous rocks. Sulphides in a quarry face, which remains intact for any length of time, will weather and decay rapidly and thus lower the geoconservation value for the mineralisation. This would





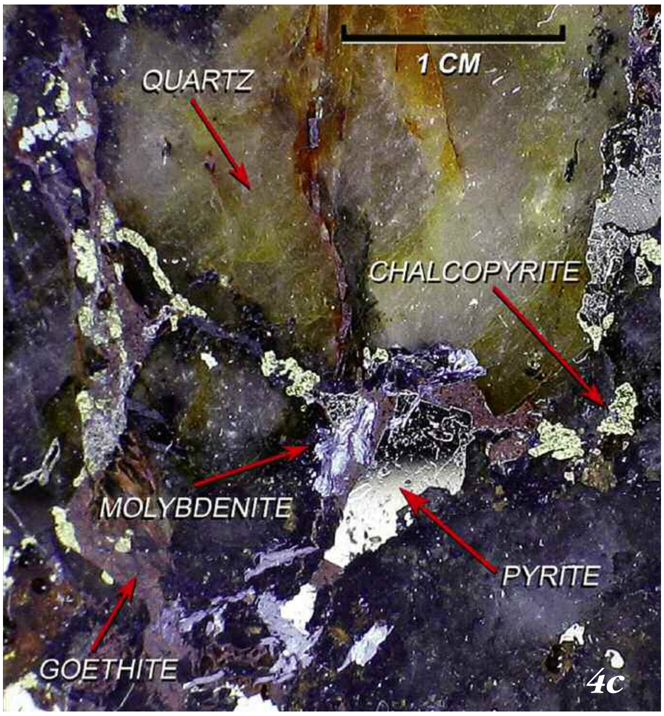


Figure 4. *Details of mineralisation found in ENE-WSW veins.*
a. *Part of the vein shown in Figure 3 with quartz arsenopyrite, and bornite.*
b. *8cm vein with quartz, arsenopyrite and chlorite.*
c. *Part of a vein with chalcopyrite, goethite, pyrite and molybdenite in a matrix of quartz. (from Denby, 2004).*

occur once extraction of rock in the quarry ceases and the after-use as a marina is established.

Quarry history

Excavation of the metadolerite at the quarry started in the late1880s and the workings developed rapidly as a hillside quarry. Initially the rock quality was quite uniform, the quarry was dry; development proceeded to the west and north following the construction of a diverted section of the road between Newlyn and the village of Paul. Operations involved the drilling and firing of horizontal toe holes and the scaling of rocks from the quarry faces by men suspended on ropes. Recovered mineral was used for road construction as well as for ship ballast.

The early workings produced reasonable quantities of overburden (colluvium and beach sand) as well as fines from crushing. During the First World War this material and some routine quarry product was used for constructing the contiguous Royal Naval Air Station

Figure 5. *Part of the quarry with the centre of the photograph showing a promontory that includes a large composite NW-SE quartz vein with attendant kaolinisation. The quarry sump has subsequently been lowered by 9m.*

shown in Figure 6. By 1936 the quarry faces were 60m-70m high and un-benched and the workings covered an area of 9ha. Waste, including top and sub soils, appears to have been tipped to the north of the quarry and extensions seem to have been based on the regular acquisition of separate fields with no particular geological constraints. There were many accidents resulting from the methods of quarrying, since benching does not appear to have been developed until the late 1930s.

Figure 6. *Royal Naval Flying Corps air photograph of Penlee Quarry workings and adjacent naval air station in 1917. Note the diverted Newlyn – Paul road between the main quarry workings and the processing area on the right hand side. The remains of the road and the archway connecting these workings are shown on Figure 11.*

Shortly after the Second World War workings had extended to cover more than 15ha and had been deepened below sea level. No significant groundwater seepages were reported, but the catchment was such that discharge was important. In 1948, a small shaft was sunk with an adit driven onto the foreshore (see Figure 7). With pumping this permitted future workings to extend to a depth of about 30m below sea level. Although the metadolerite was jointed with variably spaced joints in up to 6 principal joint sets, the joints were tight and there has never been any indication of seawater ingress. However by the 1960s the 90m high western faces had been split into benches of 45m, 23m and 22m in height and the existence of the significant NW – SE quartz cross course noted above had been identified. The presence of kaolinite on either side of the network of quartz veins made this material unsuitable for aggregate production and a promontory of ground was left unexcavated. By the 1950s the quarry had become a major source of road stone both in England and Northern Europe. Since the early years of the 20th Century a narrow gauge railway had conveyed stone to Newlyn South Pier for shipment even though the harbour was tidal and only small vessels could be loaded (see Figure 8).

The aggregate sent to Northern Europe was in demand since the water absorption was low (0.64%) and its crushing strength was very high (475MPa). The material

Figure 7. *The 1948 adit used for discharging surface water collecting in the workings. This adit passes under the Newlyn – Mousehole road onto the foreshore. The adit lies near the proposed breakthrough to the sea.*

Figure 8. *An aerial view of the main shipping arrangements for the export of aggregate circa 1970 showing two trains carrying tubs to a vessel at Newlyn south pier. The local road network includes several pinch points with road widths of less than 4.5m compounding export problems.*

was particularly suitable for use in base and sub-base courses for roads where winter temperatures were regularly below -20°C. Unfortunately the material was used eventually for road surfacing and the PSV was found to be low at a value of 43. Shortly after a series of skidding incidents on the continent, the ship loading facility which by then had become conveyor linked, was irretrievably damaged by a collision with a ship. Although materials continued to be produced and exported by road, the road traffic from the quarry through the centre of Newlyn became socially unacceptable in the local narrow roads given the large tonnages produced. Together these constraints led to the cessation of workings in 1993.

Future use of quarry

In 2002, the site was acquired by MDL Developments Ltd., with a view to its development as a marina with residential and commercial elements. By that time groundwater rebound, but more probably ponding of surface water, had occurred. The workings were flooded to a level of 10m AOD and the slopes were in a poor condition with frequent rockfall and many inaccessible sections of the quarry (see Figure 5). A period of 14 months of clearance operations and face scaling were necessary before more detailed investigations could be undertaken and an adequate quarry survey prepared. There were no available pre-existing quarry surveys, the Health and Safety Executive having preserved no records relating to previous quarry workings and Ordnance Survey data was totally inadequate. It was decided to compile a complete record of available terrestrial photographs and air photographs. The earliest terrestrial photographs are dated 1910, in the British Geological Survey archives, and the earliest air photographs are dated from 1917, having been taken by the Royal Naval Flying Corps.

Particular concern related to the various configurations of the quarry floor over time. From the 1940s onwards it appeared that although some material had been removed from the quarry to an external tip in the 1960s, other waste had been tipped on quarry benches. From air photographs it was possible to demonstrate that sections of the quarry floor, that appeared to have a uniform gradient, were in fact backfilled previous workings. Some of these workings were more than 20m deep and subsequently found to have been backfilled with a range of waste materials. Such information is vital when built development is proposed in quarry voids. Similarly, it was also possible to locate the position of previous quarry plant. This had been quite extensive with at least three main crushers and secondary and tertiary crushers, screen houses and silos, each with their own foundation structures.

Based on the above information it was apparent that conventional drilling investigations were of limited value and that extensive trial pitting and excavation could reveal more useful and relevant information. This trial pitting was undertaken using 25t backhoes and long reach excavators and proved in several locations heavily reinforced concrete up to 2.5m in thickness together with numerous 11kV cables, both live and dead. With the faces properly scaled it was possible to undertake detailed geological and geotechnical logging, to assess potential modes of slope failure and to examine the character of materials that required additional excavation.

A detailed cut and fill exercise was undertaken in 2004 to establish the feasibility of forming development benches for housing and for commercial development. This was required to support the infrastructure costs of developing the marina, installing services and constructing a breakthrough to the sea (a distance of 75m) with a lift bridge over the main road between Newlyn and Mousehole. In addition, it was necessary to construct a new entrance road, and to build a substantial breakwater to protect the new entrance to the sea, the proposed marina being directly linked to the sea. Since there were no plans and no air photographs taken immediately prior to the abandonment of the quarry, there were no plans of the floor of the quarry to assess the full extent of navigable water. Sonic profiling was undertaken of the 5ha flooded area of the quarry that showed the majority of the area to be more than 7m below Ordnance Datum. A quarry earthworks scheme was therefore developed to allow for:-

- Excavation of a breakthrough to the sea and the dredging of a trench in the contiguous sea floor
- Excavation of development benches
- Production of armourstone from the development benches for the breakwater and for other immediate local uses
- Compaction of waste rock products in the floor of the quarry sump up to a level of 7m BOD to enable the construction of pontoon supports unaffected by differential settlement
- Construction of an improved entrance
- Provision of buttress material for potentially hazardous slopes and for rockfall protection bunds
- Identification of waste materials for re-processing for new construction materials and restoration soils including the stockpiling of finer materials for placement on rock benches prior to development (to allow for service trenches)

Figure 9 shows the initial proposed scheme with extensive housing on the southern side of the quarry, along with the marina access and other commercial and residential property on the northern side of the quarry. The western side of the quarry comprises high slopes prone to significant rockfall; the upper 45m is where peregrine falcons and ravens nest periodically. The lower part of this slope would be buttressed with fill and provide a rockfall trap. A viewing platform was proposed for part of the eastern side of the quarry from which the principal geological features can be seen as well as other features of local interest including St. Michael's Mount, the Ordnance Survey Datum for Great Britain and Penlee Lifeboat House.

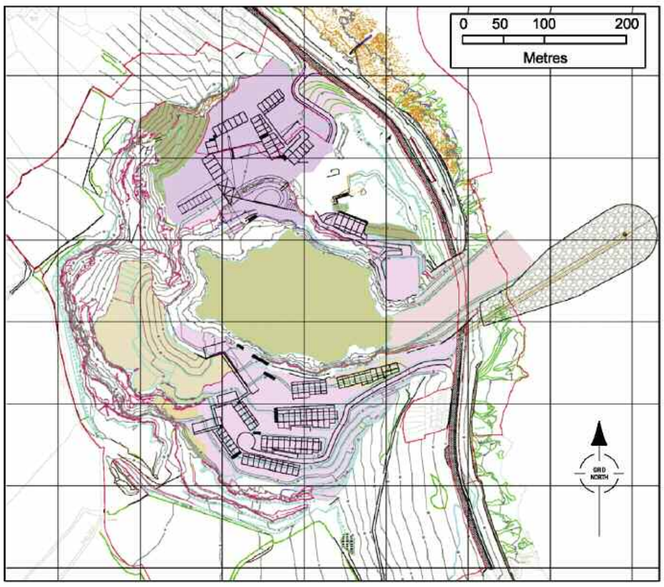


Figure 9. *Proposed afteruse quarry development. Housing lies to the south in the former armourstone quarry area. Marina pontoons will connect with the northern side of the water, now linked to the sea, with commercial and residential development further north. The breakwater will be constructed from onsite armourstone.*

Specific investigations were necessary to plan the development in more detail and to meet the requirements of the Mineral Planning Authority with respect to the initial development of a short-term armourstone quarry to address local needs as well as stockpiling material for the development. The planning status of the quarry was such that approval had been received in 1999 under the Review of Mineral Planning Permissions for a development extending to a depth of 100m BOD. Theoretically this would have released 28Mt of aggregate; the proposals would involve the sterilisation of much of this material. In the context of the absence of a harbour and harbour access, of the restrictions on large scale road access and the quality problems in terms of its use as a surfacing aggregate, there was little scope for significant sales outside the immediate vicinity of the quarry. This was especially the case given the impact of the Aggregates Levy in Cornwall where the large scale exploitation of secondary aggregates has severely impacted on primary aggregate production. In addition the approved plans did not accommodate waste materials or the requirements of the 1999 Quarries Regulations in terms of viable slopes or the planning constraints on blasting. A separate study showed that less than 7.5Mt could economically be recovered with safety and environmental constraints in place.

A number of schemes were required to address the conditions of the 1999 permission before armourstone production could take place (Anon, 2006). These included *inter alia* a review of geoconservation issues, schemes for noise, dust and blast vibration monitoring, a new access road and landscaping. The geological investigations described above were directed towards assessing the geoconservation interests associated with the site and particularly the SSSI features. At the same time geotechnical investigations addressed the underlying discontinuity patterns and trial blasting was undertaken to assess the yield of armourstone as well as the vibration characteristics of the setting. Geochemical investigations were made of the chemistry of the pond water that has been periodically pumped from the quarry since 1948 and of directional dust both entering and leaving the quarry. Basic slope instability assessments were undertaken, but the principal failure mode was rockfall. In addition, ecological investigations were undertaken to ensure that the active parts of the quarry had not been occupied by significant wildlife.

The initial part of the scheme to re-open the quarry as an armourstone operation required the construction of a new entrance with appropriate visibility splays. This section of the site formerly had a steep single track access linking, at an acute angle, with the public road. The majority of the area required for the entrance lay beneath thick heavily reinforced concrete, much of which had been covered by subsequent quarry waste tips. From the limited trial pitting that was possible, future excavations were thought to be largely in fill. In practice, the proposed route that lay beneath the concrete covered by tipping and other later quarry structures, was found to lie in massive metadolerite that would have required a major blasting operation near a residential area and a public road. A re-examination of air photographs indicated an alternative route through quarry backfill that avoided any blasting although it still required 2,000 m^3 of rock breaking. Additional problems then arose when a massively reinforced underground reclaim structure was found embedded in the fill that also required breaking. The initial and subsequent routes are shown on Figure 10 and the completed road into the site is shown on Figure 11.

The location of the proposed armourstone quarry is shown in Figure 12 and its initial development is under way. Unfortunately a previous quarry operator had a series of misfires that were buried and concealed. These left a number of unexploded explosives including detonators and primers that remained live. A further scheme was required to enable the recovery/destruction of these explosives; this has now been completed.

The planning application for the marina is currently in detailed preparation; it will no doubt include further refinements of the model shown in Figure 9, but on the basis of previous experience great flexibility will be required to accommodate the unknown.

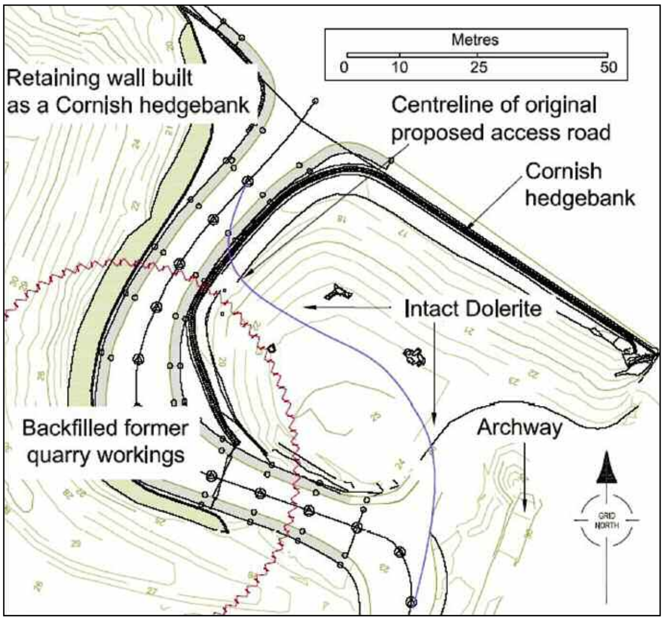


Figure 10. *The new quarry entrance constructed as an alternative to that initially proposed (shown as a blue line and also seen on Figure 9) in order to avoid blasting adjacent to a major public road. The new entrance looking south east is shown in Figure 11.*

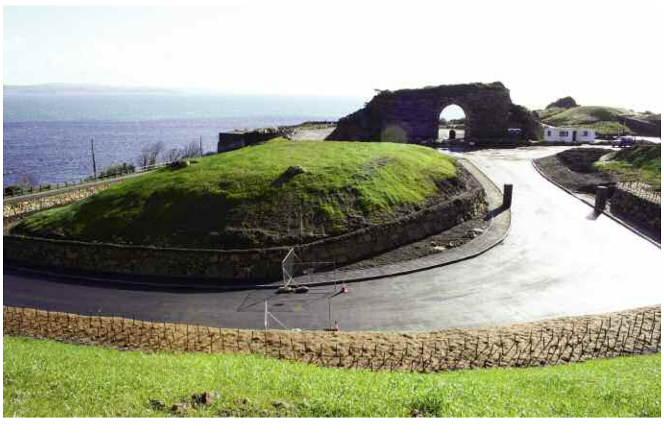


Figure 11. *The new quarry entrance just prior to completion showing the archway that formerly carried the Newlyn – Paul road. The elevated ground in front and to the left of the archway comprises mainly metadolerite whereas the road runs through former quarry backfill.*

Figure 12. *A general view of the proposed armourstone quarry benches looking SSE immediately after the removal of unexploded explosives.*

Conclusions

Penlee Quarry shows quite clearly the influence that geology has on the development of an excavation and on its subsequent use. The history of a quarry and its development is equally important for afteruse since it is essential to identify the ground conditions that relate to former excavations; these may be buried and greatly impact on foundation investigations and future foundation requirements.

It is always important to remember that the geology of a site is a natural phenomenon and no site investigation can ever be perfect and fully identify every feature that may be found. This uncertainty is enlarged when there has been a significant human impact on the site. Contractual arrangements for afteruse in such areas need to be flexible. Nevertheless a clear understanding of the geological and geotechnical constraints are a major, if not the major, influence on future built development which should not be left to architects or spatial planners on their own.

Acknowledgements

The authors wish to acknowledge information collected on behalf of the owners, MDL Developments Ltd.; the opinions expressed are the authors and not necessarily the owners. Additional acknowledgement must be given to those involved in the site investigation work including others from the Geoffrey Walton Practice and PGW&A LLP, and to staff and graduate students of Camborne School of Mines, University of Exeter and Mining and Minerals Engineering, University of Leeds.

References

Anon., 2006. Penlee Armourstone Quarry Scheme Submission under Decision Number 97/W/003 and Related Environmental Assessments. Walton, G. Editor, submission to Cornwall Mineral Planning Authority.

Denby, P.T. 2004. The issues associated with geoconservation at Penlee Quarry, Cornwall, England. Unpublished MSc Dissertation, Camborne School of Mines, University of Exeter, 151pp.

Floyd, P.A., Exley, C.S. and Styles, M.T. 1993. Igneous rocks of South West England. Joint Nature Conservation Committee and Chapman and Hall, 243pp.

Goode, A.J.J. and Taylor, R.T. 1988. Geology of the country around Penzance. Memoir of the British Geological Survey.

Markham, M. and Floyd, P.A. 1998. Geochemical fingerprinting of West Cornish greenstones as an aid to provenancing Neolithic axes. Geoscience in south-west England, 9, 218-223.