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A compendium of concrete aggregates used in Southwest England

Contents

1	Introduction	1
2	Degradation Mechanisms	8
3	Concrete Aggregates	21
4	Aggregate Distribution Maps	126
5	References	132



1 INTRODUCTION



1 Introduction

S ince the decline in use of natural stone at the beginning of the twentieth century most domestic and small commercial properties in Cornwall and South Devon have been built with concrete blocks or mass concrete. Until the mid-1950's concrete blocks were often locally made, sometimes by individual builders, and shuttered concrete was mixed on site. Before the second world war concrete products were rarely transported more than 20 km. Because concrete was made where it was needed and as transport was difficult and costly, aggregates were sought locally. Now all blocks are factory produced and mass concrete is supplied ready-mixed from facilities where manufacture is strictly controlled.

In many parts of Cornwall and South Devon ample supplies of cheap and often suitablygraded aggregate were available as waste materials from the region's metalliferous mining industry. The use of mining and, more particularly, ore processing wastes as aggregates, is central to the problem of accelerated concrete degradation in the region. It is widely called "the *mundic* block problem". Mundic is an old Cornish word for the common mineral pyrite (FeS₂). Accelerated deterioration is generally associated with the *in situ* oxidation of pyrite (and other sulphide minerals) in mine waste aggregates and sulphuric acid attack on the cement. Deterioration is occasionally so severe that concrete becomes structurally unsafe and some properties have had to be demolished.

Mine wastes in Southwest England are geologically complex materials made up from mineralised veinstones (from lodes), altered wallrock and unaltered country rock in varying proportions. Mining wastes sensu stricto from shaft sinking, cross cutting and development are composed largely of unaltered country rocks. They are usually very coarse. The maximum fragment size is the largest piece of rock that could be manhandled into a wagon. Such wastes, unless they were re-crushed, would have been quite unsuitable for use as concrete aggregates. Most waste materials that were subsequently used as concrete aggregates were tailings products from various ore concentration processes. Ore concentration takes place in two stages. First, the mineralogically complex ore is crushed to achieve liberation. Then it is subjected to benefication when the valuable material is separated from the gangue to produce a concentrate. Mineral concentration processes work most efficiently with closely-graded feeds so careful screening and regrinding led to the province-wide generation of millions of tonnes of wastes which were often of a convenient size for use as concrete aggregates. Unlike coarse mining wastes, which are usually just ordinary rock, mineral processing wastes are composed mostly of veinstone or lode minerals and of fragments of altered wallrocks that border the mineral lodes.

Many kinds of tin, copper and arsenic processing wastes have been identified in concrete aggregates. Some are benign. The wastes from granite-hosted tin mineralisation are safe if used as aggregates because the ores have low sulphide mineral content, the gangue and altered wallrocks are made from quartz and stable silicate minerals (figure 1-1).

Exogranitic tin and copper mining wastes were abundant in many parts of Southwest England, notably in the Camborne - Redruth mineralised district. These ores were rich in sulphide

minerals, in veins and altered wallrock (figure 1-2). Fine-grained and potentially very reactive sulphide minerals were not recovered before the introduction of flotation separation techniques in the early part of the twentieth century. In the eighteenth and nineteenth centuries rich copper ores, with coarse chalcopyrite, were often broken by hand and sorted before grinding and further benefication. The waste, typically with 50mm - 100mm top size, contained some residual chalcopyrite and other sulphide minerals including pyrite and arsenopyrite. Hand-cobbed copper wastes were used as aggregate in low fines mass concrete in the Camborne - Redruth district. Poor construction and high sulphide mineral content have sometimes led to very serious degradation.



Figure 1-1. Processing waste from granite-hosted tin mineralisation at the former Geevor Mine, near St Just - a stable Group 1-6 aggregate.

Southwest England was never an important lead producing region but two former lead mines, East Wheal Rose, near St Newlyn East (figure 1-3), and Wheal Mary Ann, near Liskeard, are of enormous consequence in terms of deleterious aggregates. The lead ore, galena (PbS), occurred in narrow veins with quartz and, at Wheal Mary Ann, abundant fluorite. At both mines the wallrocks were graphitic mudstones and these were impregnated with fine-grained, disseminated pyrite during mineralisation (figure 1-4). Dense galena was separated from the lighter gangue and pyritic wallrocks in jigs. Before jigging the ore was crushed to give a product evenly graded between < 1mm and 10mm or 15mm. The techniques did not change through the lifetime of the mines so enormous quantities of similar waste accumulated at both sites. The material was perfectly graded for all-in concrete block aggregate and manufacturing plants were established at both mine sites in the 1920's. Concrete degradation results from oxidation of disseminated wallrock pyrite and aggregate expansion. East Wheal Rose jig tailings are the major cause of concrete degradation in Perranporth; those from Liskeard are responsible for nearly all degraded and potentially unsafe concrete in East Cornwall.



Figure 1-2. An idealised cross section through a high temperature tin - copper - arsenic lode like those in the Camborne - Redruth - St Day mineralised district. The lodes are vertically zoned with sulphide-deficient tin mineralisation at depth and sulphide-rich copper and arsenic mineralisation at higher levels. Lodes are generally narrow so the miners were often forced to extract altered wall rock and even unaltered country rock in addition to the vein material itself. Mining and processing wastes are necessarily complicated, consisting of veinstones, altered wall rock (often with disseminated sulphides) and unaltered host rocks.

Tin mining/processing waste.

Veinstones	quartz + tourmaline + cassiterite (tin ore)
Wall rock	tourmalinised and haematised granite
Host rock	porphyritic muscovite-biotite granite

Copper mining/processing waste.

Veinstones	<i>quartz</i> + <i>chlorite</i> + <i>fluorite</i> + <i>pyrite</i> + <i>chalcopyrite</i> + <i>arsenopyrite</i>
Wall rock	chloritised pelitic and/or mafic hornfels with disseminated sulphides
Host rock	pelitic and/or mafic hornfels



Figue 1-3. Strongly oxidised tailings at the former West Chiverton Mine, near St Newlyn East. Similar material from the nearby East Wheal Rose Lead Mine is responsible for most accelerated concrete degradation in the Perranporth area.



Figure 1-4. Idealised cross section though a Cornish lead lode. From the standpoint of aggregate performance the dangerous materials are the altered wall rocks which often contain abundant very fine-grained, disseminated pyrite.

Not all pre-1950 concrete in the region was made with mine waste aggregates. Cornwall and South Devon have a huge variety of sedimentary, igneous and metamorphic rocks that are suitable for and have been used as concrete aggregates. In the past most of the granite plutons hosted quarries that produced aggregates. Mafic and ultramafic igneous rocks, including dolerites in East Cornwall and South Devon, the picrite at Clicker Tor near Liskeard, ophiolitic mafic and ultramafic rocks of the Lizard Complex and the metamorphosed dolerite of Penlee Quarry, at Newlyn in West Cornwall have all been important sources of aggregate. The Penlee dolerite is heavily mineralised. It carries more sulphide minerals than many mine wastes and its long term stability is still uncertain. Crushed slate, waste from the great quarry at Delabole, was widely used in North Cornwall while Devonian limestone is common in East Cornwall and South Devon.

Nowhere in Cornwall is more than 20 km from the sea; the region abounds with short rivers. Beach and river gravels and sands are still important locally. In the past beaches and rivers throughout the region yielded sand and gravel for concrete making. In the early part of the twentieth century, and in the Carnon valley till the 1970s, many river valleys were exploited for alluvial tin. Processed gravels were a cheap source of concrete aggregate. Beach and river gravels are usually stable, making excellent aggregates, but there are important exceptions. Some beach gravels derived from Upper Devonian rocks around the Camel estuary sometimes contain abundant pyritic mudstones - these materials can behave like pelite-hosted mine wastes. During the nineteenth and early twentieth centuries waste materials from the region's metal mines were commonly discharged directly into rivers. The waste-laden sediments were often worked for tin. The great mounds of processed sediment were attractive sources of concrete aggregate. Usually they were benign, but some gravels, heavily contaminated with hard rock mining waste, were rich in unoxidised sulphide minerals. They may be as unstable as sulphide-rich mine wastes.

Furnace clinkers are found throughout Cornwall and South Devon. There were major coalburning power stations in Plymouth and at Hayle. These were important aggregate sources. There were also many smaller sources including gas works, commercial operations such as laundries, and innumerable steam raising furnaces on the region's mines. Clinkers usually make safe aggregates but there are important exceptions. An electricity generating plant which operated in Falmouth during the 1920s and 1930s burned domestic and commercial waste to augment coal. The resulting clinker, employed locally as an aggregate, is compositionally complex and usually unstable.

The regions's most important natural resource is china clay. It was formed in granites, by destruction of feldspars reacting with heated, descending meteoric water. The reserves are enormous - probably in excess of 10 billion tonnes. The major by-product of hydraulic china clay extraction is quartz-rich sand that is stable and ideally graded for concrete making (figure 1-5). Mountains of this waste dominate the landscape in Mid Cornwall. It is scarcely surprising, and very fortunate, that china clay waste is the most important concrete aggregate in the whole region.



Figure 1-5. Hydraulic mining of china clay from the strongly kaolinised St Austell granite. Waste materials from this important industry are quartz-rich sands. They are very stable and usually have ideal natural grading for concrete aggregates. China clay waste is the most widely used concrete aggregate in the region.

This compendium has been assembled primarily as an aid to the identification of concrete aggregates used in the region, though section 2 provides a brief outline of degradation mechanisms associated with different types of mine wastes. The aggregates are illustrated in section 3. The classification is that set out in the Royal Institution of Chartered Surveyors Guidelines (The *'Mundic'* Problem - A Guidance Note, Second Edition, RICS Books, London, 1997). The plates show carefully ground surfaces of concrete, usually prepared from 50 mm or 75 mm diameter diamond drill cores. They are the kind of specimens normally used for Stage 1 examination and classification under RICS Guidelines. Most aggregates used in the region are illustrated, though new materials, some of them potentially unstable, appear from time to time. They are usually found in "one off" houses built near convenient and probably free aggregate from old mine burrows. New aggregates are also encountered as more concrete testing is carried out in South Devon.

Section 4 comprises distribution maps of the principal aggregate types. These should be treated as only as general guides. Mine waste aggregates are sometimes found in areas far removed from the main mineralised districts. They may have been won from some small and now forgotten mine of which no surface evidence remains. More probably, the use of free aggregate outweighed transport costs so that even on the difficult roads of the 1920s and 1930s it paid to carry cheap blocks for long distances.

2 DEGRADATION MECHANISMS



2 Degradation mechanisms

undic degradation is overwhelmingly associated with the oxidation of sulphide minerals, mainly pyrite, in mine waste and other mineralised aggregates. Howie (1979, 1992) and Newman (1998) recognised three mechanisms for pyrite oxidation.

1 Oxidation by a sequence of chemical reactions. The overall reaction at high relative humidity (RH) is usually given as:

$$2\text{FeS}_2 + 2\text{H}_2\text{O} + 7\text{O}_2 \rightarrow 2\text{FeSO}_4 + 2\text{H}_2\text{SO}_4$$

At low to moderate RH the following reaction also occurs:

$$FeS_2 + H_2O + 3O_2 \rightarrow FeSO_4.H_2O + SO_2$$

Both reactions involve expansion and because the oxidation products are hygroscopic they may be facilitated by absorption of water.

2. Bacteriological oxidation. The oxidation of pyrite and other sulphide minerals by *Thiobacilli* and similar genera have been extensively studied because of their economic significance in ore leaching (Smith and Schumate, 1970; Jorgensen, 1983; Pugh *et al*, 1984; Williams, 1990). Direct bacterial attack at sulphide surfaces probably does occur though two other processes may also be important. *Thiobacilli* may remove sulphur films, that would otherwise inhibit further oxidation, from pyrite surfaces. The *Thiobacilli* and some of their congeners can also catalyse the oxidation of Fe(II) to Fe(III). Ferric ion is, itself, an extremely important oxidising agent.

$$7\text{Fe}_2(\text{SO}_4)_3 + \text{FeS}_2 + 8\text{H}_2\text{O} \rightarrow 15\text{FeSO}_4 + 8\text{H}_2\text{SO}_4$$

Two groups of bacteria are capable of facilitating the oxidation of pyrite in acid and near neutral environments. The *Thiobacilli* and related genera are effective only under acid conditions. In concrete low pH domains are probably restricted to individual aggregate fragments exposed at the surface or projecting into large voids. Neutral pH bacteria include many genera (Lundgren and Dean, 1979) that may be capable of facilitating pyrite oxidation in concrete with carbonated cement.

3. Electrochemical oxidation. Howie (1992), Peters (1984) and Williams (1990) have discussed electrochemical mechanisms for pyrite oxidation. Howie, discussing the deterioration of museum specimens, noted that framboidal pyrite (Rust, 1935; Wilkin and Barnes, 1997) in organic matrices was very susceptible to oxidation. Bang (1994) proposed that each pyrite framboid behaves as a galvanic system when moisture enters it by capillary action. Pyrite is oxidised anodically creating acid conditions that lead to the chemical and mechanical breakdown of the framboids. Electrochemical breakdown may be an important mechanism in concrete made with lead ore processing waste where some pyrite is present as framboidal grains in dark, graphitic mudstones.

Newman (1998), reviewing previous literature, suggested that surface area, availability of water, temperature, pH, oxygen concentration and the presence of certain trace elements may

influence the rate of pyrite oxidation.

Experimental studies (Smith and Schumate, 1970; Howie, 1979, 1992) suggest that surface area of pyrite strongly influences its oxidation rate. Pugh *et al* (1984) reported a twofold increase in reaction rate in framboidal compared with massive pyrite. Khawaja (1975) demonstrated a very close relationship between crystal size and oxidation rate though Caruccio (1972) had ground coarse pyrite to $0.5 \,\mu$ m and found that it showed no signs of oxidation even after three weeks. He concluded that grain size was not the single controlling factor in pyrite oxidation.

Morth and Smith (1966) and Smith and Schumate (1970) reported that at constant RH the oxidation rate doubled for a 10°C rise in temperature. In Cornwall mean January and July temperatures are 6.8°C and 16.0°C respectively. Pyrite oxidation may be faster under warm summer conditions than in winter. Kim (1964), Morth and Smith (1966) and Smith and Schumate (1970) demonstrated that oxidation rate increases as a function of RH. They also suggested that water may be necessary to remove oxidation products from the pyrite surface, permitting the reaction to proceed. It is also important because above RH of approximately 60% ferrous sulphate can hydrate with resultant volumetric expansion of 256%. Mean minimum RH in Cornwall is about 60% in January, falling to 30% in July. Seasonal variation in relative humidity may work in the opposite direction to that of temperature, favouring more rapid pyrite oxidation during the wetter winter months.

Pyrite oxidation is pH dependent (Smith and Schumate, 1970; Waller, 1987; Howie, 1992). Under strongly alkaline conditions oxidation products tend to build up on mineral surfaces, inhibiting further reaction. This is of critical importance in concrete. In uncarbonated cement the pH of pore fluids is greater than 12. Pyrite remains stable. On carbonation the pH falls below 9 and pyrite oxidation proceeds rapidly. Morth and Smith (1966) and Smith and Schumate (1970) demonstrated experimentally that oxidation rate increased as the oxygen concentration in water at the reaction site was raised.

Many authors have proposed that oxidation rate is influenced by trace element concentrations. Caruccio (1972) suggested that pyrite was stabilised by the presence of titanium and very prone to oxidation if it contained high concentrations of silver. Other authors, e.g., Smith and Schumate (1970), argued that the presence of particular trace elements in pyrite did not appear to influence oxidation rates. It is interesting that concrete made with strongly mineralised dolerite aggregate, from the former Penlee Quarry at Newlyn, usually remains stable. Strong pyrite oxidation is rare. The pyrite is reputed to contain much higher levels of cobalt and nickel than that associated with fissure lode mineralisation (Prof. K.F.G. Hosking, personal communication), suggesting that trace element concentrations may influence oxidation rates.

An idealised section through the foundation and wall of a typical domestic property is shown in figure 2-1. There are many variations, particularly in older houses, such as absence of a damp proof membrane or solid walls built with mass concrete or concrete blocks.



Figure 2-1. Physiochemical conditions in foundations and walls.

Physiochemical conditions are strongly contrasted in different structural elements (figure 2-1). The pH of pore fluids in concrete with uncarbonated cement is > 12.5. When the cement is fully carbonated it falls to about 8.5. Mass concrete used in foundations and even in some walls, has cement:aggregate ratios and macroscopic pore volumes comparable to those of modern structural concrete. Carbonation depth is often only a few millimetres, even after many years. Foundation concrete is often saturated with groundwater from which oxygen has been removed by reaction with Fe(II) minerals and organic matter in soil. Pyrite in wet mass concrete foundations usually shows only superficial oxidation. The stability of pyrite in contact with uncarbonated cement paste may be a result of oxygen depletion or build up of a layer of oxidation products that are insoluble under alkaline conditions, effectively rendering the pyrite passive (figures 2-2, 2-3). Additionally, it is possible that pyrite oxidation is

facilitated by the action of sulphur bacteria that are dormant under alkaline conditions.



Figure 2-2. Concrete with uncarbonated cement. Sulphide minerals are protected from oxidation by strongly alkaline conditions. The uncarbonated cement is stained pink with phenolphthalein indicator solution.



Figure 2-3. Concrete with carbonated cement. Sulphide minerals are readily oxidised under near neutral conditions. Cement next to the sulphidic aggregate is strongly impregnated with iron oxides and gypsum.

Low strength concrete blocks and much poorly-constructed mass concrete in the region have cement:aggregate ratios between 1:6 and 1:15. Void volume is typically 5% - 10% and can be as high as 20%. The concrete has a 'honeycomb' structure. In such materials carbonation might be expected to proceed very rapidly because air can circulate freely through the strongly interconnected voids, but it is not always complete in blockwork walls, even after 70 - 80 years. In cavity wall construction, where the outer leaf is protected by sound render and the inner leaf is covered by mortar or plaster, carbonation usually begins at the cavity (figure 2-4). Moisture-laden air flowing through the cavity diffuses into the blockwork. Carbonation fronts migrate from the cavity towards the protected surfaces of the blocks. In single block walls protected externally by sound render the progress of carbonation depends mainly on the

nature of the internal covering. If the inner surface of the blockwork is exposed carbonation proceeds from the inner face towards the external render. If both surfaces are protected by mortar render or if the inner surface is covered in gypsum plaster carbonation normally proceeds inwards leaving a 'core' of uncarbonated cement.



Figure 2-4. Partial carbonation of concrete block from the outer leaf of a cavity wall. Carbonation begins at the cavity and proceeds towards the external rendered surface. The specimen has been treated with phenolphthalein indicator solution to show the distribution of uncarbonated and carbonated cement.

Sometimes in blockwork rendered externally and internally carbonation is very patchy, possibly as a result of air movement along partly open mortar joints. Carbonation penetration is also influenced locally by the presence of cracked or porous render. In porous concrete blocks pyrite oxidation is initially slow and superficial while the cement paste remains uncarbonated. Rapid pyrite oxidation follows carbonation of the cement paste. Degradation begins at the cavity (figure 2-5). Debris spalls from the inner faces of the blockwork and accumulates in the bottom of the cavity. It is only when pyrite oxidation has penetrated deep into the blockwork that characteristic cracking appears in external render.



Figure 2-5. Progressive degradation of concrete made with lead ore processing waste from Wheal Mary Ann Mine, near Liskeard.

The relative importance of molecular, bacteriological and electrolytic oxidation has not yet been established but two main degradation mechanisms are recognised, each associated with specific types of pyritic aggregate (Bromley and Pettifer, 1997; Bromley and Sibbick, 1999). The first is associated mainly with hypothermal, exogranitic tin - copper - arsenic wastes like those which characterise the Camborne - Redruth mineralised district. Degradation is caused by oxidation of liberated and easily accessed pyrite and other sulphide minerals in tailings products and re-crushed mining wastes and direct sulphate attack on carbonated cement paste (figures 2-6, 2-7).



Figure 2-6. Polished specimen viewed under the microscope showing part of a large sulphide-bearing aggregate fragment in contact with degraded cement. A limonite (iron oxide) crust encloses the aggregate fragment.



Figure 2-7. Microscope thin section showing strongly oxidised pyrite in contact with friable cement that has partly collapsed into an air void. Calcium carbonate in the cement has been converted to gypsum by reaction with sulphuric acid. The acid forms as pyrite is oxidised.

In low strength, high voidage concrete (low fines mass concrete and blockwork) degradation results mainly from sulphide oxidation and direct sulphate attack on the cement. Secondary gypsum grows at aggregate - cement interfaces and in the carbonated cement matrix. Degradation is caused by rupture of cement-aggregate bonds, disintegration of cement 'bridges' between aggregate fragments and pore volume collapse. Initial pyrite concentrations of at least 0.5% are generally required for major degradation to occur.

The second mechanism is associated with the use of mesothermal, mudstone-hosted lead ore processing wastes like those used in the Perranporth area and East Cornwall. These aggregates carry little liberated sulphide but have abundant graphitic mudstone wallrock with fine-grained, disseminated, sometimes framboidal pyrite (figure 2-8). Degradation results from oxidation of fine pyrite and bulk expansion of the mudstone aggregate. Expansion is caused by growth of secondary minerals in lensoid veinlets parallel with bedding and/or cleavage in the mudstone and at the interface between the aggregate and the cement (figures 2-9, 2-10, 2-11). Gypsum is the most important secondary mineral (figure 2-12). Watersoluble phases including Fe(II) sulphates and potash alum, formed by direct sulphate attack on phyllosilicates in the mudstone, are also found. Expansion of mudstone aggregate leads to propagation of open microfractures in the cement matrix (figure 2-13). Paucity of secondary sulphates in matrix cracks and absence of replacement gypsum indicate that direct sulphate attack on the cement is of minor importance. Degradation proceeds slowly and serious effects may not be apparent even after 50-60 years. Initial pyrite contents less than 0.2% may be enough to cause major damage.



Figure 2-8. Lead ore processing waste from Wheal Mary Ann Mine, Menheniot, near Liskeard. Microscope polished specimen showing mudstone aggregate fragment with very fine-grained, disseminated pyrite (pale yellow).Graphite is medium grey. It is typical of material from the zone of wallrock alteration, adjacent to the lode.



Figure 2-9. Microscope thin section of concrete made with lead ore processing waste aggregate from Wheal Mary Ann Mine, near Liskeard. Lensoid veinlets of very fine-grained fibrous gypsum have grown along cleavage planes and at interfaces between the aggregate and the cement.



Figure 2-10. Photomicrograph taken under the scanning electron microscope (secondary electron image), showing a mudstone aggregate fragment in concrete made with lead ore processing waste aggregate from Wheal Mary Ann Mine. The mudstone shows severe cleavage-parallel spalling caused by growth of secondary sulphate minerals. The secondary phases include gypsum, potassium alum and hydrated ferrous sulphate. Gypsum forms by reaction between soluble sulphate ions (oxidation product of pyrite) and calcium-rich pore fluids in the cement. The alum is probably formed by sulphate attack on phyllosilicate minerals in the mudstone. Ferrous sulphate is a primary oxidation product of pyrite.



Figure 2-11. Strongly exfoliated mudstone aggregate in mass concrete. Ruined mill building at West Wheal Kitty Mine, near St Agnes.



Figure 2-12. Photomicrograph taken under the scanning electron microscope (secondary electron image) showing very fine-grained fibrous gypsum growing on the surface of a pyritic mudstone aggregate fragment.



Figure 2-13. Photomicrograph of thin section showing microcrack propagation in the cement surrounding an expanded mudstone aggregate fragment. The aggregate is the lead ore processing waste from the former East Wheal Rose Mine, near St Newlyn East. This material is responsible for most concrete degradation in the Perranporth area.

External evidence of aggregate-related deterioration only appears when degradation has reached an advanced stage and affected the full thickness of the wall. Serious cracking may develop in the render cover and sometimes large pieces of render become detached from the walls. Advanced degradation of concrete made with coarse tin - copper -arsenic wastes usually causes the development of branching irregular open cracks in render overlying blockwork and mass concrete. This type of deterioration is characteristic of the Camborne - Redruth area (figures 2-14, 2-15).



Figure 2-14. Irregular branching cracks (many recently repaired) in render overlying seriously degraded blockwork. The aggregate is a sulphide-rich copper-arsenic mining waste typical of the northern part of the Camborne -Redruth mineralised district. House near Camborne.



Figure 2-15. Wide branching cracks in render overlying severely degraded mass concrete. The aggregate is a very coarse, low fines copper mining waste. Commercial property in Camborne.

Degradation of concrete blocks made with lead ore processing waste, rich in pyritic mudstone, is usually characterised by quasi-rectilinear cracks that follow mortar joints between the underlying blocks (figure 2-16). Lead ore processing wastes are unknown in mass concrete walls.



Figure 2-16. Severe cracking in render overlying blockwork. The cracks commonly follow mortar joints between blocks in the underlying wall. This type of render cracking is characteristic of degradation of blockwork made with lead ore processing wastes in the Perranporth area and East Cornwall. House at Perranporth (now demolished).

Crack patterns in render overlying degraded concrete seem to depend more on the nature of the aggregate than the structure of the wall. The reasons for this are not fully understood and further investigation is required. They may be related to contrasted degradation mechanisms. Direct sulphate attack on the cement and pore volume collapse, which is characteristic of sulphide-rich tin-copper arsenic wastes in West Cornwall, does not appear to be accompanied by bulk expansion of the concrete (Lane *et al.*, 1999). Alteration of pyritic mudstones - the failure mechanism of lead ore processing waste aggregates - does lead to bulk expansion of the concrete.

It is usually difficult to study concrete deterioration in the field, except occasionally when houses are being demolished, or in dark and cramped conditions under floors or in roof voids. However, the many disused mine buildings in the region provide useful examples of aggregate-related concrete degradation. Mass concrete and locally-made blocks have been used in mine buildings since the last years of the nineteenth century. Most of these can be accurately dated. The range of aggregates used is the same as that found in domestic properties. Figure 2-17 shows a mass concrete pillar at the former Levant Mine at Pendeen. It

was probably built during the early 1920s. Though it is in an exposed position near the top of a cliff the concrete remains completely sound. Even the chamfered corners of the pillar are preserved in sharp outline. The aggregate is a stable granite hosted mine waste with no sulphide minerals.

Figure 2-18 shows concrete pillars at Wheal Kitty Mine, near St Agnes. They are in the remains of a processing plant built in 1925 - 1926. Here, the local mine waste is made up mainly of fine-grained pelitic hornfels that often carries fine-grained, disseminated pyrite. The concrete is strongly degraded due to oxidation of the pyrite and spalling and expansion of the aggregate. Similar aggregates in domestic properties are responsible for much accelerated concrete degradation in the St Agnes - Perranporth area and in East Cornwall



Figure 2-17. Mass concrete pillar at Levant Mine, near St Just in Penwith.



Figure 2-18. Mass concrete pillars in ruined mill buildings at West Wheal Kitty Mine, near St Agnes.

3 CONCRETE AGGREGATES



China Clay Waste

St Austell



10

Quartz-rich waste is an important byproduct of china clay extraction from the St Austell and Dartmoor granite plutons. At present it is the most widely used aggregate for concrete block manufacture in the region. In the past china clay wastes from the St Just area of the Land's End, the Tregonning - Godolphin and Bodmin Moor granites were also used for concrete block manufacture.

Because the china clay wastes of Southwest England are all produced from granites of restricted composition, by very similar extraction and processing methods, they are mineralogically very similar.

The major component is glassy grey quartz (qz). Minor components include tourmaline or schorl (to), partly kaolinised and sericitised alkali feldspar (fs), muscovite, pale brown lithium mica. Topaz and fluorite are common in china clay wastes from topaz granite which makes up part of the western lobe of the St Austell pluton.

All-in china clay waste aggregates are generally graded between < $100 \mu m$ and 5 mm - 10 mm. All minerals are strongly liberated. Quartz is characteristically equidimensional with rough, pitted surfaces.

China clay waste is normally regarded as a stable and durable aggregate. Rare instances of defective concrete made with china clay waste are usually explained in terms of stale cement, inadequate cement content, prolonged poor maintenance or chemical attack from flue gases or acid groundwater.

Coarse china clay waste is widely used in structural concrete at the present time. It was formerly used in mass concrete walls of domestic properties in a restricted area west of the St Austell granite, notably Indian Queens and St Columb Road. This aggregate is made up from composite fragments including tournalinised and kaolinised granite, quartz - tournaline veinstones, quartz - feldspar porphyry and rhyolite.

China Clay Waste

Bodmin



The aggregate is a normal china clay waste from the western part of the St Austell granite. The specimen is from a single thickness concrete block wall. The cement shows external carbonation. The front between carbonated and uncarbonated paste is marked by a sharp change in colour from cream to pale greyish white. External carbonation is common in single thickness concrete block wall, especially if the render coat is thin.

The aggregate is made up mainly from quartz (qz) with subordinate tourmaline, partly kaolinised feldspar, muscovite and pale brown lithium mica.

The enlarged photograph (below) shows a composite tourmalinised granite fragment (quartz - qz, feldspar - fs, tourmaline - to) together with liberated fragments of quartz, tourmaline, feldspar and pale brown lithium mica (lim).



Truro



This specimen is from a concrete block in the outer leaf of a cavity wall. The aggregate is a fine china clay waste from the St Austell granite. The concrete shows normal internal carbonation. The outer face of the block, protected from carbonation by low permeability mortar render, is at the top of the plate. The right-hand illustration shows the same specimen after treatment with phenolphthalein indicator solution.

Wadebridge

China Clay Waste



This fine china clay waste is commonly found in blockwork used for chimneys, internal walls, etc.

It consists mainly of liberated quartz grains (qz) with a maximum size of about 2 mm. Partly kaolinised feldspar, tourmaline and micas occur in minor amounts. There are also occasional fine-grained quartz - tourmaline veinstones (qtv).

China Clay Waste

Newquay



Most china clay waste aggregates are dominated by liberated quartz grains. The maximum aggregate size is determined by quartz crystal size in the parent granite. Occasionally, concrete aggregates were produced by crushing coarse china clay wastes composed mainly of hard tourmalinised granite and quartz tourmaline veinstones.

This example is from blockwork in a house in Newquay. The major components are fine-grained quartz - tourmaline veinstones (qtv) and tourmalinised and kaolinised granite (tkg). The other components are liberated quartz (qz) and tourmaline (to) and subordinate amounts of muscovite and lithium mica and kaolinised feldspar. Occasional limonitisation (lm) is the result of low temperature oxidative hydrothermal alteration before the concrete was made.

The aggregate components are all stable and no problems have been reported in associated with the use of this material.

Aggregate Groups 1-1 1-4

China Clay Waste, Furnace Clinker Penzance



This concrete is made with a mixture of china clay waste (approximately 60%) and furnace clinker (40%).

The main component of the china clay waste is quartz (qz). Tourmaline locked with quartz, partly kaolinised alkali feldspar (fs), muscovite and pale brown lithium mica occur in minor amounts.

The Group 1-4 aggregate consists mainly of carbonaceous-vesicular clinker (cvc), laminated clinker (clc) and partly burned coal (pbc).

Concrete made with this combination of aggregates may be found anywhere in the region though it is especially common in the Penzance district.

Concrete made with these materials normally performs well, especially if the dominant aggregate is china clay waste and the aggregates are well-graded.

Poor quality mass concrete made with china clay waste and very coarse clinker aggregate is sometimes found in the area immediately west of St Austell. The clinker is believed to be from furnaces at former coal-fired china clay driers. The material often contains large fragments of unburned and partly burned coal. Swelling of these materials under damp conditions is believed to be responsible for degradation of the concrete.

China Clay Waste, Beach Gravel Padstow



This combination of aggregates is found occasionally in north coast towns such as Newquay, Padstow and Wadebridge.

The poorly graded china clay waste consists of large angular fragments of tourmalinised granite (tg) made up from black tourmaline, greyish quartz and traces of white, kaolinised feldspar, and quartz - tourmaline veinstones. The finer size fractions are made up principally from liberated quartz (qz) and subordinate tourmaline, kaolinised feldspar and micas.

The beach gravel aggregate is made up from rounded mudstone and fine-grained sandstone pebbles (sdst), from Lower Devonian Staddon Grits and Meadfoot Beds. Many pebbles are pervasively limonitised as a result of natural weathering. The other major components of the gravel are vein quartz and calcareous shell fragments, including purplish blue fragments of *Mytilus* (my), the common mussel.

North coast beach gravel aggregates sometimes contain disseminated pyrite. When used alone, especially in low fines concrete, they are sometimes responsible for general degradation. However, there are no recorded cases of concrete degradation when the gravels are diluted by substantial amounts of stable china clay waste.

This specimen is from blockwork but the aggregate combination is more commonly found in mass concrete footings and foundations.

Coarse Grained Granite



Coarse-grained granite has been quarried from all of the major plutons in southwest England. It is widely used as aggregate in blockwork and in mass concrete.

The main components of the aggregate are slightly kaolinised and sericitised alkali feldspar and plagioclase and quartz, with subordinate amounts of muscovite, biotite, chlorite and tourmaline. Small amounts of vein quartz, quartz - tourmaline and quartz haematite veinstones also occur occasionally.

This aggregate is from the southern part of the Carnmenellis granite. It consists of a mixture of unweathered "blue" granite and slightly weathered "brown" granite. The patchy pervasive limonitisation is a result of natural weathering. It does not indicate *in situ* alteration of the aggregate.

Coarse-grained granite aggregates from the Carnmenellis pluton are found in concrete blocks and mass concrete in Falmouth, Penryn and surrounding villages and less commonly in the Camborne - Redruth area. In mass concrete they are sometimes found in combination with beach or river sand or even mine waste fine aggregates.

Granite aggregates from the St Austell and Bodmin Moor granites are found occasionally in blockwork in the St Austell, St Blazey and Bodmin areas. Dartmoor granite aggregates were used extensively in South Devon.

Granite aggregates are stable. There are no records of concrete degradation associated with their use.

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Coarse Grained Granite

Mabe



This specimen if from blockwork. The material has high cement:aggregate ratio and is extremely hard. The all-in granite aggregate has larger maximum size than is normally found in concrete blocks.

The aggregate is typical of the southern part of the Carnmenellis pluton. It consists of composite granite fragments (feldspars + quartz + micas + chlorite + tourmaline) and liberated mineral grains, especially in the finer size fractions.

Note the combination of unweathered "blue" and weathered "brown" granite. This example contains an unusually high proportion of "blue" material. Devoran



This specimen is from mass concrete foundations of a house in Devoran. The aggregate is a coarsegrained, two-mica granite quarried in the southern part of the Carnmenellis pluton. This material consists entirely of "blue" granite, quarried from below the zone of surface weathering. Note the characteristic porphyritic texture preserved in the large fragment near the middle of the plate. The main stage Carnmenellis granite consists of phenocrysts of alkali feldspar, up to 15 mm long, set in a matrix of orthoclase feldspar, plagioclase feldspar and quartz with subordinate muscovite, biotite, chlorite and tourmaline. The abundance of composite fragments, feldspar greatly in excess of quartz and biotite in excess of tourmaline, serve to differentiate quarried granite from china clay wastes.





This specimen is from the mass concrete foundations of a house at Pool, between Camborne and Redruth. The aggregate is coarse-grained, two-mica granite, probably from Carn Brea or the Carnmenellis pluton. The concrete has low fines content and very high interconnected voidage.

The cement is only slightly carbonated (note the pink colour produced by treatment with phenolphthalein indicator solution) which is surprising in view of the very high interconnected porosity.

In the context of current RICS Guidelines this concrete could be classified as a Class A material because it contains only Group 1 aggregate and it remains sound. It is a poorly-constructed material that might be very susceptible to *local* degradation by cement recrystallisation and leaching in very damp areas. This is a large chisel sample. It is almost certain that this concrete would fragment if sampled by drilling, even with a large diameter core barrel.

Coarse Grained Granite

Bodmin



Concrete blockwork made with weathered coarse-grained granite aggregate is found occasionally in Bodmin and in scattered villages on and around Bodmin Moor. The source of the aggregate is not known but the lithology suggests a quarry or quarries in the coarse-grained Bodmin Moor granite.

The aggregate is made up from feldspars (fs), quartz (qz) and subordinate fine muscovite, biotite, chlorite and tourmaline. The aggregate has a maximum size of about 5 mm so most of the granite minerals are present as liberated grains.

There are small amounts of quartz tourmaline veinstones (qtv) and milky vein quartz stained with limonite.

Slight weathering of granite aggregate is typical of material produced from small shallow quarries.

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Princetown, Devon

Coarse Grained Granite



This specimen is from the mass concrete walls of a former prison warder's house in Princetown. The aggregate is coarse-grained, porphyrytic, two-mica granite, probably from the former quarry operated by Dartmoor Prison.

The main components are alkali and plagioclase feldspars and quartz. Quartz tourmaline and quartz - haematite veinstones (qhv) occur in minor amounts. The red iron oxide formed as a result of low temperature, oxidative, hydrothermal processes.

Note that composite granite fragments consist of unaltered "blue" and limonitised "brown" material. The limonitisation is a result of natural, surface-related weathering. Neither haematisation or limonitisation are indicative of *in situ* alteration of the aggregate in this instance.

Dartmoor granite aggregate has a rather restricted occurrence, probably because of the remoteness of many former Dartmoor quarries and the availability of alternative materials near large centres of population (for example, china clay waste and limestone near Plymouth).

The aggregate is very stable and there are no records of any problems associated with its use.
Fine Grained Granite

Gunnislake



Fine-grained, two-mica granite, probably from the small Hingston Down granite mass between Callington and Gunnislake, was widely used as concrete aggregate in northeast Cornwall. It is often found in Bodmin, Liskeard, Callington, Saltash and surrounding villages.

The main components of the aggregate are slightly kaolinised and sericitised alkali feldspars and plagioclase and quartz, with subordinate amounts of muscovite, biotite, chlorite and tourmaline. The minerals occur in composite fragments and as liberated grains. The aggregate is often partly limonitised (lm) but this is a result of natural weathering rather than *in situ* alteration.

The Hingston Down granite stock is locally mineralised. Sometimes small amounts of sulphide minerals, incuding pyrite, chalcopyrite and arsenopyrite, and less commonly stannite and molybdenite, are found as disseminations in granite or in veinstone fragments.

The material is usually found as an all-in aggregate, with a maximum size of 5 mm or 10 mm, in concrete blocks. Occasionally, coarser material is used in mass concrete footings or foundations.

In spite of its oxidised appearance, and the occasional presence of sulphide minerals, there are no known instances of degradation associated with the use of this material.

Fine Grained Granite

Liskeard



Fine-grained, two-mica granites were used extensively as concrete aggregates in East Cornwall. They came mainly from the Hingston Down granite stock, near Gunnislake, though it is possible that some aggregates were produced from finegrained granites in the Bodmin Moor pluton. The granite is made up from feldspars and quartz with subordinate biotite, muscovite, chlorite and tourmaline. Some granite from the Hingston Down stock carries sulphide minerals, though usually in very low concentrations.

In the near surface zone the granite is often pervasively oxidised as a result of natural weathering and many fragments are strongly impregnated with secondary brown limonite. The cement in this concrete has a strong brown colour but this is not the result of *in situ* oxidation of the aggregate. It is caused by sliming of limonite dust from weathered aggregate during handling or mixing of the concrete. In spite of its appearance the concrete is sound. No problems have been reported with the use of this aggregate.

Metamorphosed Dolerite and Gabbro Falmouth



This aggregate is from the Crousa Downs tectonic unit of the Lizard ophiolite complex. The main source was probably the former West of England quarry at Porthoustock. The quarry is developed in the root zone of the sheeted dyke complex and the product includes gabbros and various fine to mediumgrained dolerite dyke rocks. White plagiogranite, amphibolite, granulite and mafic mylonite from high strain zones occur in minor amounts.

The major mineralogical components are plagioclase feldspar (+ saussuritised feldspar), diopside and hornblende. Ilmenite, sphene, chlorite and carbonates occur in minor amounts. Finely comminuted ferromagnesian silicates (diopside and hornblende) give the cement a characteristic greenish colour.

The gabbro and dolerite commonly carry small quantities of sulphide minerals including pyrite, pyrrhotite, chalcopyrite, pentlandite and niccolite though concentrations are usually much less than 0.1%.

This aggregate was used exclusively in Falmouth and Penryn and nearby villages. It is usually found alone as an all-in aggregate in concrete blocks, with a maximum size of 5 mm or 10 mm. Less commonly, it is blended with china clay waste or granite.

There are no known problems associated with the use of the Lizard aggregate. Occasionally, however, it was blended with sulphide-bearing tin gravel from the Carnon Valley in concrete that has suffered degradation as a result of *in situ* sulphide oxidation.

Hornblende Granulite



This Lizard aggregate is from a house in Mullion on the northwest coast of the peninsula. It is probably of local origin, won from one of the small former quarries in hornblende granulite between Mullion and Mullion Cove.

The major components are fine and coarsegrained hornblende and pyroxene granulites (hg). Serpentinised peridotite, with characteristic variegated red and green colours (sp) and various serpentine and steatite veinstones (sv) occur in minor amounts.

The aggregate is mineralogically similar to the less deformed and metamorphosed gabbros and dolerites of the northeastern Lizard but it is of more restricted occurrence, being found only in the neighbourhood of Mullion.

It is occasionally found in blockwork (as in this example) though more commonly it was used as all-in aggregate, or coarse aggregate in combination with beach sand or gravel, in mass concrete footings and foundations.

There are no records of problems associated with the use of this material.

Metamorphosed Dolerite

Newlyn



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enlee or Gwavas Quarry, near Newlyn, was developed in a large, lensoid intrusion of fine to medium-grained dolerite. The Penlee intrusion lies wholly within the contact metamorphic aureole of the later Land's End granite. As a result of metamorphism the dolerite was converted to a fine to medium-grained plagioclase feldspar + green hornblende + sphene \pm biotite assemblage with characteristic decussate texture. The dolerite was also pervasively mineralised with a complex suite of sulphides including pyrite, chalcopyrite, pyrrhotite, stannite and molybdenite. Total sulphide mineral content is commonly between 1% and 2%.

The Penlee aggregate was widely used in blockwork in Penzance and Newlyn and surrounding villages and occasionally in Marazion, St Ives, Carbis Bay and Hayle. Its use in structural concrete was more widespread and it is found in bridges, for example, all over West Cornwall.

This specimen is from blockwork in a house at Newlyn. The aggregate consists mainly of fine and medium-grained metadolerite (fmd, mmd). Vein quartz (qz), various veinstones and biotite hornfels, from above the intrusion, are found in minor amounts. Sulphide minerals, mainly pyrite (py), chalcopyrite and pyrrhotite, occur as disseminated crystals and stringers in metadolerite and as liberated grains in the cement matrix. Note that some aggregate fragments show slight pervasive limonitisation and have incomplete limonitic crusts (lm) that merge into narrow haloes of oxide-impregnated cement.

The performance of this aggregate is not

well-understood. It is often strongly oxidised but its condition usually owes more to stockpile weathering than *in situ* alteration. There are no well-documented cases of general degradation in domestic properties. An industrial building, constructed in 1941 with Penlee blockwork and poorly-maintained, shows classic symptoms of general accelerated degradation, included rectilinear cracking in the overlying mortar render, detachment of render and gypsum exuding from the inner exposed surface of the concrete.

Current RICS Guidelines advise that concrete made with this aggregate may be assigned to Class A if it has less than 1.5% equivalent pyrite and shows no obvious evidence of aggregate-related degradation.

Metamorphosed Dolerite

Penzance



The aggregate in this blockwork from a house in Penzance is the well-known metamorphosed dolerite from Penlee (Gwavas) Quarry at Newlyn. Fine-grained and medium-grained metadolerite fragments (fgd, mgd) predominate. Various veinstones and vein quartz occur in minor amounts. Several veinstone fragments carry disseminated sulphide minerals, including pyrite (py), chalcopyrite (cpy) and arsenopyrite (asp).

Some aggregate fragments are pervasively oxidised with limonite (lm) but there is no obvious correlation between sulphide abundance and alteration. All sulphidebearing aggregate fragments in this specimen are unaltered. Occasional limonitised fragments are probably indicative of natural weathering or stockpile oxidation. There are no iron oxide impregnation haloes or any evidence of cement degradation.

Altered Dolerite

Gunnislake



The specimen is from blockwork in Gunnislake though the aggregate is probably from South Devon. It is quarried dolerite. As usual, the primary assemblage of clinopyroxene + plagioclase feldspar ` olivine is partly replaced by saussuritised plagioclase + green hornblende + chlorite + leucoxene.

This aggregate is made up from a mixture of medium-grained dolerite, with relict ophitic texture (mgd) and fine-grained aphyric and plagioclase-phyric rocks (fgd).

There are also small amounts of vein quartz and calcite and chloritic veinstones. The aggregates commonly carry traces of pyrite and other sulphide minerals but always in quantities that are too small to give cause for concern. Pervasive limonitisation (lm) of some fragments is a result of natural weathering. It does not indicate *in situ* oxidation of the aggregate.

Finely comminuted ferromagnesian minerals give the cement a characteristic greenish colour associated with many dolerite aggregates.

This material is usually found as an all-in aggregate, with maximum size of 5 mm to 10 mm, in concrete blocks. Occasionally, it is blended with china clay waste, limestone or furnace clinker.

No problems have been reported with this material.

Altered Dolerite

Saltash



Many high level dolerites and basalts were used as concrete aggregates in East Cornwall and South Devon. There are two primary dolerite suites (calcic augite plagioclase feldspar - ilmenite and olivine titanaugite - plagioclase feldspar - brown amphibole - biotite - ilmenite), though differences are not easily recognised under a low power stereomicroscope.

This example, from Saltash, consists of uniform medium-grained augite dolerite made from saussuritised plagioclase feldspar, uralitic amphibole, chlorite, carbonates and leucoxene. Ill-defined subophitic texture and the presence of almost white grains of leucoxene after ilmenite are characteristic. The aggregate often contains small amounts of vein quartz (qz) or calcite or chloritic veinstones. East Cornwall dolerite aggregates sometimes carry traces of sulphide minerals, including pyrite, chalcopyrite and pyrrhotite.

They are found as all-in aggregates in blockwork and mass concrete and they may be blended with china clay waste, limestone, various gravels and furnace clinker.

There are no known problems associated with the use of East Cornwall dolerite aggregates. Occasionally, in the Liskeard -Looe area, dolerites were blended with Menheniot mining waste in concrete that has suffered degradation in response to alteration of the mine waste component.

Altered Dolerite

Saltash



This is mass concrete from the foundations of a house in Saltash. It is a quarried dolerite from East Cornwall. The aggregate is probably an all-in material though it is less well-graded than that normally used in blockwork and has a larger maximum size.

It is composed of saussuritised calcic plagioclase, diopside, green hornblende, chlorite, ilmenite and leucoxene. Relict, mottled, sub-ophitic texture can be recognised in some of the larger fragments. The aggregate also carries small amounts of vein quartz and chloritic veinstones (cv).

Note the presence of several neat cement balls (ncb). In mass concrete, that is made with higher water:cement ratio than concrete blocks, neat cement balls may indicate that the concrete was made with stale cement.

The aggregate in the mortar render is weathered granite, probably from Dartmoor.

Altered Dolerite and Chert

Bere Alston



This aggregate is a single quarried product. It consists of a mixture of fine-grained, altered dolerite (fg), probably from a small, high level intrusion and black, often pyritic chert (ch). The chert comes from wall rocks adjacent to the dolerite intrusion. Other minor components include vein quartz (qz) and chloritic veinstones.

The abundance of chert varies substantially in different properties and even in different samples from the same property. It usually occurs in trace amounts, as in this example, but sometimes it makes up between 10% and 20% of the aggregate. The chert is sometimes mineralised with disseminated pyrite, too small to be recognised with a low power stereomicroscope. There is some evidence of concrete degradation associated with the use of high chert aggregates, involving oxidation of disseminated pyrite and cracking and expansion of the chert aggregate. Any concrete with more than traces of chert aggregate should be treated with caution.

This type of material is found mainly in South Devon in Tavistock and the surrounding villages.

Partly Serpentinised Picrite

Polperro



The former Clicker Tor Quarry, Liskeard was developed in a serpentinised cumulate picrite. The primary assemblage is cumulus olivine + intercumulus clinopyroxene + abundant granular magnetite. It is moderately to completely altered with the primary minerals replaced by serpentine + tremolite + stilpnomelane. There are also occasional fragments of serpentine + carbonate veinstones. The aggregate is easily recognised by its dark green colour and the distinctive mottled texture of large composite fragments. The aggregate was used extensively in the Liskeard - Looe area of East Cornwall.

The picrite was used as all-in aggregate concrete blocks and as coarse aggregate in mass concrete. Occasionally, it was blended with lead ore processing waste (Wheal Mary Anne) to make concrete blocks.

The aggregate is normally regarded as stable and there are no known problems associated with the use of the material in concrete blocks. There are rare instances of degradation of mass concrete. Degradation is possibly the result of *in situ* aggregate expansion caused by hydration of residual olivine. Olivine is a high temperature mineral that alters readily to secondary serpentine as a result of hydrothermal processes and weathering, though normally this takes place over geological time scales.

Olivine is unstable in strongly alkaline solutions at slightly elevated temperatures. It is possible that a combination of high alkali cement and local heating during setting provided conditions under which hydration of olivine could occur. Alteration of even a small of part of the olivine would be enough to cause expansion and structural weakening of the concrete and this may have been exacerbated by the crystallisation of secondary hydrated magnesium silicates in voids. The picrite was formerly used in the region as coarse aggregate in high strength concrete, notably in railway bridges. No evidence has been found which suggests it is unstable in these structures.

West Looe

Serpentinised Picrite



These gap-graded aggregates in foundation concrete from a house in West Looe, are both from the former Clicker Tor Quarry, near Menheniot.

The aggregate is a serpentinised picrite. It can be recognised by relict cumulus texture with almost black serpentine pseudomorphs after cumulus olivine and pale green intercumulus clinopyroxene. Some fragments are pervasively limonitised (lm) but the absence of iron oxide impregnation haloes shows that this is the result of natural weathering.

This aggregate is normally considered stable. Rare instances of severely degraded mass concrete made with this material are known (page 45) but it is uncertain if deterioration was caused by *in situ* alteration of the aggregate.

Aggregate Groups 1-2 1-3 Fine Grained Granite, Metadolerite Drift, near Penzance



The sulphide-mineralised metamorphosed dolerite from Penlee Quarry, near Newlyn, is normally stable, even though it may contain more than 1% equivalent pyrite. The potential effects of *in situ* sulphide oxidation are reduced when the metadolerite is blended with other stable aggregates.

In this example, from blockwork in a house at Drift, the metadolerite is blended with approximately 25% of fine-grained granite, probably from Castle an Dinas Quarry, near Penzance.

The main components of the aggregate are fine and medium-grained metadolerite (fgd, mgd) with occasional feldspar - hornblende veinstones (fhv). Many dolerite fragments carry disseminated sulphide minerals, mainly pyrite (py). Chalcopyrite, pyrrhotite and arsenopyrite occur in subordinate amounts.

The second aggregate is made up mainly from composite fragments of fine-grained granite (fgg), togther with occasional fragments of vein quartz (qz) and haematite-rich veinstones (qht). Note that many granite fragments are pervasively limonitised. This is a result of natural weathering before the concrete was made. There is no obvious evidence of *in situ* sulphide mineral oxidation.

There are no records of problems associated with the use of this combination of aggregates.

Aggregate Groups 1-1 1-3

China Clay Waste, Dolerite

Tavistock



This combination of aggregates is very common in concrete blockwork in the area around Tavistock.

The aggregate consists of approximately equal proportions of china clay waste and fine to medium-grained, slightly altered dolerite.

The main component of the china clay waste is liberated, grey, glassy quartz (qz) with subordinate tourmaline, kaolinised feldspar (fs) and micas.

The Group 1-3 aggregate is made up from fine to medium-grained dolerite (dol) and occasional veinstone fragments (vs).

Both aggregates have a maximum size of approximately 8 mm. The dolerite is obviously crushed and screened though the maximum size of the china clay waste reflects quartz crystal size in the parent granite.

No problems have been reported with this combination of aggregates.

China Clay Waste, Picrite

Truro



B oth these aggregates, from blockwork in Truro, are widely used though they are rarely found blended in the same concrete.

The coarser aggregate is serpentinised picrite (pc) from the abandoned Clicker Tor Quarry near Menheniot. The mottled almost black and pale green colour is characteristic. Occasionally, relict cumulate texture may be visible. There are also a few serpentine veinstones (sv). Note, the picrite is continuously graded from a few hundred micrometers to about 15 mm, it is not strictly a coarse aggregate.

The secondary aggregate is normal china clay waste, made from glassy, grey granitic quartz (qz) and subordinate feldspar (fs), tourmaline and micas.

The combination of aggregates is stable.

Aggregate Groups 1-1 1-3

China Clay Waste, Dolerite

Wadebridge



his unusual combination of aggregates is from blockwork. The principal aggregate, making up approximately 90% of the total, consists of altered fine-grained dolerite (fgd) and occasional fragments of medium-grained dolerite (mgd) with relict subophitic texture. The dolerite is made up from saussuritised plagioclase feldspar, diopside, green hornblende, chlorite, ilmenite and leucoxene. Many fragments in this specimen are pervasively limonitised (lm) but the absence of well-defined iron oxide impregnation haloes suggests natural weathering rather than in situ oxidation. Dispersal of fine iron oxides during handling or mixing is responsible for the brownish colour of the cement.

The china clay waste aggregate is made up mainly from liberated quartz grains (qz) with subordinate tourmaline, partly kaolinised feldspars and micas.

The low concentration of china clay waste in this specimen suggests it may be an accidental contaminant. However, six specimens from the same property had identical composition indicating that the aggregates were carefully blended.

Both aggregates are stable.

Hayle



This well-made concrete is from the foundations of a house in Hayle. The aggregate is furnace clinker, probably from the former coal-fired power station at Hayle.

The well-graded aggregate is made up mainly from carbonaceous-vesicular clinker (cvc) and smaller amounts of hyaline and hypohyaline-vesicular clinker (hvc). There are only a few fragments of partly burned coal (pbc). The cement is strongly discoloured by very fine debris, eroded from fragile carbonaceous clinker during handling or mixing. Red and orange iron oxides, which are developed sporadically in a few fragments, are the result of processes related to combustion.

Clinker aggregates are normally regarded as non-deleterious especially if they are of uniform composition and have a low partly burned coal content.

Though this concrete has high interconnected porosity, enhanced by the abundance of vesicular clinker, it appears very sound and in terms of current RICS Guidelines it is a Class A material.

Falmouth



Furnace clinkers are widely used as concrete aggregates throughout the region. Ample supplies were available from steam-raising furnaces at former mines, from coking plants, small coal-fired power stations and other industrial sources.

This specimen is from blockwork in a house at Falmouth.

The aggregate consists of the usual mixture of hyaline and hypohyaline (silicate + oxide + glass) clinker (hvc), carbonaceousvesicular (cvc) and laminated clinker (lc) and incompletely burned coal (pbc). Replacement and rimming by red iron oxides is the result of processes related to combustion. It is not evidence of *in situ* oxidation. The abundant fine clinker debris that gives the cement in many clinker concretes a characteristically "dirty" appearance, is a result of fragmentation of fragile carbonaceous-vesicular clinker during handling or mixing of the concrete.

Clinker aggregates normally perform well. Problems are sometimes caused by the use of clinkers that contain high proportions of unburned coal, lime sulphide minerals such as marcasite or if the coal was supplemented by inhomogeneous waste materials.

St Just in Penwith



Furnace clinker aggregates are common throughout the region. This example is from St Just in Penwith. It is very likely that the clinker is from a steam-raising furnace associated with the mining industry. Strongly oxidised clinkers appear to be characterictic of mine furnaces and are found in most of the former mining areas of Cornwall.

The specimen is from blockwork forming an external, load-bearing wall and unlike many clinker concretes it has high cement:aggregate ratio and low interconnected porosity. The property was built in the early 1920s and the concrete remains completely sound.

The main components are hypohyaline (hvc) and carbonaceous-vesicular and dense clinker, laminated hyaline clinker and small amounts of incompletely burned coal.

The clinker is often strongly oxidised, though by processes related to combustion, not because of *in situ* alteration. Iron oxide dust gives the cement a brownish colour rather than the dark grey coloration usually associated with the use of clinker aggregates. Occasional fragments of red iron oxide, haematite *sensu lato* (he), are also characteristic. Aggregate Groups 1-1 1-4 China Clay Waste, Furnace Clinker Hayle



Furnace clinker and copper smelter slag are common aggregates in the Hayle area. The sources are a former coal-fired power station and important copper smelting works that operated during the eighteenth and nineteenth centuries. This specimen is from mass concrete foundations. The aggregates are furnace clinker and china clay waste in approximately equal proportions.

The china clay waste consists principally of liberated quartz (qz) with subordinate amounts of tourmaline, kaolinised feldspar (fs) and micas. The clinker aggregate consists of hyaline and hypohyaline-vesicular (hvc), carbonaceous vesicular clinker and small amounts of partly-burned coal. The greyish brown appearance of the cement is caused by fine debris removed from fragile vesicular clinker fragments during handling and mixing the concrete.

The aggregates are well-graded and the concrete is sound though clinker-rich concretes often perform badly under wet conditions in footings and foundations. This is partly because of enhanced permeability due to abundant vesicular clinker and the tendency of partly burned coal to swell and crack, especially under conditions of cyclic wetting and drying.

Aggregate Groups 1-4 1-6

Furnace Clinker, Devonian Limestone Plymouth



This mixture of aggregates is common in the Plymouth area and Northeast Cornwall. It is found only in concrete blocks.

The clinker is probably a power station waste and consists mainly of well-graded hyaline and hypohyaline-vesicular (hvc) and carbonaceous-vesicular (cvc) material. There are only small amounts of incompletely burned coal.

The rock aggregate is a quarried product from the Plymouth area. It consists of finegrained, light and dark grey, recrystallised limestone (lmst) with subordinate vein calcite (ca) and calcite - haematite veinstones (he).

The characteristic pink-coloured cement, associated with the use of pure limestone aggregate, is masked by fine clinker debris.

No problems are known with this combination of aggregates.

Aggregate Groups 1-2 1-4

Fine Grained Granite, Furnace Clinker Launceston



This specimen is from concrete blockwork in a house at Launceston. The aggregates are fine-grained granite, probably from the Hingston Down stock, near Callington, and furnace clinker.

Complex aggregate mixtures are common in Launceston. Clinker is often blended with china clay waste, granite, dolerite, river gravel or chert and mudstone. Some concrete has three or four aggregates which are obviously from different sources.

The clinker concrete is often not well made and has poorly-graded clinker aggregate and high interconnected porosity. Its performance is variable. Aggregate-related degradation is often exacerbated by poor construction.

This concrete is sound though some specimens, from the same house, that had been subject to prolonged wet conditions showed strongly degraded cement.

The main aggregate is poorly-graded clinker, made up mainly from carbonaceous- vesicular (cvc) and hypohyaline-vesicular clinker (hvc). There is very little incompletely burned coal.

The second aggregate consists mainly of composite unweathered "blue" and weathered "brown" fine-grained granite (fgg) and occasional fragments of vein quartz.

This concrete was assessed as sound but great care is needed in the classification of complex clinker-bearing aggregates in the Launceston area, especially when they include chert and mudstone.

The irregular transverse crack is the result of damage during core recovery.

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Sintered Pulverised Fuel Ash

St Ives



ightweight synthetic aggregates are found in concrete blocks throughout the region though they are not common.

This example is probably Lytag, manufactured by sintering pulverised fuel ash. It is readily identified by the spherical and subspherical shapes of the aggregate fragments and their high vesicularity. The zonal structure with reddish brown, oxidised rims and almost black cores is characteristic.

The aggregate is found in low fines, lightweight insulation blocks, usually in internal walls. There are no known problems associated with its use but its high porosity suggests it may be susceptible to degradation in prolonged wet regimes.

Torpoint



This aggregate is found only in old mass concrete walls and foundations of some houses in Torpoint. It is sometimes used alone but it is also found blended with weathered mudstone, furnace clinker, dolerite, limestone and fragments of older masonry. When used alone it usually performs well but some mixed aggregate concrete shows evidence of strong degradation that is ascribed to *in situ* expansion of pyritic mudstone and general poor quality of construction.

The gravel aggregate is lithologically complex and often shows considerable variation, even in specimens from the same property.

This aggregate contains unweathered and weathered grey and brown mudstones (md), and occasional purple (Lower Devonian) mudstones (pmd), vein quartz (qz), various veinstones, altered dolerite (dol) and granite. The aggregate sometimes contains lithologies unknown in the region and these may be from ballast, discharged by ships in Plymouth Sound.

This concrete appears sound. There is no obvious evidence of *in situ* alteration of the aggregate. It was assigned to Group 1-5 and the concrete was classified as a Class A material.

Beach Gravel

West Looe



Beach gravels, derived mainly from Lower Devonian mudstones and fine sandstones, were widely used as aggregate in blockwork and mass concrete in East and West Looe, Polperro and neighbouring villages.

The distinctive major components are purple mudstones (pmd) and green mudstones (gmd) from the Dartmouth Beds and vein quartz (qz). Grey mudstones, finegrained grey sandstone, granite, altered dolerite, calcareous shell fragments, stable silicate minerals and brown iron oxides occur in minor amounts in the fine size fractions.

Aggregate used in blockwork was screened and usually has a maximum size of 10 mm to 15 mm. Poorly-graded all-in aggregate, with maximum size of 100 mm to 200 mm is commonly found in mass concrete foundations.

There are no records of aggregate-related degradation associated with this material. However, some mass concrete and blocks were made with very low cement content and have suffered local degradation as a result of strong recrystallisation and leaching of the cement.

West Looe

Beach Gravel



This specimen is from mass concrete foundations of a house in West Looe. The beach gravel aggregate is made up almost entirely from Lower Devonian purple and green mudstones (pmd, gmd) and subordinate vein quartz (qz). The source rocks form the cliffs between Looe and Polperro. Because of strong cleavage, most pebbles in this material tend to be flat and disc-shaped.

The specimen was recovered by drilling down at an angle of 45° into the foundation concrete. Note the strong preferred horizontal orientation of the mudstone pebbles.



Boulders of Lower Devonian purple and green mudstones, Talland Bay, near Polperro - source material for the aggregate.

Beach Gravel

West Looe



This gravel aggregate is common in blockwork and mass concrete in Looe, Polperro and nearby villages. It is a beach gravel dominated by Lower Devonian purple, green and grey mudstone (pmd, gmd), fine-grained grey sandstones and vein quartz (qz). Veinstones, granite, dolerite, calcareous shell fragments, stable silicate minerals and iron oxides occur in minor amounts.

The aggregate is stable. Blocks and mass concrete made with this material are normally safe.

This specimen is from mass concrete foundations. The concrete was wet when recovered and showed considerable void enlargement. Void walls are stained dark brown, probably by reaction with organic acids in groundwater. Adjacent concrete was strongly degraded because of severe cement recrystallisation and leaching and it required replacement.

Mass concrete foundations with gravel aggregate, especially if it has low fines content, is often prone to local degradation by interaction between cement and groundwater.

Beach Gravel

East Looe



This specimen is from blockwork in a house at East Looe. The aggregate is a local beach gravel dominated by purple, green and grey mudstone and fine-grained greyish brown sandstone derived from local Lower Devonian rocks. The other major components of the aggregate are vein quartz (qz) and quartz-dominated veinstones (qzv).

The specimen illustrates the use of unscreened, poorly sorted materials. Often, when sampling these materials, the concrete breaks up badly if the drill strikes large rounded pebbles of hard vein quartz. This may give the impression that the material is degraded. Great care is needed in the interpretation of fragmented specimens from concrete that is made with poorly sorted aggregates that have large, rounded fragments of very hard materials.

Beach Gravel

Helston



The gravel beaches which extend along Mount's Bay from Porthleven to Gunwalloe Church Cove were widely exploited as sources of aggregate for concrete blocks and mass concrete. The gravel aggregate is found mainly in towns and villages bordering Mount's Bay including Marazion, Porthleven and Helston.

This well-rounded aggregate is lithologically complex and its composition varies slightly in different localities. The major components are yellowish and reddish brown chert (ch), from offshore Eocene gravels, white vein quartz (qz) and fine-grained mudstones (md) and siltstones of local origin. Quartz-dominated veinstones (vs), altered fine-grained basic igneous rocks and calcareous shell fragments are other important components.

The gravel is usually found as an all-in aggregate with maximum size of 5 mm or 10 mm, though much coarser-grained material is sometimes used in mass concrete. Occasionally, in inland areas such as Breage and Porkellis, it is blended with mining waste or furnace clinker.

The aggregate usually performs very well though, because it often has low fines content, concrete made with this material may have very high interconnected porosity. Under wet conditions, in some footings and foundations, such concrete has degraded because of prolonged recrystallization and leaching of the cement.

Because the major components of the aggregate (chert, quartz) are very hard it is difficult to recover intact diamond drill cores, even from perfectly sound concrete. St Ives



This appears to be a gap-graded aggregate but it is actually a single source material from Porthmeor Beach at St Ives.

Beach sand and gravel have a strongly bimodal distribution with strands of coarse pebbles of metadolerite, veinstone, granite and pelitic hornfels lying on sand dominated by calcareous shell fragments and quartz.

The aggregate is found only in mass concrete in St Ives and Carbis Bay. It is usually found in foundations though occasionally it was used in mass concrete walls and chimneys.

This material is made up from rounded and subrounded pebbles of fine-grained metadolerite (fmd) and vein quartz (qz) set in a matrix of sand composed of quartz, calcareous shell fragments and subordinate stable silicate minerals and iron oxide.

This specimen is from very damp but sound foundation concrete. Brownish staining of usually white uncarbonated cement is probably the result of reaction with organic acids in percolating groundwater.

There are no known problems associated with the use of this material.



This example of mass concrete made with aggregate from Porthmeor Beach, St Ives, illustrates how sporadically coarse fragments are distributed and shows the strong lithological contrast between the coarse and fine fractions of the aggregate.

The large pebbles include fine-grained metadolerite (fmd), pelitic hornfels (ph), coarse-grained granite (cgg) and occasional quartz - tourmaline (- chlorite) veinstones (qtv). The sand fraction is made up mainly from quartz and calcareous shell fragments with small amounts of stable silicate minerals. The enlarged photograph below shows details of the fine fraction of the aggregate. Quartz is white, calcareous shell fragments are generally cream, except for purple *Mytilus*, silicate minerals (mainly hornblende and tourmaline) are green or black.



Beach Gravel

Crantock



A wide variety of beach and estuarine gravels were used as concrete aggregates along the north coast of Cornwall. This material is probably from the Gannel Estuary, south of Newquay.

The aggregate is made up from unweathered and weathered grey and brown mudstones (md), fine-grained sandstones (sdst) and subordinate vein quartz (qz). Stable silicate minerals and calcareous shell fragments are important in the finer size fractions.

In this concrete the absence of iron oxide impregnation haloes round altered aggregate fragments indicates that their condition is the result of natural weathering before the concrete was made. Normally, these gravel aggregates are considered safe but there are instances of severely degraded concrete made with this type of material. The degradation mechanism is associated with in situ oxidation of very fine-grained disseminated pyrite in some mudstone pebbles. The sulphide mineral has sometimes survived unaltered through the weathering cycle. In some poorlymaintained concrete it has oxidised in place, causing expansion of mudstone pebbles and severe degradation of the concrete.

If there is any evidence of degradation in concrete containing these materials, they should be carefully examined in polished section to establish if they carry disseminated pyrite.

Mawgan Porth

Estuarine Gravel



This estuarine gravel from Mawgan Porth is made up from cleaved grey mudstones (md) from the local Lower Devonian Meadfoot Beds and vein quartz (qz) with subordinate iron oxides and occasional pebbles of weathered granite (gr).

The specimen is from poor quality blockwork. Many mudstone aggregate fragments are strongly oxidised suggesting that they may originally have contained disseminated pyrite though it is uncertain if this oxidised in response to natural weathering or if it has undergone alteration in place.

Note how the binder tends to form coatings round many of the larger aggregate fragments, suggesting that the concrete was made at very low water:cement ratio.

Problems associated with the use of mineralised gravel aggregates are increasingly recognised in North Coast towns and villages. In this instance it is uncertain whether the degraded condition of the concrete is due to unstable aggregate or if it is the result of poor manufacture.

Trevone



B each and estuarine gravels were widely used as aggregate in coastal areas throughout the region. Normally they are stable. Some North Coast beach gravels are derived from sulphide-mineralised source rocks and they contain unoxidised, finegrained, disseminated pyrite. These materials can behave like mesothermal mine wastes that have disseminated pyrite in mudstone wallrocks. *In situ* oxidation of disseminated pyrite causes bulk expansion of the aggregate which, in turn, promotes microcracking and loss of cohesion in the cement matrix.

The major components of this gravel are cleaved, dark grey, calcareous mudstones from the Middle Devonian Meadfoot Beds (md), fine-grained greywacke sandstone (sdst) and vein quartz (qz). Minor components include quartz - feldspar porphyry, weathered lamprophyre, calcareous shell fragments (especially *Mytilus*) and stable silicate minerals.

Mudstone fragments often carry abundant disseminated pyrite (py) while others have abundant limonitic pseudomorphs or disseminated limonite (lm) that has formed by oxidation of disseminated sulphides.

This aggregate is found in blockwork and mass concrete in the coastal area between Newquay and Trevone. It is sometimes found as an all-in, low fines aggregate in blockwork (as in this example) but is more common blended with beach or dune sands rich in shell fragments. In blockwork the maximum aggregate size is usually 10 mm or 15 mm but in mass concrete poorlygraded gravel with maximum cobble size of more than 100 mm is common.

Several examples of general accelerated concrete degradation are ascribed to the use of this aggregate.

River Gravel

Pentire



Many of the small rivers and streams that drain the western part of the St Austell granite have been worked for alluvial tin and the sands and gravels were used occasionally as aggregate in Newquay and villages such as St Mawgan, Trenance, St Merryn and even in Padstow.

The gravels have complex lithology and consist of mixtures of rounded pebbles and angular fragments, suggesting they may have been contaminated by penecontemporaneous hard rock tin mining waste from tin mining operations near Fraddon and Indian Queens. In contrast to the Carnon Valley gravels, which are commonly sulphide-bearing, these gravels are benign because the mineralised rocks that crop out in the Fraddon - Indian Queens area have very low sulphide mineral content.

The aggregate consists mainly of vein quartz (qz), quartz - tourmaline veinstones (qtv), quartz - tourmaline hornfels, granite (gr), calc-silicate hornfels (csh) and various fine-grained pelitic rocks. Limonite is often abundant but this is clearly the result of natural weathering. Note that there are no iron oxide impregnation haloes in the cement enclosing weathered aggregate fragments.

The aggregate is found exclusively in blockwork. In spite of its appearance there are no records of degradation associated with the use of this material.

Truro



Formerly, much china clay waste was discharged into streams and rivers draining from the strongly kaolinised St Austell granite. These "white rivers" became badly silted in their lower courses and needed constant dredging. China clay waste-dominated sands and fine gravels from dredging operations in Charlestown Harbour and at Ruan Lanihorne were used for concrete block manufacture.

The aggregates are dominated by liberated grains of grey, glassy, granitic quartz (qz) with subordinate tourmaline (to) and other stable silicate minerals. There are usually a few pelitic rock pebbles and fragments of vesicular furnace clinker. These materials are never found in unmodified china clay wastes. China clay-contaminated sand and gravel aggregates from Charlestown Harbour are common in blockwork in St Austell, St Blazey and Truro. Material from the river at Ruan Lanihorne was transported to Penryn by barge. It is common as aggregate in blockwork in the Falmouth area.

The aggregate is stable and there are no problems associated with its use. It is usually mistaken for china clay waste because of its composition. Slight rounding and the presence of occasional rounded pelitic rock pebbles and furnace clinker should serve to identify this aggregate.

Note the irregularly-shaped masses of neat cement (ncb) suggesting the binder might have been slightly stale when used.
Perranwell



10

his gravel aggregate is from the lower Carnon Valley. Carnon Valley gravels were worked for alluvial tin from the earliest times until the 1970s. Processed gravels provided a cheap and abundant source of concrete aggregate. During the 18th, 19th and early 20th centuries wastes from underground mines in the St Day mineralised district were discharged into the river system. The gravels were often strongly contaminated by unstable, partly oxidised mining waste. The gravels are lithologically variable and complex. Some are relatively clean and dominated by mature, stable mineral and rock fragments; others are heavily contaminated by unstable, sulphide-bearing mine wastes.

The major components of the gravel are vein quartz (qz), quartz - chlorite (qcv) and quartz - tourmaline veinstones, cleaved mudstone (Mylor - Gramscatho Beds) and fine-grained pelitic hornfels. Minor components include greisen, granite, quartz - feldspar porphyry, iron oxides (mainly goethite), furnace clinker and chopped straw.

The gravels are often made up from mixtures of rounded pebbles and angular to sub-angular fragments that represent penecontemporaneous mine waste. In some aggregates most of the fragments have patinas or crusts of limonite. Limonitic pebbles (lm) may conceal cores of unaltered sulphide minerals. Fine-grained authigenic pyrite may occur sparingly as replacement of organic debris. Calculated pyrite concentrations as high as 0.5% are recorded from these materials. Carnon Valley gravels are usually found as all-in aggregates, with

maximum size of 5 mm or 10 mm, in blockwork. Occasionally, they were used as sand in mass concrete with granite, Lizard dolerite and gabbro, or even mine waste coarse aggregate. The performance of concrete made with Carnon Valley aggregates is very variable because of their wide compositional range. Clean aggregates, dominated by rounded fragments, that are not strongly oxidised and have very low sulphide concentrations, are stable. Aggregates with abundant iron oxides often contain residual sulphide minerals and they are known to be responsible for general accelerated degradation of concrete blockwork. The aggregate is found in Falmouth and Penryn, in villages in the Carnon Valley and occasionally in Truro.

Contaminated River Gravel

Truro



This problematical gravel aggregate is probably from the Carnon Valley though it could be from another river system that was contaminated by hard rock mining waste.

It consists of a mixture of rounded pebbles and angular fragments and it is characterized by extreme lithological complexity.

The components include fine-grained pelitic hornfels (ph), vein quartz (qz), quartz chlorite veinstones (qcv), quartz tourmaline veinstones (qtv) and chloritised coarse-grained granite (cg) and greisen. Minor components in the finer size ranges include stable silicate minerals and iron oxides. Note that this specimen also contains a fragment of wood and some hyaline laminated clinker (hlc).

Some fragments shows pervasive haematisation (he) or limonitisation (lm) but the absence of limonitic crusts and haloes of iron oxide-impregnated cement suggests alteration occurred in response to natural low temperature hydrothermal processes or weathering. This aggregate is sulphide-free and there is no evidence that it has undergone any significant *in situ* alteration.

Mine waste-contaminated gravels that are usually by-products of alluvial tin extraction are generally found as aggregates in Falmouth, Penryn and the Carnon Valley itself. Occasionally they occur in Truro, both in blockwork and mass concrete. The difficulty in assessing these materials lies in their variable lithologies and sulphide contents. Some aggregates, like this one, are safe. Although they are very complex and inhomogeneous they have negligible sulphide content. Others are potentially deleterious or have caused degradation because they carry abundant sulphides in mine tailings contaminants.

St Columb Road



This poorly-sorted river gravel is from mass concrete walls in a house at St Columb Road. It is probably a by-product of alluvial tin extraction from one of the streams that drains the western margin of the St Austell granite.

The combination of rounded pebbles and angular and subangular fragments suggest the gravel was contaminated by penecontemporaneous tin mining wastes from the area around Indian Queens and Fraddon. The mineralisation in that area is extremely sulphide-deficient so the gravels are unlikely to contain any deleterious materials. This gravel is made up from quartz - tourmaline veinstones (qtv), quartz - haematite veinstones (qhv), quartz tourmaline hornfels (qth), vein quartz (qz) and fragments of weathered granite (gr). Fine-grained pelitic hornfels (ph) and other low-grade metamorphic rocks occur in minor amounts. The aggregate contains fragments that are haematised (red) as a result of low temperature oxidative hydrothermal alteration and limonitised (brown) in response to weathering. Absence of iron oxide impregnation haloes round the oxidised fragments shows that there has been no significant in situ alteration of the aggregate.

There are no recorded problems associated with the use of this material.

River Gravel

St Blazey Gate



The aggregate in this specimen from a concrete block is a river gravel. It is probably a by-product of alluvial tin extraction from a stream draining the south-eastern part of the St Austell granite. The aggregate consists principally of quartz (qz) and tourmaline (to), togther with minor amounts of other silicate minerals including feldspar and muscovite. It contains abundant fine-grained iron oxides and other silt-size material suggesting it was not washed before use.

The aggregate contains no sulphide minerals but the cement is very soft and friable, probably because of the abundance of very fine iron oxides in the aggregate. Darker areas of cement are regions of very high microporsoity where it is strongly impregnated by resin. Large resin-filled voids have a glassy appearance.

This concrete was assigned to Class C2 because although the aggregate is inherently stable the cement is extremely soft, friable and porous. It would certainly be prone to severe local degradation in areas of poor maintenance.

Aggregate Group 1-5/2-2

Contaminated River Gravel

St Blazey



The specimen is from a concrete block. The aggregate is a river gravel. It is probably a by-product of alluvial tin extraction from a stream draining the southeastern part of the St Austell granite and its metamorphic aureole.

The aggregate consists of rounded to subangular pebbles of fine-grained pelitic hornfels (ph), fine-grained quartz tourmaline and quartz - chlorite veinstones and vein quartz (qz). Stable silicate minerals make up part of the finer size fractions.

Most of the aggregate fragments have crusts or patinas of secondary iron oxides and this is responsible for the dark brown colour of the cement. Note that the neat cement ball (ncb) is not coloured by iron oxides. Much oxidation is ascribed to natural weathering though some veinstone fragments carry relict pyrite and chalcopyrite that has survived weathering. The sulphides are generally too fine grained and corroded to be easily recognised under a low power stereomicroscope.

Petrographic study showed that areas of white cement contained abundant secondary gypsum indicating that sulphide minerals in the aggregate have oxidised in place and attacked the binder. The presence of residual sulphides suggests potential for further degradation. The aggregate, though a river gravel, should be assigned to Group 2 on lithological grounds. The concrete is a Class B material.

Contaminated River Gravel

Lostwithiel



This gravel aggregate is from blockwork in a house at Lostwithiel. The aggregate is a river gravel. It is probably a by-product of alluvial tin extraction in the valley of the River Fowey.

The aggregate is lithologically complex. The main components are vein quartz (qz), often stained with limonite, glassy, grey quartz from granite (gqz) and various finegrained pelitic rocks including mudstones and hornfels (md) and veinstones. Finegrained sandstone, dolerite, stable silicate minerals and furnace clinker (fc) occur in minor amounts. The aggregate is strongly oxidised but this is the result of natural weathering. Petrographic study of this material showed that it contains no residual sulphide minerals and there was no evidence of *in situ* aggregate alteration or degradation of the cement. The brownish colour of the binder is due to fine iron oxides derived from weathered aggregate during handling or mixing.

This aggregate is classified as a Group 1-5 material and the concrete should be assigned to Class A.

Flushing



This aggregate looks like a china clay waste. It is lithologically closely similar to china clay waste, dominated by quartz (qz) with subordinate tourmaline (to), kaolinised feldspar (fs) and micas.

It is actually a gravel, dredged from the lower reaches of the River Fal at Ruan Lanihorne. China clay wastes were discharged into many rivers and streams that drain the strongly kaolinised St Austell granite and they caused serious silting problems at small ports around the Fal estuary. Fine gravel and sand from the creek at Ruan Lanihorne was transported by barge to Penryn where it was used as an aggregate for concrete block making.

The aggregate may be distinguished from normal china clay waste by the presence of occasional rounded pebbles of mudstone and hornfels (ho) and fragments of furnace clinker.

This aggregate is only found in Falmouth, Penryn and surrounding villages, though similar material was dredged from Charlestown Harbour and is found in blockwork in St Austell, St Blazey and Truro.

The material is essentially a china clay waste and there are no records of any problems associated with its use.

Fine River Gravel

St Mawes



This is an unusual aggregate from old blockwork in a house at St Mawes. It is a mudstone-rich fine gravel, probably from a beach bordering the Fal Estuary. The main component is dark grey mudstone (Mylor Series). Vein quartz occurs in subordinate amounts. The small cream-coloured nodules are microcrystalline calcite. They are probably carbonated neat cement balls.

The dark brown colour of the cement is due to abundant fine silt-size material, indicating that the aggregate was not washed.

The concrete is very friable and some specimens recovered from this property were incoherent. The mudstone does not have any sulphide minerals and there is no evidence that it has undergone any *in situ* alteration or expansion. The poor condition of the material is presumed to have resulted from the use of unwashed aggregate perhaps exacerbated by the use of stale cement.

Gravel aggregates are common in the towns and villages bordering the Fal river system but this concrete is probably unique. The blocks were probably made on-site by an individual builder.

Upper Devonian Delabole Slate Wadebridge



Crushed slate from the great quarry at Delabole has been widely used as a concrete block aggregate. It is found mainly in North Cornwall, between Wadebridge and Camelford, though occasionally it was used in West Cornwall, for example at St Agnes.

The aggregate is easily recognized by its distinctive greenish grey colour, uniform lithology and strong penetrative cleavage. The slate is often weakly mineralised. It often has traces of pyrite and sometimes chalcopyrite and pale brown, low iron sphalerite that occur in discrete, cleavage-parallel lenses. The sulphide mineral content is normally very low, much less than 0.1%.

It is usually found as an all-in aggregate with a maximum size of 5 mm or 10 mm. Fine slate dust imparts a characteristic pale greenish grey colour to the cement.

Delabole roofing slates are very durable and even in polluted atmospheres they may last for more than one hundred years. The material is stable as a concrete aggregate. There are no known instances of degradation associated with its use.

Devonian Limestone

Plymouth



Devonian limestone aggregate, from quarries in South Devon, is found in concrete blocks in East Cornwall and in the Plymouth area.

It is used alone as an all-in aggregate and it is also found blended with china clay waste, dolerite, various gravels or furnace clinker.

The main components are fine-grained light and dark grey recrystallised limestone. Calcite (ca) and calcite - haematite veinstones (chv) occur in minor amounts.

Concrete made with this aggregate commonly has distinctive pink or pinkish brown cement caused by sliming of earthy red haematite from the veinstones.

There are no known problems associated with the use of this material.

Note the fine-grained dolerite aggregate used in the mortar render.

Devonian Limestone

Plymstock



This is the same Devonian Limestone aggregate as that shown in the previous plate. It is made up from the same mixture of light and dark grey recrystallised limestone (lmst) and calcite (ca) and calcite - haematite veinstones (chv).

The aggregate in this concrete block is rather poorly graded.

Though the aggregate contains abundant haematite in veinstones, the cement does not have the usual pink or pinkish brown colour.

The reason for this is unclear. Haematite dust may have been removed by washing or the concrete may have been made with low water:cement ratio, preventing dispersal of fine-grained haematite.

Aggregate Groups 1-6 (1-1)

Devonian Limestone

Plymouth



This concrete, from blockwork, is made with two aggregates that are often found blended in the Plymouth area.

The coarse aggregate is Devonian Limestone (lmst) with subordinate calcite haematite veinstones (chv). Its size range is between approximately 5 mm and 25 mm and it makes up about 75% of the aggregate total.

The fine aggregate is china clay waste made from quartz (qz) and subordinate tourmaline, kaolinised feldspar and micas. They occur as liberated grains and composite quartz - tourmaline veinstone and tourmalinised granite (tgr) fragments. The size range is between about 75 μ m and 10 mm. The use of gap-graded aggregates in blockwork is unusual.

Note that the cement does not have the characteristic pinkish colour normally associated with the use of this limestone aggregate.

Granite Hosted Mine Waste

Praa Sands



The aggregate in this concrete block is a granite-hosted ore processing waste. It is probably a heavy medium separation (HMS) reject from the former South Crofty Mine. However, the widespread occurrence of similar materials throughout the County suggests there may have been other sources of similar aggregate (there was definitely a block-making plant near St Ives that used this type of material, probably from Wheal Reeth).

The main components of the aggregate are tourmalinised and haematised granite (thg), quartz - tourmaline (qtv) and quartz haematite (qhv) veinstones and quartz (qz). Stable silicate minerals and iron oxides occur in minor amounts. Sulphide minerals are absent or present only in trace amounts.

There are no known problems associated with the use of this type of aggregate. Though it is clearly an ore processing waste, it is assigned to RICS Group 1-6.

Granite Hosted Mine Waste

St Ives



Hypothermal, endogranitic, lowsulphide or sulphide-free mining wastes were used as concrete aggregate in the St Ives and Camborne - Redruth areas. This aggregate, found only in St Ives, probably came from the former Wheal Reeth Mine.

It consists of coarse-grained, two-mica granite (gr), tourmalinised (tgr), chloritised (cgr) and haematised granite (hgr), quartz tourmaline and quartz - haematite veinstones (qhv), vein quartz, stable silicate minerals and iron oxides. Abundant haematite formed in response to low temperature, oxidative hydrothermal alteration. The aggregate is sulphide-free or carries only minute traces of pyrite.

Occasionally, the material was used alone as an all-in aggregate with a maximum size of 10 mm or 15 mm, though in concrete blocks it was usually blended with 10% to 15% of local beach sand.

There are no known problems associated with the use of this aggregate.

Granite Hosted Mine Waste

Camborne



Tailings from heavy medium separation (HMS) plant at the former South Crofty Mine, Pool, were used in West Cornwall until the mid-1970s. The aggregate is found mainly in mass concrete though blocks made with this material are found in Camborne, Pool and Redruth and occasionally much further afield, for example in Bodmin, Wadebridge and Camelford.

In blockwork the material is usually found as an all-in aggregate with maximum size of 10 mm to 15 mm. In mass concrete it is found as coarse aggregate in combination with fine tailings material or beach or dune sand.

This specimen is from blockwork. The main component is quartz (qz), from granite and veins. Characteristic materials are tourmalinised and haematised granite (thg), fine-grained quartz - tourmaline veinstones (qtv) and quartz - haematite veinstones. Liberated stable silicate minerals including tourmaline, muscovite and feldspar occur in minor amounts.

The HMS reject is a by-product of tin extraction from hypothermal endogranitic ores that occur below the levels of strong sulphide mineralisation. Consequently, the aggregate usually contains very low concentrations of sulphide minerals, typically less than 0.1%.

Sliming of haematite from altered granite and veinstones often gives the cement a characteristic pale to strong pink colour.

There are no recorded problems of concrete degradation associated with the use of this aggregate.

Tourmaline Hornfels Hosted Mine Waste Indian Queens



This concrete is made with tin mining waste from the metamorphic aureole overlying the western flank of the St Austell granite. The host rocks include finely banded quartz - tourmaline hornfels (qth), quartz - tourmaline veinstones (qtv) and vein quartz. Granite and quartz - haematite veinstones (qtt) occur in minor amounts. The mineralisation is characterised by extremely low sulphide mineral concentrations. Sulphides are very rarely found in the aggregate. Because the principal components are made from resistant tourmaline and quartz the aggregate is very stable. There are no recorded instances of aggregate-related degradation and for this reason it is classified as a group 1-6 material. Pervasive limonitisation of some veinstone fragments is the result of low temperature hydrothermal alteration or weathering before the concrete was made (note the absence of an iron oxide impregnation halo round the large limonitised quartz - tourmaline veinstone fragment).

Sometimes this aggregate is found in poorly-constructed mass concrete walls that show evidence of degradation related to cement recrystallisation and leaching. Chimney flues were often cast in the mass concrete and flue gas related degradation is very common in areas surrounding chimneys.

Granite Hosted Mine Waste

St Neot



It is uncertain if this aggregate is a mine waste from granite-hosted tin mineralisation or if it is quarried, slightly mineralised and weathered granite. The abundance of small granite-hosted tin mining operations in the neighbourhood of St Neot suggest it is a mine waste.

The main components of the aggregate are coarse-grained granite fragments (cgg), liberated feldspar (fs) and quartz grains (qz). Haematised granite (hg) and quartz tourmaline - haematite veinstones (qthv) are the other major components. There are no visible sulphide minerals. The granitehosted tin mineralisation in the neighbourhood of St Neot has extremely low sulphide concentrations.

This aggregate is rare. It has been found only in blockwork in St Neot. There is no evidence of accelerated degradation associated with its use.

Tywardreath

0 1 2 3 4 Centimetres 5 6 7 8 9 10

N atural highly vesicular, hyaline pumice has been imported into the United Kingdom as an aggregate for use in low strength thermal insulation blocks. It is probably from the Lipari Islands.

Concrete made with this aggregate is found occasionally throughout the region in nonloading bearing internal walls.

The aggregate is easily recognised by its white or pale grey colour, glassy texture and high vesicularity. It is usually found alone as an all-in aggregate with a size range between about 1 mm and 5 mm or 10 mm. Occasionally, it is blended with a small amount of fine, quartz-dominated china clay waste sand, suggesting that some pumice blocks were manufactured locally.

There are no known problems associated with the use of this material when it is used in appropriate circumstances.

Pumice

Aggregate Groups 1-1 2-1

China Clay Waste, Chert and Mudstone Launceston



I mpure chert and black mudstone aggregates from Lower Carbonifeous Meldon Chert and Slate Formations are found exclusively in Launceston. They are found in blockwork and mass concrete. The chert and mudstone were rarely used alone. It was blended with china clay waste, granite, dolerite, furnace clinker and various gravels. It is common to find three or even four aggregates from different sources in the same concrete.

This specimen is from blockwork. The main aggregate, making up about 70% of the total, consists of a mixture of black, impure chert (ch), dark grey mudstone (md) and occasional fragments of weathered, pale grey mudstone with limonite staining. Fragments of milky white vein quartz (vqz) occur in minor amounts.

The second aggregate is probably china clay waste consisting mainly of liberated, grey, glassy quartz grains (qz) with subordinate tourmaline, micas and kaolinised feldspar.

Both chert and mudstone aggregates sometimes contain substantial amounts of very fine-grained disseminated, often framboidal pyrite though this is nearly always too small for recognition with a low power stereomicroscope.

This concrete should be assigned to Class B under current RICS Guidelines because it contains more than 30% of Group 2-1 aggregate. Though this material appears completely sound there are problems of concrete deterioration associated with this material, especially when it is blended with furnace clinker. Oxidation of disseminated pyrite is presumed to be responsible for degradation.

Cleaved Mudstone, Beach Sand Wadebridge



The specimen is from mass concrete foundations of a house in Wadebridge. The concrete is uncommon and has been found only in a few properties in that area.

The coarse aggregate is a cleaved bluish grey mudstone (md) of local origin. It is uncertain if it is a quarried product or if it was merely won from shallow trenches made to accommodate the foundations. Its unweathered condition suggests it is probably a locally quarried product from Middle - Upper Devonian Slates.

The fine aggregate is a beach or dune sand dominated by calcareous shell fragments and quartz. Stable silicate minerals and iron oxides occur in minor amounts.

This specimen is from sound concrete but other material of similar composition has been found in a strongly degraded condition. In preliminary moisture sensitivity tests carried out at the Building Research Establishment a specimen of this concrete showed the largest unconstrained linear expansion of all the materials investigated. Expansion appears to be due to cleavage-parallel spalling of the mudstone aggregate. The reasons for degradation of the mudstone have not been investigated. It is not known if it contains fine-grained disseminated pyrite though mudstones from this area are often pervasively mineralised.

Note the dark brown colouration at the top, right-hand corner of the specimen. This is probably due to staining of the cement by humic acids in percolating groundwater.

High Sulphide Mine Waste

Redruth



This aggregate is typical of a range of high sulphide mine wastes that are responsible for most serious concrete degradation in the Camborne - Redruth area. It is a by-product of the hypothermal, exogranitic tin - copper - arsenic mineralisation in the area overlying the Carn Brea granite ridge. Similar materials were used as concrete aggregates in the St Day mineralised district.

This aggregate consists mainly of finegrained, chlorite-rich hornfels (ch), derived from basic igneous rocks, quartz - chlorite veinstones (qcv), subordinate quartz tourmaline veinstones (qtv), quartz haematite veinstones and vein quartz (qz). Some aggregates from this area contain pelitic hornfels rather than metamorphosed basic igneous rocks.

The main sulphide minerals are pyrite, arsenopyrite (asp) and chalcopyrite (cpy). Secondary copper sulphides (bornite, chalcocite, covellite) sometimes occur in subordinate amounts. The sulphide minerals occur as locked crystals in veinstones and as liberated grains in the cement matrix. Sulphide concentrations are often about 0.5% and sometimes exceed 1%. The large quartz - chlorite veinstone near the lower end of the specimen contains abundant partly oxidised chalcopyrite and arsenopyrite.

The deep reddish brown colour of the cement matrix is the result of sliming of haematite from the aggregate during handling or mixing of the concrete.

The degradation mechanism associated with this type of aggregate involves *in situ* sulphide oxidation and direct sulphate attack on the cement, often resulting in pore volume collapse and "crumbling" of the cement matrix.

Sulphide Bearing Mine Waste Redruth

This aggregate is an ore processing waste. It is a by-product from the mining and processing of exogranitic hypothermal tin - copper ore from the district to the north of the Carn Brea granite ridge.

The material consists mainly of finegrained chlorite-rich hornfels (ch), quartz chlorite veinstones (qcv), quartz - haematite veinstones (qhv) and vein quartz (qz). It carries only traces of sulphide minerals. The pinkish brown colour of the cement is the result of sliming of fine haematite from veinstones during handling or mixing of the concrete. In this specimen there is no obvious evidence of significant *in situ* aggregate alteration or degradation of the concrete. The transverse cracks are a result of damage during extraction of the core.

This type of material presents great difficulties in classification. It is a mining waste (Group 2-2), though most of the aggregate components are inherently stable and the sulphide content is low. There is an obvious temptation to reclassify the aggregate as a Group 1-6 material. However, it is possible to find all transitions between this aggregate and waste that has high sulphide mineral content and is known to promote accelerated concrete degradation. Until additional methods of assessing aggregate performance are available, the material should be assigned to Group 2-2.

High Sulphide Mine Waste

Camborne



Sulphide-rich mining and ore processing wastes are responsible for most aggregate-related concrete degradation in the Camborne and Redruth areas. This aggregate, from blockwork, is a typical byproduct of the processing of hypothermal, exogranitic tin - copper ores.

The main components in this aggregate are quartz - chlorite (qcv), quartz - tourmaline and quartz - haematite veinstones (qhv) and vein quartz (qz). The other components are fine-grained chloritic hornfels (ch), limonite (lm) and occasional fragments of furnace clinker (fc).

Sulphide minerals, including pyrite (py), chalcopyrite (cpy) and arsenopyrite (asp) occur as locked crystals in quartz - chlorite veinstones and as corroded, liberated grains in the cement matrix. The total residual sulphide content of this concrete is approximately 0.5% equivalent pyrite.

The reddish brown colour of the cement matrix is due largely to the presence of fine haematite dust eroded from veinstone fragments during handling or mixing. However, there has also been significant *in situ* aggregate oxidation. The large mass of earthy limonite near the upper left hand side of the plate has completely replaced the cement enclosing a strongly oxidised sulphide grain.

Though this concrete remains sound in bulk, in terms of RICS Guidelines it is definitely a Class B material.

Pelite Hosted Mine Waste

Camborne



Mining and ore processing wastes dominated by pelitic and chloriterich hornfels are common aggregates in the Camborne - Redruth area. They are derived from massive tin - copper mining operations along the northern flank of the Carn Brea granite ridge. Such aggregates are responsible for almost all general concrete degradation in Camborne, Redruth and nearby villages such as Portreath and Illogan. Similar aggregates from the St Day mineralised district are found in Truro and Falmouth.

Though all of these aggregates are considered potentially deleterious at the present time there is increasing evidence that some low sulphide, chloritic hornfelsdominated materials are probably very stable.

This aggregate, probably an ore processing waste, is made up from fine-grained pelitic hornfels (ph), fine-grained chlorite-rich hornfels, derived from fine-grained basic igneous rocks (ch), quartz - chlorite veinstones (qcv) and vein quartz (qz). Quartz - tourmaline and quartz - tourmaline - chlorite veinstones, fluorite, stable silicate minerals and iron oxides occur in minor amounts.

Pyrite, chalcopyrite and arsenopyrite are the main sulphide minerals. Secondary copper sulphides, including bornite, chalcocite and covellite are also found. Sulphide concentration varies between traces and about 0.5%, exceptionally they may reach 1%. Sulphide minerals normally occur as locked crystals in veinstones and occasionally as liberated grains. Fine, disseminated pyrite may also occur in pelitic and chloritic hornfels. This specimen has low sulphide mineral content though millimetre size arsenopyrite crystals (asp)

occur in some veinstone fragments. In the Camborne - Redruth area this type of mine waste aggregate is found alone in blockwork, usually with a maximum size of 10 mm to 20 mm, and in mass concrete. In mass concrete it is found in walls and foundations, either alone or in combination with furnace clinker, granite or various gravels. Some of the most serious concrete degradation in Camborne is found in mass concrete with very coarse, low fines aggregate of this general type.

Aggregate Groups 2-2 (2-2)

Tin - Copper Ore Mine Wastes Camborne



10

This is mass concrete made with gapgraded aggregates. Both aggregates are tin - copper mining/ore processing wastes from hypothermal tin mineralisation in the Camborne - Redruth area.

The main components of the coarse aggregate are fine-grained chlorie-rich hornfels (chh), derived from fine-grained basic igneous rocks, quartz - chlorite veinstones (qcv) and vein quartz. Pelitic hornfels, granite and haematite-rich veinstones (he) may also be present.

Sulphide minerals, including pyrite, arsenopyrite and chalcopyrite, occur in variable amounts in veinstones. It is usually difficult to estimate average sulphide abundances because they often occur in high concentrations in a small number of widely scattered veinstone fragments. Limonitic crusts are often developed round veinstone fragments carrying sulphide minerals that are too fine to be visible under a low power stereomicroscope.

The fine aggregate is probably from the same source materials. It consists of hornfels, veinstone and vein quartz fragments, together with stable silicate minerals, such as chlorite, muscovite and tourmaline, fluorite and iron oxides. Liberated sulphide minerals often occur in the fine aggregate. They may be unaltered or strongly corroded and replaced by iron oxides.

Tin - copper mine waste aggregates have very variable composition and sulphide mineral contents. Some appear to be stable while others are responsible for very

serious concrete degradation. Deterioration is mainly the result of *in situ* sulphide oxidation and direct sulphate attack on the cement. Degraded concrete often carries visible ettringite, thaumasite or gypsum at aggregate - cement interfaces, in voids and replacing the cement matrix.

Aggregate Groups 2-2 1-5

Pelite Hosted Mine Waste, River Sand Redruth



This concrete, with gap-graded aggregates, is from blockwork in a house at Redruth.

The coarse aggregate is a mine waste from hypothermal, exogranitic tin-copper mineralisation. It consists mainly of pelitic, often spotted hornfels (ph), quartz - chlorite veinstones (qcv) and vein quartz (qz). This material makes up about 60% of the aggregate total. Some aggregate fragments are pervasively limonitised (lm) and have limonitic crusts that merge into haloes of iron oxide impregnated cement. There are no visible sulphide minerals but this aggregate commonly carries pyrite, chalcopyrite and arsenopyrite, often in high concentrations, in a few scattered veinstone fragments.

The fine aggregate is a river sand and it is probably a by-product of alluvial tin extraction. It is very fine grained, with a maximum size of less than 1 mm, and is made up from quartz, stable silicate minerals and minor iron oxides. There are no liberated sulphide grains in the sand fraction.

The concrete appears sound in bulk but because it contains more than 30% potentially deleterious Group 2 aggregate it should be assigned to Class B under current RICS Guidelines.

Pelite Dominated Mine Waste Crowlas



In many villages to the southwest of Camborne a variety of pelite-hosted mine wastes were used as concrete aggregates. The wastes were probably from former copper and tin mines developed on lode systems that trend NE-SW between the Carnmenellis and Land's End granites.

The main components of this aggregate are dark bluish grey mudstones (md). Vein quartz (qz) and quartz - chlorite veinstones occur in subordinate amounts. Some aggregate fragments are strongly limonitised (lm) and some are enclosed by haloes of iron oxide-impregnated cement. The main sulphide minerals are pyrite, chalcopyrite and arsenopyrite (asp). These occur in veinstones and as liberated, partly oxidised grains in the cement matrix. Commonly, some mudstone fragments are from wallrock alteration zones and these may carry very fine-grained, disseminated pyrite that is too small to be seen under a low power stereomicroscope. Total sulphide mineral content varies considerably in this group of aggregates, probably because they are from several sources. The sulphide content of analysed specimens varies between less than 0.2% and more than 1%equivalent pyrite.

There are not enough examples of this aggregate to make generalisations about its performance. It composition demands that it is treated as potentially deleterious. Concrete containing this material should be assigned to Class B.

Pelite Hosted Mine Waste

St Hilary



This specimen is from blockwork in a house at St Hilary on the flank of the Tregonning - Godolphin granite. It is probably an ore processing waste from pelite hosted copper mineralisation.

The main components of the aggregate are low grade pelitic hornfels (ph) and vein quartz (qz). Quartz - chlorite veinstones, iron oxides and stable silicate minerals occur in minor amounts.

Sulphide minerals include pyrite, chalcopyrite, arsenopyrite, sphalerite and, less commonly, secondary copper sulphides. Galena, from later crosscourse mineralisation, is found occasionally. Sulphide mineral concentrations may be as high as 0.5%. The sulphides occur as locked crystals with vein quartz and veinstones and as liberated grains. Sometimes mudstones carry disseminated pyrite that is too small to be seen under a low power stereomicroscope. This specimen shows liberated arsenopyrite enclosed by a strong oxidation halo (asp) and several veinstone fragments with small clusters of arsenopyrite crystals. Note that many vein quartz, veinstone and hornfels fragments have limonitic crusts and haloes of oxide-impregnated cement, suggesting that the aggregate has suffered in situ alteration.

This type of aggregate is known to be responsible for several instances of accelerated general concrete degradation and it is known to have been used in a few instances during the late 1950s or early 1960s. Aggregate Groups 1-4 2-2

Furnace Clinker, Mine Waste

Goldsithney



This specimen is from the mass concrete foundations of a house in Goldstithney. Combinations of furnace clinker and complex mining wastes are common in this area. Mine wastes are derived from hypothermal tin - copper mineralisation that occurs on the western and eastern flanks of the Tregonning - Godolphin granite. Mixed aggregates are found occasionally in blockwork though they are much more common in mass concrete. The mine waste has variable and often high sulphide mineral content. In this specimen the furnace clinker aggregate consists of carbonaceous-vesicular clinker (cvc), hyaline and hypohyaline-vesicular clinker (hvc) and small amounts of partly burned coal. The mine waste is lithologically complex and includes quartz - chlorite - muscovite veinstones (qcmv), quartz - chlorite veinstones, vein quartz, fine-grained pelitic hornfels (ph), iron oxides and small amounts of stable silicate minerals among the finer size fractions. Note the iron oxide haloes that partly enclose some veinstone fragments, suggesting that the aggregate has undergone some *in situ* oxidation.

This type of concrete is very difficult to assess because of the lithological complexity of the mine waste aggregate, "nugget"-like distribution of sulphide minerals and erratic distribution of the aggregate components.

Classification by density determination is often unsatisfactory because abundant vesicular clinker reduces the overall density of the concrete. Materials that appear to be sound and have high cement:aggregate ratio may have densities considerably less than 2,000 kgm³.



Furnace Clinker, Mine Waste Praa Sands



This specimen is from the mass concrete foundations of a house in Praa Sands. The aggregate is a mixture of furnace clinker and pelite-hosted mine waste from exogranitic, hypothermal tin - copper mineralisation.

The clinker aggregate is made up from hypohyaline-vesicular (hvc), carbonaceous-vesicular (cvc) and laminated furnace clinker (lc) and small amounts of partly burned coal.

The mine waste aggregate consists of fine-grained pelitic hornfels, quartz - chlorite veinstones and vein quartz. The aggregate fragment in the middle of the plate shows a cluster of coarse arsenopyrite crystals (asp). The mine waste aggregate is slightly oxidised but the concrete has high cement:aggregate ratio and is clearly sound in bulk.

The concrete presents difficulties in classification under current RICS Guidelines because the mine waste aggregate makes up close to 30% of the aggregate total. The density of this material is only 1850 kgm³ because of the abundance of light vesicular clinker. Therefore the concrete should be assigned to Class B even though it is apparently sound and is perfectly adequate foundation material.

Rosudgeon



Mass concrete from the walls of a house in Rosudgeon, near Marazion. The all-in aggregate is a mining waste, probably from exogranitic copper - tin mineralisation on the western flank of the Tregonning - Godolphin granite.

The aggregate consists mainly of pale grey, low grade, pelitic hornfels (ph). Vein quartz (qz) and quartz - chlorite veinstones occur in minor amounts. The aggregate shows pervasive limonitisation. Many fragments have limonite-filled microcracks and crusts that merge into haloes of iron oxide impregnated cement. Though no sulphide minerals are visible in this specimen, the aggregate has pyrite and chalcopyrite in veinstones and vein quartz and some mudstone fragments carry fine-grained, disseminated pyrite. *In situ* oxidation of the aggregate is demonstrated by the presence of iron oxide impregnation haloes and the presence of gypsum (gy) around the margins of some aggregate fragments. The incipient crack (A-A) in the cement matrix may be the result of aggregate oxidation and expansion.

Though this concrete has high cement:aggregate ratio and its density is probably greater than 2000 kgm³ it cannot be classified by density determination because it forms the main walls of the property. In terms of current RICS Guidelines this is Class B concrete.



Truro



This specimen is from the mass concrete foundations of a house in Truro. The aggregate is probably a pelite-hosted mine waste from the St Day mineralised district though it contains no visible sulphide minerals and the quartz (qz) is probably from syntectonic veins rather than mineralised lodes. The aggregate is only slightly oxidised, there are only occasional, impersistent limonite rims on mudstone fragments and no iron oxide impregnation haloes in the cement. The concrete generally has high cement:aggregate ratio though there are some large, irregular voids that suggest restricted zones of high interconnected porosity.

This concrete has a density of 2180 kgm³. In view of the high cement:aggregate ratio, absence of sulphides and lack of any significant aggregate alteration of degradation of the cement this concrete should be assigned to Class AB (dense concrete) under current RICS Guidelines.





This specimen is from mass concrete foundations of a house in Truro. The coarse aggregate is probably a pelite-dominated mine waste from the St Day mineralised area though it carries only traces of sulphide minerals. The fine aggregate is a mixture of china clay waste and furnace clinker.

The coarse aggregate is poorly sorted and has a maximum size greater than 100 mm. It consists mainly of weathered pelitic hornfels with cleavage-parallel syntectonic quartz veins. The single fragment of quartz - chlorite veinstone (qcv) is also probably part of this aggregate. Oxidation of the coarse aggregate is probably the result of natural weathering (note the absence of an oxidation halo around the large fragment).

The fine aggregate consists of china clay waste dominated by quartz (qz) and hypohyaline-vesicular (hvc) and carbonaceous-vesicular (cvc) clinker and partly burned coal (pbc). The dull brownish grey colour of the cement is caused by fine clinker debris eroded from fragile carbonaceous clinker.

This concrete has a density of 2120 kgm³. Because of its high density, absence of significant *in situ* aggregate alteration or degradation of the cement the concrete was assigned to Class AB (dense concrete).

Pelite Hosted Mine Waste

Carnon Downs



The specimen is from mass concrete foundations of a house in Carnon Downs, between Truro and Falmouth. The aggregate is a coarse pelite-dominated mine waste, probably from the nearby St Day mineralised district.

The main components are low grade, often finely banded pelitic hornfels (ph), quartz - chlorite veinstones (qcv), vein quartz (qz) and haematised (he) and limonitised (lm) veinstones. The aggregate is strongly oxidised but this is probably the result of low temperature, oxidative hydrothermal alteration (haematisation) and weathering (limonitisation). The brown colour of the cement is due to sliming of fine iron oxides from the aggregate during handling and mixing.

The cement:aggregate ratio in this concrete is high and it has low macroporosity. There is no obvious evidence of significant *in situ* aggregate alteration or degradation of the cement. Its density is 2040 kgm³. Under current RICS Guidelines this material should be assigned to Class AB (dense concrete).



The coarse aggregate in this mass concrete from the foundations of a house in Falmouth is a pelitehosted mine waste. The main components are dark bluish grey pelitic hornfels (ph), quartz chlorite veinstones and vein quartz. Some veinstone fragments may be very rich in sulphide minerals. The veinstone in the middle of the plate is almost half arsenopyrite (asp). Sulphide minerals tend to be concentrated in a small number of widely dispersed aggregate fragments (the "nugget" effect) and the average sulphide mineral content of the concrete may be less than 0.5%. The second aggregate is crushed granite (gr), consisting of large composite fragments and smaller liberated grains of feldspar, quartz (qz) and subordinate muscovite, biotite, chlorite and tourmaline.

There is very little evidence of *in situ* alteration of the mine waste aggregate in spite of its high sulphide content. This is probably because of high cement:aggregate ratio and low permeability. Oxidation of some large granite aggregate fragments is due to natural weathering.

This concrete presents difficulties in classification under current RICS Guidelines. Sulphide-bearing mine waste makes up about 30% of the aggregate total. The density is 1980 kgm³, probably because of the abundance of light granite aggregate. If the Guidelines are strictly applied this material must be assigned to Class B, even though it is obviously sound.

Pelite Hosted Mine Waste

St Agnes



This specimen is from blockwork in a house at St Agnes. The aggregate is a pelite-dominated mine waste from hypothermal, exogranitic tin - copper mineralisation in the St Agnes - Perranporth district.

The main components are low grade pelitic hornfels (ph). Vein quartz (qz) and quartz tourmaline veinstones occur in minor amounts. There are no visible sulphide minerals in this specimen. However, many mudstone fragments have limonite crusts that merge into haloes of iron oxide impregnated cement. Locally, the cement is very friable and has been completely replaced by secondary iron oxides (lim). Many pelite fragments in this aggregate carry very fine-grained, disseminated pyrite that is too small to be recognised under a low power stereomicroscope. In situ oxidation of disseminated pyrite is responsible for cement degradation. Petrographic investigation showed abundant microcrystallne gypsum in the iron oxide impregnation haloes.

Note the abundance of neat cement masses (ncb), suggesting that the cement was slightly stale when the concrete was made.

The aggregate is clearly a Group 2 material. The concrete should be assigned to Class B, even though this specimen remains sound in bulk.
Pelite Dominated Mine Waste Perranporth



The specimen is from the mass concrete foundations of a house in Perranporth. It is a pelite-dominated, sulphide-bearing mine waste of local origin.

The main components are fine-grained, often spotted pelitic hornfels, quartz chlorite veinstones (qcv) and vein quartz (qz). Stable silicate minerals and liberated iron oxides occur in the finer size fractions.

This specimen shows locally abundant sulphide minerals, mainly chalcopyrite, in the large veinstone fragments (see detail below) and strongly oxidised pyrite in the large vein quartz fragment near the lower end of the specimen. Note strong iron oxide impregnation of the vein quartz and the limonitic haloes developed round this and other altered aggregate fragments.

The reddish-brown colour of the cement is due to disseminated iron oxide but it is uncertain to what extent this was slimed from aggregate that was already strongly oxidised when the concrete was made.

This material has high cement:aggregate ratio and, because it is from mass concrete foundations, it could be classified by density determination, provided it appears to be sound.



Pelite Hosted Mine Waste

Perranporth



This specimen is from the mass concrete foundations of a house near Perranporth. It is a strongly oxidised, pelite dominated mine waste that contains traces of strongly oxidised sulphide minerals.

It is an all-in aggregate. The main components are vein quartz (qz), strongly oxidised quartz - chlorite veinstones (qcv) and weathered pelitic hornfels (ph). The abundance of red iron oxide (haematite) suggests that oxidation was the result of low temperature hydrothermal alteration rather than weathering. The pinkish brown colour of the cement is due to the presence of very fine haematite dust eroded from veinstone aggregate during handling or mixing.

In spite of the strongly oxidised condition of the aggregate there is no obvious evidence of *in situ* alteration or degradation of the cement. The cement:aggregate ratio is high. The concrete has a density of 2050 kgm³ so it was assigned to Class AB (dense concrete).

Pelite Dominated Mine Waste St Agnes



This aggregate is characteristic of the St Agnes area. It is derived from pelitehosted tin - copper mineralisation that was widely exploited in the St Agnes area until the 1930s.

The main components are dark blue, often tourmalinised, pelitic hornfels (ph), quartz tourmaline veinstones (qtv) and vein quartz (qz). Stable silicate minerals occur in minor amounts in the finer size fractions. Though this specimen shows no visible sulphide minerals the aggregate is often strongly mineralised with pyrite and subordinate copper sulphides and arsenopyrite. Equivalent pyrite contents of 0.5 % have been recorded. Sulphides may occur as large crystals in veinstones, liberated grains in the cement matrix and, occasionally, disseminated in hornfels fragments.

Note, while no sulphide minerals are visible in the specimen some aggregate fragments are limonitised (lm) and enclosed by weak iron oxide-impregnation haloes (ha), suggesting that alteration has occurred in place.

The aggregate is found occasionally in blockwork (as in this example) but it is more common in mass concrete where it is either used alone or in combination with local beach sands.

Because the aggregate has only been found in a small number of properties it is difficult to assess its performance though in terms of RICS Guidelines it must be classified as a Group 2 material because of its composition. Aggregate Groups 2-2 (1-1)

Pelite Hosted Mine Waste

Perranporth



This specimen is from mass concrete foundations of a house in Perranporth. The coarse aggregate is a pelite-hosted mine waste. It makes up about 60% of the aggregate total. The fine aggregate is china clay waste. The coarse aggregate consists mainly of spotted pelitic hornfels (ph), and tourmalinised hornfels (th) with crosscutting quartz - chlorite - muscovite (greisen) veins. The aggregate is probably from exogranitic greisen-hosted tin mineralisation in the area between Perranporth and St Agnes. The aggregate is strongly oxidised but the absence of iron oxide impregnation haloes suggests that alteration occurred mainly before the concrete was made. The fine aggregate is made up mainly from liberated quartz (qz) with subordinate tourmaline, kaolinised feldspars and micas.

Though the concrete has some large, irregular voids the density of two specimens was 2310 kgm³ and 2320 kgm³ respectively. In view of the high density, absence of serious *in situ* aggregate alteration and the stability of the fine aggregate this specimen was assigned to Class AB (dense concrete).Note the strong colour difference between uncarbonated (pinkish grey) and carbonated (pinkish cream) cement in this specimen.

The next plate shows a specimen of the same concrete that contains part of a large placed block or "fig". Figs are large pieces of quarried stone, beach or river boulders or even older concrete or bricks that are placed in some mass concrete. They are not normally considered part of the aggregate for classification purposes and should be excluded from any specimens used for density determination.

Perranporth



Aggregate Groups 2-2 (1-1)

St Agnes



This is mass concrete from the foundations of a house in St Agnes. The coarse aggregate is a mine waste from exogranitic tin mineralisation in the area between St Agnes and Perranporth. The fine aggregate is china clay waste sand.

The coarse aggregate consists of fine-grained, strongly tourmalinised pelitic hornfels (ph) and quartz tourmaline veinstones (qtv). Some aggregate fragments show strong limonitisation and carry relict sulphide minerals (pyrite, arsenopyrite, chalcopyrite) though the absence of iron oxide-impregnation haloes in the cement suggests that the oxidation occurred before the concrete was made.

The fine aggregate consists mainly of liberated quartz (qz) with subordinate tourmaline, kaolinised feldspar and micas.

This concrete has a density of 2210 kgm³. Because it shows no obvious evidence of significant *in situ* aggregate alteration or degradation of the cement it was assigned to Class AB (dense concrete).

Lead Ore Processing Waste St Newlyn East



This well-known aggregate is found mainly in concrete blocks, especially in Perranporth and Newlyn East. It occurs occasionally in Newquay, Truro and surrounding villages.

The major components are cleaved, dark and pale grey mudstone (md), black pyritic mudstone and vein quartz (qz). The latter often contains abundant limonite (lm).

Minor components include quartz - chlorite (ch) and quartz - sericite veinstones and calcite.

Sulphide minerals include galena, pale brown sphalerite and pyrite in veinstones and as liberated grains. Very fine-grained disseminated pyrite occurs in dark mudstones but usually it is too fine-grained to be seen under a low power stereomicroscope. Residual sulphide mineral concentrations are commonly about 0.2%.

The aggregate is often strongly limoniteencrusted though it is not always clear whether this is a result of *in situ* oxidation or if it is a consequence of natural weathering before the concrete was made. Iron oxides are usually dispersed through the cement, giving a characteristic brown colour.

The material was generally used as all-in aggregate, graded between about 100 μ m and 5 mm or 10 mm, in concrete blocks. Similar material is occasionally found as coarse aggregate in mass concrete footings and foundations, in combination with fine aggregate from the same source, china clay waste or beach gravel.

The aggregate is responsible for most general concrete degradation in the

Perranporth area. Deterioration is believed to result from *in situ* oxidation of disseminated pyrite in mudstone fragments and bulk expansion of the aggregate. Direct sulphate attack on the cement has an insignificant role in degradation. Secondary sulphate minerals are rare.

Lead Ore Processing Waste Perranporth



The aggregate in this concrete block, from a house in Perranporth, is a lead ore processing waste, probably from East Wheal Rose Mine, near St Newlyn East.

It is made up from cleaved grey mudstone (md) and silicified mudstone (smd) from the Ladock Beds and vein quartz (qz). This aggregate is much less strongly oxidised than most East Wheal Rose material. Many mudstone fragments carry abundant very fine-grained, disseminated pyrite (py). Others have minute limonitic pseudomorphs after pyrite.

The degradation mechanism associated with this aggregate is believed to involve *in situ* oxidation of disseminated pyrite and bulk expansion of the mudstone aggregate, causing microcracking and loss of strength of the cement matrix.

Though all specimens of concrete from this property appeared sound the abundance of disseminated pyrite in mudstone aggregate indicates that it has potential for general accelerated degradation.



This concrete is from the foundations of a house in Perranporth. The aggregate is a lead mining waste, probably from East Wheal Rose, near St Newlyn East. It consists of mudstones (md), vein quartz (qz), quartz - chlorite veinstones (qcv) and abundant limonitic iron oxides. Partly oxidised galena (ga) occurs in some of the veinstones. The aggregate has suffered severe oxidation and the presence of limonitic crusts on many aggregate fragments, iron oxide impregnation haloes and soft, granular cement (lower left of specimen) suggest that at least part of the degradation has occurred in place.

Generally the concrete has high cement:aggregate ratio though there are some large, irregular voids. Its density is 2030 kgm³. The aggregate is known to be responsible for general concrete degradation, especially in blockwork. In view of this, and the obvious evidence of *in situ* aggregate alteration and cement degradation the concrete was subjected to detailed petrographic study. This revealed substantial aggregate-related degradation and suggested potential for further deterioration. It was assigned to Class B in spite of having a density > 2000 kgm³.

Pelite Hosted Mine Waste

Perranporth



This specimen is from the same mass concrete as that shown in the previous plate. Its density is 2050 kgm³. The aggregate is lead ore mining waste made up from mudstone (md), vein quartz (qz) and strongly oxidised quartz - chlorite veinstones (qcv) with very strongly oxidised sulphide minerals. Many fragments have complete or partial limonitic crusts that merge into haloes of iron oxide-impregnated cement and locally the cement has been completely replaced by structureless limonite (lcr).

Petrographic study showed that many mudstone fragments contained very fine-grained, disseminated pyrite, too small to be visible under a low power stereomicroscope, ettringite replacement of the cement matrix and microcracks that are crudely radial to large oxidised aggregate fragments. The specimen was assigned to Class B even though its density is > 2000 kgm³.

Pelite Hosted Mine Waste Newmill, near Truro



The waste tips from an ancient silver lead mine at Garras, near Truro, were a source of aggregate for concrete blocks and mass concrete used in a few villages northwest of Truro. The host rocks are grey mudstones (md) of the Ladock Beds and the mineralisation occurred in quartz veins (qz). Many mudstone fragments are bleached and limonitised though this is largely due to natural weathering in waste heaps before the concrete was made. In this specimen there are no iron oxide impregnation haloes around the weathered aggregate fragments.

The aggregate usually has low sulphide mineral content. There are traces of galena (ga), sphalerite and pyrite in veinstones and some mudstone fragments have very finegrained, disseminated pyrite that is too small to be recognised under a low power stereomicroscope.

Because the aggregate is rare there is little information about its performance. This concrete appears sound though there is one well-documented case of serious general degradation associated with its use in concrete blocks. It should be classified as a Group 2-2 material.



The aggregate is a pelite-hosted mine waste from mass concrete walls of a house at Charlestown. It is uncertain if it is an all-in aggregate or if separate coarse and fine aggregates are present. However, all of the material is from a similar source, probably former copper mines that worked lodes to the east of the St Austell granite.

The aggregate consists of low-grade pelitic hornfels (ph), quartz - chlorite veinstones (qcv) and vein quartz (qz). The aggregate is very strongly oxidised. Many veinstone fragments contain abundant sulphide minerals, including chalcopyrite, arsenopyrite (asp) and pyrite, though these are generally fine-grained and not easily recognised under a low power stereomicroscope. Partly corroded, liberated sulphide grains also occur in the fine aggregate. The aggregate is very strongly oxidised.

Detailed petrographic study showed strong aggregate-related degradation of the cement including growth of ettringite, strong iron oxide impregnation and microcracking. The concrete was assigned to Class B on the basis of aggregate composition, high sulphide content and aggregate-related degradation. The property showed polygonal cracking in the cement render that was plausibly related to degradation and expansion of the underlying concrete. The partially open vertical crack on the left side of the specimen is possibly a consequence of aggregate-related degradation.

Pelite Hosted Mine Waste

Callington



This specimen is from the mass concrete walls of a house in Callington. The aggregate is a pelite-hosted mine waste of uncertain provenance. Coarse material like this is unlikely to have been transported very far but its lithology (cleaved, unmetamorphosed mudstones and vein quartz) suggests mesothermal silver - lead zinc mineralisation rather than the hypothermal tin - copper mineralisation that charcterises the area immediately round Callington.

The absence of fluorite shows clearly that it is not the Wheal Mary Anne aggregate, even though concrete blocks made with that material are common in Callington.

The main components of this material are cleaved grey mudstones (md), some of which have disseminated pyrite crystals and cleavage-parallel veinlets (py), and vein quartz (qz). Many fragments are pervasively limonitised and have limonitic crusts that merge into narrow haloes of iron oxide-impregnated cement.

In spite of the *in situ* aggregate alteration the concrete appears sound and it has high cement:aggregate ratio. Its density is probably greater than 2000 kgm³ but because it is from the main walls of the house it cannot be classified on the basis of its density. The aggregate composition demands that the concrete is assigned to RICS Class B.

Liskeard



The source of this deleterious aggregate has been traced to a block making plant located at the former Wheal Mary Anne Mine, near Menheniot. The plant is still recognizable though the site is now used for other industrial purposes.

The condition of concrete made with this aggregate is very variable. Identical blocks in some properties remain completely sound while in others they have degraded to a condition where demolition has been necessary. Concrete made with this aggregate generally has a low sulphide mineral content, typically < 0.5% pyrite equivalent. Most of the pyrite is present as very finely disseminated grains in mudstone wallrocks and is not visible under the stereomicroscope. Mudstone wallrocks commonly make up < 30% of the aggregate. It is possible, by strict application of the RICS Guidelines, that concrete made with this aggregate could be assigned to Class AB.

The principal components of the Wheal Mary Anne aggregate are cleaved grey mudstones (md), dark grey pyritic mudstones, vein quartz (qz) and colourless and pale yellow fluorite (fl).

Minor components include limonite (lm) chalcedonic quartz (cq), calcite, siderite and barite.

Sulphide minerals are pyrite, galena, minor chalcopyrite and sphalerite (in veinstones), and fine-grained disseminated, commonly framboidal pyrite (in mudstone). Total sulphide mineral concentrations are generally < 0.5%.

The aggregate is angular and graded between approximately 100 μ m and 10 mm or 15 mm. It was used mainly as single source all-in aggregate but occasionally it is found blended with about 20% of picrite from the nearby Clicker Tor Quarry or with medium-grained dolerite.

Lead Ore Processing Waste Lower Tremar



This is the well-known lead ore processing waste aggregate from Wheal Mary Anne Mine at Menheniot. This aggregate is responsible for most general accelerated concrete degradation in East Cornwall.

The aggregate has very uniform composition but the performance of concrete made with the material is extremely variable. In some instances it has degraded so badly that properties have had to be demolished. Elsewhere, it has remained in extremely good condition with no evidence of significant aggregate alteration or deterioration of the concrete.

This example is from a property at Lower Tremar, near Liskeard. The property shows no external evidence of concrete degradation and all specimens appeared completely sound when recovered.

The aggregate components are grey mudstone (md), vein quartz (qz) and fluorite (fl). There are trace amounts of ankerite and barite though these are not often recognised under the low power stereomicroscope.

Sulphide minerals are galena and pyrite. They occur as locked crystals in vein quartz and fluorite and occasionally as liberated grains. Pyrite also occurs as fine, disseminated crystals in mudstone wall rock but these are very fine-grained and they are rarely recognised under the stereomicroscope. Total sulphide mineral content is usually less than 0.25%.

Some aggregate fragments in this specimen show patchy pervasive limonitisation and have partial limonitic crusts. There are no iron oxide impregnation haloes in the cement and it is likely that the iron oxides formed as a result of natural weathering.

Lead Ore Processing Waste

West Looe



The lead ore processing waste from Wheal Mary Anne Mine, Menheniot, is usually found in blockwork. Occasionally, coarse waste is found in mass concrete foundations. This example is from the foundations of a house in West Looe.

The aggregate is made up from cleaved grey mudstone (md), vein quartz (qz) and fluorite (fl). Limonite, ankerite and barite are found in minor amounts. In this specimen the two large fragments of slightly oxidised mudstone contain several stringers of disseminated pyrite crystals (py). Galena (ga) occurs in some vein quartz and as occasional liberated grains.

The degradation mechanism associated with this aggregate involves *in situ* oxidation of pyrite disseminated pyrite in mudstone fragments and bulk expansion of the aggregate, causing rupturing of aggregate cement bonds and general cracking in the concrete. Direct sulphate attack on the cement is of secondary importance though this specimen shows some secondary ettringite (et) in voids just below the mortar render. The diagonal crack (A-A) may be the result of pyrite oxidation and expansion of the mudstone aggregate.

Lead Ore Processing Waste

West Looe



The aggregate in this concrete is lead ore processing waste from Wheal Mary Anne Mine, Menheniot. It differs from most Wheal Mary Anne aggregate in that it has much lower mudstone content, typically about 25%, and significantly more galena. It may have been produced from a different ore type or its composition may be due to a different beneficiation process. Generally, concrete blocks made with this aggregate are found sporadically among those made with the more common mudstone-rich waste.

In this specimen the main components are vein quartz (qz), fluorite (fl) and dark grey mudstone (md). Some fragments are limonitised (lm) but this is probably the result of natural weathering. Galena (ga) is abundant as coarse crystals locked in veinstones and as liberated grains. Some of the mudstone fragments carry disseminated pyrite though this is too fine-grained to be recognised under a low power stereomicroscope.

This concrete appears to be completely sound. Because concrete blocks made with this material are only found occasionally, their performance has not been assessed. The aggregate should be considered potentially deleterious because of its provenance and the deleterious properties of related, more mudstone-rich materials.



During the 1920s and 1930s a small electricity generating plant in Falmouth used commercial and domestic wastes blended with coal in its furnaces. The furnace clinker was used as concrete aggregate in blockwork and mass concrete in a small area of Falmouth. There are several well-documented cases of severe concrete degradation associated with the use of this material.

The aggregate is usually poorly-graded. In addition to the normal products of coal burning, hypohyaline-vesicular (hvc) and carbonaceous clinker and partly burned coal (pbc), the aggregate contains broken glass and ceramic materials (cer), ferrous and nonferrous scrap and abundant partly calcined sea shells (shell fish were an important component of the local diet). Degradation is believed to be associated with:

- (i) expansion of incompletely burned coal
- (ii) hydration of lime in clinker
- (iii) rehydration, carbonation and expansion of partly calcined sea shells
- (iv) expansion and cracking of partly devitrified synthetic glass, and
- (v) oxidation and expansion of ferrous scrap.

The incinerator waste aggregate often contains rock and mineral fragments, including granite and veinstones (vs) but it is uncertain if these were deliberately blended or if they are accidental contaminants.

The aggregate is recognised by poor grading and the presence of chalk white, partly calcined sea shell fragments, glass and ceramics and metallic scrap. It is now classified as a Group 2-3 material under RICS Guidelines.

Multiple Render Layers Falmouth



This specimen shows multiple render layers overlying concrete blockwork made with incinerator waste aggregate. It is from the wall of a house in Falmouth.

The aggregates in the render layers are:

- 4 metadolerite (Lizard)
- 3 china clay waste
- 2 china clay waste
- 1 pelite-hosted mine waste.

Multiple render layers are sometimes an indication of degradation and expansion of the underlying concrete and reflect attempts to effect local repairs.

In this case the concrete blocks showed evidence of aggregate alteration and expansion and general degradation of the concrete. The original render (layer 1) is made with sulphide-bearing mine waste and may have undergone degradation independently.

Note the discontinuous, open crack (now filled with resin) between layers 1 and 2.

4 AGGREGATE DISTRIBUTION MAPS























5 REFERENCES



5 References

Bang, B.S., Framboidal pyrite and associated organic matrices, a risky composite for preservation of fossils. In Kejser, U.B. (ed.), Surface treatment: Cleaning, Stabilisation and Coatings, Pre-print, Copenhagen, September, 1994 Nordic group, Danish section, XIII Congress, Copenhagen, pp. 7-11.

Bromley, A.V. and Pettifer, K., Sulfide-related degradation of concrete in Southwest England. CRC Ltd., London, 1997, 200 pp.

Bromley, A.V. and Sibbick, R.G., The accelerated degradation of concrete in Southwest England. Proceedings of the 7th Euroseminar on Microscopy Applied to Building Materials, Delft University of Technology, Delft, The Netherlands, 1999, pp. 81-90.

Caruccio, F.T., Trace element distribution in reactive and inert pyrite. Proceedings of the 4th symposium on coal mine drainage, Pittsburgh, 1972, pp. 48-54.

Howie, F.M.P., Physical conservation of fossils in existing collections. Newsletter of the Geological Curators' Group, **2**, 1979, pp. 269-280.

Howie, F.M.P., Pyrite and marcasite. In Howie, F.M.P. (ed), The care and conservation of geological material, minerals, rocks, meteorites and lunar finds. Butterworth-Heinemann, Oxford, 1992, pp. 70-84.

Jorgensen, B.B., in Microbial Geochemistry, Krumbein, W.E. (ed), Blackwell, Oxford, 1983, p.91.

Khawaja, I.U., Pyrite in the Springfield coal member (V), Pittsburgh Formation, Sullivan County, Indiana. Special Report No. 9, Geological Survey, Indiana, 1975, pp. 1-19.

Kim, H.A.W., Vapour phase oxidation of pyrite. Unpublished M.Sc. Thesis, Ohio State University, 1964.

Lane, S.J., Sibbick, R.G. and Bromley, A.V., The application of microscopy and moisture sensitivity testing to the expansive 'mundic' concrete block problem in Southwest England. Proceedings of the 7th Euroseminar on Microscopy Applied to Building Materials, Delft University of Technology, Delft, The Netherlands, 1999, pp. 557-566.

Lundgren, D.G. and Dean, W., in Biogeochemical Cycling of Mineral Forming Elements, Trudinger, P.A. and Swaine, D.J. (eds.), Elsevier, Amsterdam, 1979, 211 pp.

Morth, A.H. and Smith, E.E., Kinetics of the sulphide to sulphate reaction. American Chemical Society, Division of Fuel Chemistry, Pre-prints 10(1), 1966, pp. 83-92.

Newman, A., Pyrite oxidation and museum collections: a review of theory and conservation treatments. The Geological Curator, 6(10), 1998, pp. 363-371.

Peters, E., Electrochemical mechanisms for decomposing sulphide minerals. Proceedings of the Electrochemical Society, 84, 1984, pp. 343-361.

Pugh, C.E., Hossner, L.R. and Dixon, J.B., Oxidation rate of iron sulphides as affected by surface area, morphology, oxygen concentration and automorphic bacteria. Soil Science, 137(5), 1984, pp. 309-314.

Rust, G.W., Colloidal primary copper ores at Cornwall Mines, Southeastern Missouri. Journal of Geology, 43, 1935, pp. 398-426.

Royal Institution of Chartered Surveyors. The '*Mundic*' Problem - A Guidance Note. 2nd Edition. RICS Books, London, 1997, 40 pp.

Smith, E.E. and Schumate, K.S., The sulphate to sulphide reaction mechanism. Water Pollution Control, Research Series, Ohio State University Research Foundation, Columbus, Ohio, 1970, 129 pp.

Waller, R., An experimental ammonia gas treatment method for oxidised pyrite mineral specimens. Triennial Report. ICOM Committee for Conservation, 1987, pp. 623-630.

Wilkin, R.T. and Barnes, H.L., Formational processes of framboidal pyrite. Geochimica et Cosmochimica Acta, 61, 1997, pp. 323-339.

Williams, P.A., Oxide Zone Geochemistry. Ellis Horwood, London, 1990, 286 pp.