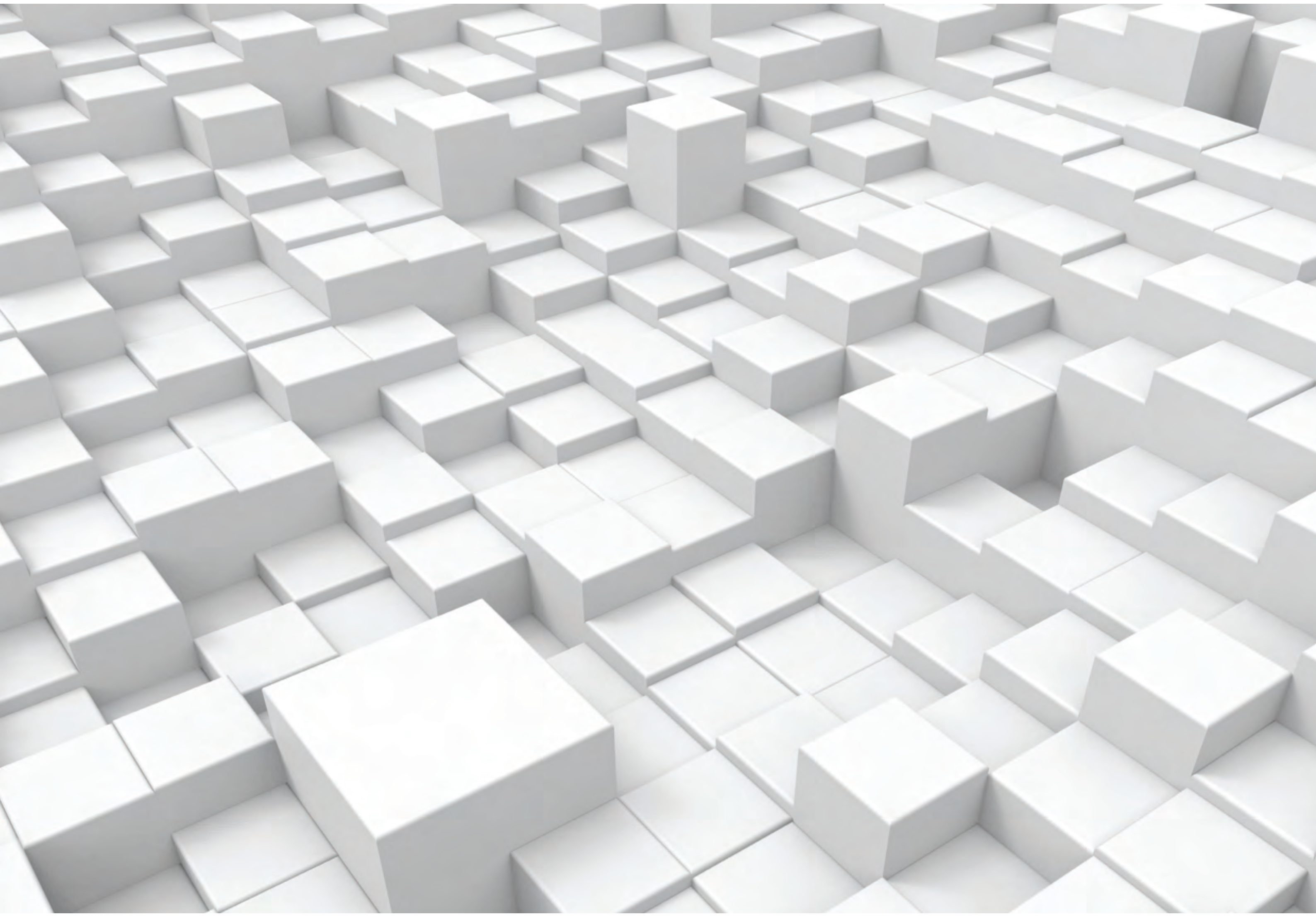
RICS guidance note

RICS

RICS Professional Guidance, UK

The mundic problem

3rd edition



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Contents

RICS guidance notes

International standards

RICS is at the forefront of developing international standards, working in coalitions with organisations around the world, acting in the public interest to raise standards and increase transparency within markets. International Property Measurement Standards (IPMS – ipmsc.org), International Construction Measurement Standards (ICMS), International Ethics Standards (IES) and others will be published and will be mandatory for RICS members. This guidance note links directly to these standards and underpins them. RICS members are advised to make themselves aware of the international standards (see www.rics.org) and the overarching principles with which this guidance note complies. Members of RICS are uniquely placed in the market by being trained, qualified and regulated by working to international standards and complying with this guidance note.

RICS guidance notes

This is a guidance note. Where recommendations are made for specific professional tasks, these are intended to represent 'best practice', i.e. recommendations that in the opinion of RICS meet a high standard of professional competence.

Although members are not required to follow the recommendations contained in the guidance note, they should take into account the following points.

When an allegation of professional negligence is made against a surveyor, a court or tribunal may take account of the contents of any relevant guidance notes published by RICS in deciding whether or not the member acted with reasonable competence.

In the opinion of RICS, a member conforming to the practices recommended in this guidance note should have at least a partial defence to an allegation of negligence if they have followed those practices. However, members have the responsibility of deciding when it is inappropriate to follow the guidance

It is for each member to decide on the appropriate procedure to follow in any professional task. However, where members do not comply with the practice recommended in this guidance note, they should do so only for good reason. In the event of a legal dispute, a court or tribunal may require them to explain why they decided not to adopt the recommended practice.

Also, if members have not followed this guidance, and their actions are questioned in an RICS disciplinary case, they will be asked to explain the actions they did take and this may be taken into account by the Panel.

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In addition, guidance notes are relevant to professional competence in that each member should be up to date and should have knowledge of guidance notes within a reasonable time of their coming into effect.

This guidance note is believed to reflect case law and legislation applicable at its date of publication. It is the member's responsibility to establish if any changes in case law or legislation after the publication date have an impact on the guidance or information in this document.

Document status defined

RICS produces a range of professional guidance and standards products. These have been defined in the table below. This document is a guidance note.

Type of document	Definition	Status
Standard		
International standard	An international high-level principle-based standard developed in collaboration with other relevant bodies.	Mandatory
Practice statement		
RICS practice statement	A document that provides members with mandatory requirements or a rule that a member or firm is expected to adhere to. This term encompasses practice statements, Red Book professional standards, global valuation practice statements, regulatory rules, RICS Rules of Conduct and government codes of practice.	Mandatory
Guidance		
RICS code of practice	Document approved by RICS, and endorsed by another professional body/stakeholder, that provides users with recommendations for accepted good practice as followed by conscientious practitioners.	Mandatory or recommended good practice (will be confirmed in the document itself).
RICS guidance note (GN)	Document that provides users with recommendations or approach for accepted good practice as followed by competent and conscientious practitioners.	Recommended best practice. Usual principles apply in cases of negligence if best practice is not followed.
RICS information paper (IP)	Practice-based document that provides users with the latest technical information, knowledge or common findings from regulatory reviews.	Information and/or recommended good practice. Usual principles apply in cases of negligence if technical information is known in the market.

Preface to the third edition

This new edition of the RICS guidance note has been issued to clarify a number of developments in the testing of concrete samples for evidence of mundic. It also provides a rationale for the classification of samples to help lenders distinguish between those properties accepted as mortgageable and those that are not.

It imparts clearer guidance on the conduct of surveying practice, including the custody of samples, and records a number of minor changes in petrographers' testing regimes. It also includes new guidance on the assessment of mass concrete by testing density.

In addition, this edition records the consolidation of the various test processes that were developed and introduced as a consequence of research by the Building Research Establishment (BRE) and others following the second edition of the guidance.

The mundic testing process is now well established and understood in the affected region. It is hoped that this edition will pave the way for a third-party database that will eventually eliminate the unnecessary re-testing of properties previously identified as 'not at risk'.

It is expected that a suitable database will facilitate mortgage lending by recording the results of samples tested under the guidance. As test results are progressively registered on the database, it is anticipated that the current delays and costs associated with mundic will be significantly reduced for the majority of affected homeowners and purchasers.

This third edition of the guidance replaces the second edition with effect from **1 January 2016**.

Please note this version is a reissue of the guidance note first published in March 2015. The main focus of the changes relate to suggested sampling options contained in Annex B3.

1 The mundic problem

1.1 Background

1.1.1 'Mundic' is a Cornish word used to describe the disulphide mineral of iron generally known as pyrite or iron pyrites (FeS_2). However, the term is now widely used to describe a cause of deterioration in concrete resulting from the decomposition of various aggregate mineral constituents, of which iron pyrites is but one.

1.1.2 The term 'mundic' should primarily be applied to concrete problems where sulphides and the products of sulphide decomposition can be identified by petrographic means; mundic degradation is not to be confused with 'concrete cancer' (alkali-aggregate reaction) or other forms of concrete degradation. It should be noted, however, that the Cornwall and Devon region is not unique in having problems with concrete products where sulphide minerals have been present in the aggregates.

1.1.3 This publication aims to explain the mundic problem that results in the deterioration of the physical strength of concrete building materials. It also details a recommended sampling and testing procedure to identify the condition of the aggregate in domestic and small commercial properties built mainly prior to 1950 (or 1965 for parts of east Cornwall). It also describes the recommended procedure for sample extraction and aggregate assessment that has developed from current working knowledge of the subject.

1.1.4 This publication has been compiled from the scientific experience of several petrographers and the practical knowledge of local surveyors. It is directed mainly at surveyors, structural engineers and petrographers who undertake this type of work, and offers guidance on the survey and laboratory techniques recommended for sampling, identifying and reporting. The BRE, in conjunction with Sandberg LLP and STATS Limited (now RSK Environment Ltd), the Camborne School of Mines and the working group, have assembled the format and grouping of a known range of aggregates.

1.1.5 As various improvements in the processes of mundic testing have developed following the second edition, these have been included here. This edition also provides a structure for the future testing of concrete samples to ensure an improved, consistent rationale for classifying these materials. Once a property has been identified as 'not at risk' and all test results can be recorded in an independent database, it will no longer be necessary to reassign reports to lenders or to re-test such properties when the previous tester ceases practising.

1.2 Application

1.2.1 When the guidance was first introduced in 1994, it applied to the whole of Cornwall and Devon. Further investigation, along with the outcome of examinations undertaken in accordance with guidance procedures, has led to the conclusion that the area of routine application should be reduced. Since the second edition, the area of routine testing has been defined as including the whole of Cornwall and the areas of Devon indicated on the map in Figure 1, but not excluding properties outside these areas where there are visual or other signs that suggest the possibility of mundic-related deterioration.

1.2.2 Material published since the second edition supports this assessment; therefore, the guidance will continue to apply to the whole of Cornwall and the area of Devon within a 15km radius of the centre of the Tavistock-Gunnislake mineralised district.

1.2.3 The areas of Devon in which mining wastes might have been used as concrete aggregate continue to be much more limited, therefore routine application of the guidance throughout Devon remains inappropriate. Areas in Devon where mining is known to have taken place are indicated on the map (Figure 1). Local practitioners should continue to exercise caution in these localities, and to use their local knowledge and established best practice to judge whether a test may be necessary (see section 1.6.2).

Figure 1: The dotted line on the map shows the approximate area of Devon where it is recommended routine testing be conducted. The dark bands indicate approximate areas of metalliferous mining in Devon; testing in and around such areas is recommended for properties displaying mundic-related deterioration

1.3 The development of mundic testing

1.3.1 In the early part of the 20th century, before standards were laid down for the quality of aggregates in concrete, it appears that many builders were making their own blocks and mass concrete from readily available aggregates. The history of mining in Cornwall and Devon has meant that vast quantities of mining spoil and processing waste throughout the county were frequently used as a source of aggregate for concrete.

1.3.2 When mundic deterioration occurs, it is necessary for affected building elements to be replaced and, in severe cases, for whole properties to be demolished. Usually, the presence of mundic cannot be reliably identified visually, and a building may show no obvious signs of distress until the deterioration is well advanced.

1.3.3 The wider implications of this problem became apparent during the mid-1980s. In 1985, the Cornwall area of the RICS Devon and Cornwall branch formed a steering committee to investigate the subject. The committee quickly identified the need to understand the actual mechanism causing the breakdown and the range of suspected deleterious materials. The Camborne School of Mines, which has a wide knowledge of the local geology, developed theories regarding the recognised instability in certain types of concrete and has provided a valuable source of information for local surveyors.

1.3.4 The BRE has also contributed to the predictive testing of concrete thought to be potentially unstable by developing long-term performance testing (Stage 3) to assist in the reclassification of some concretes identified by initial Stage 1 and Stage 2 testing as currently sound, but potentially unstable in the future.

1.3.5 Since 1992, understanding of the processes that can take place within concrete has significantly improved, where chemical deterioration of aggregates can occur in the presence of oxygen (from the air) and moisture, which interacts with the aggregate rock to form secondary minerals. These effects appear not to be solely related to the decomposition of sulphide minerals to form metal oxides and sulphates that react with the cement-paste bonding of the aggregate particles, but can also include water-related swelling and shrinkage of clay-type minerals that are present in locally available, fine-grained sedimentary and meta-sedimentary rocks (often referred to in Cornwall as 'killas'). A comprehensive overview of the many materials and combinations of materials that have been identified and classified can be found in *A compendium of concrete aggregates used in Southwest England* (Bromley, 2002).[1]

1.3.6 The deterioration of such aggregates within concrete products leads to problems with the structural integrity of the property due to a weakening of load-bearing and non-load-bearing walls. This could also affect other parts of the structure, e.g. window lintels, sills, beams and concrete work in foundations and solid-floor construction, which may require additional assessment if the structural evidence suggests this would be appropriate.

1.3.7 The testing regime to which samples are submitted has developed since the first introduction of the guidance in 1994. In 1997, the second edition recommended a method of petrographic assessment, confident that the main problems of mundic were then understood; these recommendations have essentially stood the test of time.

1.3.8 Typically, samples are subjected to Stage 1 testing, which is a visual test of the sample to determine whether the concrete is sound or unsound, and what types of aggregates are present. Aggregates are defined as either 'stable' (Group 1) or 'potentially deleterious' (Group 2). The identification of Group 2 aggregates is key to the classification of the samples.

1.3.9 Where Group 2 aggregates are present in visually sound concrete, it is recommended that further detailed analysis (Stage 2 testing) be carried out before classification can be made.

1.3.10 In the last decade BRE concluded research leading to the introduction of a Stage 3 test to predict the long-term stability of Class B (see section 1.5) concrete blocks containing Group 2 aggregates. The Stage 3 test procedure involves the measurement of the expansion of concrete cores during long-term (e.g. a minimum of 250 days) exposure to a water-saturated atmosphere at a constant temperature (see section 4).

1.4 Revised mundic classifications

1.4.1 This edition of the guidance introduces revisions to the classification of concrete samples to reflect the needs of property owners and lenders, and to define more clearly the classifications of properties that are mortgageable. This is described in more detail in section 1.5, but briefly, the samples from mortgageable properties will all be classified as A, with a subscript to indicate the testing stage at which the classification was determined.

As new tests are carried out, the concrete classifications A_1, A_2 and A_3 will be used to define mortgageable properties, while concrete Classes B and C will define properties that remain unmortgageable. Existing tests and reports with original classifications will remain valid. When existing reports are assigned or updated, the equivalent revised classifications can be explained in a covering letter, but there is absolutely no requirement to repeat a test or to retype a report simply to provide a version with the revised classification.

1.4.2 When the second edition of this guidance was published, experience of the revised procedures was limited. As there was still some uncertainty concerning the direction of future research, the guidance recommended a standard procedure to consider re-testing after six years had elapsed following the previous test. A legal assignment of a test was also required on change of ownership or registration of new charges against the property. This also included properties with Class A results, although the second edition did state that ‘It is not expected that further sampling or laboratory testing will be required in respect of samples originally identified as Class A by Stage 1 examination’ (Annex B, 9(b)).

1.4.3 Over the past few years, homeowners have increasingly encountered problems when an assignment of a satisfactory existing test is required, but the original tester has ceased practising. Understandably, no other practice will accept responsibility for a test undertaken by a different practitioner, and therefore the terms of the second edition have meant that a new test was needed to obtain mortgage finance. It is not unknown for properties to have been subjected to three successive tests over the past 15 years, despite each in turn confirming the Class A test results that show there is absolutely no possibility of the property ever being affected by mundic deterioration. It is hoped that this edition will lead to developments that will eliminate any unnecessary repetition of tests.

1.4.4 It has been estimated that since 1997, some 30,000 tests have been conducted. Analysis of 12,000 of these tests showed that over 80% of properties were found to have Class A samples. Class A samples (which are now A_1; see subsection 1.5.2) can never deteriorate due to mundic because, by definition, they contain no form of aggregate that is susceptible to this condition. A further 5% of the samples were classified as A/B (these are now reclassified as A_2; see section 1.5.2). Although an A/B classification describes samples that could potentially be affected by mundic deterioration, there have, in fact, been no recorded cases of any property with Class A/B samples suffering deterioration or requiring reclassification as Class B since the second edition of the guidance was published in 1997.

1.4.5 After due consideration, the mundic petrographers have confirmed to RICS, and the valuation panels of the Council of Mortgage Lenders (CML) and Building Societies Association (BSA), that there is no longer any scientific justification for repeating satisfactory tests that were completed in accordance with the second edition of the guidance or any subsequent amendments.

1.4.6 This edition therefore anticipates the development and introduction of an independently managed database of test results, intended primarily for lenders to use when seeking confirmation that a property has been tested for mundic and the samples have been classified as mortgageable A_1, A_2 or A_3. This will make it unnecessary for them to obtain formal legal assignments of previous mundic tests. It is expected that this will result in a significant saving of time and expense during sales and remortgages – especially in cases where the original mundic tester is no longer practising and a new test would otherwise need to be commissioned before a mortgage could be granted.

1.4.7 Although lenders may be able to make an acceptable business decision based on the assessment of risk from the information in the database, when lending to homeowners, the latter should be cautioned that an assignment of previous mundic test documentation will still be required when a property is purchased in order to establish a legal relationship and liability between the original tester and the new owner.

1.4.8 The CML and the BSA have confirmed that the procedures described in this publication reflect the current best practice for establishing whether a property is constructed with a deleterious aggregate within the concrete. It is expected that mortgage lenders will continue to require that these procedures, as modified by this edition, be adopted when considering whether a property is a suitable security for mortgage purposes in respect to mundic.

1.5 Classification of samples

1.5.1 This edition includes a revised classification of concrete samples that reflects the needs of property owners and lenders in order to clarify whether a property is mortgageable or not. Previous editions outlined the sampling procedure and provided a series of laboratory methods for classifying relatively low-density concrete samples (see sections 1.5.3 and 1.5.4) into one of four classes.

1.5.2 These have now been reclassified into five classes of concrete samples (see Figure 2), as follows:

Class A_1 *(formerly Class A)* – These are sound concretes containing only Group 1 aggregate types (see section 3.3 – Table 1) that can be categorised as normally stable (i.e. not likely to cause mundic problems). They may contain, among other things, crushed igneous rocks (e.g. granite); non-mineralised meta-basic rocks, river and beach gravels; the washed coarse-fraction wastes from the china clay industry; and furnace clinker or coking breeze.

Class A_2 *(formerly Class A/B)* – These are concretes that are considered sound, subject to normal adequate protective maintenance. They contain up to 30% of Group 2 aggregate types (see section 3.3 – Table 1), except in the case of footings (see section 1.5.3).

Class A_3 *(new classification)* – The development of the Stage 3 test, which involves a long-term testing of concrete that was formerly designated as Class B, has provided a process to check the stability of concrete samples, and therefore the suitability of a tested house for mortgage security. Previously, Class B samples passing the Stage 3 test were reclassified as A/B, but they will now be designated as Class A_3. As at present, those failing the Stage 3 test will continue to be designated as Class B (see section 4).

Class B *(unchanged)* – These are concretes that contain more than 30% Group 2 aggregate types (see section 3.3 – Table 1), which, although appearing currently sound, could potentially cause loss of strength in the concrete products used. This category includes some sedimentary and meta-sedimentary rocks, such as the locally known 'killas', and metalliferous mine wastes, which can include killas and sulphide minerals, but not limestones, sandstones or slates.

Sometimes non-ferrous metallurgical slags can be found in concrete, and such concretes would generally fall into this classification. Concretes in this category are those that are currently sound, but it has not been possible to establish beyond reasonable doubt that these will not be subject to future degradation if used for wall construction. Certainty of the material can only be determined by using Stage 3 testing.

Where Class B concrete has been identified in concealed foundations, surveyors are advised to consider whether it might pose a structural risk (see Annex B, B1.6, which states that: 'For the purposes of this guidance note, the foundations are regarded as that part of the supporting structure of the building which is and has always been wholly enclosed on each side by the ground.' Annex B, B1.7 also states, 'Footings that are exposed externally above ground level, or internally within spaces such as basements or sub-floor areas, should be regarded as part of the wall construction.')

Class C *(unchanged)* – The concretes within Class C are those found to be clearly unsound from the initial examination of cores, or from the detailed petrographic tests. Class C1 concretes contain mainly Group 2 aggregates showing obvious signs of degradation, with additional evidence of deterioration of cement-paste matrix; Class C2 concretes contain mainly Group 1 aggregates. Unsoundness in such cases may be due either to poor quality or to a non-mundic cause.

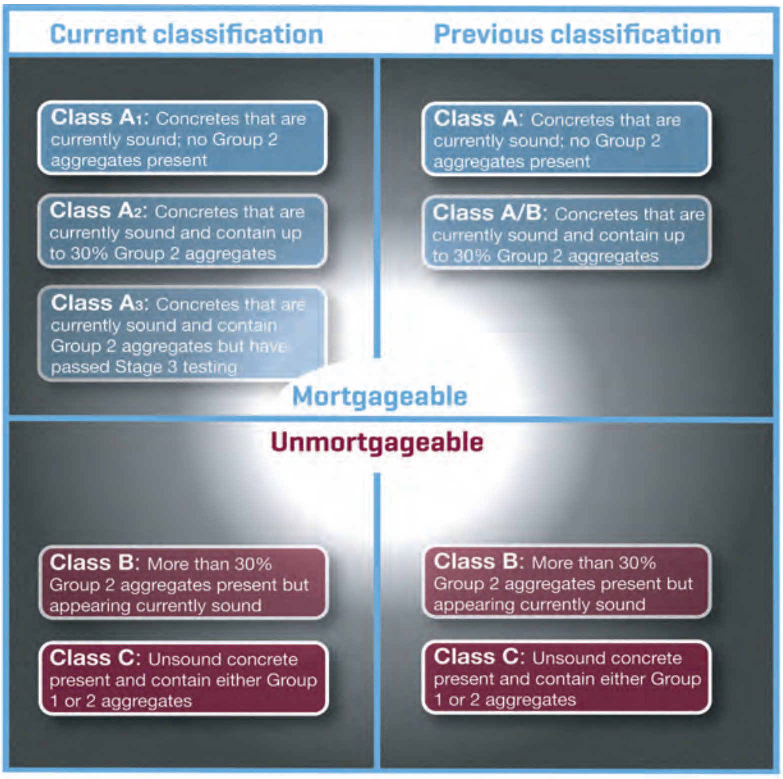


Figure 2: A comparison of previous and revised classifications of mundic concrete samples taken from walls (excluding mass concrete footings)

1.5.3 The classification procedure is applied in a modified form to mass-concrete footings (i.e. above ground level and below the damp-proof course (DPC)). Samples should be examined in accordance with the Stage 1 procedure described in section 3.1.4. If it is not possible to classify the concrete as within Class A or as unsound concrete (Class C), and the concrete appears dense, with an aggregate within the normal density range, the concrete dry density may be determined in accordance with BS EN 12930-7 (see section 3.11). Samples exhibiting a dry density of 2,000 kg/m^3 or more should be placed in Class A_2. Samples exhibiting a dry density of less than 2,000 kg/m^3, or which are not suitable for density testing, should be subjected to the Stage 2 examination procedure described in section 3.1.5 and classified accordingly (see section 3.3).

1.5.4 Occasionally, mass concrete used in wall construction may be treated in the same way as concrete footings and classified Class A_2 if its density exceeds 2,000 kg/m^3, provided an adequate number of suitable samples indicates that it shows no evidence of physical unsoundness (see subsection 1.5.3 above). Some lenders might not accept properties with mass concrete walls in Cornwall and Devon as being mortgageable, even if the density permits an A_2 classification.

1.5.5 The concrete classifications A_1, A_2 and A_3 define mortgageable properties, while concrete Classes B and C define properties that are considered unmortgageable (see Figure 2). Existing reports and classifications from previous tests remain valid. When existing reports are assigned or updated, the equivalent revised classifications can be explained in a covering letter, but there is absolutely no requirement to repeat a test or to retype a report simply to provide a version with the revised classification.

1.5.6 Note that these procedures for the classification of concretes are considered to be the latest 'state of the science' procedures for such material as of autumn 2014.

1.6 Post-1950 properties

1.6.1 The introduction of British Standards for aggregates means it is much less likely that unsuitable material was used after 1950. Additionally, after the Second World War the practice of building larger residential estates, rather than the pre-war construction of individual or smaller numbers of properties, resulted in greater development of factory block-making plants, and encouraged better quality control of aggregates and mixes. Later, isolated examples of poor aggregates would normally be the result of handmade blocks, or in situ concrete from a 'do-it-yourself' source.

1.6.2 Nevertheless, there is evidence of the occasional use of potentially deleterious aggregates in some localities in the years immediately after 1950, and (rarely) as late as 1965, so it will remain necessary for inspecting valuers to practise vigilance. RICS issued a statement in March 2003 recommending caution regarding the 1950 cut-off date in the following postcode areas: PL12, PL13, PL14, PL15, PL17, PL18, PL22 and PL23. In addition, on the basis of experience, most surveyors in the region now also recommend testing in the PL10 and PL11 postcode areas. Surveyors are expected to use their local knowledge and established best practice to judge whether to test for mundic.

1.6.3 The CML advises that lenders will not normally require tests on post-1950 concrete-constructed properties unless the surveyor has determined that there are visual or other signs to suggest the possibility of mundic-related deterioration. There is no justification for the routine testing of such properties where there is no risk to the structure.

2 The survey and core sampling procedure

2.1 Surveyor qualifications

2.1.1 Mortgage lenders and best practice require that the site survey and core sampling procedure should be carried out by, or under the direct supervision on site of, a suitably experienced person. This should be a chartered surveyor, chartered architect, chartered engineer or other suitably qualified person (hereafter referred to as 'the surveyor'), who is able to demonstrate the necessary level of knowledge and expertise in the structure of dwellings and the defects in such structures.

2.1.2 Before agreeing the conditions of engagement, it is recommended that the surveyor advise the client to satisfy themselves that the surveyor's report is acceptable in principle to lenders at that time, and that the surveyor has the authority to then upload the mundic test results to the mundic database, if one is established.

2.1.3 The surveyor will refer samples of material extracted from the property to a petrographer for analysis and assessment; once the petrographer's report has been received, the surveyor will advise, make recommendations and provide conclusions to the client in layman's terms. The surveyor will also upload the mundic test results to the mundic database, if one is established.

2.1.4 All persons involved should advise their professional indemnity insurers that they will be carrying out this type of work and obtain the appropriate professional indemnity insurance, because both clients and lenders will require evidence of this cover.

2.1.5 Surveyors are advised to confirm that the appointed petrographer, or firm through which the petrographer operates, carries appropriate professional indemnity insurance.

2.2 Settling the surveyor's conditions of engagement

2.2.1 It is essential that the conditions of engagement be agreed in writing with the client prior to commencement of the commission, and that the client – and, if different, the owner and any tenant – provide written consent for the taking of samples that acknowledges there is likely to be surface damage to the property as a result of the survey.

2.2.2 In order to establish the conditions of engagement and determine a fee or estimated total fee (to include the drilling company and petrographer's charges, if relevant), the surveyor will need to make enquires about the subject property, including its approximate age and type. It is also necessary to check that an electrical mains supply is available within or nearby to the property. Should an electricity supply be unavailable, the client should be informed of the additional costs involved in hiring a generator. A water supply will also be needed to repair the core holes.

2.2.3 It is essential that the conditions of engagement between the surveyor and the client define the matters indicated in the model clauses and topics in Annex A as a minimum.

2.2.4 In explaining and agreeing the nature of the survey and core sampling procedure to the client, it is necessary to draw the client's specific attention to the likely ensuing damage involved in the process, and the extent to which the damage (e.g. wallpaper or blemishes of the render surface) may need to be repaired.

2.2.5 In explaining the petrographic testing process to the client, the surveyor is advised to make it clear that the client may incur additional fees if, as a result of the initial Stage 1 examination (see section 3.1.4), a definite classification of the concretes is not possible. The surveyor is also advised to ensure the client is aware that the fees will depend on the number of samples and varieties of concrete that will require a detailed Stage 2 examination (see section 3.1.5). If sampling for Stage 3 examination is appropriate, it will typically be dealt with as a separate, later service.

2.3 The survey

2.3.1 The surveyor is ultimately responsible and potentially liable for the content of the concrete-screening assessment report, and is expected to be present on site for the entire procedure.

2.3.2 To limit the damage to the property, nuisance to the occupier and cost to the client, a compromise may be necessary. If there are any grounds for believing that the property may contain unsatisfactory materials, the surveyor is advised to exercise professional judgment. This includes in determining the number and location of cores to be extracted in order to be reasonably satisfied about the identity of the materials in: the main external walls (inner and outer leaves), internal load-bearing dividing walls, any pre-1950 extension(s) and foundations (note: in this case, additional disturbance to the structure or its environs is inevitable). A suggested sampling strategy is given in Annex B.

2.3.3 Choosing suitable locations for core extraction is important for confirming the identity and condition of concealed materials. Some samples should be taken from as low down as possible, preferably either side of the DPC. This should indicate the condition of the cores, with moisture from beneath the DPC in possible contrast to the drier material above.

2.3.4 The surveyor is responsible for selecting the sample locations and overseeing the extractions. It is recommended that the core samples be recorded and detailed on a chain of custody form, and then submitted to the petrographer. A sample of the form is included in Annex B, section B4 (p.38).

2.3.5 The surveyor should note the height, depth, condition and position of the sample, and include a signature on the chain of custody form to indicate that the surveyor has undertaken full supervision of the sample removal. The surveyor is also responsible for ensuring that the samples are provided to the petrographer in sealable polythene bags, and presented in a clear sequence with the property address clearly marked on each bag.

2.3.6 Possible sampling locations are indicated in Annex B, but it is not suggested that these replace the surveyor's professional judgment in each case.

2.3.7 If the client or owner is not prepared to allow sufficient samples to be taken from suitable locations, as deemed appropriate in the judgment of the surveyor, it is recommended that the instruction be declined.

2.3.8 The surveyor should adopt a methodical survey procedure, starting with a careful examination of the property that identifies the construction, its apparent condition, layout and any subsequent extensions, and to select or confirm (or otherwise) the locations from which samples are to be taken. The examination will entail access to as many parts of the property as is feasible, and will include a roof-void inspection and any subfloor area, where this is safely accessible and not unduly difficult.

2.3.9 It is expected that the surveyor will take detailed field notes during the examination, as an aid for producing the report and for any subsequent assignments. The notes will usually contain a description of the property, including its estimated age; orientation; the form of construction used in the principal elements of the building, extensions and additions (i.e. external and internal walls, roofs and floors, adaptations and relevant major alterations); and the condition of the building in overall terms, with particular reference to defects or lack of maintenance, which either has resulted, or is likely to result, in exposure to or ingress of water and dampness. The notes will usually record any relevant limitations to the inspection, for example, weather conditions. Some examples of mundic-affected buildings are shown in Figure 3.

2.3.10 The surveyor's notes should be comprehensive and presented in a form that can be easily understood for any future assignments.

2.3.11 Prepare sketches of the floor layout and elevation drawings, and include any suitable photographic evidence to help identify the location of samples.

2.3.12 The surveyor's notes (and later report) are to include an accurate description of the position, depth of penetration and appearance of each core taken, with the size of the extracted core noted (a minimum nominal diameter of 50mm is required). Mass-concrete materials (sometimes also blocks) often contain aggregate fragments with a top size of greater than 30mm; such material requires a larger sample (of a minimum of 75mm nominal diameter) or a suitably coherent cut sample.

2.3.13 A dry-core sampling procedure is required, for which the surveyor will need specialised equipment. The minimum items considered essential as a supplement to the normal equipment utilised by a surveyor are as follows:

- An electric drill, preferably a power-operated, non-percussion type with a minimum 1.15kW power output. In the interests of personal safety, it is recommended that the drill features a clutch-slip facility and is capable of low drilling speeds (between 0 and 2,000rpm). Operators should ensure that neither drill bit nor core become overheated during drilling, pausing at intervals if necessary.
- Adequate length of extension cable with waterproof plugs for the connection. 110V low voltage supplied by transformer should be used for safety compliance, especially as the work may be carried out in damp conditions.

Figure 3: Photographs of two different properties exhibiting characteristic mundic damage

- A dry core sampler bit of 50mm minimum internal diameter and capable of drilling a depth of at least 150mm. Medium to soft diamond tips are recommended, as these have the most successful cutting ability and extend the life of the bit in the majority of practical experience. It is also recommended that the unit include a dust-extraction facility of at least 1.5kW to prolong the life of cutter tips and reduce the hazards of dusty working conditions.
- Sealable polythene sample bags and waterproof marker pens.
- Adequate safety clothing and equipment, specifically a facial mask offering eye protection.
- A range of ancillary tools for cutting samples in varying circumstances, plus a garden spade for excavation purposes.
- A fresh supply of quick-set dry mix (cement/fine aggregate) and tools for backfilling holes in walls caused by sampling. Reparation of the core-holes must be carefully undertaken, with particular care of the exposed cavity area. Back spacers are required to avoid new fill debris bridging or falling into the cavity. Shrinkage of the repair material should also be avoided (shrinkage-compensated proprietary repair materials are available from several manufacturers).

2.3.14 Appropriate Health and Safety at Work legislation must be complied with, and it is recommended that sensible safety precautions – e.g. not working from an unsecured ladder – are taken at all times.

2.3.15 Classification of material from the inner leaf of normal cavity walls is required. As repairs of interior parts are harder to conceal, care is advised in choosing sample locations. A longer core bit, taken through the outer leaf and cavity, is feasible and avoids damage to the internal surfaces.

2.3.16 If any difficulty in extracting core samples is experienced, cut samples can be taken as an alternative under certain circumstances. Normally, this will be within the roof void from the wall-plate areas of the outer walls, from internal walls above ceiling height, or from party walls, divisions and chimney breasts. It should be noted that when taking cut pieces by chisel, hammer blows may cause micro-cracking, which might not always be easy for the petrographer to distinguish from cracking resulting from other deleterious causes.

2.3.17 It is emphasised that the method of solid drilling to extract dust from a variety of wall areas to use for collective chemical examination is inappropriate. Lightly wire-brushing the outer surface of the core to remove any polished dust is acceptable, however. The supervising surveyor should record the visual condition of each core piece when extracted.

2.3.18 The external surface of core samples should not be washed on site to improve their visual appearance, because this may confuse the analysis. Oxidisation of pyrite may occur within a few hours of extraction, and some sedimentary rocks can quickly delaminate in the presence of moisture.

2.3.19 As the supervising surveyor is responsible for each extracted core sample, it is necessary to ensure these are each collated accurately and packaged individually in sealable plastic bags. Labelling and numbering each sample – including the date, address and location – should be completed before leaving the site, and a signed and dated chain of custody form to indicate where the samples have been taken from should be included with the samples for dispatch to the laboratory. The surveyor has a duty of care to ensure privity of contract and establish a clear chain of liability.

2.3.20 Assessment of additional samples will need to be contemplated by the surveyor where a mixture of material types and/or material conditions is likely.

Observations regarding surveys and samples can be found in Annex B.

2.4 The surveyor's report

2.4.1 It is necessary for the initial petrographic report (Stage 1) to be returned to the supervising surveyor without delay, and for the results to state clearly the classification of each sample examined (see 'Petrographic examination procedures', section 3). If a Stage 2 test is required (see 2.4.6 below), the surveyor, in consultation with the petrographer, will decide which extracted samples to subject to further examination. As analysing a large range of samples is costly, it is prudent to balance the benefit against the client's outlay.

2.4.2 The surveyor will include a professional opinion and interpretation of the results in a report to the client, which will also feature comments on the suitability (or otherwise) of the material and its possible effects on the property involved. The surveyor's report will also include appropriate recommendations as to how to proceed, dealing separately with internal and external wall construction, the foundations and footings (see Annex B (B1.6 & B1.7)), as relevant.

2.4.3 The surveyor's report will also include the time and date on which the survey was carried out, and clarify those parts of the property that are variously included or excluded from the survey and its conclusions (e.g. see Annex section B1.16). Any refusal by owners or occupiers to permit sampling deemed necessary by the surveyor should be recorded and detailed in the report.

2.4.4 The signed petrographer's report is to be included as an appendix of the surveyor's report (see Annex C for a checklist of headings). The petrographer's report should contain any observations or information that may help the surveyor form a conclusion or recommendation. Petrographers' or other laboratory reports (whether Stage 1, 2 or 3) are not standalone documents; the surveyor should provide an addendum report on supplementary stages and any resultant reclassification.

2.4.5 It is suggested that the surveyor always makes recommendations for regular, protective, internal and external maintenance to prevent water/damp ingress, and to preserve the durability and stability of all walls.

2.4.6 The visual assessment of concrete (Stage 1) may indicate a need for further examination or Stage 2 testing. An example of this might be when samples cannot be accurately categorised, or where there is an unexpected variation between the samples initially selected at Stage 1 by the surveyor for examination.

2.4.7 It is expected that the surveyor will endeavour to use terms a lay person can understand, both in written and oral communications with the client.

2.4.8 It is necessary for the surveyor's report to declare that the surveyor has:

- carried out the survey and chosen the sample locations
- concluded that the sample material selected for concrete assessment is reasonably representative of the parts of the structure inspected
- commissioned the assessment of the samples taken
- considered the results and findings
- carried out the survey, and
- prepared the report in complete compliance with this document.

2.4.9 The completed mundic report will contain no opinions or reports other than those of the surveyor and the petrographer. Both the surveyor's and petrographer's reports should be clearly legible, preferably in typed, printed or electronic formats, as agreed with the client. Any other reports referred to in the mundic report can be included in an annex.

2.4.10 The report must conclude with a clear statement regarding the effect of the test result on the suitability of the property for mortgage-lending purposes.

2.4.11 Annex C provides a checklist of headings for the report, which will bear the surveyor's signature alone. Signed copies of the petrographer's report can be appended to the report, but the surveyor is responsible for the conclusion and recommendations in respect of the property, and for demonstrating a sound understanding of the procedure. In cases in which the assessment has had to proceed through several stages before a final recommendation could be reached, it is suggested that compilation of a final all-inclusive report should be considered.

2.5 Subsequent service

2.5.1 When deciding whether to proceed in accordance with paragraph A1.9 of Annex A regarding assignment, the surveyor will wish, among other things:

- to refer to the original classification
- to consult the petrographer to confirm the continued availability of professional indemnity insurance
- to consider how the property has been maintained, and
- to include the results of any subsequent research since the publication of this document.

3 Petrographic examination procedure, interpretation and classification

3.1 Application and introduction

3.1.1 This examination procedure applies only to samples of concrete material, usually from blocks but also including elements cast in situ. Any rendering, pebble-dashing and/or bedding mortar attached to the sample (or plaster in the case of internal samples) should normally be disregarded for the purposes of this examination. However, a comment on its general type and adhesion to the concrete may be helpful.

3.1.2 The principal purpose of this procedure is to classify the concrete material into one of the classes defined in sections 1.5 and 3.4.2. Such a classification requires:

(a) identification of the aggregate type, and

(b) assessment of the condition of the concrete.

3.1.3 This section describes the progressive phases in the examination of concrete. There are two stages of examination and a third testing stage (see sections 3.1.6 and 4). Not all of these examination stages will be required for every sample, and it is emphasised that the progressive procedure described here will be concluded when a satisfactory classification of the concrete can be made. An outline of the typical investigation procedure using Stages 1 and 2 is shown in Figure 4, which also indicates the potential outcome of Stage 3, as detailed in section 4.

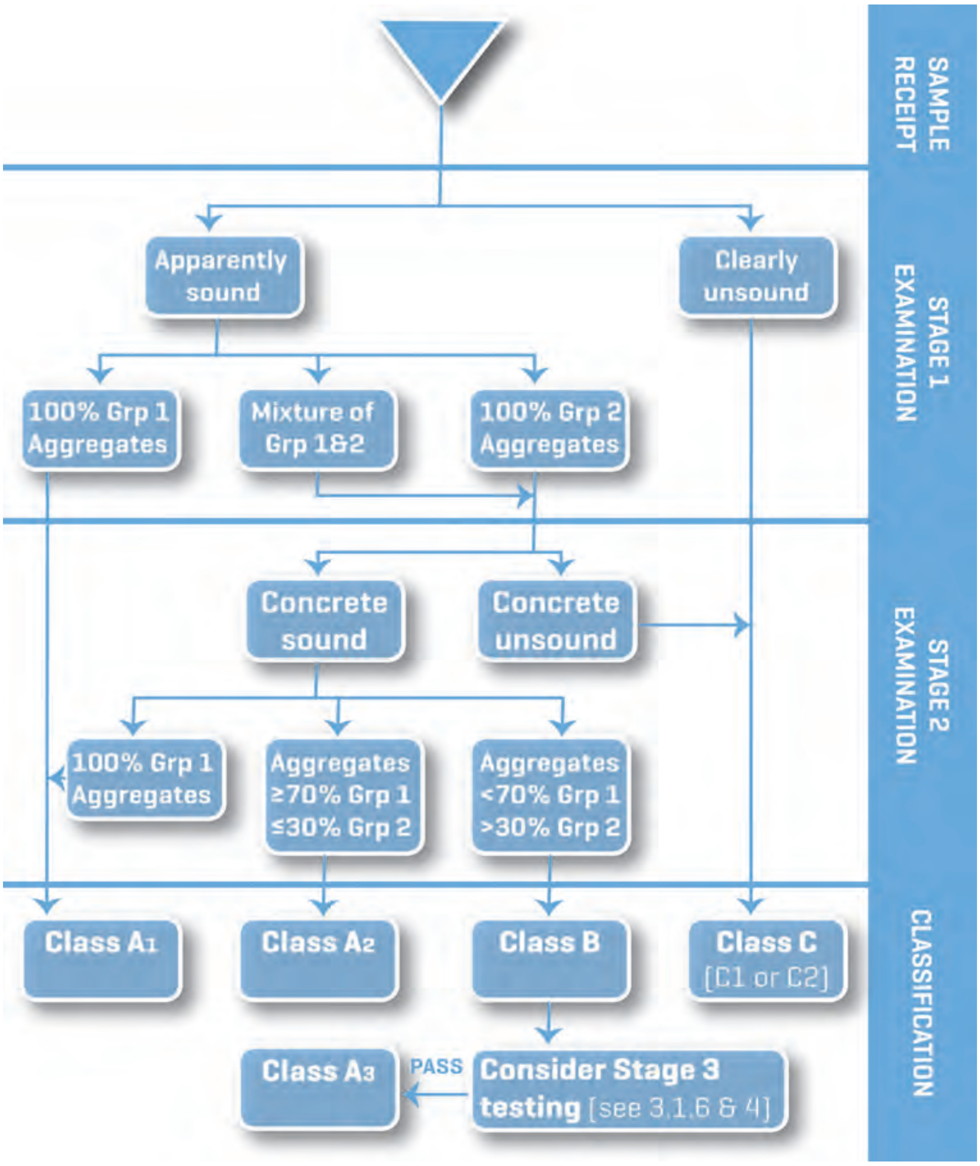


Figure 4: Examination and classification procedure

Note: The flow chart is simplified and reference should be made to the full text.

3.1.4 Stage 1 constitutes the examination of samples 'as received' (see section 3.6), enabling many samples to be classified with confidence as either Class A or Class C. Samples for which classification is not possible at the conclusion of Stage 1 can be referred on to Stage 2. In such cases provisional classification must *not* be attempted. The petrographer will need to seek the surveyor's approval (and agreement to any extra fee required) before proceeding with a Stage 2 examination.

3.1.5 The Stage 2 assessment (see section 3.7) usually constitutes the microscopical examination of thin-sections. In some cases, large area polished surfaces may be appropriate and/or produce useful additional information. Stage 2 may also include, or very occasionally be limited to, chemical analysis or other ancillary techniques.

3.1.6 Stage 3 testing is for Class B concrete (containing Group 2 aggregate, but otherwise apparently sound). Stage 3 is a laboratory-based, empirical 'moisture sensitivity' test. It aims to simulate, in a period of months, the predicted performance of the concrete over a number of years – in other words, it is an accelerated weathering test. Concrete cores are exposed to a water-saturated atmosphere at a constant temperature of 38°C for a period of at least 250 days. At regular intervals, measurements are taken of the unconstrained linear expansion (see section 4.7). Concrete that shows an average expansion of less than the permissible amount and that remains sound, as determined by petrographic examination at the end of the test period, may be reclassified as Class A_3 (*Stable Group 2 aggregate*). The test procedure, prerequisite and on-site requirements for Stage 3 testing are covered in detail in section 4.

3.1.7 Mass concrete footings samples (those taken from above ground level, but below the DPC) that cannot be classified as either Class A or Class C by the Stage 1 examination may need to be subjected to concrete-density analysis (see section 3.11).

3.2 Petrographer qualifications and facilities

3.2.1 Members of the Applied Petrography Group (APG) of the Engineering Group of the Geological Society consider that an appropriate definition of petrographic competence for the purposes of this guidance note can be expressed along the lines of those specified in section 4.1 of ASTM C856-11:[2]

> 'All petrographic examinations of hardened concrete described in this practice shall be performed by or under the technical direction of a full-time supervising petrographer with at least five years' experience in petrographic examinations of concrete and concrete-making materials. The supervising concrete petrographer shall have college level courses that include petrography, mineralogy, and optical mineralogy, or five years of documented equivalent experience, and experience in their application to evaluations of concrete-making materials and concrete products in which they are used and in cementitious-based materials. A resume of the professional background and qualifications of all concrete petrographers shall be available.'

The laboratory facilities need to be conventionally equipped for the petrographical examination of concrete, for example as described in APG SR2,[3] and should ideally have access to a range of auxiliary techniques (e.g. chemical analysis).

The petrographer (or the petrographic company) is expected to maintain adequate professional indemnity insurance, evidence of which should be provided to the commissioning surveyor.

3.3 Aggregate types

3.3.1 Both coarse and fine aggregates shall be identified according to the principal rock or material aggregate types identified, and placed into one of the groups defined in Table 1. Selected sawn longitudinal sections from concrete core samples, showing some examples of the aggregate types summarised in Table 1, are provided in Figure 5 (for Group 1 aggregates) and Figure 6 (for Group 2 aggregates).

3.3.2 Detailed descriptions of many concrete aggregates typically found in Cornwall and parts of Devon are provided in Annex D.

Table 1 – Aggregate groups (see also the table notes overleaf)

Group 1:	1–1	China clay waste
	1–2	Crushed granite and related igneous rocks (e.g. elvan)
	1–3	Crushed basic and metabasic igneous rocks (e.g. epidiorite, serpentinite) [1, 2]
	1–4	Furnace clinker or coking breeze [3]
	1–5	Beach or river sands and gravels
	1–6	Others (e.g. Group 2, reclassified as a result of current knowledge and/or further investigation) [5]
Group 2:	2–1	Crushed sedimentary or meta-sedimentary rocks ('killas') [2, 4, 5]
Considered potentially deleterious	2–2	Most metalliferous mining and/or processing wastes [6, 7]
	2–3	Slags (largely non-ferrous) and incinerator waste [8]

Notes on Table 1

1 Meta-basic igneous rocks from the Newlyn-Penzance area have a long history of use as aggregates, and there is little evidence that they have been associated with concrete degradation, despite an often significant content of well-crystallised pyrite. It is for the petrographer to judge in specific cases whether or not chemical analysis should be carried out.

2 See guidance on chemical analysis in section 3.10.

3 If a particular furnace clinker is found to contain unstable or potentially unstable constituents, it should be classified as Group 2–3.

4 Certain quarried sedimentary and meta-sedimentary rocks in North Cornwall (Newquay, north-eastwards) have been used widely as aggregates, and apparently there is little evidence that they are associated with accelerated concrete degradation. It is for the petrographer to judge whether to include the subject material within Group 1–6, usually following a Stage 2 examination.

5 Crushed limestone or sandstone (except greywacke) should usually be classified as Group 1–6.

6 Granite mining and/or processing waste with a low sulphide content would be an example of an exception (see section 3.10 for a method for checking sulphide content); provided the waste is made essentially from quartz and stable silicate and oxide minerals, the sulphide minerals are present mainly as coarse discrete grains, and the concrete is judged to be sound. It is for the petrographer to judge whether to include the subject material within Group 1–6, usually following a Stage 2 examination and/or chemical analysis.

7 Most metalliferous mining/processing wastes are readily apparent to the petrographer because of their mineralogical constituents. However, in some cases, such indicative minerals are present in only low concentration and/or are very finely disseminated (e.g. the silver-lead mine wastes of East Cornwall), so that Stage 2 examination may be required to establish a reliable identification.

8 Incinerator wastes may derive from the burning of industrial and/or domestic refuse, and are characterised by the diversity of their constituents and the variability of their composition; they may also contain amounts of furnace clinker and various slag-like components, as well as a variety of other debris.

Figure 5: Examples of Group 1 aggregates in concrete

5(a) Group 1–1 (China clay waste)

Quartz-rich sand is an important by-product of china clay extraction from the St Austell granite in mid-Cornwall. 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, Bodmin Moor and Dartmoor granites were also used for concrete block manufacture. The major component is glassy grey quartz. Minor components include tourmaline, partly kaolinised and sericitised alkali feldspar and micas. Quartz is characteristically equidimensional with rough, pitted surfaces.

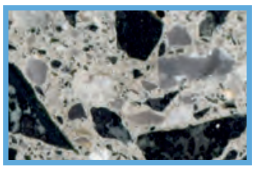
5(b) Group 1–2 (fine-grained granite, Hingston Down)

Fine-grained, two-mica granite, probably from the small Hingston Down granite mass between Callington and Gunnislake, which was widely used as concrete aggregate in north-east Cornwall. It is often found in Bodmin, Liskeard, Callington, Saltash and surrounding villages. The main components of the aggregate are alkali feldspars, plagioclase and quartz, with subordinate amounts of mica and tourmaline. The minerals occur in composite fragments and as liberated grains. The aggregate is often partly limonitised as a result of natural weathering.

5(c) Group 1–3 (metamorphosed dolerite and gabbro, near Falmouth)

This aggregate is from 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-medium-grained dolerite dyke rocks. The major minerals are plagioclase feldspar, diopside and hornblende. Ilmenite, sphene, chlorite and carbonates occur in minor amounts. Finely comminuted ferromagnesian silicates (diopside and hornblende) give the binder a characteristic greenish colour. The gabbro and dolerite commonly carry small quantities of sulphide minerals though concentrations are usually much less than 0.1%.

5(d) Groups 1–1, 1–3 (china clay waste and picrite, Truro)



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

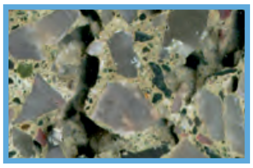
5(e) Group 1–4 (furnace clinker, Falmouth)

Furnace clinker was widely as concrete aggregate throughout the region, in blocks and mass concrete. Ample supplies were available from steam-raising furnaces at former mines, from coking plants, small coal-fired power stations and other industrial sources. This irregular specimen is from blockwork in a house at Falmouth. The aggregate consists of the usual mixture of hyaline and hypohyaline (silicate + oxide + glass) clinker, carbonaceous-vesicular and laminated clinker and partly burned coal. Replacement and rimming by red iron oxides is the result of processes related to combustion.

5(f) Group 1–5 (beach gravel, Porthleven)

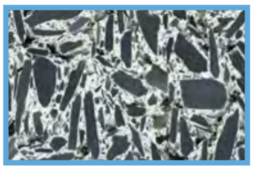
The gravel beaches that extend along Mount's Bay from Porthleven to Gunwalloe Church Cove were widely exploited as sources of aggregate for concrete blocks and mass concrete. The gravel aggregate is found mainly in towns and villages bordering Mount's Bay including Marazion, Porthleven and Helston. This well-rounded aggregate is lithologically complex and its composition varies slightly in different localities. The major components are yellowish and reddish brown chert, from offshore Eocene gravels, white vein quartz and fine-grained mudstones and siltstones of local origin.

5(g) Group 1–6 (Devonian limestone, Plymouth)



The principal aggregate is Devonian Limestone (Group 1–6) with subordinate calcite – haematite veinstones. The fine aggregate is china clay waste made from quartz and subordinate tourmaline, kaolinised feldspar and micas. They occur as liberated grains and composite quartz – tourmaline veinstone and tourmalinised granite fragments. Note: the binder in blocks made with this aggregate sometimes has a distinctive pink colour caused by sliming of haematite from veinstones.

5(h) Group 1–6 (crushed slate, North Cornwall)



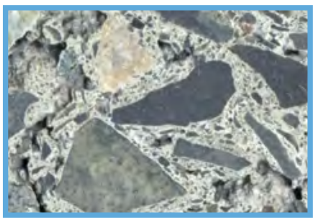
Crushed slate from the great quarry at Delabole has been widely used as a concrete block aggregate. It is found mainly in North Cornwall, between Wadebridge and Camelford, though occasionally it was used in West Cornwall, for example at St Agnes. The aggregate is easily recognised by its distinctive greenish grey colour, uniform lithology and strong penetrative cleavage. The slate is often weakly mineralised with traces of pyrite and sometimes chalcopyrite and sphalerite that occur in discrete, cleavage-parallel lenses. The sulphide mineral content is normally very low, much less than 0.1%. This example was reclassified as Group 1–6 from its original identification as Group 2.1.

Figure 6: Examples of Group 2 aggregates in concrete

6(a) Group 2–1 (chert, black mudstone, Launceston)

Impure chert and black mudstone aggregates from lower carboniferous Meldon chert and slate formations are found exclusively around Launceston in blockwork and mass concrete. The chert and mudstone were rarely used alone. They were 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, dark grey mudstone and occasional fragments of weathered, pale grey mudstone with limonite staining. Fragments of milky white vein quartz occur in minor amounts. The minor aggregate is probably china clay waste consisting mainly of liberated, grey, glassy quartz grains 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.

6(b) Group 2–2 (high sulphide mining waste, Camborne)

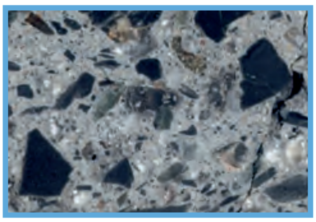


Sulphide-rich mining and ore processing wastes are responsible for most aggregate-related concrete degradation in the Camborne and Redruth areas. This aggregate, from blockwork, is a typical by-product of the processing of hypothermal, exogranitic tin–copper ores. The main components in this aggregate are quartz–chlorite, quartz–tourmaline and quartz–haematite veinstones and vein quartz. The other components are fine-grained chloritic hornfels, limonite and occasional fragments of furnace clinker. Sulphide minerals, including pyrite, chalcopyrite and arsenopyrite 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.

6(c) Group 2–2 (lead ore processing waste, 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 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. The principal components of the Wheal Mary Anne aggregate are cleaved grey mudstones, dark grey pyritic mudstones, vein quartz and colourless and pale yellow fluorite. Minor components include limonite, chalcedonic quartz, 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%.

6(d) Group 2–2 (pelite-dominated mine waste, Crowlas, near Camborne)



In many villages to the south west 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. Vein quartz and quartz–chlorite veinstones occur in subordinate amounts. Some aggregate fragments are strongly limonitised and some are enclosed by haloes of iron oxide-impregnated cement. The main sulphide minerals are pyrite, chalcopyrite and arsenopyrite. 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 <0.2% and >1% equivalent pyrite.

3.4 Concrete condition and classification

3.4.1 The condition of the concrete is assessed during each stage, and is based on any evidence of deterioration including, *inter alia*, sulphide decay, associated staining, matrix alteration, sulphate minerals and physical incoherence (see sections 3.6 and 3.7). Samples may also include evidence of non-mundic forms of deterioration, which should be included in the assessment. At the conclusion of any stage, the condition of the concrete samples shall be designated according to the definitions in Table 2.

Table 2 – Concrete condition

Sound	Showing no, or only rare evidence of deterioration and in either case exhibiting properties that are considered unlikely to adversely affect future concrete performance, subject to the qualifying notes in Table 3.
Unsound	Lacking physical coherence and/or showing common or abundant evidence of matrix deterioration (see Table 4), also concrete too deteriorated to be sampled intact.

Classification of the concrete can be made at the appropriate stage by integrating the aggregate grouping and concrete condition, as defined in Table 3.

Table 3 – Concrete classification

Aggregate(s) (see section 3.3)	Concrete condition (see section 3.4.1)	Concrete class	Table notes
Group 1 only	Sound	A_1	1
Group 1, plus up to 30% of Group 2	Sound	A_2	1,3,4,5
Greater than 30% of Group 2	Sound	A_2 A_3	1,3,5,6
Greater than 30% of Group 2	Sound	B	2,3
Mainly Group 2	Unsound	C1	
Mainly Group 1	Unsound	C2	

Notes on Table 3

1 Appears sound and likely to remain so, subject to normal regular protective internal and external maintenance to prevent water/damp ingress (above DPC) and to preserve the durability and stability of all walls.

2 Currently appearing sound, but due to the percentage of Group 2 aggregates, may retain potential for degradation, with possible consequent loss of structural strength and integrity.

3 Classes A_2 and B (concrete containing Group 2 aggregate/s) shall only be determined after Stage 2 examination(s), including, where appropriate, chemical analysis (see note 4) and/or, for mass-concrete footings, after being assessed using the density-test option (see note 5).

4 Class A_2 (concrete containing up to 30% of Group 2 aggregate/s) shall be allocated to samples that are judged sound and have a pyrite-equivalent sulphur content of up to 1% by mass of concrete (see section 3.10), whereas concrete containing more than 1% pyrite-equivalent sulphur content by mass of concrete, but otherwise appearing sound, should be allocated to Class B.

5 Class A_2 may also be allocated to mass concrete footing samples that are judged to be sound by Stage 1 examination on the basis of the density (section 3.11) and exhibit a dry density of >2,000kg/m^3. Exceptionally, class A_2 may also be allocated to sound mass concrete footings that exhibit a dry density of <2000 kg/m^3 providing a petrographer has demonstrated that the low density is wholly attributable to the presence of lightweight aggregate (section 3.11.4).

6 Class A_3 (concrete containing greater than 30% of Group 2 aggregate/s) shall be allocated to Class B samples that have passed the Stage 3 test criteria.

3.5 Preliminary examination and recording

3.5.1 The submitted sample or samples (usually concrete cores) should be entered into the routine laboratory sample register, including all details supplied with the samples, sample dimensions and 'as received' weights. The samples, as received, should be briefly examined at this stage, particularly to record any features or markings that might be destroyed or altered during the subsequent preparation and examination procedures (e.g. chalk markings, which might be lost when the samples are wetted).

3.6 Stage 1 examination

3.6.1 The Stage 1 examination is a visual assessment of the concrete which, in most cases, enables the preliminary identification of aggregate materials according to the groups defined in Table 1 and the assessment of concrete condition (see Table 2).

3.6.2 Samples must first be examined 'as received' and then washed with tap water to remove loose material generated by the drilling process. They should then be subjected to examination while still wet using the unaided eye, a low-power magnifier and, where appropriate, a low- to medium-power stereoscopic microscope.

3.6.3 The following details should be described and recorded:

- Coarse and fine aggregates – including nominal maximum size; grading (continuous or discontinuous); particle shape and colour; particle density (within normal range or possibly heavyweight or lightweight – see section 3.11); a preliminary identification of composition if possible (see section 3.3); any evidence of aggregate reaction, including iron oxide staining or secondary mineral deposits; and any evidence of aggregate cracking and/or delamination in fine-grained metasediments.
- Sulphide minerals – note presence or absence of visible sulphide minerals and, if possible; a preliminary identification; estimate abundance (none/rare/common/abundant); and note any evidence of reaction, including iron oxide staining (especially when within or surrounding aggregate particles).
- Cement matrix – including colour; colour variations; relative hardness; relative proportion (i.e. low proportion as in porous building blocks or higher proportion more typical of 'normal' concrete); apparent condition; any evidence of inter-matrix or aggregate-matrix cracking; and associated secondary mineral deposits.
- Distribution of constituents – including uniformity of distribution, any evidence of cement 'balling', poor mixing or segregation.
- Compaction and voids – including void sizes, shapes and distributions.
- Any evidence of secondary mineral deposits, exudations or efflorescence.
- Physical coherence - any visual evidence and occurrence of incoherence.

3.6.4 The concrete condition is then assessed based on the occurrence of features that indicate concrete deterioration. A scheme that may assist in the visual assessment of concrete condition is given in Table 4.

Table 4

Tick the various boxes as appropriate for the sample in question, then trace the column bearing the tick appearing nearest to the right of the table to the bottom of the table, where the assessed concrete condition is given.

	Occurrence[4]			
Observed feature	***None***	***Rare***	***Common***	***Abundant***
1 Sulphide decay and associated staining of surrounding matrix				
2 Concrete matrix degradation, inc. weakening, alteration & recrystallisation				
3 Secondary sulphate mineral development				
4 Evidence of moisture susceptibility in fine-grained meta-sediment				
5 Physical incoherence				
6 Cracking (other than externally induced)				
Condition assessment:	**Sound**		**Unsound**	

3.6.5 If sufficient information can be obtained from the visual examination of the concrete sample to classify it as Class A_I, Class C1 or Class C2 (see Table 3), then no further investigation is required.

3.7 Stage 2 examination

3.7.1 The Stage 2 examination consists of a microscopical visual examination and/or analyses as follows:

- examination of thin-section
- examination of polished surface
- chemical analyses for sulphur and sulphate contents
- cement content analysis (mass concrete footings only and when appropriate: see section 3.11).

3.7.2 The petrographic examination of a thin section is the most common Stage 2 examination undertaken on a concrete sample that cannot be classified by Stage 1.

Thin-section examination will allow reliable identification and quantification of aggregate(s), including those considered potentially deleterious. It will also allow detailed assessment of the concrete condition (see section 3.8).

3.7.3 In circumstances where thin-section examination may clearly not be representative of the concrete sample in bulk – e.g. when the nominal aggregate size is large relative to the size of the thin-section(s) – and a modal analysis to determine the amount of potentially deleterious aggregate is deemed necessary, it can be more appropriate to prepare a large area polished surface for examination. In such circumstances, it may also still be necessary to prepare and examine a thin-section to identify the aggregate(s) reliably and to assess the condition of the concrete (see section 3.9).

3.7.4 Chemical analyses may be required for samples where it is suspected that the sulphide and sulphate contents are above the permissible amounts following a Stage 1 or a Stage 2 microscopical examination (see section 3.10).

3.7.5 In the case of sound mass concrete footings that cannot be classified by Stage 1 examination, it will sometimes be appropriate to carry out a concrete density analysis of the concrete prior to classification. Where sound mass concrete footings cannot be classified on the basis of density, then representative samples should be subjected to thin section analysis and possibly additional cement content testing procedures (see section 3.11).

3.8 Thin section preparation and examination

3.8.1 Concretes are heterogeneous materials – therefore, petrographic thin sections should be as large as possible. If the concrete examined at Stage 1 appears particularly heterogeneous, or, where the nominal coarse aggregate size is large relative to the size of the thin-section, then more than one thin section should be prepared and examined in order to provide a better representation of the concrete.

3.8.2 Good working practice for the preparation and examination of thin-sections is to be found in APG SR2.[3] In addition, it is recommended that the features described in the observations box overleaf are recorded in the Stage 2 thin section examination.

Stage 2 thin section examination: recommended observations and recording of features

1 Aggregate composition

1.1 Coarse fraction

1.1.1 Identify rock types and qualitatively rank these in order of abundance.

1.1.2 Record any relevant details, including the nominal maximum size, grading (continuous or discontinuous) and particle shape; describe any sulphide minerals present and their mode of occurrence (e.g. framboidal, or finely divided in meta-sedimentary rock, or as larger, more crystalline forms in veinstone: see Figure 7(a), 7(b)). Any evidence of aggregate reaction, including iron-oxide staining or secondary mineral deposits, and any evidence of aggregate cracking and/or delamination in fine-grained meta-sediments.

1.2 Fine fraction (<4mm)

1.2.1 Establish whether or not this is of the same general composition as the coarse fraction. If not, record the rock/mineral types (where possible) in order of abundance, and comment on any mineral grains present.

1.2.2 Record details as per 1.1.2.

1.3 Deleterious aggregate

1.3.1 For coarse and fine (if present) aggregates, identify and quantify the total volume of potentially deleterious aggregates.[5]

2 Cement/binder

2.1 Cement-paste matrix – examine the cement-paste matrix at moderate magnification; identify the type of cement used; identify residual, unhydrated cement-clinker grains; and, if possible, give a qualitative assessment of abundance. Indicate states of hydration – are there any remaining cement minerals in the grains, or are they isotropic relicts? Are any reaction rims visible?

2.2 Neat cement balls – record the presence of neat cement lumps or balls, which indicate whether the cement was 'stale' when the concrete was made. If present, record quantity and size.

2.3 Portlandite – determine whether or not portlandite [$Ca(OH)_2$] is present (usually none in carbonated concrete). If present, record details of distribution, form (anhedral or euthedral) and maximum size.

2.4 Microtexture and condition of matrix – assess extent of carbonation and express as percentage of area of section. Examine the state of carbonates and determine whether or not they are:

- primary (i.e. initially carbonated cement paste), or
- secondary due to recrystallisation.

(The former will be compact and coherent; the latter will be much coarser and granular in nature, sometimes forming rosettes and often with high interstitial porosity.)

2.5 Reaction products in the cement

2.5.1 Sulphate minerals. Record the presence and locations of any sulphate minerals and if possible, identify species – gypsum, ettringite, thaumasite, jarosite, and others: see Figure 7(c).

2.5.2 Secondary iron oxides. Record the presence and locations of secondary iron oxides, i.e. limonite halos of stained cement-paste matrix around aggregate fragments. Differentiate between pre-existing limonite crusts and stains, and staining of cement paste due to reactions subsequent to concrete hardening, as these constitute evidence of in situ degradation.

2.6 Other causes of degradation – other forms of chemical and physical damage should be considered and any evidence of such recorded.

3 Cracking

3.1 Cracking – any cracking present should be studied in detail and its possible relationship with causal factors examined.

3.1.1 Internal cracking of aggregates.[6] Record width and location of cracking. Identify and record any contents.

3.1.2 Peripheral cracking of aggregates[7] and at aggregate/cement interface. Record width and location of any cracking, with special reference to any relationships with specific aggregates. Identify and record any contents.

3.1.3 Cracking of cement paste matrix. Record width and location of any matrix cracking. Identify and record any contents. Any relationships with aggregates, e.g. cracking propagating in the matrix indicative of possible aggregate expansion, are important and should be recorded (although this can be difficult to interpret in poorly compacted concrete).

3.1.4 Cracking due to sampling: damage caused by sampling should be considered particularly if methods other than coring were used to extract samples (e.g. chiselling).

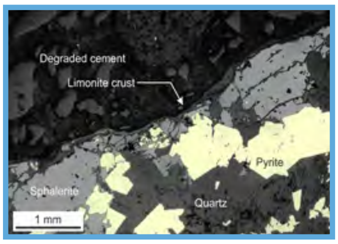
4 Voids

4.1 Shape, size and distribution – spherical, sub-spherical (air voids) or irregular (often water voids), size range and distribution of voids over the scale of the thin-section and their interconnectivity, abundance of voids (visual estimate or point counting).

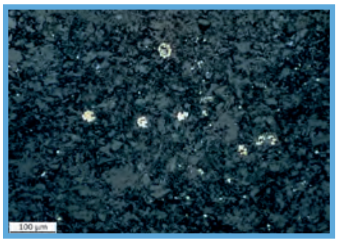
4.2 Reaction products – record presence and relative abundance of secondary minerals or gels in voids, with special reference to sulphates (e.g. ettringite, gypsum, thaumasite). Note location, i.e. in the uncarbonated paste or carbonated paste.

Figure 7: Examples of sulphide and reaction in concrete: (a) coarse pyrite, (b) framboidal pyrite and (c) gypsum at particle edge

7(a) Coarse sulphide minerals

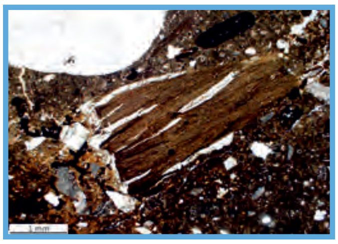


Mass concrete. Camborne area. Polished specimen viewed under the microscope in plane polarised incident light. Part of a large sulphide-bearing fragment in contact with degraded binder. The fragment contains pyrite (yellow) and sphalerite (light grey) in a matrix of quartz (medium grey). A limonite (iron oxide) encloses the fragment and the enclosing binder is impregnated with secondary iron oxide.



7(b) Disseminated pyrite in siltstone

Concrete block, Liskeard. Polished specimen viewed under plane polarised incident light. Lead ore processing waste, Wheal Mary Ann Mine, near Liskeard. Altered siltstone wallrock adjacent to a lead load. The rock is made up mainly from quartz (dark grey) and fine-grained mica and clay minerals (almost black). It contains abundant fine-grained disseminated galena (almost white) and pyrite (pale yellow). Much of the pyrite is in the form of framboids (microspheres made up from minute rounded crystals). Some authorities suggest framboidal pyrite is extremely unstable in oxidising environments; however, framboids are infrequently observed in Cornish rocks, possibly because geological deformation has caused the framboids to recrystallise.



7(c) Gypsum at margin of aggregate fragment

Mudstone aggregate fragment in concrete block. Thin section viewed in plane polarised light. The mudstone contained fine-grained pyrite that has oxidised with the formation of secondary sulphates. Reaction between sulphate ions and calcium (from the cement) promoted growth of secondary gypsum in lenses within and at the margins of the mudstone fragment.

3.9 Polished surface preparation and examination

3.9.1 A considerable amount of information can be obtained about the composition, quality and condition of a concrete by the examination of large-area polished surfaces/ plates. A properly ground and polished concrete surface should show the concrete texture and features clearly, as if permanently wet. However, concrete materials in an advanced state of deterioration will not be capable of being ground to this finish and this in itself could be used in the condition assessment. More detail on suitable methods for the preparation of large area polished surfaces/plates for petrographic examination can be found in APG SR2.[3]

3.9.2 Polished surfaces should be carefully examined first by the unaided eye and then using a medium-power stereoscopic microscope. The features listed in section 3.6.3 for Stage 1 examination can be similarly recorded and verified when examining the large-area polished surface/plate specimen. In addition, it is recommended that the features described in the box below should be recorded during a polished surface examination.

Stage 2 large-area polished surface examination: recommended observations and recording of features

Examine and record the following details:

1. Coarse and fine aggregates – identification of compositions: many rock types will be capable of reliable identification at this stage; others will only be confirmed by the examination of a thin section (see section 3.8).
2. Cement matrix – consideration of the apparent porosity, hardness and general condition of the matrix; look for evidence of additions (e.g. pulverised-fuel ash (PFA), ground granulated blastfurnace slag (GGBS), pigments, etc.).
3. Voids – description of the size, shape and pattern of entrapped air-voids and recording of whether they are filled or lined with secondary deposits; the presence and abundance of any air entrainment; the evidence of any bleeding, including water voids beneath (as placed) aggregate particles.
4. Cracks – the presence, width, abundance and disposition of any cracking visible; in particular distinguishing between cracks which variously pass around aggregate particles, intersect aggregate particles or traverse the matrix between aggregate particles.
5. Secondary deposits – identification and/or description of any secondary materials, particularly sulphate salts, noting their abundance and disposition.
6. Reaction sites – record, for example, particles of decomposing pyrite, particularly when associated with brown iron-oxide staining and/or any local evidence of expansion.
7. Carbonation – assess the degree of carbonation (including the depth of carbonation from the core end, which represents the concrete surface) with the aid of phenolphthalein;[8] unhydrated grains and 'balls' of cement will be stained by this technique even if the surrounding hydrated cement paste is carbonated. Carbonation can also be examined in detail in thin-section: see section 3.8.

3.10 Chemical analysis and criteria

3.10.1 As part of the Stage 2 examination process, the petrographer may wish to identify concrete samples for total sulphur and acid-soluble sulphate analyses in order to aid the assessment. Appropriate and documented test procedures in accordance with BS EN 1744-1:2009+A1:2012 should be followed to obtain results for total sulphur (expressed as S) and acid-soluble sulphate (expressed as SO_4).[9]

3.10.2 The numerical difference between the determined percentage of total sulphur (S) and the determined percentage of acid-soluble sulphate (also expressed as S) gives a measure of the 'sulphide content', including pyritic sulphur and sulphide. This can then be converted to give an estimation of the equivalent pyrite content.

3.10.3 The value of determined acid-soluble sulphate (expressed as SO_4) provides a measure of any sulphate reactions which have occurred within the concrete, for example the oxidation of pyrite (iron disulphide) to form iron hydroxides and calcium sulphates. However, it is important to recognise that some quantity of acid-soluble sulphate is normal for all Portland cement concretes and, e.g. values of up to 0.5% of SO_4 by mass of concrete are considered normal.

3.10.4 When such analyses are carried out, the following criteria will apply. These criteria may need to be amended in the light of future research.

- For concrete containing Group 1–3 aggregate, the maximum permissible amounts are 1.5% of pyrite equivalent by mass of concrete and 0.5% acid-soluble sulphate by mass of concrete.
- In the case of concretes containing granite mining and/or processing waste (Group 1–6 aggregate), the maximum permissible amounts are 1.0% pyrite equivalent by mass of concrete and 0.5% acid-soluble sulphate by mass of concrete.
- In the case of concrete containing up to 30% Group 2 aggregate, which otherwise appears to be in sound condition, the maximum permissible amounts are 1.0% pyrite equivalent by mass of concrete and 0.5% acid-soluble sulphate by mass of concrete.
- No chemical criteria are suggested for concrete containing more than 30% Group 2 aggregate, but these materials might be considered for Stage 3 testing (see section 4).

3.10.5 If the presence or origin of sulphate minerals cannot be determined by optical microscopy, then supplemental methods may be utilised; e.g. SEM/EDS[10] analysis.

3.11 Concrete footings

3.11.1 In the case of mass concrete footings samples, first conduct the Stage 1 examination. If it is not possible thereby to classify the concrete as either Class A or Class C, consider assessing the sample as a dense concrete material. First, check whether the concrete has the appearance of dense concrete, i.e. low voidage and relatively high cement matrix content. Secondly, check whether the aggregate is likely to be within the normal particle density range. If the concrete appears dense with a normal density aggregate, determine dry density in accordance with BS EN 12390-7:2009.[11] This special procedure for mass concrete footings is outlined in Figure 8.

3.11.2 Samples exhibiting a dry density of 2000kg/m³ or more should be placed into Class A_2. Samples that do not appear dense and/or seem likely to contain either relatively heavyweight (say >2.8Mg/m³) or lightweight (say <2.4Mg/m³) aggregates, or tested samples exhibiting a dry density of less than 2000kg/m³ (unless reassessed as explained in sections 3.11.4 and 3.11.5), should be subjected to the Stage 2 examination procedure and classified accordingly (see sections 3.8 and especially 3.8.2).

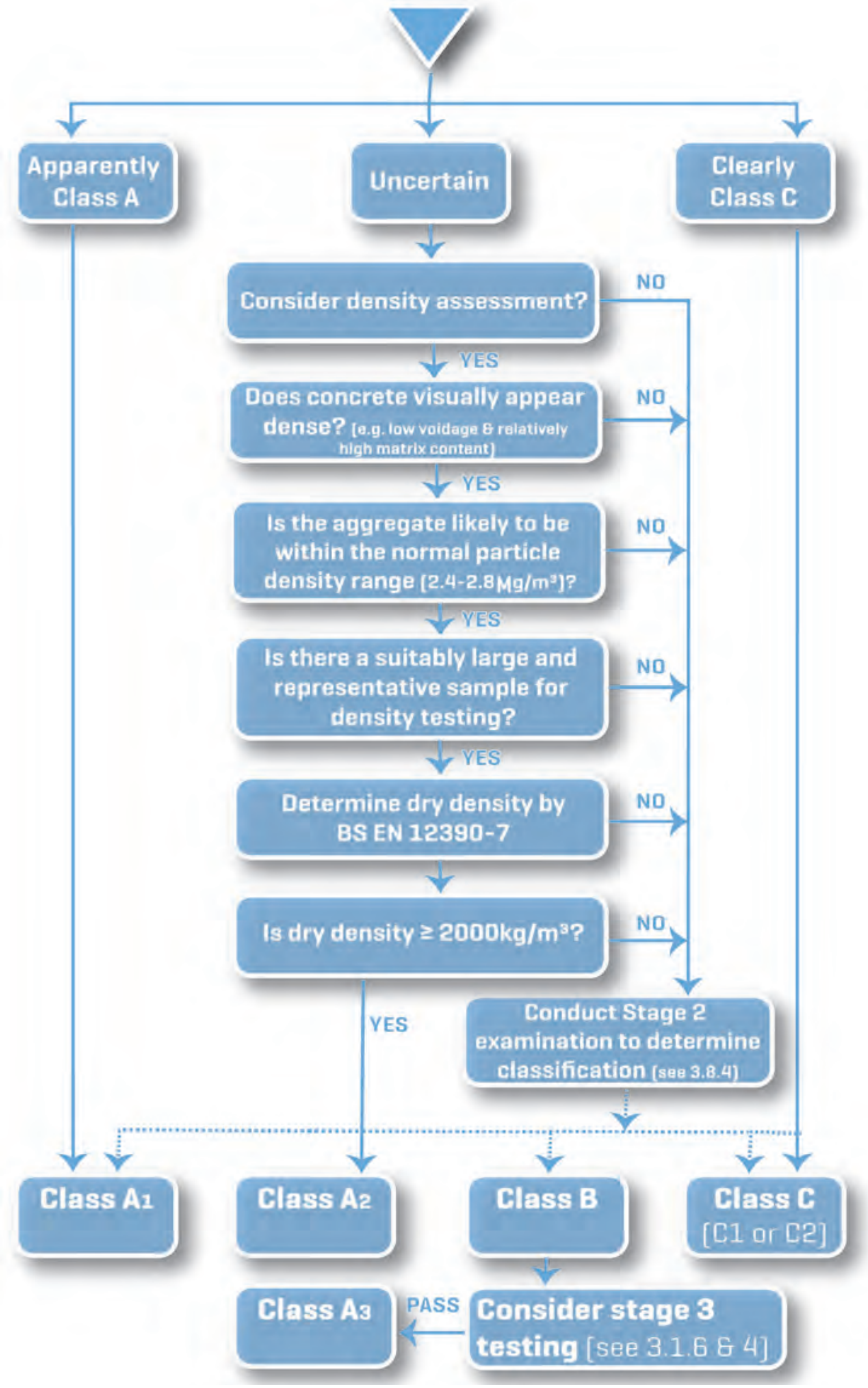


Figure 8: Flow chart showing special procedure for mass concrete footings

3.11.3 Some types of mass concrete footings will be found to contain very large-sized aggregate (say particles up to 50mm, or 75mm or occasionally greater) and sometimes also irregularly distributed large voids within an otherwise low-voidage material. Such concrete cannot always be reliably assessed by the density test or the Stage 2 examination method, because it is not possible to obtain BS-compliant or suitably representative core samples. In these particular cases, it is recommended that consideration be given to the Stage 2 examination being augmented by (or very occasionally being replaced by) in situ inspection by the petrographer of a larger quantity of the concrete in question.[12]

3.11.4 When a tested sample has a density <2,000kg/m^3 (or <2.0Mg/m^3), consider whether the low density could be explained by the nature of the aggregate rather than the quality or condition of the concrete. In particular, consider whether the inherent density of the aggregate might significantly influence the density test result – aggregate density >2.8Mg/m^3 could give a misleadingly satisfactory concrete density, whereas aggregate density <2.4Mg/m^3, and especially <2.0Mg/m^3, could give a misleadingly unsatisfactory concrete density (some aggregate density data is presented for guidance in Table 4 of Annex D). Also assess the contents and distributions of both voids[13] and cement matrix, because a well-compacted conventional concrete for footings will have a low overall voidage (say at least <5%, with <3% preferred), plus an adequate (say at least >8%, with >10% preferred) cement content; it is especially important for the cement content to be normally hydrated[14] and well distributed throughout the concrete material.[15]

3.11.5 In exceptional cases, the petrographer may consider that a low value in the density test (<2000 kg/m^3) can be explained by the aggregate being low density in character, while the voidage and cement content are both consistent with good quality conventional concrete for footings. In such circumstances, the petrographer may decide to deem the concrete 'sound' and proceed to classification in accordance with the scheme given in section 3.4.

3.12 Reporting

3.12.1 The petrographer shall prepare a report at the conclusion of each stage. The report will affirm compliance in all respects with these guidelines (or otherwise state deviations) and include at least the following information:

- dates of sample(s) receipt and examination
- sample number(s) and/or labelling details (as advised by the surveyor)
- sample type, size, weight and general condition on receipt
- the stage of the examination and the techniques used
- aggregate grouping(s)
- the condition of the concrete – if the concrete is judged unsound, the petrographer will include the reasons for this assessment
- when appropriate, details of the chemical analyses results (e.g. the total contents of sulphur and acid-soluble sulphate, and the calculated sulphide content and equivalent pyrite content by weight)
- when appropriate, dry density test result determined in accordance with BS EN 12930-7:2009
- when appropriate, cement content determined in accordance with BS 1881-124:1988
- concrete classifications for each sample (with exceptions being recommendations for Stage 2 at the conclusion of a Stage 1, or other factors, e.g. insufficient sample).

3.12.2 The petrographer shall present this information in a clear and concise format and style, insofar as possible avoiding technical jargon and unwarranted detail. The surveyor is principally concerned to know the classification of the concrete in accordance with these guidelines. Some suggested example reporting forms are provided in Annex E.

4 Stage 3 testing

4.1 Background to the development of the Stage 3 testing procedure

4.1.1 The RICS Mundic Group Committee and the lending institutions have always been aware of the need to refine and improve concrete-screening procedures. A major concern has been to devise and approve testing procedures that enable previously unmortgageable properties to be released onto the mortgage market. These are mainly houses built with concrete containing Group 2 aggregates (chiefly mine wastes) and assigned to Class B, which show no obvious signs of aggregate-related or other degradation.

4.1.2 Density testing was introduced in 1994 and further developed in 1997 to refine classification of mass-concrete footings and foundations. In May 2000, certain Group 2 aggregates in North Cornwall were reclassified as Group 1–6 materials following extensive petrographic investigations and a programme of expansion testing by the BRE. That work formed part of an extensive research programme by the BRE to develop a test to predict the long-term stability of Class B concrete blocks containing Group 2 aggregates.[16]

4.1.3 Visibly sound concrete containing more than 30% of Group 2 (potentially deleterious) aggregates is initially assigned to Class B regardless of its performance to date. Concrete containing less than 30% of Group 2 aggregates is assigned to Class A_2 and should be mortgageable with most lenders. Normally, properties built with Class B concrete are considered unmortgageable. The Stage 3 moisture sensitivity test aims to indicate the performance of the concrete regardless of its aggregate type. It is only applicable to Class B concretes (and, in exceptional circumstances, possibly A_2 and formerly A/B concretes) that show no obvious evidence of aggregate-related or other degradation.

4.1.4 Stage 3 testing should only be recommended by the supervising surveyor in consultation with the petrographer after both Stage 1 and Stage 2 petrographic screening tests have been carried out. A separate coring programme is required to provide suitable concrete samples for the moisture sensitivity test. It is currently considered less appropriate for this Stage 3 test procedure to be undertaken on concrete made with mine waste aggregates that have been found to contain 0.5% or more pyrite equivalent.

4.1.5 The Stage 3 test procedure involves measuring the unconstrained linear expansion of concrete cores that have been exposed to a water-saturated atmosphere at a constant temperature of 38°C for a period of at least 250 days. Concrete that shows an average linear expansion of less than 0.025%, following an initial seven-day conditioning period in which its wetting expansion does not exceed 0.075%, and that remains intact at the end of the test period, may be reclassified as Class A_3 (stable Group 2 aggregate). This is provided that no individual core exceeds 0.04% expansion, in which case the material will be deemed to have failed and will remain Class B.

4.2 Prerequisites for Stage 3 testing

4.2.1 The Stage 3 test will only be carried out on the recommendation of the supervising surveyor following completion of Stage 1 and Stage 2 test procedures, and the assignment of the concrete to Class B. The Stage 3 test is strictly only relevant to Class B (or, rarely, A_2) concretes. As Stage 3 testing is relatively expensive, potentially time-consuming and unsuitable for some types of aggregates, the supervising surveyor should ensure that this additional procedure is appropriate.

4.2.2 If the following conditions are met, additional core samples should be removed for expansion testing, by or under the supervision of the surveyor:

(a) The subject property, wholly or largely comprising Class B concrete, should show no evidence of concrete deterioration, including any characteristic crack patterns in render, detachment of render or clearly defective concrete in roof areas or sub-floor voids.

(b) Some types of concrete used in the region can undergo degradation without bulk expansion. The surveyor, in consultation with the petrographer, should endeavour to ensure that such concrete is not submitted for Stage 3 expansion testing.

4.3 Sampling method

4.3.1 Expansion testing requires five cores from each type of Class B concrete under investigation: four cores for expansion testing, and one core for pre-testing petrographic examination. The cores used for expansion testing must be nominal 75mm in diameter and should be at least 70mm in length, and intact, excluding the outer render and any mortar joints. Cores that include mortar joints or drill-induced fractures are not suitable for expansion testing. In practice, it is often necessary to drill more than five cores in order to provide samples suitable for expansion testing, but all samples must be recorded and reasons for exclusion explained.

4.3.2 The surveyor should select sample locations that are as representative as possible of the range of environmental conditions to which the concrete is subjected (e.g. damp and dry areas, exposed and sheltered elevations, low and high levels). Samples need to be dry cored and their locations accurately determined. Preferably, depending on accessibility, and at the discretion of the surveyor, one core should be taken from each elevation.

4.3.3 Cores must be tightly wrapped in clingfilm on site, immediately after extraction, to prevent loss of moisture from the sample. They should then be clearly labelled using a permanent marker and placed in a sealed and labelled sample bag for transport back to the laboratory. All samples, including those excluded from the set for testing, should be sent to the test laboratory as soon as possible. Cores should be adequately packed to prevent mechanical damage during transit. If more than one type of Class B concrete is identified, then where possible, a further five cores containing that additional material should be sampled and tested in a similar manner. Reparation of the core-holes must be carefully undertaken, with particular care of the exposed cavity area. Back spacers are required to avoid new fill debris bridging or falling into the cavity. Shrinkage of the repair material should also be avoided (shrinkage-compensated proprietary repair materials are available from several manufacturers).

4.3.4 A record of all samples should be made at the time of coring (including any that are aborted or later excluded from the test set), noting:

- the apparent moisture condition of the cores obtained
- the type and condition of any render or plaster
- the condition of the inner end face of the core, also that of the inner leaf of cavity constructed properties, with comments regarding any large build-up of debris within the cavity or any other unrelated construction defects (including tie-bar corrosion, mortar joints and mortar bridging the cavity), and
- the reason for aborting coring and/or for exclusion from the final test set.

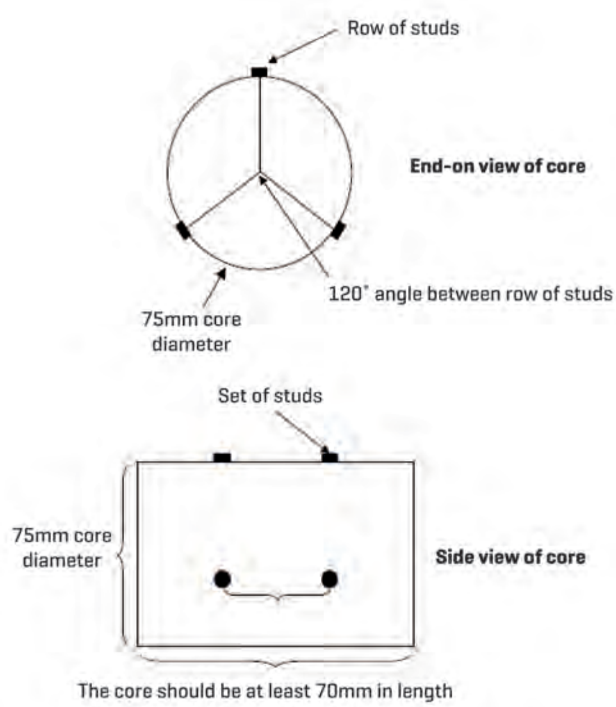
These records, preferably presented as a sample schedule, should accompany all the samples to the testing laboratory.

4.4 Preparation of cores

4.4.1 Trim four of the cores by dry cutting to remove any external render or plaster, so that they fit into a plastic container with a resealable lid. A BDH Merck wide mouth polyethylene 1.3 litre capacity bottle is suitable. Dry the set of four cores for seven days in laboratory conditions of 20 ± 5ºC, and between 40 and 60% relative humidity.

4.4.2 Three sets of Demec studs are fixed along the length of the dried core perpendicular to the trimmed surface at 120º intervals of 50mm gauge length, using Schnellklebstoff X60 glue, or appropriate equivalent,[17] with the sets of studs clearly differentiated by labelling. The utmost effort should be exerted to keep the cores as dry as possible during preparation, as any excess moisture at this stage has the potential to initiate unrecorded expansion prior to the actual testing. The three sets of Demec studs should be placed to avoid areas of severe core-voiding or surface damage (see Figure 9).

Figure 9: Diagram of test specimen showing location of Demec studs



4.4.3 The additional core from each test set is to be prepared for petrographical examination (as for Stage 2). This is required to check that the new samples are similar to that or those originally designated as Class B and to determine the extent, if any, of deleterious mechanisms occurring within the concrete. This thin section will also be used for comparison with an additional thin section to be made from the most expansive core after the full testing period is complete. The purpose of this post-test comparison is to establish:

(a) whether any additional degradation has occurred and whether this is an expansive 'mundic' type of degradation

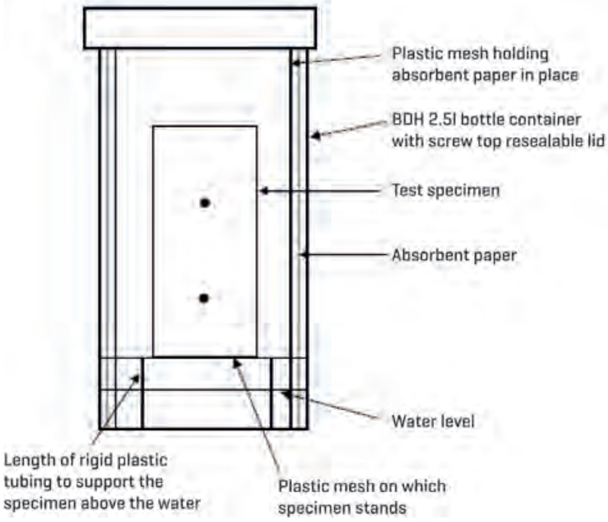
(b) whether any degradation observed is in accordance with the amount of expansion reported

(c) whether there is any other potentially deleterious, but non-'mundic'-like, degradation process apparent.

4.5 Preparation of sealed plastic containers

4.5.1 Line the sides of the container with absorbent paper and secure this with a plastic mesh. The sample will sit in the container in an upright position, on a disc of mesh that will rest on a section of plastic tubing. This raises the sample above the level of water, which should be no more than 10mm in depth, so that no part of the core is actually submerged in water. To achieve this, it is usual to add between 50–100ml of distilled water to the container. It is intended that the absorbent paper maintains a relative humidity of around 100% within the container (Figure 10).

Figure 10: Cross-section of test specimen within a suitable test container



4.6 Storage temperature

4.6.1 The specimens and containers need to be kept within a constant temperature room or cabinet at 38 ± 2°C.[18]

4.7 Measurements and observations

4.7.1 Dimensional measuring of the cores during testing is carried out to a precision of 0.002mm using a Demec strain gauge. Initial lengths of the cores at 20 ± 2°C and their dry weights are determined before placing them upright into the sealed plastic containers.

4.7.2 Measurements are initially taken during and at least at the end of the first week (seven days) and then, providing wetting expansion has not exceeded 0.075% for any core at seven days, monthly until the end of the test period. As a minimum, the cores should be weighed at the start and at the end of testing to ensure that no significant drying has occurred. Samples will be measured within the 38 ± 2°C constant temperature room, or immediately on removal.

4.7.3 The cores should be examined each time they are measured and any visible changes in condition recorded, including any discoloration, fracturing or cracking and any evidence of a loss of integrity.

4.8 Length of test

4.8.1 If the mean average wetting expansion exceeds 0.075% at seven days for any one or more of the four cores, the test set has failed the test, which shall then be aborted.

4.8.2 Otherwise, expansion testing shall proceed for a minimum of 250 days to indicate whether or not a 'mundic'-type expansion is occurring. If a material is tested that clearly indicates a slower but continuing reaction type (this being based on the trend line of the resultant expansion versus time graph, wherein expansion is clearly still continuing at 250 days), expansion testing shall be continued for up to at least 350 days.

4.8.3 The expansion measurements actually used in this test will be taken from the seven-day reading; i.e. the seven-day figure shall represent a revised zero point for any further expansion. It is anticipated that any true 'mundic'-related expansion figures will develop from this point onwards.

4.9 Reporting of results

4.9.1 An expansion-versus-time graph shall be produced for each core: this will show expansion values for each individual row of studs and the combined overall mean level of expansion for that core. Additionally, an expansion-versus-time graph shall be produced for each test set of four cores: this will show the mean expansion levels for each individual core and the combined overall mean level of expansion for that test set. It is important that all graphs are produced to the same scale, so that direct visual comparison can be made.

4.10 Concrete classification following Stage 3 testing

4.10.1 The Stage 3 expansion (or 'moisture sensitivity') test is an accelerated weathering test that uses a minimum of four cores of the same type of concrete. It attempts to simulate, in a period of months, the predicted performance of the concrete over a number of years. Current research suggests that concrete that shows a wetting expansion no greater than 0.075% over the initial seven days of testing, and an average linear expansion of less than 0.025% over the remaining part of the 250-day (or 350-day; see section 4.8.2) test period, is likely to remain stable under ambient conditions for many years, provided normal levels of care are maintained.

4.10.2 Concrete assigned to Class B following Stage 2 testing, and which has an average unconstrained linear expansion of less than 0.025% between seven and 250 (or 350) days in the Stage 3 test, may be reassigned to Class A_3 (stable Group 2 aggregate), provided expansion did not exceed 0.075% over the initial seven days, and no single core within the Stage 3 test set exceeds 0.040% expansion between seven and 250 (or 350) days.

4.10.3 Concrete that has an average unconstrained linear expansion of 0.025% or greater under the test conditions, or shows other evidence of degradation during the test period, will remain in Class B.

4.10.4 The test is considered to have failed and should be aborted if:

(a) the average wetting expansion exceed 0.075% at seven days for any one or more of the four cores in the test set, or.

(b) any individual core exceeds 0.040% mean expansion at any point between seven and 250 days.

5 Summary

Over more than 20 years, surveyors and allied professionals in Cornwall and parts of Devon have become familiar with the so-called 'mundic problem', associated with some of the concrete and concrete block buildings constructed in their region during the first half of the 20th century.

Where properties are being considered for mortgage lending purposes, and where there is any possibility that mundic-affected materials may be present, mortgage lenders typically require a specialised assessment of the concrete material to be carried out.

RICS has provided suitable guidance on the subject for quite some time (first edition 1994; second edition 1997). This earlier guidance, based on obtaining suitable samples for examination and classification using petrographic (systematic description of rocks) principles, has stood the test of time. As such, it has enabled the great majority of subject properties to be assessed as mortgageable.

However, amendments have been issued over the intervening period and further experience gained, plus a whole new Stage 3 procedure has evolved to enable the further evaluation of properties wholly or largely containing Class B concrete. This necessitated consolidating and fully revising the guidance.

This edition of the guidance does not invalidate the findings previously obtained by full and compliant application of the technique described in the second edition and its amendments (2002; revised 2005). Rather, it has built on that earlier guidance, introduced new options, updated the background information and endeavoured to clarify some of the uncertainties that have occasionally arisen in carrying out the work according to the previous guidance.

This has been a comprehensive revision, which makes a thorough reading of the full guidance text completely necessary. However, some of the key developments outlined can be summarised as follows (not intended to be in any particular order of importance). This guidance note has:

- introduced a streamlined concrete classification system, which complements the previous system, and is intended to ensure that all routes to demonstrating the mortgageable nature of a property are regarded equally
- adopted and updated the Stage 3 moisture sensitivity test as an optional means of further assessing Class B concrete
- consolidated and updated the alternative classification approach to certain types of mass concrete, using density testing and other concrete parameters
- confirmed earlier adjustments, based on experience, to the recommendations in respect of post-1950s properties in certain Plymouth postcode areas
- improved guidance on sampling, as widely requested, including a new chain of custody form (Annex B4 on page 38), while stressing that the actual sampling strategy at any particular site will always be a responsibility of the surveyor on the ground at the time
- revised background guidance on concrete materials and their aggregates likely to be encountered in the region, including better provision of some example photographs
- updated petrography reporting templates, developed and agreed by practising petrographers experienced in these procedures, and
- anticipated the establishment of a third-party database, to save time, eliminate unnecessary re-testing and reduce the costs for home-owners and purchasers alike.

Annexes A–E

Annex A Model clauses and topics for the conditions of engagement

A1 Conditions of engagement between the client and the surveyor

A1.1 Name and address of the client(s).

A1.2 Name and address of the surveyor.

A1.3 Name and address of the petrographer and any drilling company to be engaged by the surveyor.

A1.4 Name and address of the subject property.

A1.5 Any special limitations on the extent of the inspection to be undertaken by the surveyor.

A1.6 The service to be provided:

The surveyor will:

(a) inspect the subject property, determine the positions from which core samples of the materials should be taken for petrographic assessment, which he/she believes to be reasonably representative of the parts of the property inspected, so that the materials in the main external walls – e.g. any internal load-bearing dividing walls, any pre-1950 extensions and, if there are grounds which suggest to the surveyor that they may contain unsatisfactory materials which may be detrimental to the stability of the building, the foundations, can be established to the surveyor's reasonable satisfaction; possibly plus

(i) samples will not be taken from more than [specify number] positions, and/or

(ii) samples will not be taken from the following places: (This proviso can only be appropriate if the surveyor is of the opinion that the aforementioned purpose of the survey can still be fulfilled.)

(b) take the core samples or personally instruct a suitably trained and experienced operative on site on the taking thereof and satisfy him/herself that the core samples taken are suitable for assessment and sufficient to be representative

(c) cause the resulting damage to the property to be repaired, as far as is reasonably practicable

(d) engage the petrographer to undertake a Stage 1 examination and assessment of the core samples to be taken as the surveyor, in consultation with the petrographer, considers necessary, in accordance with the procedures specified in Part 3 of this publication.

The surveyor will also provide a report in accordance with that part of the document in order to advise, where possible, whether the concrete examined is classified as Class A_1 (appearing to be sound subject to regular protective internal and external maintenance to prevent water/damp ingress, and to preserve the durability and stability of all walls); Class A_2 (appearing to be sound subject to the same stipulations listed for A_1); Class B (currently appearing sound but, due to containing a percentage of Group 2 aggregates, retains a potential for degradation, with the possible consequent loss of structural strength and integrity); or Class C (clearly unsound)

(e) provide a report to the client making statements providing confirmation relating to (a) and (b) above, and, having regard to the classification and report by the petrographer, give an opinion on the suitability or otherwise of the materials identified and the likely effect of the test result on the suitability of the property for mortgage-lending purposes, and any appropriate recommendations as to how to proceed

(f) provide a declaration that he/she has inspected the property; chosen the locations, and taken or directed the taking of samples; commissioned laboratory tests; considered the results and findings; and prepared a report in complete compliance with the RICS document referred to in (d) above

(g) provide a copy of the petrographer's report.

A1.7 While due care will be taken in undertaking the service, the client accepts that the survey cannot provide a guarantee that the property is free from defect or deleterious materials, or will not become defective in future. In particular, it is accepted that the future performance of the concrete may be affected by damp penetration permitted by neglect. Defects of a non-related type are beyond the scope of the service.

A1.8 The contents of and/or extracts from the reports supplied may not be copied or published without the written consent of their authors.

A1.9 In respect of the service described in paragraph A1.6 above, and subject to professional indemnity insurance continuing to be available, the surveyor is prepared in principle after six years from the date of his/her original report (but subject to a further inspection and supplementary report if considered necessary), to assign the benefit of the service to the client's mortgage lender(s), and subsequent purchasers and their mortgage lender(s), and to supply copies of any reports on payment of a reasonable fee. It is not expected that any further sampling or laboratory testing will be required for samples originally identified as Class A_1, A_2 or A_3.

A1.10 The amount/basis of calculation of the fee(s) payable by and incidental expenses to be reimbursed by the client are .... and will cover such work of the petrographer as is necessary for a Stage 1 examination and assessment, as described in the RICS guidance note *The mundic problem*, 3rd edition. In the event of mass concrete being present and requiring a density test, an additional charge will be payable. In the event of the petrographer being unable to reach a conclusion as to the appropriate classification as a result, and therefore reaching the conclusion that an additional investigation is required, a further fee will need to be agreed.

A1.11 The fee/expenses referred to in paragraph 10 is payable [state when]. In the event that payment is not made by this date, any accruing interest will be due thereafter until payment is received at the rate of................%.

A1.12 The core samples taken in accordance with 6(b) above will become the property of the surveyor, who will then be entitled to dispose of them after two months in view of the fact that they may subsequently deteriorate. The client should note, therefore, that any necessary Stage 2 examination should be commissioned within that period if the same samples are to be used.

A1.13* The surveyor reserves the right to provide the same or a further report on the subject property to other interested parties, without reference to the client or any subsequent client, 28 days after the date of the surveyor's final report on the matter has been issued.

*__Note__: If this clause is not agreed between the surveyor and the client, the surveyor cannot provide the service to another client without the agreement of the earlier client(s), since this would be a conflict of interest under RICS Rules of Conduct.

A2 Form of consent for sampling

Consent for the removal and testing of concrete samples

Surveyor: ____________________

Owner: ____________________

Address of property to be sampled: ____________________

I/We hereby consent to the surveyor or the surveyor's sub-contractor taking samples of concrete/concrete products on my/our property subject to the terms below:

1. I will give the surveyor access to the whole of the property for the purposes of obtaining samples. The surveyor will be free to decide the number of and positions from which the samples will be taken.
2. I agree that the samples may be obtained by hammer and chisel, core drill (up to 100mm diameter) or any other reasonable method.
3. Where access traps are present to roof void(s) or traps/loose floorboards are present on timber ground floors, I will notify the surveyor and arrange for them to be opened in preparation for inspection and sampling.
4. I understand that the core drill holes will be filled with sand/cement mortar. I agree not to make a claim on the surveyor or their client in respect of damage caused by the sensible removal of a reasonable number of samples in accordance with RICS guidance, and will undertake and/or arrange to make any additional making good that is necessary and bear the cost myself.
5. The report is confidential to the person who commissioned it.
6. The samples will not be returned to me.
7. At the surveyor's discretion, he/she may decide to submit preliminary samples for testing and, if necessary, follow these up by a more extensive sampling programme.

Signed ………………………………………………… Date ……………………………………..

OWNER/OWNER'S AGENT

Please note the location of traps

Roof/void………………………………………………………………………………………………………

Timber ground floor………...………………………………………………………….......................................

Explanatory note (see 2 above)

The removal of samples normally involves the drilling of several holes in the concrete built outside walls, footings, partitions and usually one hole in any partition. In sub-floor voids and roof voids samples are usually removed by hammer and chisel instead. It is normal to remove at least 12 samples in total. The drill used has a vacuum fitted so the process is usually fairly clean. The accessible roof void and sub-floor voids (timber ground floors) will be inspected. Your co-operation in opening these areas before we arrive is helpful and prevents our having to qualify the report as falling short of the required standards. The holes are filled with sand/cement mortar but not painted. The concrete removed is sent away to be assessed and is retained rather than returned. There is no reason to expect that any material damage will be caused but by agreeing to the test, the owner accepts responsibility for any loss that may arise.

Annex B Guidance and suggestions on surveys and sampling

B1 Surveys

B1.1 The surveyor should observe any structural additions likely to have occurred since original construction. A variety of extensions and adaptations are quite possible, and a full understanding of the types of material now incorporated within the complete property should be obtained.

B1.2 The initial inspection of the overall condition of the property may indicate areas of the walls at risk from the most advanced deterioration, readily suggesting positions for some sampling. However, the surveyor should also extract samples from apparently sound areas of the building, thus ensuring the best possible range of comparisons to be made by the petrographer.

B1.3 It is essential that particular care be exercised when removing samples from chimney breast areas or used flues. A high incidence of sulphate will be present due to the burning of fossil fuels, which may have penetrated the blockwork, especially when the flues are unlined. Any deterioration of blockwork caused by the corrosive nature of these flue deposits would of course be misleading, and certainly not suitable for any chemical assessment. The surveyor should identify for the petrographer where samples are taken from, including specific note where these are taken from chimney breasts.

B1.4 The roof void area can suggest the uniformity of material incorporated throughout the structure. The surveyor must not assume this from investigation of this area alone because a change of material or even the use of a variety of sources of aggregates in the manufacture of concrete may have occurred. The primary objective is to establish the type and condition of the aggregate content in the main structure; while it is intended that all possible variations of wall material be identified, including their relationship and importance to the support of the main structure.

B1.5 In the event of a suspended ground-floor construction, an inspection of the sub-floor void, if practicable, can help to illustrate not only the type and condition of blocks used, but also the possible footings make-up and condition where these are exposed. This is a useful location for core or cut-sample removal of both materials, if suitably accessible with equipment.

B1.6 **Foundations**. For the purposes of this guidance note, the foundations are regarded as that part of the supporting structure of the building which is and has always been wholly enclosed on each side by the ground. Such concealed foundation material has not usually been found to be a crucial consideration in the effect of 'mundic' deterioration. However, if the surveyor finds evidence of unidentified settlement that is possibly attributable to degradation of the foundation material, they should undertake appropriate investigation and sampling on the basis of an additional charge, if necessary, after agreement with the instructing client.

a) The possibility of the use of low quality aggregate in foundations is widespread. Suitable selected, washed and graded quarried material may have been adopted by a knowledgeable builder, but the temptation to utilise the free and accessible spoil heaps of a sedimentary rock hosted mine waste was great. The susceptibility to early or eventual disintegration of the sedimentary type material, whether as mine spoil or as quarried aggregate, was not likely to have been fully understood in that era. This material was more freely available throughout the area than the preferred and more costly granitic or other igneous type of aggregates, which would be taken from carefully selected open faced quarries.

b) Concrete foundations indicating some deterioration may not necessarily cause structural damage to the building. It is possible that the structural integrity will remain quite adequate for domestic load-bearing requirements. An assessment that the foundations may disintegrate, with a condemnation of the whole structure, is not usually considered appropriate unless on-site evidence to the contrary is established. Nevertheless, the final judgment is the surveyor's.

B1.7 **Footings**. A frequent procedure when installing strip foundations with mass concrete was to extend these as footings above external ground level and up to the damp proof course position. Sloping contours of various sites encouraged this practice, and it would be undertaken by a simple shuttering process, with non-reinforced concrete.

Footings that are exposed externally above ground level, or internally within spaces such as basements or sub-floor areas, should be regarded as part of the wall construction. Frequently, a greater deterioration of the exposed surface will be confirmed due to the exposure to both air and moisture absorption from ground areas, but these may nevertheless provide useful information as to the probable nature of the foundations (see B1.6).

The enclosure of exposed faces of footing plinths (e.g. by raising external ground levels or casting concrete paths against the exposed external face of the plinth, or by replacing suspended timber floors with concrete floors to encase the exposed inner faces of plinths) while a method adopted in the past, is no longer acceptable as a means of 'converting' footings to fully enclosed foundations. This is because B1.6, above in this guidance now defines foundations as having 'always been' fully enclosed. Footings enclosed in this way no longer meet the required definition.

B1.8 While the external wall construction is the principal area of concern, having the important load-bearing element, it is also important to identify the internal load-bearing and semi-load-bearing walls at each level. Suitable materials are necessary for all load-bearing walls, but preferably for the semi- or non-load-bearing parts as well.

B1.9 A variety of cracks may be visible and the surveyor will diagnose from a range of possible causes including: ground heave; general settlement; wall tie failure; roof spread; inappropriate wall loading; poorly bonded blockwork to extensions; inadequate wall thickness and structural incapability, etc., together with attendant problems of render condition and initial mix. Alternatively, the cracks can of course be evidence of wall expansion, illustrating early or advanced failure, caused by concrete deterioration or associated mortar problems.

a) Evidence of cracking, which indicates that concrete wall deterioration has commenced, will normally appear in the form of a variety of fine to medium hair cracks in the render coat and/or internal plaster surface, which do not normally suggest structural movement. These cracks usually follow the outline of blockwork bedding joints, both horizontally and vertically, but sometimes run diagonally. They are likely to be the effect of expansion occurring within the overall material causing the added render surfaces to crack, thereafter permitting a further ingress of moisture and thus increasing the process of internal decay.

b) Lateral cracking could indicate that the mortar bedding is suspect, with an unstable sand/cement mix affected by moisture absorption, and therefore not necessarily the expansion of blockwork. In such suspected cases, samples to include some mortar should be taken by positioning a core piece between two blocks, and this will provide useful information on the present bonding ability as well as on the integrity of the mortar.

B1.10 Later alterations can trigger problems, and include the installation of replacement window frames, improperly installed or properly installed but causing disturbance, permitting water ingress into the reveals of the original openings. Careful examination of blockwork in such areas is to be recommended.

B1.11 Other parts of the building, such as lintels and window sills, may have been cast on site with ‘imported’ aggregates from a speculative source. The presence of deleterious aggregates within in situ concrete of lintels and sills is not as serious as their presence within main wall constructions, as these parts can usually be replaced without excessive interference with the structural requirements of the building. The surveyor’s report should advise on the ease, or otherwise, of replacing localised parts of a building, where this is identified as necessary.

B1.12 The presence of moisture is normally associated with rainwater penetration or rising ground water. A humidity build-up within the interior of a dwelling should not be ignored. Poor internal ventilation, increased insulation to parts and the variation of heating periods during the day and night can encourage precipitation on plaster wall surfaces of the colder external walls, and will be occurring on a continual basis. This persistent moisture absorption will produce off-key plaster. This may indicate a fairly significant deterioration of parts of the blockwork and will notably affect the internal leaf of cavity construction.

B1.13 The condition of any external render/coat protecting the blockwork must be examined. It can sometimes reveal an unsuitable original render mix, but sound blockwork behind. It is useful to ensure that the render piece remains with the core sample whether intact or not. It will establish its adherence or otherwise to the wall surface behind. Testing, by tapping for ‘off-key’ hollowness, will be an indicator of a possible variable condition of either or both materials.

B1.14 Possible localised elevational deterioration, and its relation to the impact from the prevailing weather, needs to be considered. Subsequent repairs in the form of tile-/slate-hanging or replacement, or any over-treated render, are also areas for possible investigation, and can indicate a history of possible deterioration.

B1.15 The condition of rain water/soil goods, roofs, window frames and sills, flashings, adhering foliage and any other defective elements likely to cause or to be causing damp/water ingress should be noted and reported.

B1.16 Some properties might include garages and/or outbuildings and the surveyor will need to assess, on an individual site basis, the extent to which such structures are sufficiently part of the property to be included in the survey and, if included, the extent to which further samples will be needed from those elements (see section B3). The surveyor’s report should clearly indicate which parts of the property are variously included in or excluded from the survey.

B1.17 When selecting suitable positions for core sampling internally, great care should be exercised to avoid concealed electrical, gas and water service routes.

B2 Typical sampling locations

The locations noted in the isometric sketch in Figure B1 (on page 74) illustrate typical sampling locations, but do not replace the surveyor's professional judgment in each case.

B3 Suggested sampling options

B3.1 Regarding the appropriate number and locations of samples, the surveyor will exercise professional judgment in the case of each property and its circumstances. Figure B1 on page 74 provides guidance on the range of areas to be included in a sampling regime for a typical dwelling. Yet these do not replace the surveyor's professional judgment in each case.

B3.2 The current sampling regime evolved over the life of the 2nd edition guidance note by general consensus among surveyors involved in the mundic concrete testing field. Practical experience has demonstrated that current sampling practice has been successful in identifying properties affected by mundic concrete, and consequently it has acceptance among property professionals and the confidence of the public.

B3.3 Each property is individual and surveyors must recognise the potential for unusual or unexpected areas of concrete construction which may need to be included in a particular sampling regime.

For guidance, however, the following sets out the sampling regime that has been generally adopted by surveyors involved in mundic concrete testing for a typical two-storey, two-to-four bedroom dwelling.

B3.4 From the main two-storey building (four main walls, some of which may be party walls):

- two samples taken from the footings or sub damp proof course level
- one sample from each main elevation between ground and first floor level
- one sample minimum between first floor level and wall plate level, often supplemented by additional samples from gable apexes taken from within the roof void
- one sample minimum taken from the inner leaf in the case of cavity constructed walls
- one sample minimum taken from internal partitions
- one sample from each accessible chimney stack or breast, usually taken from within the roof void
- one sample minimum taken from a party wall.

B3.5 Extensions

Additional sampling, as required, to achieve a representative range of concrete samples from the property. The principles summarised in Figure B1 on page 74 should be applied. The extent of sampling will be dependent on the design and scale of the extension(s).

B3.6 Additional sampling

To be undertaken according to circumstances at the surveyor's discretion.

In many properties, there are unusual circumstances such as:

- only small areas of concrete
- several different types of concrete
- internal or external walls linings
- flying or submerged freeholds.

In these cases, the sampling regime needs to be curtailed or extended to suit the circumstances, to be noted in the report.

B3.7 In some cases, cores may be drilled to establish the construction materials used. If these are clearly not concrete, they do not need to be sent for analysis; however, the cores need to be recorded in the site notes and summarised in the report.

Probe drilling (e.g. using a twist drill) is also an acceptable way of determining the construction. The positions of the holes need to be recorded in the site notes and summarised in the report.

B3.8 The above relates to a typically sized domestic structure. Larger houses, commercial buildings, blocks of flats, etc. will require additional samples for the regime to remain representative.

B3.9 It is not normal to sample concrete roof or floor slabs, or any other reinforced concrete, lintels, beams, stanchions, etc. as structural damage may result.

B3.10 Care needs to be taken to avoid damage to services. Health and Safety At Work requirements may limit the sampling that is possible; if so, record the circumstances in the report.

B3.11 The sampling regime is reduced for a single-storey property by omitting the first floor, but if the building has a large footprint, extra samples may be appropriate from the footings/foundations and walls.

B3.12 Leaseholds (e.g. flats) are a special case as they usually have communal maintenance arrangements of some sort, which include the foundations, footings, walls, partitions, party walls, flues, chimneys, etc.

It is therefore necessary to test the whole building(s) included in the maintenance arrangement. The report is best done for the management company or freeholder with liability extended to particular (flat) owners and their mortgagees, as appropriate.

If a test is for a specific flat only, or some flats cannot be accessed, briefly outline the limitations and mention that this may not be acceptable to all lenders in the contract and the report.

B3.13 The existing sampling protocol has evolved and become established over a period of some 20 years, but it is possible that the sampling regime may evolve further over time. Surveyors undertaking mundic concrete testing should liaise with other surveyors operating in this field in order to maintain a consensus-based approach.

B4 Chain of custody form

Custody Form / Sampling Schedule

Client:						Order No:		
Client Address:								
Site Address:						Ref No:		
Turnaround Required (working days)		10	7	5*	3*	*by prior arrangement		

Sample Reference	Sampling Information							
	Location (elevation)	Above DPC	Below DPC	I (inner leaf) O (outer leaf) S (single skin)	Penetration (mm)	Sample type	Drilling Characteristics / Remarks	Photograph

	Name	of	Date
Samples Taken by			
Samples Approved by:			
Samples Received by:			

COMMENTS:

Note: *This form is intended to be included as part of an attributed and signed test report.*

Annex C Checklist of headings & statements to be included in surveyor's report

C1 Name and address of the property (including postcode).

C2 Name and address of the client and the name and address of the specific lender (if notified by the client and the surveyor is accepting a duty of care to that lender).

C3 Reference to the terms and conditions of engagement (e.g. whether the RICS model conditions apply). A copy of the terms and conditions applying. It is recommended that the surveyor include a statement that the inspection and this report thereon is not a building survey, and that its purpose is purely to report on concrete parts of the property and aspects of the condition of the property which may affect the performance of the concrete elements.

C4 Date of inspection

C5 Weather conditions at the time of the inspection

C6 Brief description of the property and extent of the accommodation (e.g. detached/semi-detached house/bungalow, any extensions). The surveyor may consider it appropriate to attach a photograph and this is recommended.

C7 Orientation

C8 Material, location and climatic factors (e.g. steeply sloping site/exposed position).

C9 Approximate age of the building, including age of any extensions/conversions.

C10 Limits on inspection, including reference to foundations and footings – see sections B1.6 and B1.7.

C11 A brief description of the structure, including confirmation of wall construction, the relevant components of the property, with any extensions.

C12 General condition

The surveyor is recommended to state that the condition has been assessed only in respect of the relevant components affecting directly or indirectly the performance of the concrete.

C13 Information on samples, including the location, numbers, diameter, length and quality of each sample taken.

The report should normally include sketches or photographs to indicate the position of samples taken (see Annex B), but where this is impractical a precise description is necessary. Surveyors should refer to their selection of the sampling positions and any relevant limitations on the positions from which samples could be taken.

Surveyors are recommended, where applicable, to include a statement to the effect that lintels and windowsills have not been selected for sampling because they are relatively easily replaced if necessary.

C14 Cross-references to and conclusions on the petrographic report, including stage or stages carried out (1, 2 or 3), concrete sample classification and any related advice, and the name and address of the petrographer engaged. A copy of the petrographer's full report is to be appended to the surveyor's report.

C15 Declaration

The surveyor should include a declaration that he/she has inspected the property, chosen the locations, taken or directed the taking of samples, commissioned laboratory tests, considered the results and findings, and prepared a report in complete compliance with the guidance note (section 2.4.9) for Stage 1 (and Stage 2 if involved). If necessary, he/she should explain any deviations from the guidance and the reasons for these.

In circumstances where the surveyor is providing supplementary advice to an earlier report, or reporting a revised classification to a property – e.g. following remedial work to remove a section of Class C concrete or following a Stage 3 test – this declaration should make appropriate reference to any earlier report, describe any works undertaken and the surveyor's involvement and confirm that work at all stages has been conducted in complete compliance with the guidance note.

C16 Effect of mundic classification on mortgagability

The report must make a clear statement, having regard to the classification result from the petrographer, regarding the effect of the test result on the suitability of the property for mortgage-lending purposes.

Outbuildings and structures of no significance for valuation purposes, and very minor additions or localised sections of buildings with no structural significance, can be disregarded if they have no bearing on a mortgage-lending decision.

If the report is being provided to revise a previous mundic classification there must be a clear statement explaining the changes which have taken place, the reason for the revision in the mundic classification and the effect of these changes on the suitability of the property for mortgage-lending purposes.

C17 Recommendations

In most cases there will be no recommendations for further action and the report should state 'None'. If appropriate, for example, if areas of Class C concrete have been identified, the surveyor may make recommendations for further action which would be effective in bringing the property up to mortgageable status.

For the avoidance of doubt, with the exceptions noted in C16 above, the principle behind recommendations for remedial work should be the removal and replacement of all Class C concrete. A Class C party wall, for example, should be removed and replaced in its entirety, not simply retained with a new inner skin concealing the original wall.

C18 Name of the surveyor and their professional qualifications, and the name and address of the firm.

Annex D Concrete aggregates in Cornwall and parts of Devon

These notes on aggregates are largely reproduced from those previously comprising Annex E in the 2nd edition. This should be read in conjunction with *A compendium of concrete aggregates used in Southwest England* by Alan Bromley, 2002, which can be downloaded from www.petrolab.co.uk/mundicproblem.html

D1 China clay waste (RICS Classification Group 1–1)

Quartz-rich waste is an important by-product 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 south-west England are all produced from granites of restricted composition, by very similar extraction and processing methods, they are mineralogically very similar.

Major components:	glassy grey quartz from granite.
Minor components:	tourmaline (schorl), partly kaolinised and sericitised alkali feldspar, muscovite, pale brown lithium mica topaz, fluorite - 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 <100µm and 5mm to 10mm. 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. Very rarely, in old concrete made with china clay waste, the albite component of microperthitic feldspar is replaced by calcite which has identical morphology and crystal size to that which makes up the bulk of the carbonated cement paste. The replacement textures are unlike any known from natural systems in the region. They are presumed to result from reaction between the Na-feldspar in the microperthite and pore fluids in the concrete. It is not known if the reaction occurs before carbonation, when the pore fluids are strongly alkaline, and the reaction product is subsequently replaced by calcite, or if it takes place after carbonation by reaction with nearly neutral pore fluids. As yet there is no evidence that the reaction is accompanied by expansion.

China clay waste is now the most extensively used aggregate for block making in Central Cornwall, especially in the St Austell, Newquay and Bodmin areas, but it has been widely used in the entire region since the 1920s. It is very common as fine aggregate in mass concrete throughout south-west England.

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 of composite fragments including tourmalinised and kaolinised granite, quartz-tourmaline veinstones, quartz-feldspar porphyry and rhyolite.

D2 Granite and related rocks (RICS Classification Group 1–2)

All six major granite plutons and most of the smaller satellitic masses have been quarried for concrete aggregate. There are active quarries in the Land's End, Carnmenellis, St Austell, Bodmin Moor and Dartmoor granites and in the minor Hingston Down and Crownhill Down stocks.

Most aggregate is won from coarse-grained, porphyritic, two-mica granites (types 1A, 1B, 1C); lesser amounts are from fine-grained (type 3) granites (Hawkes and Dangerfield, 1978).[19] In the past small quantities of concrete aggregate were obtained from quartz-feldspar porphyry dyke rocks, known locally as 'elvans' and from the granite-hosted greisen-bordered sheeted vein complex at Cligga Head near Perranporth.

The granitic rocks of south-west England have very restricted chemical and mineralogical compositions.

Major components:	alkali feldspar, plagioclase feldspar, quartz.
Minor components:	biotite, muscovite, tourmaline, chlorite.

Most granite aggregates also contain small amounts of quartz-tourmaline and quartz- haematite veinstones and vein quartz. Aggregate from the southern part of the Carnmenellis pluton is commonly pervasively limonitised as a result of natural weathering.

The all-in granite aggregates used in concrete block manufacture are usually graded between about 100µm and 10mm or 15mm. Aggregate fragments include liberated grains and composite particles.

Crushed granite is a stable and durable aggregate in the region. There are no reported problems associated with its use in concrete blocks or mass concrete.

Granite is the second most abundant concrete aggregate used in the region. Concrete blocks made with all-in granite aggregate are especially common in west Cornwall (Falmouth, Penryn, Truro, Camborne, Redruth) and in the Bodmin area, though they may be found anywhere in the region. Granite is commonly used as the coarse aggregate in mass concrete, generally in combination with china clay waste or beach or dune sand.

Quartz-feldspar porphyry dyke rocks were used very locally as aggregate in Pool, between Camborne and Redruth. They are easily recognised by their pale green colour, porphyritic texture with small phenocrysts of quartz and alkali feldspar, and finegrained groundmass. Quartz-feldspar porphyry was won from small quarries in the Watergate Bay elvan. This dyke extends from the coast at Watergate Bay (SW 839 647), southwards for 10km to Carland Cross (SW 852 543).

D3 Basic and metabasic igneous rocks (RICS Classification Group 1–3)

In south-west England there are all gradations between unaltered basic and ultrabasic igneous rocks and their strongly metamorphosed equivalents. In the Lizard peninsula, unaltered gabbro and dolerite pass into high grade granulites over distances of a few centimetres. Aggregates produced from former quarries in the neighbourhood of Porthoustock (SW 810 216) often included, from the same quarry, unmetamorphosed gabbro and dolerite and intensely deformed amphibolites and granulites. The basic rocks emplaced into the Devonian and Carboniferous successions include unmetamorphosed picrite, gabbro, dolerite and basic lavas, texturally unmodified 'epidiorite' proterobases, greenschists, and contact metamorphosed and mineralised dolerites such as that which was extensively produced as aggregate from Penlee Quarry, near Newlyn. Three main aggregate sources are recognised.

D3.1 The Lizard complex

Much concrete aggregate was formerly produced from the Crousa Downs tectonic unit of the Lizard ophiolite complex, South Cornwall (Bromley, 1976).[20] The main source was probably the former West of England quarry at Porthoustock (SW 810 2161). The quarry is developed in the root zone of the sheeted dyke complex and the product includes coarse-grained gabbro and fine-to medium-grained dolerite dyke rocks. Dioritic rocks, and amphiobolite, granulite and mafic mylonite from high strain zones occur in minor amounts.

Major components:	plagioclase feldspar (+ saussuritised feldspar), diopside, hornblende
Minor components:	ilmenite, sphene, chlorite, carbonates

The gabbro and dolerite commonly carry small quantities of sulphide minerals including pyrite, pyrrhotite, chalcopyrite, pentlandite and niccolite. They occur in amounts <0.1%.

Aggregate was formerly produced from quarries in fine-grained, strongly foliated amphibolite which lie to the north of Porthoustock, in the Goonhilly Downs tectonic unit, and from coarse-grained pyroxene and hornblende granulites from the neighbourhood of Mullion, in the western part of the Lizard peninsula.

Amphibolite

Major components:	plagioclase feldspar (+ saussuritised feldspar), green hornblende
Minor components:	ilmenite, sphene, leucoxene

Granulite

Major components:	plagioclase feldspar (+ saussuritised feldspar), diopside, brown hornblende
Minor components:	ilmenite, sphene, leucoxene

Lizard rocks were generally used as all-in aggregate, either alone or in combination with approximately equal amounts of granite. They are found almost exclusively in Falmouth and Penryn and surrounding villages, and they have also been discovered in some properties in a single street in Saltash.

The Lizard peridotite was formerly quarried for aggregate, notably at County Bridge (SW 721 219) and Trevassick quarries (SW 712 222). There is no evidence of its general use in block making though it is found occasionally as coarse aggregate in mass concrete footings.

D3.2 Metadolerite, Penlee Quarry, Newlyn

Penlee or Gwavas Quarry at Newlyn (SW 468 278) produced dolerite aggregate for almost 100 years. The Penlee aggregate contains variable amounts of pyrite and other sulphide minerals (chalcopyrite, arsenopyrite, pyrrhotite, stannite, molybdenite). Total sulphide mineral concentrations in some analysed samples of the aggregate are between 1% and 2% pyrite equivalent. Until the mid-1970s Penlee aggregate was exported in large quantities by sea to the Netherlands and Germany.

The trade ceased when the aggregate failed to meet revised DIN standards with respect to sulphide content. Cornwall County Council stopped using Penlee aggregate in the early 1980s because of their concern about sulphide levels. The loss of these major outlets forced the quarry to close in the mid-1980s. Concrete blocks and mass concrete made with Penlee aggregate were widely used in domestic and commercial properties in Penzance, Newlyn and surrounding villages. Because of its high sulphide mineral content, and intense and often uninformed local speculation about its stability, this aggregate is discussed in detail.

Penlee Quarry was developed in a large, lensoid intrusion of metamorphosed, medium-grained dolerite, which is one of a suite of intrusive and extrusive basic rocks emplaced into Devonian Mylor Series around the Mount's Bay area and on the northern coast of the Land's End peninsula. The Penlee intrusion has an amygdaloidal and autobrecciated upper contact, suggesting that it was emplaced into wet sediments immediately beneath the contemporary sea floor. Originally, the rocks consisted of plagioclase feldspar + clinopyroxene + ilmenite. They suffered variable lower greenschist facies regional metamorphism in the main deformational phase of the Variscan orogeny, when the primary mineral assemblage was partially retrogressed to albite + uralitic amphibole + chlorite + sphene.

The Penlee intrusion was subjected to later contact metamorphism and mineralisation because it lies wholly within the thermal aureole of the post-kinematic Land's End granite. The margin of the granite lies only a few tens of metres west of the former quarry. During the emplacement of the main-stage Land's End granite the Penlee dolerite was converted to a fine-to medium-grained plagioclase feldspar (An50) + green hornblende + sphene ± biotite assemblage with characteristic decussate texture. During the thermal decay of the main-stage granite the metamorphosed dolerite was pervasively mineralised. Firstly, outgoing magmatic-hydrothermal fluids deposited traces of scheelite + molybdenite, and then disseminated pyrite + minor pyrrhotite were deposited from inward-collapsing hydrothermal circulation which involved sulphur-rich formation waters. A second phase of mineralisation occurred during and after the emplacement of the second-stage Land's End granite when cassiterite and sulphide minerals were emplaced, generally in discrete hydrothermal lodes.

More than 90% of sulphide in the Penlee metadolerite is pyrite. It occurs mainly as fine to coarse disseminated crystals (<10µm - 5mm) in the body of the rock and less commonly as stringers in crosscutting veins. Its modal concentration was measured annually during the 1970s and was found to vary between 1% and 2%. Local high concentrations of pyrite and other sulphide minerals occur in hydrothermal lodes which cut the metadolerite. No attempts were made to exclude such material from the product.

Major components:	plagioclase feldspar, green hornblende
Minor components:	biotite, chlorite, ilmenite, sphene
Sulphide minerals:	pyrite, pyrrhotite, chalcopyrite, arsenopyrite, stannite, molybdenite

Most standard and pot or cavity blocks made with Penlee metadolerite contain all-in aggregate graded from <100 µm to approximately 10mm or 15mm. Some properties are built with blocks which have gap-graded aggregates. The coarse aggregate is Penlee metadolerite, generally between 5mm and 10mm or 15mm, and the fine aggregate is a local beach sand. A few properties have blocks with blended all-in aggregate made from approximately equal amounts of Penlee metadolerite and china clay waste from the St Just area. In blocks made with all-in aggregate, pyrite occurs as locked crystals in the metadolerite and occasional veinstones and as fine to coarse liberated grains which are in direct contact with the cement matrix. Where Penlee metadolerite is used as coarse aggregate in combination with beach sand, nearly all sulphide is locked in the aggregate.

Fifty-four specimens of concrete made with all-in Penlee metadolerite aggregate have been analysed for S (total) and SO_4. The specimens were from different properties in Penzance and Newlyn but they were chosen for their uniformity. Visual and microscopic examinations suggest they came from the same plant and were manufactured to the same mix design. Summary statistics are shown in Table D1.

Table D1: Sulphide and sulphate content of Penlee aggregate

	Total sulphur, as S	Sulphate, as SO_4	Pyrite, as FeS_2
	% by mass		
Mean	0.37	0.17	0.43
Median	0.28	0.12	0.26
Maximum	0.99	0.92	1.64
Minimum	0.10	0.07	0.00
Standard deviation	0.22	0.18	0.40

Figure D1 shows the calculated pyrite content of the analysed specimens. The data suggest that pyrite is bimodally distributed in the aggregate with maxima at approximately 0.15% and 0.8%. This may reflect gross variations in the disseminated pyrite content of the metadolerite. Alternatively, the high-pyrite aggregate may have been quarried from rock volumes that included sulphide-rich lode material emplaced into the metadolerite during the second stage of mineralisation.

Figure D1: Calculated pyrite content in 54 concrete blocks made with Penlee aggregate

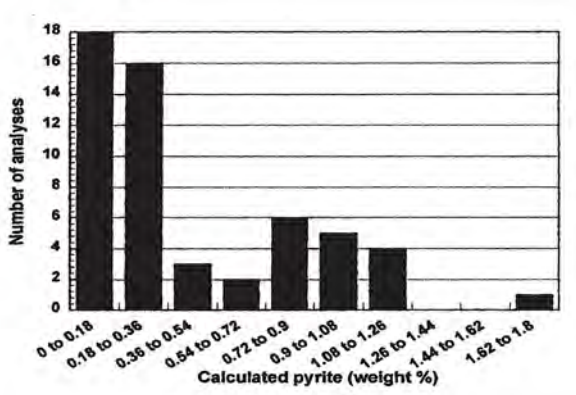


Figure D2 is a plot of calculated pyrite v. total sulphur. Most analyses lie very close to the regression line, which indicates that in the majority of cases pyrite has suffered very little in situ oxidation. The regression line intersects the Y-axis at approximately 0.12% S. This probably represents original sulphur present in the cement as sulphate. Analyses that plot above the regression line are from specimens which contain excess sulphate formed by the oxidation of pyrite. This is supported by petrographic study of specimens 50 and 53 which show strongly oxidised pyrite, limonite-impregnated cement, and in the case of specimen 53, secondary gypsum growth in voids.

Figure D2: Plot of calculated pyrite v. total sulphur in 54 concrete blocks made with Penlee aggregate

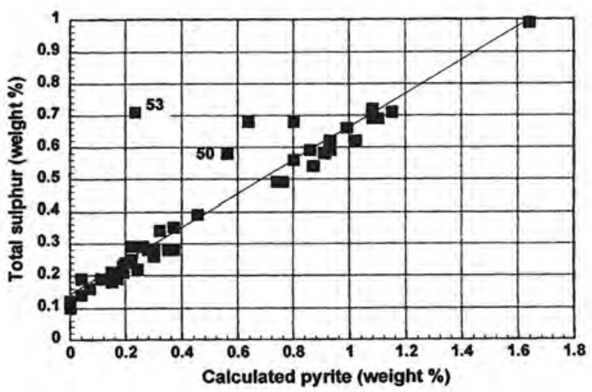
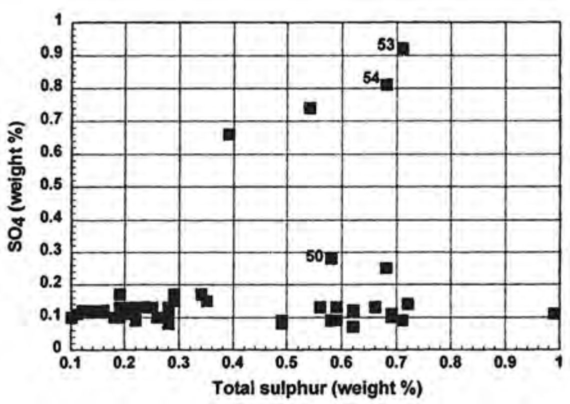


Figure D3 is a plot of total sulphur v. sulphate (as SO_4) The nearly constant sulphate concentrations at increasing pyrite content demonstrate that in most concrete made with Penlee aggregate little sulphide oxidation has occurred. Only four specimens have strongly anomalous sulphate concentrations that are ascribed to in situ pyrite oxidation. For example, the excess sulphate in specimen 53 represents in situ oxidation of approximately 0.3% pyrite equivalent:

$$([0.92 \times 0.33] - 0.12) \times 0.33 \times 1.86 = 0.34$$

(total sulphate - original sulphate in cement) x (S/SO_4) x ($FeS_2/2S$) = oxidised pyrite

Figure D3: Plot of total sulphur v. sulphate (as SO_4) in 54 specimens of concrete made with Penlee Metadolerite aggregate

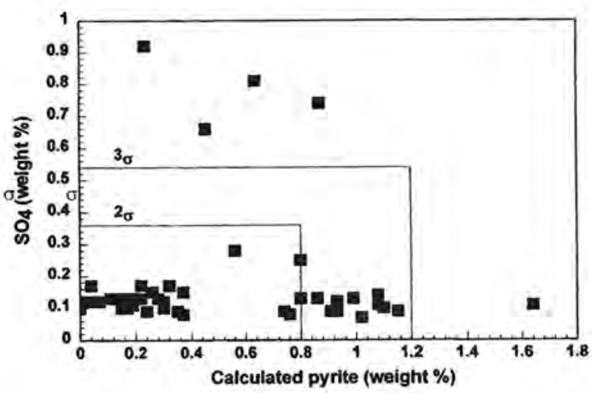


There is little hard evidence concerning general accelerated degradation of low strength concrete made with Penlee metadolerite aggregate though two testing laboratories have expressed concern about a small number of old properties in the Penzance - Newlyn area. One case is known where strongly degraded concrete blocks made with all-in Penlee aggregate were used in footings. The cement was completely carbonated and very damp. A small commercial property in Camborne was built in 1941 using standard blocks made with all-in Penlee aggregate. It has been poorly maintained and the rough cast render shows characteristic reticulate cracking, particularly on exposed, south-westerly-facing walls. Locally the underlying concrete blocks are friable, show evidence of severe in situ sulphide oxidation and have gypsum growing at aggregate-cement interfaces and in voids.

Concrete blocks made with all-in Penlee metadolerite aggregate contain between 0 and approximately 1.6% calculated pyrite. Available analyses suggest that two populations of pyrite concentration may be present with maxima at approximately 0.15% and 0.8% respectively. Pyrite is present as locked crystals and as fine to coarse, liberated grains. In most concrete made with Penlee metadolerite aggregate there has been very little in situ pyrite oxidation. However, in a few instances concrete contains excess sulphate and shows clear evidence that pyrite oxidation has occurred in place.

Figure D4 is a plot of calculated pyrite v. sulphate (as SO_4). The boxes define regions in which calculated pyrite content and sulphate (as SO_4) are less than 2σ and 3σ respectively. The 2σ box encloses 37 (approx. 70%) of the analyses, including all of the low pyrite–low sulphate population. The 2σ pyrite line intersects the high pyrite population and its boundary might be lowered to about 0.6%. The 3σ box includes all but the specimen with highest pyrite content and four specimens with excess sulphate and which show clear evidence of in situ pyrite oxidation.

Figure D4: Plot of calculated Pyrite v. sulphate in 54 analysed samples of concrete made with Penlee aggregate. The boxes labelled 2σ and 3σ define compositions where pyrite and sulphate concentrations are less than 2σ and 3σ standard deviations respectively



In concrete made with all-in Penlee metadolerite aggregate, one of the following safe limits might be advisable for sulphate and calculated pyrite concentrations:

- 0.6% pyrite and 0.4% sulphate (approx. 2σ). This is a very safe option but it would exclude many properties built with Penlee aggregate blocks in which there is no evidence of general concrete deterioration that might be ascribed to in situ pyrite oxidation.
- 1.2% pyrite and 0.6% sulphate (approx. 3σ). This would include many properties made with concrete having high pyrite concentrations but exclude the small number in which there is obvious evidence of sulphide-related concrete degradation.

D3.3 East Cornwall and south Devon

Many high level dolerites and basalts, and the picrite at Clicker Tor (SX 285 614) near Liskeard, have been used as sources of concrete aggregate. At present, Lean Quarry (SX 264 613) and Greystone Quarry (SX 367 613) produce dolerite aggregate and in the past several small quarries in similar rocks yielded material for block making.

There are two primary dolerite suites.

1 Anhydrous assemblage:	calcite augite – plagioclase feldspar – ilmenite ± olivine
2 Hydrous assemblage:	olivine – titanaugite – plagioclase – brown amphibole – biotite – ilmenite

In both suites the primary minerals are partly to completely replaced by retrogressive assemblages, which include saussuritised plagioclase feldspar, uralitic amphibole, chlorite, carbonates and leucoxene. In the case of the hydrous assemblage, olivine is replaced by serpentine. They are characterised by subophitic, plagioclase-phyric and aphyric textures. Fine-grained rocks are commonly vesicular.

Some dolerite aggregates from east Cornwall and south Devon include small amounts (generally <10%) of the associated country rocks including fine-grained, almost white-pale pink adinoles or black chert. In some recently investigated properties in the Tavistock area of Devon impure black chert makes up approximately 30% of the aggregate. The chert is often intensely pyritised. The sulphide mineral occurs as fine-grained, disseminated crystals and framboids with high surface area:volume ratios. No chemical analyses of this material are available, but visual estimation suggests pyrite content of individual chert fragments may be as high as 10%. Pyrite content of the concrete may exceed 1.5%, which is the proposed safe limit for sulphides in the mineralised Penlee dolerite. So far there is no evidence of general accelerated concrete degradation associated with the use of this aggregate, but the high pyrite concentration, and its occurrence as potentially reactive, finely disseminated crystals, suggests it may behave like a mudstone-hosted lead mining waste (section 6.4 of this Annex). More experience is needed to assess the performance of this aggregate before it can be reliably classified.

The dolerites of east Cornwall are usually found as all-in aggregates. Occasionally they were blended with lead ore processing waste from Wheal Mary Anne, Menheniot. They were also used as coarse aggregate in mass concrete, combined with china clay waste or beach sands.

Clicker Tor Quarry, Liskeard (SX 285 614), 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.

The picrite is found as all-in concrete block aggregate and as coarse aggregate in mass concrete in the Liskeard–Looe area. Occasionally, the mass concrete is degraded though no evidence has been found of deterioration in low strength, high-voidage blocks. Dense mass concrete shows general cracking of the cement matrix and the cracks often radiate from serpentinised picrite fragments. Secondary magnesium silicate minerals occur in voids. 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 timescales.

The alteration of olivine to serpentine involves volumetric expansion:

$$5Mg_2SiO_4 + SiO_2 + 6H_2O \rightarrow 3Mg_3Si_2O_5(OH)_4 + MgO$$

olivine *added* *serpentine* *lost in solution*

704g (220cc) of olivine are converted to 810g (330cc) of serpentine, i.e. about 50% expansion. It is known that 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 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. Further investigation of this aggregate is necessary, but it should have low priority because it has only been found in a few properties. The picrite was formerly used in the region as coarse aggregate in high strength concrete, notably in railway bridges. No evidence has been found that suggests it is unstable in these structures.

D4 Furnace clinkers (RICS Classification Group 1–4)

Furnace clinkers have been widely used as aggregate in lightweight concrete throughout the UK and abroad. Their composition is very variable and some have proved extremely unsatisfactory for a variety of reasons, including the presence of unburned coal which expands on hydration and absorption of oxygen, expansive hydration of lime and in situ oxidation of pyrite or marcasite.

In Cornwall and south Devon, clinkers were widely used locally in concrete block manufacture, as single all-in aggregates and blended with other materials such as china clay waste, mine waste and gravel, and as coarse aggregate in mass concrete. Several sources have been identified. These include the former Hayle power station (Hayle, Lelant, Carbis Bay), Penzance steam laundry (Penzance, Newlyn and surrounding villages), former gasworks at St Blazey and Grampound and steam locomotive clinker which was used in south Devon villages including Bere Alston and Bere Ferrers. Power station clinkers were also extensively used in Plymouth.

Most of these products consist of mixtures of vesicular and laminated clinker with subordinate amounts of vesicular, hypohyaline material, oxidised laminated mudstone and varying proportions of partly burned and unburned coal. Clinker is commonly found mixed with mining waste in the Camborne-Redruth area. This is not necessarily indicative of deliberate blending; furnace clinker from mine steam plants was commonly discharged along with mining and ore processing wastes.

The performance of clinker aggregates in the region is very variable. Well-graded, all-in clinker aggregates found in Hayle, Penzance, Newlyn and Falmouth have often performed well. Blended clinker-china clay waste aggregate is found in excellent concrete in the Heamoor district of Penzance. There is evidence of concrete degradation associated with clinker aggregates in the St Blazey and Par districts, at Grampound and in the south Devon villages. Blended clinker-mine waste aggregates, in the Camborne-Redruth area and at Praa Sands, have been responsible for severe concrete degradation. Where unstable or potentially unstable clinker is identified, it should be classified as Group 2–3 aggregate (see D8.4).

Clinker from a former commercial waste incinerator was used very locally in Falmouth (see D8.4).

D5 Sands and gravels (RICS Classification Group 1–5)

Dune sands and beach, estuarine and river gravels were widely used locally as aggregates in Cornwall and Devon. Gravels that were by-products of alluvial tin extraction were used extensively in west Cornwall. Some of these were strongly contaminated with penecontemporaneous sulphide-bearing hard rock mining waste and are known to cause general concrete degradation. Windblown sands are still used as fine aggregate and mortar sand throughout the region. The most important source areas were as described in the following sub-sections.

D5.1 South coast beach gravels

Loe Bar

The mature gravel that forms Loe Bar and the adjacent beaches was widely used as aggregate for concrete blocks and mass concrete in Marazion, Porthleven, Helston and the surrounding villages.

Major components:	chert, white vein quartz
Minor components:	local pelitic and semipelitic rocks, metamorphosed basic igneous rocks, stable silicate minerals, calcareous shell fragments

The gravel is well-graded between approximately 200µm and 5mm or 10mm. Grains and pebbles are polished, very well rounded and have high sphericity.

Silica-alkali metal gels are occasionally found in voids in low strength concrete made with this aggregate and crusts of gel sometimes partly enclose chert pebbles. The gel is presumed to be a product of alkali-silica reaction (ASR) between alkaline pore fluids in the cement and cryptocrystalline silica in chert pebbles. There are no reported cases of degradation, probably because there is ample void space in low strength concrete to accommodate the gels without causing cracking in the cement matrix.

Mullion Harbour

This material, dominated by lithologies characteristic of the western part of the Lizard ophiolite, was used locally around Mullion and Mullion Cove, generally in mass concrete.

Major components:	hornblende and pyroxene granulite, amphibolite, serpentinised peridotite
Minor components:	white vein quartz, chert, calcareous shell fragments

Size distribution and grading are very variable. The material is sometimes found as coarse aggregate in combination with china clay waste or beach sand from a different source.

Pentewan Harbour

Gravel for concrete block making was dredged from Pentewan Harbour. It was heavily contaminated by penecontemporaneous china clay waste discharged via the Pentewan stream, one of the former 'white rivers' of the St Austell area. It is characterised by a mixture of angular to sub-angular, grey glassy quartz and black tourmaline, characteristic of china clay waste, and much less abundant rounded pebbles of local rocks.

Major components:	quartz (from china clay waste)
Minor components:	tourmaline, cleaved grey mudstone, brown-grey feldspathic greywacke, white vein quartz, fine-grained basic igneous rocks, calcareous shell fragments, furnace clinker

The material is always found as all-in aggregate in concrete blocks. Its normal size range is between approximately 200µm and 5mm.

The aggregate was widely used in St Blazey and nearby villages and in parts of Truro. It is easily mistaken for china clay waste.

Fowey

Estuarine gravels from the river Fowey were used as aggregate for block making and in mass concrete in the Fowey–Polruan district.

Major components:	cleaved, purple and green mudstones (Dartmouth Beds), cleaved grey mudstone, white and limonite-stained vein quartz
Minor components:	fine-grained grey sandstone, greywacke, metabasic igneous rocks, glassy grey granitic quartz, calcareous shell fragments, stable silicate minerals (mainly tourmaline)

The material is used as poorly to moderately well-graded all-in aggregate in concrete blocks and as coarse aggregate in combination with local beach sands in mass concrete. Some concrete made with Fowey gravels is degraded, not because of aggregate-cement reaction, but as a result of exceptionally low cement content.

Looe–Polperro

Gravels from the estuaries of the east or west Looe river were used locally in Looe and Polperro, as all-in aggregate in concrete blocks and in combination with beach sand in mass concrete. The rivers drain a region of complex geology and the gravels are lithologically complicated.

Major components:	cleaved, purple and green mudstones (Dartmouth Beds), cleaved dark grey calcareous mudstone (Meadfoot Beds), fine-grained sandstone, vein quartz
Minor components:	metabasic igneous rock, lithic tuff, pelitic hornfels, stable silicate minerals (mainly tourmaline), calcareous shell fragments

Grains and pebbles are well rounded. All-in aggregate is generally graded between about 200µm and 10mm or 20mm. Material selected for coarse aggregate in mass concrete may have cobbles >100mm in size. There are no records of concrete degradation associated with the use of this material.

D5.2 North coast beach gravels

Porthmeor Cove, St Ives

Sediment from Porthmeor beach was widely used in mass concrete footings in St Ives and Carbis Bay. It has the appearance of gap-graded aggregate but it is a single product derived from a bimodally distributed beach deposit.

Coarse fraction

Major components:	metadolerite
Minor components:	fine-grained biotite hornfels, vein quartz, weathered granite

Fine fraction

Major components:	quartz, calcareous shell fragments
Minor components:	stable silicate minerals, iron oxides

Both fractions are well rounded. Pebbles are sparse, making up between 10% and 25% of the aggregate. Their size range is generally between approximately 5mm and 40mm. The sand is closely-graded between approximately 200µm and 1mm.

Portreath beach

The aggregate is a single product and consists of a mixture of poorly graded gravel and sand.

Coarse fraction

Cleaved dark grey mudstone (Mylor Series), vein quartz

Fine fraction

Major components:	quartz, calcareous shell fragments
Minor components:	stable silicate minerals (mainly tourmaline), coal

The coarse fraction is sub-rounded to rounded and ranges in size between about 5mm and at least 100mm. The sand is rounded and closely graded between approximately 200μm and 2mm. Proportions of coarse and fine fractions are very variable.

The aggregate is found in locally made blocks and mass concrete in Portreath and Bridgemoor.

Gannel Estuary–Crantock Bay

The aggregates include estuarine and beach gravels and sands used locally in the Newquay district, especially in mass concrete.

Gravels

Major components: cleaved dark grey calcareous mudstones (Meadfoot Beds), commonly with syntectonic quartz veins, white vein quartz

Minor components: fine-grained, dark grey sandstone, quartz-feldspar porphyry, lamprophyre, calcareous shell fragments (especially Mytilus)

Sands

Major components: quartz, calcareous shell fragments

Minor components: stable silicate minerals (mainly tourmaline), mudstone

Size range of individual aggregates is very variable.

In rare instances, concrete degradation which appears to be a consequence of aggregate expansion, is associated with the use of this material. The degradation mechanism has not been investigated.

Camel Estuary–Padstow Bay

The Camel Estuary was an important source of aggregate for concrete blocks and mass concrete.

Because the River Camel and its tributaries drain a region of complex geology, and because the upper reaches of some streams were areas of alluvial tin extraction, lithologies are very varied.

Major components: cleaved grey mudstone, cleaved purple and green mudstones (Lower Delabole slate), white and limonite-stained vein quartz

Minor components: fine-grained grey sandstone, metamorphosed dolerite, proterobase, lamprophyre, glassy grey granitic quartz, stable silicate minerals (mainly tourmaline), calcareous shell fragments, iron oxides (mainly goethite)

Fine gravel, (circa 200μm–10mm) was used in concrete blocks which are found in Wadebridge and Padstow and some of the nearby villages. Coarse, poorly sorted gravels, sometimes in combination with beach or dune sand, were often used in the Wadebridge area for mass concrete in footings and foundation concrete.

D5.3 River gravels

River gravels have been widely used as concrete aggregate throughout the region. Most streams and rivers in Cornwall were worked intermittently for alluvial tin from the Bronze Age until the early 20th century. Several rivers were used as discharge sites for the waste materials of underground metal mining and china clay extraction.

For these reasons sediments are often no longer naturally graded and in some cases they are heavily contaminated with mining waste. Four sources of river gravel have been identified. All are probably by-products of alluvial tin extraction.

Carnon Valley

The Carnon Valley drains the important St Day mineralised district, which includes the former United Mines complex, the Wheal Busy-Killefrith Mines and the recently abandoned Wheal Jane Mine. The valley was an important area for alluvial tin extraction until the early 1970s. Processed gravels provided a cheap and abundant source of concrete aggregate. Because underground mining proceeded at the same time as alluvial tin extraction and since the mines discharged their tailings into the river system, the gravels are often strongly contaminated by partially oxidised, sulphide-bearing waste.

Carnon Valley gravels are lithologically variable and complex. Some are relatively clean and dominated by mature, stable rock and minerals fragments; others are heavily contaminated by unstable, partly oxidised mining waste.

Major components: vein quartz, quartz-chlorite veinstones, quartz-tourmaline veinstones, cleaved grey mudstones (Mylor-Gramscatho Beds), pelitic hornfels

Minor components: greisen, granite, quartz-feldspar porphyry, iron oxides (mainly goethite), furnace clinker, chopped straw

Size range is usually between approximately 100μm and 5mm to 10mm. The gravels are made up of mixtures of rounded pebbles and grains and angular to sub-angular fragments that represent penecontemporaneous mine waste. In some materials most of the particles have patinas or crusts of limonite. Limonitic pebbles may enclose cores of unaltered sulphide minerals. Fine-grained authigenic pyrite occurs sparingly as replacements of organic debris. Calculated pyrite contents as high as 0.5% have been recorded from concrete made with these materials.

Concrete blocks made with Carnon gravels are found in Falmouth and villages bordering the valley, including Perranwell, Perranwell Station and Perranaworthal. They are sometimes seriously degraded.

Camborne–Redruth district

Fine gravels and river sands were occasionally used in concrete in the Camborne-Redruth district. Specific sources have not been identified with certainty but there are many possibilities because most streams in the area were worked for alluvial tin in the 19th and early 20th centuries.

Major components:	quartz, stable silicate minerals (mainly tourmaline, micas and chlorite), fine-grained veinstone fragments
Minor components:	iron oxides, fine-grained pelitic hornfels, fine-grained basic hornfels

The materials are fine grained (circa between 100μm and 2mm to 5mm) and are usually found as the sand fraction in gap-graded aggregates where the coarse material is often local mining waste. Their sulphide content is generally very low (<0.1%) but because they were commonly used in combination with high-sulphide mine waste they are often found in degraded concrete.

Tresillian River, Ladock area

The Tresillian River was formerly an important source of alluvial tin. Its headwaters are on the St Austell granite and the cassiterite was derived mainly from sulphide-poor lodes and disseminated deposits in the pluton. The Tresillian sediments were not significantly contaminated by sulphide-bearing waste.

Major components:	cleaved dark grey, calcareous mudstones (Meadfoot Beds), fine-to medium-grained, brown-coloured feldspathic greywacke (Grampound Grit), limonite-stained vein quartz, glassy grey granitic quartz
Minor components:	stable silicate minerals (mainly tourmaline and muscovite), quartz tourmaline veinstones, iron oxides

Tresillian valley gravels are generally mixtures of rounded pebbles and grains and angular to sub-angular fragments graded between approximately 100μm and 10mm. They are found in concrete blocks in Ladock, Tresillian and parts of Truro.

St Columb Minor area

The unnamed stream that enters the sea immediately north of Newquay at St Columb Porth (SW 831 628) was an important site of alluvial tin working. It appears to have yielded gravel which was used very locally for concrete block manufacture in St Columb Minor and probably also in other villages including St Columb Road and Whitecross. The headwaters of this stream rise in the Indian Queens area, where sulphide-free tin ores were mined extensively between the 17th and 19th centuries.

Major components:	limonite-stained vein quartz, glassy grey granite quartz, fine-grained grey sandstone (Staddon Grit)
Minor components:	cleaved grey mudstone, metadolerite, stable silicate minerals (mainly tourmaline), iron oxides

The gravel contains a mixture of rounded grains and pebbles and angular to sub-angular fragments characteristic of steam sediments contaminated by mining waste. It is graded between approximately 100μm and 5mm to 10mm.

Other areas

River gravels and sand have been identified as aggregate in other areas of Cornwall and south Devon, but their provenance has not yet been established with certainty. For example, gravels from the River Lynher were probably used extensively as concrete aggregate in the Saltash and Torpoint areas. Poorly made concrete in Salcombe contains gravel with Start Complex greenschist pebbles that must have been extracted from the lower reaches of the Kingsbridge estuary.

D6 Sedimentary and metasedimentary rocks (RICS Classification Groups 1–6, 2–1)

Sedimentary and metasedimentary rock aggregates were for some time assumed to be responsible for accelerated general degradation of concrete in the region (Department of the Environment Circular BSBRC/P(91), February 1991). Usually, the materials in question were not quarried rock aggregates but pelite-dominated mining and ore processing wastes (Group 2–2). In the past very little quarried sedimentary and metasedimentary rock was used as aggregate. Two main sources are identified.

D6.1 Upper Delabole Slate

Crushed slate from Delabole or nearby quarries was used as aggregate for concrete block manufacture until quite recently and there are no known cases where it has caused concrete degradation.

Major component:	pale green-grey slate
Minor components:	quartz and calcite veinstones

The aggregate is angular and its size range is generally between approximately 100μm and 10mm. It contains traces of sulphide minerals including pyrite, pyrrhotite, chalcopyrite and pale brown sphalerite, generally as disseminated crystals and in cleavage-parallel stringers. The total sulphide mineral concentration in the aggregate is normally <0.1%.

Concrete blocks made with Delabole Slate aggregate are found mainly in north Cornwall (Wadebridge, Camelford, Bude) but are also occasionally encountered elsewhere in the county, for example the Camborne–Redruth area and St Agnes. There is no evidence that the aggregate is responsible for accelerated concrete degradation.

D6.2 Devonian Limestone

Limestone aggregate, from quarries in south Devon, is found in concrete blocks in east Cornwall and the Plymouth area, either alone as an all-in aggregate or blended with china clay waste, dolerite or gravel.

Major components:	fine-grained, recrystallised pale to dark grey limestone
Minor components:	calcite, calcite-haematite veinstones

The aggregate is angular and its size range is generally between approximately 100μm and 10mm. Concrete made with this aggregate commonly has distinctive pink-coloured cement caused by sliming of earth red haematite from the veinstones.

D6.3 Miscellaneous sedimentary rocks

Quarried Lower Carboniferous mudstone and chert were formerly used as an aggregate for concrete block manufacture in the Launceston area. The aggregate is sometimes weakly mineralised and it was originally classified as a Group 2–1 material. Investigations of many properties built with concrete blocks containing mudstone/chert aggregate indicate that it is normally stable. This is supported by recent research at BRE Ltd, which shows that concrete made with the aggregate does not undergo significant expansion when subjected to moisture sensitivity (Stage 3) testing. The aggregate may be classified as a Group 1–6 material. If there is no evidence of aggregate-related or other degradation, concrete made with mudstone/chert aggregate may be assigned to Class A_1. Chert-dominated aggregates are also found in parts of South Devon, for example at Lydford. These also appear to be stable and may be classified as Group 1–6 materials. Concrete made with the aggregate may be assigned to Class A_1, provided it appears sound.

Coarse, poorly graded sedimentary rock aggregates of Devonian age are often found in mass concrete footings or foundations in combination with china clay waste or beach sand, especially in Newquay and some rural areas. The aggregates are often partly weathered and usually of very local origin. Commonly, they appear to have been produced from excavations carried out in conjunction with the building of the property or from one of the numerous small quarries opened to provide stone for the repair of tracks and dry stone walls. Some of this concrete is poorly constructed, but there is no evidence of aggregate-related degradation. If the concrete is well constructed and appears sound, and if there is no evidence of in situ aggregate alteration or aggregate-related degradation, these aggregates may also be classified as Group 1–6 materials.

D7 Mining and ore processing wastes (RICS Classification Groups 1–6, 2–2)

The mines of Cornwall and Devon produced more than two and a half million tonnes of tin and two million tonnes of copper, together with smaller quantities of many other metals including tungsten, arsenic, lead, zinc, silver, antimony and uranium (Table D2). In view of the fact that tin ores typically had grades of about 1%–2% and copper ores 4%–6%, it is scarcely surprising that huge quantities of spoil accumulated in the former mining districts. This material was a cheap, abundant and often conveniently-sized source of concrete aggregate.

It is important to distinguish between mining and ore processing wastes. Mining wastes, from shaft sinking, crosscutting, etc., are mainly normal host rocks. Such wastes were generally too coarse to have been used as concrete aggregates unless they were re-crushed, though they are found very rarely as coarse aggregate in mass concrete. Processing wastes, on the other hand, were often already of an ideal size range for use as all-in aggregate (usually jig tailings or more recently ‘heavy medium separation’ (HMS) rejects) or sand (from shaking tables, spirals, etc.). Coarse, hand-cobbed copper waste was used in mass concrete in parts of Camborne. Calciner tailings are found in Camborne and Redruth. Processing wastes usually contain less sulphide minerals than the run of mine ore, though this is not necessarily the case. For example, some sand tailings from granite-hosted tin ores may contain several percent of liberated pyrite even though the feed material carried much less than 1%.

TABLE D2: Cornwall and Devon mining statistics

Metal/mineral	Estimated total production (tonnes)
Tin (metal)	2,500,000
Copper (metal)	2,000,000
Arsenic (As_2O_3)	250,000
Lead (metal)	250,000
Zinc (metal)	25,000
Tungsten (WO_3)	5,600
Silver (ores)	2,000
Silver (from lead)	235
Uranium (ores)	2,000
Antimony (ores)	1,000
Cobalt and nickel (ores)	500
Iron ore	2,000,000
Manganese ore	100,000
Barite	500,000
Fluorite	10,000
Pyrite	150,000
China clay	100,000,000

The province has also yielded very small and unrecorded quantities of gold, radium (from uranium ores) and molybdenum.

Most iron and manganese ores were won from deposits not associated with the granite-related mineralised system.

Most metalliferous ores in south-west England occur in narrow, steeply-dipping lodes. The run of mine ore usually has three components. These are the lode material itself, altered wallrock which forms halos adjacent to the lode, and unaltered country rocks.

From a geological standpoint, and in terms of their performance as concrete aggregates, the ores may be divided into three classes:

1 hypothermal, endogranitic ores
2 hypothermal, exogranitic tin-copper ores
3 mesothermal, mudstone-hosted lead ores.

The principal components of these materials are listed below; less common ones are shown in parentheses.

Hypothermal, endogranitic tin ores

Lode materials: polyphase quartz-tourmaline microbreccia (coarse vein quartz, quartz-chlorite-green fluorite veinstones)

Altered wallrock: haematised and tourmalinised granite (greisen, chloritised granite)

Host rock: coarse-grained two-mica granite (quartz feldspar porphyry)

Sulphide minerals: pyrite, arsenopyrite, chalcopyrite, usually <0.1%

Hypothermal, exogranitic tin-copper-arsenic ores

Lode materials: quartz-chlorite-green fluorite veinstones (quartz- tourmaline veinstones)

Altered wallrock: chloritised and tourmalinised metapelite, sometimes with disseminated sulphide minerals, metadolerite muscovitised metapelite, basic skarns)

Host rock: pelitic hornfels, metadolerite (cleaved grey mudstone)

Sulphide minerals: chalcopyrite, arsenopyrite, pyrite (dark brown sphalerite)

Mesothermal, mudstone-hosted lead ores

Lode materials: Vein quartz, quartz-colourless, yellow or purple fluorite veinstones, quartz-carbonate veinstones (barite, ankerite)

Altered wallrock: pyritised mudstone (chloritised mudstone)

Host rock: cleaved, pale and dark grey mudstone (dolerite)

Sulphide minerals: galena, pyrite (pale brown sphalerite, chalcopyrite, grey copper sulphides, bournonite)

D7.1 Granite-hosted tin (tungsten) mining waste

In some cases it has been possible to identify specific sources, in others it is only possible to suggest general indications of provenance. The cement in concrete made with these materials is commonly stained pink by fine haematite eroded from the aggregate.

HMS rejects, South Crofty mine

Tailings from the former heavy medium separation (HMS) plant at South Crofty Mine, Pool (SW 664 411), were used locally as concrete aggregate until the mid-1970s.

The material is found mainly in mass concrete though some blocks made with this aggregate are known from Camborne, Redruth and Illogan.

Major components: haematised and tourmalinised granite, quartz-tourmaline veinstones

Minor components: unmineralised granite + component minerals, quartz-haematite veinstones, quartz-chlorite veinstones, vein quartz, green fluorite

Sulphide minerals: pyrite, arsenopyrite, chalcopyrite

The total sulphide mineral concentration in the aggregate is usually <0.2%. The material is angular with size range between <1mm and 10mm or 15mm. It is sometimes found as an all-in aggregate or as the coarse fraction in combination with tailings sand or dune sand from Gwithian, near Hayle. There are no recorded instances of concrete degradation associated with this material.

Granite-hosted tin mining waste, St Ives area

The source of this material is believed to be the former Wheal Reeth mine (SW 503 370). The aggregate is found exclusively in St Ives, mostly in concrete blocks where it is often blended with about 15% of local beach sand.

Major components:	tourmalinised, chloritised and haematised granite, quartz-tourmaline veinstones, vein quartz
Minor components:	quartz-chlorite veinstones, quartz-haematite veinstones, stable silicate minerals (mainly tourmaline and chlorite)
Sulphide minerals:	pyrite (<0.1%)

The aggregate is angular and ranges in size between approximately 100µm and 12mm to 20mm. There are no recorded instances of concrete degradation associated with this material. Cement is stained orange-pink by fine-grained iron oxides eroded from the aggregate.

Tungsten mining waste, Castle an Dinas mine, Indian Queens

This small former tungsten mine in the Castle an Dinas granite stock (SW 947 629) was operated by South Crofty between 1918 and its closure in 1956. Ore was jigged at the mine and then sent to South Crofty in Camborne for further processing. Concrete blocks made with this aggregate are found occasionally in the Camborne–Redruth area and in Newquay. It is not clear whether they were manufactured at the mine or at South Crofty.

Major components:	coarse splintery vein quartz, greisen, striped tourmalinised pelitic hornfels
Minor components:	lithium mica granite, sericitised mudstone, cleaved grey mudstone, stable silicate minerals (mainly tourmaline and muscovite
Sulphide minerals:	chalcopyrite (traces only), the steel grey mineral which resembles arsenopyrite is actually lollingite ($FeAs_2$)

The aggregate is angular and graded between approximately 100µm and 10mm. It is easily recognised by the presence of traces of wolframite locked with vein quartz. There are no records of concrete degradation associated with this material and, providing the concrete is sound, this aggregate type can be assigned to Group 1–6.

D7.2 Exogranitic tin – copper – arsenic ores

These materials are responsible for most aggregate-related concrete deterioration in west Cornwall. Degradation is caused mainly by oxidation of liberated and easily accessible sulphide minerals and direct sulphate attack on carbonated cement paste.

This causes local expansion of the cement, failure of cement aggregate bonds and pore volume collapse. Deterioration generally occurred rapidly after construction though the concrete has usually remained serviceable for many years.

The use of aggregates made from exogranitic tin-copper mining and processing wastes in concrete blocks and mass concrete was widespread in the Camborne–Redruth and St Agnes–Perranporth areas and in villages on the flanks of the Tregonning-Godolphin granite pluton. Similar aggregates are also found in Hayle. Coarse mine waste, in combination with china clay waste, beach or river sand, is common in mass concrete footings and foundations in Falmouth and surrounding villages and in Truro. Because of the very large number of former mines that exploited these ores it has proved impossible to identify specific sources.

In the Camborne–Redruth area many mines worked exogranitic tin-copper ores emplaced into pelitic and basic hornfels above the northern flank of the Carn Brea granite. The enormous areas of spoil that formerly occupied the site of the Pool Industrial Estate (SW 674 414) are a likely source for much aggregate in this area. The presence of abundant sphalerite indicates that the coarse aggregate used in mass concrete in Truro and Falmouth came from the St Day mineralised area. The aggregate commonly used in mass concrete in Perranporth probably came from the former Wheal Leisure Mine, located where the Ponsmere Hotel now stands (SW 758 444). It is difficult to establish sources of aggregate in the area overlooking Mount's Bay though the presence of galena in some concrete in Goldsithney suggests Penberthy Croft Mine (SW 555 331) as a possible candidate.

Major components:	quartz-chlorite-(green fluorite) veinstones, vein quartz, pelitic hornfels, chloritised metapelite, cleaved grey and blue-grey mudstones
Minor components:	metadolerite, quartz-feldspar porphyry (major components locally), quartz-tourmaline veinstones, tourmalinised metapelite, iron oxides (mainly goethite), stable silicate minerals (mainly chlorite and tourmaline)
Sulphide minerals:	pyrite, chalcopyrite, arsenopyrite, sphalerite (not in Camborne-Redruth area), trace amounts of bornite, chalcocite, digenite, covellite and galena (Mount's Bay area only)

Initial sulphide mineral concentrations may exceed 1%. In some aggregates the sulphides have a strong 'nugget'-like distribution and it is difficult to estimate average concentrations from single specimens.

Aggregates of this type were used in a wide variety of size distributions. Low fines mass concrete with maximum aggregate size of >100mm was made in Camborne. The materials are also found in concrete blocks as single source all-in aggregate ranging in size between about 100μm and 10mm to 30mm. They occur as blended all-in aggregate with furnace clinker, crushed granite, china clay waste and various gravels. In mass concrete in Falmouth and Truro they are combined with china clay waste, granite and beach gravel.

Concentrations of acid soluble sulphate, total sulphur and calculated pyrite are extremely variable. Some completely degraded concretes have sulphate contents >1.5% as SO_4. Calculated pyrite content varies between <0.1% and >2%. In low fines mass concrete in Camborne, large variations commonly occur in closely adjacent parts of the same structure. This is attributed to the 'nugget'-like distribution of coarse sulphide minerals and difficulties in obtaining suitably large, representative specimens during the course of standard sampling procedures.

D7.3 Arsenic calciner wastes

Arsenic minerals are associated with sulphide copper ores in most parts of the Cornubian orefield. Arsenic was recovered from ores in several areas of south-west England during the late 19th and early 20th centuries. Arsenical ores were roasted under strongly oxidising conditions in calciners; sulphur oxides were discharged to the atmosphere and the white arsenious oxide was condensed in stone-lined or concrete labyrinths. Calciner wastes were occasionally used as concrete aggregates in Camborne and Redruth. They are composed of thermally stable quartz and silicate minerals, abundant fine-grained red haematite and variable amounts of unoxidised sulphide minerals. The most distinctive feature of concrete made with calciner waste is its deep red-brown colour, the consequence of abundant fine-grained iron oxides (mainly haematite) in the cement.

Major components:	reddened quartz-chlorite veinstones and pelitic hornfels, vein quartz, red iron oxides
Minor components:	quartz-tourmaline veinstones, vein quartz, silicate minerals (iron II minerals are always strongly oxidised)
Sulphide minerals:	pyrite, chalcopyrite and arsenopyrite may be preserved as unreacted cores in iron oxide pellets

Arsenic calciner wastes are found as all-in aggregates, generally graded between <50μm and about 5mm to 15mm. They are not sufficiently abundant for their performance to be judged with confidence though instances of accelerated deterioration of concrete with calciner waste aggregate are known from parts of Camborne.

D7.4 Mudstone-hosted lead ores

Unlike aggregates made from tin and copper ores these materials can be traced to two specific sources: the former East Wheal Rose lead mine, near Newlyn East, and Wheal Mary Anne at Menheniot. Both mines produced enormous quantities of conveniently sized and graded jig tailings. A concrete block plant was operated at East Wheal Rose during the 1920s and 1930s; at Wheal Mary Anne the block plant was in production at least until 1951 and possibly into the early 1960s. The use of these wastes is responsible for most concrete degradation in the Perranporth-Newlyn East area and virtually all of that in east Cornwall. The materials carry little liberated pyrite or other sulphides but have altered wall rock with fine, disseminated pyrite. Degradation results from oxidation of this fine pyrite, bulk expansion of the aggregate and growth of secondary sulphate minerals at aggregate-cement interfaces. Deterioration proceeds more slowly than that associated with the use of tin-copper ores and may not be apparent even after 50–60 years. Initial pyrite concentrations of less than 0.5%, possibly only 0.2%, may be enough to cause major damage.

Lead ore processing waste, East Wheal Rose mine

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

Major components:	cleaved, dark grey mudstone, black pyritic mudstone, vein quartz
Minor components:	calcite, purple fluorite, barite
Sulphide minerals:	galena, pale brown sphalerite, pyrite (in veinstones), very fine-grained disseminated pyrite (in mudstone)

Residual sulphide mineral concentrations are commonly about 0.2%. The aggregate is often strongly limonite-encrusted, though it is not always clear whether this is a result of in situ oxidation or a consequence of natural weathering before the concrete was made.

The material was generally used as all-in aggregate, graded between about 100μm and 5mm or 10mm 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 or china clay waste.

Lead ore processing waste, East Cornwall

The main source of the aggregate has been traced to a block making plant located at the former Wheal Mary Anne Mine (SX 288 634), near Menheniot. The plant is still recognisable, though the site is now used for other industrial purposes. There were two other silver-lead mines of comparable size in the area and it is possible that these also provided material for concrete manufacture.

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 A_2.

There are two main groups of old silver-lead mines in east Cornwall. They were developed on N-S trending lode systems which lie to the south-west and east of Liskeard. Both lode systems supported a number of small mines which operated mainly in the second half of the 19th century.

The most important mines were:

Wheal Mary Anne	4km south-east of Liskeard	SX 288 634
Wheal Trelawney	3.5km east of Liskeard	SX 287 635
Herodsfoot	6km south-west of Liskeard	SX 212 600

Wheal Mary Anne and Herodsfoot Mine were in production before 1845 when the Mining Records Office was established. However, at Wheal Mary Anne the main period of production was between about 1850 and 1875. Wheal Trelawney was reworked for arsenic between 1898 and 1902. During the 1940s and 1950s attempts were made to recover fluorite from the dumps at Wheal Mary Anne and Wheal Trelawney.

The only significant lead producer in the east of the county was Wheal Callington (SX 357 710), near Callington town. This mine was unusual because it lay in the heart of a prolific tin and copper mining area. Tin and copper mining wastes were far more abundant and it is likely that any local block production was from these sources.

Wheal Mary Anne and Wheal Trelawney worked adjacent parts of the same lode system. The host rocks are soft, cleaved Middle Devonian mudstones with occasional lenticular horizons of lithic tuff.

The N-S trending lode varied in width between 0.75m and 1.25m. It was made up principally from quartz, fluorite, calcite, siderite, barite and galena, with minor amounts of chalcopyrite and sphalerite. Small quantities of cerussite and pyromorphite occurred at shallow levels. The lode was bordered by a zone of wallrock alteration of unrecorded width in which the mudstones were indurated and carried abundant disseminated pyrite. Because of the width of the lode, altered wallrock would have been sent to ore.

The principal mineralogical characteristics of the Wheal Mary Anne aggregate are as follows:

Major components: cleaved grey mudstones, dark grey pyritic mudstones, vein quartz, colourless and pale yellow fluorite

Minor components: chalcedonic quartz, calcite, siderite, barite

Sulphide minerals: pyrite, galena, minor chalopyrite and sphalerite (in veinstones), fine-grained disseminated, commonly framboidal pyrite in mudstone

Total sulphide mineral concentrations are generally <0.5%.

The aggregate is angular and graded between approximately 100µm and 10mm or 15mm. 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.

The N-S lode at Herodsfoot is emplaced into Lower Devonian Meadfoot Beds (cleaved, calcareous mudstones, sandstones, siltstones and thin limestones). It varied in width between approximately 0.3m and 1.25m. It was made up principally of quartz, ankerite, calcite and galena. There were small amounts of sphalerite, barite and dolomite. Antimonite, tetrahedrite and bournonite were recorded from higher levels; chalcopyrite was present in the deeper parts of the mine. There was no fluorite, nor is there any record of wallrock alteration.

The presence or absence of fluorite serves to differentiate between materials from Wheal Mary Anne and Trelawney and from Herodsfoot. Distinctive pink-coloured ankerite and the sulphosalts in the Herodsfoot ore are also useful for source identification.

Wheal Mary Anne and Wheal Trelawney each produced between 20,000t and 30,000t of ore after 1845. This suggests that 100,000 to 150,000t of processing wastes, mainly jig tailings, were generated at each site.

The aggregate is found in concrete blocks in many towns and villages in east Cornwall, notably Liskeard, Callington, East and West Looe, Polperro and many nearby villages. The performance of concrete made with Wheal Mary Anne waste is very variable. In some properties built in the 1930s the concrete remains in sound condition; in others there is clear evidence of incipient degradation, especially at the inner faces of blocks used in cavity wall construction. In a few instances degradation has proceeded so far that demolition has been necessary.

It is possible that material from the former Herodsfoot Mine, south-east of Liskeard, was used as aggregate. There is clear evidence that material has been removed from waste dumps in large quantities. Its distinctive mineral assemblage is easily recognised, but so far it has not been found in domestic concrete.

Only a few reliable chemical analyses of concrete made with lead ore processing wastes are available (Table D3). Wastes from East Wheal Rose and Wheal Mary Anne have considerable ranges of sulphate, total sulphur and calculated pyrite contents. Two specimens with high sulphate content (one from each source) are strongly degraded Class C concrete. The remaining specimens, with <0.5% SO4 and about 0.5% or less calculated pyrite, include material which appears completely sound and that which shows incipient to moderate degradation. Generally, sulphide content determined by visual estimation under the stereomicroscope is significantly less than the calculated pyrite content. This is because of the difficulty in identifying extremely fine-grained, disseminated pyrite in altered wallrock fragments without recourse to study of polished specimens under the reflected light polarising microscope.

Table D3: Example analyses of concrete made using aggregates from lead over processing wastes

Specimen no.	Source of aggregate	Sulphate, as SO_4 (% by mass)	Total sulphur, as S weight (% by mass)	Calculated pyrite, FeS_2 (% by mass)
1,488/1	East Wheal Rose	0.24	0.14	0.11
1,685/1	Wheal Mary Anne	0.06	0.18	0.29
2,184/1	Wheal Mary Anne	0.47	0.39	0.44
2,558/1*	East Wheal Rose	0.12	0.05	0.02
2,558/2*	East Wheal Rose	0.13	0.05	0.01
2,612/1	East Wheal Rose	0.88	0.38	0.16
2,617/1*	Wheal Mary Anne	0.36	0.42	0.56
2,617/2*	Wheal Mary Anne	0.31	0.33	0.42
2,698/1*	Wheal Mary Anne	1.69	0.62	0.10
2,698/2*	Wheal Mary Anne	0.14	0.20	0.28

**Denotes analysis from different concrete blocks in the same property*

D8 Metalliferous smelter slags and incinerator wastes (RICS Classification Group 2–3)

Tin, copper and lead ores were formerly smelted at many sites in Cornwall. Copper and lead smelting ceased in the early 19th century but tin smelting continued in west Cornwall until the 1920s.

At Hayle, copper slag was cast into blocks for construction purposes. These proved very durable and examples may be seen in retaining walls and jetties at Hayle harbour and in Phillack Church.

Smelter slags were also crushed for use as aggregate though they have only been identified with certainty as the coarse fraction in mass concrete. The slags may be divided into three groups.

D8.1 Tin slags

Cassiterite tin ores were freed as far as possible from sulphide minerals before smelting. Because of the high temperature at which cassiterite ores were smelted, any remaining sulphides were usually removed leaving an oxide-silicate slag. Tin slags are typically black, hypohyaline, vesicular materials in which prills of metallic tin are easily recognised in polished section under the ore (reflected-light) microscope. Though experience of these materials is limited there is no evidence which suggests they have deleterious properties when used as concrete aggregates.

D8.2 Copper slags

Sulphide copper ores were smelted at lower temperatures than oxide tin ores and sulphide phases are present in the slags. Copper slags are generally black, hypohyaline and variably vesicular. They may sometimes be recognised in hand specimen by patchy green encrustations of secondary basic copper carbonate. In polished specimen identification is easily confirmed by the presence of prills of metallic copper and grey copper sulphide minerals. Experience of these materials is very limited though there is evidence of degradation of mass concrete associated with sulphide oxidation in slag in the St Blazey and Par districts.

D8.3 Sulphide tin slag

During the 1920s a small smelter operated in Penryn to treat imported Bolivian tin ores. Unlike Cornish ores, the tin was present in a variety of sulphide minerals including stannite, teallite, cylindrite and herzenbergite. The ores were smelted at lower temperatures than oxide ores and sulphides are present in the slags. The slag has been found in partly degraded concrete in the footings of a single property in Penryn. Its recognition depends on identification of traces of tin sulphides and sulphosalts, under the ore microscope or by scanning electron microscopy/energy dispersive X-ray microanalysis.

No lead slags have been recognised as concrete aggregates in the region.

D8.4 Incinerator waste

The commercial incinerator waste used in Falmouth presents special problems. It is a very inhomogeneous material, which carries, in addition to the products of coal burning, fragments of metal artefacts, partly devitrified glass, carbonised wood and abundant sea shell fragments (shell fish were an important item in the local diet during the 1920s and 1930s). At least four problems have been recognised in this material:

1 expansion of partly burned and unburned coal and carbonised wood
2 oxidation of pyrite or marcasite
3 hydration and expansion of devitrified glass
4 during combustion calcareous shell fragments were partly converted to lime (CaO); rehydration and carbonation of lime after concrete manufacture have led to expansion and damage to the concrete.

The material is easily recognised by its inhomogeneity and especially the presence of metal fragments, glass and sea shells.

D9 Miscellaneous aggregates

A number of other materials have been used as concrete aggregate on rare occasions in the region. These include crushed brick (Redruth) and a single instance of unburned coal used as coarse aggregate in mass concrete. A variety of natural and artificial lightweight aggregates is found in concrete blocks used in inner leaf and internal wall constructions. These include natural hyaline pumice (Group 1–6), sintered pulverised-fuel ash and foamed slag (Group 1–4). Except for the unburned coal, there are no problems associated with these materials.

D10 Density of aggregate constituents

It is sometimes necessary for the petrographer to assess the influence of the aggregate material on overall concrete density (see section 3.11). Table D4 (overleaf) presents typical particle and bulk density data for a selection of natural and synthetic aggregate constituents for guidance purposes, but wherever possible the petrographer should endeavour to obtain data specific for the particular materials encountered.

Table D4: Aggregate density data

The density data in this table are mainly distilled from information given in St John, Poole and Sims 1998,[21] Sims and Brown 1998,[22] Smith 1999,[23] and Alexander and Mindess 2005.[24] Particle-density values (‘apparent’ basis) are provided for a range of dense or normal weight, mainly natural aggregates, while bulk density values are provided for a range of artificial, mainly lightweight materials. The density categories ‘extra dense’ (or ‘heavyweight’), dense (or ‘normal weight’), ‘lightweight’ or ‘ultra lightweight’ are defined by their bulk density ranges, as shown in the more darkly shaded rows at the start of the table.

Constituent	Type	Particle density* (apparent) Mg/m^3	Bulk density† (dry, uncompacted) kg/m^3
Extra-dense or heavyweight			>1,700
Dense or normal weight			1,000–1,700
Lightweight			300–1,000
Ultra-lightweight			<300
Air-cooled blast furnace slag	Synthetic – waste	2.0–4.8	1,000–1,500 or >1500
Andesite	Natural – igneous volcanic	2.5–2.8	
Barytes (barite)	Natural mineral		~2800
Basalt	Natural – igneous volcanic	2.6–3.0 (2.8)	
Beach sand and gravel	Natural – igneous, sedimentary and meta-basic	2.5–2.8	
Brick and tile	Synthetic – recycled		760–1,120

Constituent	Type	Particle density* (apparent) Mg/m³	Bulk density† (dry, uncompacted) kg/m³
China clay waste	Natural – waste	2.6–2.7	(1,000–1,700)
Colliery waste	Natural – waste		(1,000–1,700)
Concrete	Synthetic – recycled		(1,000–1,700)
Diorite	Natural – igneous	2.7–3.0	
Dolerite (or diabase)	Natural – igneous	2.8–3.0	
Dolomite (or dolostone)	Natural – sedimentary	~2.7	
Epidiorite	Natural – meta-igneous	~3.0	
Exfoliated vermiculite	Natural – processed		60–160
Expanded perlite	Natural – processed		50–40 or 320
Expanded polystyrene	Synthetic – manufactured		10–20
Expanded shale and clay	Natural – processed		320–720 or 960
Expanded slag	Synthetic – processed waste		700–970
Expanded slate	Natural – processed		460–800 or 860
Felsite	Natural – igneous	2.6–2.7	
Ferrosilicon/ferrophosphorus	Synthetic – waste		~4300
Flint sand and gravel	Natural – sedimentary	2.4–2.7 (2.5)	
Foamed glass	Synthetic – manufactured		240–260
Foamed slag	Synthetic – processed waste		480–960
Furnace bottom ash	Synthetic – waste		(300–1,000)
Furnace clinker and breeze	Synthetic – waste		720–1,040
Gabbro	Natural – igneous	2.8–3.0	
Glass	Synthetic – waste		(1,000–1,700)
Gneiss	Natural – metamorphic	2.6–3.4	
Granite	Natural – igneous	2.6–3.0 (2.7)	
Ground, granulated blast furnace slag (GGBS)	Synthetic – processed waste		(1,000–1,700)
Greywacke (sandstone type)	Natural – sedimentary	2.5–2.9	
Haematite (hematite)	Natural mineral		~3,000
Hornfels	Natural – metamorphic	2.7–3.0 (2.8)	
Iron and steel shot/ fragments	Synthetic		~4,800
Iron separated from slag	Synthetic – processed		~3,800
Lead shot	Synthetic		~8,000
Limestone	Natural – sedimentary	2.5–2.9 (2,7)	
Limonite or goethite	Natural minerals		2,100–2,200
Lytag (sintered PFA)	Synthetic – processed waste		770–1,040

Constituent	Type	Particle density* (apparent) Mg/m³	Bulk density† (dry, uncompacted) kg/m³
Magnetite or ilmenite	Natural minerals		2,600–2,700
Marble	Natural – metamorphic	2.6–2.8 or 3.2	
Mixed sand and gravel	Natural – igneous, sedimentary and metamorphic	2.5–2.8	
Mixed igneous gravel	Natural – igneous and metamorphic	2.6–2.9 (2.7)	
Non-ferrous slags	Synthetic – waste		(1,000–1,700)
Pelletised expanded slag	Synthetic – processed waste		~900
Pulverised-fuel ash (PFA)	Synthetic – waste		(1,000–1,700)
Pumice	Natural –acid volcanic		480–880
Quartzite rock or gravel	Natural – sed. & meta.	2.6–2.8 (2.6)	
Rhyolite	Natural – igneous	2.6–2.9 (2.7)	
Sandstone	Natural – sedimentary	2.5 –2.9 (2.7)	
Scoria	Natural – basic volcanic		720–1,300
Serpentinite	Natural – altered igneous	2.4–2.7	
Sintered colliery waste	Natural – processed		550–900
Sintered diatomite	Natural – processed		450–800
Sintered incinerator ash	Synthetic – processed waste		(300–1,000 or 1,700)
Sintered PFA (Lytag)	Synthetic – processed waste		770–960 or 1,040
Slate	Natural – rock or waste	2.7–2.9	(1,600–1,700)
Steel slag	Synthetic – waste		1,600–1,700
Syenite	Natural – igneous	2.7–3.0	
Volcanic slag	Natural – vesicular		700–1,200
Wood shaving and sawdust	Natural material – waste		3,520–480

** syn. 'relative density' or 'specific gravity' – values in parentheses are cited averages*

† value ranges in parentheses are those representing the relevant density category

Annex E Example templates for reporting Stage 1, 2 and 3 findings

Certificate of Test

Stage 1 Examination

RICS guidance note *The mundic problem*, 3rd edition

Your Ref		Lab Report Ref	R999
Address		Date of Receipt	
		Date of Examination/by	
		Report prepared by	
Surveyor		No of samples rec'd	

SAMPLE LOG

Sample ref	Type	Condition	Length (mm)	Mass (g)
C1	Core, 50mm diameter	Intact	75	164
C2	Core, 50mm diameter	Broken		203
C3	Core, 50mm diameter	Fragmented		153
C4	Core, 75mm diameter	Broken, damp		1954
C5	Core, 50mm diameter	Intact	105	223
C6	Chisel			407

TEST METHODS AND RESULTS

Examination in accordance with the RICS guidance note *The mundic problem*. The results of the Stage 1 testing and examination are given on the following pages. A summary of the results is presented below.

SUMMARY (details on following sheets)

Sample	Concrete Class / Aggregate Group(s) [25, 26]					Recommendations			
	A_1	U/C	C1	C2	N/A	Re-sample/ Inspect on site	Mass Concrete	Stage 2	
	Group 1 only	Group 1 & / or Group 2	Mainly Group 2	Mainly Group 1	Cannot assess		Dry density	Petro exam	Sulphide content
	Sound		Unsound						
C1	1–4								
C2	1–4								
C3	1–4								
C4		2–2 (1–1)					☒		
C6	1–4								

REMARKS

Sample C5 was entirely composed of red brick. Classification as concrete is not appropriate.
Sample C4, though broken, appears suitable for possible classification by the Dry Density test.

Certificate prepared by
John Smith
Petrographer

Certificate reviewed by
John Smith
Director

Date of issue: dd/mm/yy

Stage 1 Examination – supporting sheet(s), as required

RICS guidance note *The mundic problem*, 3rd edition

Concrete examination findings

Lab Sample Refs	*C1, 2, 3, 6*	Client Sample Refs	*CSTR 1, 2, 3, 6*

AGGREGATES				
Group	**Aggregate type**	**Description**	**Approx. size**	**Est. %**
1–4	*Furnace clinker and coking breeze*	*Carbonaceous-vesicular, hyaline and hypohyaline-vesicular and laminated furnace clinker, incompletely burned coal*	*1mm to 10mm*	*100*
Aggregate shape	*Angular*	**Aggregate grading**	*Continuous, moderate to good*	

SOUNDNESS ASSESSMENT[27]			
Aggregate reaction	*No obvious in situ oxidation*	**Aggregate cracking**	*Minor open cracking in laminated clinker*
Sulphide minerals	*None observed*	**Sulphide details**	*N/a*
Matrix colour	*Dark grey*	**Matrix condition**	*Uniform*
Degree of coating	*>50%*	**Bonding**	*Strong*
Carbonation	*Completely carbonated*	**Neat cement balls**	*None observed*
Matrix cracking	*None observed*	**Secondary minerals**	*None observed*
Voids, shape	*Sub-spherical*	**Voids, size**	*5mm*
Voids, distribution	*Moderate to high inter-connectivity slightly uneven distribution*	**Voids, secondary minerals**	*Calcite – rare*

Continued on next sheet, if required

Stage 1 Examination – supporting sheet(s), as required

RICS guidance note *The mundic problem*, 3rd edition

Concrete examination findings

Lab Sample Refs	*C4*	Client Sample Refs	*CSTR 4*

AGGREGATES				
Group	**Aggregate type**	**Description**	**Approx. size**	**Est. %**
2–2	*Furnace clinker and coking breeze*	*fine-grained pelitic hornfels, quartz–chlorite veinstones, vein quartz, iron oxides*	*5mm to 30mm*	*60*
(1–1)	*Granite-derived china clay waste*	*quartz, subordinate tourmaline, partly kaolinised feldspar, muscovite, pale brown mica*	*100µm – 5mm*	*40*
Aggregate shape	*Both angular*	**Aggregate grading**	*Both continuous, 2–2 moderate to poor, 1–1 good*	

SOUNDNESS ASSESSMENT[27]			
Aggregate reaction	*Limonite crusts on sulphide bearing veinstones and some hornfels, iron oxide halos in cement*	**Aggregate cracking**	*Minor limonite-filled fractures in veinstones*
Sulphide minerals	*Pyrite, chalcopyrite, arsenopyrite, sphalerite (0.5% vol visual estimate)*	**Sulphide details**	*Locked in veinstones and vein quartz, occasional pyrite veinlets in hornfels*
Matrix colour	*Greyish white to brownish cream, slightly discoloured by disseminated iron oxides*	**Matrix condition**	*Generally uniform, slightly soft and friable around strongly oxidised coarse aggregate fragments*
Degree of coating	*>90%*	**Bonding**	*Strong*
Carbonation	*Uncarbonated*	**Neat cement balls**	*None observed*
Matrix cracking	*Closed peripheral cracks round some large oxidised aggregate fragments*	**Secondary minerals**	*Limonite*
Voids, shape	*Sub-spherical*	**Voids, size**	*5mm*
Voids, distribution	*Low inter-connectivity, uneven distribution*	**Voids, secondary minerals**	*–None seen*

Certificate of Test

Stage 1 Testing – Density - extra supporting sheet, as required

RICS guidance note *The mundic problem*, 3rd edition

Your Ref		**Stage 1 Lab Exam Ref**	R999
Address		**Stage 1 Exam Date**	
		Lab Sample Ref	C4
		Client Sample Ref	
		Date Instructed	
Surveyor		**Date of Density Test**	
		Report prepared by	

TEST METHODS AND RESULTS

Examination in accordance with RICS guidance note *The mundic problem*, 3rd edition. A summary of the results is presented below. This procedure is only applicable to mass concrete assessed as 'sound' on Stage 1 examination but believed to contain a Group 2 aggregate. The density was determined in accordance with BS EN 12390-7.[28]

SUMMARY

Core portions:		1	2	3	4	5	Combined
Does concrete visually appear dense?		Yes / ~~No~~	Yes / ~~No~~	Yes / ~~No~~	Yes / No	Yes / No	
Density, kg/m^3	Dry	1990	2090	2000			2040
	Saturated	2100	2180	2110			2150

RECOMMENDATIONS – choose one of the three (the text in black fits the example)

The dry density of the size-compliant concrete sample is ≥2000kg/m^3 (or ≥2200kg/m^3 for a size non-compliant concrete sample), therefore the concrete should be classified as Class A_2.

Or

The mean dry density of a set of individually non-compliant concrete samples is ≥2000 kg/m^3, therefore the concrete should be classified as Class A_2.

Or

The dry density of the concrete is <2000kg/m^3, and therefore the sample should be subject to Stage 2 examination to determine classification.

REMARKS

Enter any relevant comments, or otherwise just enter 'None'.

Certificate prepared by

John Smith
Technician

Certificate reviewed by

John Smith
Director

Date of issue: dd/mm/yy

Certificate of Test
Stage 2 Testing
RICS guidance note *The mundic problem*, 3rd edition

Your Ref		Stage 1 Lab Exam Ref	
Address		Stage 1 Exam Date	
		Lab Sample Ref(s)	
		Client Sample Ref(s)	
		Date Instructed	
Surveyor		Examination date	
		Report prepared by	

TEST METHODS AND RESULTS

Examination in accordance with RICS guidance note *The mundic problem*, 3rd edition. The detailed Stage 2 examination findings and/or test results are given on the following pages. A summary of the results is presented below.

SUMMARY CLASSIFICATION & RECOMMENDATIONS

Sample	Concrete class / aggregate group(s)[29]					Chemical analysis undertaken[30]	Concrete recommended for Stage 3 expansion test
	A_1	A_2	B	C1	C2		
	Group 1 only	Group 1 & up to 30% Group 2	More than 30% Group 2	Mainly Group 2	Mainly Group 1		
	Sound			Unsound			
C1		1-6/2-2				☐	☐
C3			2–2, 1–1			☐	☒
C6			2–2, 1–1			☐	☒

REMARKS

The concrete represented by samples C3 and C6 must be assigned to Class B because of the aggregate composition. However, it may be appropriate material for further testing and possible reclassification under the Stage 3 moisture sensitivity (expansion) test.

Certificate prepared by
John Smith
Petrographer

Certificate reviewed by
John Smith
Director

Date of issue: dd/mm/yy

Stage 2 Examination – supporting sheets, as required

RICS guidance note *The mundic problem*, 3rd edition

Concrete examination findings

Lab Sample Refs	*C1*	**Client Sample Refs**	*CSTR 1*

AGGREGATES				
Group	**Aggregate type**	**Constituents**	**Approx. size**	**Est. %**
1–6 / 2–2	*complex mine waste*	*granite, mafic hornfels, quartz – chlorite (– haematite) veinstones, quartz–tourmaline veinstones, fine-grained pelitic hornfels, vein quartz, iron oxides*	*<100µm to 12mm*	*100*

Aggregate shape	*Angular*	**Aggregate grading**	*Continuous, moderate to good*

CONCRETE SOUNDNESS ASSESSMENT[31]			
Potentially deleterious Group 2–2 aggregates	*Pelitic hornfels, sulphide bearing veinstones*	**Est. % deleterious aggregates**	*<15%* *Visual est. ☐ OR point-count ☑*
Aggregate reaction	*Patchy pervasive haematisation in some hornfels and veinstone fragments, the absence of significant iron oxide impregnation halos in the enclosing cement suggest that the oxide coatings formed as a result of low temperature oxidative hydrothermal alteration and/or natural weathering before the concrete was made*	**Aggregate cracking**	*Internal cracking – none.* *Rare discontinuous peripheral cracks round some veinstone and hornfels fragments*
Sulphide minerals and occurrence	*Pyrite, chalcopyrite – locked in veinstones*	**Est. % sulphide**	*<0.5% Visual est. ☐ OR* *Point-count ☑ OR Chemistry ☐*
Matrix details and condition	*Mottled, pale brown to cream. No portlandite present. Sporadic, typically coarse clusters of relict hydrated clinker*	**Matrix cracking**	*None.*
Carbonation	*Completely carbonated, coarsely recrystallised paste with sporadic snowflake calcite, locally strong evidence of significant leaching*	**Matrix secondary minerals**	*Microcrystalline calcite – common*
Voids, shape and size range	*Sub-spherical to irregular, <100µm to 5mm, average 2mm*	**Est. % voids**	*<20%* *Visual est. ☐ OR point-count ☑*
Voids, distribution	*Moderate inter-connectivity slightly uneven distribution*	**Voids, secondary minerals**	*Calcite – rare*
Other observations	*There is evidence that the concrete has undergone locally strong recrystallisation and leaching, but the concrete remains sound in bulk with no other significant evidence of deterioration*		

REMARKS

Stable (non-deleterious) components of the mine waste aggregate are re-grouped to Group 1–6.

Stage 2 Examination – supporting sheets, as required

RICS guidance note *The mundic problem*, 3rd edition

Concrete examination findings

Lab Sample Refs	*C3 & C6*	**Client Sample Refs**	*CSTR 3 & 6*

AGGREGATES				
Group	**Aggregate type**	**Constituents**	**Approx. size**	**Est. %**
2–2	*Pelite hosted mine waste*	*Low grade pelitic hornfels, weathered brown mudstone, quartz – limonite veinstones, quartz – chlorite veinstones, stable silicate minerals, iron oxides.*	*5mm to 35mm*	*70*
1–1	*China clay waste*	*Quartz, subordinate tourmaline, partly kaolinised feldspar, muscovite, pale brown mica, quartz-tourmaline veinstones.*	*<100µm to 5mm*	*30*
Aggregate shape	*Both angular*	**Aggregate grading**	*Aggregate 2–2 continuous, moderate* *Aggregate 1–1 continuous, good*	

CONCRETE SOUNDNESS ASSESSMENT[31]			
Potentially deleterious Group 2–2 aggregates	*Fine-grained pelitic hornfels, sulphide bearing veinstones, aggregate fragments showing evidence of in situ oxidation*	**Est. % deleterious aggregates**	*45%* *Visual est. ☐ OR point-count ☒*
Aggregate reaction	*Aggregate 2–2: Locally strong limonitisation and haematisation in veinstones and hornfels. Common crusts on sulphide bearing veinstones and liberated sulphide grains up to 200µm wide* *Aggregate 1–1: No obvious in situ oxidation*	**Aggregate cracking**	*Aggregate 2–2: Rare internal cracks in some pelitic aggregate fragments <200µm with partial calcite fills. Rare peripheral cracks in some pelitic aggregate fragments <50µm with partial calcite fills* *Aggregate 1–1: None*
Sulphide minerals and occurrence	*Aggregate 2–2: Pyrite, chalcopyrite – locked in vein quartz and veinstones, disseminated pyrite in mudstones* *Aggregate 1–1: None*	**Est. % sulphide**	*<0.5% Visual est. ☒ OR* *Point-count ☐ OR Chemistry ☐*
Matrix details and condition	*Uniform, pale brown. No portlandite present. Sporadic, typically coarse clusters of relict hydrated clinker*	**Matrix cracking**	*Rare open microfractures in proximity to some pelitic aggregate fragments*
Carbonation	*Completely carbonated, fine recrystallised paste, no evidence of significant leaching*	**Matrix secondary minerals**	*Calcite – rare.* *Ettringite – rare.*
Voids, shape and size range	*Sub-spherical to irregular, <100µm to 5mm, average 2mm*	**Est. % voids**	*<20%* *Visual est. ☐ OR point-count ☒*
Voids, distribution	*Moderate inter-connectivity, slightly uneven distribution*	**Voids, secondary minerals**	*Calcite – rare* *Ettringite – rare*
Other observations	*The concrete appeared sound with no significant evidence of deterioration* *However, the proportion of potentially deleterious aggregate is above the allowable limit for Class A_2 concrete and, therefore, the concrete in these samples should be assigned to Class B*		

REMARKS

None.

Certificate of Test

Stage 2 Testing – Chemical Analysis – extra supporting sheet, as required

RICS guidance note *The mundic problem*, 3rd edition

Your Ref		Stage 1 Lab Exam Ref	
Address		Stage 1 Exam Date	
		Lab Sample Ref	
		Client Sample Ref	
		Date Instructed	
Surveyor		Date of Chemical Test	
		Report prepared by	

TEST METHODS AND RESULTS

Test in accordance with RICS guidance note *The mundic problem*, 3rd edition. A summary of the results is presented below. This procedure is only applicable to concrete assessed as 'sound' on Stage 1 or Stage 2 examination but visually appearing to contain a high sulphide and/or sulphate content. The chemical analyses were determined in accordance with BS EN 1744-1:2009+A1:2012.[32]

SUMMARY

Chemical analysis	Aggregate group	Maximum criteria	Result
- S, Total sulphur (%S)			
- AS, Acid soluble sulphide (%SO_3)		*0.5%*	
- SC, Calculated sulphide content (S – (AS x 0.33))			
- Calculated equivalent pyrite content (SC x1.86)		*1.5%, Group 1–3* *1.0%, Group 1–6/2–2* *1.0%, Group 2*	

RECOMMENDATIONS

The results of the chemical analyses for total sulphur and acid soluble sulphate of the sample give the concrete tested an acid soluble sulphate and/or calculated pyrite equivalent content above the limit criteria. The concrete should be classified as **Class B.**

Or

The results of the chemical analyses for total sulphur and acid soluble sulphate of the sample give the concrete tested an acid soluble sulphate and/or calculated pyrite equivalent content not exceeding the limit criteria. **The concrete should be classified by the findings of the Stage 1 or Stage 2 petrographic examinations.**

REMARKS

None

Certificate prepared by

John Smith
Technician

Certificate reviewed by

John Smith
Director

Date of issue: dd/mm/yy

Certificate of Test

Stage 3 testing – Moisture Sensitivity/Expansion

RICS guidance note *The mundic problem*, 3rd edition

Your Ref		**Stage 1 Lab Exam Ref**	
Address		**Stage 1 Exam Date**	
		Lab Sample Ref(s)	
		Client Sample Ref(s)	
		Date Instructed	
		Date of Test Start	
		Date of Petrographic Comparison	
Surveyor		**Report prepared by**	

TEST METHODS AND RESULTS

Expansion testing and high-power microscopic examination in accordance with RICS guidance note *The mundic problem*, 3rd edition and APG SR2.[3] The Stage 3 test is primarily applicable to Class B concrete, as determined by Stage 2 examination.

The results of the Stage 3 testing and examination are given on the following pages. The detailed data are held on file for any further reference. A summary of the results is presented below.

SUMMARY

Lab Sample Ref	Client Sample Ref	Expansion at 7 days, % (0.075% max.)	Expansion data from 7 days, at 250 days, %[33]				
			Row			Core mean	Overall expansion
			A	B	C		
			Maximum criteria:			0.040	0.025
			Test outcomes:				PASS/FAIL
			Petrographic comparison between non-tested control and test core:[34]				
			Recommended classification:			Class A_3 (stable Group 2 aggregate) or Retain Class B	

Expansion curves may be presented on the following sheet(s), plus details of the pre- and post-test petrographic comparison.

Stage 3 Testing – Pre/Post-test Petrographic Comparison – supporting sheet(s) as required

RICS guidance note *The mundic problem*, 3rd edition

Petrographic examination of hardened concrete
High-power microscopical observations

BACKGROUND

It was advised that the original concrete had already been subjected to Stage 1 and 2 investigations, which resulted in it being assigned a Class B concrete classification (containing Group 2 aggregates, indicating it could include crushed sedimentary/metasedimentary rock, mining and processing waste, slags and incinerator waste).

In accordance with the RICS guidelines, the core which exhibited the most expansion during the course of the test was petrographically examined and compared to an untested sample in order to observe whether any 'mundic-type' expansive deleterious activity had occurred.

SUMMARY OVERVIEW

UNTESTED SAMPLE			
Lab Sample Ref		**Client Sample Ref**	
Composition and Constituents			
Mix Quality			
Condition			
Other Remarks			
MOISTURE SENSITIVITY TESTED SAMPLE			
Lab Sample Ref		**Client Sample Ref**	
Composition and Constituents			
Mix Quality			
Condition			
Other Remarks	*Evidence of alteration of aggregate particles, increase in crack density, increase in microcracks, matrix recrystallisation, leaching, etc.*		

CONCLUSION

The petrographic examination at the end of the expansion test period (250 days), indicated that the 'untested' and 'tested' samples both appeared sound and that no 'mundic-type' deleterious activity had occurred during the Stage 3 test.

Or

The petrographic examination at the end of the expansion test period (250 days), indicated that, by comparison with the sound untested sample, the 'tested' samples exhibited some 'mundic-type' deleterious activity that had probably occurred during the Stage 3 test.

Certificate of Test

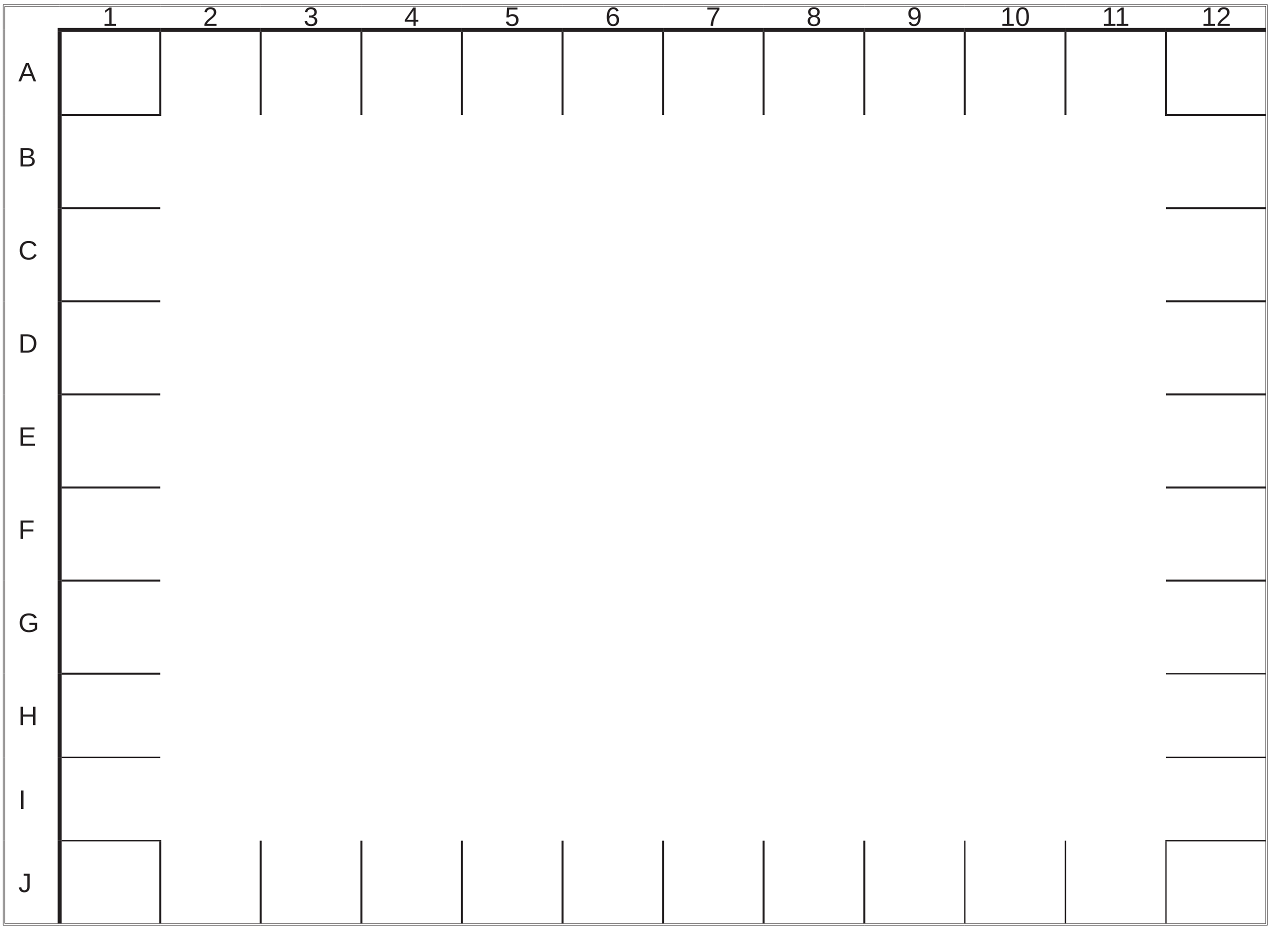
Stage 3 Testing – Pre/Post-test Petrographic Comparison –

optional supporting sheet(s) as required

RICS guidance note *The mundic problem*, 3rd edition

High-power microscopical observations

PHOTOGRAPH TAKEN USING LEICA DMRX



RECORD PHOTOMICROGRAPH			
Lab Sample Ref.		**Client Sample Ref.**	
Approx. Magnification	x35	**Approx. Scale**	10mm = 285μm
Portion Described	Concrete	**Viewing Light**	Cross-polarised
Description			

Endnotes

1 Bromley, A., *A compendium of concrete aggregates used in Southwest England,* 2002, www.petrolab.co.uk

2 ASTM C856-11, *Standard practice for petrographic examination of hardened concrete*, via www.atsm.org/standards

3 APG SR2, *A code of practice for the petrographic examination of concrete*, April 2008, via www.appliedpetrographygroup.com

4 The categories given in Table 4 can be described as follows: *none:* not observed, despite thorough searching; *rare:* only observed by thorough searching; *common:* easily observed during normal examination; *abundant:* immediately apparent to initial examination.

5 Mining/ore processing waste aggregate components considered to be potentially deleterious include: fine-grained pelitic hornfels (metasedimentary argillaceous rocks), mudstones, sulphide bearing veinstones and aggregate components showing evidence of in situ alteration. Potentially deleterious aggregate components should be separately identified and quantified by visual estimate or conventional point-counting techniques. Conversely, some mining/ore processing waste aggregate components are inherently stable and should not be considered potentially deleterious. These are typically higher-grade metamorphic rocks including mafic hornfels (altered dolerite) and quartz-tourmaline (+/- biotite) hornfels; non-sulphide bearing veinstones showing no evidence of in situ alteration should also be considered non-deleterious.

6 Most commonly found in finely layered metasedimentary rocks (known in Cornwall as 'killas'). The cracking will usually follow the original bedding or cleavage of the sediment and may be either single or multiple. The cause may be due to expansive oxidation of finely divided pyrite (and should be verified) or may be due to anisotropic shrinkage caused by moisture sensitivity.

7 Peripheral cracking on one or both sides of flaky metasedimentary aggregate fragments is observed in conjunction with interlayer cracking. This may be due to rock shrinkage caused by moisture sensitivity. If evidence of oxidation of pyrite has been observed within the fragment then this may be the primary cause of damage and may, in addition, propagate cracking into the adjacent matrix.

8 BRE Information Paper IP6/81, *Carbonation of concrete made with dense material aggregates*, Building Research Establishment, Watford, 1981.

9 Sulphates are expressed throughout this guidance as SO_4, but sometimes it will be necessary to convert sulphate values or criteria expressed as SO_3 (SO_3 x 1.2 = SO_4); e.g., the standard procedure in BS EN 1744-1:2009+A1:2012 produces sulphate values expressed as SO_3.

10 Winter, N. B., S*canning electron microscopy of cement and concrete*, WHD Microanalysis Consultants Ltd., Woodbridge, Suffolk, 2012.

11 BS EN 12390-7:2009, *Testing hardened concrete, part 7: Density of hardened concrete*, British Standards Institution, London, 2009. This test should only be undertaken for classifying purposes when there is a sample available for testing that both complies with the minimum size requirement of BS EN 12390-7 (volume not less than 50D3 where D is the nominal maximum particle size of the aggregate within the concrete) and is deemed suitably representative. In many cases this might require the surveyor to return to site in order to obtain additional samples. If compliant test samples are not obtainable, then any resultant density values obtained using this method for smaller samples will be less reliable than expected for the specified minimum sample size. In such a case, concrete samples should only be considered as a dense concrete material if the determined dry density for concrete with a normal density aggregate is unequivocally greater than the 2000 kg/m³ criterion (a minimum of 2200 kg/m³ is recommended in this circumstance). Alternatively, if several non-compliant but intact cores are available from the same general location, whereby taken together they would meet the minimum volume requirement, then it is acceptable to consider the mean density against the 2000 kg/m³ criterion.

12 Any such site work by the petrographer must always be undertaken under the supervision of the surveyor, who retains the responsibility for the overall assessment of the property in question, and the petrographer's site observations must be supported by a photographic record. The petrographer's final assessment should then be based on consideration of both the site and any laboratory observations.

13 A procedure for estimating 'excess voidage' is given in Concrete Society TR11 (including addendum), *Concrete core testing for strength*, 1987. It is based on the notion that even the best compacted concrete will contain up to about 0.5% voids, so that an assessment of compaction quality depends on the amount of voidage in 'excess' of that best-achievable condition.

14 In Stage 2 examination, the concrete will be examined in thin section under a polarising microscope, when the 'normally hydrated' cement matrix will appear as predominantly hydrated material, which may or may not be wholly or partly carbonated, with scattered residual grains of unhydrated cement. In modern concrete, microscopic unhydrated relicts of finely ground cement are typically rare and small (say <60µm but often <20µm), but in the older concrete subject to examination using this guidance, unhydrated cement relics are likely to include a greater abundance of larger and much larger grains (say >100µm). It is also important to ensure that the effectiveness of the cement binder is not compromised by being concentrated into air-set lumps (formed by partial hydration prior to use) or by cement balls (formed during mixing).

15 A chemical analysis procedure for determining the approximate Portland cement content of concrete is given in BS 1881-124:1988 (including guidance on repeatability and reproducibility), but this must be carried out by a laboratory experienced in the test and the petrographer must ensure that the other constituents of the concrete will not adversely affect the result (e.g. sources of acid soluble calcium and/or soluble silica in aggregates or mineral additions, such as pulverised-fuel ash or ground granulated blastfurnace slag, can lead to seriously overestimated cement content results; ideally reference samples of aggregate and/or any additions would be analysed alongside the concrete, but these are unlikely to be available). Conversion of the analytical result, as a cement percentage by mass, into a kg/m³ value using the measured dry density of the concrete, should be undertaken with caution. The cement content of a concrete with low density caused by lightweight aggregates will appear misleadingly high by comparison with conventional concrete. Also, even when reliable chemical analysis suggests a cement content to be adequate, the petrographer must ascertain whether the cement binder is evenly distributed within the concrete.

16 The test method described is based on the standard shrinkage and expansion prism-test methods described in BS 812-120:1989, *Testing aggregates: Method for testing and classifying drying shrinkage of aggregates in concrete* British Standards Institution, London, 1989, and BS 812-123:1999: *Testing aggregates: Method for determination of alkali-silica reactivity, concrete prism method*, British Standards Institution, London, 1999.

17 The 'appropriate' glue needs to be able to resist the warm humid test conditions, as there have been problems of stud detachment with some alternative glues.

18 Based on the research findings, the most reproducible test results were obtained at a storage temperature of 38 ± 2°C, by comparison with the lower and higher temperatures investigated.

19 Hawkes, J.R. and Dangerfield, J. *The Variscan granites of south-west England: a progress report,* Proc. Ussher Soc., 4, 1978. (See pp.58–171.)

20 Bromley, A.V. *A new interpretation of the Lizard Complex,* S. Cornwall, in the light of the ocean crust model, J. Geol. Soc. 132 (1), Proceedings, 114, London, 1976.

21 St John, D. A., Poole, A. B., and Sims, I., *Concrete petrography: a handbook of investigative techniques*, Arnold, London 1998. (See p.474, especially Table 7.1.) A second edition of this textbook is due for publication by Taylor & Francis in 2015.

22 Sims, I., Brown, B. V., Concrete aggregates (chapter 16, pp. 903–1011) in Hewlett, P. C., *Lea's Chemistry of Cement and Concrete*, 4th edition, Arnold, London. (See Table 16.1 and 16.7.)

23 Smith, M. R. (ed.), *Stone: building stone, rock fill and armour stone in construction*, Geological Society Engineering, Geology special publication #16, Geological Society, London, 1999. (See p.478, especially Table C2.)

24 Alexander, M., Mindess, S., *Aggregates in concrete*, Taylor & Francis, London, 2005. (See p.436, especially Tables 3.2 and 7.2.)

25 U/C = unclassified by Stage 1; requires Stage 2 for classification.

26 Group 1: 1–1 = China clay waste; 1–2 = crushed granite and related igneous rocks (e.g. elvan); 1–3 = crushed basic and metabasic igneous rocks (e.g. epidiorite, serpentinite); 1–4 = furnace clinker or coking breeze; 1–5 = beach or river sands and gravels; 1–6 = others (e.g. Group 2, reclassified as a result of current knowledge and/or further investigation).

Group 2: 2–1 = crushed sedimentary or meta-sedimentary rocks ('killas'), 2–2 = most metalliferous mining and/or processing waste, 2–3 = slags (largely non-ferrous) and incinerator wastes.

27 When used, these subjective assessments of occurrence may be defined as follows: *none*: not observed, despite thorough searching; *rare*: only observed by thorough searching; *common*: easily observed during normal examination; *abundant*: immediately apparent to initial examination.

28 BS EN 12390-7: 2009, Testing hardened concrete, Part 7: Density of hardened concrete, British Standards Institution, London, 2009.

29 Group 1: 1–1 = China clay waste; 1–2 = crushed granite and related igneous rocks (e.g. elvan); 1–3 = crushed basic and metabasic igneous rocks (e.g. epidiorite, serpentinite); 1–4 = furnace clinker or coking breeze; 1–5 = beach or river sands and gravels; 1–6 = others (e.g. Group 2, reclassified as a result of current knowledge and/or further investigation).

Group 2: 2–1 = crushed sedimentary or meta-sedimentary rocks ('killas'), 2–2 = most metalliferous mining and/or processing waste, 2–3 = slags (largely non-ferrous) and incinerator wastes.

30 Concrete subjected to chemical analysis that exceeds the chemical criteria is placed in Class B.

31 Based on microscopic evidence and occurrence. These subjective assessments of occurrence may be defined as follows: *none*: not observed, despite thorough searching; *rare*: only observed by thorough searching; *common*: easily observed during normal examination; *abundant*: immediately apparent to initial examination.

32 BS EN 1744-1:2009+A1:2012, *Tests for chemical properties of aggregates: Chemical analysis*, British Standards Institution, London, 2012.

33 In the event of data at >250 days, state the relevant test duration from seven days.

34 Record evidence of any deterioration during the expansion test, even if the expansion results pass the criteria. Class B concrete can only be re-classified as A_3 if the expansion criteria are satisfied *and* there is no evidence of any deterioration during the test.

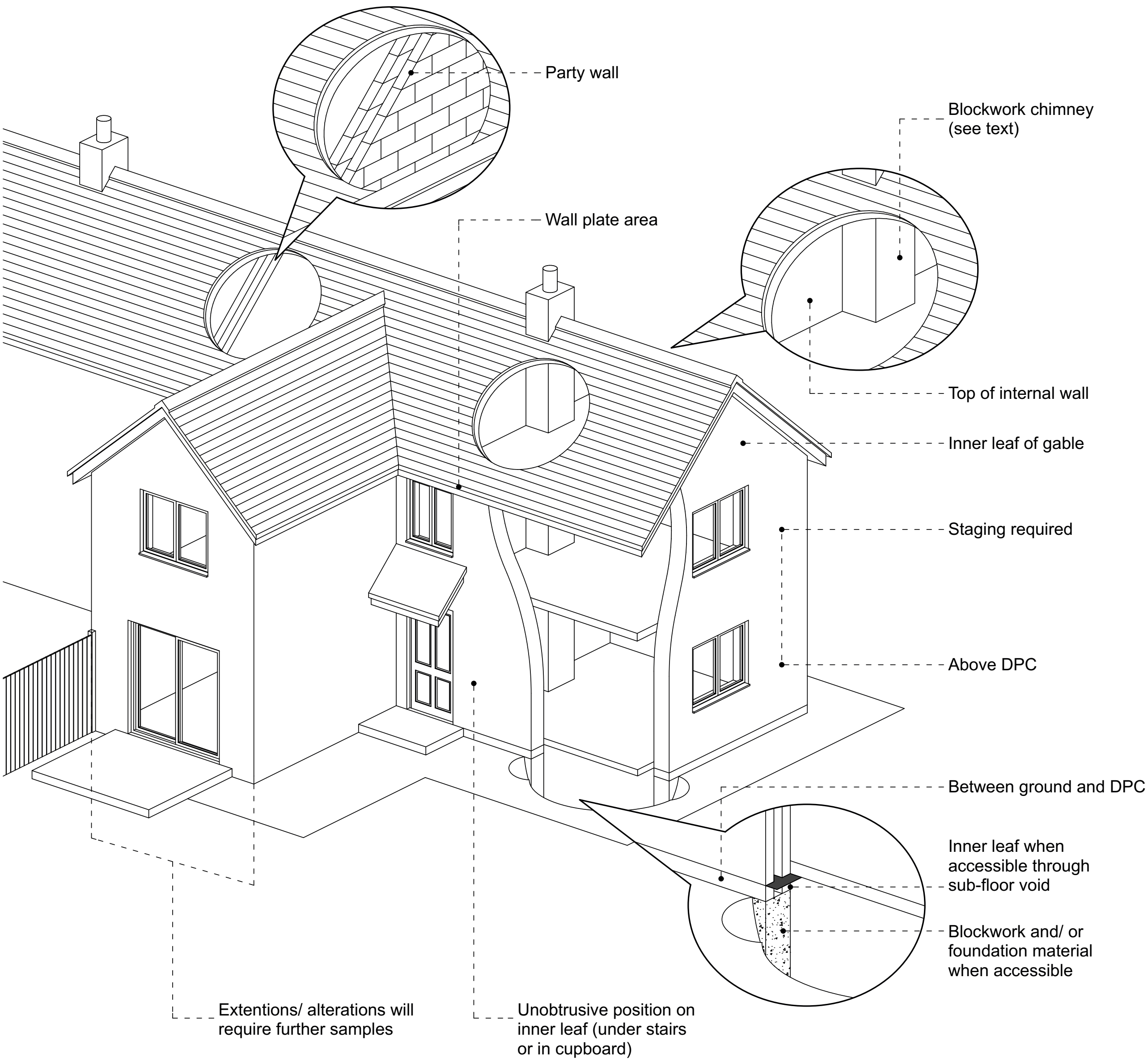


Figure B1: Isometric sketch of typical sampling locations

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