The BGS conducts a reconnaissance assessment at a high purity limestone deposit in the Middle East

High purity limestone quest

Reconnaissance assessments are one of the first steps in identifying new commercial mining projects. *Clive Mitchell* outlines the British Geological Survey's recent evaluation of high purity limestone deposits worldwide, including in the Middle East

Limestone probably has the largest number of commercial applications of all the industrial minerals. These include construction (aggregate, rail ballast and dimension stone), mineral fillers (in paper, paint, plastic, rubber and pharmaceuticals), adhesives, abrasives, fertilisers, food additives, environmental applications (acidity neutralisation, flue gas desulphurisation, soil conditioning and stabilisation), and production of cement, lime and calcium chemicals.

'High purity' limestone is defined as carbonate rock that contains greater than 97% calcium carbonate ($CaCO_3$, usually as calcite). It is often referred to as high-calcium, highly-calcitic or industrial limestone. Its suitability as a high purity industrial mineral (sold as calcium carbonate) is defined by the intended applications, as outlined in specification agreements between producers and consumers.

These applications define the required chemical properties (such as lime, silica, magnesia and iron contents), the physical properties (such as particle size distribution, colour and surface area) and the mechanical properties (such as strength, abrasiveness and durability). Detailed information is available in many industrial mineral reference sources (Harben, 2002; Kogel *et al*, 2006; and BGS, 2006). Limestone resource assessments carried out by the British Geological Survey (BGS) are guided by these industrial requirements.

Reconnaissance survey

Limestone usually occurs as extensive sedimentary deposits with a generally consistent composition. Lateral variations reflect differing depositional environments, with, for example, coarser-grained, sandy limestone deposited closer to shore and finer-grained, calcite-mudstone deposited in deeper water.

Mineral impurities that may occur in limestone include dolomite and other carbonate minerals (such as siderite), silica (as fine-grained quartz or chert), clay minerals (such as kaolinite, illite or chlorite), organic matter (often bituminous), pyrite and fluorite. Trace amounts of 'accessory' minerals such as zircon, tourmaline, feldspar, iron minerals (haematite, magnetite and limonite), garnet and titanium minerals (ilmenite, rutile and leucoxene) may also occur (Summerson *et al* 1957).

The first stage of a reconnaissance survey is a review of the existing available geological information in maps and reports. This information is usually limited to descriptions of the stratigraphy, lithology and palaeontology. Apart from the occasional petrographic description and chemical analysis, there is usually little information on the technical properties of the limestone.

As far as possible, limestone resources are categorised into priorities for the reconnaissance survey field work. The highest priority is given to those formations with thick, uniform sequences that consist largely of limestone. The lowest priorities are given to those formations that do not contain significant amounts of limestone; have large amounts of dolomite, chert and other non-limestone mineral impurities; have thin, inconsistent sequences; and that are interbedded with non-limestone rock types such as sandstone, siltstone and mudstone. A GIS (Geographical Information System) reconnaissance map is then created to incorporate all the available information on geology including limestone resources (ranked as potentially high, medium or low purity), topography, satellite imagery and infrastructure.

The next stage is the reconnaissance survey field work. This is carried out with the aim of collecting 'representative' samples of all the limestone formations identified over a wide geographical area. The location of each locality is recorded using a hand held GPS (Global Positioning System) device using WGS84 (World Geodetic System) coordinate system and UTM (Universal Transverse Mercator) map projection system is used as a standard.

Table 1: Limestone purity classification

Purity classification	$CaCO_3$ wt%	CaO wt%	MgO wt%	SiO_2 wt%	Fe_2O_3 wt%
Very high purity	>98.5	>55.2	<0.8	<0.2	<0.05
High purity	97.0-98.5	54.3-55.2	0.8-1.0	0.2-0.6	0 05-0.1
Medium purity	93.5-97.0	52.4-54.3	1.0-3.0	0.6-1.0	0.1-1.0
Low purity	85.0-93.5	47.6-52.4	>3.0	<2.0	>1.0
Impure	<85.0	<47.6		>2.0	

Limestone samples (typically 1.5kg) are taken from rock outcrops avoiding overly weathered, fractured and mineralised surfaces. Due to the nature of the survey work these are surface samples and not taken from boreholes or as channel samples. Other information recorded includes descriptions of the lithology and rock mass (including bedding, jointing, fractures and other discontinuities), name of the area and accessibility.

Technical evaluation

The samples collected by reconnaissance surveys are analysed to determine their chemical, mineralogical and physical properties (Harrison, 1992). The technical evaluation of the data is informed by the needs of industry and relies on the availability of technical data and specifications.

The major element oxide chemical composition is typically determined by X-ray fluorescence (XRF) analysis. The BGS limestone purity classification (as devised by Cox *et al* in 1977) is based on the calcium carbonate content (*Table 1*). The BGS has used this classification in all major limestone resource work carried out in the UK and other parts of the world over the last 30 years (Harrison, 1985).

Recent BGS reconnaissance surveys have added magnesia (MgO), silica (SiO_2) and iron oxide (Fe_2O_3) as quality criteria, as shown in Table 1. This was devised by the author based on the data in industrial mineral reference sources (Harben, 2002 and Kogel *et al*, 2006) and in commercial data sheets (summarised in Table 2). Table 3 gives the chemical composition of high purity limestone from past BGS reconnaissance surveys.

The mineralogical composition is determined by X-ray diffraction (XRD) analysis. This will determine the presence of calcite and dolomite together with common impurities such as quartz, feldspars, clay minerals, pyrite and iron oxides. Thermogravimetric analysis (TGA) is carried out to determine the carbonate mineral content to lower levels than those achieved by

Table 2: Chemical properties and brightness of commercially available calcium carbonate

Properties	Paint		Paper		Plastic		Food & pharmaceutical	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Calcium Carbonate, $CaCO_3$ (%)	97.80	92 - 99.35	98.46	96 - 99.35	97.97	92 - 99.35	98.29	97 - 99.5
Lime, CaO (%)	54.80	51.55 - 55.67	55.17	53.79 - 55.67	54.89	51.55 - 55.67	55.07	54.35 - 55.75
Magnesia, MgO (%)	0.42	0.15 - 1.2	0.45	0.15 - 1.2	0.46	0.15 - 1.2	0.29	0.24 - 0.42
Silica, SiO_2 (%)	0.72	0.05 - 4.5	0.11	0.05 - 0.4	0.46	0.05 - 4.5	0.11	0.1 - 0.12
Iron oxide, Fe_2O_3 (%)	0.04	0.01 - 0.1	0.04	0.01 - 0.1	0.04	0.01 - 0.1	0.06	0.011 - 0.1
Brightness (%)	92.8	78 - 99	96.7	93.5 - 99	92.7	75 - 98.1	96.5	90 - 99
No. of datasheets	100		35		88		34	
Properties	**Ceramic**		**Rubber**		**Adhesives & sealants**		**Agriculture & animal feed**	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Calcium Carbonate, $CaCO_3$ (%)	99.05	98.8 - 99.35	97.37	92 - 99.35	97.48	92 - 99.35	95.55	92 - 99.35
Lime, CaO (%)	55.50	55.36 - 55.67	54.56	51.55 - 55.67	54.62	51.55 - 55.67	54.09	51.55 - 55.67
Magnesia, MgO (%)	0.27	0.22 - 0.38	0.62	0.15 - 1.2	0.54	0.15 - 1.2	0.66	0.22 - 0.96
Silica, SiO_2 (%)	0.08	0.06 - 0.12	0.82	0.05 - 4.5	1.14	0.05 - 4.5	1.28	0.06 - 4.5
Iron oxide, Fe_2O_3 (%)	0.03	0.02 - 0.044	0.04	0.01 - 0.1	0.02	0.01 - 0.1	0.01	0.037 - 0.1
Brightness (%)	95.6	95.3 - 96	90.6	75 - 98.5	91.0	75 - 98	81.8	70 - 95.5
No. of datasheets	14		51		65		14	

Source: This information was collated from the datasheets available online for 198 commercial calcium carbonate products.

XRD. Petrographic analysis is carried out on thin sections using a binocular microscope in order to provide information on the lithology, fabric, texture and mineralogy. Samples can be impregnated with blue-dye resin in order to facilitate identification and description of their pore space characteristics. Thin sections can be stained using a standard dual carbonate alizarin red-S and potassium ferricyanide chemical stain to help differentiate non-ferroan calcite, ferroan calcite, dolomite and ferroan dolomite.

Commercial data sheets also provide information on many other properties including moisture, pH, bulk density, specific gravity, oil absorption, surface area and particle size (top size, mean size and proportion finer than two microns). These can be determined for samples collected in a reconnaissance survey. However, many of these properties are directly influenced by the particle size of the test material. This can vary according to the amount and type of milling carried out. Therefore, these are not as reliable as chemical properties to indicate the quality for a reconnaissance survey.

One physical property that has been included in BGS reconnaissance surveys is the whiteness (or brightness). This property is also influenced by the particle size of the test material but it is such an important commercial parameter that it is included. Brightness is measured (in accordance with ISO 2470:1977) using a reflectance spectrophotometer, with the percentage of reflectance being directly proportional to the 'whiteness' and, to some extent, the purity of the sample. Brightness values of greater than 80% are a minimum threshold for high purity limestone samples. The brightness of commercial calcium carbonate products is shown in Table 2.

Table 3: High purity limestone from recent BGS reconnaissance surveys

Limestone resources	SiO_2 wt%	Fe_2O_3t wt%	MgO wt%	CaO wt%
UK (Carboniferous)				
• Bee Low Limestone Fm, Derbyshire	0.43	0.07	0.27	55.41
• Burrington Oolite Subgroup, Somerset	0.02	0.01	0.62	55.24
• Oxwich Head Limestone Fm, Pembrokeshire	0.44	0.02	0.07	55.80
• Loggerheads Limestone Fm, Denbighshire	0.50	0.10	0.35	55.38
• Malham Fm, North Yorkshire	0.00	0.01	0.10	55.73
• Park Limestone Fm, Cumbria	0.04	0.03	0.72	55.52
Surat Thani, Thailand				
• Phra Nom Wang Fm	0.00	0.04	0.19	55.13
• Um Luk Fm	0.01	0.03	0.17	55.07
Zambia				
• Lower Kundelungu Fm, Copperbelt Province	0.11	0.04	0.38	55.59

NB Fm = Formation

BGS limestone resource assessments

The BGS undertook a comprehensive limestone resource survey of England and Wales in the 1980s. This study produced a geological map of the limestone resources (1:625,000 scale) and collated chemical data (as shown in Table 3).

Limestones of high purity are shown to be extensive in many parts of England and Wales, particularly in the Carboniferous Limestone of the Peak District, North and South Wales, North Pennines, Lake District and Mendips, as well as in the Cretaceous Chalk. It was also found that many of those areas containing pure limestone also contain limestones of lower purity or are affected by mineralisation. This reinforced the importance of a thorough understanding of the regional geology in resource surveys (Harrison *et al*, 1991).

Since the 1990s the BGS has been involved in limestone resource studies in Thailand, Zambia and the Middle East. In Thailand, the limestone resource survey was carried out in collaboration with the Department of Mineral Resources (Harrison *et al*, 1998). As part of the work carried out cost effective field and laboratory procedures were developed for the rapid assessment of limestone resources. High purity limestone resources were identified in the Surat Thani area of southern Thailand (*Table 3*). In Zambia, a resource survey was carried out which sampled all of the main limestone areas (Mitchell *et al*, 1997). This identified high purity limestone in the Copperbelt Province that was being worked by Ndola Lime Co. (*Table 3*).

Limestone resource work recently carried out in the Middle East identified over 65 occurrences of high purity limestone (this work is due to be published). Some limestone resource work was also carried out by the BGS in Kabul as part of the institutional strengthening work for the Afghanistan Geological Survey in 2005 to 2007.

Often high purity dolomite is identified as a consequence of carrying out a survey for high purity limestone. In the recent limestone study in the Middle East, six occurrences of high purity dolomite were identified. Dolomite was the target for a second resource survey carried out in Zambia. The aim was to identify suitable raw material for the production of agricultural lime (Mitchell *et al*, 2005). Occurrences of potentially high purity dolomite were identified in the Central Province.

Conclusions

Limestone resources are widespread in many countries of the world and are often well documented in geological reports and maps. The identification of high purity limestone requires a technical assessment that includes a reconnaissance survey, field sampling and laboratory analysis. The evaluation of the technical data relies on a detailed knowledge of the industrial market needs, typically expressed as technical data sheets and specifications. It is important that national geological surveys maintain a detailed knowledge of the use of minerals, current industrial practice and trends in raw material usage.

Identification of high purity limestone resources is just one component of the economic, environmental and social equation that needs to be solved before resources can be mined. The role of a national geological survey is to provide impartial, accurate and relevant geological and technical information on resources for mining companies, planning authorities, government and the public. Ensuring that the mineral resource information remains in step with current industrial demands and is also available in accessible formats, especially online, is an ongoing challenge for all surveys. The BGS provides this information via its website, www.mineralsuk.com.

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