Read at the Annual Conference of the Ussher Society, January 1995

THE GEOLOGICAL AND GEOTECHNICAL PROPERTIES OF EARTH MATERIAL FROM CENTRAL DEVON IN RELATION TO ITS SUITABILITY FOR BUILDING IN 'COB'.

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Harries, R., Saxton, B. and Coventry, K. 1995. The geological and geotechnical properties of earth material from central Devon in relation to its suitability for building in 'cob'. *Proceedings of the Ussher Society*, **8**, 441-444

Earth mixed with straw and water to produce 'Cob' (Skinner *et al*., 1992) was the traditional method of building in much of rural Devon during the seventeenth and eighteenth Centuries. As a consequence, many villages, hamlets and farms are constructed almost exclusively of cob; and it is this more than any other feature which imprints on them a unique and distinctive regional character. With industrialization and the coming of the railways, new materials and building methods were introduced. As a consequence, traditional methods and skills were no longer practised and a working knowledge of the material was gradually lost.
The realization in the past decade that these buildings form an important part of our national heritage has led to the implementation of a research programme at the University of Plymouth. This research programme aims to develop through geological and geotechnical investigations a coherent set of guidelines and 'best-practice' techniques for building in earth, and to develop a methodology and guidelines for setting up an inventory of earth buildings.
The multidisciplinary research programme is coordinated by the Centre for Earthen Architecture, within the School of Architecture.

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INTRODUCTION

The area chosen for an initial 'pilot study' was required to satisfy the following criteria:-

1. Cob buildings would make up a significant proportion of the building stock in villages, hamlets and farms.

2. The earth material used would consist of a significant variety of soil types.

3. The variety of soil types would reflect the principal geological formations.

An area within a 10 km radius of Crediton (Figure 1) was considered suitable, bounded to the east by the River Exe and to the west by the River Yeo.

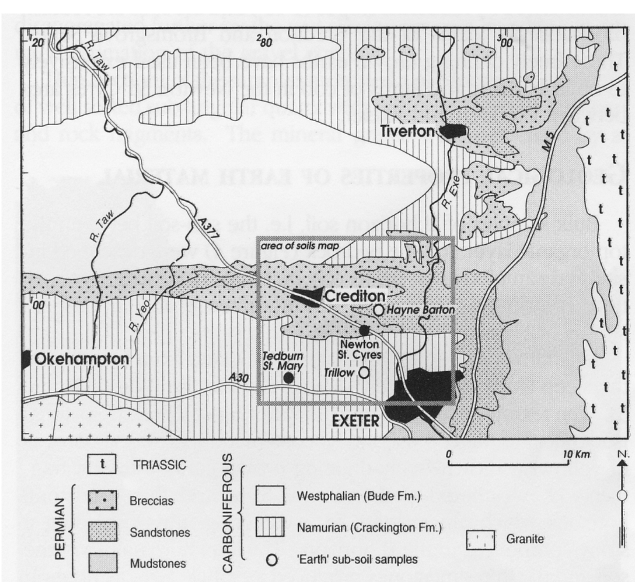

Figure 1. Geology of the Crediton area

GEOLOGY

The geology of the area (Edmonds *et al*., 1975), (Figure 1) consists of Carboniferous slates, siltstones and sandstones which are overlain unconformably by Permian breccias and sandstones now preserved within the downfaulted Crediton Trough (Table 1). The Carboniferous rocks (Durrance and Laming, 1982) to the south of the Crediton trough - the Crackington Formation, consists predominantly of mudstones with thin siltstones and sandstones. To the north of the Crediton trough, the Bude Formation is characterised by thicker and more persistent sandstone units. These are more resistant to weathering and they produce soil profiles which are shallower and more stony in character.

The Permian rocks (Durrance and Laming, 1982) consist of poorly-cemented breccias and sandstones to the west of Crediton and predominantly sandstones between Crediton and Exeter.

Stratigraphy	Age Ma	Lithologies
		West of Crediton Reddish brown breccias and conglomerates
Permian	280	with thin sandstones. East of Crediton Reddish brown sandstones with thin breccias and conglomerates. Unconformity/faulting
Carboniferous (Upper) Bude Formation (Westphalian) Crackington Formation (Namurian)	 310 320	 Sandstones and siltstones with thin slates north of the Crediton Trough. Slates with thin sandstones and siltstones south of the Crediton Trough.

Table l. Simplified Geology of the Area

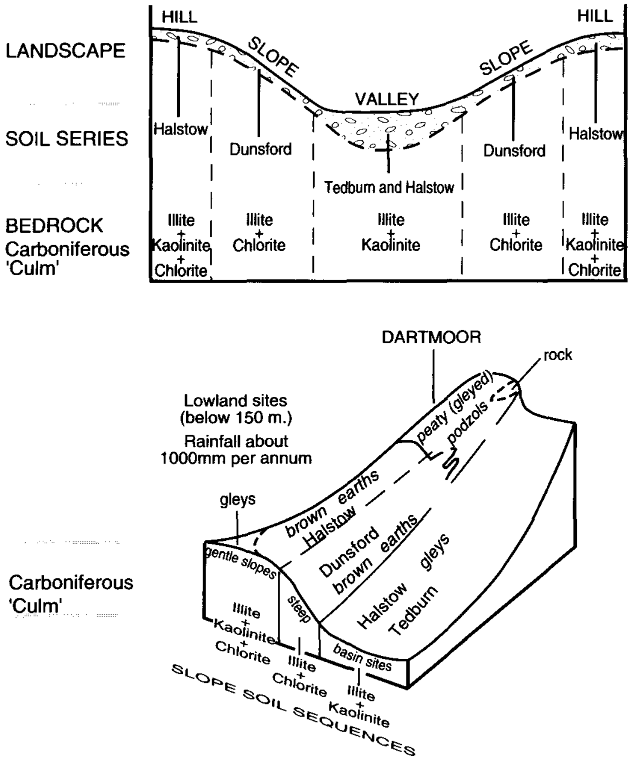

Figure 2. Relationships between bedrock landscape and soil type

Geology	Soil Series	Soil Group	Description
PERMIAN - REDLAND			
Permian Breccias and Conglomerates	Crediton	Brown Earths	Reddish-brown friable sandy loam - freely draining.
Permian Sandstones	Bromsgrove and Bridgnorth	Brown Earths	Reddish-brown friable sandy loam - freely draining.
CARBONIFEROUS (Upper) - 'DUNLAND'			
Bude Formation 'Morchard Siltstone Hills'	Swindon Bank (Neath)	Brown Earths	Yellowish or reddish-brown, strong silty loam - freely draining.
Crackington Formation 'Exeter Shale Hills'	Dunsford (Denbigh 1)	Brown Earths	Yellowish-brown clayey loam - freely draining
	Halstow	Gleyed Brown Earths	Yellowish-brown mottled clayey loam
	Tedburn (Hallsworth 1)	Gleyed Brown Earths	Light grey mottled silty clays - waterlogged in winter

Compiled from Clayden, 1971.

Table 2 Soils of the Crediton area

SOILS

Soil characteristics are influenced largely by the nature of the bedrock, topography, slope and drainage (Findlay *et al.,* 1984), (Figure 2). The relationships between the soils of the Crediton area (Clayden, 1971), (Figure 3) and the underlying bedrock types are summarized in Table 2.

Soils overlying the Carboniferous 'Culm' - Dunland Soils.

The heavy rather clayey soils overlying the Carboniferous rocks are frequently referred to as Dunland Soils and these occupy much of the area to the south of the Crediton Trough. These have been divided into a number of Soil Series, namely Dunsford, Halstow and Tedbum, which are characterised by an increasing degree of weathering, gleying and waterlogging in the brown earths (Table 2).

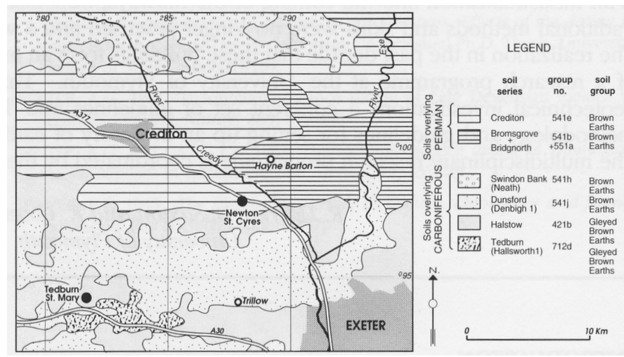

Figure 3 Soils of the Crediton area

North of the Crediton Trough the higher ground consists of well-drained brown earths of the Swindon Bank Series. These have been considerably reddened near the contact with the Permian rocks of the Crediton Trough. This red staining extends much farther north than in the soils to the south of the Crediton Trough. This could be related to the presence of thicker sandstone and siltstone units in the Bude Formation, allowing water to percolate to greater depths and precipitate iron both within the permeable sandstones and along joints and faults.

Soils overlying the Permian - Redland Soils

The soil survey has subdivided the Redland areas into a number of physiographic regions on the basis of hill, plateau, ridge and lowland. The east-west trending hills and valleys are characterised by moderate slopes (5-10°) and the soils are reddish brown sandy loams of the Crediton and Bromsgrove Series. These freely draining brown earths have been used extensively to build hamlets and farms of cob in the Newton St. Gyres area between Crediton and Exeter.

GEOLOGICAL PROPERTIES OF EARTH MATERIAL

Bulk samples of B horizon soil, i.e. the sub-soil between the top organic layer and the bedrock (Figure 4) were described in-situ and sampled adjacent to cob buildings of similar composition. Typical soil profiles over the Carboniferous and Permian are shown in Figure 4.

At Trillow [SX 878 939] samples were taken from a cutting in the steep slope immediately behind the cob farmhouse (Figure 5). The texture, grain size and composition of the earth material is identical to the cob used in its construction. The soil consists of yellowish brown freely-draining brown earth with soft fragments of weathered Carboniferous Slate and thin sandstone horizons which are resistant to weathering, thus providing a stony component to the B horizon. The immature nature of the soil and the thin sandstones produced a particle size distribution of 22% Gravel (consisting of sandstone and siltstone fragments), 16% sand, 34% silt and 28% clay. This is considered to be a suitable mix for cob, although there is more silt and less sand than a preferred even distribution of approximately 1/3 coarse (gravel), 1/3 medium (sand) and 1/3 fine (silt and clay combined). In practise, a wide variation in the percentages of grain sizes is observed in cob houses, even over a relatively small area.

The coarse fragments provide strength and the clay content sufficient bonding of the various fractions, both to each other and to the straw, to facilitate placing on the wall when wet and ensuring stability and strength when dry. Thin-sections of these samples (Bullock *et al.,* 1985) indicated angular fragments of siltstones (mainly quartz) and slates cemented by an iron-stained silty clay matrix. X-ray diffraction analysis confirmed the findings of Grainger (1984) which indicated that the clays consisted predominantly of illite with minor amounts of kaolinite and chlorite.

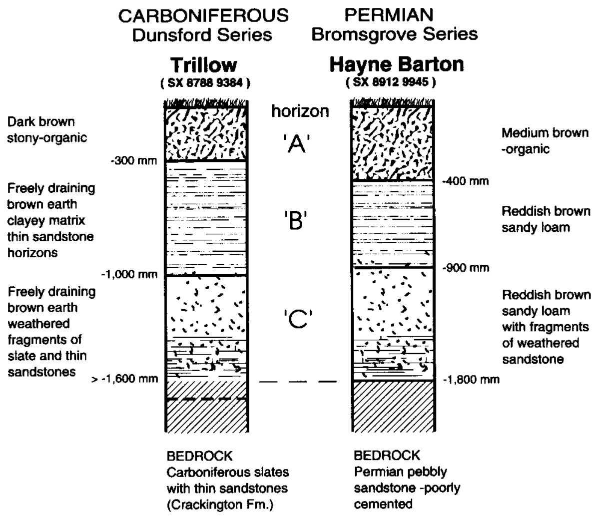

Figure 4 Soil profiles sampled over the Carboniferous and Permian rocks near Crediton, Devon

At Hayne Barton [SX 891 994] the Permian pebbly sandstone is exposed in-situ at the base of a nearby reddish brown cob barn. The soil profile consists of a reddish brown sandy loam (Figure 4) with a particle size distribution of 2% gravel, 38% sand, 42% silt and 18% clay. The sand and silt fractions dominate the sample, although there is sufficient clay (10-20%) to bond the grains and the straw. The low gravel content is not ideal, although there are considerably more coarser fragments in the adjacent cob buildings than are present in the soil profile examined. Some of the weakly-cemented sandstone units were disaggregated further by the wet sieving process, resulting in an underestimation of the gravel content.

Thin-sections of the samples indicated a predominance (>90%) of well sorted sub-angular quartz with minor amounts of feldspar and rock fragments. The mineral grains were cemented by a heavily iron-stained clayey-silt matrix.

Figure 5 Trillow Farmhouse

X-ray diffraction analysis confirmed the findings of Grainger (1984) with the clays consisting of illite with subordinate amounts of kaolinite and muscovite.

Further analysis by scanning electron microscopy will determine the nature of the clay minerals present and, in particular, their role in the bonding of both the coarser fragments, and the straw, as well as the shrinkage characteristics during drying.

GEOTECHNICAL PROPERTIES OF EARTH MATERIAL

In the past, common sense, experience and a 'feel for the material' were sufficient for building in cob, but this is no longer so. Increasingly, planners, building control officers and developers are required to meet specifications laid down as British Standards or as building regulations. Unlike aggregates or cement, however, there are no regulations which specify a range of suitable earth materials for building. Consequently it is appropriate and timely to attempt to produce practical working guidelines for building in cob. Geotechnical properties (BSI 1990) which are considered appropriate for this purpose include compressive, tensile and shear strengths, density, plasticity, shrinkage, cracking and bonding characteristics. A further practical consideration is the behavioural property of earth material during mixing, working, placing and drying in relation to gravel, sand, silt, clay, straw and water contents (Houben and Guillaud, 1994).

STRUCTURAL STABILITY OF EARTH MATERIAL

The structural stability of earth material from Hayne Barton and Trillow were determined by tamping moist earth into 100 mm and 150 mm circular moulds and then drying the samples slowly under controlled conditions (Figure 6).

Unconfined compressive testing indicated that the Carboniferous soils (Trillow) failed at 600 kN/m^2 and the Permian soils (Hayne Barton) failed at 800 kN/m^2. However, the failure mode did tend to vary with sample composition and mode of preparation. The compressive stress on a two-storey cob wall 600 mm wide (a typical house) is estimated to be about 120 kN/m. The difference between this and the compressive test suggests a factor of safety of at least x5, which confirms that the material has no inherent structural stability problems provided it is kept dry.

BEHAVIOURAL PROPERTIES OF EARTH MATERIAL IN RELATION TO MOISTURE CONTENT.

The variation in moisture content is the most important parameter in influencing the structural stability of earth material. Addition of water during mixing and wetting progressively changes the consistency of the material from solid to plastic and eventually to liquid. The limits between these three consistencies have been expressed by Atterberg in terms of their moisture content, and this can be used to describe the behavioural properties of the material.

The liquid limit is the minimum moisture content, expressed as a percent, at which the material will flow under its own weight. For the Permian sandy loams it is 28% and for the Carboniferous silty clays it is 43%. This indicates that the Permian sandy loams require less water for mixing and can accommodate less water during wetting, before a change in consistency takes place and this is related to their lower clay content. The plastic limit is the minimum moisture content at which the earth material begins to deform like putty but will not crack. It occurs for the Permian sandy loams at 20% and for the Carboniferous silty clays at 27%. The difference in moisture content between the plastic limit and liquid limit - the Plasticity Index - is 8% for the Permian soils and 15% for the Carboniferous soils. This indicates a narrower range of 20-28% (optimum -25%) moisture content for mixing and placing Permian Earth Material compared with 27-43% (optimum -35%) for the Carboniferous earth material. The increased amount of water required for mixing the Carboniferous earth material

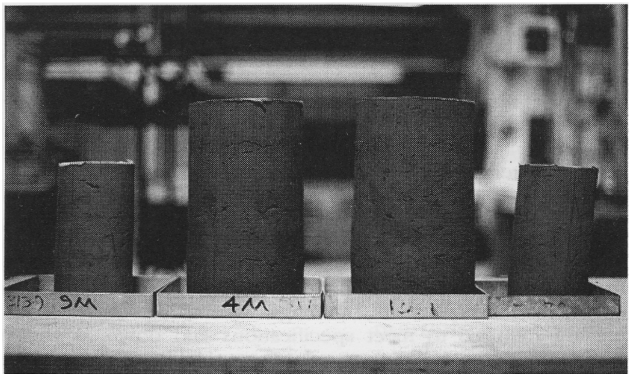

Figure 6. Earth samples prepared for testing unconfirmed compressive strength

is directly related to its higher clay content. A plasticity index of less than 5% may indicate a less than ideal proportion of clay to bind the coarser fractions and the straw.

THE INFLUENCE OF MOISTURE AND STRAW CONTENT ON THE STRENGTH OF COB.

Permian earth material of the Redland Soils (Figure 7) was used in an initial testing programme (Saxton, 1995) to determine the strength of cob with variable moisture and straw contents. The cob mix was compacted into 150 mm diameter cylindrical moulds, (300 mm high) jacked out, and subjected to an unconfined compression test to indicate its initial wet strength. Other samples were tested at intermediate moisture contents, while the remainder were tested after being allowed to dry completely. In addition, samples were made up with straw contents varying from 0 - 3.0% by weight.

The optimum initial wet strength (Figure 7) was considered to be >50 kN/m^2 and the final air dried strength to be >800 kN/m^2. Below a moisture content of 10% no further linear shrinkage occurred irrespective of the straw content. The results (Figure 7) indicated that from an initial moisture content of 20-25% the cob gradually increased in strength as it dried out to 120 kN/m^2 at 18% moisture content (the normal loading on a two-storey cob building); 360 kN/m^2 at 15% moisture content; and 600 kN/m^2 at 10% moisture content. The final strength of the cob at the equilibrium moisture content of about 4% (the normal moisture content of a cob wall) was about 800 kN/m^2 and this increased with further drying to 1000 kN/m^2. Clearly, a cob wall in Permian earth material is structurally sound below a moisture content of 10% for a normal two-storey building. If the cob is allowed to get wet, however, there is a linear decrease in strength from 600 kN/m^2 at 10% moisture content to 120 kN/m^2 at 18% moisture content with a risk of catastrophic failure likely to occur above this moisture content. Preliminary tests suggest that the Carboniferous Dunland Soils behave in a similar manner. It is

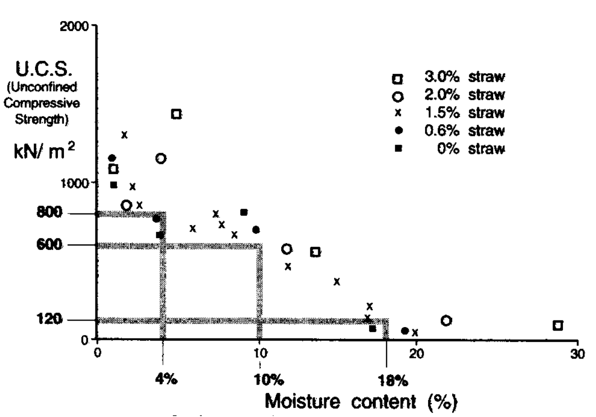

Figure 7. Variation of cob strength with moisture and straw content for the Permian 'Redland' soils

therefore essential to keep a cob wall relatively dry (<10% moisture content) and if periodic wetting does occur, to allow the moisture to evaporate naturally through both the inner and outer surfaces of the wall (Keefe, 1993). For this to be effective a permeable render is required, e.g. lime plaster (BSI 1984, 1987). An impermeable Portland cement render should never be used, although this has become common practice in the recent past - an example of traditional skills and knowledge being gradually lost and replaced by modem but inappropriate methods and materials.

An increase in straw content from 1% to 3% by weight increases the strength of the cob through the critical 20-15% moisture content as it dries. It also helps to reduce cracking, despite the fact that more shrinkage may occur due to the higher initial moisture content required to mix in the straw.

CONCLUSIONS

1. The area within a 10 km radius of Crediton contains many cob buildings constructed from earth material overlying both the Permian and Carboniferous Rocks.
2. Dunland Soils overlying the Carboniferous Crackington Formation consist of brown earths of the Dunsford, Halstow and Tedbum Series.
3. Soils overlying the Carboniferous Bude Formation north of Crediton consist of freely-draining brown earths of the Swindon Bank Series.
4. Redland Soils overlying the Permian Breccias and Sandstones consist of reddish brown sandy loams of the Crediton and Bromsgrove Series.
5. Both the Dunland and Redland Soils contain 25-60% fines and 40-60% sand and gravel.
6. The clay fraction consists predominantly of illite and varies between 10-30% - an ideal proportion which acts as a binder of both coarser fragments and straw.
7. The compressive stress on a 2-storey cob wall is approximately 120 kN/m^2 and if kept dry it will not fail below a compressive stress of 600 kN/m^2 - a factor of safety of at least x5.
8. Moisture content is the most important factor in reducing the compressive strength of a cob wall from 800 kN/m^2 at 4% to 120 kN/m^2 at 18%, above which catastrophic failure may occur.
9. The optimum straw content of 1-2% (by weight) improves the wet strength of cob when placing on a wall and reduces the likelihood of cracks occuring during drying.
10. Moisture must be allowed to evaporate naturally from a cob wall through a permeable lime-based render. Impermeable Portland cement renders should never be used.

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