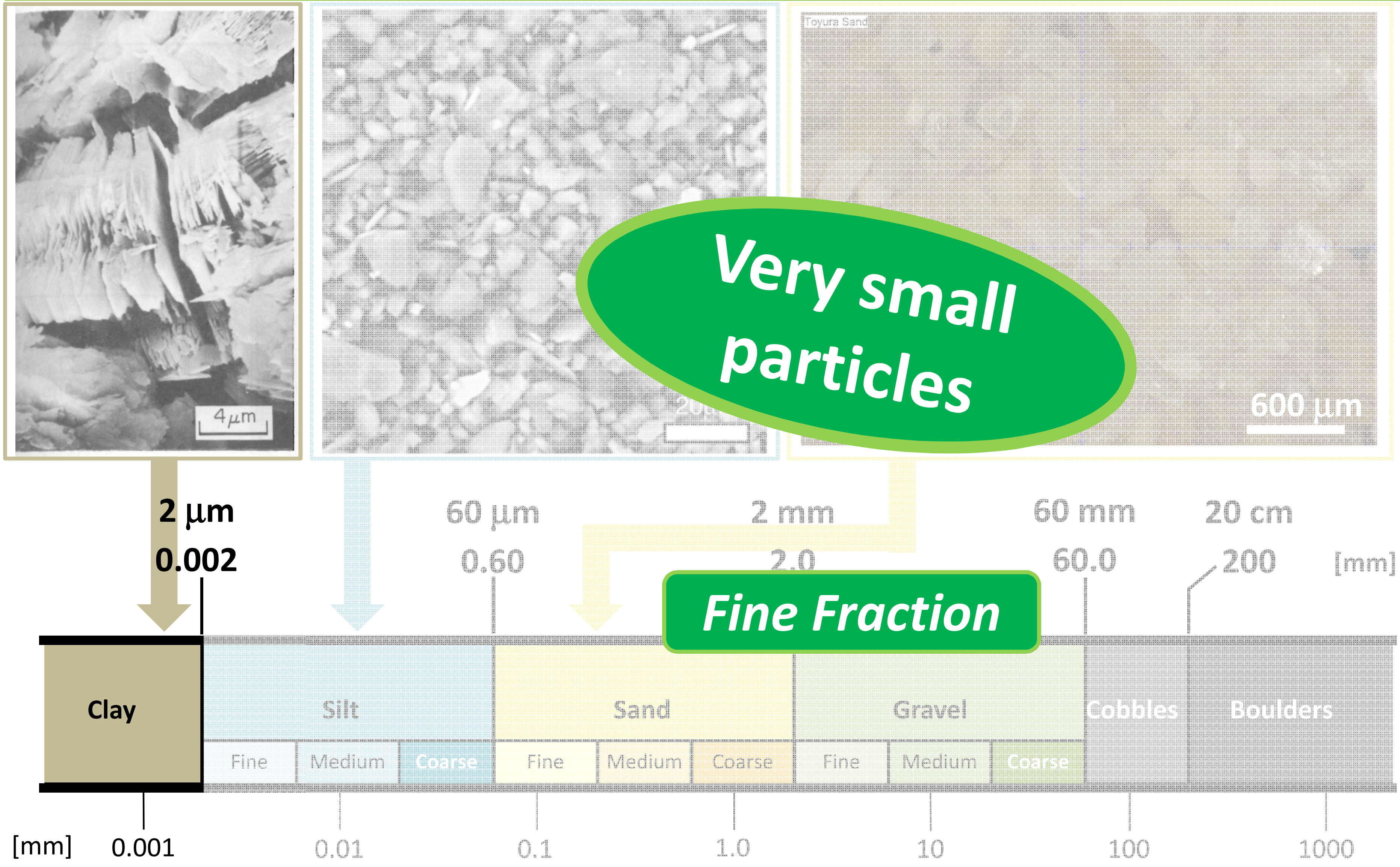
Clays

CI1-150 Geotechnics

Introduction to Clays

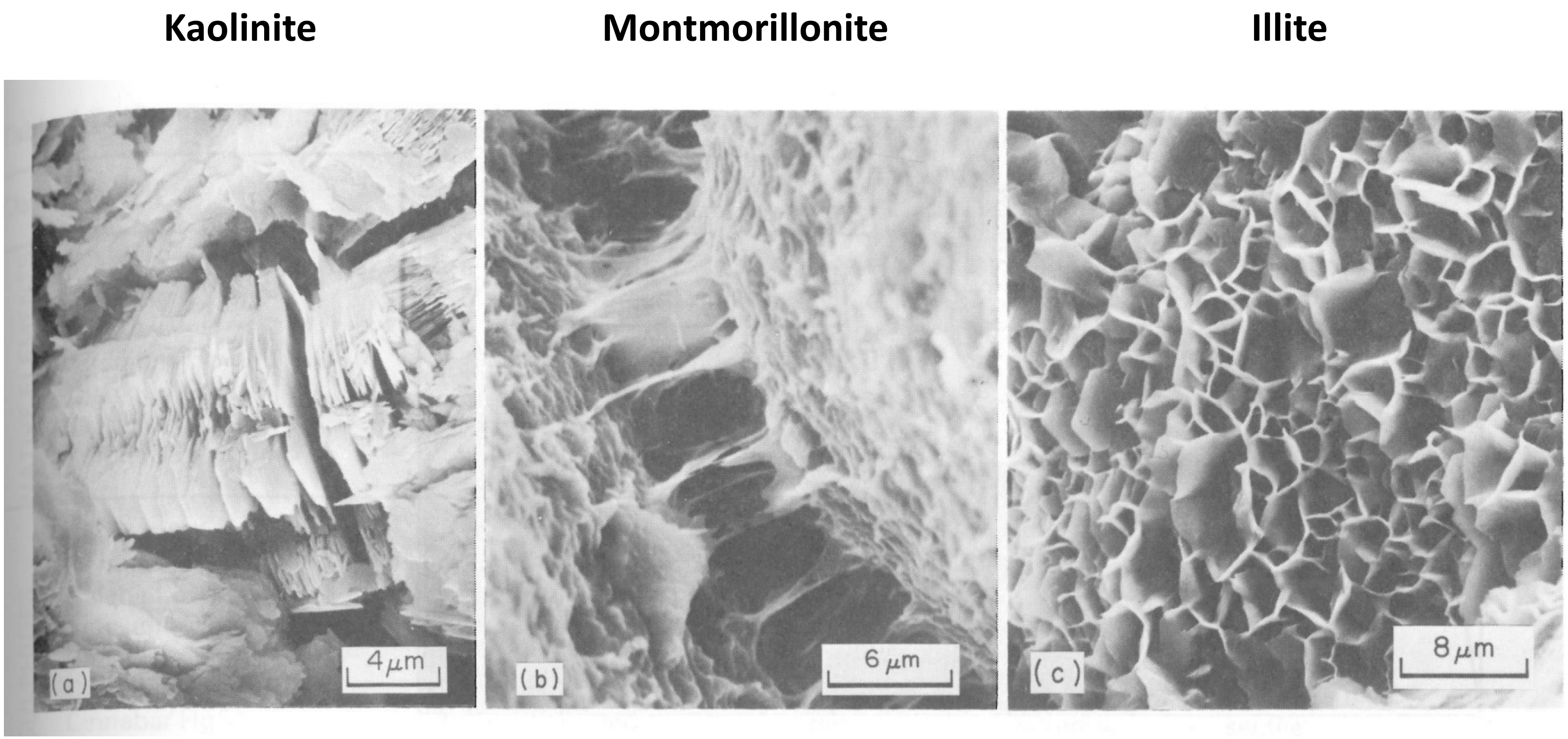
Fine Grained (Continuum) Material

Particle Size - Definitions



BSI (1999) BS 5930:1999 + A2:2010 *Code of practice for site investigations.* London, British Standards Institution.

Clay



Electron microscope images of clay minerals

Blyth & De Freitas (2001) A Geology for Engineers. 7th Ed, Oxford, Butterworth-Heinemann, page 81

Examples of UK Clay

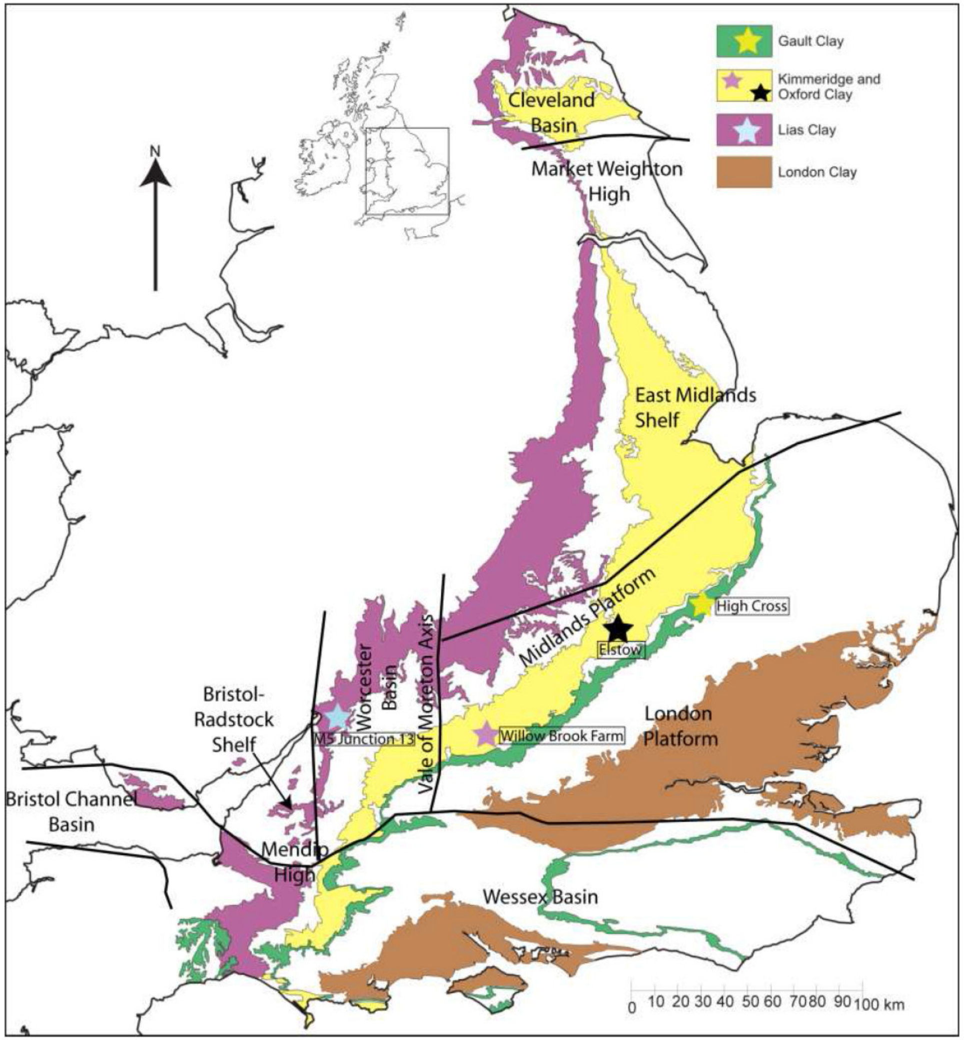
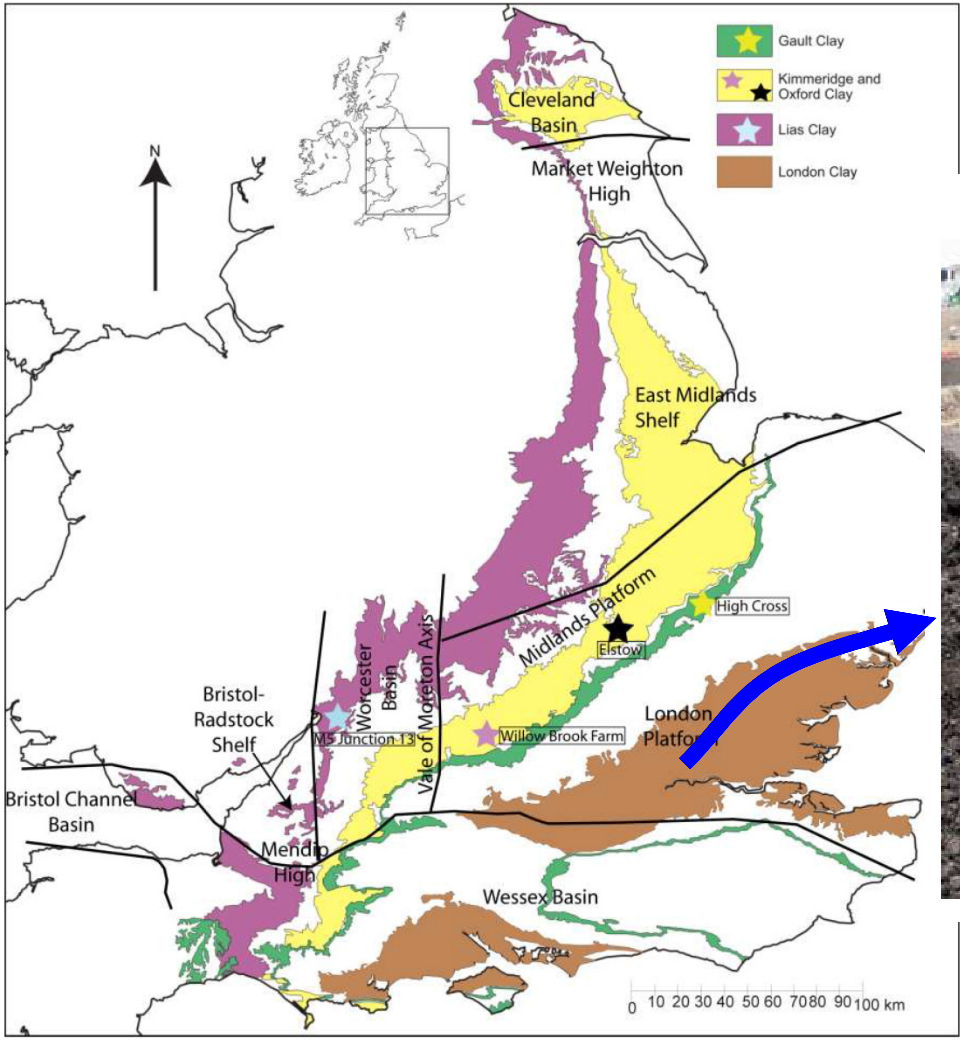


Figure 3.10 The basins of the UK, geology after (British Geological Survey, 2008) UK basins after (Cox *et al.*, 1999). Stars indicate the sampling locations for each of the mudrocks.

Wilkinson, S. (2011) The microstructure of UK mudrocks. PhD Thesis, Imperial College London.

London Clay



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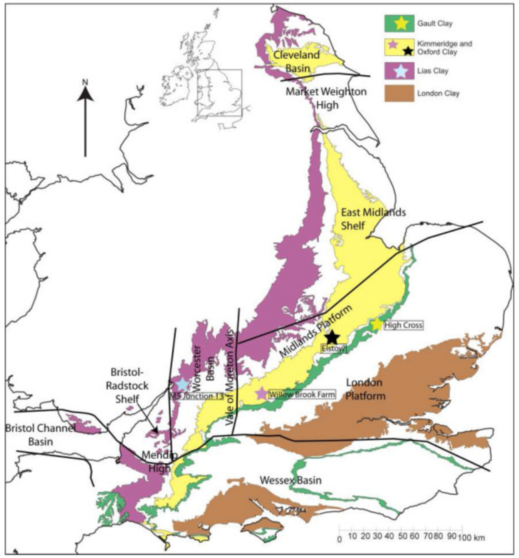

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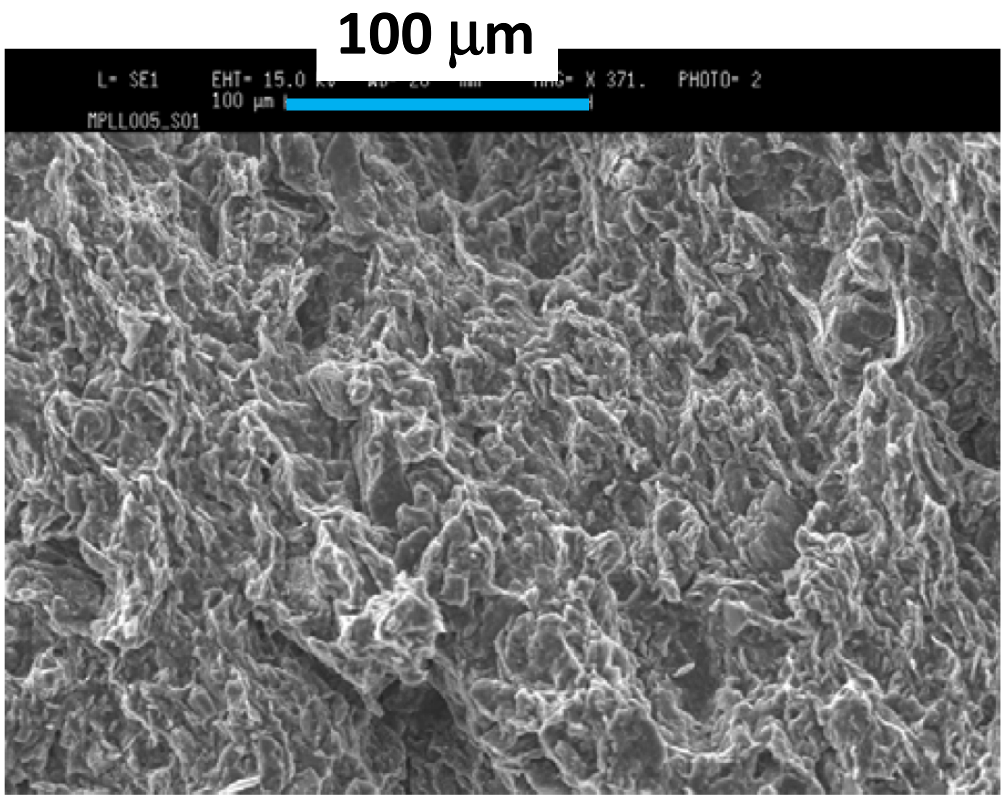
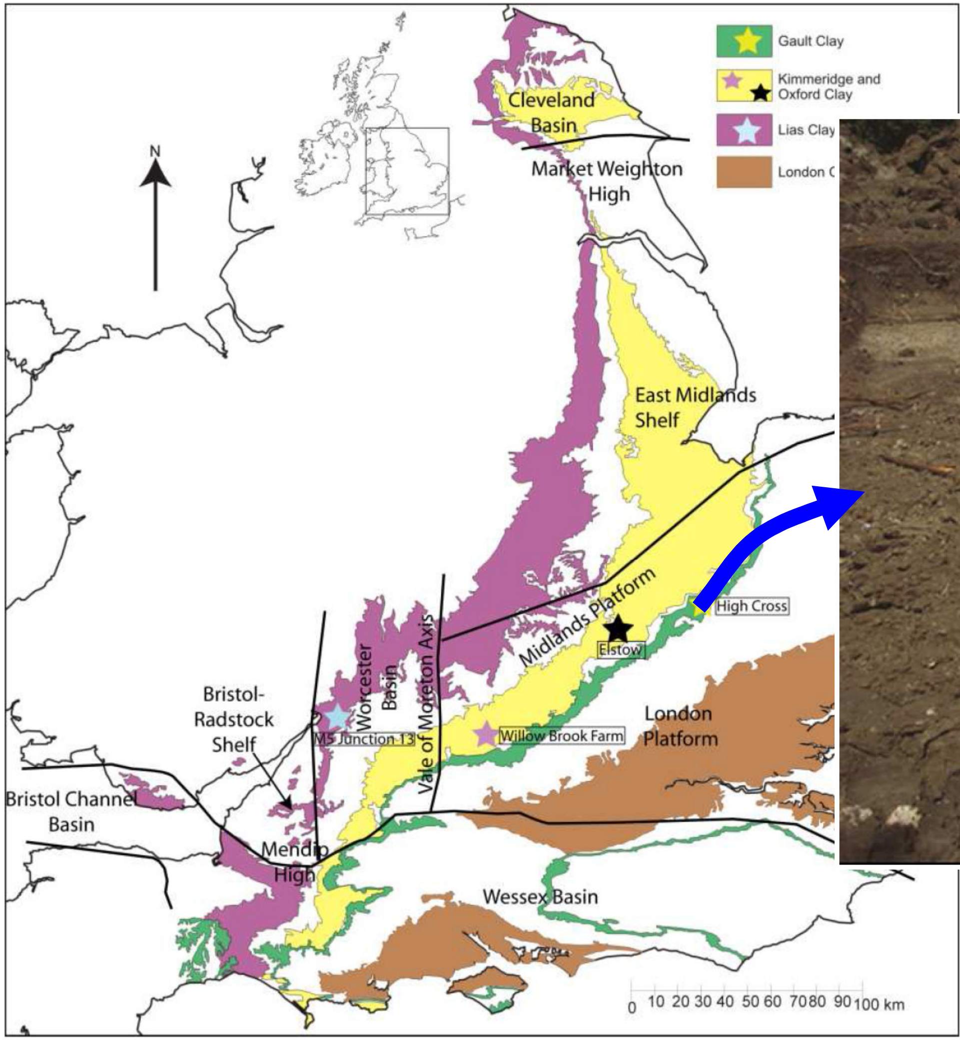


Illite and Montmorillonite and some Kaolinite

Bouch, J.E. (2006) SEM petrography of samples of the London Clay of southern England. (IR/05/126).

Gault Clay



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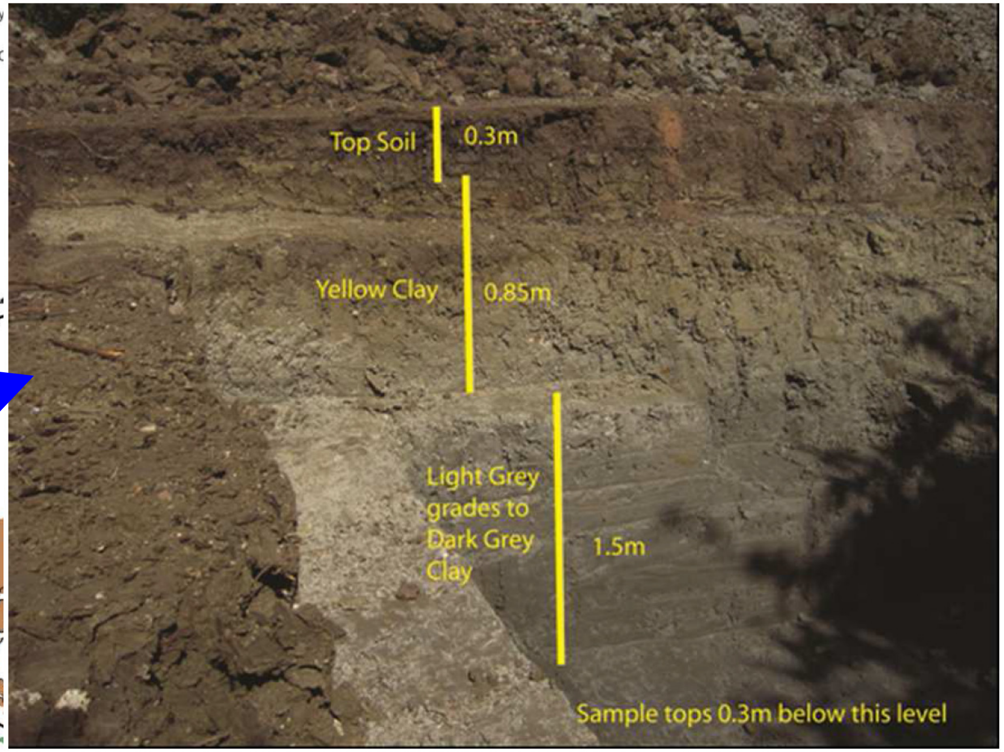
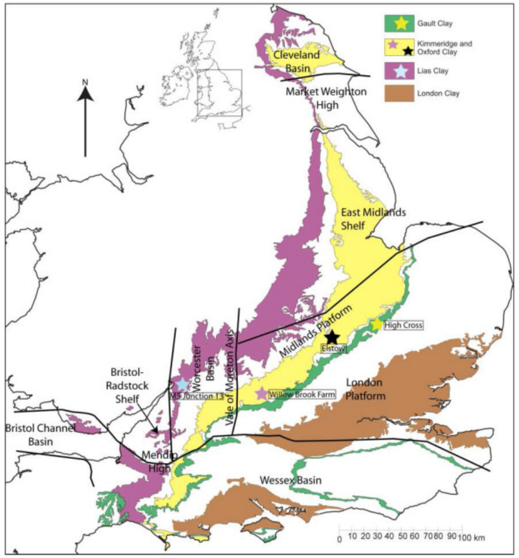


Wilkinson, S. (2011) The microstructure of UK mudrocks. PhD Thesis, Imperial College London.

Gault Clay



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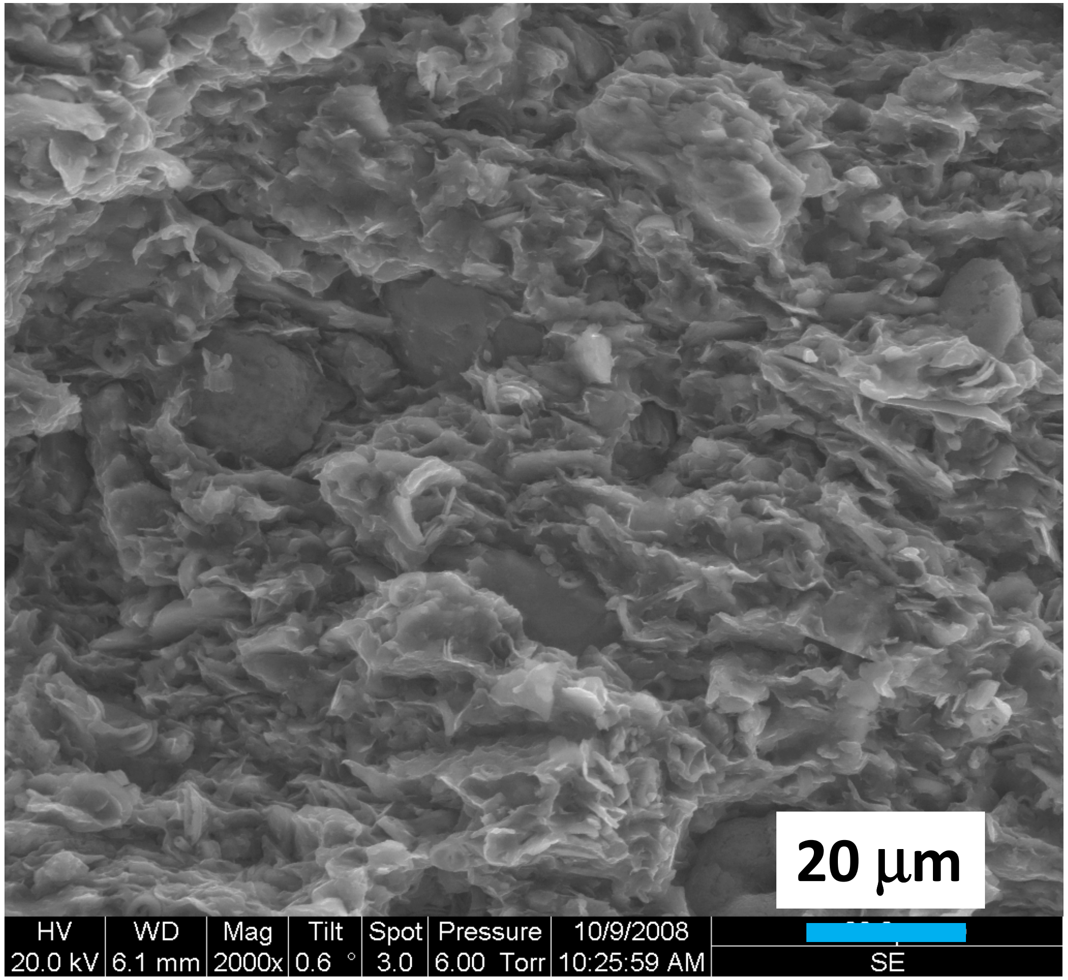
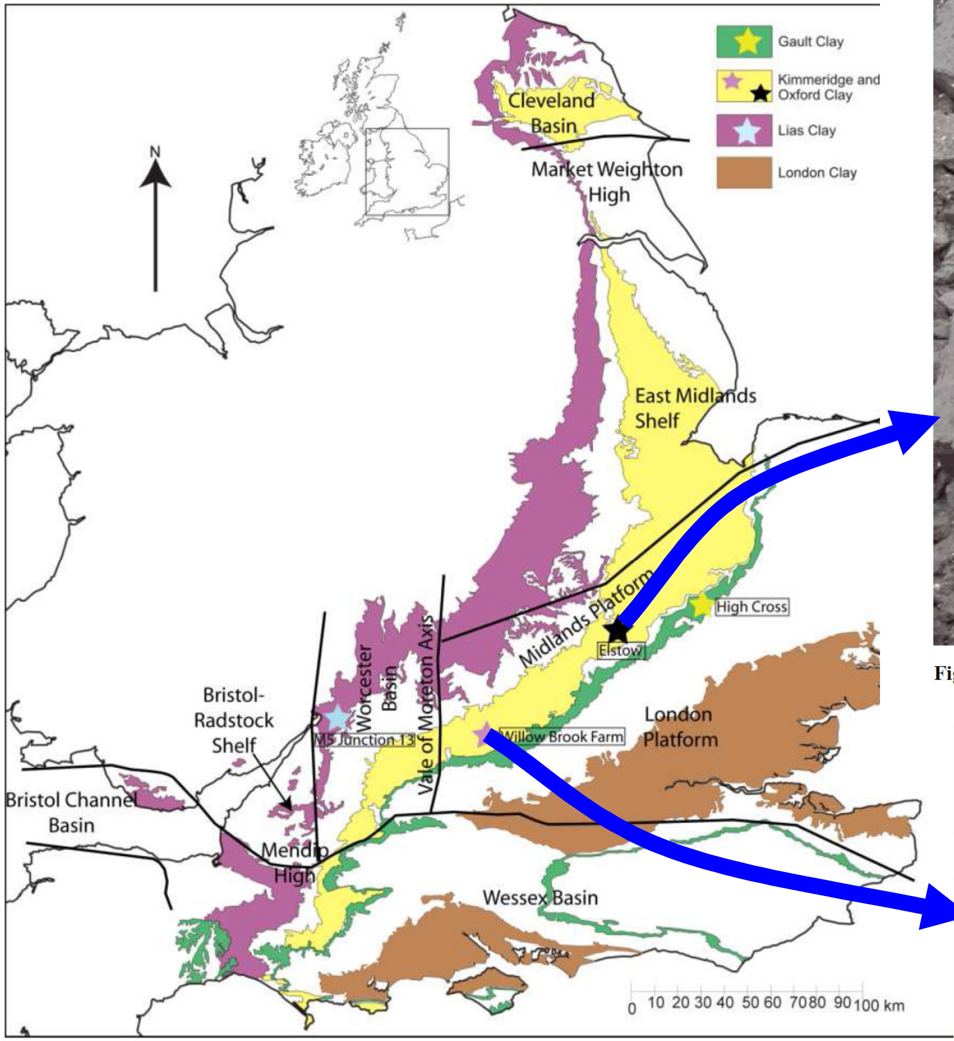


Illite with Calcium Carbonate inclusions

(shells, nanoshells) and some pyrite

Oxford and Kimmeridge Clays



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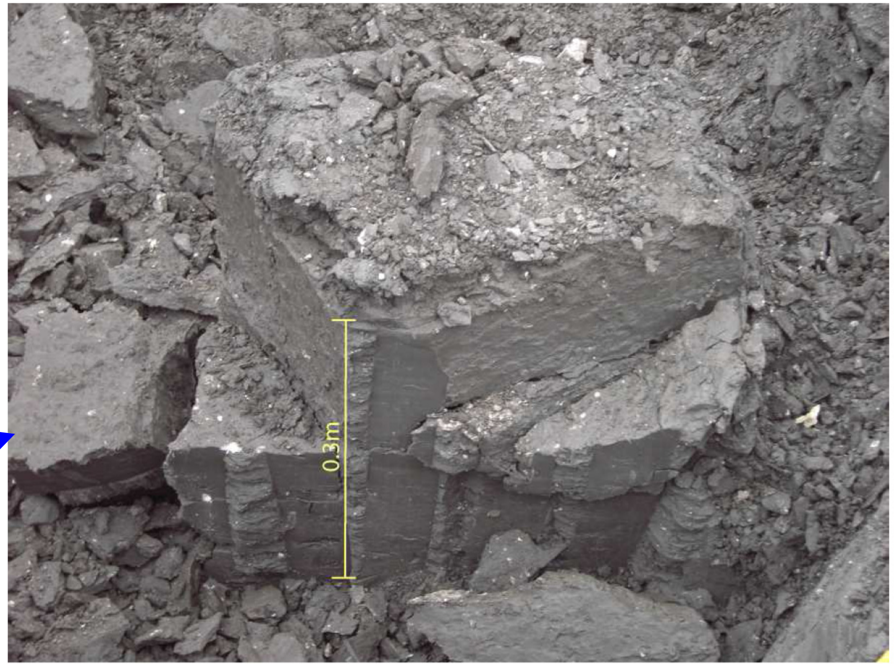


Figure 5.9 Two joints running through a block sample of the Oxford Clay. Scale approximate

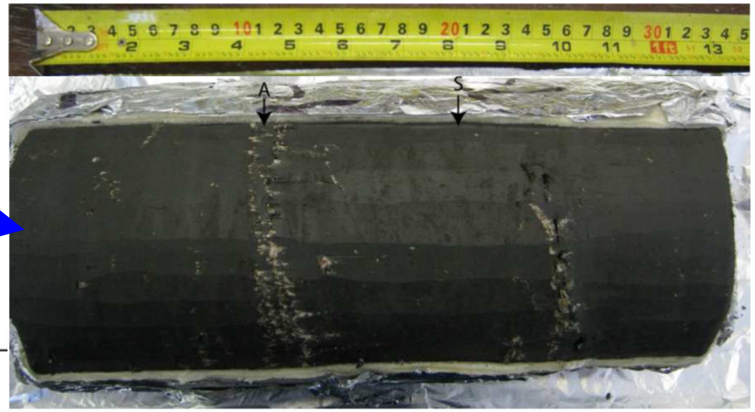
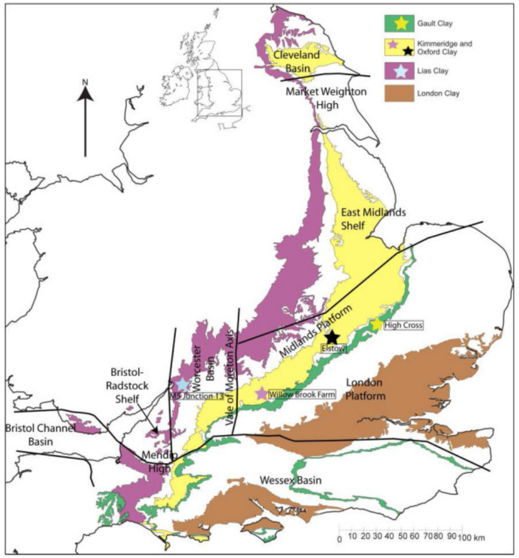


Figure 7.17 Kimmeridge Clay, core WBF2, 11.81-12.06m some ammonite shells (A) and some silty lenses (S). T = top of core B = base of core, tape measure showing cm (top) inches (bottom).

Wilkinson, S. (2011) The microstructure of UK mudrocks. PhD Thesis, Imperial College London.

Oxford Clay



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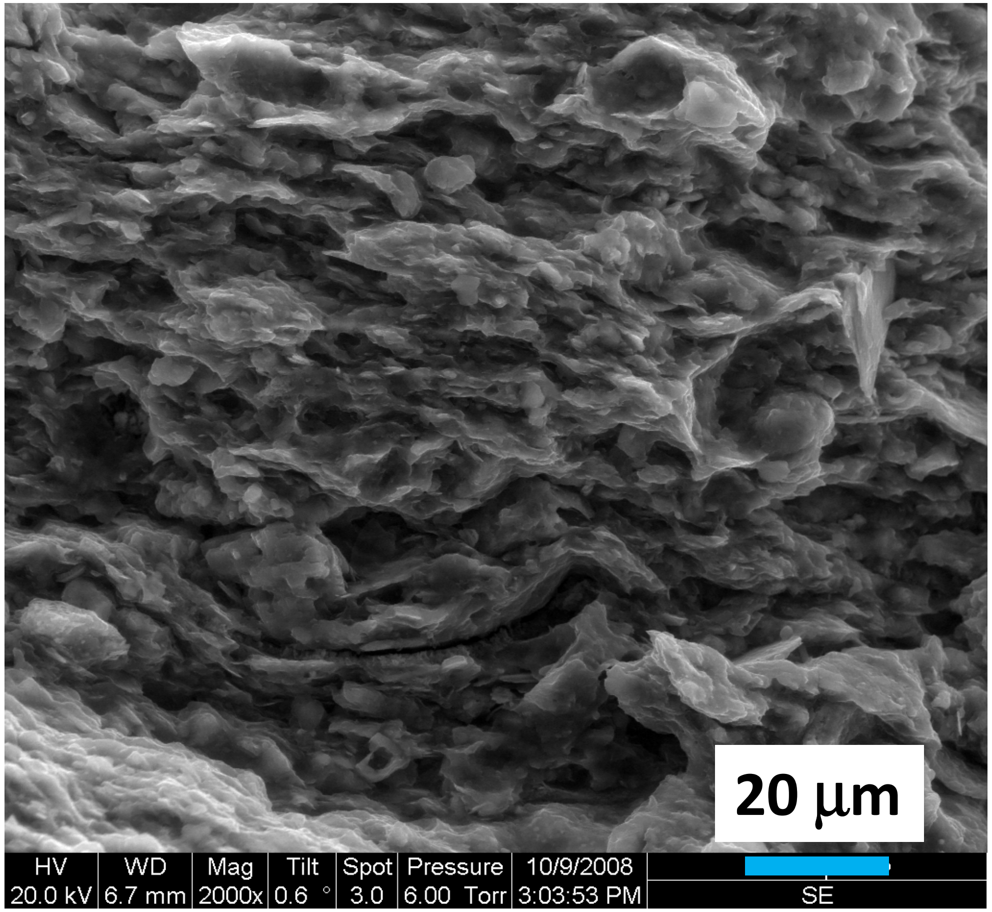
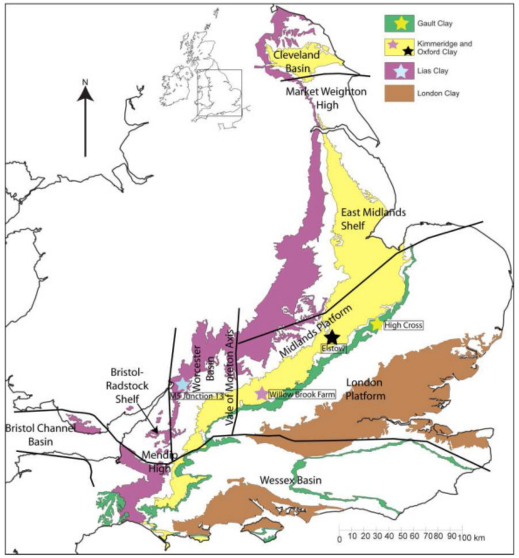


High Illite content and Calcuim Carbonate cementation

Kimmeridge Clay



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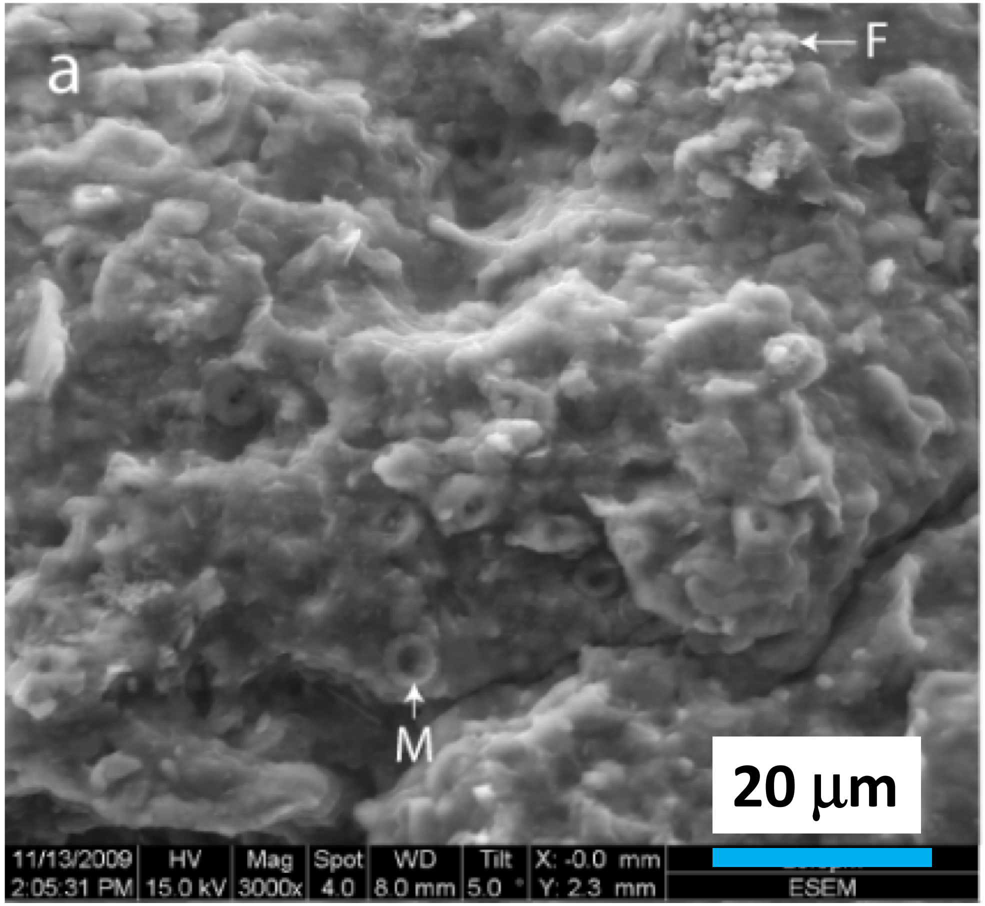


Rich in Illite and Montmorillonite and some Kaolinite

Wilkinson, S. (2011) The microstructure of UK mudrocks. PhD Thesis, Imperial College London.

Characteristics of Clay

Characteristics

- Clay particles tend to have a net negative charge
- Exhibit plasticity when mixed with water
    - Silt has a gritty texture whereas clay is smooth
- High resistance to weathering
- Particles are usually flat/platey

Terminology

Clays are formed slowly in calm water environments

Marine Clays	**Lacustrine Clays**	**Esturine Clays**
Formed under the sea	**Formed in lakes**	**Formed in estuaries**

Old Terminology

Fat Clays;

A sticky, highly plastic clay which is ‘greasy’ to the touch.

Lean Clays;

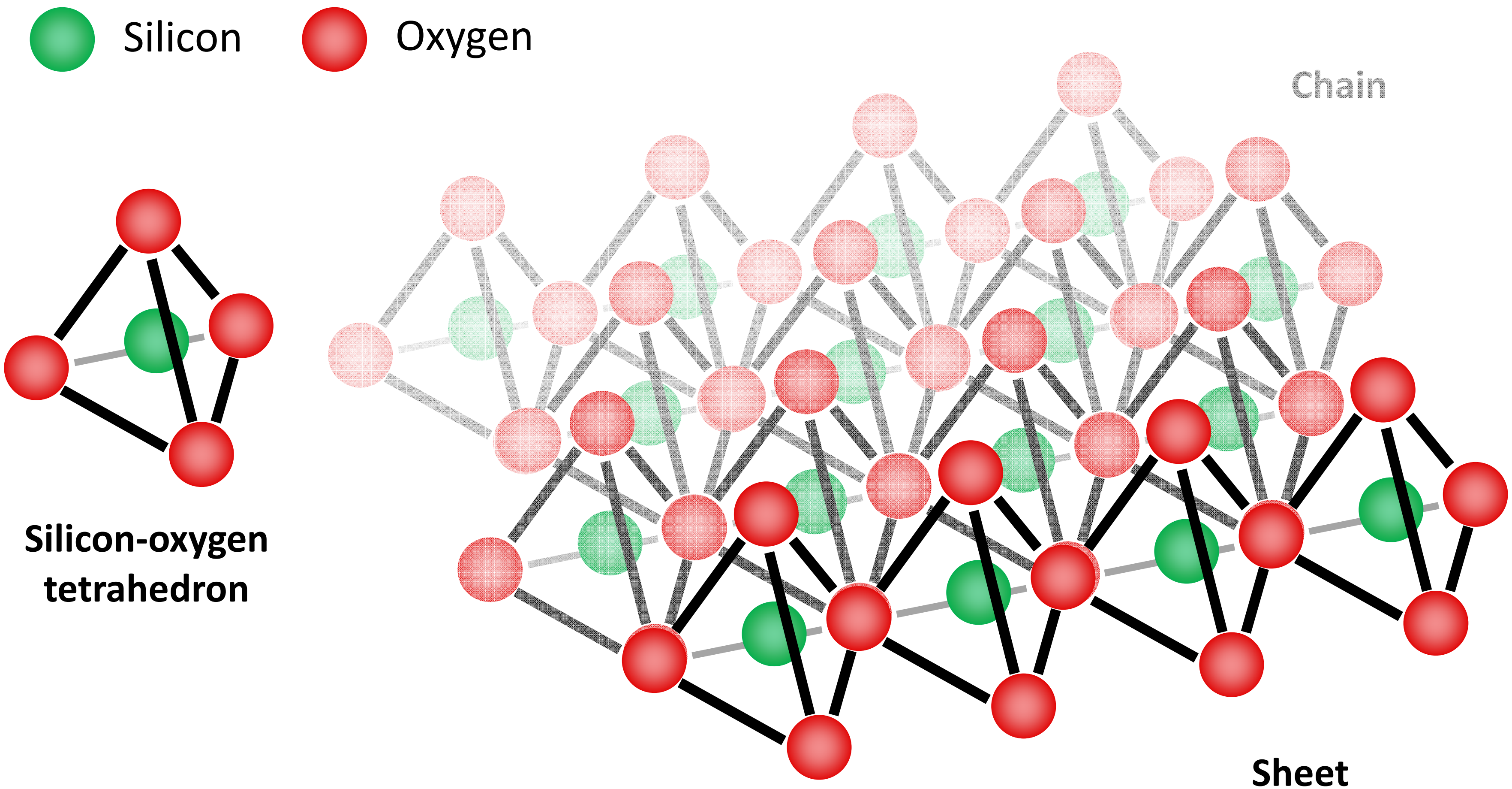
Clay of low plasticity

Quick Clays;

Highly sensitive clays, with a strong disparity between the intact, undisturbed soil strength and the re-moulded soil strength [Rissa Landslide, Norway, 1978]

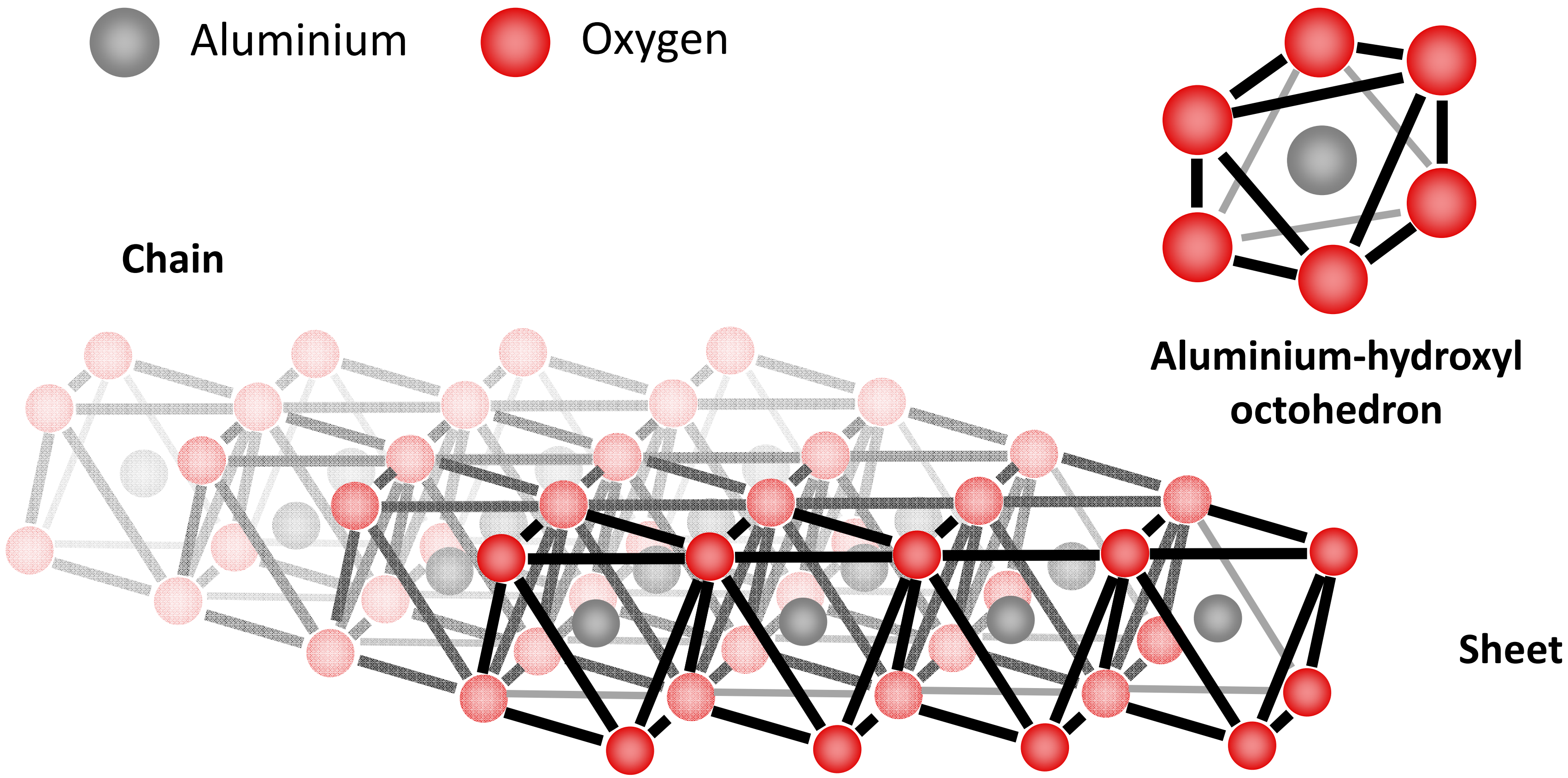
Chemistry

Clay: the building blocks



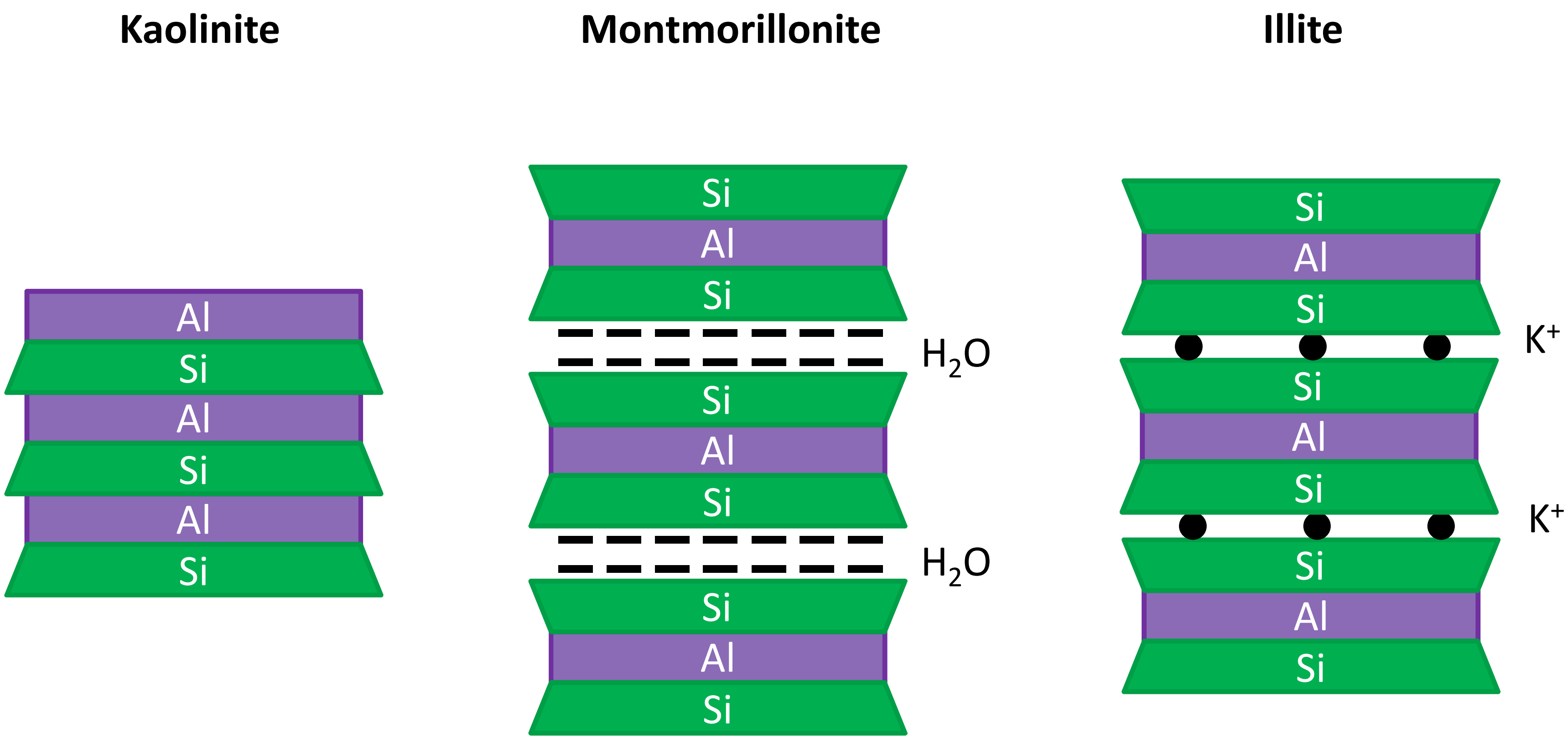
Silica Layer

Clay: the building blocks



Octahedral layer

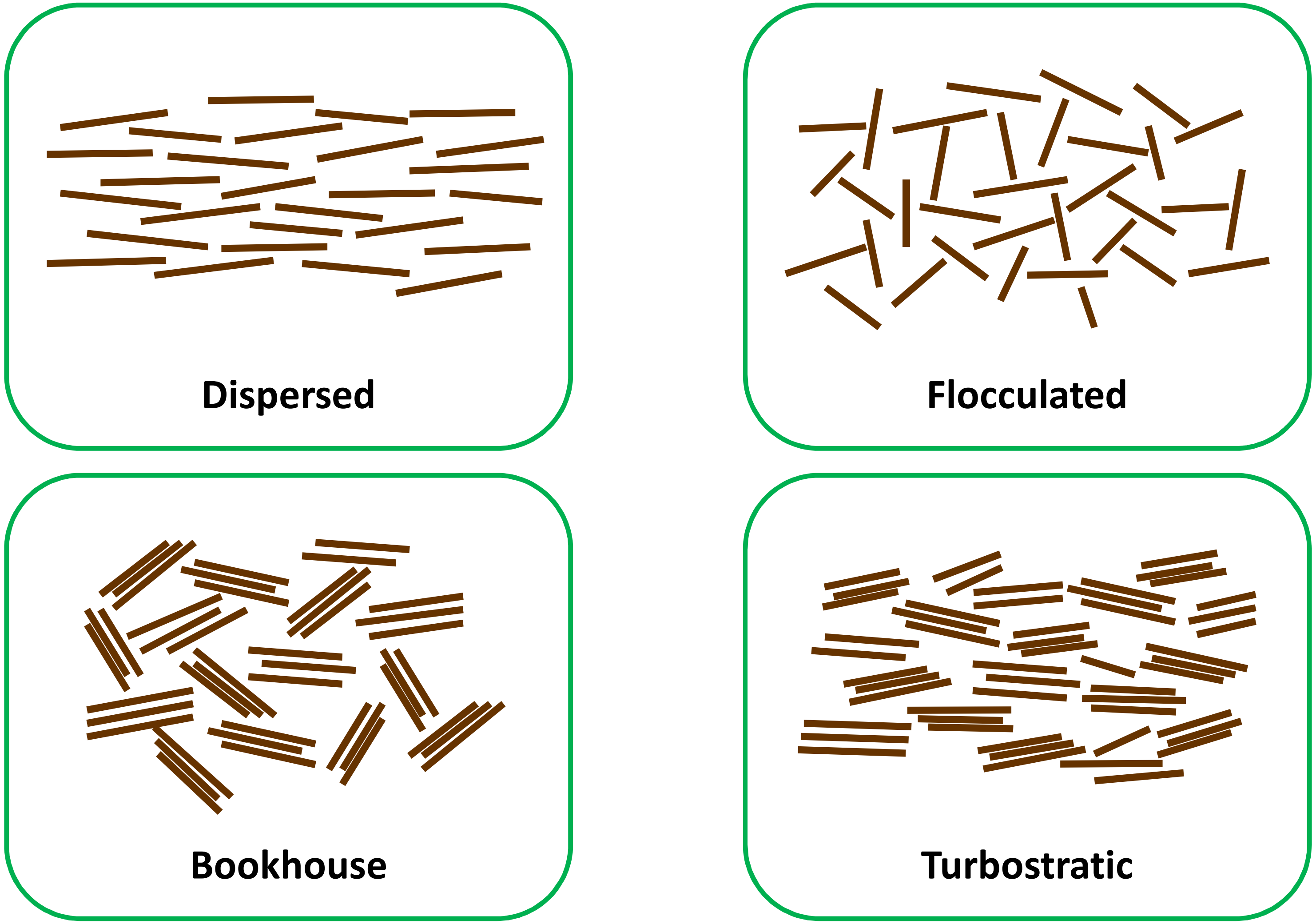
Clay



Clay minerals are made of two-dimensional atomic layers or sheets

Knappett & Craig (2012) Craig's Soil Mechanics. 8th Ed, Abingdon, Spon Press, page 9

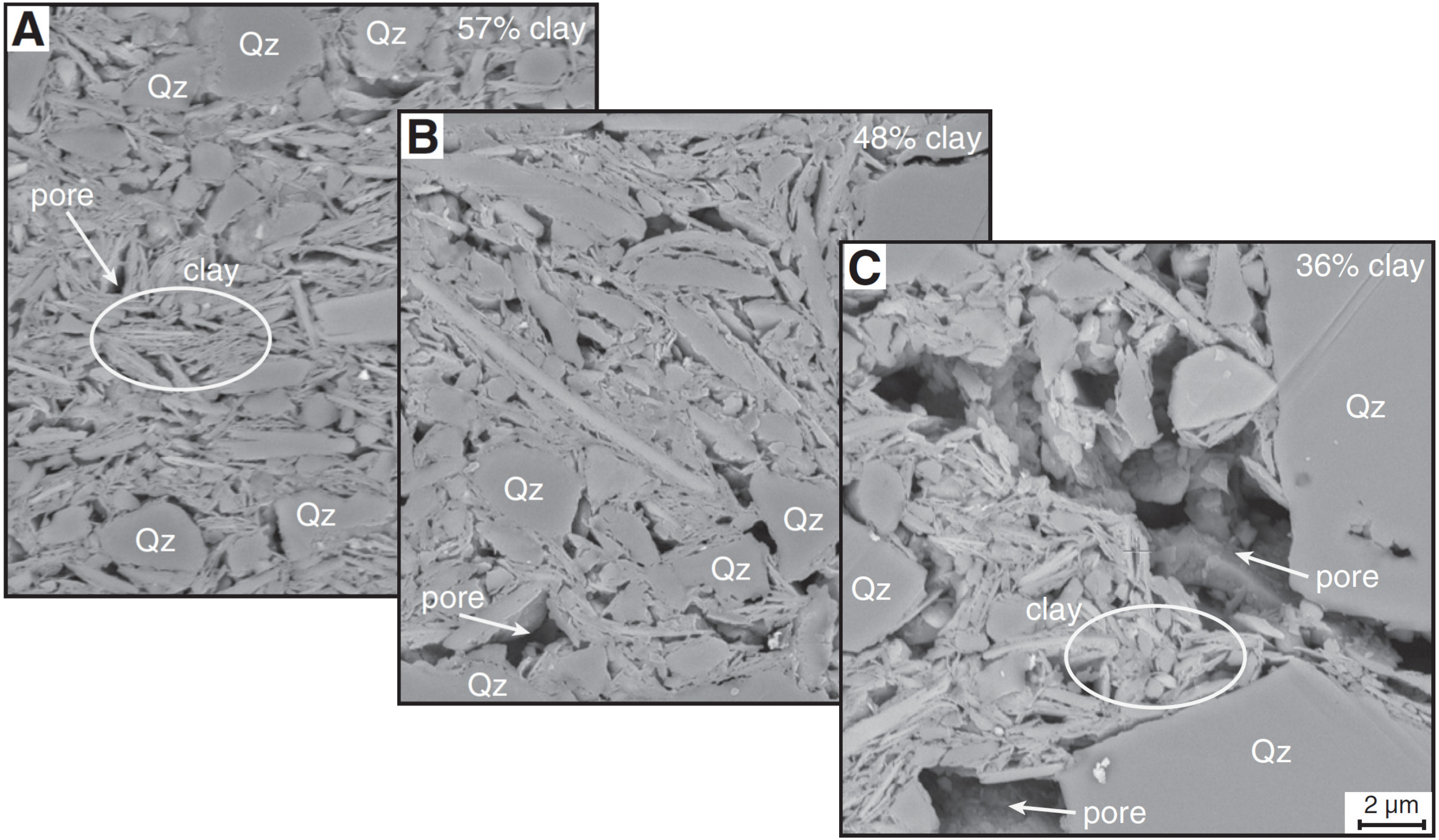
Clay Structure



Knappett & Craig (2012) Craig's Soil Mechanics. 8th Ed, Abingdon, Spon Press, page 9

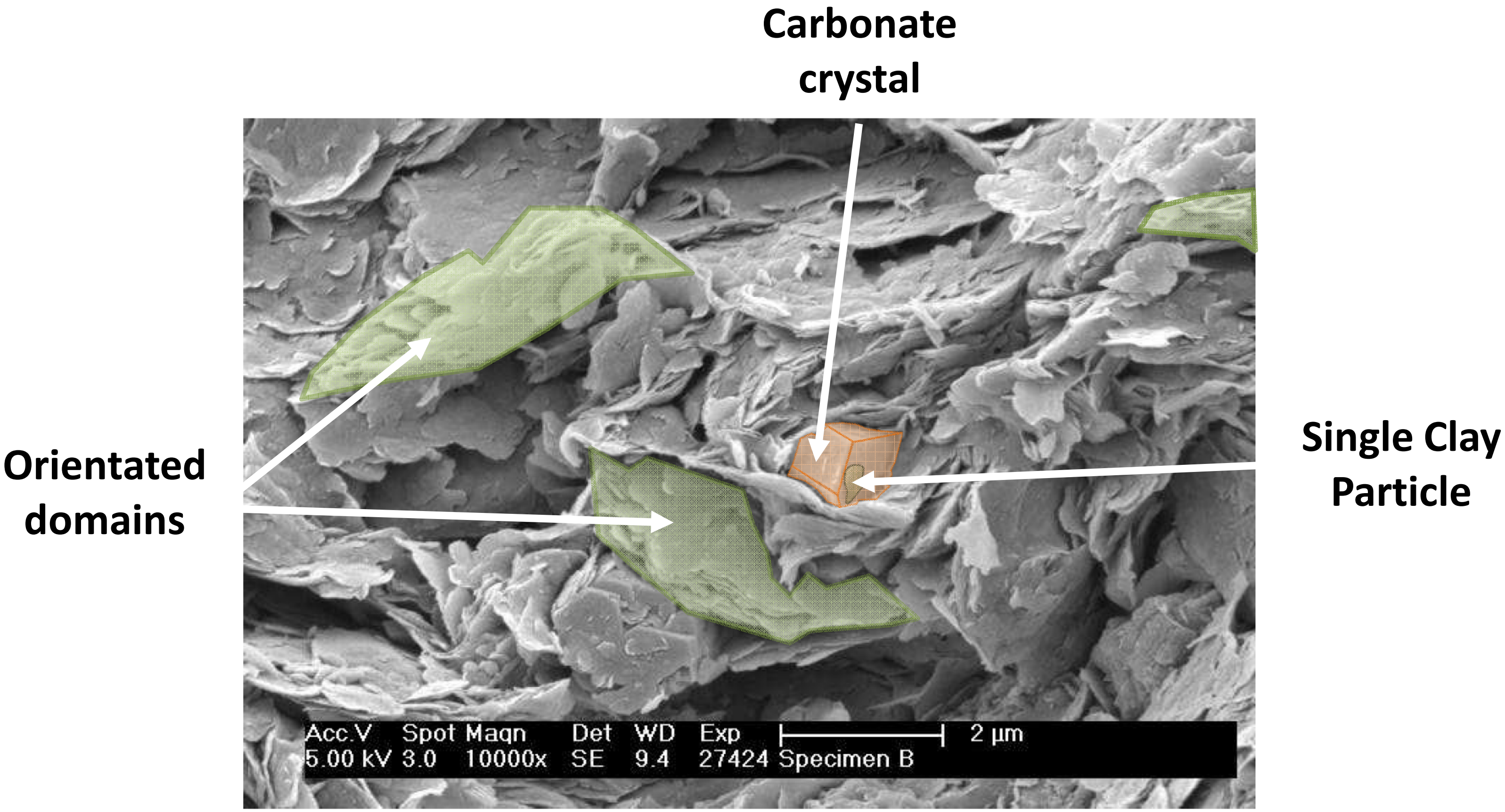
Also see: Sides and Barden (1970) the microstructure of dispersed and flocculated samples of kaolinite, illite and montmorillonite, Canadian Geotechnical Journal, ***8****: 391-399.*

Clay Structure



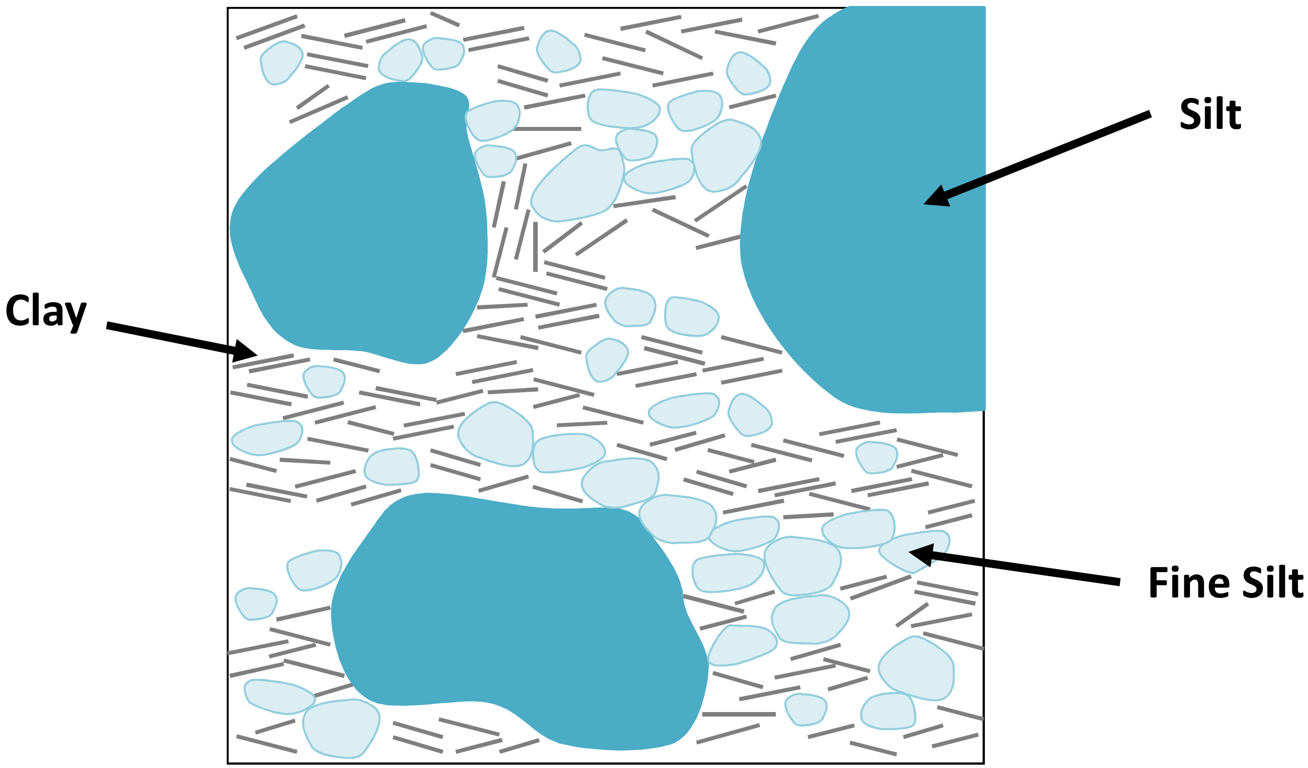
Schneider et al. (2011) Insights into pore-scale controls on mudstone permeability through resedimentation experiments. *Geology* **39** (11): 1011-1014.

Clay Structure

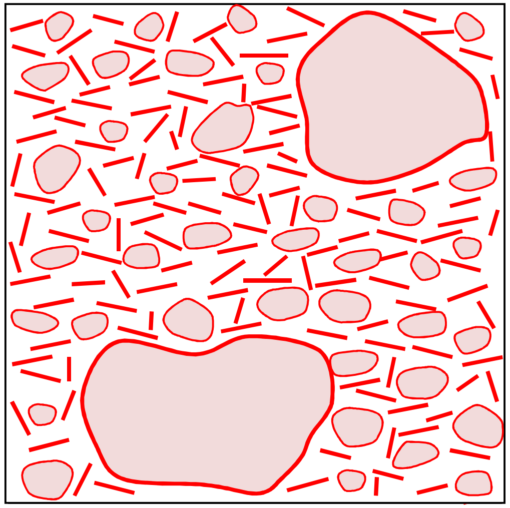


Gasparre, A (2005) *Advanced laboratory characterisation of London Clay*. PhD thesis, Imperial College London.

Natural Clay Structure



Definitions



Natural State;

Undisturbed soil sample

Remoulded;

A soil sample which has been disturbed from its natural state with some or most of its natural structure removed due to mechanical means.

Reconstituted;

A soil sample which has all of its natural structure removed due to mechanical mixing at 1.5 to 2 times its liquid limit.

Description

Consistency

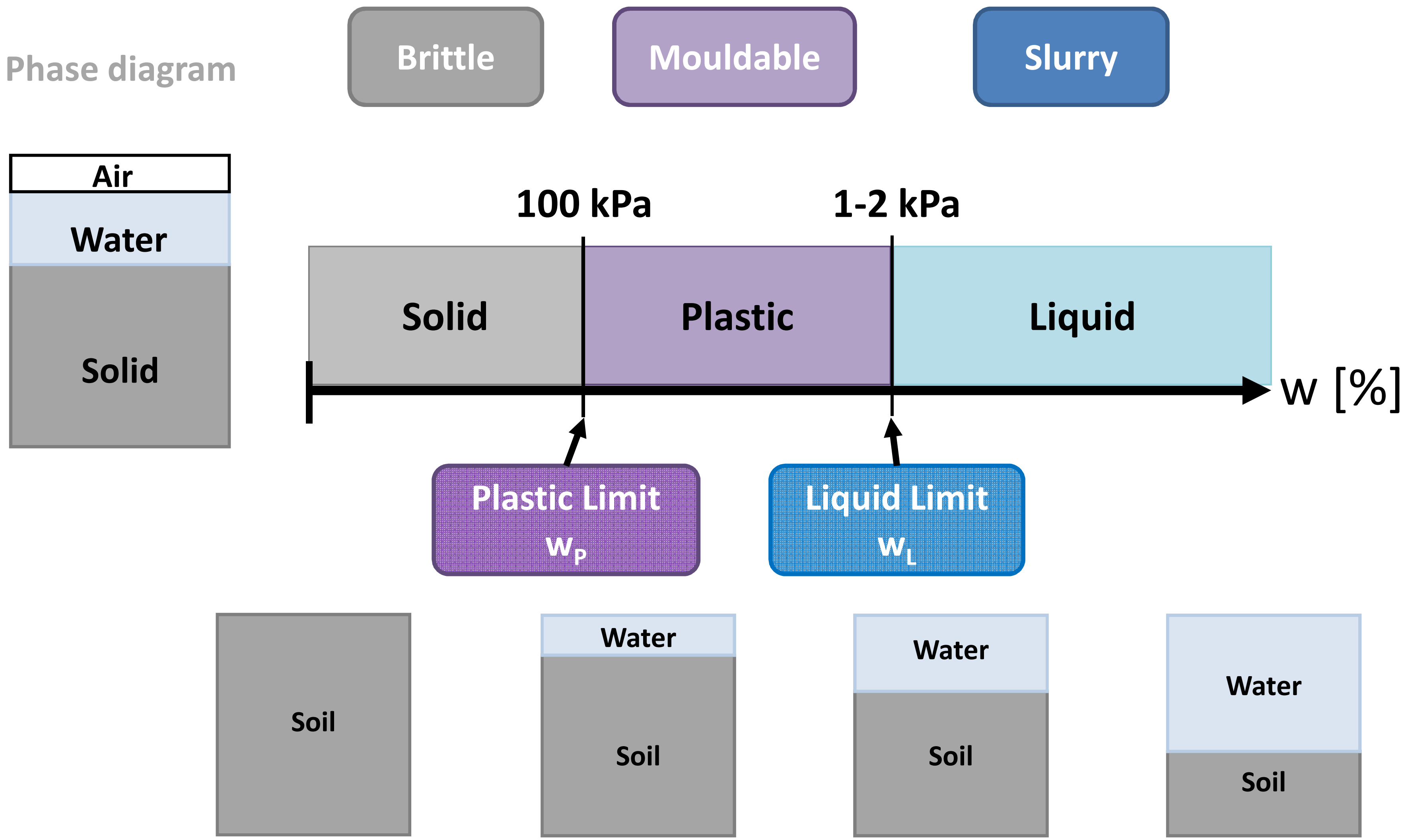
Term used for field description	**Consistency description definition** [after BS EN ISO 14688-1:2002, **5.14**]
Very soft	Finger easily pushed in up to 25 mm. Exudes between fingers
Soft	Finger pushed in up to 10 mm. Moulds by light finger pressure
Firm	Thumb makes impression easily. Cannot be moulded by fingers, rolls in the hand to a 3 mm thick thread without breaking or crumbling
Stiff	Can be indented slightly by thumb. Crumbles in rolling a 3 mm thick thread, but can then be remoulded into a lump
Very stiff	Can be indented by thumb nail. Cannot be moulded but crumbles under pressure
Hard	Can be scratched by thumbnail

BSI (1999) BS 5930:1999 + A2:2010 *Code of practice for site investigations.* London, British Standards Institution.

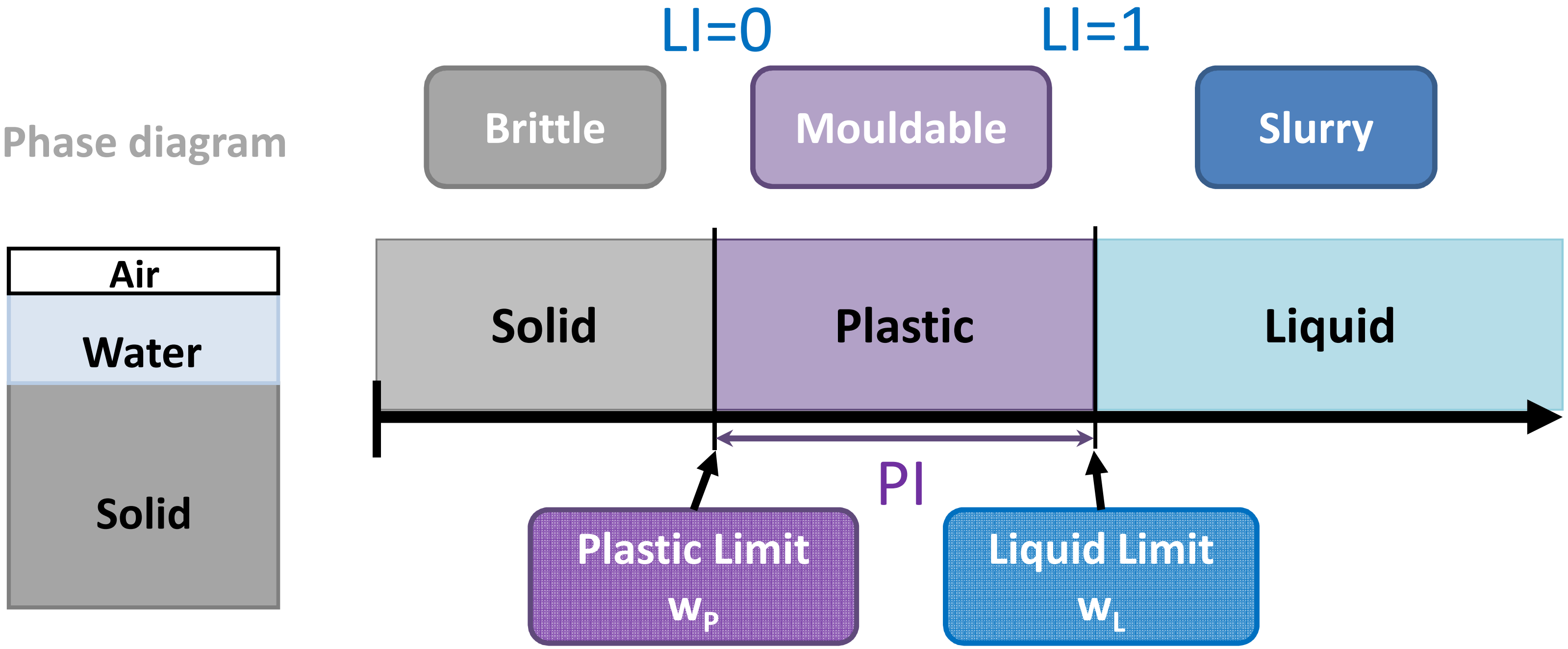
Atterberg Limits

Classifying the ‘fines’ fraction of soil

Atterberg Limits



Atterberg Limits



$$PI = w_L - w_P$$

Plasticity Index

$$LI = \frac{w - w_P}{w_L - w_P}$$

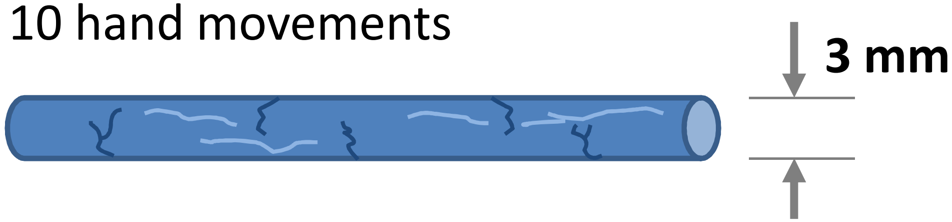
Liquidity Index

Plastic limit, w_P

- The *empirically established* moisture content at which the soil becomes too dry to be plastic.

Plastic Limit

Soil shears both longitudinally and transversely when it has been rolled to about 3 mm in diameter after 5 – 10 hand movements



- It is recognised that the results are subject to the judgement of the operator and that some variability in results will occur

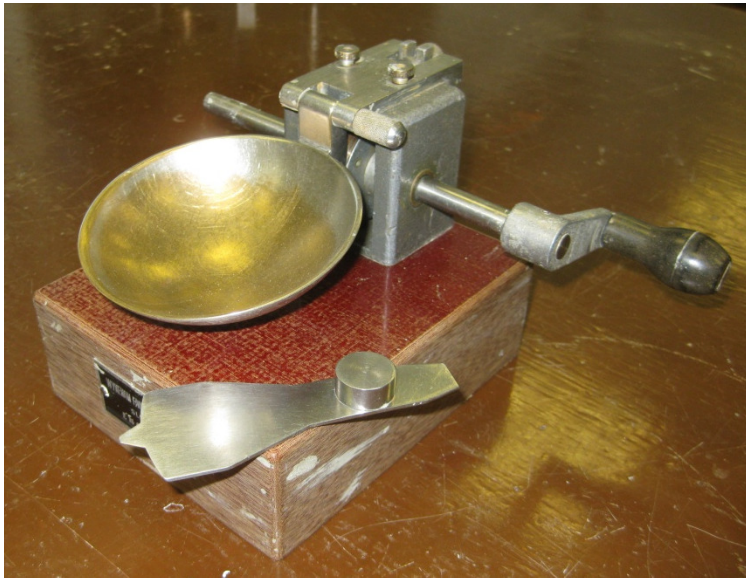
Subjective

BSI (1990) BS 1377-2 *Methods of test for soils for civil engineering purposes – Part 2: Classification tests.* London, British Standards Institution.

Liquid limit, w_L

- There are two widely accepted methods to determine liquid limit.

Casagrande;

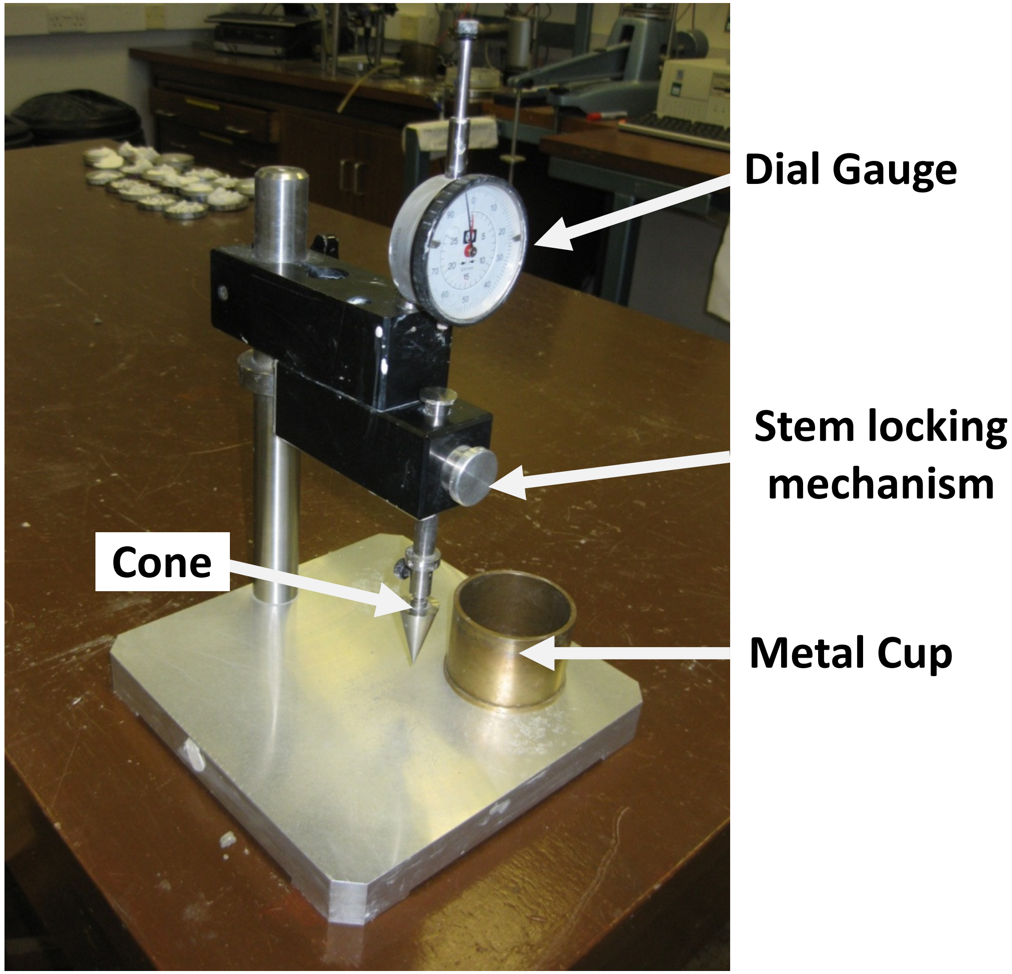


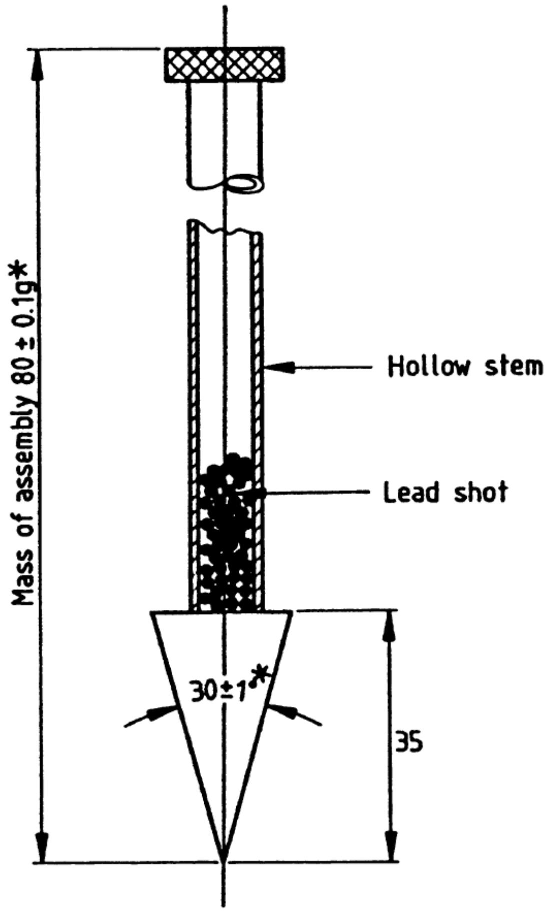
Cone penetrometer;

Cone Penetrometer

Liquid Limit w_L

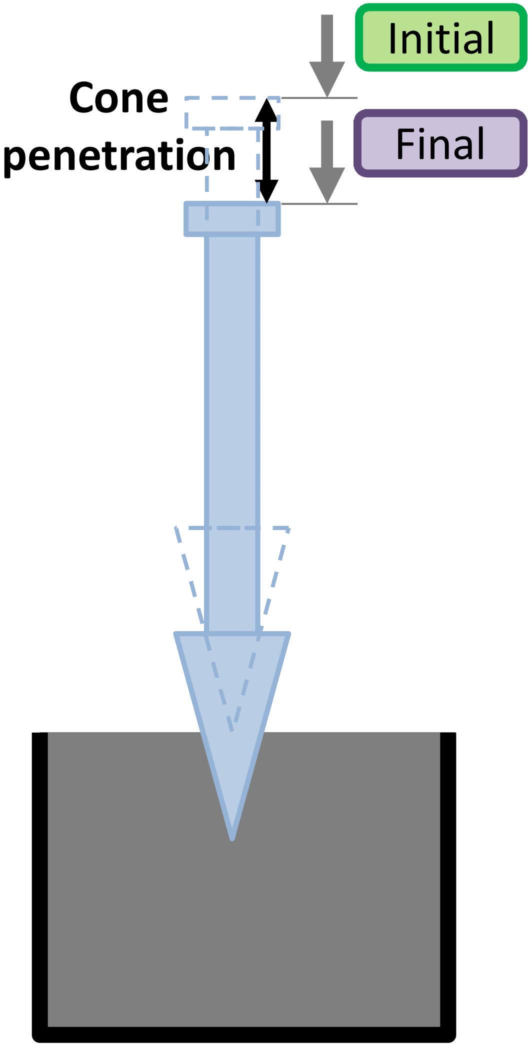
The moisture content corresponding to a cone penetration of 20mm





BSI (1990) BS 1377-2 *Methods of test for soils for civil engineering purposes – Part 2: Classification tests.* London, British Standards Institution.

Cone Penetrometer

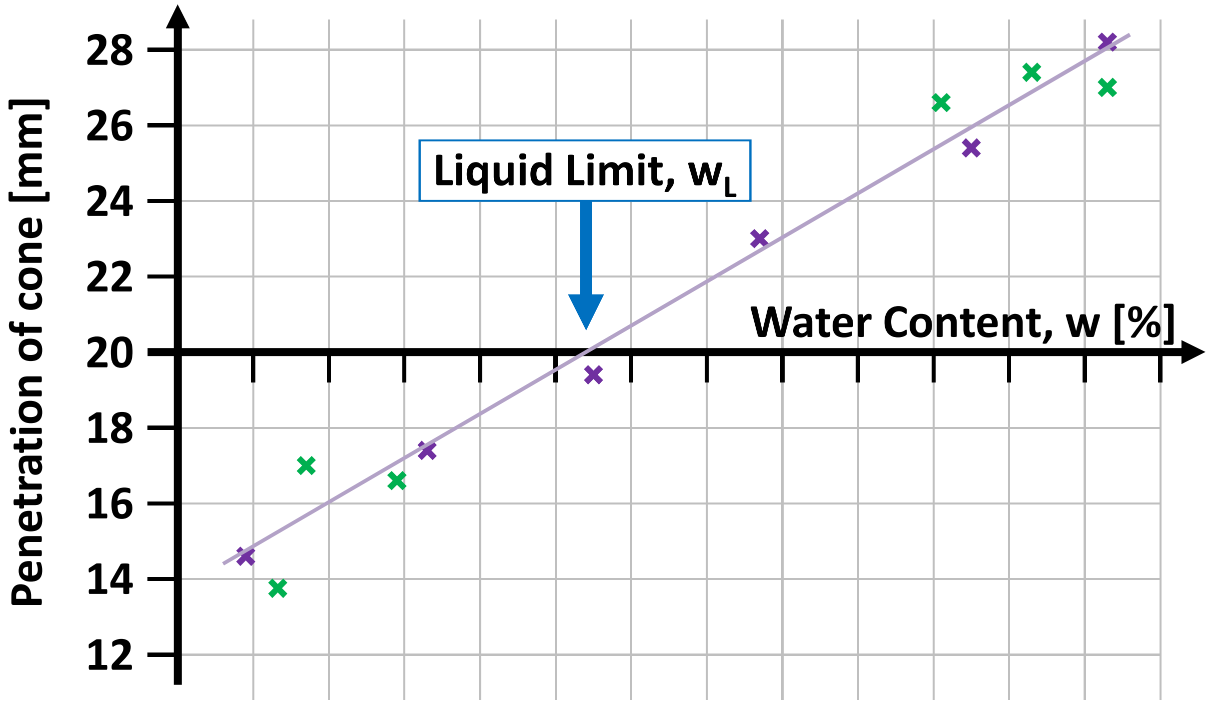


- Mix soil into a smooth paste using 2 metal spatulas and distilled water.
- Fill metal cup with the mixed soil taking care not to trap air.
- Strike off extra soil to give a smooth level surface.
- Lower the tip of the cone to the surface of the soil
- Lower the stem of the dial gauge to contact the cone shaft and record the reading.
- Release the cone for 5 secs
- Lock cone position.
- Lower the stem of the dial gauge to contact the cone shaft and record the reading.
- Extract a small sample of soil from the cup to measure the water content.

BSI (1990) BS 1377-2 *Methods of test for soils for civil engineering purposes – Part 2: Classification tests.* London, British Standards Institution.

Cone Penetrometer

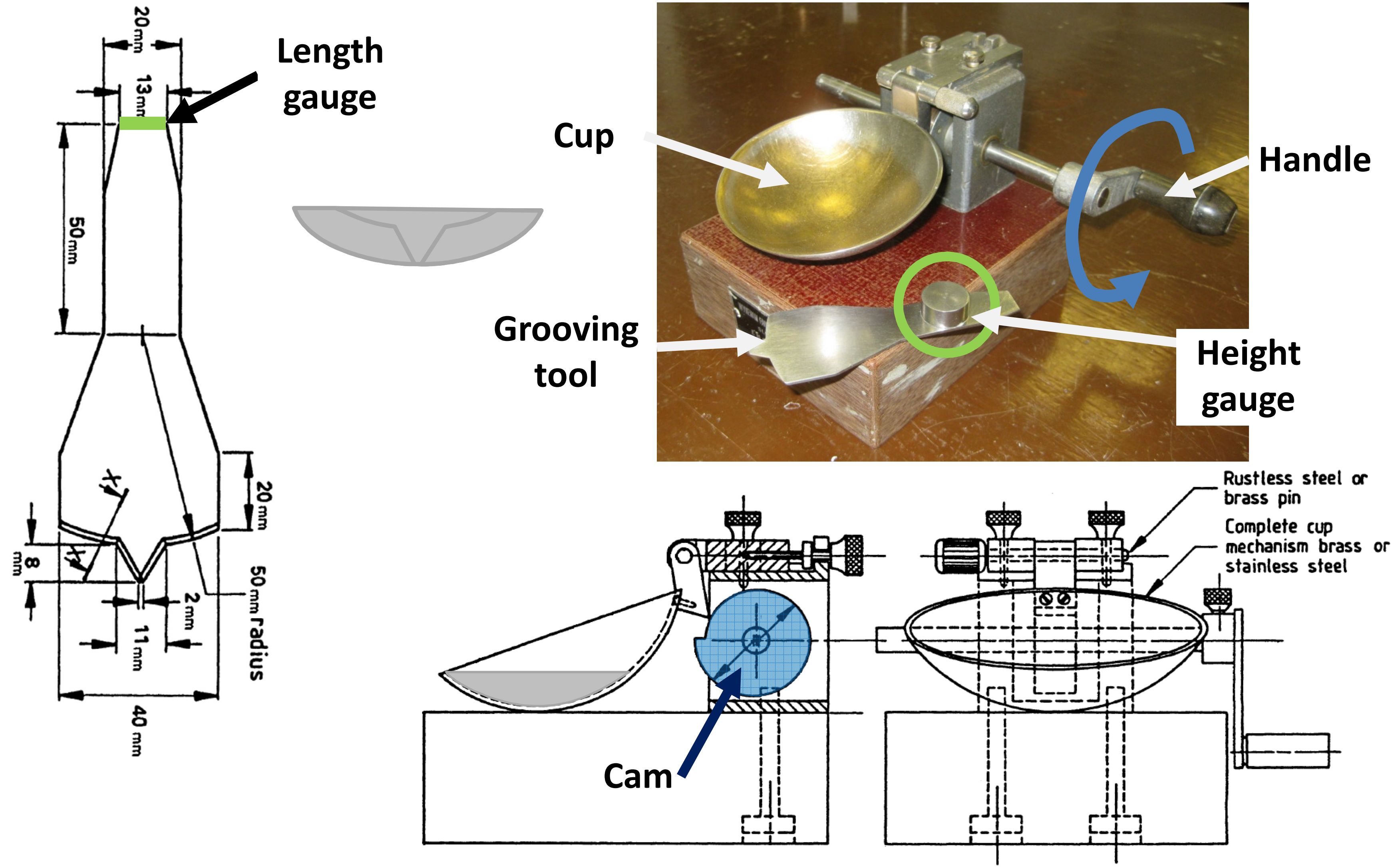
Liquid Limit w_L
The moisture content corresponding to a cone penetration of 20mm



Minimum of 4 evenly distributed readings ranging from 15mm to 25mm penetration

BSI (1990) BS 1377-2 *Methods of test for soils for civil engineering purposes – Part 2: Classification tests.* London, British Standards Institution.

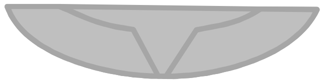
Casagrande



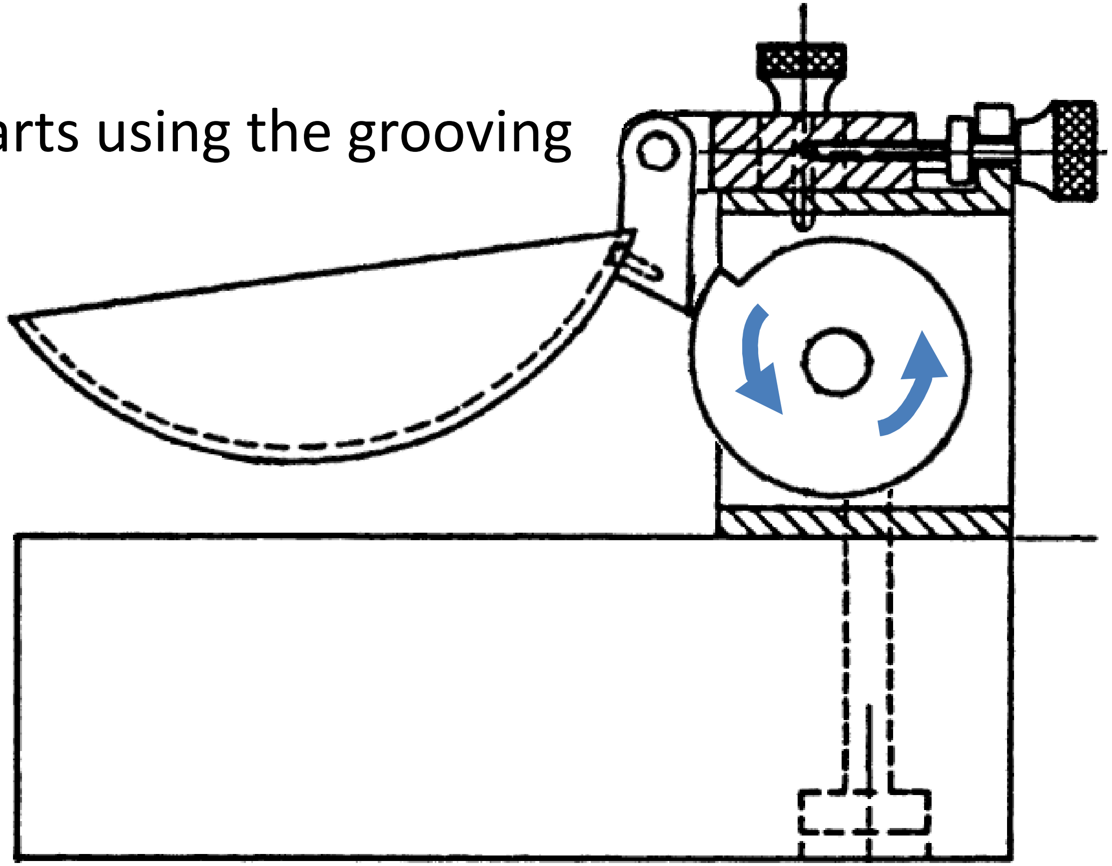
BSI (1990) BS 1377-2 *Methods of test for soils for civil engineering purposes – Part 2: Classification tests.* London, British Standards Institution.

Casagrande

Liquid Limit w_L
The moisture content corresponding to 25 blows closing the base of the groove over 13 mm



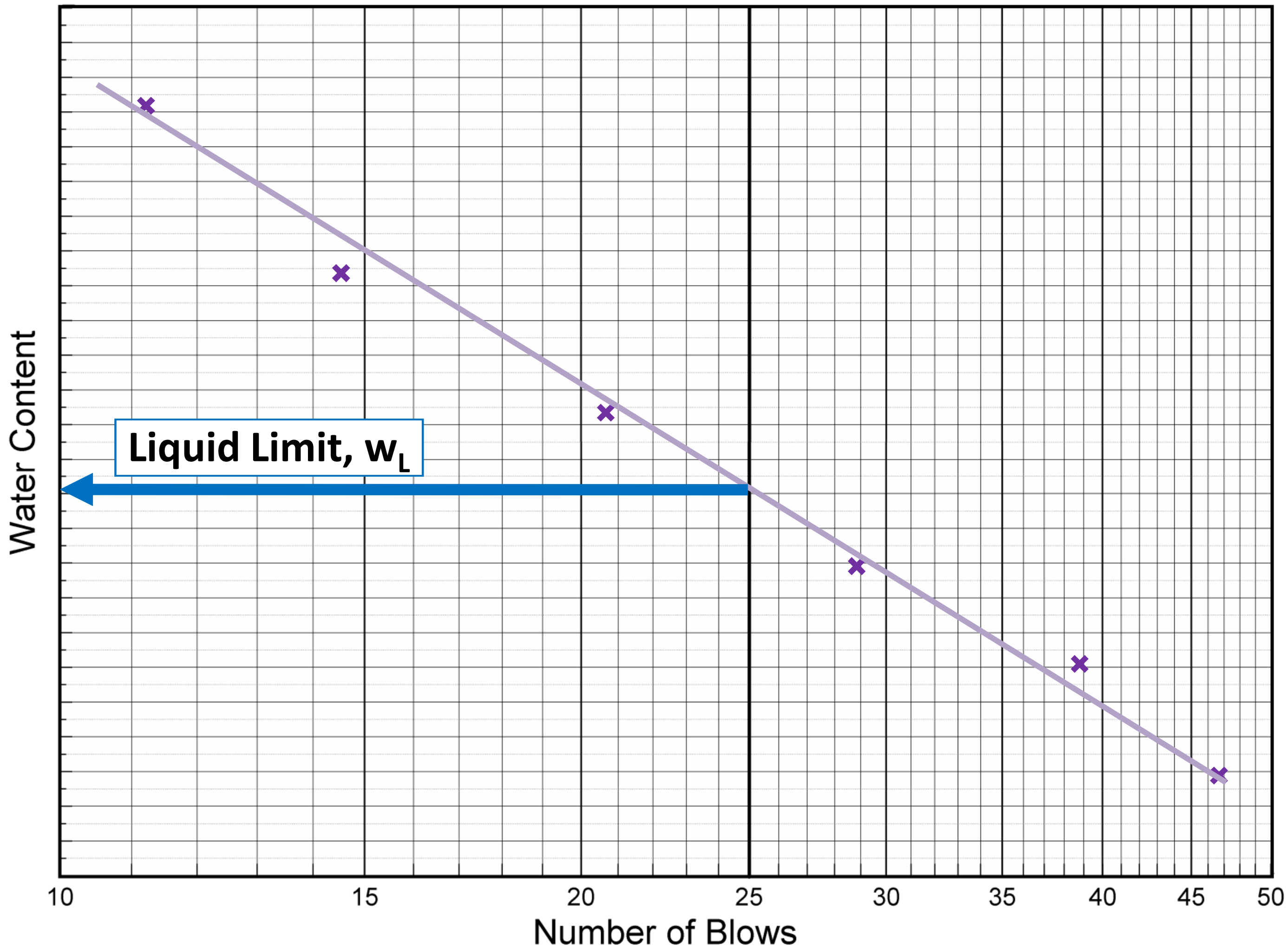
- Ensure that the cup falls through a height of 10 mm.
- Place mixed soil into the cup and level off the surface parallel to the base.
- Divide the soil into 2 equal parts using the grooving tool.
- Turn crank handle at 2 r/sec
- Count the number of bumps it takes until two parts of the soil are in contact over 13mm.
- Extract a small sample of soil from the cup to measure the water content.



Casagrande

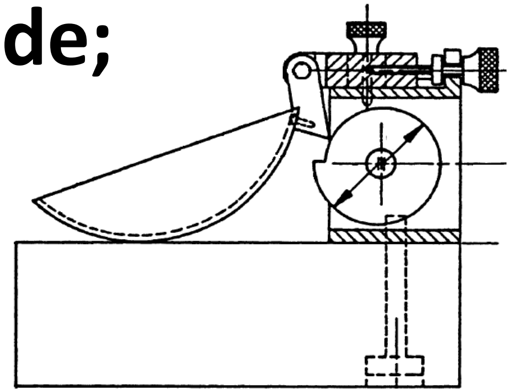
Liquid Limit w_L
The moisture content corresponding to 25 blows closing the base of the groove over 13 mm

Plot results on semi-log paper



Liquid limit, w_L

Casagrande;



Simple apparatus

Subjective

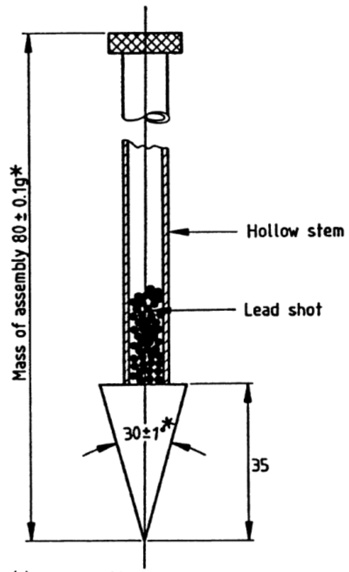
Operator dependant

Cone penetrometer;

Simple apparatus

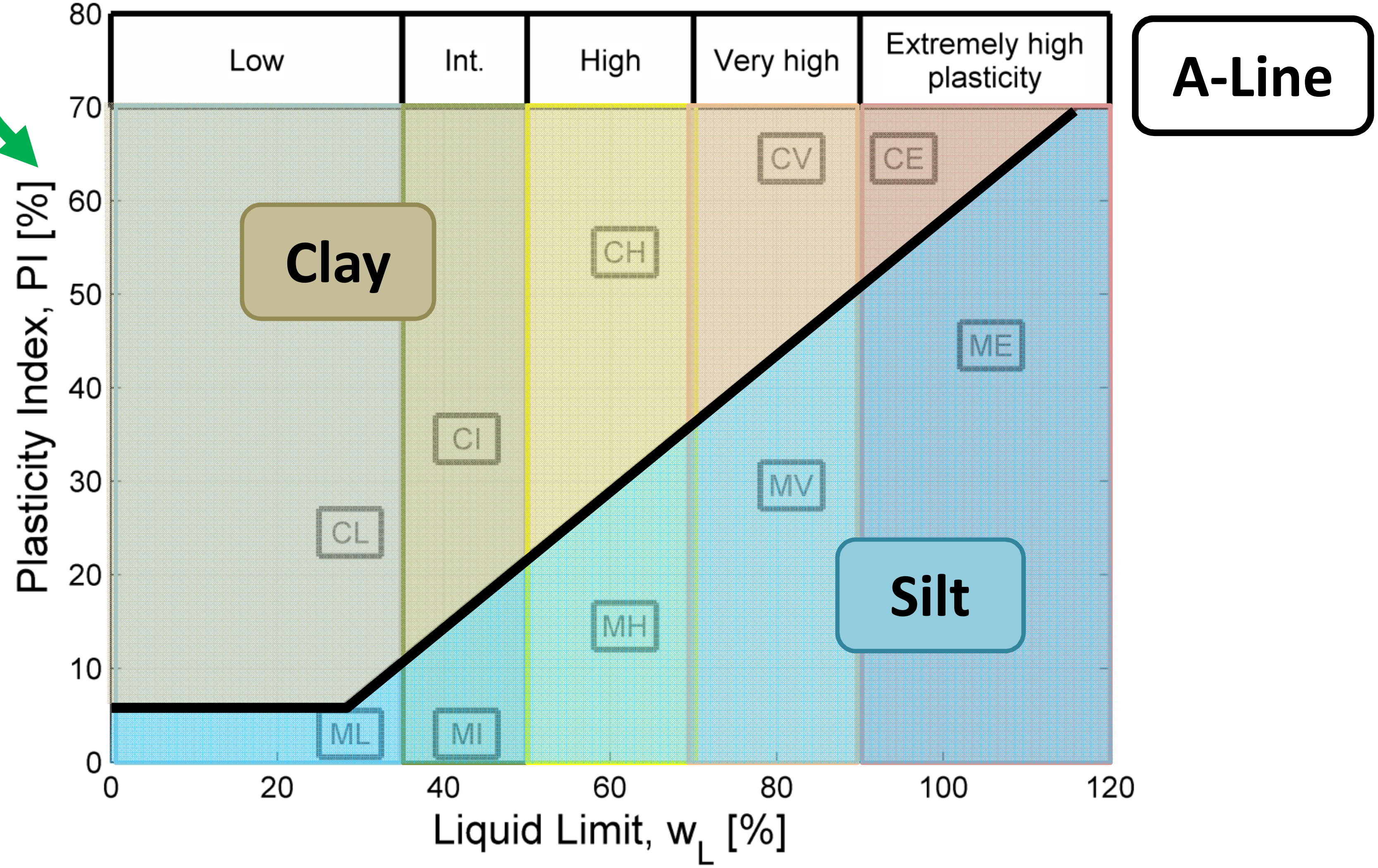
Objective

More repeatable results



A-line chart

$$PI = w_L - w_P$$



Activity, A

$$A = \frac{PI}{C}$$

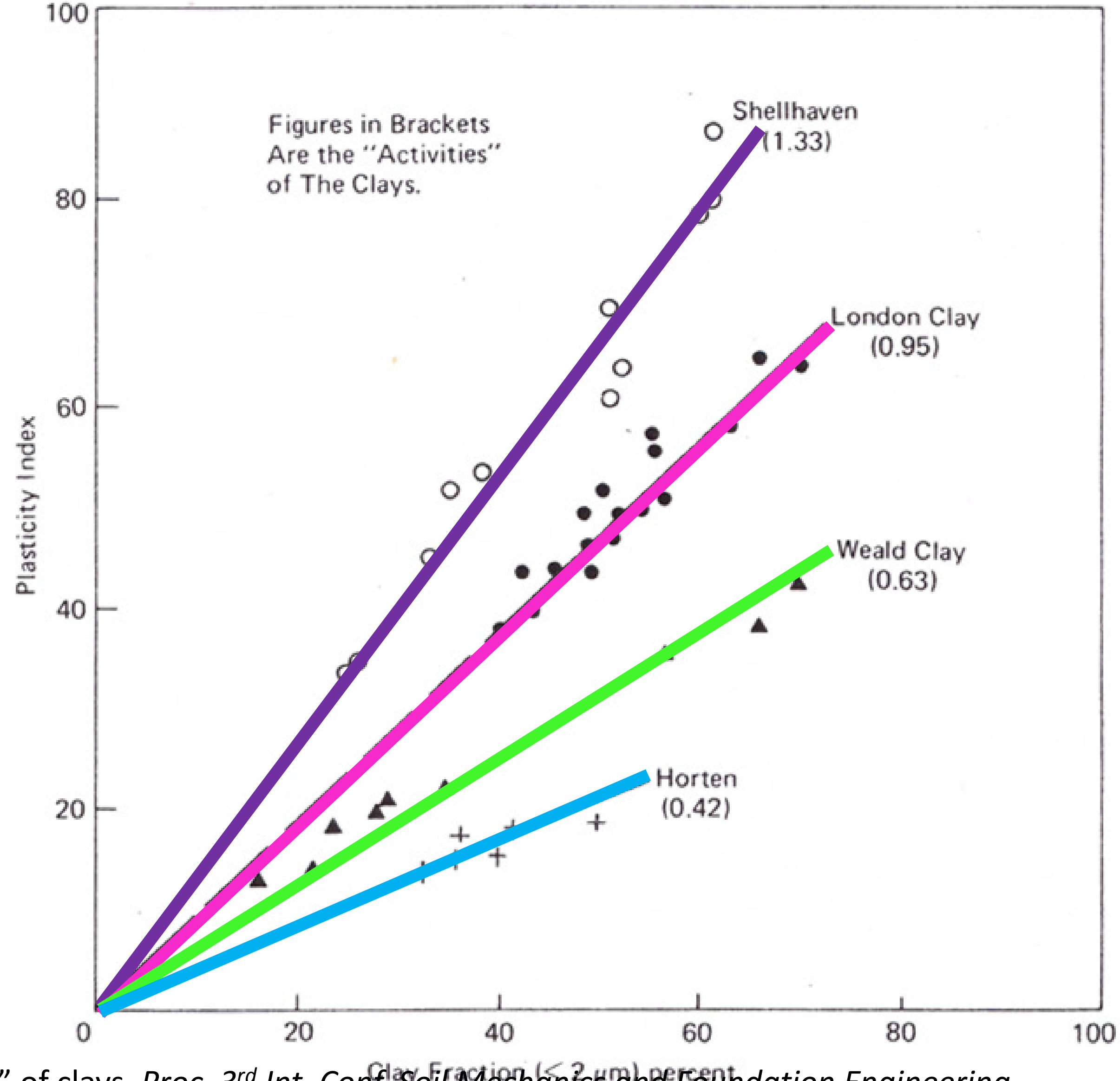
Plasticity Index

Clay Fraction

Activity

CLAY FRACTION;

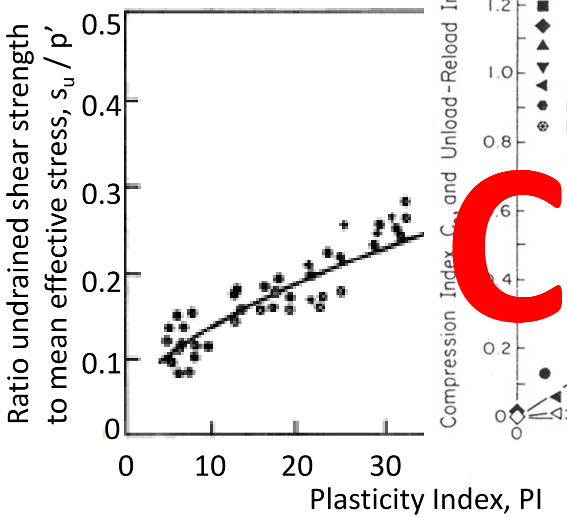
% (by dry mass) of particles < 2 μm

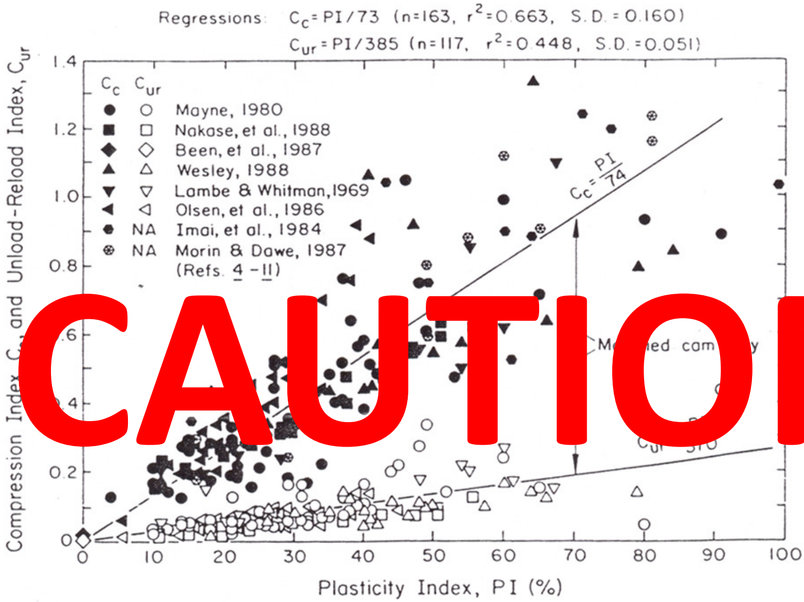


Skempton, A.W. (1953) The colloidal "activity" of clays. *Proc. 3rd Int. Conf. Soil Mechanics and Foundation Engineering, Zurich*, **1**, pp57-61.

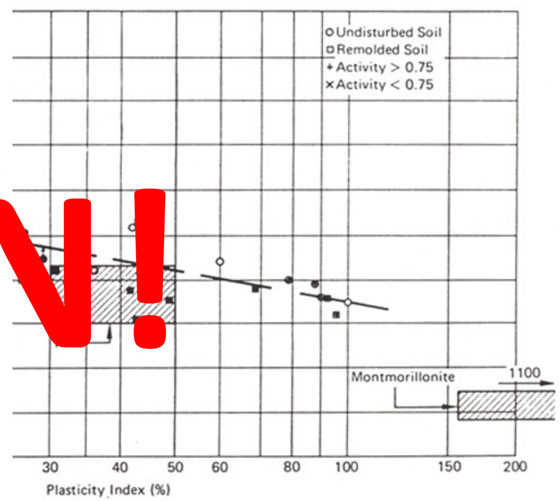
Empirical Correlations

Various researchers over the years have developed relationships between Atterberg limits and engineering parameters such as strength and compressibility:





Kulhawy and Mayne (1990)



tionship between sin ϕ' and plasticity index for normally consolidated
n Kenney, 1959). Data for pure clays from Olson, 1974.

Bjerrum and Simons (1960)

Nature and State

Nature;

The essential characteristics or basic qualities of the soil

State;

The physical condition in which the soil exists

Nature and State

Clays

Nature;

The essential characteristics or basic qualities of the soil

- Liquid Limit w_L
- Plastic Limit w_P
- Plasticity Index PI
- Mineral Composition

State;

The physical condition in which the soil exists

- Liquidity Index LI
- Clay Structure
- Insitu Void Ratio e_{insitu}
- Natural Water Content, w

Learning Outcomes

Learning outcomes

1. Be able to describe clay particles
2. Be able to explain in diagrams and words the terms:
   a) Liquid Limit, w_L
   b) Plastic Limit, w_P
   c) Plasticity Index, *PI*
   d) Liquidity Index, *LI*

   …and how to calculate them.
3. Use and A-line chart to classify a soil.

Learning outcomes

4. Understand and explain the difference between *nature* and *state.*
5. Be aware of the perils of using empirical relationships to estimate engineering parameters from Atterberg limits

References

Blyth, F.G.H. & De Freitas, M.H. (2001) *A Geology for Engineers*. 7th Ed, Oxford, Butterworth-Heinemann.

Bouch, J.E. (2006) SEM petrography of samples of the London Clay of southern England. Keyworth, Nottingham, British Geological Survey Internal Report, 42pp (IR/05/126).

British Geological Survey (2008) Bedrock Geology UK, scale 1:625 000

BSI (1990) BS 1377-2 *Methods of test for soils for civil engineering purposes – Part 2: Classification tests.* London, British Standards Institution.

BSI (1999) BS 5930:1999 + A2:2010 *Code of practice for site investigations.* London, British Standards Institution.

Cox, B.M., Sumbler, M.G., and Ivimey-Cook, H.C. (1999) A formational framework for the Lower Jurassic of England and Wales (onshore area). Keyworth, Nottingham, British Geological Survey, 25pp (RR/99/001).

Knappett, J.A. & Craig, R.F. (2012) *Craig's Soil Mechanics*. 8th Ed, Abingdon, Spon Press.

Sides and Barden (1970) the microstructure of dispersed and flocculated samples of kaolinite, illite and montmorillonite, *Canadian Geotechnical Journal*, **8**: 391-399.

Skempton, A.W. (1953) The colloidal "activity" of clays. *Proc. 3rd Int. Conf. Soil Mechanics and Foundation Engineering, Zurich*, **1**, pp57-61.

Wilkinson, S. (2011) *The microstructure of UK mudrocks*. PhD Thesis, Imperial College London.

References for interest

The BS standards (1377) outline the procedure for laboratory testing of soils, however a set of practical text books by Head, K. H. are a little easier to read.

There are 3 volumes.

Please check the library.

Head, K.H. (1980). *Manual of Soil Laboratory Testing. Vol.1, Soil Classification and Compaction Tests,* Pentech Press, London.