Marine Bio-Geo Based Geo-Technology and Manifestation of Coaxial and Non-Coaxial Components of Shear Strength of Soils

J. Rajaraman, K. Thiruvenkatasamy, and S. Narasimha Rao

Abstract—**Nature is always a source of inspiration. Natural production, protection and degradation are more balanced. In this paper the natural production of shear strength and degradation of the soils are examined through facts and figures. Limestones commonly contain only one or two dominant minerals. They are composite grains made up of large number of small calcite or aragonite crystals. The term allochem cover all of these organized carbonate aggregates that make up the bulk of many limestones. Skempton points (Clay types with varying percentage of clay size particles) are compared to different stages in the formation of aggregate grains through natural processes which results in manifestation of coaxial and non-coaxial components of shear strength of soils in shallow/deep marine environment. All these aggregates slowly reach CCD (Carbonate Compensation Depth). In CCD all the carbonates in any form are dissolved completely and only mud (silt and clay) and sand are separated. At this stage both coaxial and non-coaxial components of shear strength is drastically reduced and in abyssal plains as evidences show that the shear strength is barest minimum or residual.**

Index Terms—**Allochem, carbonate compensation depth, coaxial and non-coaxial shear strength, residual shear strength of soils, Skempton points.**

I. Introduction

Since land and water separated, and land was channelled by streams for its drainage, rivers have been bearing to ocean, quantities of calcareous matter, sufficient to have choked up the ocean in some 6,000 years if left unhindered to that end, and earth and water might have then blended again in a muddy chaos: but that has not happened in 4,000,000 years; for the catastrophe was averted by the activity of living things, who stepped in to the rescue when the laws governing inanimate nature began to prove insufficient.

Ages passed and earth continued to rise from the waters and dry herself. New continents had been formed, new rivers drained them, carrying yet greater quantities of carbonates of calcium into the sea.

After trilobites, crinoids, the coral polyps took charge of the crises (calcium carbonate accumulation in the sea). Coral polyps can build chains of mountains under the sea cemented by their forms. The remains of these animals (Foraminifera) compose chalk and clay. All the continents, and perhaps even the earth upon which we dwell, has been built up by animal life (bio-geo combination).

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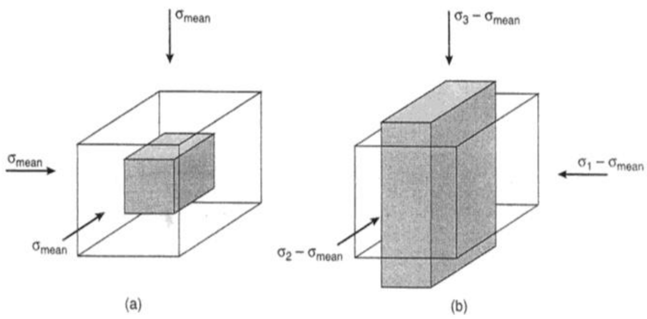
II. Isotropic Stress and Deviotiric Stress

Isotropic stress acts equally in all directions, it results in a *volume change* of the body. Deviatoric stress, on the other hand, changes the *shape* of a body as shown in Fig. 1 [1].



III. The Concept of Coaxial and Non-Coaxial Components of Shear Strength

In a homogeneously strained, two-dimensional body there will be at least two material lines that do not rotate relative to each other, meaning that their angle remains the same before and after strain. A material line connects features, such as an array of grains that are recognizable throughout a body's strain history. The circle deforms and changes into an ellipse. In homogeneous strain, two orientations of material lines remain perpendicular before and after strain. These two material lines form the axes of an ellipse that is called strain ellipse. The principal incremental strain axes rotate to the finite strain axes, a scenario that is called non-coaxial strain accumulation. The case in which the same material lines remain the principal strain axes at each increment is called coaxial strain accumulation. The coaxial component of shear strength is called pure shear and the non-coaxial component of shear strength is called simple shear. The combination of simple shear (a special case of non-coaxial strain) and pure shear (coaxial strain) is called general shear or general non-coaxial strain. Two types of general shear are possible. One by one the shear types are discussed below.

The following Fig. 2 explains simple shear and pure shear. [1].

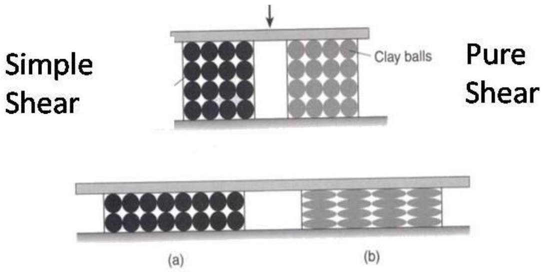


Fig. 2. Simple shear and pure shear.

In Fig. 2(a), the rigid spheres slide past one another to accommodate the shape change without distortion of the individual marbles. In Fig. 2(b) the shape change is achieved by changes in the shape of individual clay balls to ellipsoids, are quite different.

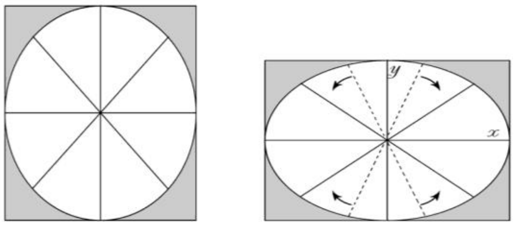


Fig. 3. Transformation of a square to a rectangle or a circle to an ellipse [1].

In Fig. 3, Homogeneous strain describes the transformation of a square to a rectangle or a circle to an ellipse. Two material lines that remain perpendicular before and after strain are the principal axes of the strain ellipse [solid lines]. The dashed lines are material lines that do not remain perpendicular after strain; they rotate toward the long axis of the strain ellipse.

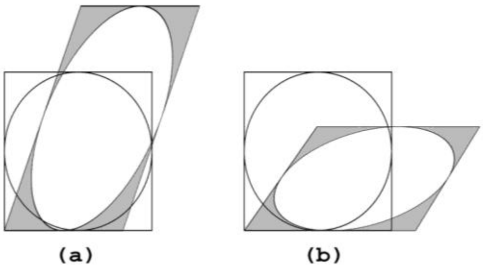


Fig. 4. General shear or general non-coaxial strain [1].

In Fig. 4(a) combination of simple shear [a special case of non-coaxial strain] and pure shear [coaxial strain] is called general shear or general non-coaxial strain. Two types of general shear are transtension Fig. 4(a) and transpression Fig. 4(b), reflecting extension and shortening components.

IV. The Properties of Sediments Derived from Secondary Rocks and Manifestation of Coaxial and Non-Coaxial Components of Shear Strength

The properties of sediments derived from secondary rocks are worth mentioning in this context:

1) Rock is aggregate of minerals. Chemical composition is a direct function of mineralogy, and mineral composition varies with grain size. The major element chemical composition of shales and mudstones is related also to grain size.
2) Grain size and shape, control coaxial and non-coaxial strains of the sediments. Angular grains increase the angle of internal -friction of the soil.
3) Because the chemical composition of siliciclastic sedimentary rocks is closely related to the mineral composition of these rocks, the chemical composition varies as a function of grain size along with variations in mineralogy. For example that SiO_2 abundance decreases progressively from fine sands to fine clays, whereas the Al_2O_3 content systematically increases.
4) Quartz arenites composed of 90 to 95% siliceous grains quartz, chert, quartzose rock fragments).
5) Fine grained siliciclastic sedimentary rocks, composed mainly of particles smaller than approximately 62 microns, make up approximately 50% of all sedimentary rocks in stratigraphic record.
6) Quartz tends to be more abundant in coarse grained mudstones and shales, whereas clay minerals are more abundant in fine grain mudstones and shales.
7) Quartz arenites are more poorly sorted and may contain high percentages of sub-angular to angular grains. Some quartz arenites exhibit textural inversions such as a combination of poor sorting and high rounding, a lack of correlation between roundness and size, such as small round grains and larger angular grains, or mixtures of rounded and angular grains within the same size fraction. These textural inversions probably result from mixing of grains from different sources, erosion of older sandstones, or environmental variables such as wind transport of rounded grains into a quiet- water environment.
8) Angular grains may result also from development of secondary overgrowths.
9) Now the problem has to do with the inherent relationship of parent rock grain size and size of rock fragments. Only fine size parent rocks yield substantial quantities of rock fragments of sand size. Therefore, coarse grained parent rocks are poorly represented by rock fragments in sandstones.
10) Collectively, the changes brought about in the composition of sediment by weathering and erosion, transport, reworking at the depositional site can be significant. Provenance analysis requires that we cannot use the absence of particular constituents as a guide to provenance interpretation; we can use only the presence. The fact that feldspars and heavy minerals may be absent or scarce in sandstone, for example, does not mean that they were necessarily absent or scarce in the source rocks. Feldspars would have been converted chemically to clays.

The ultimate products of weathering following the above properties of sediments ends up in sand and clay. The coaxial and non-coaxial components of shear strength are the hidden, second nature to sediments in the presence of water.

V. Mathematical Representation of Sharing of the Coaxial and Non-Coaxial Components of Shear Strength by Sand and Clay [2]

Permeability is a complex function of particle size, sorting, shape, packing ,and orientation of sediments. These variable factors can be expressed in terms of heterogeneity factor. For a formation with a mixture of clay and sand the following equations with this heterogeneity factors C_{v_1} C_{v_2} This variable factor C_V is believed to decrease with decreasing particle size and decreasing sorting .This factor C_V is affected by particle orientation. It is also affected by the orientation parallel to bedding plane or perpendicular to the orientation. To make it a simple factors for the purpose of calculation the heterogeneity of clay is taken as C_{v_1} and for sand as C_{v_2}.

The general eqn for C_V total is (C_V = Coefficient of variation or Heterogeneity)

$$c_{v_{total}} = \sqrt{pc_{v1}^2 + (1-p)\,pc_{v2}^2}$$

$P = 1$ (Taking element No: 1 as clay)
Element 2 sand $(1 - p) = 0$

$$c_{v_{total}} = \sqrt{1c_{v1}^2 + (1-1)c_{v2}^2}$$

$$c_{v_{total}} = \sqrt{c_{v1}^2} = c_{v_2} \text{ (for clay)}$$

Similarly for $p = 0$ for clay

$$c_{v_{total}} = \sqrt{0c_{v1}^2} = (1-0)c_{v_2}^2$$

$$c_{v_{total}} = \sqrt{c_{v2}^2} = c_{v_2} \text{ (for sand)}$$

The common shear strength eqn is $\boldsymbol{\tau} = [C + \sigma \tan \phi]$ where τ is shear strength, C is cohesion and σ is normal stress and φ is the angle of internal friction of the soil.

$\boldsymbol{\tau} = [C + \sigma \tan \phi] \cos \alpha$, and

$$\cos\alpha = \sqrt{pc_{v_1}^2 + (1-p)c_{v_2}^2}$$

$$\tau = (c + \sigma\tan\varphi)\sqrt{pc_{v_1}^2 + (1-p)c_{v_2}^2}$$

When $\alpha = 90^0$, $\cos \alpha = 0$ for pure clay $p = 1$, Sand $(1 - p) = 0$, $\varphi = 0$.

$$\tau = (c + \sigma\tan\phi)\sqrt{c_{v_1}^2 + 0c_{v_2}^2} \text{ , for cos(90°)=0}$$

$$\tau = c(c_{v_1}) \text{ for pure clay. } c_{v_1}, \tau = c$$

For pure sand $p = 1$. $\tau = (C + \sigma \tan \phi)$

$$\tau = (c + \sigma\tan\phi)\sqrt{pC_{v_1}^2 + (1-p)C_{v_2}^2} \text{ for cos 0=1}$$

For pure sand $p = 0$.

$$\tau = (c + \sigma\tan\phi)\sqrt{0C_{v_1}^2 + (1-0)C_{v_2}^2}$$

$$\tau = (c + \sigma\tan\phi)(\sqrt{0 + C_{v_2}^2})$$

$$\tau = (c + \sigma\tan\phi)C_{v_2}$$

For clay $C = 0$,

$$\tau = (C_{v_2})\sigma\tan\phi \text{ , and } C_{v_2} = 1$$

Heterogeneity

$$C_{v_1} \text{ or } C_{v_2} = 1$$

$$\tau = \sigma\tan\phi,$$

VI. The Relation between Coaxial and Non-Coaxial Strain and Skempton Points [3]

In Fig. 5 the particle paths or flow lines during progressive strain accumulation are shown.

These flow lines represent pure shear Fig. 5(a), general shear Fig. 5(b), simple shear Fig. 5(c), and rigid –body rotation Fig. 5(d). The cosine of the angle α is the kinematic vorticity number, W_k for these strain histories; W_k =0,0 < W_k <1, W_k=1, and $W_k = \infty$ respectively. Avoiding the math, a convenient graphical way to understand this parameter is shown in Fig. 5.

When tracking the movement of individual points within a deforming body relative to a reference line, we obtain a displacement field (or flow lines) that enables us to quantify the internal vorticity. The angular relationship between the asymptotes and the reference line defines W_k. $W_k = \cos \alpha$.

For pure shear W_k= 0 Fig. 5(a), for general shear 0< W_k <1 Fig. 5b and for simple shear W_k = 1 Fig 5(c). Rigid- body rotation or spin can also be described by the kinematic vorticity number (in this case, $W_k = \infty$ Fig. 5(d).When $\alpha = 0^0$, Cos α= 1, represents simple shear. When $\alpha = 90^0$, Cos α = 0, represents pure shear [1].

The component describing the rotation of the material lines with respect to the principal strain axis is called the internal vorticity, which is a measure of the degree of non-coaxiality.

If there is zero internal vorticity, the strain history is coaxial, which is sometimes called pure shear. The non-coaxial strain history describes the case in which the distance perpendicular to the shear plane remains constant; this is also known as simple shear.

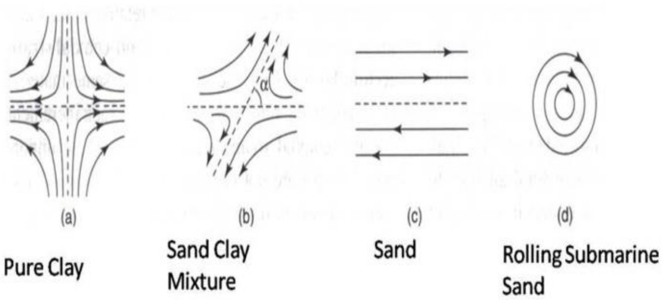


Fig. 5. Particle paths or flow lines during progressive strain accumulation.

For interpretation the data (after Skempton, 1964) indicating the variations of angle of internal friction (φ) with percentage of clay content is shown in a family of nine points, distributed over the first three quadrants as shown in Fig. 6 This Fig. 6, shows the sharing of coaxial and non-coaxial strain or strength by different soil samples. No point lies in quadrant IV which is high cohesion and high friction zone but in nature high cohesion and high friction cannot exist together in a soil sediment system, when sharing the same volume or space between clay and sand (0.0,1.0 or 1.0,0.0).

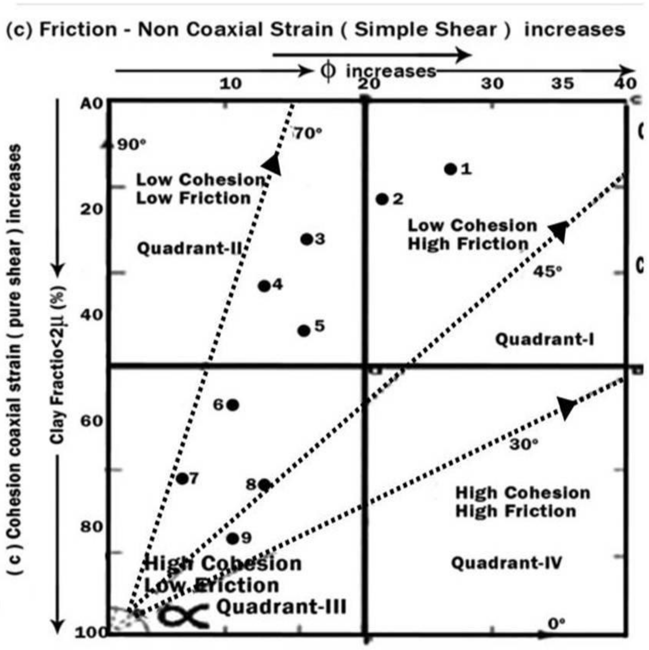


Fig. 6. Variation of φ_{ult} with percentage of clay content. (After Skempton 1964) all Skempton points lie in quadrants I, II, III [3].

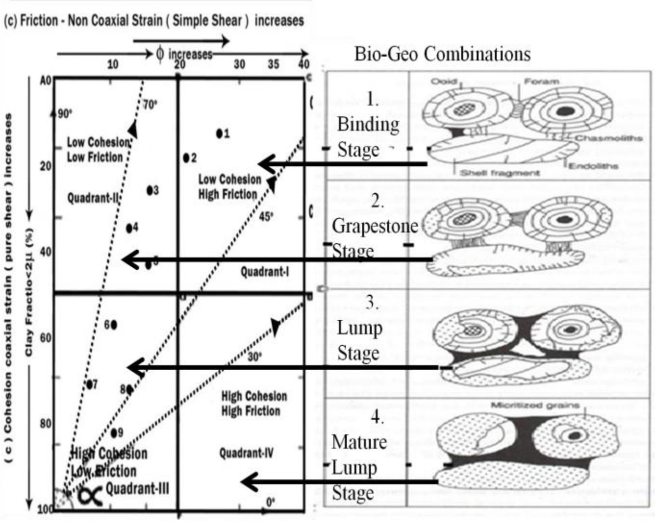


Fig. 7. Skempton points and stages in the formation of aggregate grains [4].

In Table I, the Skempton points distribution, cohesion and friction in different quadrants are shown.

As the percentage of clay fraction increases the soil sample representative points move from quadrant I to II and then to III. Quadrant IV represents high friction and high cohesion area. Both high friction and high cohesion cannot exist together. The sharing depends upon P,(1-P) combination as stated in the mathematical method in previous pages.

In the above Fig. 6, if $\propto = 0$, the slope line coincides with x axis, GFE, cos $\propto$ = cos0 = 1.0. If $\propto = 90^0$, the slope line becomes vertical and coincides with y axis, GHA, cos $\propto$ = cos 90^0 = 0.0.

TABLE I: SKEMPTON POINTS, COHESION AND FRICTION REPRESENTED IN QUADRANTS I, II, III, IV

Quadrant	No. of Skempton Points	Type of Quadrant
I	02.	Low cohesion, High friction
II	03.	Low cohesion, Low friction
III	04.	High cohesion, Low friction
IV	nil	High cohesion, High friction

A. Bio-Geo Combinations (See Fig. 7)

Stage 1: Carbonate grains are bound together by foraminifers, microbial filaments and mucilage. Chasmolitic micro-organisms occur between the grains, whereas endolithic forms bore into the carbonate substrates. In this stage since grains are very strong with mud or silica content the angle of internal friction will be more and cohesion will be less because the binding materials are just in formation stage. This stage represents high friction and low cohesion or high simple shear and low pure shear or high non-coaxial shear and low coaxial shear. This stage is represented in the quadrant I points in the Skempton's Fig. 6 and Fig. 7.

Stage 2: Calsification of the microbial braces occurs, typically by high magnesian calcite, to form a cemented grapestone. Progressive micritization (conversion to lime mud) of carbonate grains takes place. Since mud is involved this stage represents low friction and low cohesion (low non-coaxial shear and low coaxial shear). This stage is represented in the quadrant II points in the Skempton's Fig. 6 and Fig. 7.

Stage 3: Increased cementation at grain contacts , by microbially induced precipitation, fills depressions to create smoother relief. The fine grains cementation increases the pure or coaxial shear and the weakening of grains decreases simple shear or non-coaxial shear. This stage is represented in the quadrant III points in the Skempton's Fig. 6 and Fig. 7.

Stage 4: High cohesion and high friction stage is not possible and therefore in quadrant IV there is no Skempton points Fig. 6 and Fig. 7. In ideal case very high friction and very low cohesion or very high cohesion and very low friction can be considered for practical purposes. In stage 4 the separation is possible in an idealized condition below the depth of carbonate compensation depth. In this stage filling of any central cavity to form a dense, heavily micritized and matrix – rich aggregate takes place and the shear strength is shared between coaxial shear and non-coaxial shear.

The further manifestation or the association and dissociation of shear strength in and below CCD (Carbonate Compensation Depth) is discussed below:

VII. THE BIO-GEO GEOTECHNICAL PROCESSES IN NATURE

Skeletal Grains (Bioclasts): In Fig. 8 the weathering effects from angular grains to well rounded grains in skeletal grains are shown.

Skeletal grains are among the most abundant and important kinds of grains that occur in limestones of Phanerozoic age. Skeletal grains may consist of whole fossil organisms, angular fragments of fossils, or fragments rounded to various degrees by abrasion. Skeletal grains may occur with other kinds of carbonate grains. This forms the resistant portion of the aggregate.

Microcrystalline Carbonate (Lime Mud)

Some limestones are made up of sand- silt- size grains. Texturally, lime mud is analogous to clay –size matrix in siliciclastic sedimentary rocks. Lime muds may also contain clay size non-carbonate impurities such as clay minerals, quartz, feldspars, and organic matter.

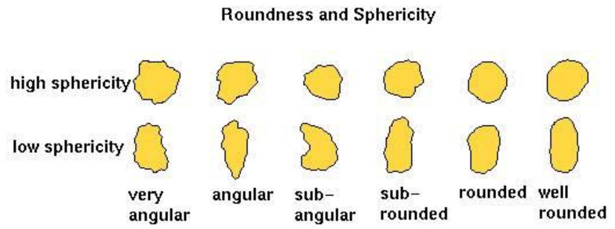


Fig. 8. Different types of carbonate particles.

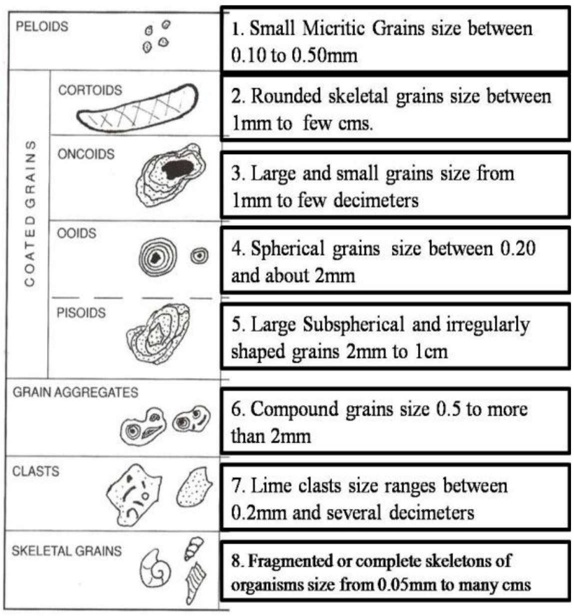


Fig. 9. Descriptive terminology of the major kinds of carbonate (size and shape) [5].

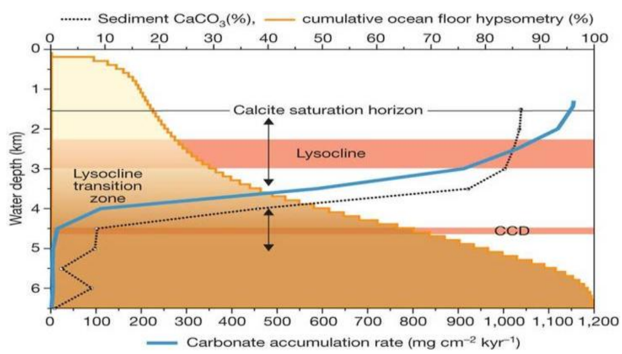


Fig. 10. Details of the environment of carbonate compensation depth [6].

In Fig. 9 the carbonate skeleton particle sizes and shapes are shown.

Fig. 10 shows the carbonate compensation depth with Lysocline layer. In this depth carbonate is dissolved. The C CD varies depending upon the ocean type.

A. Environment and CCD(Calcium Compensation Depth)

Facts about CCD:

1) $CaCo_3$ shells (tests) sink from surface waters.
2) Tests may reach a depth where water is significantly under-saturated with respect to $CaCo_3$.
3) At this depth, called lysocline, shells begin to dissolve.
4) In the modern oceans, there is also a depth at which there is no longer any free $CaCo_3$.
5) This depth is called the Carbonate Compensation depth (CCD) = ~ -4 km.
6) $CaCo_3$ tests accumulate only if they settle on seafloor above CCD.

B. Four Stages of Bio-Geo Mass Are Considered

1) Before Crossing CCD
2) When crossing lysocline zone.
3) When crossing the CCD.
4) After Crossing CCD.

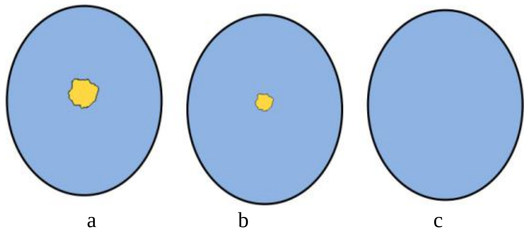


Fig. 11

Fig. 11a shows Carbonate particle above CCD

Fig. 11b shows Carbonate dissolving in lysocline depth

Fig. 11c shows Carbonate particle completely dissolved (Cal-gone)

The calcium carbonate which is a binding material or cementing material for the soil is dissolved and the shear strength is reduced due to loss of grains. But sand, silt and clay are not affected because they are sparingly soluble in CCD.

VIII. Available Documented Photographic Evidences of the Carbonate Compensation Depth Environment [7]

In Fig. 12 abundant whole foraminifer tests (some opaque due to size and presence of air bubbles within test chambers), foraminifer fragments from larger foraminifera and pteropods comprised of calcium carbonate and aragonite indicate a sample from well above the CCD. Benthic foraminifera and sponge spicules are also present. The foraminifera are in the size range 0.05-0.10 mm.

In Fig. 13 at deeper water depths the calcareous ooze consists mainly of fragmented foraminifera tests; complete foraminifera tests are rare. The sediment is still highly calcareous and larger fragments are in the size range 0.05-0.10 mm.

In Fig. 14 at water depths approaching the CCD, foraminifers are mostly dissolved; only very small calcareous fragments remain. Siliceous microfossils are not dissolved. Fragments of siliceous radiolarians are present. The larger grains are of the order of 0.05 mm in size.

Above the CCD

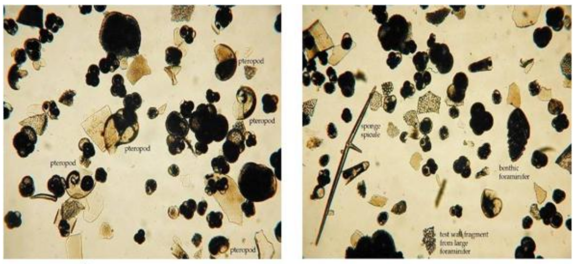
SOUTH CENTRAL ATLANTIC
Water depth: 1959m
PPL

10 °S, 15 °W
Sample Ref: INMD-110BX
Courtesy: Paula Worstell, SIO

Approaching the CCD

EASTERN NORTH PACIFIC
Water depth: 3891m
PPL

12 °N, 110 °W
Sample Ref: BNFC-53P, 6cm
Courtesy: Paula Worstell, SIO



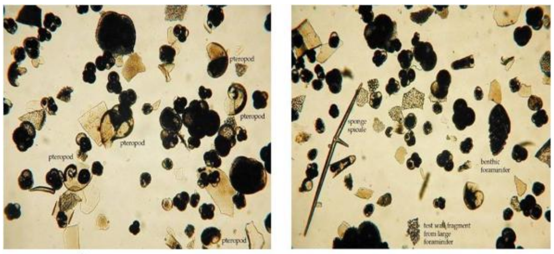
a b

Fig. 12. Foraminiferal ooze with pteropods.

Partway down to CCD

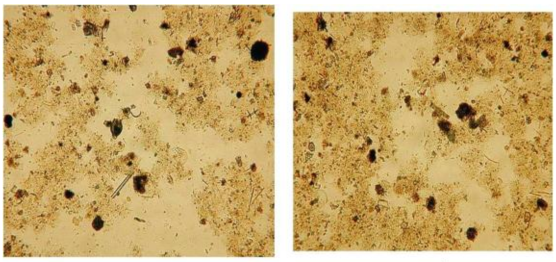
EASTERN NORTH PACIFIC
Water depth: 2845m
PPL

10 °N, 109 °W
Sample Ref: BNFC-44P, 1cm
Courtesy: Paula Worstell, SIO



a b

Fig. 13. Calcareous ooze.



a b

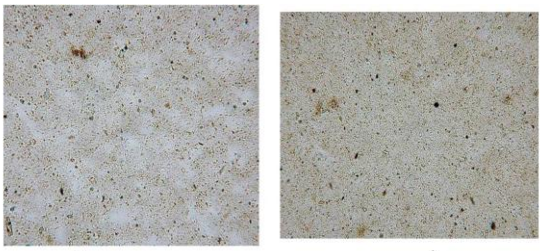
Fig. 14. Clayey calcareous ooze.

In Fig. 15 below the CCD calcium carbonate is dissolved. Although calcareous microfossils may be living in the water column, their tests are not preserved in sediments on the sea floor. Seen here is a barren, fine-grained clay. Reddish-brown grains and irregular flecks of iron oxides are present together with clay- and very fine silt- grade mineral particles. Individual grains are under 4 µm (0.004 mm) in size.

Below the CCD

NORTH PACIFIC, EAST OF HAWAII
Water depth: 5365m
PPL

27 °N, 147 °W
Sample Ref: ZETES-38G, 64cm
Courtesy: Paula Worstell



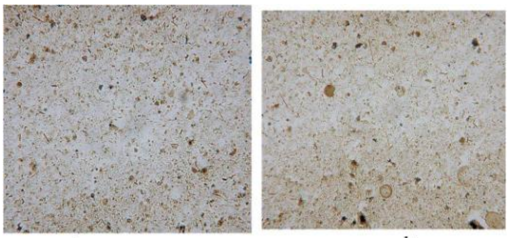
a b

Fig. 15. Deep sea red clay.

Below the CCD

NORTH CENTRAL PACIFIC
Water depth: 5530m
PPL

33 °N, 174 °W
Sample Ref: JYN-4G, 27cm
Courtesy: Paula Worstell, SIO



a b

Fig. 16. Deep sea red clay.

Rapid burial, below CCD

SW PACIFIC, SAMOAN PASSAGE
Water depth: 5763m
PPL

17 °S, 168 °W
Sample Ref: CATO-29PG, 25cm
Courtesy: Paula Worstell, SIO

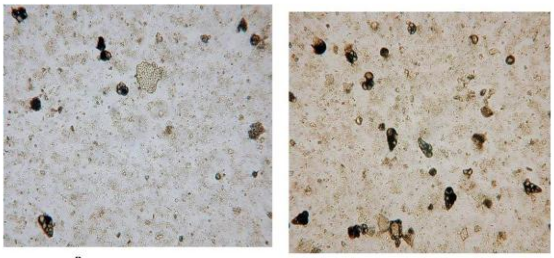


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Fig. 17. Foraminifer nanno fossil ooze.

In Fig. 16 deposited below the CCD, this fine-grained deep-sea clay contains some diatoms and siliceous spicules. Because the calcareous components are dissolved, siliceous microfossils are often concentrated in sediments deposited below the CCD. Diatoms are in the size range 10-100 µm (0.01-0.1 mm) and individual clay grains are under 4 µm (0.004 mm) in size.

In Fig. 17 an unusual occurrence of a foraminifer nannofossil ooze recovered from well below the CCD. A turbidity current transported these calcareous sediments from a nearby topographic high. Rapid burial protected the calcareous microfossils from dissolution. The small planktonic foraminifers are in the size range of 0.05-0.10mm.

Fragments of larger foraminifera are also present.

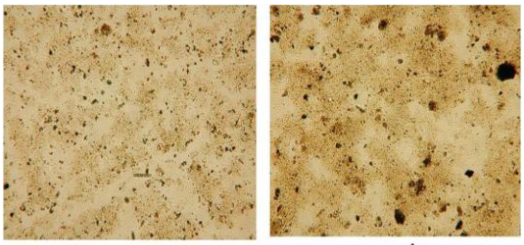

Fig. 18. Deep sea red clay.

In Fig. 18 the CCD in the Pacific Ocean lies between 4200-4500 meters. This barren fine-grained red clay was recovered at a water depth of 5060m, well below the CCD in the central Pacific. Reddish-brown grains and irregular flecks of iron oxides are present, together with clay- and very fine to fine silt-grade mineral particles. Large grains are about, or under, 0.01 mm in size.

IX. Bio-Turbation [8]

A. Bio-Turbation

The presence of evidence of organisms disturbing sediment is known as Bio-Turbation, and is a very common feature in sedimentary rocks. In fact the absence of bio-turbation in shallow marine deposits may be taken as an indicator of something unusual about environmental conditions, such as anoxic sea floor. The intensity of bio- turbation in a body of sediment is an indication of the number of animals living there and the length of time over which they were active. A scale of bio-turbation intensity has been devised to allow comparison between deposits in different places.

Grade 1: A few discrete traces

Grade 2: Bio-turbation affects less than 30% of the sediment, bedding is distinct

Grade 3: Between 30% and 60% of the sediment affected, bedding is distinct

Grade 4: 60% to 90% of the sediment bio-turbated, bedding indistinct

Grade 5: Over 90% of sediment bio-turbated and bedding is barely detectable

Grade 6: Sediment is totally reworked by bio-turbation.

It should be noted that when a body of sediment is wholly bio-turbated it can be difficult to recognize individual traces, and sometimes difficult to recognize that there is bio-turbation present at all. The sediment will simply appear to be structureless, with the only evidence of trace fossils being that the sediment appears to be slightly mottled or with patches of different grain sizes.

In this way bio-turbation produces very fine grain clay particles and fine sands. In Geotechnical terms if clay particle % increases the coaxial shear component (pure shear) will also increase. Similarly if the sand particles increase the non-coaxial shear component (simple shear) will increase.

X. Conclusions

To understand the inherent and intrinsic nature of bio-geo processes multi-disciplinary approach is needed. The optimizing capacity of nature creates inherent secrets and uncertainties.

In conventional laboratory based and non-marine field based consolidation test the water is expelled from the pores as excess pressure. In deep Marine Geo-technology the solids, mostly carbonate particles of the sediments disappear (dissolved) as the saline water space closes.

In reality the dynamic frictional resistance among particle to particle in contacts play an important role in the build up of frictional resistance, and gradually losing the resistance by losing (dissolving) of Carbonate particles which were cementing or binding material.

On favorable conditions finer particle create more and more contact resistance with other particles. Gravity effect is less on finer particles.

The destructive or constructive nature of Bio- Turbation or Bio-Masses is not independent. It is nose-lead by the environment as discussed in CCD and related environments.

The ultimate deposits on the Abyssal plain consists of oozes, sands and clays.

Deposits of low shear strength sediments on Abyssal plain is due to frictional resistance of sand (non-coaxial component of shear strength) and cohesion due to clays (coaxial component of shear strength) in the presence of saline water environment and in the absence of binding carbonate particles.

The restless nature of the earth is more only in shallow water. In deep ocean the environment is calm, controlled by the still nature of Abyssal plain and the saline water associated with it.

Multi-disciplinary approach is the only option to understand ocean and ocean engineering more.

References

[1] V. D. Pluijm and A. Ben, *Earth Structure*, New York: W.W.Norton & Company Inc, 2003, pp. 65–68.

[2] J. Jerry, *Statistics for Petroleum Engineers and Geoscientists*, Prentice Hall, Cuevas, 1993, ch. 6, pp. 143-150.

[3] A. W. Skempton, "Stability of clay slopes," *Geotechnique*, vol. 14, p. 77, 1964.

[4] M. E. Tucker and V. P. Wright, *Carbonate Sedimentology*, Oxford: Blackwell Scientific, 1990, pp. 10-12.

[5] E. Flugel, "Microfacies of carbonate rocks," Berlin: Springer – Verlag, p. 100, 2004.

[6] *Nature International Weekly Journal of Science*, vol. 488, issue 7413, 2012.

[7] Underwater Images, *British Ocean Sediment Core Research Faciliity*, National Environmental Research Council. National Oceanography Centre.

[8] M. L. Droser and D. J. Bottjer, *Journal of Sedimentary Research*, pp. 558-559, 1986.

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