The Intrinsic Relationship Among Coaxial and Non-Coaxial Strain, Bowen's Series of Minerals and Textural Maturity of Sediments in Lowlands

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Abstract—**Lowland denotes regions of low elevation, which are vulnerable to environmental changes and global warming. In this paper an attempt is made to link the qualitative concepts of Bowen's series of minerals and the quantitative concepts of geotechnical engineering methods, intrinsically related to the various stages of maturity levels of sediments. In the ever changing environment the need to understand the inter-disciplinary aspects of common research topics is on the increase considering the environmental problems at global level in lowlands.**

Keywords- ***coaxial, non-coaxial,components of shear strength,textural maturity and geotechnical properties,Bowen's series.***

I. INTRODUCTION

Lowland development is important for all countries. In spite of many challenges there is every prospect of settlement of lowland areas will intensify. Under these conditions the only alternative is to learn to meet challenges of building cities in lowlands. The following factors will change the properties of sediments(1) urban revolution (2) river characteristics (3) sea shore type and location (4) increase in pollution due to increase in population (5) infrastructures affecting natural drainage of water and movement of sediments (6) over exploitation of river and ground water (irreversible change) (7) floods (8) sea level changes (9) seismicity (10) tsunamis (11) liquefaction of soils (12) land reclamation programmes and coastal erosion A single method of investigation in the field or in the laboratory will not yield the desired results. An integrated approach is essential in order to reach the correct solutions.

II. THE CONCEPT OF TEXTURAL MATURITY

The term textural maturity refers to the textural characteristics of a particular weathering formation or sediments. The textural maturity of sediments encompasses three textural properties:
(1) The amount of clay size particles in the sediments
(2) The sorting of the framework grains, and (3) The rounding of the framework grains. It is often visualized in four stages of textural maturity: immature, submature, mature and supermature. Any sediment containing considerable clay, say more than 5% is in the immature stage. Also, the framework grains in immature sediments are poorly sorted and poorly rounded. Presumably, immature sediments have not undergone sufficient sediment transport and reworking to remove fine sized materials and produce sorting and rounding of grains. With additional transport and reworking, sediments enter the submature stage, in which the sediments are characterized by low clay content but grains are still not well sorted or well rounded. This stage is followed by the mature stage, in which the clay content is low and framework grains become well sorted but are not yet well rounded. Sediments in the supermature stage are essentially clay free, and framework grains are both well sorted and well rounded.

III. THE WEATHERING PROCESS IN COASTAL AREAS

In general the degree of weathering fundamentally is a function of mineralogy. The accepted and time tested Bowen's series states that, minerals are most stable at the temperature and pressure at which they form. In the case of the igneous rock minerals described in Bowen's Reaction Series, the higher temperature minerals (such as olivine, pyroxene, etc.), when exposed at the surface, will be farthest from their comfort zone, and will therefore chemically weather at a faster rate. Quartz, at the other end of Bowen's, is closer to its preferred temperature and should therefore be more stable (and it is). This is one reason why we find quartz sand at the beach, instead of olivine sand.

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(a)

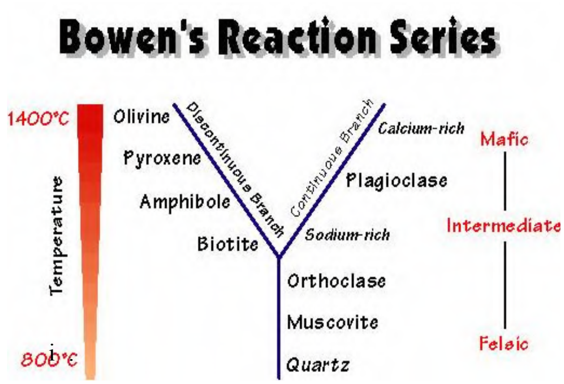


Fig.1 [1].

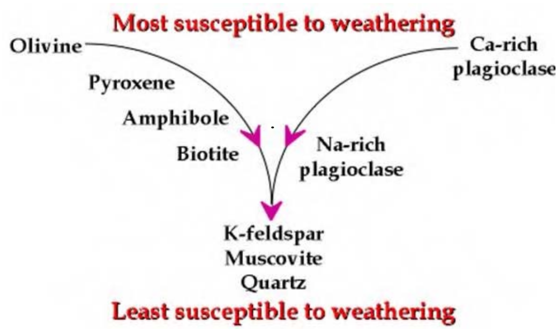


Fig.2

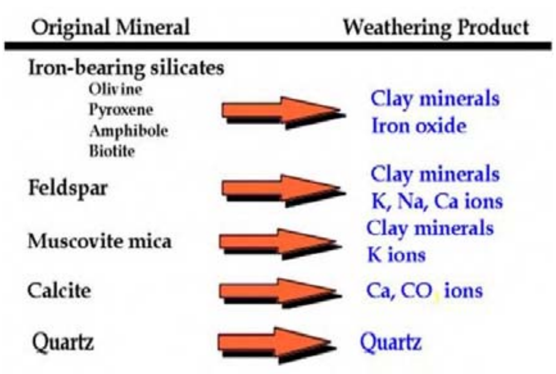
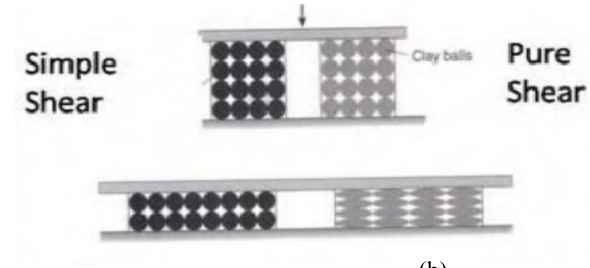


Fig.3

The ultimate weathered products are clays and sand (quartz sand) as shown in the above figure Now a simple treatment relating the energy or stress on the weathered products is considered.

IV. THE CONCEPT OF THE COAXIAL AND NON-COAXIAL COMPONENTS OF THE SHEAR STRESS

The circle and the strained ellipsoids to identify the anisotropic behavior of clay. Since the sample is pure clay only pure shear is involved and the simple shear is applicable only for sand. The following figure explains simple shear and pure shear.



F g 4 (b)

In the figure 4 (a) The rigid spheres slide past one another to accommodate the shape change without distortion of the individual marbles. In figure 4(b) The shape change is achieved by changes in the shape of individual clay balls to ellipsoids, are different. [2].

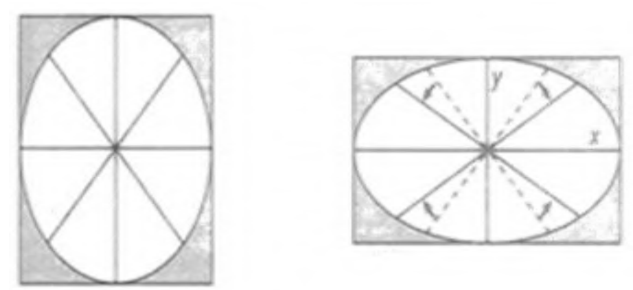


Fig.5

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 strained ellipse.

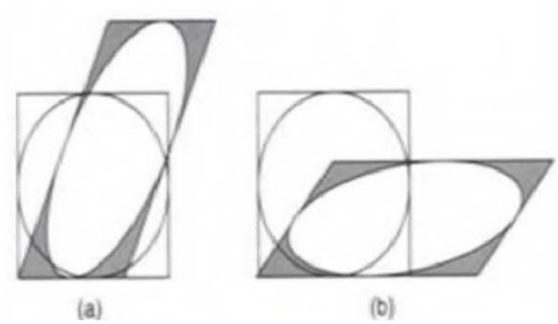


Fig.6

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 (a) and transpression(b) reflecting extension and shortening components. [2].

V. THE PROPERTIES OF SEDIMENTS DERIVED FROM SECONDARY ROCKS

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.

VI. THE COMPLEX FUNCTION – PERMEABILITY

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} and 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) [3].

$$C_{V\ total} = \sqrt{pC_{V_1}^2 + (1-p)C_{V_2}^2}$$ P = 1 (Taking element No: 1 as clay)

Element 2 sand (1 - p) = o

$$C_{V\ total} = \sqrt{1C_{V_1}^2 + (1-1)C_{V_2}^2}$$

$$C_V\ total = \sqrt{C_{v1}^2} = C_{v1}\ \text{(clay)}$$

Similarly for p = 0 for clay

$$C_{V\ total} = \sqrt{0C_{V_1}^2 \quad (1 \quad 0)C_{V_2}^2}$$

$$C_V\ total = \sqrt{C_{V_2}^2} = C_{V\ 2}\ \text{for sand}$$

The common shear strength eqn is

τ= [C + σ tan ϕ][Cos α] from fig.8, take cos∝ 1

$$\text{Cos}\ \alpha = \sqrt{pC_{V_1}^2 + (1-p)C_{V_2}^2}$$

$$\tau = (C + \sigma \tan \phi) \sqrt{pC_{V1}^2 + (1-p)C_{V2}^2}$$

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

$$\tau = [(C + \sigma \tan (0)) \sqrt{C_{V_1}^2 + 0\, C_{V2}^2}\ .\ \text{Cos}\ (90^0)] = 1$$

(Equation 6)

τ = C (C_{V1}) = for pure clay. C_{V1} = 1, τ= C

For pure sand p = 1. τ= (C + σ tan ϕ)

$$\sqrt{pC_{V_1}^2 + (1-p)C_{V_2}^2}$$

For pure sand p = 0. τ= (C + σ tan ϕ)

$$\tau \sqrt{0C_{V_1}^2 + (1-0)C_{V2}^2}$$

$$= (C + \sigma \tan \phi) (\sqrt{0} + C_{V_2}^2)$$

$$\tau = (C + \sigma \tan \phi) C_{V_2}$$

For clay C = 0, τ = (C_{V_2}) σ tan ϕ of $C_{V_2} = 1$

Heterogeneity C_{V_1} or $C_{V_2} = 1$

τ= σ tan ϕ

VII. THE RELATIONSHIP BETWEEN COAXIAL AND NON-COAXIAL STRAIN AND SKEMPTON POINTS

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. 8. This fig.8 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).

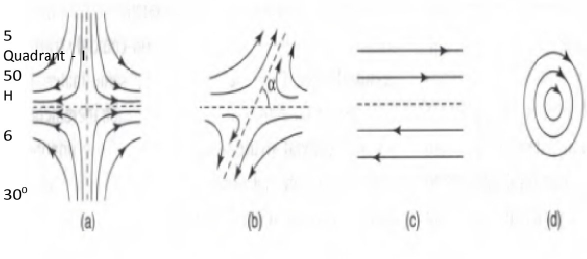
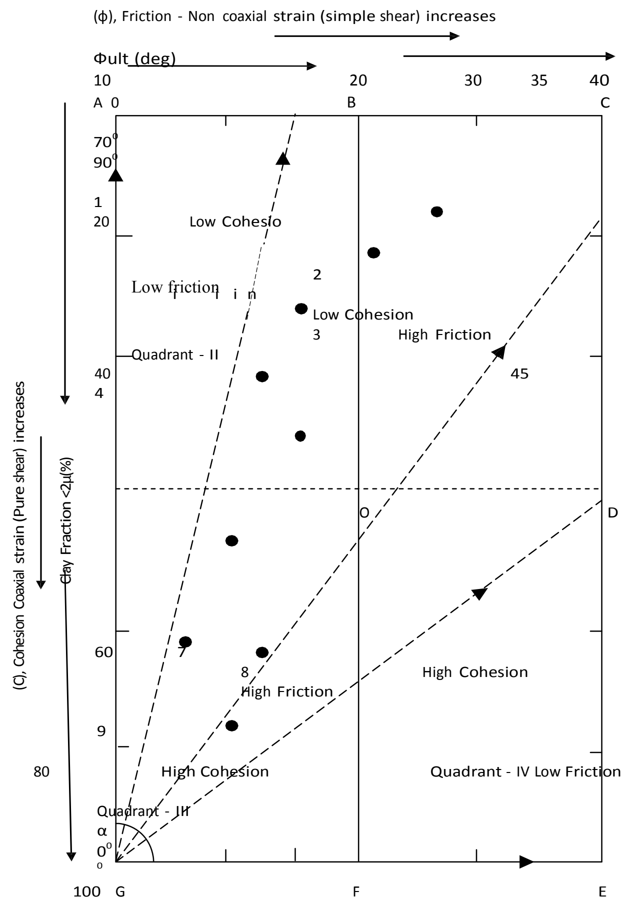


Fig.7

Particle paths or flow lines during progressive strain accumulation. These flow lines represent pure shear [a], general shear [b], simple shear [c], and rigid –body rotation [d]. The cosine of the angle is the kinematic vorticity number, W_k for these strain histories; W_k =0,0 < W_k <1, W_k=1, and W_k =∞ respectively. Avoiding the math, a convenient graphical way to understand this parameter is shown in figure 7. 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 asymptote and the reference line defines W_k: W_k =cos α For pure shear W_k= 0 fig. 7a, for general shear 0 < W_k < 1 fig. 7b and for simple shear W_k = 1 fig7c . Rigid- body rotation or spin can also be described by the kinematic vorticity number (in this case, W_k = ∞ fig. 7d. When α = 0^0, Cos α= 1, represents simple shear. When α = 90^0, Cos α = 0, represents pure shear. [2].



In the fig.8 Variation of ϕ ult with percentage of clay content. (After Skempton, 1964)

All Skempton points lie in quadrant I ,II, & III [4]

In the above fig.8,if α = 0, the slope line coincides with x axis , GFE, cosα = cos0 = 1.0. If α = 90, the slope line becomes vertical and coincides with y axis, GHA, cosα= cos 90= 0.0.

TABLE – I

Coaxial & Non Coaxial (Pure & Simple shear) Strain Combinations:

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

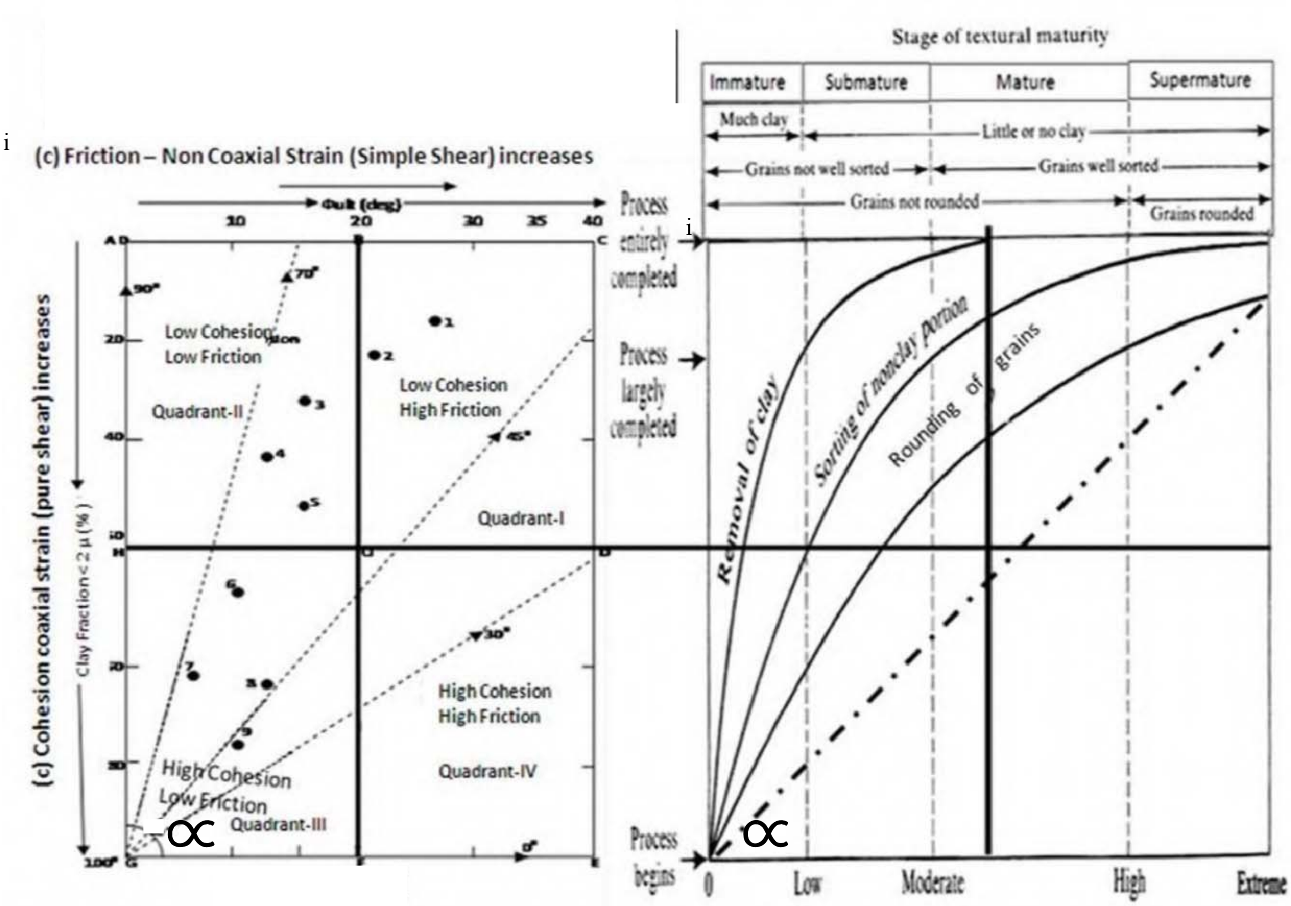
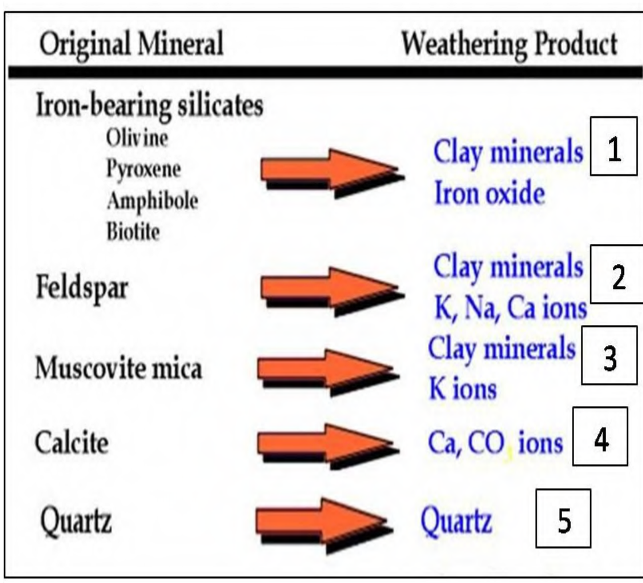


Fig.9



immature	submature	mature	supermature
Much clay	Grains not well sorted	Little or no clay Well sorted	Well rounded
1	1		
+	+	1	
		+	
	2		
2		2	
+	+		
3	3	+	
	+	3	
		+	
	4	4	
	+	+	
			5 only
	5	5	Quartz sand
			BEACH

Fig.10

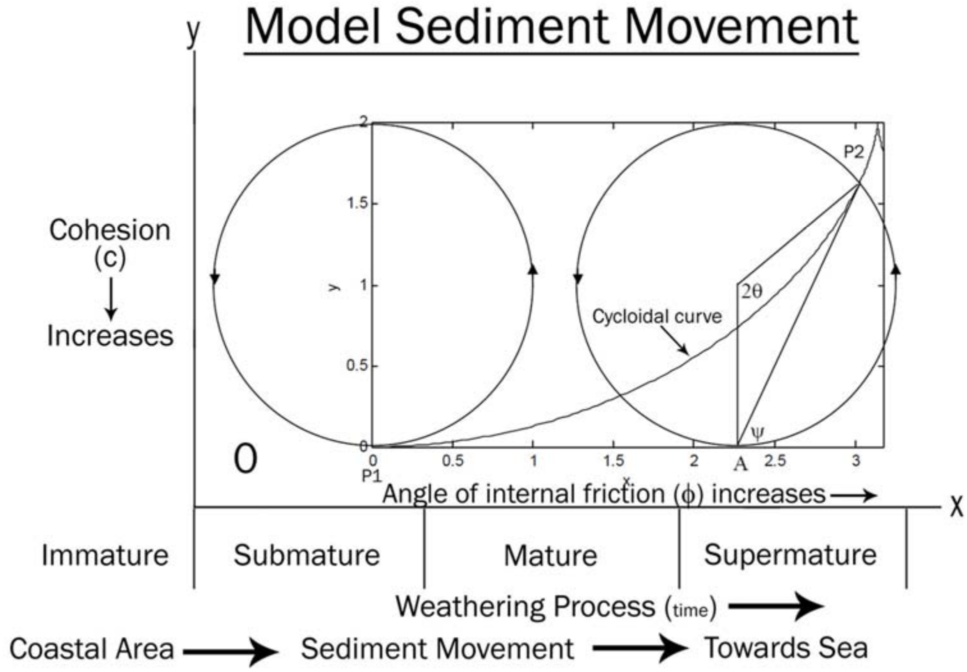


Fig 10 (a)

A basic Cycloide curve is shown in Fig 10 (a). In the x, y Coordinate System y = 2a is a horizontal line. The diameter of the moving sediment block is shown by the initial position of the circle p1. Now allowing the circle to roll counterclockwise(sediment movement) without slipping line y = 2a, so that the center of the circle moves to the right. As the circle (sediment mass) rolls on the line, the point P describes a curve, which is known as a cycloid. The horizontal and vertical distance of the point p from the center of the circle is a sin 2ϴ and a cos 2ϴ respectively.

The relationship between Cohesion (c) and angle of internal friction (ϕ) is Cycloidal in Sediment movements Factors influencing sediment movements are (1)Cohesion(c) (2) Angle of internal friction (ϕ) (3) Unit Weight (Size and Shape of grains) (ɤ) (4) Depth (z) (5) Stress Vertical Stress (ɤ z) and Slope horizontal to Vertical. The Sediments passes various stages of textural maturity from immature, submature, Mature and Supermature. This transformation can be represented in a cycloidal curve.

Position (1):

The point P represents Maximum Cohesion (c) and minimum friction (ϕ) . When P moves on the cycloidal cure, the horizontal distance from centre of the circle (centre of gravity of the sediment in motion) is asin 2ϴ. And the Vertical distance of the point P below the centre of the circle is acos 2 ϴ

The following Table (II) shows the variation,ϕ , c with ϴ.For a = 1.

ϴ	2ϴ	friction a Sin 2 ϴ (Horizontal)	Cohesion a cos 2 ϴ (Vertical)
0	0	0.0	1.0
45^0	90	1.0	0.0
90	180	0.0	-1.0

Where a is the radius of influence of soil mass.

-ve signs have no significance.

When immature sediments lose clay (cohesion) they are transformed to Submature sediments. When p moves on the cycloid curve the cohesion reduces and internal friction ϕ increases.In the final position of P cohesion becomes zero and only friction remains. When the Coaxial Component of shear strength reduces and the simple shear increases so that the stability is maintained. When frictional type sand remains without clay content, they develop strength using non coaxial component of shear strength by mobilizing ϴ, ɤ, and z. for stability. When sediments are transformed from immature stage to Super Mature stage there is a unique cycloidal relationship that exists between cohesion(coaxial component of shear strength) and friction of sediments(non coaxial component of shear strength.

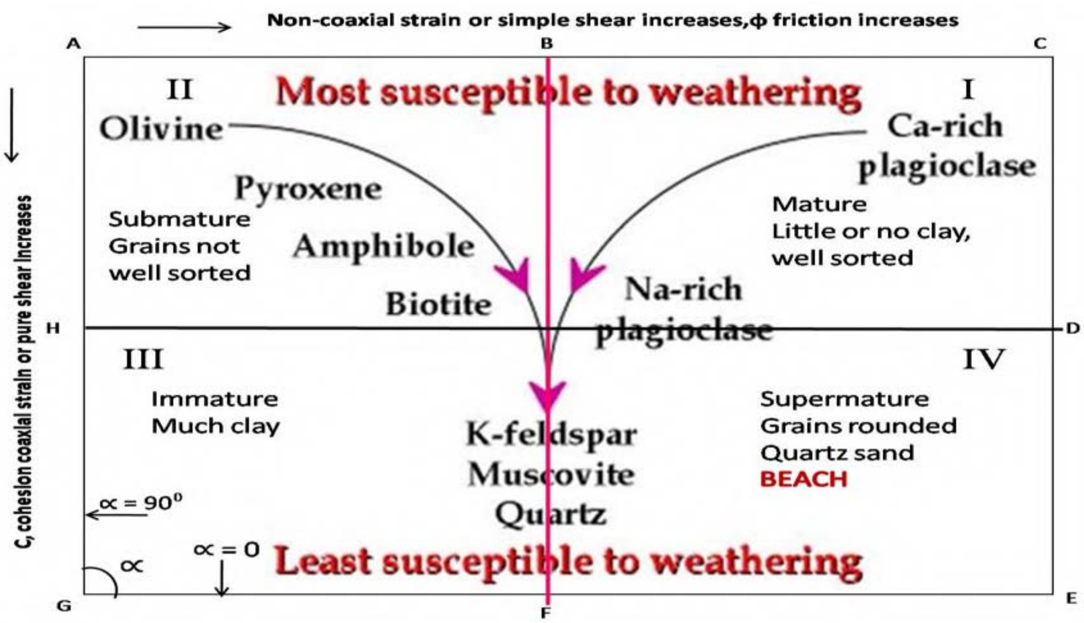


Fig.11

The figure 11 illustrates the integrated, intrinsic relationship among coaxial and non coaxial components of shear strength of sediments, Bowen's series of minerals and textural maturity of sediments.

VIII. CONCLUSIONS

1. Stage of maturity depends upon heterogeneity factor C_V which is complex but ultimately related to grain size and shape of the soil or sediment.

2.In immature textural stage the sediments contains much clay and are sensitive to coaxial strain or pure shear .These sediments are poorly sorted (well graded) and poorly rounded. Immature sediments have not undergone sufficient transport and reworking. After removal of clay the sediment grades into sub-mature stage. Pure shear (coaxial strain) decreases and simple shear (non-coaxial strain) is also introduced along with pure shear.

3. In sub-mature textural stage the angle of internal friction Φ increases because sand percentage increases and the sediment is not well sorted or rounded

4. In mature textural stage sediment is well sorted (poorly graded) but at the same time not well rounded therefore the Φ value increases at optimum level. The increase in non clay portion also increases Φ value.

5. In supermature stage little or no clay stage, the sand dominates and Φ reaches a constant value. At this stage the sediment grains are well sorted (poorly graded) and well rounded.

6. In figure 9 right upper top half is low cohesion zone, representing quadrants I, II, the angle of internal friction Φ increases, the non-coaxial strain (simple shear) increases .In other words in low cohesion zone quadrant II represents low friction and the sediment is in sub-mature or mature stage.(left upper top half).Similarly in low cohesion zone quadrant I represents high friction representing mature or supermature textural stage.

7. In figure 9 right bottom half is in high cohesion zone representing quadrant III and IV. The angle of internal friction slightly increases because much clay increases cohesion. In quadrant IV no Skempton point is found. The reason is that high cohesion and high friction cannot exist together. In high friction the soil consists of only pure well rounded well sorted grains and these grains just roll without any shear strength.

The coaxial and non-coaxial shear components control sediment movement.

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