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GLOSSARY

FOR : -

***THE ORIGIN OF ROCKS
AND MINERAL DEPOSITS
- USING CURRENT PHYSICAL CHEMISTRY
OF SMALL PARTICLE SYSTEMS***

by

John Elliston

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Glossary of terms

Please Note: -

References to page numbers and figures in this glossary are to pages and to figure/diagram numbers in the e-book “THE ORIGIN OF ROCKS AND MINERAL DEPOSITS - using current physical chemistry of small particle systems”.

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**ELLISTON RESEARCH
ASSOCIATES PTY LTD,**
10 (B) The Bulwark,
CASTLECrag,
N.S.W. 2068

Glossary

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Glossary and explanation of terms

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- **Accretion** – is rapid formation of clusters of similar shaped particles to form ‘close packed’ and pre-ordered aggregations at net lower surface energy in any remobilised concentrated fluid paste containing colloids. Crystallisation of these pre-ordered aggregates occurs subsequently to then form a ‘porphyroblastic’ texture where the large crystals are set in a finer grained matrix of crystallised sedimentary material.
- **Accretion and Concretion - the difference** - Both *accretions* and *concretions* are sub-spherical aggregates of higher density gelatinous material that form in colloidal slimes, pastes or mud. In the case of accretions, particles and aggregates are added to the surface of a developing accretion in a mobile paste which contains colloidal components. This occurs as a result of shear-induced reduction in interparticle distances, allowing the establishment of interparticle (van der Waal's) linkages. Accretionary growth is therefore a dynamic process which is not diffusion-dependent.

In contrast, *concretions* form by diffusive migration of dispersed sol particles to the surface of a densifying gel aggregate. They precipitate at this 'internal' surface as a consequence of a marked change in electrolyte concentration, produced by synerectic exudation of the interparticle fluid from the densifying gel. Concretions require a synerectic nucleus on which the metastable sol particles can precipitate. These then in the 'close packed' condition, draw together under van der Waal's strong attractive forces to desorb their own adsorbed species so that the concretion continues to grow. Concretion is therefore a static process dependent on the concentrations of electrolytes and smaller particles dispersed within the gel meshwork, and not on the operation of external agencies such as shearing.

There is, however, some common ground between the two processes in that the denser gel aggregate produced by either process is self-densifying (synerectic) with its particles linking to each other by van der Waal's attractive forces. Denser gel aggregates formed by either accretion or concretion have similar properties, and in fact the 'core' or nucleus for many types of concretionary overgrowth may itself have originally formed by accretion.

- **Acicular** – describes a crystal that is needle-like in form. It is also used to describe rod-shaped sedimentary particles when their length is more than three times their width.
- **Adsorbate** – adsorbates are the mobile ions, complexes, or charged particles that can be adsorbed on charged surfaces.
- **Adsorbed** – refers to ions or charged particles held on charged surfaces in mutual satisfaction of the electric charge as opposed to a chemical bond or electron sharing. (see Adsorption).
- **Adsorbed water monolayer** – describes the first layer of polar water molecules that are adsorbed on charged surfaces. Coverage may be partial, complete, or multi layered but water molecules adsorbed on a surface are polarised (all stand on end) and affect the adsorption of additional layers. Most surfaces are covered with an adsorbed water monolayer and in the case of very small particles approaching each other their respective water layers or hydration shells must be desorbed before chemical bonds can be established between them.

- **Adsorbent** – the charged surfaces or substrates in contact with a solvent that adsorb ions, complexes, or charged particles are called adsorbents.
- **Adsorption** – is the adherence or fixation on a surface (usually but not necessarily a colloid because of the enormous area, surface energy, and charge) of an ion or charged particle. The uptake by a surface of a solute or dispersion can occur by electrostatic, dipolar, quadrupolar, linkages or hydrogen bonding, etc. Where a chemical linkage is involved, the surface controlled reaction is called chemisorption. The dispersed ions and charged particles compete for adsorption sites on all available surfaces. Changes in concentration, pH, in the availability of surfaces, and in the permeability (spacing of the meshwork through which the ions and particles can diffuse) often have quite marked effects in exchanging and replacing surface adsorbed species.
- **Adsorptive capacity** – is also referred to as ‘adsorbate uptake’. It is the capacity of a given adsorbent to become loaded with charged particles or ions.
- **Aggregate** – refers to a mass or body of any sub-units such as smaller gelatinous accretions or concretions. These can crystallise as a mosaic of small interlocking crystals, as a composite of complexly intergrown crystals, or in optical continuity as a single ovoidal crystal. Rounded or irregular zones and patches of granular sediment or matrix cemented by infill concretion have also been referred to as aggregates. (Typical aggregates of particles are illustrated in [Figure 1.4.](#))
- **Agmatite** – Is an intrusive breccia often described as eruptive. These breccias are now known to reflect the fractural nature of the hydrous precursors. Found in granites they have been called injection gneiss. Angular fragments give the rock a breccia structure in which the edges of fragments often correspond. Fragments appear to have broken in place by the intervention of later granite host.
- **Allochem** – an allochem is a fragment, accretion, nodule, oolite, etc. that is chemically different and out of context with its surrounding matrix. It is a general term but it has been used to describe clear calcite nodules in lime-rich sediments because the formation of precursor accretions and concretions has not been widely recognised.
- **Allophane** – is a hydrous aluminium silicate gel of highly variable composition especially with regard to its water content. It is essentially an amorphous clay mineral $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2 \cdot n\text{H}_2\text{O}$.
- **Amygdales** – are ovoidal and irregular mineral aggregates occurring in basic or ferromagnesian-rich rocks that have quite different compositions to the major mineral components of their hosts. Minerals comprising the amygdales are commonly calcite, quartz, chalcedony, chlorite, zeolite, or agate. They occur as ovoids of a single mineral, mixtures of one or more minerals in the same ovoid, and frequently as many ovoids of quite different compositions in the same host rock. Concentric Liesegang bands and miarolitic cavities are developed in the many of the amygdales that have the same characteristics as geodes except for their generally smaller size.
- **Amethyst** – is a transparent to translucent variety of quartz crystal coloured purple to pale violet by a sparse dispersion of iron compounds such as ferric hydroxide through its polymeric precursor.

Glossary of terms

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- **Analcime (or Analcite)** – is a hydrous zeolite mineral commonly found formerly mobile ferromagnesian-rich rocks and greenstones. Its composition is $\text{NaAlSi}_2\text{O}_6 \cdot \text{H}_2\text{O}$.
- **Anatexis** - the melting of pre-existing rock.
- **Andalusite** – is a brown, yellow, green, red or grey crystalline form of one of the three common simple aluminium silicates that occur in schists, gneiss, granites and some hornfels. Its composition is $\text{Al}_2\text{Si}_2\text{O}_5$.
- **Andradite** – is a calcium-iron garnet $\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$.
- **Anorthite** - a white to gray calcium feldspar $\text{Ca Al}_2 \text{ Si}_2 \text{ O}_8$.
- **Anoxic** – this means without oxygen. Anoxic conditions in natural sediments are chemically reducing environments usually characterised by the presence of H_2S .
- **Anthophyllite** – is a hydrous ferromagnesian mineral $(\text{Mg,Fe})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$ that commonly occurs in association with serpentines or talcose ultra-basic rocks.
- **Antigorite** – is a brown to green hydrous ferromagnesian mineral that occurs in serpentine.
- **Apatite** – refers to a group of variously coloured calcium phosphate that contain variable amounts of water, fluorine, and chlorine. Their general formula is $\text{Ca}_5(\text{PO}_4, \text{CO}_3)_3(\text{F,OH,Cl})$.
- **Aplite** – is a light coloured fine-grained completely crystalline rock (crystals molded to each other without intervening spaces). The composition of aplites ranges from granitic to gabbroic but the term ‘aplite’ usually refers to veins, dykes or plutons of granitic composition consisting essentially of quartz, potassium feldspar, and calcic plagioclase. Aplitic rocks have the appearance of fine-grained pink granite.
- **Argillaceous** – describes a sediment largely composed of or containing clay sized particles or clay minerals. Argillites are the compact rocks such as claystone, siltstone, or shale.
- **Arterite** – or arteritic migmatites are essentially schistose lensoid fragments divided along planes of foliation. In the precursors of metamorphic rocks and granites these structural patterns are now recognised as having the same origin as pelletoid conglomerates in shaly sediments.
- **Atomic force microscopy (AFM)** – a technique for determining the surface microtopography and atomic structure of the surface.
- **Atomic geometry** – refers to the physical or geometric orientation of atoms at a surface. It is also called the microtopography of atoms held in a crystal lattice at a surface or interface.
- **Attraction – Repulsion** forces between charged particles in natural sediment pastes and slurries. Interaction energy can be plotted in relation to the interparticle separation. The charged particles “lock on” to each other and aggregate at very small interparticle distances (in concentrated pastes and slurries).
- **Augen** – is from the German meaning eye-shaped in the geological context.

- **Authigenic minerals** – are those that crystallise in place from the materials that occupied that space before crystallisation. Authigenic minerals come into existence usually at the same time or sometimes after the formation of the rock in which they occur. Authigenesis generally applies to all crystalline minerals that are formed other than from melts such as basalt.
- **Auto-brecciation** – is a fragmentation process whereby the initially rheopectically re-set fluid sediment or porphyroid is hydraulically fractured by further injection of thixotropically re-liquefied matrix during a subsequent episode of movement or earthquake shock. Wetter parts of the matrix or more hydrous and mobile minerals are usually involved in the later re-liquefaction. "Porphyroid in porphyroid" textures comprising angular fragments of porphyroid in a very similar porphyroid matrix are a common result of auto-brecciation.
- **Autolith** – is a xenolithic fragment of granitic rock within a granite matrix to which it is related. Granites are formed by repeated thixotropic mobilisation and rheopectic re-setting of the original intrusive sediment diapir. The potential fluidity of the matrix is maintained or increased between each successive liquefaction by synectic desorption of fluids from the accretions. The more hydrous and fluid ferromagnesian components tend to separate physically during each episode of liquefaction. They flow out from the stiffer more cohesive clay – polymeric silica residual. Autoliths are cohesive fragments from an earlier stage of consolidation that remain as pieces, streaks, wisps, chunks, etc. preserved in the final episode of liquefaction before consolidation of the whole rock mass. Prior to crystallisation autoliths are soft, plastically deformed, mix with or include accretions from their surrounding matrix, occur abundantly as fragment swarms, and the are invariably more basic (contain more ferromagnesian minerals) than their final host rock. The term 'autolith' properly describes the self-breaking of granite and often two or three generations of the more basic phases are represented among the autolithic fragments.
- **Basal glide plane** - the plane (often curved) of slippage or failure at the base of large masses of sediment moving down slope by failure of the continental shelf or deep within large sediment accumulations.
- **Banded iron formation** – is the common description of the extensive bedded and variously mobilised deposits of ferric hydroxides and polymeric silica that have consolidated to the world's major iron ore provinces. Banded iron formations are represented on every continent and the interbedded silica and haematite is commonly associated with chert, jasper, magnetite, ferromagnesian ooze, greenstone, grünerite, greenalite, minnesotaite, siderite, etc. Evidence of mobility in the form of flow banding, plastic deformation, brecciation, accretions, veins, dykes, fluidal folding, etc. is abundant. Banded iron formations contain and produce from the largest iron ore resources.
- **Bentonite** – a soft, plastic, porous, light coloured material composed essentially of clay minerals belonging to the montmorillonite (smectite) group. As for most natural clays, it also contains amorphous colloidal silica particles adsorbed on the surfaces of the clay platelets. The material is greasy and soap-like to touch and it has the ability to expand greatly (swell) in water. As a general term it is used to describe smectite clay deposits and it is used to thicken oil-well drilling muds.

- **Bingham Yield Point** – Charged particle systems “gelled” as cohesive, fractural, thixotropic, and visco-elastic solids may be envisaged as having many weak links between particles and fewer strong ones. Stress (application of force) disrupts weak linkages continuously and stronger linkages at an increasing rate until uniform viscous flow is achieved (the rate of shear is proportional to the shearing stress). In systems like natural sediments, viscous flow begins gradually through a plastic deformation stage. The theoretical point at which stress would be sufficient to initiate uniform viscous flow is called the Bingham yield point.
- **Blastomylonite** – is a historic name given to rocks characterised by a fine-grained weakly foliated matrix that contains a volumetrically significant proportion of large rounded porphyroblasts that are usually highly “corroded” or inclusion-rich feldspars and smaller rounded, irregular, and idiomorphic plagioclase crystals. The foliation, and often extreme elongation or plastic distortion of the quartz wisps remained unrecognised as resulting from viscous flow when it was thought that the texture resulted from hard rock deformation instead of the fairly common development of large accretions in viscous flow of the precursors.
- **Blind faulting** – small tensional faults that clearly displace one or several beds in a sequence but do not persist across overlying or underlying beds are called ‘blind faults’. This displacement and movement of layers between undisturbed beds indicates unconsolidated sediment deformation because the localised disruption involved ‘yield’ by liquefaction or plasticity of the affected layers. Some ‘blind’ faulting and interlayer disruption can be seen in [Figure 6.8](#).
- **‘Blue’ quartz** – pure crystalline quartz is like clear glass but when it contains a light dispersion or ‘dusting’ of exceedingly fine hydrous titanium oxide particles (probably leucoxene) it appears blue or pale bluish-white. Accretionary siliceous ovoids that are formed from the silica and residual trace elements from octahedral layers that are generated by the hydrolysis of primary clays characteristically contain ‘blue’ quartz. The translucent colour of common milky white vein quartz is due to gaps in the crystal lattice caused by the dispersion of minute hydrous inclusions or retention of hydroxyl groups. No metal oxides are involved except in some cases where the colouration of quartz is due to both.
- **Boehm lamellae** – are chains or bands of fluid inclusions within quartz crystals that are usually deformed or folded. They are a feature of the precursor polymeric silica and unrelated to the later crystal lattice structure.
- **Botryoidal** – means having the form of a bunch of grapes. It is used to describe some hardened colloform structures like those preserved in hematite but it has also been applied to rounded crust-like deposits such as cave corals. The term botryoidal has been extended to describe spherical aggregates of radiating crystals or spherulites. Earth scientists have been unable to distinguish the different origins of these three types of structures without the appropriate surface chemistry.
- **Boudin** – one of the series of elongate sausage shaped segments occurring in boudinage structure.
- **Boudinage structure** – is a pattern of deformation in which an original more competent layer between less competent beds is plastically stretched, thinned, and broken at irregular intervals into rounded sausage or elongate dumbbell shaped bodies that are often tightly packed with little or no matrix between boudins.

- **Brownian motion** – is the continuous agitation and movement of charged particles and ions in a sol caused by unbalanced impacts with molecules of the surrounding medium. For coarser particles the motion may be observed with a microscope and Brownian movement may be thought of as the ‘engine’ of diffusion. Where the concentration of charged particles or ions varies between different parts of the medium Brownian motion has the effect of equalising the concentration. Ions or charged particles move towards the region of lower concentration because they encounter fewer impacts with similarly charged particles or ions in this direction. The phenomenon is called a diffusion gradient.
- **Brucite** – is a white fibrous or foliated mineral form of magnesium hydroxide $Mg(OH)_2$.
- **Bustamite** – is a grayish-red mineral – $CaMnSi_2O_6$.
- **Carbonatite** – is used to describe coarsely crystalline intrusive calcium carbonate or dolomitic rocks that have been intruded as pipes or irregular intrusive masses. A few earth scientist unaware of the ancient lime kiln chemistry have applied the term to surface flows they regarded as lavas but the only carbonates chemically stable enough to melt at atmospheric pressures are sodium and potassium carbonates and the silicate minerals to which they act as ‘fluxes’.
- **Cassiterite** – is the brown or black mineral form of tin oxide SnO_2 that is the principal ore of tin. It is sometimes colloform but usually massive or fibrous and characterised by its light brown or straw-coloured streak.
- **Catalysis - at and by surfaces** - The catalytic surface coating which enhances crystal growth in gels and facilitates the growth and development of well faceted crystals in gelatinous media directly from dispersed particulate species is very significant. The phenomenon has been recognised for many years following the experiments of Hatschek and Simon (1912) and Boydell (1925) who demonstrated that gold sols diffused into silica gel would crystallise directly to metallic gold. In fact silica gel appears to be a ‘scavenger’ for insoluble gold particles dispersed in aqueous fluid. The irregular and sometimes high concentrations of metallic gold in quartz veins is thought to be due to the ‘quality’, that is the gel structure and degree of hydration, of the polymeric precursor silica in the vein and to its maintenance for a long period during hydrothermal fluid seepage so that very low trace levels of gold particles are concentrated. Hatschek and Simon’s experiments have since been repeated and further investigated by [Henisch \(1970, p. 19\)](#). Henisch points out that the gel structure has some degree of long range ordering which is why crystal faces of different orientations and having a different relationship to this ordering, are “catalysed” to different extents. Stumm (1992, p. 218) confirms that a surface catalytic effect is observed when the surface of the substrate or gel coating “matches well” with the crystal to be formed.
- **Catalytic bed** – a layer or accumulation of sediments in which the enormous area of particle surfaces can act as a catalyst to chemical reactions.
- **Cationic** – a positively charged metal ion or complex that would move to the negatively charged cathode is described as cationic.

- **Chalcedony** – is a crypto-crystalline wax-like variety of silica that may be translucent in tints and colours of white, pale blue, grey, brown, or black. The name chalcedony essentially covers the varieties of chert that include carnelian, sard, chrysoprase, prase, plasma, bloodstone, onyx, and sardonyx. They are all meta-colloidal varieties of crypto-crystalline silica that are coloured by the inclusion of more or less pigmenting materials such as organic substances, metal oxides, talc, fine sericite, etc.
- **Chamosite** – is a green-brown variety of chlorite – a hydrous ferromagnesian mineral.
- **Chaos Zone** – is a jumbled mass of disrupted sediment layers resulting from laminose flow or mass sediment slides at a stage where the semi-consolidated sediments have retained only sufficient water for limited thixotropic liquefaction. Deformation is essentially fractural and plastic.
- **Chaotic breccia** – a mass of large and small disordered blocks of irregular shape with limited fine-grained or porphyritic matrix material. The breccias usually result from massive slope failures and movement of large volumes of sediment down-slope.
- **Chaotic sediments or Chaotic shale** – describes highly disturbed bedded sediments that are locally intensely and randomly folded and faulted in completely chaotic fashion. The localisation and association with re-mobilised sediments indicates it is pre-consolidation deformation but the distinction with chaotic breccia and olistostromes is that disturbed chaotic shales have no matrix.
- **Chelate** – is a stable and soluble metal-organic or metal-amine complex formed by reaction between a metal ion (usually on surface or in a structure such as a clay platelet) and a suitable chelating agent. Organic acids and substances such as salicylic acid, humic acid, tannic acid, fulvic acid, catechol, oxy-dihydroxy aromatic compounds, 2,3naphthalenediol, etc., have been found to be chelating agents. The function of a chelating agent is to present functional groups on its molecule (such as –COOH and –OH) at the right spacing for an ion (such as a charged metal ion hungry for electrons) to form a ring structure by sharing electrons with the functional groups and elimination of a water molecule. Chelation can be an effective way of extracting ions from surfaces or otherwise insoluble compounds.
- **Chemical bond** – a chemical bond is formed when atoms or groups of atoms form a compound by sharing electrons.
- **Chemisorption** – occurs when an adsorbed ion, complex, or charged particle forms a chemical bond with the surface on which it is adsorbed.
- **Chlorite porphyry** – hydrous ferromagnesian minerals and ferric hydroxide retain water of hydration later in diagenesis than argillaceous and some siliceous components of sediment. Rheological separation of more mobile (lower viscosity) components can occur, simply by “running out”, if semi-consolidated sediments are disturbed at the appropriate stage. Large diapirs of hematite, magnetite, quartz-magnetite, magnetite-chlorite and sometimes just chlorite are formed in this way. In cases where the chlorite contains sufficient polymeric silica, quartz accretions form a chlorite-quartz porphyry or chlorite porphyry.

- **Chromatography** – the study of colour bands in diffusive media such as blotting paper, sandstone, sediments, gels, etc. where different diffusion rates for ions in solution result in a succession of bands at different concentration such that vividly different colours can be produced by chemical reactions or particle displacements that are dependent on the concentration of the reactants.
- **Chromite** – is a brownish black mixed chromate of iron $[(\text{Fe},\text{Mg})(\text{Cr},\text{Al})_2\text{O}_4]$. It occurs as a minor constituent dispersed in many types of basic rock but also as massive bodies and veins in serpentine. Fairly extensive bands and layers of chromitite that occur in anorthosite – pyroxenite layered complexes are an important source of chromium ore.
- **Clay hydrolysis** – clay minerals are created by the reaction of water (hydrolysis) with more structured silicates to form sandwich-structured platelets that are fully hydrated with silanol terminations on their external surfaces. Hydrolysis of existing clay minerals therefore refers to the slow progression of hydrolysis inward along the octahedral (brucite or gibbsite) layers from the edge of the platelets. This further hydrolysis occurs during diagenesis when clay-rich sediments are ‘soaking’ for long periods in slightly alkaline seawater or exposed to pore fluids in thick sediment accumulations. The progression of the hydrolysis reaction between the tetrahedral and octahedral layers in clay platelets has been referred to as the “zip fastener reaction”.
- **Close packing** – is used to describe a dense gel such as an accretion or concretion where the particles are arranged in accord with their shape to fit as closely as possible together. Clay platelets pack like leaves in a book, ferromagnesian hydrated ‘rod minerals’ like bundles of pencils, and polymeric silica spheres pack like apples in a case. Close packed particle clusters are physically stronger, synerectic and ordered. They crystallise readily because of spontaneous water loss and their macromolecular homogeneity.
- **Cluster** – a number of things of the same kind growing or held together to form a bunch or group. The term is used to describe aggregations of small accretions merging to form macro-accretions, aggregations of primary colloidal particles to form very small ordered or random structures that are still in the colloidal size range, and minute aggregations of precipitating molecules into ordered crystallite nuclei that represent the first emergence of a solid-liquid interface.
- **Coagulant** – refers to a coagulating agent such as an electrolyte that will reduce the thickness of the Helmholtz double layer and allow colloidal particles to precipitate on a surface or attach to each other (by van der Waal’s attraction) to form a precipitate or ‘curd’.
- **Coagulation** - the kinetic stability of colloidal dispersions depends on similar surface charges on all the particles. They repel each other as they approach under Brownian motion. The addition of an electrolyte (salt) to a colloidal dispersion can reduce the range or neutralise the electrical repulsive forces between particles. On collision they then approach close enough for the strong short range van der Waal’s attractive forces to promote intimate particle to particle contact such that the particles coalesce into aggregates. Muddy river water entering the sea is coagulated by the increased electrolyte concentration it encounters. ‘Coagulation’ is sometimes used interchangeably with ‘flocculation’. However, ‘flocculation’ may more correctly describe the action of bridging polymers that link dispersed sol particles so that a ‘floc’ or ‘curd’ will precipitate.

- **Cockade structure** – describes the crystallisation of ore or gangue minerals as a succession of comb-like layers or ‘crusts’ of outward radiating crystals from the underlying layer, fragment, vein wall, or any surface of a formerly synerectic material. Cockade structures where different colours or differences in the mineral layers are involved can be quite spectacular but they simply reflect the enhanced radial crystallisation pattern of successively deposited concretionary or condensing gel layers of the hydrous precursors of the relevant minerals.
- **Cohesion** - of a sedimentary particle system is due to the polar nature of macromolecules and the electric charge on the particle surfaces. Sediments to depths in excess of 7 km retain their cohesion and visco-elastic properties as ‘gelled’ and diffusive particulate materials. Because gels and gelled materials are very fine-grained solids, they are capable of conchoidal (glass like) fracture if stressed to an appropriate degree and at an appropriate rate. Gel fracture usually occurs in sedimentary materials when stress or shock has caused some of the sediment to thixotropically reliquefy. There is then a pasty matrix of almost the same density (but very different viscosity) in which the fragments can freely rotate. Frequently, semi-consolidated sedimentary and lode materials break into fragments and ‘chunks’ as reliquefied pastes are intruded among them (hydraulic fracture).
- **Cohesion and Fractural Nature** - of gelatinous solids which, depending on water content and rate of shear, can behave as fractural solids, deform plastically, or reliquefy thixotropically.
- **Co-ion** – an ion in the solvent having the same electric charge sign as a charged surface in its immediate vicinity with which it is interacting is called a co-ion.
- **Colloform texture** – describes the finely banded semi-circular or spheroidal layering of minerals that are precipitated from colloidal sols and crystallise from these gelatinous rhythmically layered precursors.
- **Colloid** - A colloid is any form of finely divided matter where the surface energy represents a significant proportion of the total energy of the system and affects or governs the bulk behaviour of the material. The colloidal size range is essentially between 1 and 1000 nanometres. Because small grains of detrital feldspar and sand continue to further hydrolyse and break down (chemically) during subaqueous diagenesis, the average sized sedimentary basin contains some 10^{35} particles in this size range. The colloidal state is a high energy state of matter and colloids revert to the lower energy crystalline state in any situation where they are able to divest surface adsorbed water monolayers and reverse the hydrolysis reactions.
- **Colloidal dispersion** - This colloidal state describes particles in the colloidal size range distributed as primary particles throughout a continuous solid, liquid, or gas phase medium. The dispersion is stable when the particles show no tendency to aggregate during random collision induced by their thermal (Brownian) motion. Dispersions of solids in liquids are called sols, liquids in gases are called fogs or clouds (their surface energy is manifest as lightning when they condense to droplets), liquids in liquids are called emulsions, and liquids in solids (within the interparticle pore spaces as in sediments) are called gels. Dispersions may be kinetically stable but are thermodynamically unstable since there is a reduction in the total surface energy by coalescence or aggregation. Repulsive barriers due to charge or to steric effects may render a dispersion kinetically stable.

- **Colloidal particles** – are any form of finely divided matter where the size of the particles falls in the range 0.5 to 1500 nanometers. Properties of colloidal particles grade to those of molecules and ions at the lower end of the scale and to those of grains and small fragments at the larger sizes.
- **Colloidal process** – is any change in the physical or surface chemical properties of a particle system that are due to the static or dynamic interactions between its charged particles.
- **Colloidal solution** – is an outdated term for a sol or a dispersion of colloidal particles.
- **Comb layers (in granite)** – are sinuous darker bands of feldspar and ferromagnesian minerals that have crystallised perpendicularly in a comb-like pattern across the banding. The comb layers usually occur as a single band or fluidal pattern of layering on the margin of small intrusions or later plutons that have re-invaded a pre-existing semi-solid granite mass. They have crystallised from the more fluid hydrates that have separated (because of their different viscosity) on flow laminae within and on the margins of the pluton as the later viscous precursor paste intruded.
- **Conchoidal fracture** – the fracture of fine-grained substances that produces smoothly curved sharp edged fracture planes is described as conchoidal.
- **Concretion** – this is the slow or step-wise accumulation of material about a central nucleus to produce a banded-textured spherical or elliptical accumulation of higher particle density and compaction than the medium in which the particles are diffusing. A concretion may be homogeneous, being self-nucleated, homogeneous but nucleated on a foreign body, or heterogeneous (i.e. banded) with or without a specific nucleus. The active process of concretion depends on colloidal particles individually diffusing towards the precipitating surface represented by the boundary of a higher density gel aggregate with the less dense surrounding medium through which the particles are diffusing. Concretion could be considered to represent “adsorption” of ions or colloidal sol particles onto a growing nucleus, and finally onto a growing macroscopic aggregate of particles or a denser gel surface. Removal of such particles from dispersion by precipitation at a nucleus or at an interface between random open meshwork gel and denser ordered gel creates a diffusion gradient (fewer particles in that vicinity). To equalise the concentration, other particles under Brownian motion arrive in turn to precipitate (adsorb) and accumulate on the surface.
- **Concretionary overgrowth** – this term refers to the accumulated layer of particles from the surrounding dispersion (sol) that have precipitated on and become part of a close packed synerectic nucleus. Depletion of one type of charged particle from the dispersed phase by its precipitation and accumulation on the nucleating surface can result in precipitation of another species of charged particle. Concretionary overgrowths are often rhythmic as different particle types are successively deposited on the nucleating surface. The thickness of successive layers is controlled by the diffusion rates by which each successive dispersed particle type is replenished near the precipitating surface.

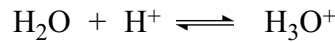
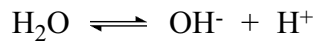
- **Co-precipitation** – means precipitation together. For example silica co-precipitates with other metal ion species and particularly with other amorphous or gel type hydroxides such as hydrated aluminium hydroxide or ferric hydroxide. Co-precipitation may be important in the accumulation of iron-rich siliceous oozes that are deposited in deep ocean basins.
- **Cordierite** – is a light to dark blue iron-magnesium alumino-silicate formed by shearing of hydrolysed primary clays in the development of metamorphic textures by viscous flow of the precursor sediment pastes. Its composition is $(\text{Mg,Fe})_2\text{Al}_4\text{Si}_5\text{O}_{18}$.
- **Corona** – is a general term for describing occurrences of bands of radially arranged acicular or spiky crystals round another spherical or nodular core mineral. Coronas are synonymous with kelyphitic rims but kelyphite is used for the particular case where all the olivine nodules or garnets in the basic rock are surrounded with radiating pyroxene or amphibole. ‘Corona’ relates to a wide range of other minerals that have crystallised from a synrectic accretionary core nodule on which an outer rim or band of had been deposited or accreted. The crystallisation of these overgrowths is nucleated on the surface of the underlying accretion and enhanced by the gelatinous nature of the rimming precursor.
- **Corundum** – is the hard mineral form of simple aluminium oxide (Al_2O_3). It is variously coloured usually occurring in shapeless masses that could be derived from crystallisation of aluminium hydroxide liberated from gibbsite layers by shear of hydrolysed precursor clays. It is sometimes found as beautiful crystals of ruby or sapphire.
- **Coulombic** – a coulomb is a quantity of electricity and coulombic describes the electricity situated at a charge site on a surface or on the surface of a particle.
- **Coulombic charge or linkage** – refers to the positive or negative electric charge on surfaces including those of particles by which the surfaces or particles attract or repel each other. The similarly charged surface sites repel each other and the oppositely charged sites attract each other and form linkages that mutually satisfy the respective charges. These are physical attachments (as opposed to chemical bonds) that can be broken but they are responsible for the cohesion of gel meshworks or particle systems.
- **Counter-ion** – an ion in the solvent having the opposite charge sign as a charged surface in its immediate vicinity with which it is interacting is called a counter-ion.
- **Crypto-crystalline** – means ‘hidden crystals’ (too small to be seen). It describes a permeable meshwork of exceedingly fine ‘welded’ or chemically linked micro-crystals such as those in chert or agate.
- **Crystal growth- requires particles to move to the surface** - Removal of a mobile species from dispersion in the gel by its crystallisation creates a diffusion gradient towards the crystal surface. Henisch (p. 51) notes that convection currents are suppressed in gelatinous media and therefore movement must be essentially by diffusion but a very important function of the gel media is also to suppress nucleation. Without growth on many closely spaced competing nuclei, the faces of crystals supported in the gel medium are supplied by a steady diffusion of particles or ions so that large and well formed crystals are able to develop.

- **Crystal lattice** – describes the stable meshwork of chemical bonds that hold the atoms of a crystal together in an ordered repetitive pattern of unit cells so that the compound that has crystallised achieves a low energy state.
- **Crystallisation of feldspar** – a number of natural clays in close packed aggregates react spontaneously with alkali metal ions and monomeric silica to feldspar and water with the liberation of heat. Feldspathoids are sometimes formed as an intermediate product. Reactions are described on [page 214](#).
- **Crystallisation of quartz** – most natural quartz has crystallised from compact polymeric species to which a further and continuing supply of the monomer is available. Some details are set out on [pages 10-13](#), [pages 21-26](#), [pages 126-130](#), and [pages 215-216](#).
- **Crystallite** – a crystallite is an exceedingly small and usually nascent crystal in which the limited number of molecules aggregating have just been able to assume an ordered arrangement of the crystal lattice and establish a solid – water interface.
- **Crystalloblastic** – describes a crystalline texture where the crystals have been produced entirely by metamorphic processes the chemistry of which has not previously been defined. Typically flow foliation or schistosity is seen to have been ‘pushed aside’ or pass smoothly round the crystalloblasts indicating that they were there as entities (precursor accretions) preserved in the last episode of shear or viscous flow.
- **Cristobalite** – is a polymorph (tetragonal crystal structure) of quartz; SiO₂.
- **Dacite** – is a fine-grained formerly fluid rock that contains plagioclase and quartz with one or more mafic minerals such as biotite, hornblende, or pyroxene.
- **Dactylitic** – or dactylitic intergrowth describes a rock texture attributed to symplectic intergrowth in which one mineral is penetrated by finger-like projections of another mineral. Dactylitic intergrowth such as quartz fillings of tubule patterns into feldspar can now be recognised as due to syneresis.
- **Dangling bonds** – Where the chemical bonds of the atoms in a crystal are unable to repeat the pattern of chemical linkages (electron sharing) to adjoining atoms because they are situated at the crystal face or boundary of the crystal, they are described as “dangling bonds”. The charge on a crystal surface due to the dangling bonds is largely satisfied by surface ‘compensation’ involving some adjustment of the surface atoms but it is also responsible for coating crystal surfaces with adsorbed water monolayers.
- **Desorption** - refers to the release of an adsorbed species from an adsorption site. Such release can be effected by ion exchange or replacement by another solute species having charge properties or better suited to the surface microtopography of that site. Dilution of the solution with which the surface is in equilibrium or close packing of the gel by accretion, syneresis, or compaction will also lead to desorption of ions or smaller charged particles. Typical particles of this nature are short-chain polymers of silicic acid, metal hydroxides, and hydroxy-sulphides which are released from the sediment substrates back to the pore fluid. Increased salinity can also desorb species that were adsorbed at lower concentrations of salt.

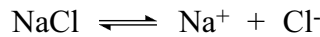
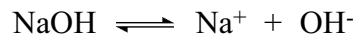
- **Diaspore** – is the white, gray, yellowish to greenish hydrous mineral form of hydrated aluminium oxide $\text{AlO}(\text{OH})$.
- **Diffuse cationic layer** – refers to the Gouy-Chapman diffuse layer where the concentration of counter ions is greater than that in the surrounding solution giving the particle an apparent Coulombic charge.
- **Diffusion** - describes the ability of ions, other solute species, or colloidal particles, to move through the fluid or within the gel meshwork and inter-granular fluid spaces comprising the sediment or rock fabric. Diffusion of species is at different rates depending on the particle size of the dispersed species and the size of the meshwork or intergranular spaces through which it is diffusing. In time diffusion would tend to achieve a uniform concentration of the dispersed species over all available medium through which it could disperse. Within particulate systems however, the marked differences in diffusion rates tend to change the concentration of ions and thereby often cause precipitation. Within blotting paper or a powder column, this is called chromatography. Within gel, it is called gel chromatography or Liesegang bands.
- **Diffusion controlled chemical precipitation** – the dynamics of chemical reactions that occur in the pores of a sediment are controlled by diffusion. The precipitation of ore metal sulphides formed by sulphidation of sparsely adsorbed trace metal ions is retarded to molecule by molecule growth as it achieves the solid crystalline state. This results in exceedingly small crystallites with "dangling bonds", extremely high surface energy, or insufficient surface area to achieve the normal internal compensation of charge at crystal surfaces. Nascent ore metal sulphide crystallites react chemically with water (chemisorb) to form hydroxy-sulphides. These disperse readily in aqueous fluids as proton promoted soluble species or sols.
- **Diffusion controlled particle precipitation** – in gelatinous media or the pores of fine-grained sediments, the rate that particles can move down a concentration gradient to precipitate at a coagulating surface or interface is controlled by diffusion. Relatively rapid precipitation of a dispersed species at an interface such as at the surface of a synerectic nucleus in the case of a growing concretion, can deplete nearby media with respect to that species. If diffusion rates are insufficient to replenish the precipitating species other dispersed species may become unstable relative to the precipitating interface. This diffusion controlled alternation of the concentration of dispersed charged particles near a coagulating surface results in rhythmic precipitation bands.
- **Diffusion gradient** – diffusion by Brownian motion of each mobile species dispersed in a fluid acts to maintain a uniform concentration throughout the entire fluid volume. However, the removal of ionic, molecular, or particulate species from dispersion in the fluid creates a diffusion gradient with respect to the species removed (precipitated). Diffusion gradients are particularly important in diffusive media like gels or fine particle systems where diffusion rates control chemical reactions or particle interactions by which the species are precipitating. Enhanced crystal growth in gels is largely due to an orderly successive arrival of a continuing supply of particulate or ionic species to join the specific growth points or 'steps' on a developing crystal face. Rounded or irregular shaped accretions in large volumes of re-mobilised sediment develop euhedral crystal faces or euhedral shapes because component species move down diffusion gradients to provide additional material to crystallising nuclei.

- **Dilatancy** – dilatant systems are those in which the viscosity increases with applied shear. Dilatancy occurs in particle systems of silt and sand size (non-colloidal) and is not primarily due to electric charge on the particles. When shear is applied to sand and silt saturated with clean interparticle water, mechanical rotation of non-uniform grain shapes expands intergranular spaces. The sand is temporarily undersaturated and the grains come in contact with each other to offer greater resistance to shear.
- **Diopside** – a clinopyroxene of calcium and magnesium, $\text{CaMg}(\text{SiO}_3)_2$.
- **Diorite** – describes a range of plutonic rocks defined by their composition that is granitic and between quartz-containing and ferromagnesian-rich characteristically composed of dark coloured hornblende, oligoclase – andesine plagioclase, pyroxene, and sometimes a small amount of quartz. The bulk composition of diorites generally corresponds to that of black shale or argillaceous sediments and they appear to be formed by the first or earlier stages of mobilisation and intrusion that if repeated give rise to more acidic phases of granite.
- **Dipole** – is a combination of two electrically or magnetically charged particles of opposite sign that are separated by a very small distance.
- **Dipole moment** – is a mathematical entity. It is the product of one of the charges of a dipole unit by the distance separating the two dipolar charges. Dipole moments are important in studying molecular structure. In measuring the dielectric constant by its temperature dependence as in the Debye equation for total polarization, it has been found that certain molecules have permanent dipole moments. These moments are associated with transfer of charge within the molecule and provide valuable information as to the molecular structure.
- **Discordant folding** – is where the folded beds are not parallel round the limbs of the fold or to those above or below the folded zone. It is characterised by the plasticity or liquefaction that is necessary to accommodate the departure from concordance. Where thixotropic liquefaction has allowed fluid sediment (or porphyroid) to fill the inter-beds or spaces between folds, the folding may be completely disrupted. Segments of beds, disconnected limbs of folds, or fragments can occur isolated in the formerly fluid material.
- **Disordered solvated layer** – Both hydroxyl groups and water molecules are adsorbed on mineral oxide surfaces under ambient conditions but the surfaces of natural sediment substrates also become ‘coated’ with other smaller particulate species. The “little balls” of polymeric silica that are adsorbed on the surfaces of quartz grains tend to form a structurally continuous coating that may have a surface catalytic effect if its structure ‘matches well’ with the crystal to be formed. Disordered solvated layer refers to the more usual random sizes and arrangement of polymeric silica particles and their adsorbed water molecules that build up to relatively greater thicknesses on the surfaces of quartz and other crystals.
- **Dispersion** - refers to the distribution of ions, molecules, macro-molecules, or small particles through the body of a medium like a gas, solvent, or a gel. It is important to distinguish the mechanism of dispersion from the solution of an electrolyte because many molecular, macro-molecular, or very small particle dispersions are commonly referred to as “solution”. The difference is in the nature of the

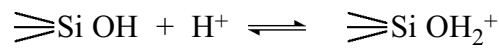
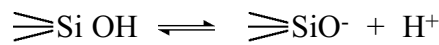
dissociation. Water as the most common solvent dissociates to equilibrium (depending on temperature, pH, etc.): -



A strong cation for example would dissociate: -



However, a number of hydroxylated organic compounds, weak acids, etc hydrolyse. For example silicon with its very strong affinity for oxygen retains the oxygen in the dissociation of silicic acid: -



The essential difference in these ionic and non-ionic dispersions is retention of the oxygen atom. Comparatively large molecules, complexes, and small particles readily disperse in water if they are hydroxylated.

- **DLVO theory** – is based on consideration of the coulombic repulsion between similarly charged particles and van der Waal’s attraction between particles at very close spacing. DLVO theory predicts the interaction between charged sediment particles in suspensions, slurries, and gels. (See explanation on [page 92.](#))
- **DLVO theory in forming accretions** –Langmuir (1938), Derjaguin and Landau (1941), and Verwey and Overbeek (1948) advanced basic colloidal theory by quantifying relationships between particles in suspensions, slurries, and gels. They developed what is now called DLVO theory that provides the classical description of these particle systems based on consideration of the two principal forces involved in their interaction (electrostatic repulsion and van der Waal’s attraction).

These advances in colloid and surface chemistry were applied to geological materials mainly in studies of clay technology and soil mechanics such as those by Hauser and LeBeau (1946), Frisch and Simha (1957), and Weyl and Ormsby (1960).

Clay platelets are electrically charged usually with a net negative charge. The charge is due primarily to defects or ‘gaps’ in the macro-molecular net-like lattice and “broken-bond” surfaces. These colloidal particles have an extraordinarily high surface to volume ratio but all surfaces have a “broken bond” charge. For colloidal particles the surface charge is invariably not fully or exactly counterbalanced by chemisorption or physical adsorption of its adhering charged particles or the co-ions and counter-ions which form the electric double layer. This results in a net residual positive or negative charge on the particle.

The distribution of coulombic charge on most clay platelet surfaces is a concentration of positive charges at the platelet margins and of negative charges toward the platelet centers. This dictates the way that platelets interact and form physical structures with other macro-molecular units.

The surface charge on similar colloidal particles means that they can form

metastable dispersions (sols) in which all particles mutually repel each other as they approach. This mutual repulsion between like particles reverses at very close interparticle spacing (i.e. in concentrated pastes and slurries) where van der Waal's attractive force between particles exceeds the Coulombic repulsion.

The potential energy of interaction is given by the sum of the forces of repulsion and attraction: -

$$V = V_{el} + V_{vw}$$

It can be plotted as a function of interparticle distance (concentration). See [Figure 4.3](#).

Each type of macromolecular particle within a specific system will have a net interaction energy curve according to the parameters of the system and the particle. [Figure 4.3](#) shows the general form of this curve of potential energy as a function of interparticle separation. For simplicity, only the major interaction energies of electrostatic repulsion and van der Waal's attraction leading to the net interaction energy are summarised.

The important feature of the curve is the potential well or primary minimum at short interparticle distances. As the particles come together, repulsion is changing more slowly (approximately proportional to $1/h^2$) and attraction more rapidly (approximately in proportion to $1/h^3$), so that the deep potential well with strong forces of attraction at close particle spacing (high concentration in partly dewatered clay - shale systems) characterises net interaction energies and predominates in these systems.

Mechanical disturbance of wetter muds (greater particle separation in the region of the secondary minimum) merely serves to re-disperse the colloids that then re-flocculate randomly. Energy must be supplied in the form of mechanical shear (laminar flow) to push the particles over the energy barrier at the primary maximum. Those moved into the critical interparticle separation at which close packing sets in (van der Waal's attractive forces predominate) adhere to each other to form accretions.

- **Dolerite** – a common fine-grained basic rock consisting mainly of plagioclase and augite that occurs as large sills, dykes, and as smaller bodies in disturbed black shale.
- **Dolomite** - is crystalline calcium-magnesium carbonate believed to have crystallised from protodolomite (a gelatinous partly ordered hydrous Ca -Mg carbonate).
- **Domain of 2Vx** – triclinic crystals (three crystal axes inclined to each other) such as microcline should have a constant angle between the crystal axes throughout a crystal that has grown by repetition of the unit lattice cell. Most natural microcline feldspar crystals are not like this. Where they have crystallised from ordered sub-units or smaller accretions that have aggregated into a large ovoid, uniform close packing of the sub-units so that all the primary clay platelets are precisely aligned is rarely achieved during viscous flow or 'snowballing' of the sub-units as the aggregate grows. Subsequent crystallisation of the large ovoid reflects the patches or domains of slightly different axial angles between the parts of the crystal that have developed from each sub-unit. This variation in the optical axial angle or triclinicity is characteristic of large potassium feldspars crystallised from precursor accretions.

- **Dynamic particle interactions** – this describes interactions between particles under conditions where the particles are moving physically in relation to each other such as during viscous flow or shear of the particle system. The particles are ‘pushed’ into closer proximity than would normally be the case in dilute suspension and they are able to ‘lock on’ to each other by van der Waal’s strong forces of attraction at close range. The formation of accretions and rheopexy are due to dynamic particle interactions in natural sediments.
- **Electric double layer** – the electric double layer at a solid – liquid interface refers to the distribution of ions in an aqueous electrolyte that is in the immediate vicinity of a solid surface. Parts of it have been named and various models developed in attempts that have been made to quantify the electric field and its influence on the solvent and ions in solution. It, or parts of it, have been referred to as the Helmholtz double layer, the diffuse double layer, the Gouy-Chapman diffuse layer, and the Stern surface.

The aqueous phase near a surface outside a hydrous oxide surface associated with the surface hydroxyl groups, can be divided into four regions of distinctive dielectric behaviour (see also [Figure 1.7](#)): -

- 1) the inner Helmholtz layer is a layer of preferentially oriented water molecules in contact with the solid-liquid boundary. In this zone the specific adsorbed ‘bare’ ions are without their hydration ‘shells’.
- 2) the outer Helmholtz layer is a region of both free water molecules and water molecules attached to hydrated ions. It is defined by the closest approach of a fully hydrated charged ion to the solid-liquid interface. Counter-ions are arranged in the outer Helmholtz layer at a distance δ from the interface.
- 3) the Gouy-Chapman diffuse layer is a region beyond the outer Helmholtz layer where the concentration of counter ions decreases (and repelled co-ions increase) with increasing distance from the surface (which has to be assumed as planar – like the face of a clay platelet).
- 4) this region has the dielectric constant of the bulk solution.

The variation of electric potential with distance from charged surfaces of arbitrary shape (such as in natural sedimentary particle systems) is a classical electrostatic problem. This is because specific adsorption results from chemical reactions at the adsorption site and from sites with atomic geometry/microtopography particularly suited to a specific adsorbate. Superposed on considerations based on idealised planar surfaces, is the fact that surfaces of small solid charged particles interacting with solvent do not have planar surfaces. Very small ones are "all corners", have very high surface energy, and hydrolyse in a similar way to highly charged ions. Also small particles diffusing in a fluid or a gel actually move in relation to their surrounding fluid. There is no movement relative to the surface adsorbed water and adsorbed species carried with the particle. However, there is a shear gradient in the diffuse double layer where the adsorbed solvent moving with the particle slips or shears through the fluid in which it is suspended. This is called the Stern surface. It occurs at a distance Δ from and parallel to the particle surface and the dielectric constant at this distance is called the zeta potential (ζ).

- **Electrolyte** – substances that conduct electricity when fused or in solution and simultaneously undergo a chemical change were described by Faraday as electrolytes. Other conductors of electricity that do not undergo chemical change are called metallic conductors.

- **Enclave** – is the French name for a xenolith or a fragment included in a granitic rock. ‘Double enclave’ refers to autoliths or xenoliths that contain fragments of original sediment, pieces of an earlier stage of re-texturing, or enclose phenocrysts from the last or earlier episode of matrix mobility.
- **Encrustation** – most common occurrences of nodular pisolites, laterite, cave pearls, stalagmites, stalactites, etc., are formed by encrustation processes. Larger particles can be precipitated in the immediate vicinity of a surface (such as by the reaction of soluble $\text{Ca}(\text{OH})_2$ with CO_2 in a very thin film of water). van der Waal’s attraction between such particles and the adjoining surface is often strong enough to divest the adsorbed water of hydration from between the particle and the surface. Chemical linkages established between the precipitated particle and the surface enable it to become part of the hard crust on which it is precipitated. In contrast, very much smaller higher energy concretionary particles precipitated at a sol – gel interface are more highly hydrated. They simply add to the gel and syneresis is required to divest water of hydration.
- **Endothermic** – a chemical reaction that requires heat or energy for it to generate its reaction products is ‘endothermic’.
- **Enhanced crystal growth** – occurs in gelatinous media because of the support for the initially delicate skeletal or needle-like crystals and the catalytic effect of certain gel coatings on solid crystal faces. The catalytic surface coating that enhances crystal growth in gels and facilitates growth and development of well faceted crystals directly from dispersed particulate species is very significant. Where the catalytic surface coating applies particularly to one facet of an initial small ‘seed crystal’, it can result in acicular or needle-like growth. Freedom of reactants to diffuse to and from a growing crystal face, and suppression of competing crystal nuclei also enhance the growth of crystals in gelatinous media. Yield of the medium to the developing crystal shape and conversion from the high-energy state of dispersed gel or sol particles to the low energy crystalline state also enhance the growth of crystals. For the crystallisation of synerectic accretions or concretions in deposits of gelatinous pastes or slurries, the pre-ordering due to close packing of the particles strongly accelerates crystal growth.
- **Entropy driving force** – Polyelectrolytes or polymers where repeating units are ionised or ionisable are strongly surface active. Their adsorption on surfaces can free to solution many previously bound water molecules to yield a net increase in the number of kinetic units in the system. Since entropy is a measure of the extent to which the energy of the system is unavailable this increase in available energy is due to the entropy driving force.
- **Epidote** – is an amorphous yellowish to dark green hydrated calcium – aluminium silicate; $\text{Ca}_2(\text{Al,Fe})_3\text{Si}_3\text{O}_{12}(\text{OH})$. It is a hydrous form of ferromagnesian minerals often associated with the metamorphism of limestones.
- **Epidosite nodule** – epidosite is a quartz-epidote rock usually containing chlorite. The calcic and ferromagnesian –rich hydrous precursors of the epidosite apparently had a different viscosity to clay-rich pelitic precursors so that large nodules or “pillows” of epidosite are found in metamorphic rocks that have been formed by the pasty flow of unconsolidated wet clay-rich sediments.

- **Euhedral** – a mineral crystal bounded by its own rational faces (faces that conform to its natural crystal system) is described as euhedral.
- **Eutectic** – relates to a system of two or more solid phases and a liquid mixture that coexists with the solids at a common melting point. Heating or cooling eutectic mixtures changes the proportion of liquid to solid phases but not the temperature of the system or the composition of any phases. The eutectic point is the lowest temperature at which a eutectic mixture will melt. It is usually lower than that of individual components. Unsuccessful attempts have been made to relate this property of molten anhydrous crystalline solids to the crystallisation of molten granite minerals. Consideration of eutectic mixtures in relation to granites assumes that melted crystalline silicates are physically crystallising from a molten condition and that “water in the magma to lower the melting point” would not react chemically with the silicates such that it is the hydrous compounds that are crystallising.
- **Exothermic** – a chemical reaction that liberates heat or energy as it generates its reaction products is ‘exothermic’
- **Facet** – is one of the plane polished surfaces on a gemstone or the natural euhedral face of a crystal surface. The term is also sometimes extended to other plane or flat surfaces occurring on otherwise rounded or irregular objects.
- **Fayalite** – is the simple brown to black mineral form of iron silicate (Fe_2SiO_4).
- **Feldspar crystallisation chemistry** – clay, silica, and metal ions from pore fluid solutions react chemically to produce feldspar and water in accord with a simple general exothermic reaction which achieves a lower energy state. Natural feldspars crystallising from clay do so in stages. Energy "barriers" have to be overcome (small energy inputs are required) for extensive crystallisation in a rock mass. The surface energy of natural clay is reduced by the formation of accretions by shear during viscous flow. The denser synerectic and ordered (close packed) accretions then have to divest water of hydration (by syneresis and compaction) for them to establish a feldspar crystal lattice.
- **Feldspathoids** – are feldspar-like rock forming minerals for which there was insufficient mobile silica [$\text{Si}(\text{OH})_4$] to complete the alumino-silicate lattice of potassium or of sodium-calcium feldspars developing in pre-ordered clay accretions. Feldspathoids are chemically related to feldspars and are found in intrusive rocks together with feldspars but not with quartz.
- **Fiamme-like** – ‘fiamme’ is from the Italian ‘fiamma’ meaning flame. Fiamme-like describes dark very fine-grained fragments or pellets that have ‘teased out’ or multiple points shaped like a flame.
- **Flaser structure** – describes elongated lenticular bodies of sediment or granular minerals between streaky layers of parallel scaly and foliated matrix. Further shearing or distortion of pelletoid conglomerate textures can develop a flaser structure.
- **Floc** - A floc is an aggregate of colloidal particles characteristically of low or random internal order. Flocs usually result when the repulsive forces between particles is slowly reduced to the point where tenuous aggregates, either by van der Waal's forces or by the attraction between dissimilar charges on different parts of the particle surfaces, can just link the particles together.

- **Flocculation** - aggregation of colloidal dispersions by the action of high molecular weight organic or inorganic polymers (usually polyelectrolytes) acting as a "bridging agent" between particles is called flocculation. It is distinguished from coagulation only by the nature of the precipitating agent.
- **Flocculent** – is a substance (like a weak electrolyte or a polymer) that will cause the colloidal particles in a sol to aggregate as flocs (flocculate). See [Figure 1.6](#).
- **Floccule sands** – with sufficient mobility or pasty flow to initiate the first stage of accretion where large clay platelets are involved, “books” of clay platelets or micro-accretions are formed. These give pelitic rocks a fine-grained granular texture such that it has been called ‘floccule sand’.
- **Flow foliation** – a general term for the planar arrangement of textural features that are preserved in any type of rock from pasty shear or fluid movement in the precursor sedimentary materials before they consolidated. The preservation is due to rheopectic re-setting. It has been used especially to describe the planar structure that results from plastic distortion and flattening of the precursor grains that crystallise to metamorphic rocks. Flow foliation has also been called ‘flow layering’ or ‘flow banding’ and the laminae often exhibit fluidal folding, contortions, crosscutting ‘unconformities’, and irregularities. Patterns of flow foliation can be overprinted by later cleavage due to re-orientation of crystalline minerals developed by prolonged regional pressure during crystal growth.
- **Fluidal folding** – describes a type of discordant folding that could only be achieved in a fluid or viscous medium. Thickening, thinning, distortion and sometimes disruption of the folded layers is observed but the characteristic of this type of folding is the plastic yield or fluid flow of the medium that was necessary to allow the deformation of the folded layer or layers to develop.
- **Fluidisation** – excess pore pressure or permeation of fluids through the pore spaces in sediment at a sufficient rate can disrupt the sediment fabric (interparticle linkages). Fine-grained sediments become increasingly sensitive to thixotropic liquefaction (lowering of the Bingham yield point) where the hydraulic pressure in pore spaces approaches or exceeds the lithostatic load. Coarse granular sediments (sandstone) or sediments where grains adhere to each other by coatings of clay or silica gel can also be fluidised in overpressured zones or by high rates of fluid seepage.
- **Fluorite** – is a translucent whitish or variously pale coloured mineral that is the simple fluoride of calcium CaF_2 .
- **Folia** – are thin leaf-like layers or laminae.
- **Fosterite** – is the simple white or yellowish mineral form of magnesium silicate (Mg_2SiO_4).
- **Framboids** – are globular clusters of iron hydroxy mono-sulphide in various stages of crystallisation to tiny pyrite cubes and grains that make up small raspberry-like spheroidal aggregates usually some 15 to 25 microns in size. Framboidal clusters are syncretic and they often nucleate infill concretion of additional hydroxy-sulphides or form the nuclei for concretionary overgrowth. Some framboidal clusters display long range ordering patterns. Framboids are usually composed of iron sulphide but framboids of brunckite (ZnS gel), sphalerite, native copper, digenite (CuS), chalcocite, covellite, native arsenic, and magnesioferrite or haematite have been recorded.

- **Fuchsite** – is a hydrous bright green chromium-rich mineral like muscovite with chromium substituting for some of the aluminium $KAl_2(Al,Cr Si_3)O_{10}(OH)_2$.
- **Gabbro** – an intrusive basic rock composed mainly of plagioclase and ferromagnesian mineral that is usually predominantly augite. Quartz in gabbro is less than 5%.
- **Gahnite** – is a dark green mineral often containing a little magnesium that gives it some variation in colour but it is essentially zinc aluminate, $ZnAl_2O_4$.
- **Gel** – a gel is essentially a semi-solid meshwork of fine particles coagulated or flocculated by the inter-tangling of long chained polymers where the particles are linked to form a visco-elastic permeable solid by interaction between electric charges on their surfaces. Synthetic gels of pure clay, silica gel, gelatin, agar, etc. contain similar particles or macromolecules but natural gelatinous sediments are complex mixtures of charged particles having a wide range of sizes, shapes, and compositions. Hydrolysis reduces most particles to the colloidal size range but these can form a matrix to larger residual grains. Gelatinous ferric hydroxide, hydroxy carbonates, hydrated organic matter and silica gel occur in most sediment and sometimes as major constituents. However, the most common particles in pelitic sediments are clays, amorphous silica, and hydrous ferromagnesian minerals. These common particles are shaped as platelets, spheres, and rods respectively and in the “gelled” or coagulated condition they link together to form ‘house of cards’ or ‘book-house’ structures, ‘strings of beads’, and ‘scaffold-like’ structures of rods. Natural sediment can be thought of as these several types of structures randomly intermeshed and securely cross-linked together by the mutual satisfaction of coulombic charge sites and by van der Waal’s attractive forces where particles are appropriately packed or close enough. It is not surprising that wet sediments have shear strength!

Semi-solid gelatinous sediments are thixotropic and have a definite yield value (Bingham yield point). The strength of the sediment fabric is very sensitive to water content and to the presence of flocculating or deflocculating agents. Liquefaction is isothermal and mechanically induced but the linkages between particles tend to re-form during viscous flow of the mud. The systems are “self healing” but there is a time delay in reverting to the original gel strength called hysteresis.

Cross-links are more readily broken at higher temperatures. Transition from an elastic gel to a liquid of relatively lower viscosity occurs revertably over a narrow temperature range. The more concentrated gels require higher temperatures but the thermal energy “softens” the paste and makes it easier to disrupt the fabric of particle linkages. Gels melt!

- **Gel Density** - This term is somewhat synonymous with porosity, diffusibility, or the degree of “packing”. It means the degree and extent of crosslinking or interparticle connection (electrostatic interaction and van der Waal’s forces) between the colloids and surfaces which have been established per unit volume within the gel. Gel density is not directly related to the compaction or the specific gravity of the sediments, but provided there is sufficient colloidal material present it follows that at higher concentrations (denser compaction) there are more interparticle linkages and therefore greater gel density.

- **Gel Fracture** - Because gels and gelled materials are very fine grained solids, they are capable of conchoidal fracture if stressed to an appropriate degree at an appropriate rate. The most usual way in which gel fracture occurs in sedimentary materials is where stress or shock has caused some of the sediment to actually re-liquefy so that there is a pasty matrix of almost the same density (but very different viscosity) for the fragments to freely rotate in, or to part into fragments and 'chunks' as it is intruded among them (hydraulic fracture).
- **Gel Plasticity** - Gels are visco-elastic solids. Even very watery gels which deform readily, are technically "solids" in that every part of the meshwork is linked to every other part, so that without disruption of the meshwork, there is no permanent deformation and after non-destructive deformation the material returns elastically to its original shape. However the meshwork linkages of gels, and particularly those of sedimentary materials, are not uniform in strength. The meshwork linkages comprise many weak linkages which offer virtually no resistance to stress, more intermediate ones, and a relatively few strong interparticle linkages which offer appreciable resistance to the deforming stress. Thus at the level of the macro-molecular linkages, gels to which stress has been applied do not completely return to their original shape when the load is removed. They retain a strain or plastic deformation, the yield being "in a series of little jerks" as the strongest linkages are broken. At slow rates of deformation, it should be pointed out that these broken linkages re-heal at an accelerated rate, so that the plastic deformation is permanent.
- **Geodes** – are large globular or ovoidal aggregates (2 to greater than 30cm) of soft polymeric silica accretions (macro-accretions) that are hollow or contain filled and part filled syneresis cavities. They are mainly found in re-mobilised limestone but sometimes in shale or greenstone consolidated from formerly mobile oozes and mud. Geodes display a remarkable variety of internal patterns of concentric Liesegang bands, crystal cavity linings, fluid extrusion channels, gaping syneresis cracks, Uruguay banding, miarolitic cavities, and phenomena relating to the re-distribution of pigments during synerectic desorption of electrolytes. Medium to large geodes are sliced and polished to display the common multi-coloured and rhythmic concentric Liesegang banding that makes them attractive for sale as ornamental curios.
- **Gibbs free energy** – is a mathematically defined thermodynamic function of state. It changes if there is a change of state but remains constant during a reversible process at constant temperature and constant temperature.
- **Gibbsite** – is a white mica-like or spheroidal mineral composed of aluminium hydroxide $\text{Al}_2(\text{OH})_3$.
- **Glauconite** – is a hydrous silicate of iron and potassium (with some sodium and aluminium) that shows considerable variation in composition. It occurs in colloidal form, as a major constituent of greensand, and commonly in marine sediments.
- **Glomerocryst** – are large rounded or irregular aggregates of differently oriented crystals of the same mineral that are found in metamorphic and granitoid rocks. They usually contain inclusions of the matrix or smaller crystals of the other rock-forming minerals.
- **Goethite** – is a yellowish-red to brown-black form of iron hydroxide [$\alpha\text{-FeO}(\text{OH})$]. It is a constituent of common rust or limonite and is related to lepidocrocite and akaganéite.

- **Gouy-Chapman diffuse layer** – the distribution of ions in aqueous electrolyte solution in the immediate vicinity of a charged surface makes a rather complex “fuzz” of co-ions (same charge as the surface) and counter-ions (opposite charge to the surface). Colloid chemists have unravelled the detail of this electric double layer (see [Figure 1.7](#)). The aqueous phase is divided into four regions of distinct electric behaviour: -
 - A. – the hydrous oxide surface associated with the surface hydroxyl groups.
 - B. – inner Helmholtz layer in which ions without hydration shells may form an “inner-sphere complex” or form a chemical bond with the atom at the surface.
 - C. – free water molecules and water molecules attached to hydrated ions may form “outer-sphere complexes”. This is also referred to as the outer Helmholtz layer and is the closest approach a fully hydrated charged ion can make to the solid-water interface.
 - D. – is the Gouy-Chapman diffuse layer where the concentration of counter-ions decreases with increasing distance from the interface.

The special physics (attraction and repulsion between electric charges) and chemistry (sharing of electrons) in the immediate vicinity of a surface are of fundamental importance to geology. All physical interactions and chemical reactions that occur within sedimentary materials as they consolidate to rocks must necessarily occur in the immediate vicinity of a surface.
- **Granitoid** – any rock that is like a granite or the granitic class of rocks.
- **Granodiorite** – is a coarse grained granitic rock intermediate in composition between quartz-diorite and quartz-monzonite. Granodiorites contain quartz, oligoclase or andesine plagioclase, and potassium feldspar with biotite, hornblende, and sometimes pyroxene as ferromagnesian components.
- **Granule chain** – describes a granular rock texture resulting from the aggregation of precursor sub-units that form a linear chain or narrow zone of significantly coarser minerals along a shear plane. The crystalline mineral shapes in a granule chain are usually smeared, stretched, broken, rotated, or augen shaped.
- **Graphic intergrowth** – is a pattern of filled syneresis shrinkage cavities in the precursor ovoids of clay that have crystallised to large feldspars. These intergrowths have a similar origin to perthite patterns or micro-pegmatites and myrmekites in rapakivi ovoids but in graphic intergrowth patterns the shape of the cavities is controlled or partly controlled by the developing crystal framework in the host feldspar. Myrmekites, micro-pegmatites, and syneresis shrinkage cavities generally are tubular and irregular but, like late perthite vein patterns, graphic textures have a fairly regular geometric outline and orientation that is commonly a pattern of little triangular areas resembling cuneiform writing. This is why they are called ‘graphic’. In all cases the later quartz filling crystallises as a single in optical continuity between the various cavities or regions of them that might be divided into several different crystals intergrown with the host feldspar.
- **Greenalite** – is an earthy pale green hydrous variety of serpentine usually found associated with banded iron formations; $(\text{Fe}^{2+}, \text{Fe}^{3+})_5\text{-6Si}_4\text{O}_{10}(\text{OH})_8$.

- **Greenschist** – hydrolysis of primary clays releases the chemical bonds between layers in their ‘sandwich’ structure so that when argillaceous sediments are subjected to shear during diagenesis (plastic deformation or viscous flow) the clay platelets disintegrate mechanically into smaller sub-units. As indicated in [Figure 8.73](#) and page 334, one of the main products of limited shear or schist formation (alignment of rod-shaped and platy particles) by diagenetic movements is chlorite. Initial shearing of semi-consolidated sediments therefore results in a schistose texture and the dark green colouration by chlorite. This is called greenschist facies.
- **Greenstone** – this term has been derived from descriptive field names for a number of rock types in different contexts. In general it describes ferromagnesian-rich sediments and rocks that are predominantly chlorite or glauconite possibly with epidote, chamosite, or actinolite. Where mobile ferromagnesian-rich marine oozes or mud have been liquefied by down-slope flow or intrusion, the ferromagnesian minerals (usually chlorite) become ‘felted’, denser, and crystals of less hydrous minerals such as augite, albite laths, biotite, amphibole, jadeite, pyroxene, etc. are often developed. This gives the original sediment an pseudo-igneous or ‘altered’ appearance.
- **Greisen** – is a mica-rich granitic rock that appears to have resulted from shearing at some depth in the wet sediment pile. Muscovite is the most common mica greisens often contain tourmaline, rutile, fluorite, cassiterite and wolfram.
- **Grossular** – is a green coloured calcium-aluminium garnet $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$.
- **Grunerite** – is a hydrous iron silicate belonging to the amphibole group: $\text{Fe}_7\text{Si}_8\text{O}_{22}(\text{OH})_2$.
- **Hedenbergite** – is a black clinopyroxene mineral $\text{CaFeSi}_2\text{O}_6$.
- **Helicitic structures** – are bands of inclusions through coarse crystals of metamorphic or granitoid rocks. Their existence before crystallisation occurred is indicated by the fact that the bands are unrelated to crystal axes or cleavage. Helicitic bands of inclusions are commonly folded, contorted, or occur as parallel bands and often reflect the spiral pattern of material added to the margin of the pre-crystalline accretion in the manner of a “rolling snowball”.
- **Helmholtz double layer** – in an aqueous electrolyte solution in the vicinity of a charged surface the aqueous phase is divided into four regions of distinct dielectric behaviour. The innermost region (α in [Figure 1.7](#)) consists of preferentially oriented water molecules in contact with the solid surface and where specific ions are adsorbed without their hydration shells. This is called the *inner Helmholtz layer*. The region further from the surface (β in [Figure 1.7](#)) contains both free water molecules and molecules attached to hydrated ions. This is called the *outer Helmholtz layer* and is defined by the by the closest approach that a fully hydrated charged ion can make to the solid – liquid interface. Further out from the surface the concentration of counter-ions (having a charge of opposite sign to the surface) decreases with increasing distance in the *Gouy-Chapman diffuse layer*. The outer and inner Helmholtz layers are referred to as the Helmholtz double layer.

- **Heterocoagulation** - If two stable colloidal dispersions of opposite charge are mixed, heterocoagulation or mutual coagulation is observed to produce a mixed floc. If the size of the particles of one dispersion is very much greater than the size of the other, a monolayer "coating" of smaller particles on the surface of the larger particles is observed.
- **Homologous series** – describes a series of plagioclase feldspars that have a similar or corresponding structure and origin but vary in the proportion of their chemical constituents. Plagioclase crystals have the same structure but are named from albite to anorthite according to the proportion of sodium to calcium in the aluminosilicate lattice.
- **Hydrogrossular** – is a more abundant member of the group of hydrated garnet-like precursors that from its composition $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_{3-x}(\text{OH})_{4x}$ appear to form a stage in the crystallisation of ordinary garnets.
- **Hydrolysate** – is the product of the reaction of water with other substances. It is the product of hydrolysis.
- **Hydrolysis** - is the chemical reaction of water with oxides and salts of weak acids such as silicates, carbonates, thiosulphates, organic acids, etc. It is the slow reaction with water during initial burial and diagenesis that continues to degrade the granular matter in sediments. The reactions tend towards hydrolytic equilibrium and the direction of these hydration reactions depends on the concentration of reactants. Excess water during subaqueous sedimentation and diagenesis produces hydrolysates that later crystallise to less hydrous or anhydrous species when water is finally reduced in the system.
- **Hydrolysed sediments without shear** - All sediment accumulations are actually hydrolysed (that is the clay octahedral linkages are "unzipped") but these reactions of clay minerals with further water are reversible (the octahedral linkages "zip up again") when the water is removed by lithification. Shear or liquefaction of the partially hydrolysed materials "degrades" the primary sediment clays producing chlorites, chamosites, glauconites, epidotes, steatites, anthophyllites, etc., usually with complimenting aluminous minerals like feldspars, andalusite, sillimanite, kyanite, corundum, diaspore, or spinel (or even sillimanite - diaspore nodules as at Broken Hill). The "zip fastener" hydrolysis reaction is the basis of significant metamorphic changes in fabric and mineralogy. Shear dynamics are much more important in metamorphism than heat but the increasing temperature due to burial depth in deep sediment accumulations certainly enhances the activity of water and hydrolysis. The essential difference between the changed and unchanged sedimentary materials depends on whether or not, and at what stage of hydrolysis, the material was involved in laminar flow (shear). Progression to lithification without liquefaction or shear yields consolidated and "cemented" ordinary mudstones and shales containing the same clay minerals as the original sediments. The clay minerals are reformed simply by reversing the hydrolysis reactions.
- **Hydrophilic** – means 'water loving' and is used to describe the tendency of a surface, particle or functional group to become wetted.

- **Hydrophobic bonding** – hydrophobic (water rejecting) colloids such as emulsions can involve the adsorption of dispersible organic particles or molecules on solid surfaces such as silica (or sulphide minerals in the important example of the floatation process). This adsorption means that the adsorbed hydrophobic molecule or particle must displace the solvent (adsorbed water monolayer) from the surface. This binding of hydrophobic molecules or particles to surfaces by short-range chemical forces or longer range (electrostatic and van der Waal's attraction) is called hydrophobic bonding.
- **Hydrosilicate** – is the product of the chemical reaction between water and a silicate mineral. The term refers to hydrolysable silicates generally and it includes partly hydrated silicate minerals (such as clays) that can be further degraded (hydrolysed) by reaction with water.
- **Hydrous ferromagnesian minerals** - are generally more 'oily', wet 'weak' gelatinous materials (mainly chlorite in pelites, glauconite in limestones, etc.). Accretions are commonly formed but hydrous ferromagnesian minerals also tend to separate in bulk from mudflows or large bodies of intrusive sediment as the more mobile components. They are lighter and have a different more fluid rheology.
- **Hydrous precursor** – refers to the hydrous mineral from which a metamorphic, ore, or rock mineral has the potential to crystallise. Typical chemically equivalent hydrates include clay, polymeric silica, chlorite, ferric hydroxide, lepidocrocite, iron hydroxy sulphide, hydrogrossular, and gaylussite. These would crystallise to feldspar, quartz, biotite, haematite, magnetite, pyrite, garnet, and calcite respectively.
- **Hydroxy-sulphide** – water molecules react chemically with exceedingly small insoluble metal sulphide particles (crystal nuclei or crystallites) due to their extremely high surface energy. The products of water in combination with exceedingly small metal sulphide particles are called hydroxy-sulphides.
- **Iddingsite** – is a reddish brown mixture of hydrous iron, magnesium and calcium silicates occurring as rust coloured patches in basic rocks. These patches are probably due to the incomplete dehydration and crystallisation of olivine precursors.
- **Illite** – this is a general name for a group of three layer mica-like clay minerals intermediate between muscovite and montmorillonite (See also [Figure 1.8](#)). Illite flakes are generally much larger than montmorillonite platelets but they do not have the expanding lattice characteristics of smectites. However, the specific adsorption of potassium ions on the hydrolysed margins of illite clay platelets is some 500 times greater than their affinity for competing ions at the same molar concentration (equivalent solution strength). Illite accretions therefore readily crystallise to potassium feldspar. Illite is also called hydromica.
- **Imogolite** – is a gelatinous water-rich aluminium silicate that is apparently formed by shearing hydrolysed clay-rich sediments. Its structure is indicated on [page 334](#).
- **Infill concretion** – growth of gelatinous precipitate on small synergetic nuclei in intergranular pore spaces can either displace the sediment grains or simply fill the pore spaces without displacement. Infill concretions are rounded "blobs" or nodules of relatively coarse sediment in which the pore spaces have been filled and the grains 'cemented' together by concretionary growth of the intergranular gel.

Infill concretions may contain concentric or rhythmic bands like displacing concretions but the bedding and granularity of the original sediment are preserved within the concretion.

- **Intraclast** – An intraclast is a torn up and re-worked fragment of the same sediment in which it occurs. Intraclasts are typical of weakly consolidated or fluid rich thixotropic sediments such as lime-rich mud or deep marine ferromagnesian hydrate-rich oozes and slimes. Cohesive gelatinous materials fracture conchoidally so that intraclast breccias are initially sharply angular or wisp-like. However, they are soft, plastic and readily moulded to rounded shapes by fluid movement or flow of the mobilised sediment in which they have originated. Re-working (kneading) of intraclasts can compress or ‘close pack’ the component gel of the fragment so that it becomes more synerectic than the fluid-rich gel of the mobile matrix. Re-worked intraclasts resemble accretions. They are often rimmed or develop other characteristics of accretions such as syneresis cracks or aggregating to clusters.
- **Ion** – an ion is an atom or group of atoms that is not electrically neutral but instead carries a positive or negative electric charge. Positive ions are formed when neutral atoms or molecules lose valence electrons; negative ions are those that have gained electrons.
- **Ion - Charged particle exchange** – refers to the exchange between ions or charged particles adsorbed on surfaces and the ions and charged particles dispersed in the surrounding fluid. Equilibria for the exchange are governed by concentration, pH, electric charge on the ion or particle and specific nature of the adsorption site.
- **Ion exchange** – is the process by which ions from surrounding solution displace ions adsorbed on the substrate because their charge or affinity for the site is greater than the ion they are displacing.
- **Ionic concentration** – refers to the concentration of ions of a given solute in solution (in mols/liter) that determine the activity coefficients and whether the ions in solution will exchange for those adsorbed on surfaces with which the solution is in contact.
- **Ionic radius** – a mobile ion is an electrically charged atom or group of atoms about which the charge has been described as a “cloud” or force field weakening rapidly as it extends indefinitely outward. The charge ‘surrounds’ free ions because of the electron movement but in ionic compounds the internuclear separation between the positive and negative ions is a distance that can be determined by x-ray measurements. The proportion of this distance between ions in a compound or lattice that can be assigned to one of the ions has been called its ionic radius. Cumbersome ions with larger ionic radii diffuse slowly through gelatinous media in comparison with ions having smaller ionic radii so that a separation develops.
- **Ionisation** – is the process by which neutral atoms or groups of atoms become electrically charged, either positively or negatively, by the loss or gain of electrons; or the state of a substance whose atoms or groups of atoms have become thus charged.
- **Ionisation constant** – is the product of the concentration of the ions produced at equilibrium in an ionisation reaction divided by the product of the concentration of the ionising substance; each concentration raised to that power which is the coefficient of the substance in the ionisation equation. The importance of the ionisation constant in

the behaviour of Si(OH)_4 , is that polysilicic acids are stronger (ionise more readily) than monosilicic acid so that Si(OH)_4 reacts (forms siloxane linkages) with higher polymers rather than another monomer. This formation of siloxane linkages is essentially the only way that dispersible silica can precipitate from aqueous solutions.

- **Isothermal** – at the same or equal temperature. Heat is neither generated nor absorbed by an isothermal process or transition.
- **Kelyphites** – is a rock in which rounded or irregular olivine or garnet phenocrysts are rimmed with a peripheral band of outward radiating crystals of pyroxene or amphibole. These rather spectacular radiating mantles of crystals are called kelyphitic rims. The rims have been developed by enhanced crystallisation of pyroxene or amphibole in the layer of their hydrous precursors that has been deposited or accreted round the synerectic olivine or garnet precursor nuclei.
- **Kimberlite** – a basic porphyritic rock that contains large ovoids of serpentine that are partly crystallised to olivine and set in a mixed matrix that is mainly calcite with phlogopite, chlorite, chromium garnet, ilmenite, magnetite, serpentine, and perovskite. Kimberlites are intruded from depth as pipes that sometimes contain diamonds.
- **Komatiite** – refers to an exceptionally mafic suite of rocks that contain olivine as a predominant mineral.
- **Kyanite** – is a blue or light green crystalline form of one of the three common simple aluminium silicates that occur in schists, gneiss, granites and some pegmatites. Its composition is $\text{Al}_2\text{Si}_2\text{O}_5$.
- **Labradorite** – is an intermediate plagioclase feldspar in the albite to anorthite series in the range $\text{Ab}_{50}\text{An}_{50}$ to $\text{Ab}_{30}\text{An}_{70}$. Labradorite crystals often show a brilliant schiller structure that is a play of blue-green colours due to preservation in the crystalline mineral of the long range ordering of its precursor smectite particles. The schiller structure in labradorite is formed in the same way as the ordered array of minute silica spheres in opal (Figure 5.47). Labradorite plagioclase crystals preserve rows of minute inclusions that form an ordered graticule to refract light (like a rainbow).
- **Lahar** – is a mudflow composed mainly of volcanic ash and debris that are carried down the side of a volcano. These mudflows are often triggered by overflow of a crater lake or the violent thunderstorms that form from the volcanic emissions during eruption. The weight of steam emitted from volcanoes exceeds the total weight of all other lavas and pyroclastics.
- **Laminar flow** – in fluids occurs when the movement of all parts of the fluid is essentially parallel to the direction of flow. Laminar flow in viscous fluids can be modelled as a series of parallel flow laminae as opposed to turbulent flow where movement is random, chaotic and irregular.
- **Laminose flow** – describes the series of parallel internal failure zones or planes developed in greasy wet sediment layers by progressive down-slope slippage of the overlying beds or blocks of sediment.

- **Lamprophyre** – refers to a range of related dark coloured porphyritic rocks that contain a high percentage of ferromagnesian minerals such as biotite, hornblende and pyroxene as porphyritic phenocrysts in a fine-grained matrix of the same minerals. Most lamprophyre matrices also contain some feldspathoids and sometimes feldspar but all the minerals in these rocks are usually incompletely crystallised and they contain an abundance of residual hydrous ferromagnesian precursors such as varieties of chlorite that have not crystallised to the common rock minerals that retain minimal hydroxyl groups.
- **Lapilli** – (from the original meaning “little stones”) are pyroclastic “rocks broken by fire” or volcanic ejecta that are usually defined as being between 2 and 64 mm in size. These volcanic fragments are mostly solid but sometimes still viscous and glassy when they land so they can weld to each other and are quite irregular in shape. ‘Volcanic gravel’ is another term that has been used to describe these accumulations of “little stones” illustrated in [Figure 7.20](#).
- **Latite** – a latite is a porphyroid that has crystals of plagioclase and potassium feldspar (often mostly sanadine) in nearly equal amounts so that there is little or no quartz. Where quartz is present it is usually in the form of chert and the rock is called a quartz latite.
- **Lechatelierite** – is the amorphous vitreous glassy form of quartz [SiO₂] that is produced when crystalline quartz is fused. Natural occurrences are rare but sometimes result from lightning strikes or meteorite impacts on sand. It is not found in granites.
- **Lenticule** – is a small lens-like shape or body of material.
- **Leucoxene** – is an opaque very fine-grained white hydrous mineral usually associated with ilmenite and anatase (TiO₂). It is thought to be a hydrated oxide of titanium but is probably a mixture of the oxide and hydrated oxide. Titanium oxide is a strong highly opaque white pigment.
- **Liesegang banding** – concentric rings or bands are developed during syneresis of pre-crystalline natural sediment colloids (such as clay, chert, hydroxy-carbonates, or siliceous shale). The Liesegang banding is a response to rhythmic changes in adsorption equilibria for pigment particles coating gel surfaces. The release/resorption of pigment particles is caused by different anion and cation diffusion rates as electrolytes are exuded from synerectic material. The bands parallel surfaces from which the fluid is lost.
- **Ligand** – is a charged chemical group or radical that can form a complex or hydrolyse ions in solution. Metal ions dissolved in water present a strong electric charge to the solvent such that the charge is neutralised or partly neutralised by distribution of the ions over the various complexing ligands present. The simplest and most common ligand in aqueous solution is the -OH⁻ group that interacts to equilibrium in the hydrolysis of charged ions and surfaces.
- **Limburgite** – is a dark coloured ferromagnesian-rich rock containing olivine and clinopyroxene ovoids in an alkali-rich glassy or crypto-crystalline matrix that may have microlites (minute crystals) of pyroxene, olivine, or iron oxide that are sufficiently ordered to polarise light.

- **Linkage (between charged particles)** – physical linkages are established between polar water molecules, ions, charged particles and surfaces by the mutual satisfaction of coulombic surface charge that effects a reduction of surface energy. Particles or particles and surfaces in very close proximity to each other can also be drawn together by van der Waal’s attractive forces. These physical linkages form a cohesive ‘fabric’ or gel structure in semi-consolidated sediments. They are weaker and distinct from chemical bonds where electron sharing between atoms determines the nature of the molecules and the way they will crystallise.
- **Liquefaction** – describes the transition of a cohesive mass of sediment from a visco-elastic solid (gelatinous) to a non-Newtonian liquid (fluid paste). Large-scale liquefaction of natural sediments is mainly by transmission of earthquake shocks (all particle linkages disrupted at the same time) or by massive shelf failure where the initial plastic deformation of the sliding sediments reaches a critical velocity such that all particle linkages are disrupted by the pasty flow. Fine-grained or granular sediments where grains adhere to each other by coatings of clay or silica gel can also be liquefied by excess pore fluid pressure (overpressured zones). They are made increasingly sensitive to thixotropic liquefaction (lowering of the Bingham yield point) where the hydraulic pressure in over saturated sediment approaches or exceeds the lithostatic load. This type of disruption of the sediment fabric occurs in both fine-grained and coarse granular (sandstone) sediments and is often referred to as fluidisation.
- **Liquidus** – is said to be the locus of points in a temperature-composition diagram representing the maximum solubility (saturation) of a solid component or phase in the liquid phase. It assumes that natural mineral crystals (usually granite minerals) have been crystallised from the same minerals dissolved in a fluid melted mixture of rock minerals where the “saturated” phase crystallises because it becomes over saturated as the melt cools. From other data it is generally claimed that granite magmas were fluid and molten at about 750 to 850°C. This is approximately half the temperature at which the refractory natural granite minerals will melt if the rock as found in the field is simply heated. Classical petrologists therefore propose that fluid granite magmas had “water in them to lower the melting point”. The question of the chemical compounds that would be formed by water in molten silicates remains unanswered. If the water in magmas “to lower the melting point” has achieved this effect by chemically combining with the silicates to form hydrous compounds then it would be the molten hydrosilicates that crystallise from the fluid condition and not the melted refractory silica and silicates at all! Hydrosilicates crystallise by chemical exothermic dehydration reactions that would increase the temperature of the crystalline rockmass. The term “liquidus” should not be used until the chemical role of “water in magmas to lower the melting point” is properly defined.
- **Listric or slip fault** – is a curved downward flattening fault, concave upwards, and commonly developed by rotation of an unsupported sliding mass of semi-consolidated sediments on unstable continental slopes.
- **Lit-par-lit** – means ‘bed by bed’ and is used to describe bedded or layered rocks where alternate layers containing more water have been remobilised thixotropically during diagenesis by laminose flow or earthquake shock and subsequent crystallisation of the accretions has resulted in an igneous-looking (usually granitic) texture for the formerly mobile interlayers. This pattern of alternate ‘granitisation’

of layers has been of interest to petrologists because the cohesive beds are rarely significantly 'altered'. In addition the granitic layers are often thin or with branching offshoots and irregularities that make it extremely difficult to understand how molten silicates could have retained sufficient heat and low viscosity to intrude between such large areas of non-molten wall rocks.

- **Loess** – a thick yellowish-brown fine-grained silty deposit that is commonly homogeneous and unstratified. It is usually regarded as an accumulation of windblown desert dust.
- **Long range ordering** - refers to the "packing" arrangement or ordering of colloidal particles, arrays, and clusters as dictated by their shape, packing, and charge distribution. Structured micelles, tactoids, tubules or other order is achieved as the particles fit together in order to most effectively reduce surface energy and mutually satisfy the charges distributed on their surfaces. Long range ordering in particle aggregates often sets the pattern for subsequent crystallisation in optical continuity, sometimes between almost disconnected or nearby masses. Long range ordering is a well-known phenomenon in colloid science. It is a type of pseudo-crystallisation of the charged hydrated particles that arrange themselves to minimise surface energy and mutually satisfy their surface charges. Micelles and similar particle aggregates are usually two dimensional and framboids, like the aligned silica spheres in opal, are three dimensional ordered "lattices" like those in crystals but with wet charged particles instead of ions.
- **Low albite** – refers to the more ordered crystalline form of the sodium plagioclase feldspar ($\text{NaAlSi}_3\text{O}_8$) that is stable up to about 450°C above which temperature it changes irreversibly to a disordered random distribution of aluminium atoms in the available crystal lattice sites. The occurrence of low albite in many plutonic rocks granites and diorites remains as a problem in the concept of *anatexis*.
- **Low energy electron diffraction (LEED)** – a technique for determining surface atomic structure.
- **Lyophilic colloid** – means 'solvent loving' and is used to describe the tendency of colloidal particles to adsorb species from or to combine with solutions in which they are dispersed.
- **Macro-accretion** – a macro-accretion is the larger accretion formed by the aggregation of pre-existing smaller accretions or sub-units during a subsequent episode of mobilisation following that which generated its sub-units.
- **Macromolecule, macromolecular** – refers to very large molecules or very small crystallites such as clay platelets that by the continuity of their chemical linkages are essentially large molecules.
- **Macromolecular homogeneity** – refers to a cluster or aggregate of large molecules or small charged particles such as those in an accretion where the large molecules or small particles are homogeneous (of the same size, shape, and composition).
- **Madam Pele's Tears** – is a common name for the very fluid glassy tear drop shaped pyroclastics emitted from basaltic lava fountains. These small molten glassy fragments are 'streamlined' as they elongate and cool in the air to fall as extremely sharp coarse glassy shards. The duckboards at Kilauea Iki on Hawaii are certainly needed to walk across these murderously sharp fields of debris!

- **Magma** – from earliest times in the English language the word “magma” meant a paste. It usually referred to an aqueous paste and it is still used with this meaning in pharmacy today e.g. “kaomagma”. In some English dictionaries it is still defined as meaning a paste, including the “amorphous basis of certain porphyritic rocks” in the geological context. For example the entry in the third edition of the *Shorter Oxford Dictionary*, p. 1186, reads: -

“**Magma** (mæ’gmâ). ME. [a. L. magma (sense I), Gr. μαγμα, f. root of μασσειν to knead.] †1. The dregs that remain from a semi-liquid substance after the liquid has been removed by pressure or evaporation - 1856. 2. Any crude mixture of mineral or organic matters in the state of a thin paste - 1681. 3. *Geol.* a. One of two or more supposed strata of fluid or semi-fluid matter lying beneath the earth’s crust. b. The amorphous basis of certain porphyritic rocks. 1804. Hence Magma’tic a.”

Cautiously, successive Oxford English dictionaries have changed the meaning of the word “magma” to reflect the more recent meaning implied in current geological usage: -

Concise Oxford (3rd edition) revised to 1946: -

“crude pasty mixture of mineral or organic matter; one of supposed fluid strata under solid crust of the earth.”

Concise Oxford (6th edition) revised to 1976: -

“crude pasty mixture of mineral matter; (semi-) molten stratum under solid crust of the earth from which igneous rock is formed by cooling.” It should be noted that this definition relies on the same assumptions as those made in drawing complex “phase diagrams”. [Note: It is assumed that hot liquid feldspars, quartz, etc. cool through a melting point like cooling molten metal with liberation of latent heat of fusion. The role of “water in the magma to lower the melting point” (to about half that of the refractory silicates) remains undefined. It must be assumed that this water has not reacted chemically with the molten silicates.]

The Australian Pocket Oxford Dictionary 1984 to 1992 is quite unambiguous: -

“magma (geol.) molten rock layer beneath the earth’s solid crust.”

This is also reflected in the *Concise Macquarie Dictionary* 1982: -

“magma Geol. Molten material under conditions of great heat and pressure occurring beneath the solid crust of the earth and from which igneous rocks are formed.”

The American *Glossary of Geology*, Bates and Jackson, 1987 reverts to the more cautions and classical definition of magma: -

“Naturally occurring mobile rock material generated within the Earth and capable of intrusion and extrusion, from which igneous rocks are thought to have been derived through solidification and related processes.”

The original meaning of the word “**magma**” would describe the fluid condition of buried semi-consolidated sediments realistically and plainly. However, for the great majority of geologists, the word now means “melted rock”. Most petrologists claim that water was re-introduced into the hot rock against pressure and temperature gradients to “lower the melting point of the magma” (very substantially). Questions of why the rocks in the roots of our mountain chains got especially hot, how the water was re-introduced, or whether or not the water envisaged in magmas to “lower the melting point” is chemically combined with the silicates, remain unanswered in

classical petrology. If water in fluid magmas is in the form of hydrosilicates these liquefy at much lower temperatures (commensurate with burial depth) and crystallise to granite minerals by exothermic chemical dehydration reactions that would raise the temperature of the crystallising rock mass significantly.

In this book the term “magma” is avoided. Euphemisms such as “hot wet paste”, “pasty flow”, “sheared paste”, “aqueous paste”, “thixotropic semi-consolidated sediment”, etc. are used instead.

- **“Magmatic corrosion” theory** – has been suggested by some petrologists attempting to explain the sphericity, deep embayments, and scalloped margins observed in large quartz and feldspar crystals they assume to have been derived by the cooling of molten rocks. However, crystal growth and reversion to the crystalline state is supposed to have been due to the cooling of the molten rocks. Further assumptions such as re-heating the cooling magma or changing its composition must be made. These are also untenable because the rounding and deep embayments occur in both the quartz and feldspar crystals that have well known and very different melting points. The temperature at which crystalline feldspars would re-melt or “corrode” should not affect crystalline quartz and the concept of “corroding” either mineral inward along deep tubular embayments like borers make in wood, appears highly improbable if not ridiculous.
- **Magnetic susceptibility** – is essentially a measure of the ability of a given material to influence the magnetic field to which it is subjected.
- **Marcasite** – is a common lighter yellowish or greyish and less dense variety of iron sulphide than pyrite. It is less stable chemically but has the same composition FeS_2 . Marcasite often occurs as nodules and concretions in fine-grained sediments such as chalk where it crystallises with a radiating fibrous or spherulitic structure.
- **Mass flow activity** – down slope movement of massive volumes of semi-consolidated sediments triggered by earthquake shocks results in deposits of turbidites, submarine mudflows, chaotic soft sediment breccias, slip complexes, and pelletoid conglomerates. Characteristic deformation due to mass flow activity includes laminose flow, internal re-mobilised ‘quickstone’ lenses, disrupted beds, chaotic breccias, relatively undisturbed blocks (olistoliths) in mudflows, plastic deformation, boudin structures, folded and contorted zones, and irregular discordant slump folding.
- **Megacryst** – this is a descriptive term simply meaning ‘large crystal’ of any shape or type without any implied origin. It is used instead of “phenocryst” (shining crystal), which usually implies that the crystal was formed by cooling a molten rock.
- **Melange** – is a semi-consolidated sediment breccia made up of a mixture of many types of sediment fragments that reflect the various strata and earlier re-textured matrices that are involved. There is little distinction between a melange and some types of mudflow conglomerate deposits or slump breccias. Melanges are usually developed at greater depths and contain twisted, folded, shredded, and part digested fragments of irregular, angular and rounded shapes. The matrix is frequently porphyroidal or a type of ‘greenstone’.
- **Melilite** – is a highly hydrated organic compound derived from aluminium hydroxide. It is a honey coloured mineral that has been found as concretions and nodules in brown coal. Its composition is $\text{Al}_2[\text{C}_6(\text{COO})_6] \cdot 18\text{H}_2\text{O}$.

- **Meshwork** – in relation to particle systems ‘meshwork’ is used to describe the static situation where particles of different shapes and sizes are randomly linked to each other by coulombic and van der Waal’s forces to form a diffusible, plastic, fractural, and thixotropic visco-elastic solid.
- **Metacolloid** – a metacolloidal substance is a colloidal that has hardened and become crystalline by a chemical dehydration reaction (such as silanol to siloxane). Common metacoloids such as flint, jasper, chert, onyx, potch, hornstone, chalcedony, etc. are usually cryptocrystalline. Metacoloids of silica harden to a dense interlocking meshwork of minute crystals and glassy amorphous silica in which crystal growth has been impeded by dispersion of an impurity (such as clay, ferric hydroxide, manganese hydroxide, leucoxene, etc.). Close packing (ordering) to dense gels and macromolecular homogeneity are required for the growth of large crystals.
- **Metasomatism** – means the changed body of the mineral or rock. See ‘**Replacement**’ for further discussion of the process in terms of current chemistry.
- **Miarolitic cavities** – rock-forming minerals protrude into small to medium sized irregular cavities that are formed by syncretic shrinkage of their enclosing rock-forming materials before they crystallised. Miarolitic cavities are commonly found in geodes, concretions, accretions, chert and jasper beds, mineral lodes and veins, and a number of igneous-looking rocks.
- **Micelles** – the size range of colloidal particles extends over four orders of magnitude. Many colloids are dispersed as aggregates of smaller particles called ‘association colloids’. These larger particles may be readily formed from the smaller ones and vice versa so that a dynamic equilibrium may exist between the two. The aggregates are generally called micelles.
- **Microgel** – is a gel formed by a meshwork of very small particles such as small globules of polymeric silica 1-5nm in diameter.
- **Microprobe analyses** – is a technique for analysing the elemental composition of a very small spot on the surface of a crystal or mineral. A series of microprobe analyses across the face of a crystal can detect variations in composition.
- **Migmatite** – a mixed rock usually a type of veined gneiss. Migmatites are megascopically composite rocks consisting of two or more parts. They are essentially an earlier country rock (called the paleosome) invaded by or partly converted to a later granitoid (called the neosome). Polymigmatites have three or four later stages of matrix mobilisation.
- **Minnesotaite** – is a green to brown ferromagnesian silicate mineral commonly found in chloritic or iron-rich sediments.
- **Molar concentration** – a one molar solution contains the molecular weight of the solute in grams in 1 litre of solution. It is related to the ‘reactivity’ of the solute and the molar concentration is the number of mols per litre of solute contained in the solution.
- **Monomer** – is the basic chemical compound or unit that can link with or join chains of the same compound to form the higher polymers.

- **Monomeric silicic acid** – is the most abundant natural monomer that links to other monomers, higher polymers, and hydrated silica and silicate surfaces to silicify, ‘cement’ sediments to rocks, and provide the additional silica for quartz crystallisation.
- **Monticellite** – is a colourless or gray mineral like olivine that is usually associated with re-mobilised limestones. Its composition is CaMgSiO_4 .
- **Montmorillonite** – this is a group of clay minerals that ‘swell’ by further reaction with water (hydrolyse). Typical montmorillonites have a three-layer crystal lattice with one sheet of aluminium/magnesium hydroxide (octahedral layers) between two sheets of hydrated silica (tetrahedral layers). A synonym for montmorillonite is smectite.
- **Monzonite** – is a granitic rock containing approximately equal amounts of potassium feldspar and plagioclase with little or no quartz and commonly augite as the main ferromagnesian mineral.
- **Mud diapir** - Updoming of fluid charged semi-consolidated sediment (like a salt dome) which is due to its lower density stemming from the additional water it contains in relation to surrounding sediments. Some mud diapirs are very large (5 - 10 km) but the doming can also be quite a small scale feature where water is trapped locally under a less permeable bed, like a chert horizon.
- **‘Mudflake’ rock** – is a lithified deposit of pelletoid conglomerate comprised of very fine sediment flakes. These aligned ‘flakes’ may occur separated in an abundant formerly fluid mud matrix with fine-grained porphyry-like texture.
- **Mudflow** – see also [‘Subaqueous slides’](#).
- **Mudflow conglomerate** – is the deposit of mixed soft pellets and fragments resulting from a preconsolidation subaqueous mudflow.
- **‘Mud glacier’ type mudflows** – sub-aqueous flows of thick thixotropic sediment where the flow is laminar and concentration of contained solids usually sufficient for the formation of accretions. Flow is intermittent with episodic fluidity following earthquake shocks.
- **Mylonite** – was introduced in 1885 before the plastic and readily deformable forms of precursors were recognised. It describes compact chert-like rocks that have no cleavage or apparent shearing of the matrix but contain a streaky or banded structure of long wispy fragments. It was also used to describe micro-breccias with fluidal or flow textures. It was assumed that the observed deformation of elongate fragments was necessarily after lithification and therefore believed that it must have been produced by extreme granulation and shearing of large volumes and thicknesses of rocks that were completely pulverised to fine powders by massive tectonic deformation and subsequently re-crystallised. These unrealistic energy assumptions implied in previous views of mylonite genesis are unnecessary if the properties of hydrous precursors are now recognised but the term has been in use for many years to describe this type of texture.
- **Mylonitic** – means like a mylonite. It describes a compact crypto-crystalline rock with long wispy fragments, elongated ovoids, or a flow foliated micro-breccia.

- **Myrmekites** – montmorillonite clays contain abundant water because of their swelling properties. During synerectic contraction of large accretions of montmorillonite, the margins of the accretions therefore become highly saturated with fluid. Continuing syneresis in this over wet marginal zone generates irregular and drop-like cavities and/or patterns of worm-like shrinkage tubules. The outward radiating irregular vermicular tubules can be quite spectacular in some cases because virtually all the saturated montmorillonite mass can be involved. Like most of the syneresis cavities in geodes and other accretions, myrmekite tubules are usually filled with silica that crystallises to chert or quartz. Myrmekitic feldspars are usually plagioclase (oligoclase) because montmorillonite surfaces take up the sodium and calcium ions. However, myrmekitic outgrowths are occasionally found in rimming plagioclase or on the margins of the large illite accretions that form potassium feldspars.
- **Nascent particles** – are newly formed (newborn) or in the process of formation. Minute newly formed mineral particles that would otherwise be insoluble have exceedingly high surface energy in relation to their very small volume. They are able to chemisorb water and disperse as temporarily stable sols.
- **Natrolite** – is one of the more common classical zeolites. It is a hydrous acicular mineral with a composition $\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10}\cdot 2\text{H}_2\text{O}$.
- **Nebulites** - nebulitic granites or nebulitic migmatites describe fragments of foreign rock almost assimilated in granite intrusions but leaving streaky fluidal or lensoid patterns.
- **Nepheline** – is a colourless or glassy feldspathoid that is found usually with feldspars and often with other feldspathoids in an amazing variety of intrusive rocks that are derived from the mobilisation of fully hydrolysed lime muds and lime-rich pelitic sediments. Its composition is $(\text{Na},\text{K})\text{AlSiO}_4$.
- **Net veined gneiss** - veined gneiss or diktyonitic structure is a net-like pattern of re-veining by later a granitoid (fluid precursor) into a newly established schistose or pelletoid texture.
- **Newtonian Fluids** – melts like that of ice and most other crystalline solids behave as Newtonian fluids. The rate of flow resulting from a shearing stress (application of a force) is proportional to the stress applied.
- **Nodule** – is a general term for small rounded or irregular knots, masses or lumps of mineral or mineral aggregates such as chert nodules in limestone or pyrite nodules in coal seams. Most nodules have a knobby surface (like geodes) and reflect their genesis by showing accretionary characteristics or their former plasticity by elongation parallel to the bedding. The term can be used descriptively when genesis is uncertain and it then includes ocean floor manganese nodules, infill concretions, tourmaline nodules, phosphate nodules, peridotite nodules, etc.
- **Non-Newtonian Fluids** – the viscosity of non-Newtonian fluids varies with the rate of flow. This fluid behaviour is typical of thixotropically liquefied ‘gels’ (pastes and slurries) where the shear strength depends on interparticle linkages. As an approximation, it can be thought of as “the faster it flows – the more fluid and mobile it becomes”. In many systems involving the flow of pastes and slurries, it is referred to as “[shear thinning](#)”.

- **Norite** – is a coarse grained intrusive ferromagnesian-rich rock containing labradorite and similar to gabbro. It differs from gabbro by containing hypersthene as the predominant mafic mineral.
- **Nucleation of insoluble crystallites** – dilute metal sulphide molecules must diffuse from dispersion to come together as a cluster. A solid – water interface or a new surface is established as soon as a minimal cluster becomes large enough for the metal sulphide molecules to assume a lattice order.
- **Ocellar porphyry** – an ocellus is one of the many rather confusing different names used (corona, rimming structure, kelyphite, ocelli, orbicules, rapakivi texture, oolitic texture, symplectite, reaction rims, etc.) to describe the commonly observed rimming or overgrowth of a layer of a different mineral round large phenocrysts or porphyroblasts in intrusive and metamorphic rocks. There is no credible explanation for these structures where they are assumed to result from melt cooling or by metamorphic processes. Spry (1969, page 106) writes “The mechanism of formation of multi-layered, complex coronas is not understood and it is at present not possible to distinguish between the five different genetic types of coronas” (that had been put forward by other petrologists as possible explanations). In terms of melt theory this is still true today. However, recognition of the particulate nature and synerectic properties of the phenocryst and porphyroblast precursors provides a simple explanation for all types of rimming structures and the patterns of their crystallisation. Synerectic desorption of electrolyte and smaller particulate species from the precursor results in internal diffusion patterns coagulation of external matrix species at the interface.
- **Ocelli** – is the plural of ocellus an individual aggregate of smaller crystals that are arranged radially or tangentially round core crystals of another mineral such as quartz, nepheline or leucite. The texture of a rock containing many such rimmed ovoids is described as ‘ocellar’.
- **Oligomeric silicic acid** – are the first products of silica polymerisation occurring as very short chain polymers (up to four or five monomeric units) that still have similar properties to monomeric silicic acid itself.
- **Olistolith** (Olistholith in older literature) – is a large and often a very large block (up to 15 km recorded) of relatively undisturbed sediment transported bodily downslope in mudflows, pasty mud slides, and slip complexes. Smaller blocks are rotated but bedding in very large olistoliths tends to remain parallel to the slope and underlying beds. A cluster or zone of many blocks carried by a mud slide is called an olistostrome.
- **Olistostrome** – is a cluster or zone of many sediment blocks and mixed fragments of bedded sediments in a porphyroidal or non re-textured mudflow. Movement and viscous flow breaks up the transported sediment pieces. The agitation exceeds the gel strength of semi-consolidated sediment.
- **Oolites** – beds or layers of small concretions occurring in a volume of rock have been called oolites or oolitic limestones. The ovoidal or spheroidal concretions were thought to resemble fish eggs. The ooliths (individual concretions in the oolitic beds) are formed by lithification of calcium hydroxy-carbonate or ferric hydroxide concretions. Siliceous oolites have also been recorded. The more or less uniform size and distribution of ooliths through the oolitic layers is due to poly-nucleation of the concretions. Thixotropic liquefaction of the hydrolysed

carbonate mud or ferric hydroxide deposit creates a distribution of micro-accretionary nuclei throughout the mobile mass. Simultaneous concretionary overgrowth on these nuclei during the subsequent rest period rapidly exhausts mobile diffusive species. Oolites show evidence of having been soft, fractural, conjoined, composite, syncretic, and of resumed overgrowth. Accretionary cores surrounded by concretionary rims can be identified in many examples.

- **Oolites - distinction between hard and soft colloidal deposits** - Pisolites and a number of botryoids, stalactites, stalagmites, pearls, hard oolites, etc. are built up as overgrowths on hard rounded or spherical substrates. They are not ‘colloidal concretions’ in the same sense as those formed diagenetically within the sediment pile, but they certainly harden from a gel coating. Open solution near the point of supersaturation is required to continuously or repeatedly coat the surface on which the hard pisolite or botryoid is building. Work on colloids (Healy, 1972) indicates that the solubility product in a surface phase may be lower than that in the bulk solution. In systems approaching disequilibrium, the precipitate is nucleated preferentially on another surface and from dilute solutions, will continue to grow on that surface rather than precipitate in bulk. Also significant is the fact that in slightly supersaturated solutions or those approaching disequilibrium, the precipitation is rapid resulting in a larger crystallite or particle being precipitated. van der Waal’s attractive forces are short range, and consequently largely dependent on the proximity of the particle to the surface it is interacting with, but they are also dependent on the size of the particles and increase with increasing particle size. Thus larger particles precipitated in very close proximity to a surface form a very thin ‘gel coating’ with strong attraction between the large particles and surface such that they can rapidly divest the water of hydration (adsorbed water monolayer) and ‘cement’ to the surface as a hard metacoloidal amorphous coating. The ‘cementation’ involves actual chemical linkages such as silanol to siloxane or hydroxy carbonate to carbonate condensations. These chemical bonds establish between the precipitating particle and the hydrated surface to which it is adhering. This process has sometimes been called **secretion**.

The essential distinction between pisolites or hard concretions and soft oolites developed within a mud is the particle size. Concretions which develop within gelatinous muds or ‘chemical sediments’ can only be comprised of exceedingly small particles such as are able to diffuse through the meshwork of the sediment gel. These have a very high surface energy, a strongly held adsorbed water monolayer and therefore build up a ‘soft’ concretion stable under hydrous conditions for a very significant period of time. By contrast, many hard pisolites periodically ‘dry out’ although, as in pearls or agitated open water oolites, it is not necessary for them to do so in order to deposit the hard amorphous coating. The oolites which show evidence of a soft plastic precursor stage and of syneresis such as internal ‘star type’ contraction cracks or outgrowth ‘blisters’ indicate an origin by the concretion of exceedingly small particles diffusing within a gelatinous medium. Both the lime mud or other gelatinous host and the concretionary oolites were gelatinous at the precursor stage.

- **Oolitic texture** – describes a rock having a fish egg-like texture because it is comprised of oolites.
- **Optical angle** – see ‘Domains of 2Vx’.

- **Orbicules** – this is the name given to the concretionary overgrowth structures most commonly to those found in granite and a number of igneous-looking rocks. The igneous looking rocks include latite, aplite, amphibolite, pyroxenite, kimberlite, norite, gabbro, peridotite, serpentine, etc. Orbicules or concretionary structures with all the characteristic features of concretions are also found in siliceous shales, dolomites, mass flow units, chert, jasper, vein quartz, quartz-magnetite lodes, chromite, carbonatite, and cassiterite, sphalerite, and pitchblende ores. The main characteristic of orbicules is that all the crystalline or lithified minerals preserved in these structures have a chemically equivalent hydrated form of the mineral that could crystallise simply by loss of water. Orbicular and concretionary structures show evidence of former plasticity, fracture, syneresis crack patterns, composites, resumed overgrowth, central miarolitic cavities, synerectic core material or nuclei, and re-liquefaction of material enclosed within the rimming overgrowths.
- **Oscillatory zoning** – refers to the concentric banded pattern of different crystal composition (such as variation in Na/Ca ratios) that are commonly found in the plagioclase crystals of granites and in andesine or olivine-rich rocks. The crystal twinning patterns are later and unrelated to the oscillatory zoning that developed in the precursor before crystallisation. The bands are formed in the synerectic precursor smectite accretions in the same manner as rapakivi textures or Liesegang bands in geodes. They are due to successive displacement of adsorbed smaller smectite particles by the variation in diffusion rates of electrolyte ions exuding towards the margin of the precursor during its syneresis. However, some oscillatory zoning patterns reflect the pre-ordering of the precursor and development of denser substrate beneath the succession of disordered or less ordered solvated surface layers.
- **Overpressured zone** – a layer or region within the sediment pile in which the pore fluid has accumulated, usually under a less permeable horizon, to the extent that its hydraulic pressure supports the weight of overlying sediments and expands or ‘overstuffs’ the interparticle spaces, breaks many interparticle linkages, and weakens the fabric of the semi-consolidated sediment.
- **Ovoid** – is a non-generic descriptive term meaning oval or egg-shaped that has been applied to rounded feldspars, ferromagnesian minerals, and quartz in porphyroids and granites pending determination of their volcanic, metamorphic, or igneous origin.
- **Palingenesis** – [Sederholm](#) (1887-1936) in his collected works (republished 1967) introduced the term ‘palingenesis’ to mean that the rocks in question had been ‘reborn’ (1967, p. 38 and 418). The concept of re-birth largely arose from his puzzling observations on Bågaskär in the Åland Archipelago. He described granite magma (with water in it to lower the melting point to some 750-850°C) that had congealed sufficiently to have basalt-like dykes (melting point about 1150°C) injected into its ‘fissures’. These basic dykes were subsequently disrupted, fragmented or plastically deformed and their older host rock rejuvenated or reliquefied to fill the spaces between fragments or re-intrude the basic dykes. This phenomena remains an enigma to melt theorists. It is illustrated in [Figures 13.27 to 13.32](#).

- **Paralloid folding** – is an effect of laminose flow or differential slippage between beds where plastic ‘heaping’ or departure from the slip plane develops in one of the beds during movement. The bed halts or slows and "tucks under" so that the beds moving behind ride up over the slower part to form an imbricate fold usually involving several folded strata between the displaced parallel beds above and below the fold or folded zone. The lower limb of such imbricate paralloid folds is typically absent being sheared out along the lower slip plane.
- **Particulate material** - visco-elastic solids comprised of very small particles are said to be particulate. Cohesion of particulate material depends on electrostatic and van der Waal’s forces between particles rather than chemical linkages.
- **Pectolite** – is a hydrated white to grayish sodium-calcium silicate mineral that is often fibrous radiating in form and occurs as nodules with calcite and chlorite in various types of greenstone. Its composition is $\text{NaCa}_2\text{Si}_3\text{O}_8(\text{OH})$.
- **Pegmatite** – is an exceptionally coarse grained rock composed of interlocking granite mineral crystals. It occurs as irregular dykes, bodies, or veins usually at the margins of large batholiths. They are thought to represent the last and most hydrous phase of granite activity and often contain higher concentrations of minerals rich in elements such as lithium, boron, beryllium, fluorine, niobium, tantalum, uranium, and rare earths. Many veins of pegmatite in sediments or metamorphic rocks at appreciable distances away or unrelated to granite batholiths are narrow and discontinuous with too much exposure to the cooling effect of wall rock area to have been injected as molten fluids.
- **Pelitic mud** – a pelite is a clay-rich shaly rock or mudstone of which pelitic mud is the precursor.
- **Pelletoid Conglomerate** – the stress applied to a semi-consolidated layer of sediment by tendency of the overlying beds to move downslope is by way of a shear couple. Tensional forces are developed in a sigmoidal pattern across the layer to which the shear couple applies. Failure in tension divides the layer into aligned thin elongate pellets that can be preserved in the sequence as an internal zone of ‘pelletoid conglomerate’. The reliquefied matrix of a pelletoid conglomerate is often missing or remains as a minor component of the resulting deposit. The fluid mud runs out from between the pellets leaving the aligned soft pellets molded and packed against each other.
- **Pelletoid mud-flake deposit** – is a type of pelletoid conglomerate in which the highly elongated small shale pellets have been developed by the shear or viscous flow of very soft precursor mud.
- **Peptization** – is the restoration of a coagulated or flocculated gel to a stable dispersion (sol). This is usually accomplished by addition of adsorbent that changes or neutralises surface charge on individual particles. Interparticle attraction can be diminished.
- **Periclase** – is a simple oxide of magnesium (MgO) that readily hydrates to brucite.
- **Peridotite** – an intrusive olivine-rich rock that crystallises from the dehydration of serpentine and its related more hydrous ferromagnesian precursors. Peridotite may contain a little pyroxene, amphibolite, mica, or haematite, magnetite and chromite. It contains virtually no feldspar or quartz. It occurs as massive intrusions that are

often pipe-like and in association with disturbed and disrupted sediments such as major shelf failures, melanges, etc. A common form is as rockmasses consisting of large nodules of massive crystalline olivine or websterite (containing a little pyroxene) surrounded by a thick mantle of antigorite or serpentine. The pattern of serpentine in the peridotite rock reflects the dehydration of the hydrous ferromagnesian precursor. Orbicular peridotite is recorded from Kylmäkoski in Finland (Figure 15.18), orbicular pyroxenite from the Foskor Open Pit at Palabora in South Africa (Figure 15.17), orbicular serpentine from 4-500m west of the Florentine River bridge on the Strathgordon Road in Tasmania (Figure 15.19) and chromite orbicules in serpentine from the Kafe Odjak Mine at Radusa in Yugoslavia (Figure 15.20). Orbicules are exclusive to diffusive particulate systems clearly indicating the hydrous particles of the serpentine and peridotite precursors.

- **Perlite** – is a volcanic glass made up of small pearl-like spheres or with a spheroidal crack pattern and generally with a higher water content than obsidian, which is more like a dark anhydrous bottle glass.
- **Perthite** – describes an intricate intergrowth pattern of feldspar crystallisation where potassium feldspar ovoids such as microcline are variously riddled with strings, lamellae, blebs, films, or irregular veinlets of soda plagioclase (usually albite). Perthitic patterns are developed at the late stage of exudation of fluids charged with precursor smectite from the condensing and crystallising accretionary illitic host. The first stage of synergetic contraction and desorption of smectite particles liberates them to diffuse to the ovoid rim. However, with the water that is produced by the chemical dehydration reaction that is developing crystal structures within the ordered illite (close packed clay platelets) of the host accretion, any additional smectite is separated into veinlets or various unmixing patterns dictated by the structure of the ordered illite. Where they are in contact or interconnected the perthitic plagioclase crystallises in optical continuity as a single skeletal or disjointed irregular crystal within its host. Perthitic feldspars are not necessarily rimmed with plagioclase but where they are the perthitic and rimming plagioclase are found crystallised in optical continuity indicating that the development of the plagioclase crystal lattice was after the rimming, perthitic veinlets, etc. had been formed.
- **Phacoid** – is the sigmoidal lens-like pellet or segment of soft sediment that is developed between tensional failure planes in semi-consolidated sediments that are subjected to a shear couple (Figure 3.25).
- **Phenocryst** – from the root meaning ‘shining crystal’ is used to describe relatively large conspicuous crystals in porphyritic rocks.
- **Phlogopite** – is a hydrated magnesium-rich yellowish-brown to copper coloured mica that is found in marble and re-mobilised limestones. Its composition is $K(Mg,Fe)_3AlSi_3O_{10}(OH,F)_2$.
- **Phreatic** – describes a non-incandescent (sub red heat) volcanic eruption of steam, mud and non-molten rock. The phreatic stage of volcanism is intermediate between thermally active areas with hot pools, mud extrusions, geysers, steam vents, etc. and violent explosive volcanic dust and debris eruptions and then to the more quiescent lava lakes, molten lava fountains, pumice and successions of lava flows that originate from deeper in the mantle.

- **Pinwheel structures** – are spiral bands of inclusions that are often found in large garnet porphyroblasts. They clearly indicate the rotation and aggregation of the soft and pliable hydrous accretions from which the garnets have crystallised. The bands of inclusions are unrelated to the crystal structure of the garnets, aggregates of ‘pinwheels’ that have crystallised as a unit crystal are recorded, and [Ehlers and Blatt, 1980, page 666](#), illustrate a “pinwheel garnet porphyry” in which all the large garnet porphyroblasts have distinct spiral pinwheel structures or are fragments of pinwheels that have been rotated in the viscous flow of their formerly pasty matrix.
- **Pisolite** – is a nodular rock or a soil in the weathering profile made up of approximately pea-sized nodules of calcium carbonate or mixtures of hydrous iron and aluminium oxides and silica. A pisolith is an individual nodule. Pisolites have not been distinguished from oolites in relation to the physico-chemical processes by which they are formed. Some pea-sized concretions may therefore have been described as pisoliths. (see “[Encrustation](#)”)
- **Pitchblende** – is a massive brown to black variety of uranium oxide or uraninite (UO₂). Pitchblende is fine-grained, usually amorphous or colloform and it has a black pitch-like to dull luster. It is found in veins with sulphides, is highly radioactive, and sometimes contains small amounts of thorium and rare earths.
- **Plasticity** – of sedimentary materials is due to the physical (electrostatic and van der Waal’s) attraction between particles that enable them to form a gel meshwork of linked particles through the entire volume of cohesive sediment. Gels are visco-elastic solids. After non-destructive deformation, the material returns elastically to its original shape. However, the meshwork linkages of mixed or heterogeneous gels are not uniform in strength. The meshwork linkages comprise many weak linkages that offer virtually no resistance to stress, more intermediate ones, and a relatively few strong interparticle linkages, which offer appreciable resistance to the deforming stress. Thus at the level of the macro-molecular linkages, gels to which stress has been applied do not completely return to their original shape when the load is removed. They retain a strain or plastic deformation.
- **Plication** – means crumpled or intense small scale corrugation-like folding that is also sometimes referred to as crenulation.
- **Pluton** – is an intrusion or one of a number of successive intrusions, updomings, or emplacements of mineral matter that has crystallised to a granitoid or more basic crystalline rock. Batholiths can be made up of a succession of plutons that intrude into each other or extend the total volume of intruded material.
- **Polarity, polar molecule** – molecules in which the positive and negative centres of charge do not coincide, are called polar molecules. For example, the average position of the paths of electrons shared between hydrogen and oxygen in a water molecule is at an angle of 104.5°. The hydrogen atoms and the positive charge tend towards one side of the molecule with the negative oxygen atom tending towards the other. Water molecules are therefore strongly polar with a negative and positive side that enables them to adsorb on charged surfaces or to form mobile links and “chains” with each other.
- **Polyelectrolytes** – are polymers whose repeating units are ionised or ionisable in water and are therefore strongly surface active. They adsorb strongly on surfaces and can displace larger numbers of other adsorbed ions.

- **Polymer** – is a chain or repetitively linked chemical compound of higher molecular weight derived by the combination of many smaller molecules or by the condensation of many smaller molecules (such as $\text{Si}(\text{OH})_4$) by the elimination of water.
- **Polymeric silicic acid** – the condensation of monomeric silica $[\text{Si}(\text{OH})_4]$ forms oligomeric silicic acids and many varieties of silica gel including the naturally occurring ‘little balls’ of amorphous silica that are adsorbed on the surfaces of most sediment substrates.
- **Polymerisation** – is the formation polymeric compounds of higher molecular weight by condensation and chemical linking of many smaller molecules of similar chemical composition. The ‘giant’ polymers that are formed are usually ‘chains’ or a meshwork that has quite different physical properties.
- **Polymorph** – minerals that have several different crystalline forms are described as polymorphous and a polymorph is one of the crystal lattice structures that such a mineral can have.
- **Polyrimmed overgrowths** – this refers to the succession of concentric mineral layers that surround the synerectic nuclei of orbicules or concretions.
- **Porcelanite** – a dense siliceous rock resembling unglazed porcelain and similar to chert but somewhat softer and less dense. It is a form of chert containing more clay or argillaceous material. Like chert, it can form accretions that do not have the macromolecular homogeneity to crystallise.
- **Porphyroblast** – is an outstanding porphyry-like crystal that has developed in the rock by "coarsening" (usually accretion of the original sediment component) and then crystallised with liberation of heat as the sediment converted to rock (metamorphic crystallisation). Porphyroblasts are also called metacrysts.
- **Porphyroid** – this term simply means ‘porphyry-like’. It describes rocks that have large rock-forming crystals that tend to be isolated in an abundant fine-grained matrix. It was first used to describe metamorphic rocks that clearly could not have originated directly by melt cooling. Because the mechanism of accretion formation from all fine-grained sediments was unknown at the time, it was usually assumed that rocks described as ‘porphyroids’ were either metamorphosed igneous rocks or metamorphosed volcanic ejecta. This igneous or volcanic alternative has been strongly debated for many years. Pre-metamorphic igneous genesis has been claimed because many porphyroids are almost holo-crystalline and the case for volcanic ejecta re-transported by mudflow has been sustained by the abundant evidence of ‘mass flow activity’.
- **Porphyroidal mudflows** – are thick pasty volumes of sliding thixotropic sediment for which movement down-slope is triggered by earthquake shocks. Flow is intermittent with episodic fluidity and concentration of contained solids must be sufficient to form accretions that characterise this type of flow.
- **Potential energy** – is energy possessed by a body by virtue of its position in a field such as gravity, magnetic, or electric. This is in contrast to kinetic energy that would be possessed by virtue of its motion.

- **Precursor principle** – this principle (Stanton, 1989) has been established for a very wide range of ore and rock-forming minerals. It was found that each mineral grain now present had crystallised by in situ growth or transformation of a pre-crystalline substance that previously occupied that grain space and had a similar overall composition (usually simply more hydrous).
- **Primary minimum** – charged particles in ‘close packed’ condition such as those aligned and densely packed by shear are subjected to both coulombic (repulsion between similarly charged particles) and van der Waal’s strong forces of attraction at very close spacing. In the DLVO consideration of these opposing forces in relation to distance between interacting particles, the primary minimum is the point of strongest attraction where charged particles become close enough to each other to ‘lock on’ under van der Waal’s attraction at close range. (Figure 4.3).
- **Proton promoted dissolution** – where hydrated silicon atoms are displaced from the surface of a crystal lattice by the presence of hydroxyl groups (OH)⁻ formed by dissociation of water molecules (presence of alkali) the resulting dispersion of silicic acid species into the solvent is called proton promoted dissolution.
- **Ptygmatic** – this word is used to describe the appearance of ‘loopy’ disharmonic folds that are obviously not due to any uniform stress field or constant direction of deformation. Internal forces within the precursor pastes of the intruded substances develop this pattern of fluidal folding as they flow into soft visco-elastic host materials. Ptygmatic folding is due to the shear thinning properties of the intruded pastes (viscosity dependent on the rate of shear) and the fold patterns are preserved by rheopectic re-setting (see Figure 5.36).
- **Pyrope** – is a deep fiery-red magnesium-rich garnet that is often associated with olivine, serpentine-rich rocks or kimberlites. Its composition is (Mg,Fe)₃Al₂(SiO₄)₃.
- **Pumice** – this could be described as ‘molten basalt foam or froth’. Internal degassing (exothermic steam emission) of basalt as it is cooling can result in spongy vesicular glass that is abrasive, often light enough to float on water, and in some volcanoes it is significant component of the pyroclastics and scoria.
- **Pyroclastic** – literally this means “broken by heat”. It refers to the rock fragments, ash, and glassy shards that are ejected from volcanoes (see Figure 7.20).
- **Pyrophyllite** – is a white, grey, or brown hydrous aluminium silicate that resembles talc and occurs in granites, metamorphics and quartz veins. It is a partly dehydrated precursor of the simple aluminium silicates (andalusite, kyanite and sillimanite) that occur in schists, gneisses, and granite. Its composition is AlSi₂O₅(OH).
- **Pyroxenite** – is an ultramafic rock composed of pyroxene with smaller amounts of hornblende, biotite, or olivine. It occurs as various intrusive bodies but also as a major component of layered complexes where flow banded and nodular varieties of pyroxenite are interlayered over long distances with thick bands of anorthosite and some chromite.
- **Quartz crystallisation chemistry** – the basic silanol – siloxane condensation reaction by which rocks harden, chert and jasper become glass-like, or natural quartz crystallises is simple, spontaneous, and heat producing. Accretion of globular amorphous silica particles during viscous flow of mud or mobilised

sediment pastes reduces their surface energy. These ordered and macromolecularly homogeneous particle clusters crystallise by diffusion of neutral $\text{Si}(\text{OH})_4$ molecules which displace the water of hydration within the gelatinous precursors.

- **‘Quickstone’ lens** – is the rock consolidated from an internal mass of aqueous slurry like quicksand. The lenses of re-mobilised sediment were buried at some depth within the sequence of greywackes and shale at the time they were fluid.
- **Rapakivi texture** – is a texture found commonly in metamorphic rocks, in some porphyroids, and abundantly in a number of granite provinces such as in southern Finland. It is characterised by large predominantly ovoid or spheroidal potassium feldspar crystals that are enclosed by a rim or ‘mantle’ of plagioclase (usually oligoclase, albite, or andesine). Quite spectacular rapakivi textures occur in some granite such as the wiborgite quarried for ornamental stone at Wiborg in Russia near the Finnish border. Rapakivi ovoids in a granite dyke in the Shachang iron quarry, Miyun county, about 75km northeast of Beijing in China are as big as cricket balls!

The term ‘rapakivi’ is derived from the Finnish for “crumbling stone” because large pockets of this otherwise massive granite were found to have no or very little matrix material between the feldspar ovoids such that it allowed them to crumble in a loose heap of golf-ball like feldspar crystals towards the bottom of the cavity. The rapakivi ovoids have crystallised from large spherical illite accretions from which the very much smaller montmorillonite particles have been released by syncretic desorption to diffuse outward to a marginal rim that then crystallises to plagioclase. The silica in rapakivi granites is also ovoidal, formerly syncretic, and some of it is rimmed with feldspar (see [Figure 14.16](#)). The origin of rapakivi texture was unknown until the development of precursor accretions in remobilised sedimentary materials was recognised as the way that most igneous-looking rocks were formed.

- **Replacement** - Where a chemisorbed group or macromolecule is displaced and exchanged for a similar one in the dispersion (because it forms a more appropriate chemical link or better fits the steric configuration of the chemisorption site), the process is called replacement, metasomatism, or metasomatic replacement. In the geological context of burial and "soaking", replacement of one mineral by another, of fossils with sulphides or opal, of logs with silica, etc. is commonly observed. Usually material undergoing "replacement" must first be fully hydrolysed (reacted with water) to enable diffusion of the exchanging dispersed species into the gelatinised mass.

No substantive ‘replacement’ would be possible within a crystal lattice because of the inability to diffuse many larger ions or particles either in or out. Therefore if observations suggest replacement of a whole mineral or rock volume it must have been porous and gel-like so that replacing ions, molecules, or particles could gain access to all parts of it. Similarly, when replacement is effected, the material substituted must remain gel-like at least for some time so that the replaced ions, molecules, or particles can continue to get out.

If the metasomatism is to “change the body” of the material being replaced, then “openings of the smallest size” must give access to all parts of the body being replaced. It must be like a sponge with very small pores. Consequently the replacement can only

be effected by ions, molecules, or very small particles. A gel or the gelatinous precursors of a wide range of ore and rock minerals which “soak” for very long periods of time in ore forming fluids, are indeed susceptible to ‘replacement’.

Transport by fluids is both by stream flow or by seepage and diffusion. Ions and charged particles diffuse down a concentration gradient. Thus if an ion or charged particle is precipitated or adsorbed from the fluid, further ions or particles will move along the gradient so created towards the place of precipitation. In the case where the diffusing ion or particle is exchanged for one then released by substitution, the concentration gradient in respect of these newly released ions or particles will be in the reverse direction and they will diffuse outward. Diffusion is therefore particularly appropriate for replacement. It allows movement of ions or charged particles to the replacement site and removal of those displaced. Lindgren's (1933) classical book “Mineral Deposits” contains remarkable accurate information on metasomatism and Holser (1947) in his paper on “Metasomatic Processes” specifies the conditions for replacement to occur extraordinarily well in regard to the chemistry of that time.

- **Reversible Hydrolysis** – Hydrolysis is the chemical reaction of water with oxides and salts of weak acids such as silicates. It is the slow reaction while water is in excess during initial burial and diagenesis that continues to degrade the granular matter in sediments. Hydration reactions reverse when hydrous minerals later crystallise to anhydrous or less hydrous species as water in the system is reduced.
- **Rheological separation** – is an important principle by which components of gel meshworks such as semi-consolidated sediments separate by differences in their fluid properties when the meshwork is physically disrupted or disturbed. The more mobile (less viscous or water-rich) components simply “flow out” of the agitated or disturbed pastes at the stage where its major components would re-assume a non-fluid or more viscous gel condition.
- **Rheoplectic re-setting** – is the reversion of a thixotropic sediment paste to a gelatinous semi-solid as flow in the mobile mass declines to a critical point where attraction between particles (the cohesion of the paste) exceeds the momentum of the moving mass.
- **Rheopexy** - is the accelerated resetting to a gel condition in a flowing colloidal dispersion subjected to shear by laminar flow of a thick paste. Thixotropic liquids may rapidly revert to a higher viscosity condition when linkages establishing between particles throughout the flowing mass overcome the momentum of the moving mass. This “instant re-freezing” preserves flow foliation, the shape and form of intrusions, suspends fragments, etc.
- **Rheoplectic condition** – refers to the property of a material that would enable it to flow or intrude. Boswell (1961) in his book on “Muddy Sediments” pointed out that the cohesion of these materials, where particles are linked simply by their electric surface charges, could be disrupted by earthquake shocks or mechanical disturbance. They are thixotropic and can assume a rheotropic (fluid) condition.
- **Rhodocrosite** – is a rose red or pink mineral form of simple manganese carbonate: $MnCO_3$.

- **Rhodonite** – is a pale red, rose red, pink to brownish red mineral form of manganese silicate MnSiO_3 that sometimes contains a little calcium, iron or magnesium.
- **Rhyolite** – is a flow-banded rock that is sometimes porphyritic and characterised by a glassy to cryptocrystalline matrix similar to chert. Where alkali feldspar and quartz phenocrysts or ovoids are developed, rhyolite bulk compositions can approach that of granitic rocks.
- **Saddle reef** – the newly deposited outer rims of growing concretions are softer and more pliable than encircling deposits closer to the core. Further disturbance at the preconsolidation stage can result in outer rims being broken, removed, or folded as a loop or bulge away from their underlying core structure. The mineral infilling (usually quartz or biotite in granite orbicules) beneath this type of rim folding has been called a ‘saddle reef’.
- **Scanning electron microscopy (SEM)** – a technique for determining surface microtopography.
- **Scanning tunnelling microscopy (STM)** – a technique for determining the surface microtopography and surface atomic structure.
- **Scanning tunnelling spectroscopy (STS)** – a technique for determining surface chemical composition.
- **Schiller** – or schiller structure describes the play of iridescent colours reflected from within some minerals. In some cases like opal and possibly in all cases it is due to the pattern of long range ordering of precursor particles being preserved in the mineral by its hardening or crystallisation.
- **Schlieren** – is from the German meaning a flaw or zone of abnormal composition in glass or, in the geological context, a rock. It generally refers to a elongate lens-like tabular zones a few centimetres to ten meters or more in length that contain different minerals and textures or, in the case of granitic and porphyritic rocks, that have different colours and mineral ratios. Boundaries of schlieren with their enclosing rocks are often gradational.
- **Scoria** – is a cindery lava crust or large pyroclastic fragment containing coarse or irregular bubble-like gas cavities due to the release of volcanic gasses before solidification. Scoria is coarser than pumice. Pyroclastics that include larger and irregular fragments containing gas cavities are described as scoriaceous.
- **Secondary Minimum** – in the DLVO consideration of coulombic repulsion and van der Waal’s attraction in relation to distance between interacting particles, the secondary minimum is the point at which charged particles in a sol are just able to precipitate as loose open meshwork "house of cards" type flocs by attraction between opposite charges on their surfaces. In terms of DLVO theory, they are said to flocculate in the secondary minimum ([Figure 4.3](#)).
- **Secretion** – see ‘Oolites – distinction between hard and soft colloidal deposits’.
- **Sederholm effect** – palingenesis describes the observed re-activation of granite bodies after their initial emplacement by further plastic distortion or liquefaction. This “rebirth” has also been called the “Sederholm effect”. It is clearly inconsistent with the theory that granites solidified by cooling molten crystalline silicates below a ‘melting point’.

- **Seismic reflection profile** – is a cross-sectional profile of reflection data obtained by recording the reflection patterns from a series of “shots” (impacts or explosions) along the survey line (including those on the sea floor).
- **Selenides** – refers to mineral compounds like sulphides where selenium has combined with copper, silver, bismuth, etc
- **Serpentine** – massive intrusions and pipes of serpentine are formed by the rheological separation of more mobile and highly hydrated ferromagnesian components during major disturbances and disruption of accumulated sediments. Serpentine is mainly antigorite, which is a more stable hydrous mineral formed as a stage in the dehydration of the highly hydrated original sediment components. It is similar in origin to massive or veins of glauconite (Figure 13.23), epidote, steatite, chlorite, etc.
- **Shear thinning** - the viscosity of liquid pastes is variable and dependent on the rate of flow (internal shear) in thixotropic particle systems that have a Bingham yield point. Higher rates of flow can markedly reduce the viscosity of the fluid paste. The viscosity of these non-Newtonian fluids has been measured and differences in viscosity at each different rate of shear accurately formulated for particular systems. Natural sedimentary pastes containing mixed particles of different shapes and degree of hydration are rather more complex but their viscosity is basically related to: -
 - 1) the concentration or volume of the particles present in relation to the total volume of the fluid.
 - 2) the ultimate size and shape of the particles.
 - 3) the degree to which the particles are dispersed into the fluid medium as individual particles or as particle clusters (fragments of gel), and the size and nature of these aggregates.
 - 4) the energy of particle to particle contacts relative to the energy of particle surface to liquid contacts.
 - 5) the adsorption of ions or other additives on particles that affect the thickness of the Helmholtz double layer and the ‘adherence’ of particles to each other.

It is obvious that higher rates of shear in more concentrated paste would break gel fragments to much smaller pieces. The fluid would behave more like a sol (dispersion of individual charged particles). Sols behave more like Newtonian liquids where viscosity is independent of the rate of shear. Despite the difficulties in formulating the viscous behaviour of complex pastes, shear thinning is a very real and measurable effect.
- **Shear modulus** – The shear strength of a material is defined as the stress or loading required to produce failure when the stress is imposed at right angles to a cross-section of the material. The shear modulus is the magnitude or absolute value of this stress for that material at the point of failure.
- **Siderite** – is the natural yellow-brown or brown-red mineral form of iron carbonate [FeCO₃] that belongs to the calcite group.
- **Sillimanite** – is a brown, grey or white usually fibrous crystalline form of one of the three common simple aluminium silicates that occur in schists, gneiss, granites and some pegmatites. Its composition is Al₂Si₂O₅.

- **Skeletal crystal growth** – the development of the outline or framework of a crystal with incomplete filling of the body of the crystal faces or shape is described as skeletal. Skeletal crystals can be microscopic but this type of crystal growth typically develops in a gelatinous medium that is able to support the delicate needle-like framework and allow the crystallising components to diffuse to the growing crystal facets. [Figure 5.60](#) illustrates an example.
- **Skialith** – is a vague remnant of a xenolith left in granite by incomplete breakup and re-liquefaction of the matrix of the precursor fragment.
- **Slip Complex** – a slip complex can be formed when a number of different strata at different stages of consolidation (different water contents) are disrupted by episodic faulting and large scale downslope sediment movements. A slip complex may therefore contain any combination or all of the following: - fluid mudflow deposits, thixotropically reliquefied slurry, pelletoid conglomerates, laminose flow, chaotic breccias, olistoliths, plastic deformation, discordant fluidal folding, overthrust folds and boudin structures.
- **Slip plane or Glide plane** – is the plane or narrow zone of failure in wet greasy semi consolidated sediments that are stressed by the tendency to slide downslope or away from a centre of uplift. In well-bedded strata such as a turbidite sequence, failure is usually parallel to bedding and along the greasy clay-rich tops of the turbidites. Cumulative movement through a succession of such clay-rich parts of a turbidite sequence is called ‘laminose flow’.
- **Slump ball** – a relatively flattened globular or rounded mass of sediment that is usually laminated and often with internal contortions that has been formed by subaqueous slumping.
- **Slump fold** – an intraformational fold within the bedded layer or layers that is produced by slumping of soft sediments.
- **Smectite** – is another name for highly hydrated montmorillonite clays.
- **Sol** – is a homogeneous suspension or dispersion of colloidal particles in a liquid or gas. In the glossary of geology a sol is also defined as a completely mobile mud that is in a more fluid form than a gel.
- **Sol to gel transition** – colloidal particles in metastable dispersion as a sol can reduce kinetic energy of the system and surface energy of the particles by transition to a gel. A gelatinous meshwork of particles is a visco-elastic solid in which every particle in the meshwork is physically linked to all the other particles (by satisfaction of opposite Coulombic charges or van der Waal’s attraction). Coagulation, flocculation, or precipitation can be triggered by quite subtle changes in conditions in the fluid in which species are dispersed.
- **Sole markings** – are the current ripples, slide marks, and a variety of erosion features that are formed by turbidity currents and preserved in turbidite sequences at the base of turbidite beds.
- **Solidus** – is said to be the locus of points in a temperature-composition diagram representing a system at temperatures above which solid and liquid are in equilibrium and below which the system is completely solid. This concept also assumes that “water in magmas to lower the melting point” does not achieve this effect by combining chemically with the silica and silicates. See “[liquidus](#)”.

- **Solubility of silica** – it doesn't dissolve - see 'The hydrolysis of silica' on [pages 10 to 13](#).
- **Solute** – the substance dissolved in a given solution. It is the component uniformly mixed throughout the solvent that is present in the lesser amount.
- **Solution** – in chemistry this usually means the spontaneous dispersion of the anions and cations of a solute throughout the solvent. Water is a particularly good solvent because it readily dissociates into hydrogen ions (H⁺) and hydroxyl ligands (OH⁻) that hydrate or form complexes with the charged ions of the solute. The term "solution" is not always used to mean the dispersion of anions and cations through a solvent in accord with its common usage in chemistry. It has become customary to describe the dispersion any substance that will readily disperse in water or some other fluid as "dissolving" or 'going into solution'. Substances like sugar, alcohol, or in fact a wide range substances that contain chemically combined hydroxyl groups, disperse readily in water. In the strict technical sense, these might be more accurately described as molecular, macro-molecular or particulate dispersions.
- **Solvated or solvated surface** – the surface of a particle is said to be solvated (or where water is the solvent 'hydrated') when it is saturated with polar water molecules in addition to hydroxyl groups that may be part of the chemical composition of the surface. The degree to which particle surfaces are solvated changes the density of its particles.
- **Solvent** – the substances that mix together uniformly to form a solution are called components. Usually the component present in greatest quantity is called the solvent.
- **Specific adsorption** – when the atomic geometry of an adsorption site is such that electron sharing can markedly reduce the surface energy or chemical energy for a particular adsorbent, it is preferentially adsorbed at that site. Mobile species favoured for certain sites or substrates are said to be "specifically adsorbed".
- **Spessartite** – is a brown-red end member of the garnet series that is manganese and aluminium silicate: $Mn_3Al_2(SiO_4)_3$.
- **Spherulite** – is a rounded or spherical body of acicular (needle-like) crystals radiating from a central point or small nucleus. Spherulites are a fairly common arrangement of feldspar crystals but are formed by many other minerals crystallising in diffusive media. Spherulites range in size from microscopic to several centimetres in diameter. [Figures 2.12](#) and [5.56](#) illustrate examples.
- **Spherulitic** – describes the texture of a rock that is composed of spherulites. In some occurrences radiating acicular crystal growth from close spaced nuclei fills the whole space between nuclei such that the whole rock is spherulitic.
- **Spilite** – is a fine-grained hydrous greenstone resulting from mobilisation and partial crystallisation of ferromagnesian-rich marine oozes. Spilitic greenstones have sometimes been mistaken for 'altered basalts' due to evidence of former fluidity and 'pillow structures' where gelatinous components of the mobile slimes and soft marine muds had different viscosities. Mixed 'pillows' of different composition from the one flow have been recorded. Spilites contain accretionary ovoids and composite ovoids of calcite, chlorite, albite, epidote, chalcedony, prehnite and other hydrous minerals. Some spilitic flows only a few centimeters thick are interbedded with marine sediments over distances of hundreds of meters.

- **Spinel** – is a hard white or coloured mineral that is basically magnesium aluminate (MgAl_2O_4) variously coloured with ferrous iron substituting for magnesium and ferric iron substituting for aluminium.
- **Spontaneous desorption** – occurs when particles are closely packed into ordered synerectic clusters and water is exuded towards the margin of the cluster. Loss of water increases salinity in the remaining interparticle spaces with consequent ion exchange for other adsorbed ionic and particulate species. These desorbed species diffuse outward with the remaining fluid.
- **Star crack pattern** – is one of several types of syneresis shrinkage crack patterns that are developed in pre-crystalline accretions or concretions. ‘Star cracks’ refer to large central star-shaped gaping cracks that develop during the shrinkage of fluid-rich hydrous precursors and most of them are filled or partly filled with the same mineral as the synerectic precursor.
- **Static particle interactions** – describes the static condition of the gel meshwork (visco-elastic solid) through which ions and smaller charged particles must diffuse in order to interact with surfaces or each other.
- **Staurolite** – is a brown to black hydrous mineral that is commonly found in mica schists and gneisses. Its twinned crystals often resemble a cross and its composition is $(\text{Fe},\text{Mg})_2\text{Al}_2\text{Si}_4\text{O}_{23}(\text{OH})$.
- **Steatite** – is a massive form of greyish-green talc or soapstone. It is essentially an impure hydrous magnesium silicate often containing a little iron, aluminium, or traces of nickel and chromium.
- **Steric** – pertaining to phenomena involving molecular dimensions or arrangements of molecular linkages, adsorption sites, chemical groups, etc., in space.
- **Steric hindrance** – surface active molecules adsorbed on particle surfaces can create a degree of ‘polarizability’ such that repulsion may occur when particles approach each other to within a distance at which the adsorbed molecules begin to interfere. This effect is considered due to steric hindrance.
- **Stictolite** - is used to describe a flecked pattern or structure in metamorphic and granitic rocks. It was mainly used to describe granites where spots of blasto-crystalline minerals (aggregates of coarser crystals) were interpreted as suggesting that former fragments had been assimilated. Glomerocrysts or rounded aggregates of mixed coarser granite crystals are now recognised as large composite accretions from the last episode of mobility that have crystallised.
- **Stilpnomelane** – is a green-black platy or fibrous iron silicate mineral commonly associated with iron ores.
- **Stoichiometric** – pertaining to the weight relations in chemical reactions. It refers to the combining weights of elements.
- **Stylolite** – an irregular interlocking very narrow veinlet that resembles the trace of an oscillating stylus when the vein is ‘empty’ and opposing tooth-like projections on one side fit their counterparts on the other. Stylolites are developed mainly in homogeneous carbonate rocks at their pre-crystalline gelatinous stage. They also develop in the gelatinous intergranular filling in sandstone or quartzites and

occasionally in chert or jasper. They can change to micro-veinlets along their length or sometimes to veins that are pygmatically folded. Stylolites are formed by the release of water or fluids by syneresis of gelatinous sedimentary materials late in diagenesis. The passage of fluid stains the trace of stylolites like ink markings but there is rarely any vein filling. Micro-breccias of wallrock are sometimes found in the sharply reversed angular changes of direction.

- **Subaqueous mudflows and ‘mud glaciers’** – are thick pasty volumes of sliding thixotropic sediment for which movement downslope is triggered by earthquake shocks. Movement is usually episodic and viscous laminar flow impedes turbulence and mixing with overlying water.
- **Submarine slides** – as for ‘Subaqueous mudflows’ but usually involving the bodily movement of large pieces or areas of layered sediments that have remained cohesive.
- **Substrate** – the general term in particulate systems for the surface or surfaces on which ions and charged particles are adsorbed. In ecological systems ‘substrate’ is also used to refer to the substance, base, or nutrient medium in which or on which organisms attach and grow.
- **Sulphidation, Sulphidise** – hydrolysed ore metal ions adsorbed on sediment particle surfaces react chemically with hydrogen sulphide when burial of the sediments exposes them to anoxic conditions. This sulphidation releases sparse molecules of metal sulphide to diffuse in the interparticle fluid.
- **Surface chemistry** – is the study of the special chemistry that is related to the solid-water interface. Surface chemistry and colloid chemistry are closely interrelated because the behaviour of colloidal particles is dependent on the properties of the very large surfaces they present to the solvent in relation to their very small volume. The solvent, ions, complexes, and other charged particles interact with all surfaces but are especially important in their interactions with colloidal particles.
- **Surface energy** – is the difference in energy per unit area between the surface of a given crystal lattice or substance and the energy of the same number of atoms (comprising the unit area) situated within the bulk of the crystal or substance. Surface energy is clearly dependent on the atomic geometry of the atoms exposed within the unit area of surface. The atoms exposed at the surface are able to interact with particles, ions, solvent, or other substances. They have ‘dangling bonds’ or charge that can compensate each other, hydrate, adsorb surface species, or form new chemical compounds. Bonds or linkages of atoms comprising a comparable area within the crystal or substance are in equilibrium with those surrounding them. The crystalline state is the low energy state of matter.
- **Surfactant** – a particular class of solutes that show dramatic effects on surface tension are highly active in relation to surface adsorption and are called surfactants. They are dispersions or solutes such as soaps, detergents, long chain alcohols, and polymeric silica.
- **Suspension currents** – the gentle flow of muddy water (created by storms, etc) that is only slightly heavier than clear seawater down submarine slopes is called a suspension current.

- **Symplectite** – an intimate fine-grained intergrowth of two and occasionally three minerals that has been puzzling for petrologists because the intergrowths are often arranged concentrically round a core mineral such as olivine, garnet or biotite. These fine mineral intergrowths are sometimes oriented (called kelyphitic rim) and have been mysterious because they occur in metamorphic and igneous rocks as mixtures that are inconsistent with a melt cooling origin. A few examples of symplectic intergrowths include spinel and hypersthene, garnet and serpentine, garnet and quartz, bytownite and pyroxene, diopside and spinel, epidote and quartz, biotite and quartz, quartz and feldspar, amphibole and spinel, plagioclase and magnetite, scapolite and orthoclase, etc. Symplectic intergrowth clearly results from crystallisation of substances that were miscible and uniformly mixed before crystallisation. As the original uniform mixture crystallised the components separated into an intricate mixture of fine individual intergrown crystals. This unmixing on crystallisation is typical of gelatinous materials. Symplectites are related to myrmekites, kelyphites, dactylitic texture, micrographic intergrowth, coronas, orbicules, ocelli, etc. that are other manifestations of the slow crystallisation of gelatinous materials by chemical dehydration reactions.
- **Synerectic clusters** – are dense gel particle aggregates where the particles are closely packed in ordered or semi-ordered arrangements and strongly drawn together by the interparticle forces. The clusters in this condition are synerectic.
- **Synerectic condensation** – refers to the shrinkage to denser more compact particle clusters due to van der Waal's forces in the primary minimum. The close packed particles by this process are able to divest surface adsorbed species and establish chemical linkages between particles.
- **Synerectic nucleus** – any aggregate of particles sufficiently large and with sufficient of its particles in close packed configuration (strongly drawn together by van der Waal's attraction) can form a synerectic nucleus. Exudation of desorbed electrolyte or other charged particles from these nuclei can coagulate dispersed species from the surroundings to precipitate as concretionary overgrowths.
- **Synerectic desorption** – is one of the most important characteristics of close-packed particle aggregates (accretions and concretions). As the particles in these clusters are drawn together by van der Waal's strong forces of attraction at very close interparticle separation (primary minimum), the particles or particle chains achieve greater co-ordination. Total surface energy is lowered and internal surface and adsorptive capacity are reduced. Species adsorbed on surfaces are desorbed. Polar water molecules, ions, and smaller charged particles are exuded from the clusters into the matrix brines. This results in Liesegang banding, rimming of synerectic aggregates (rapakivi texture and concretion), and discharge to the pore fluid brines of exceedingly small metal hydroxide and hydroxy sulphide particles. Precipitates of these metastable colloids from brines migrating out of the system accumulate as economic orebodies. Syneresis in accretionary aggregates is independent of the chemical composition of the particles. Therefore, any large volume of limestone, chert, argillaceous sediment (shale), or greenstone that has been re-textured is a potential source of ore mineral sols. These seep out of the compacting sediment pile as synerectic desorption develops brine strengths that will keep them displaced into the fluid phase.

- **Syneresis** - is the spontaneous aging or contraction of a gel meshwork within itself by the establishment of a greater density of cross-linkages and elimination of water. The particles or particle-chains achieve greater co-ordination. The total surface energy is lowered, and the internal surface and adsorptive capacity are reduced. The contraction and greater gel density causes shrinkage cracks or a pattern of holes or channels (like those in cheese) which is independent of whether or not the gel is immersed in water. In syneresis the particles move closer together under the influence of van der Waal's attractive forces so that the less dense, sparse, weak "watery" gels tend to be less or non-synerectic.
- **Syneresis crack patterns** – are developed by the considerable shrinkage during syneresis of any close packed gelatinous materials (such as clays, polymeric silica, hydrated chert, calcium hydroxy carbonates, aluminium hydroxide, cheese, junkets, etc). The shrinkage cracks and cavities usually take the form of radiating or spongy tubules, small ovoidal or drop-like cavities filled with fluid, central 'star' cracks, irregular gaping central cavities, or miarolitic cavities and vughs. They are usually filled with additional silica or other particulate species that crystallise later. Many syneresis crack patterns can be discerned as having a radial or concentric orientation to the nodule or mass of shrinking hydrated material in which they develop.
- **Synneusis** – is a term from the Greek root "to swim together" that is used to describe the way small plagioclase crystals appear to "float" into growing crystals of potassium feldspar. Potassium feldspars in granites actually include 'droplet quartz', chlorite, biotite, and plagioclase as small crystals, as encircling rims, as internal concentric zones, and as various types of perthitic intergrowths. These inclusions generally are inconsistent with melt cooling theory.
- **Syntaphral tectonics** - is the study of gravitational mass sediment movements, slope failures, and slump folding associated with the development of a geosyncline. "Syntaphral" means 'towards the trough'.
- **Tactoid** - A tactoid is like a floc but distinguished by a high internal ordering of the particles within the cluster. In the process of manipulating the repulsive forces between particles to promote coagulation or flocculation, it is possible to achieve a structured or partly structured aggregate such as stacks of platelets, interlocking arrays of chains of particles, or bundles of aligned rods.
- **Tellurides** – are mineral compounds of tellurium (silvery white element) with metals like silver or bismuth. They resemble and are often found mixed with sulphides.
- **Thixotropy** - is the isothermal reversible reliquefaction of a gel or coagulated sol. Thixotropy is due to mechanical shock or shear which disrupts the gel particle linkages allowing the colloids of the system to revert to a dispersed sol or more fluid gel at the same fluid content. This isothermal gel to sol or to more-fluid-gel transformation is reversible and repeatable. Thixotropy is mainly induced by shock. A short sharp oscillation throughout the gelatinous mass is more effective in destroying all, or sufficient of, the interparticle linkages at the one time so that the meshwork structure will collapse and the material revert to a fluid. Differential liquefaction depending on hydration (differing Bingham yield points) of different colloidal components allows separation of more mobile hydrous materials which can then simply flow out of the disturbed mixture.

- **Thuringite** – is an olive-green or paler green mineral of the chlorite group that is a more iron-rich variety of chamosite.
- **Tinguaite** – is a type of phonolite containing potassium feldspars and feldspathoids that is intruded as dykes and contains conspicuous acicular crystals of radial arranged acmite [a green clinopyroxene $\text{NaFe}(\text{SiO}_3)_2$] in criss-cross patterns in the groundmass. These crystallisation patterns reflect the enhanced crystallisation of the gelatinous hydrous precursors.
- **Tonalite** – is a white (leucocratic) quartz-plagioclase rich intrusive rock that is a variety of adamellite having a specified composition. The repeated thixotropic mobilisation of granitic rock precursors results in increasing depletion of the more mobile hydrous ferromagnesian minerals and illitic clays that separate to basic dykes and to aplite or felsite dykes. Quartz- plagioclase rocks crystallise from the residual pastes that are depleted in ferromagnesian minerals.
- **Tourmaline** – refers to a group of hydrated sodium-calcium-iron-aluminium silicates that are commonly found as dark striated columnar masses as a minor mineral in pegmatites, granites, and metamorphic rocks. The general formula is $(\text{Na,Ca})(\text{Mg,Fe}^{2+},\text{Fe}^{3+},\text{Al,Li})_3\text{Si}_6\text{O}_{18}(\text{OH})_4$.
- **Transmission electron microscopy (TEM)** – a technique for determining surface microtopography.
- **Triclinicity** – see ‘[Domains of 2Vx](#)’.
- **Tridymite** – is a polymorph (orthorhombic crystal structure) of quartz; SiO_2 .
- **Trondjemite** – is a white intrusive or dyke rock primarily composed of plagioclase and quartz with little or no ferromagnesian minerals or potassium feldspars.
- **Turbidites** – are the layered deposits of shelf sediments that have been eroded and re-transported downslope by high-velocity turbulent flows of dense muddy water.
- **Turbidity currents** – are the high velocity sediment laden submarine currents that transport disturbed continental shelf sediments to deeper water in the ocean basins. These currents of water loaded with sediment attain greater velocity as they pick up additional soft sediment from the sea floor so that immense submarine canyons are eroded in the continental shelf margins. Turbidity currents are usually initiated by earthquakes.
- **Undulatory extinction** – the extinction or darkening when minerals are examined under polarised light is often irregular, gradational, or undulatory. The ‘wavy’ or variable extinction is due to distortions or internal strain caused by imperfections in the natural crystal lattice. In the case of most natural quartz, the undulatory extinction is due to entrapment within the crystal of rows of residual hydroxyl groups remaining from incomplete condensation of its ordered precursor silica gel.
- **Uruguay banding** – occurs in shrinkage cavities or the core regions of large geodes. Geodes are large synerectic accretions of highly hydrated amorphous silica aggregated in deposits of formerly fluid and rheopectic mud. In geodes horizontal Uruguay banding is formed during synerectic contraction and diffusion of silica species. It is preserved as the silicified sedimentation levels (beds of precipitated micro gel units) in their central cavities.

- **van der Waal's forces** – the strong attraction due to interaction between dipoles when small particles or molecules are in very close proximity to each other is called van der Waal's forces of attraction. These forces exist between all matter in very close proximity (see [page 96](#)).
- **Visco-elastic solids** – are gelatinous solids in which particles forming the gel meshwork are linked to each other by their surface electric charge (coulombic) or by van der Waal's forces of attraction. They may be envisaged as having many weak links between charged particles, a lesser number of linkages having moderate strength, and relatively few strong ones. Gels are visco-elastic solids but natural sediment gels have a wide range of physical properties because of the enormous variety of mixtures of particles and polymers involved. Generally, limited stress (application of a weak deforming force) allows a visco-elastic solid to deform elastically and return to its original shape when the deforming force is removed (no or very few particle linkages are disrupted). Intermediate deforming forces disrupt more linkages in the material such that it returns elastically only partly towards its original shape and retains permanent plastic deformation. Stress (application of sufficient force) disrupts weak linkages continuously and stronger linkages at an increasing rate until uniform viscous flow is achieved (the rate of shear is proportional to the shearing stress). An increased rate of shear or shock under stress can exceed the Bingham yield point and disrupt all interparticle linkages at once. This results in viscous flow where the viscosity is dependent on the rate of shear. During plastic deformation and viscous flow interparticle linkages are continuously breaking and re-establishing. They re-link in increasing numbers as the rate of flow declines. The rapid reversion to a higher viscosity or solid condition when linkages between particles re-establish throughout the flowing mass to overcome the momentum of the moving mass, is called rheopexy.
- **Volcanics** – refers generally to all materials assumed to have reached the Earth's surface or nearly reached the surface due to volcanic activity or eruptions. By applying more recently chemistry and rheology to geological interpretation it is now possible to discern real volcanic ejecta and pyroclastics from porphyroids and similar rocks that have been incorrectly classified as "volcanics". A great variety of retextured sediments or porphyroidal and "igneous-looking" rocks have been called "volcanics" in the absence of any explanation of their composition, features, and mixture with unaltered sediments. The essential difference between re-textured sediments and real volcanics is that real volcanoes do not emit large rounded individual ovoids of crystalline feldspar or quartz.
- **Volume fraction** – is used by colloid chemists as a measure of concentration. It is the ratio of the volume of solid particles present in a system to the total volume of fluid and particles that make up the system.
- **Wollastonite** – is the simple white or grey mineral form of calcium silicate (CaSiO_3).
- **Xenolith** – the term is derived from its root 'foreign rock'. It means any fragment or irregular piece of rock that is set in a host rock of different texture and composition.

- **X-Ray adsorption spectroscopy (XAS)** – a technique for determining the chemical composition of surfaces.
- **Zeolite** – is a general term to describe a large group of feldspar-like hydrous aluminosilicates that are usually white or colourless. They are characterised by ‘open’ lattice structures that readily adsorb water (and other compounds) and release it on heating. They commonly occur in sediments as authigenic minerals partly crystallised from clays and as accretionary nodules in mobile greenstones. Classical zeolites include heulandite, phillipsite, stilbite, scolecite, laumontite, chabazite, analcite, and natrolite. heulandite, phillipsite, stilbite, laumontite, chabazite, analcite, or natrolite. Primitive zeolites include pumpellyite, hillebrandite, xonotlite, and apophyllite that tend to more closely resemble the ordered clay aggregates from which they are crystallising.
- **“Zip fastener reaction”** – see ‘[Clay hydrolysis](#)’.

