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A NEW THEORY OF THE EARTH'S CONTINENTAL CRUST: THE COLLOIDAL ORIGIN

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Abstract: On the basis of modern colloidal geochemistry and taking into account the foundations of the physical chemistry of surfaces, a new theory of the origin of the Earth's continental crust is proposed. According to this theory, the formation of the sialic crust of the Earth involved a creaming process ensuing from the spontaneous emulsification of the "truly primitive" basic magma. In this theory the basic magma is considered as an initially simple and homogeneous fluid characterized by density fluctuations in critical conditions.

Under certain circumstances immiscible nuclei of a new phase originate in the primitive magma ocean. This new liquid phase has a more acidic composition than the surrounding basic magma. As the phase separation proceeds the magma will comprise immiscible sialic portions in a state of dispersion. Under a decreasing shear rate, these portions progressively aggregate between themselves by coalescence to form larger blobs and successively these blobs, by coalescence, give origin to larger spherical bodies and so on, up to obtain, hierarchically, large enough dimensions. When the differentiated phase is very concentrated, the sialic blobs first distort, then markedly elongate and neck in to give an inverted layer: the segregated matter is forced out as a gel phase and forms the stable sialic protocrust.

The rheologic behaviour of the differentiated portions is here illustrated by a model of three types of particles: primary tactoids, spherical clusters and aggregates. In addition, the general form of the curve of potential energy as a function of interparticle separation is used to illustrate the sequence of the events which in time led, as a result of cooling, to the formation of the earliest continental crust: stable magma emulsion → phase separation → metastable immiscibility → phase inversion → stable segregate → close packing → syneresis and accretion → crystallization.

Key words: sialic continental crust, magma emulsification, creaming, colloids.

Introduction

For many years the colloidal state of matter has been largely ignored by researchers. This situation was in contrast with the fact that a profound knowledge of the Physical Chemistry of colloids and surfaces is of great importance in the interpretation of a large number of natural phenomena. Only in recent years, with the use of new analytical techniques, much work has been published and the study of colloids has grown into a true Colloid Science.

The term colloid means glue-like and dictionary definitions include colloid to mean one of the forms in which minerals occur (Elliston 1984). Colloid systems may be defined as systems containing at least two components: 1 - a continuous dispersing medium, and 2 - a disperse phase. They may be divided into two groups, namely, lyophilic (liquid-attracting) colloids and lyophobic (liquid-repelling) colloids. Today, the term colloid is indistinctly applied to all systems formed by entities having high specific surfaces independently of the dispersed substance. That is to say, the unique properties of the colloidal state reside in the large surface to volume ratio of the dispersed phase, such that the surface energy becomes an important component of the total energy of the system.

The classical view of a colloid system refers to matter (solid, liquid or gas) in a finely divided state where, usually, the particles are in the 1 nm to 1000 nm size range. However, natural laws governing the behaviour of matter in the molecular state or in bulk also apply to the colloidal state. So, when particles have a diameter greater than 1000 nm can behave as colloids. In this way, many reactions may in nature control the geochemical behaviour both of particles having diameters much greater than 1000 nm and of liquids that are in contact with these large particles (Yariv & Cross 1979).

In this article the term magma refers to a natural critical fluid decomposing spinodally (Lucido 1990) and having the composition of silicate melt. Furthermore, particles whose size greatly exceeds that of particles traditionally defined as "colloids" will be considered. Before we present our idea about the Earth's crust origin, it is necessary to introduce some general properties of emulsions and then go to recover the physico-chemical process of creaming.

Emulsions

Definition

Colloidal dispersion is a colloidal state achieved when particles are distributed as primary particles throughout a continuous phase. The dispersion is thermodynamically stable when the particles show no tendency to coalesce or aggregate during collision induced by their thermal (Brownian) motion. Conversely, dispersions are unstable when there is a reduction in the total surface energy and the attractive van der Waals forces pro-

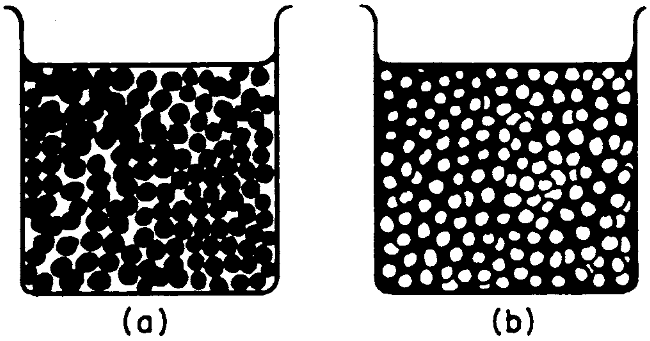

Fig. 1. The two types of emulsion: **a** - oil-in-water; **b** - water-in-oil (Adamson 1990).

mote coalescence or aggregation on collision. That being stated, an emulsion may be defined as a colloidal dispersion of one liquid in another. Since usually one of the two liquids is aqueous in nature, the two common types of emulsions are water-in-oil (W/O) and oil-in-water (O/W); the term "oil" is used as a general word denoting the water-immiscibile fluid. These two types are illustrated in Fig. 1, and it is clear that one phase (the outer phase) is continuous, whereas the other (the inner phase) is not.

Approaching drops

Apart from chemical composition, an important variable in the description of emulsions is the ratio ϕ of the volume of the inner phase plus surfactant (interface) to total volume of the system. A natural value for ϕ is 0.64, representing the close packing of spheres. In dilute emulsions, the inner phase does generally exist as spheres, and ϕ is therefore the appropriate variable to treat viscosity. Vice-versa concentrated emulsions are not Newtonian, so that their viscosity depends on shear rate. Furthermore, viscosity depends not only on ϕ but also on droplet size and size distribution (Sherman 1963). If the emulsion is very heterogeneous in droplet size, ϕ may exceed 0.64 by virtue of smaller drops occupying the spaces between larger ones, and so on with successively smaller droplets; such a system would not be one of equilibrium. However, the thin film separating two emulsion drops may have a lower surface tension than that of the bulk interfacial tension (Adamson 1990). As a consequence, two approaching drops will spontaneously deform to give a flat drop-drop contact area, with the drops taking on a polyhedral shape. The triangular space between drops is known as the Plateau border (Fig. 2), and in this case, the surface of the border does not merge smoothly with the flat drop-drop interface but forms some definite contact angle with it. Conversely, it is the existence of such an angle that leads to the formation of dense emulsions of high ϕ value. The unit cells of such emulsions are termed aphrons (Fig. 2). It might be noted that Plateau borders play an important role during syneresis, condensation and compaction of colloidal films (e.g. Gibbs 1931).

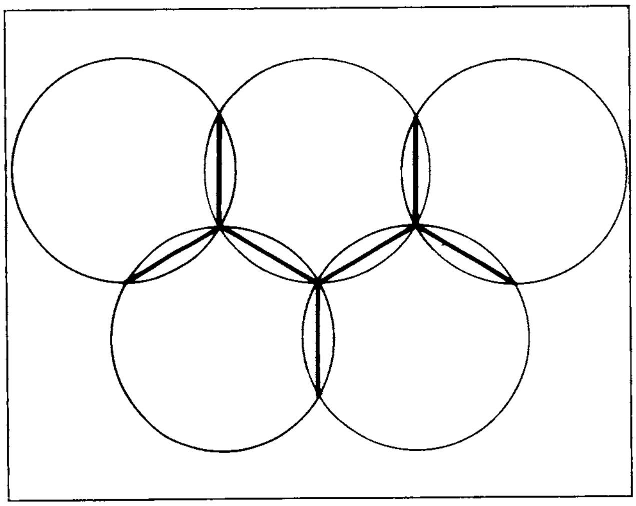

Fig. 2. Plateau's border: spontaneously deformed cluster of emulsion droplets. Note that such a two-dimensional emulsion consists of a more or less uniform hexagonal type of network, forming the so-called aphrons (Adamson 1990).

Creaming process

Ordinary cream is an oil-in-water emulsion. For a cream technologically obtained, the inner phase constitutes a sizable fraction of the total volume, and the system is characterized by a network of interfaces that are prevented from coalescing by virtue of adsorbed films, or electrical repulsions. However, in the case of spontaneous emulsification the cream consists of a network of interfaces that may cluster and coalesce in time. In this case, in fact, as illustrated in Fig. 3, at least three types of ageing processes occur. The inner phase droplets may undergo aggregation (or flocculation), that is, clustering together without losing their identity; if as part of or subsequent to aggregation, the aggregates of flocks undergo a gravity separation, the entire process is called "creaming". It refers to the tendency for an emulsion to separate into a more concentrated and a more dilute emulsion phase. If coalescence occurs, then eventual breaking of the emulsion must follow, giving two liquid layers (Fig. 3). This interesting effect is that in which an O/W type of emulsion inverts to a W/O type. Inversion can be a very dynamic and complex process; it is discussed below.

Inversion

Generally speaking, the methods whereby inversion may be caused to take place involve introducing a condition such that the opposite type of emulsion would normally be the stable one. First, an emulsion would have to invert if ϕ exceeded 0.64 (close packing), if the inner phase consisted of uniform rigid spheres. Actual emulsion droplets are deformable, of course, and not monodisperse, so the preceding criterion does have a limited applicability. Second, it will be recalled that the addition of a great number of antagonistic agents (stabilizing) can result in inversion. Third, inversion may be brought about by temperature changes. Also, a phase change in one of the two liquid phases may be helpful; thus emulsions may be broken by heating to near the boiling point of the inner phase or by freezing and then rewarming (Adamson 1990). In general, where the inner phase is not too dilute, the emulsion type responds fairly readily

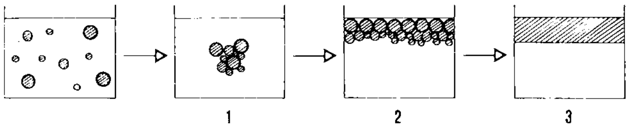

Fig. 3. Instability of emulsion: **1** - aggregation or flocculation; **2** - creaming; **3** - breaking.

to a change in conditions. In particular, the globules of a phase first distort, then elongate as the critical point is approached (with very marked "Brownian" movement) and neck in to give an inverted system. It is at this point that the stabilization of emulsion plays a significant role.

Stabilization

An important aspect of the stabilization of emulsions by adsorbed films is that of the role played by the film in resisting the coalescence of two droplets of inner phase. Such coalescence involves a local mechanical compression at the point of encounter that would be resisted and then, if coalescence is to occur, the discharge from the surface region of some of the surfactant material (Adamson 1990). Alexander (1950) pointed out that desorption may be a hindered process; it thus can provide a barrier to coalescence. Once spread, however, this and other materials do not readily return to bulk fluid. If a drop is distorted, as in the mechanical working of an emulsion, the surface area is increased and more interfacial film forms, but irreversibly so that if the drop returns to a spherical shape, film material does not go back into fluid but may wrinkle the interface or thicken it as expelled curd collects; the same is true if two drops coalesce (Adamson 1990). For what will follow, it is important to recall that such processes may account for the rather thick films. Another important consequence is that ejected surface material may come out as a gel or solid phase. That is, "whenever the surface film is sufficiently rigid, or in sufficiently slow equilibrium with the bulk phases, then, the film material may be forced out as a gel phase or solid phase of crystals as a result of the coalescence of droplets or of mechanically induced distortions in droplet shapes". With time, such a material forms a duplex film, that is, a film thick enough so that the two interfaces (e.g., liquid-film and film-air) are independent and possess their separate characteristic surface tensions. With further ageing, the film material at an interface forms a lens (Fig. 4), that is, a thick layer of finite extent whose shape is constrained by the force of gravity.

The theory

In nature, spontaneous emulsification comes from dispersed particles and goes to clusters. These clusters, progressively, aggregate between themselves by coalescence to form larger clusters and successively these clusters, by coalescence, form larger spheroidal particles (until, theoretically, only one particle is left). In this regard, it is recognized that in the formation of a new phase the general sequence of events is that primary particles form and that these grow by aggregation to the point of becoming recognizable clusters that may finally coalesce or grow to yield massive amounts of the new phase. This sequence of events can be generalised to complex systems like, magmas. Let us now see what happens if we consider magma as a spontaneously emulsifying system.

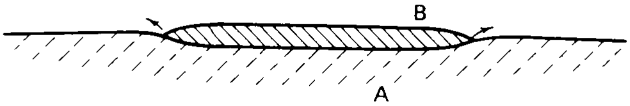

Fig. 4. Profile of a lens due to spreading of one liquid over another (Adamson 1990).

Spontaneous emulsification of magma

At very high temperatures magma consists of a single liquid phase. The temperature at which immiscibility evinces is defined as the critical consolution temperature. As the cooling magma reaches the critical consolution temperature globules in a bidispersed state are obtained. As long as the temperature of the magma remains near this critical consolution temperature, such an emulsion is metastable. This is due to the fact that at this temperature generally the liquid phases do not, closely resemble each other chemically: they are mutually immiscible (e.g. Fig. 5). Under these conditions, the densities of the liquids are unlike and the interfacial free surface energy is high. However, any decrease in the magnitude of the interfacial free surface energy as the result of cooling and/or coalescence of the differentiated globules is not negligible. Cooling damps the thermic motion of a magma and originates in it an ordered "structure" (Atkins 1984). This structure is a contribution to the universal order. It is the clue to account for the immiscibility of the two magmatic portions: the decrease of the disorder which occurs during the formation of this structure corresponds to a significant decrease of entropy. On further cooling, composition changes brought about by phase-separation, and/or the extensive interface thus created, might promote crystallization (e.g. Walton 1969; Reiss 1976; Ganguly & Saxena 1987).

According to Lucido (1989) starting from a magma in critical condition, as temperature decreases, a second liquid phase at different density initially separates on a submicroscopic scale, and then, coalescing, collects into larger clusters (Fig. 5). That is, there is a closely related new phase in the melt corresponding to a liquid in density or nearest neighbor distance. The magmatic fluid will tend to separate into two immiscible liquid fractions, one enriched in high charge ions and the other enriched in low charge ions. In this way, the fluid will split into two immiscible liquids, one enriched in elements like iron, magnesium, calcium, titanium etc., and the other enriched in elements having the tendency to form polymeric network (Lucido & Triolo 1983, 1984). In other words, low charge density ions are removed from the melt by separation of a phase as differentiation proceeds. As a consequence, we find droplets of dark (Fe rich) phase dispersed in a clearer phase richer in elements forming framework structures or vice-versa (e.g. Fisher 1967; Langer 1967; Domb 1976; Binder 1976; Glimm et al. 1976; Bruce & Wallace 1981). In conclusion, when two mutually immiscible magmatic liquids originate by phase separation and one collects into larger differentiated clusters, the total interfacial area decreases as the volume of the droplets increases; in this way the interfacial free surface energy decreases and the system becomes stable. That is, the droplets coalesce spontaneously into an independent liquid phase of minimum free surface energy.

Let us now see what happens if we consider the "truly primitive" basic magma as an initially simple and homogeneous fluid characterized by density fluctuations in critical conditions and apply to it the physico-chemical process of creaming. We urge the readers who are not familiar with the topic of critical fluctuations to consult Lucido (1990).

Creaming in the primitive magma ocean

Our starting-point is the basic magma ocean at the fluid state preceding any crystallization process; since that time indeed the Earth has undergone a continuous cooling. Under certain circumstances immiscible nuclei of a new phase originate in the

Fig. 5. Two immiscible liquid phases: dark basic globules and light coalescing felsic clusters due to spontaneous emulsification of the Sicilian basaltic magma. Oblique to the picture a fracture of the rock is evident. Scale in millimetres.

primitive magma ocean (Fig. 6). This new liquid phase has a more acidic composition than the surrounding basic magma. It is richer in silica, alumina and alkalies and is poorer in elements like Fe, Mg, Ca, Mn, Ti and P than the enclosing melt. As the phase separation proceeds the magma will comprise immiscible sialic portions in a state of dispersion. Such a separation is a phase transition which is controlled by the rates of diffusion of their component species and by the degree of supersaturation of the new phase (Lucido 1987, 1989).

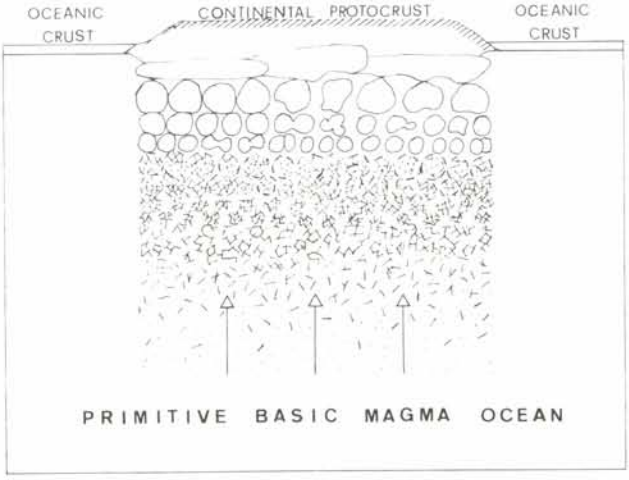

Fig. 6. Schematical representation of the creaming processs in the primitive magma ocean. It is shown a continental protocrust being pulled apart by rising light sialic liquid blobs. These upwelling blobs cluster and coalesce between themselves; they originated by phase separation which occurred in the basic magma ocean.

As the splitting proceeds the immiscible nuclei of sialic composition, progressively aggregate between themselves by coalescence to form larger blobs and successively these blobs, by coalescence, give origin to larger spherical bodies and so on, up to obtain, hierarchically, large enough dimensions (Fig. 6). Coalescence fundamentally depends on the interparticle surface forces existing in the melt. These forces that lead to aggregation are primarily van der Waals. In such a magma, as temperature decreases, also the disorder in its motion decreases and the effect of interparticle surface forces increases. In the long run these forces become more and more important and are responsible for an attraction process of very viscous colloidal clusters; these clusters tend to become larger so as to decrease the surface energy of the magma. Such a magma is an unstable system, in which there are constant changes in surface tension, viscosity and density until the melt is stabilized and the motion ceases.

Upon separation into immiscible liquids, inversion occurs in the primitive magma ocean. It is brought about by a phase change in one of the two liquid phases and by temperature changes. In general, when the differentiated phase is concentrate, the magmatic emulsion responds fairly readily to a change in conditions. In particular, the sialic blobs first distort, then markedly elongate and neck in to give an inverted system (Fig. 6). A further change in the volumes of the sialic liquid layers occurs under comparatively quiescent conditions and is controlled by the rate of floating up (or settling) of the band of clusters in the corresponding matrices. In emulsion zones that have thickened to a certain density, motion ceases (i.e. viscosity increases), so relative to zones of less dense emulsion these zones behave as "solid boundary surfaces", along which the friction is higher than elsewhere in the primitive magma ocean. Within the remaining less dense zones, the motion of magma will continue to create new zones of denser and less dense emulsion until motion ceases completely.

Differentiation of the sialic phase

Interactions between particles

Colloidal particles in magmas can be either magmaphilic or magmaphobic depending on whether the energy obtained by their net interaction is higher or lower, respectively, than the sum of their attraction energy and the repulsion energy of the silicate melt. This net interaction is dependent on temperature, electrolyte concentration, interparticle distance (concentration of the segregate) and the size and shape of the particles making up the magmatic fluid. The repulsive forces between similarly charged particles are coulombic and due to their similar charges. Such repulsion normally keeps particles in stable emulsion by tending to prevent approach at close range. However, when two particles approach each other their diffuse counter-ion atmospheres interpenetrate and deform. Electrostatic repulsion is particularly dependent on electrolyte concentration because the double layer is compressed as that concentration increases and the range of repulsion is considerably reduced (Yariv & Cross 1979). Vice-versa, van der Waals attractive forces are short-range and, consequently, largely dependent on the proximity of the particles interacting. The attraction between macromolecular particles is much stronger than that between, say, gaseous atoms and molecules, and it increases with increasing size of the particle (Elliston 1984). In essence, the interparticle force of repulsion increases approximately with the inverse of the square of the distance between particles, whereas the van der Waals force of attraction icreases more rapidly, for thick clay platelets, for example, it is approximately proportional to the inverse of the cube of the separation distance (Yariv & Cross 1979).

Fig. 7 is the DLVO diagram indicating the general form of the curve of potential energy (V) as a function of interparticle separation (h). In it different scales of the reaction times are considered and, for simplicity, only the major interaction energies of electrostatic repulsion (VR) and van der Waals attraction (VA) are summarized. The sharp upturn in the resultant curve as the particles closely approach each other is due to a complex short-range force. For the particles to approach closer than the thickness of the adsorbed fluid layers, this must be desorbed, and the work required for the desorption manifests itself as a short-range repulsion between the particles (Elliston 1984). Another short-range force is the Born repulsion which is effective as soon as extruding regions or lattice points come into contact, resisting the interpenetration of crystal lattices. These short-range forces are a barrier to crystallization. At the concentration at which close packing sets in (Fig. 7), a strong and abrupt increase in the viscosity of the fluid occurs. But the most evident feature of the curve of Fig. 7 is the potential well or primary minimum at a very short interparticle distance. As the differentiated particles come together, syneresis and accretion take place. Syneresis is the spontaneous contraction of the gel meshwork within itself by the establishment of a greater density of cross-linkages and elimination of water; it causes shrinkage cracks or a pattern of holes or channels. Accretion is the formation in the sheared magmatic fluid of macroscopic spherically symmetric clots of higher density and particle concentration than the suspending medium. Approaching clots will spontaneously deform giving Plateau borders. Finally, free energy (heat) is yielded by the magmatic system when the disordering and reduction of surface is achieved by the lower energy state of the matter, namely, the crystalline state; crystallization has to be triggered by temperature, pressure and time (Elliston 1984). In conclusion, the general behaviour of a magmatic fluid is largely related to interparticle separation and Fig. 7 indicates for an hypothetic primitive basic magma the following succession of events: stable magma emulsion →phase separation → metastable immiscibility → phase inversion → stable segregate → close packing → syneresis and accretion → crystallization.

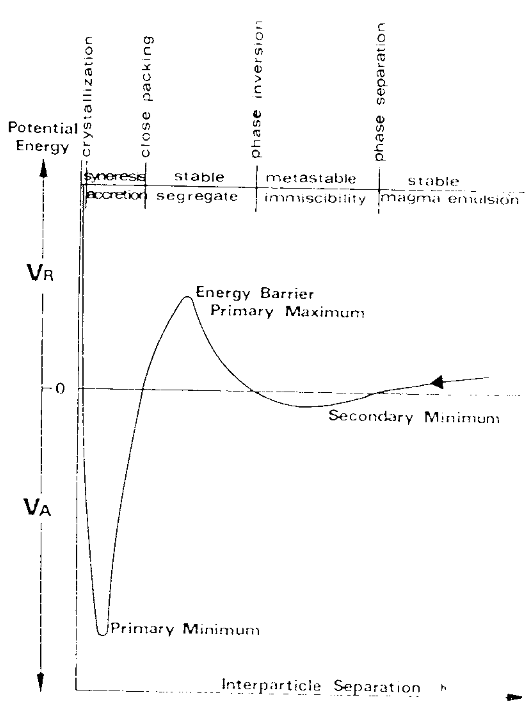

Fig. 7. DLVO diagram showing the general form of the curve of potential energy plotted as a function of interparticle separation (h). VR and VA are repulsive and attractive energies respectively (after Elliston 1984).

The rheologic behaviour

The physico-chemical conditions pertaining in the silicate acidic magma in which spheroidal textures develop are similar to those indicated for a concentrated mud flow. No other physicochemical system meets the very specific requirements to account for all the observations recorded. In particular, the solid phases comprising the body of the material are the same: essentially hydrated aluminosilicates, silica gels, and hydrous ferromagnesian minerals. The only difference could be temperature which is largely dependent on burial depth. The magma from which spheroids (ovoids or orbicules) (Fig. 8) develop is of necessity, therefore, a gelatinous system of mixed hydrosilicates. This analogy suggests that: the gel system of mixed hydrosilicates crystallizes by a series of dehydration reactions (e.g. Mysels

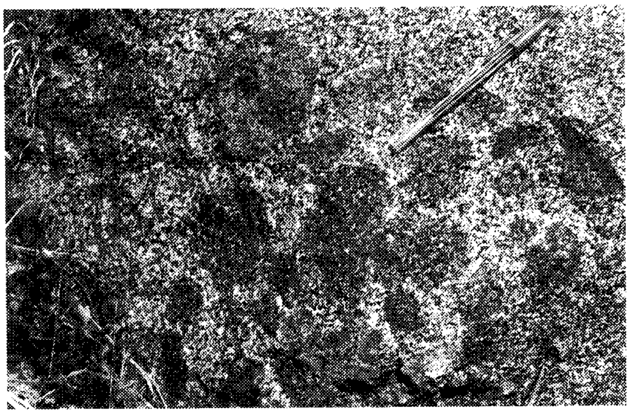

Fig. 8. Necking, clustering or coalesced orbicules in tonalite (Burgos,Sardinia).
The pen provides the scale.

1959; Elliston 1984, 1985) that are essentially the reverse reactions to the weathering and degradation of feldspars and other primary rock minerals to clays and muds. It is what enables us to consider the rheologic behaviour of silicate acidic magmas very similar to that of hydrospheric clay dispersions. For this reason, the rheologic behaviour of the differentiated magmatic fractions is here illustrated by a model of three types of particles existing simultaneously: 1 - kinetically independent primary particles, which are platelets of single unit-layers or tactoids, 2 - spherical clusters, and 3 - aggregates (Fig. 9).

The coherence of the segregated particles in the fluid shear regime is dependent on the geometric particle shape. This is important as the macromolecular particle shape is related to the chemical composition of the silicates forming the particle. With decreasing rate of shear (Fig. 9), the average size of the clusters and aggregates increases until at a sufficiently small shear rate the magmatic fluid contains spherical particles only. These spherical particles, or flocs, are Newtonian and have a structure of the card-house type, or a structure of the book-house type (Fig. 9). In other words, the differentiated particles penetrate into the vacant portion resulting in almost spherically shaped units. The particles are pushed into the proximity at which they lock on to each other due to van der Waals attraction. In the shear regime of viscous low the breaking and reforming aggregates are sensitive to purity (their cohesive property) or freedom from particles of ill-fitting phase incorporated in the cluster. Large clusters are subject to greater overall shear on the particle cluster; they are indicative of slow rates of fluid flow.

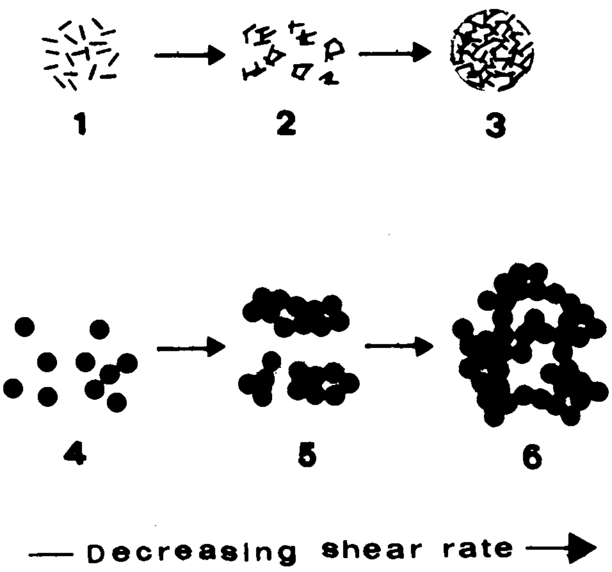

Fig. 9. Schematic illustration of the construction of structure of aggregated particles (or flocs) accompanying a decrease in flow rate. 1 - Primary particles; 2 - small clusters or flocs - card-house;3 - floc - card-house or book-house Newtonian; 4 - flocs - card-house or book-house Newtonian; 5 - aggregates of finite size - block-house non-Newtonian; 6 - continuous structure: aggregate of spherical flocs - block-house non-Newtonian.

Also at higher concentrations the differentiated material is found to exhibit shear thinning, i.e. the viscosity increases with decreasing shear rate. However, the value of the viscosity and whether or not the flow is Newtonian depend, among other factors, on the electrolyte content. In particular, when the electrolyte content is reduced, the viscosity increases markedly and the flow becomes highly non-Newtonian. Such behaviour is explained in terms of the electric double layer around the particles and the effect of electrolyte content in decreasing both the thickness of the double layer and the fraction of the remaining fluid. The non-Newtonian aggregates are of finite size and present a block-house structure (Fig. 9). Finally, the further aggregation of spherical particles originates a continuous structure. In conclusion, reduction in energy is achieved by reduction of internal surface area, elimination of pore space and, lastly, by crystallization.

Origin of the earliest continental crust

The general form of the curve of potential energy as a function of interparticle separation (Fig. 7) is appropriate to illustrate many of the interactions which occur in magmas. Moreover, considering the "truly primitive" basic magma as an initially simple and homogeneous fluid characterized by density fluctuations in critical conditions (Lucido 1990), this curve can be used to illustrate the course of the events which led to the formation of the Earth's sialic crust. In particular it is possible, in the long run, as a result of cooling, to imagine primitive basic magma fractionates spinodally in an acidic sense as temperature decreases (arrow in Fig. 7). In Fig. 7 the temperature decrease is considered in the same sense of the interparticle separation decrease. In this case the phases in equilibrium are closely related and one phase makes the other by continuous composition changes (e.g. Cahn 1961, 1968; Chan & Goldburg 1987; Ganguly & Saxena 1987).

The stability of such a primitive magma depends on the ability of the melt to maintain its disperse state. More exactly, the stability of disperse magma and its readiness to cluster depend on the sign and the magnitude of the potential energy of interaction, V, which is determined by the superposition of the electrostatic repulsive energy (VR) and the van der Waals attractive energy (VA). For large values of interparticle separation, h, repulsion normally keeps particles in stable emulsion. In fact, the potential gradient dV/dh is positive and indicates a mutual attraction between the particles. However, at shorter distances, the repulsion component VR, which increases exponentially with decreasing h, can overcompensate VA and reverse the sign of dV/dh in the direction of repulsion. In particular, at the interparticle separation where dV/dh changes from positive to negative a phase separation sets in. Following the previous rheologic model, primary particles having acidic composition originate throughout the primitive basic magma. In other words, in time, as temperature of magma decreases, a continuous liquid fractionation in an acidic sense occurs along the curve of potential energy (see arrow Fig. 7. Such a continuous differentiation is characterized by the production of intermediate liquids ranging from basic compositions to acidic ones. However, although this process is continuous, it can occur in a number of successive steps, each of which takes place with a different velocity in response to temperature-pressure gradients (Lucido 1990). On further decrease of interparticle separation a potential well is obtained, known as a secondary minimum. For interactions between small particles this secondary minimum is shallow, but for interactions involving large particles it represents a deep potential well which leads to coalescence and clustering. In this condition, the differentiated primary particles tend to associate originating Newtonian clusters (flocs) having card-house and book-house structures. Under a decreasing shear rate, these clusters are progressively built-up into greater spherical aggregates. On further reduction of the gap, VA should again predominate, reversing the sign of dV/dh in the direction of attraction, that is, a phase inversion occurs. The spherical aggregates are further built-up into non-Newtonian aggregates of finite size, until, at very low shear rate, only a continuous highly stable three-dimensional arrangement exists. The Newtonian units are therefore transformed into the greater non-Newtonian units as a result of shear. There is thus a repulsion maximum in the function V = V (h), which can be easily found from the conditions dV/dh = 0 (the primary maximum in Fig. 7). In the circumstances, the segregated matter is forced out as a gel phase and forms a sialic protocrust. The height of the energy barrier varies for the conditions of the magma. In most cases "close packing" or the denser, much more coherent gel characteristic of accretions or particles held together by the strong forces of attraction in the primary minimum, can only be achieved by supplying thermal energy to the magma. At very short distances, syneresis, condensation and compaction of the gel protocrust results in water loss, Plateau borders, and finally crystallization of the condensing gel phase by chemical dehydration reactions. In this manner, with spontaneous ageing, the total surface energy is further on lowered and the sialic protocrust forms te earliest continental solid crust. The course of the events explaining the origin of the Earth's crust is schematically indicated on Fig. 10.

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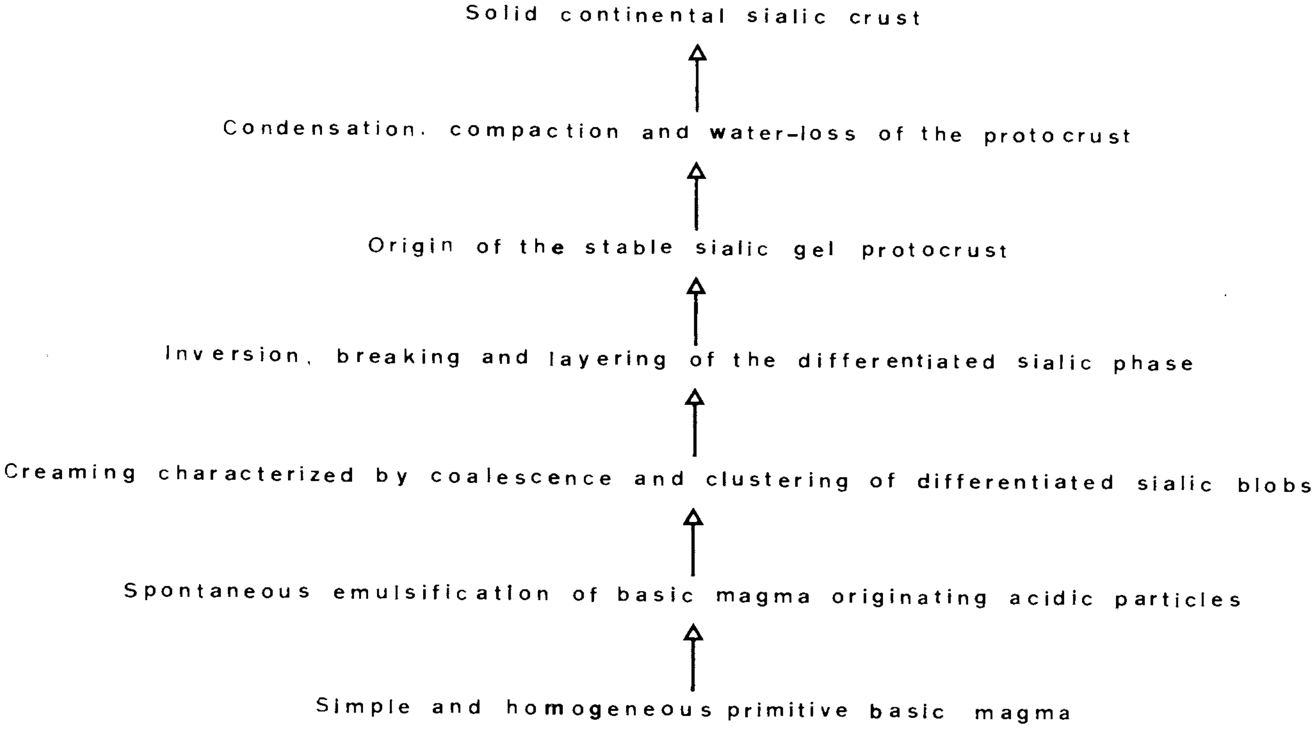

Fig. 10. General scheme showing the course of the events which led to the formation of the Earth's sialic crust.

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Announcement

Czech and Slovak Geological Associations will organize a jubilee session devoted to the anniversary of Czecho - Slovak Association for Mineralogy and Geology foundation from 8 to 10 October 1993 in Brno. Similar sessions will be held in Budapest and Belgrade subsequently.

The Brno session will deal with the problems of the Bohemian Massif and Western Carpathians junction. Outstanding specialists from Czech Republic, Slovak Republic and Austria will present their lectures on this subject. The participants will be acquainted with the activities of some Brno geological institutions and with geological situation of the Bohemian Massif and Western Carpathians junction during three field trips to surrounding of Brno.

Eventual application forms should be sent to following address:

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