Some Engineering Properties of Residual Clay Soils Occurring in Southern Brazil

Quelques propriétés techniques des terrains argileux résiduels du Brésil méridional

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Summary

The purpose of this paper is to make a contribution to the knowledge of the main features and characteristics of residual clay soils occurring in southern Brazil, where the thickness of the overburden of decomposed rock often reaches fifty metres more.

Soil profiles of decomposed gneiss, basalt and sandstone, occurring in that region are discussed. It is assumed that—from the engineering point of view—all residual soil profiles can be divided in three principal layers: (a) a surface layer of mature residual soil with a high void-ratio and a low degree of saturation, referred to, in this paper, as "porous layer"; (b) a young residual soil whose main characteristic is to show the original structure of the parent rock; (c) a desintegrated rock layer that can only be removed by explosives.

Grain size distribution, Atterberg limits, porosity, consolidation and shearing resistance of residual clays are discussed. The concept of "virtual pre-consolidation pressure", in such soils, is introduced and justified.

Sommaire

L'objet de ce travail est de contribuer à la connaissance des aspects et caractéristiques les plus importants des terrains argileux résiduels du Brésil méridional, où l'épaisseur des couches superficielles décomposées atteint souvent plus de cinquante mètres.

Les profils de terrains de gneiss, basalte et grès décomposés, que l'on trouve dans cette région, y sont décrits. Il est montré que tous les terrains provenant de la décomposition de roches peuvent – du point de vue technique – être divisés en trois couches principales: *a)* la couche superficielle de terrain résiduel mûr, avec un indice de vides élevé et un faible coefficient de saturation, laquelle dans le présent travail, sera réputée «couche poreuse»; *b)* une couche de terrain résiduel jeune, dont le principal caractère est qu'elle conserve la structure originale de la roche-mère; *c)* une couche de roche décomposée qui ne peut être extraite qu'au moyen d'explosifs.

La distribution granulométrique, les limites d'Atterberg, la porosité, la consolidation et la résistance au cisaillement des argiles résiduelles y sont étudiées. L'auteur introduit et justifie le concept de «pression virtuelle de pré-consolidation» comme une des caractéristiques de ces terrains.

Rock Weathering and Residual Soils

As defined by *Holmes:* "Weathering is the total effect of all the various sub-aerial processes that cooperate in bringing about the decay and desintegration of rocks, provided that no large-scale transport of the loosened products is involved." There are three phases in the process: (*a*) desintegration by physical or mechanical changes; (*b*) chemical weathering responsible for the decay of the desintegrated blocks; (*c*) process of evolution which brings an intensely decomposed rock to the state of an homogeneous residual clay or sand often not saturated.

Fig. 1 shows cross-sections through decomposed gneiss in two sites where earth dams are being constructed. The first dam-site (Fig. 1*a*) is near the crest of "Serra do Mar" (State of São Paulo) a site still covered with dense forest in a heavy rainfall zone (about 5 m per year). The second (Fig. 1*b*) is a deforested zone (deforestation took place about one hundred years ago) also near the crest of a lower range of mountains in the State of Rio de Janeiro. Rain precipitation is about 1 m per year in this last site. The elevation above sea level of the first site is about double that of the second.

The process of decomposition in the first site is at an earlier stage than in the second; the decomposed overburden (including desintegrated rock and residual soil) has a maximum thickness of about 30 m in the first and 75 m in the second site. The average relation between the thickness of residual soil and desintegrated rock is 1/3 in the first and 4/1 in the second site; finally the mantle of residual clay (soil which has suffered an evolution) is much thicker in the second site than in the first.

From what is shown in Fig. 1 we can deduce that in the decomposition of gneiss in Southern Brazil there is a tendency towards increase in the thickness of the residual clay top-soil and of the total decomposed overburden and towards decrease in the thickness of the disintegrated rock layer which overlies sound rock. This confirms the following interpretation of the rock weathering process: first there is a fracturing of the rock and then the chemical decomposition of the mineral constituents along fractures and clivage planes starts. The process advances giving origin to the layer of "desintegrated rock" which in the beginning is formed by blocks and boulders and, later on, by boulders bound together in a matrix of residual soil. The process continues until the rock has been transformed into a peculiar type of soil. In the case of igneous rocks the feldspars and some micas, under the action of slightly acid water, gives origin to the clay fraction of the residual soil and the quartz crystals form the sandy fraction of the soil. In the early phases of weathering there are many intact feldspars and mica crystals in the sandy fraction but, as those crystals are being decomposed, an increase in the clayey character of the residual soil is observed. The structure of the parent rock is preserved until a very advanced stage of decomposition is reached.

After throroughly decomposed, or simultaneously with the final stages of decomposition of the rock, a new process of transformation of the residual soil begins, which is referred to here as "evolution of the residual soil" and which gives origin to the yellowish or reddish superficial soil very common in Southern Brazil.

From what was said, soils originated from the decomposition of rock in Southern Brazil, can be divided—from the engineering point of view—in three principal layers: (*a*) just overlying sound rock, a desintegrated rock layer which can only be removed by explosives; (*b*) a young residual soil layer whose principal character is to show the original structure of the parent rock (the hardness of this material is extremely variable: from very soft soils removed by spade to hard concretionary mass of gravel, sand and clay needing pick or explosives to be removed); (*c*) a superficial mantle of mature residual soil which includes the thin humic top-soil layer and a redish or yellowish clayey or sandy soil with a high void-ratio and a low degree of saturation.

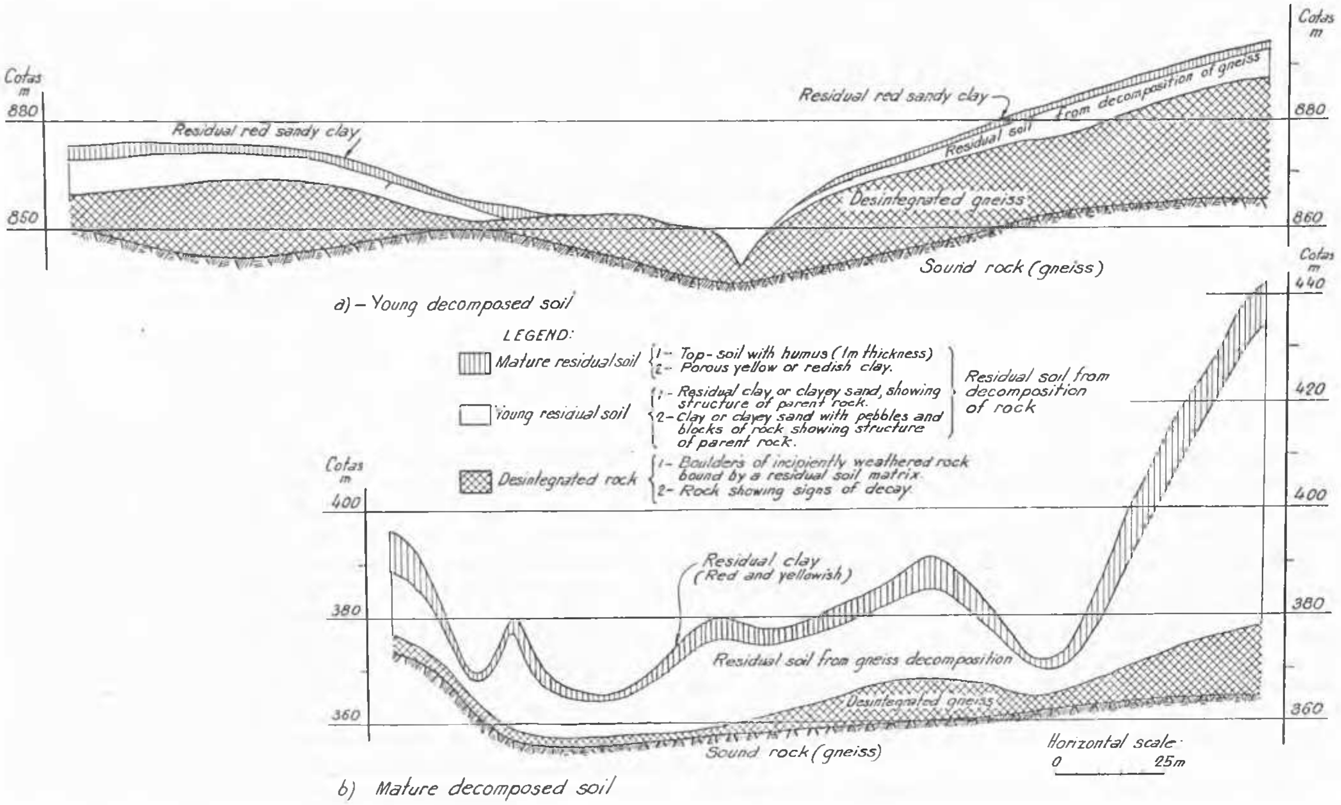

Fig. 1 Cross-Sections through Decomposed Gneiss
Sections transversales de terrains de décomposition de gneiss

Porous Residual Clay of Southern Brazil

In the highlands of Southern Brazil that superficial layer reaches tens of metres of thickness, giving rise to many troubles connected with building foundations, earth dams and cuts, due to its high compressibility and permeability.

Lixiviation and oxidation occurs in that layer with a lateritic process of evolution of the soil which gives to it a peculiar redish color. Lixiviation causes soil porosity to increase considerably; in many cases the volume of the voids reaches about 60% of the total volume. As its water contents are low, there is not enough water to saturate the voids. This is the cause of its high compressibility.

Underlying this layer there is often a hard clay layer where the lixiviated elements of the superior horizons precipitate; this causes an increase in the soil density resulting in an unusual compactness or hardness. There is also an intense oxidation resulting in a peculiar formation of limonite concretions.

Evolution is the principal cause of increase in thickness of the "porous clay layer". In young soils, it is almost absent and, consequently, no hard layer occurs. Mature soils, in turn, processes a very thick "porous clay layer".

Fig. 2 shows as an example, a soil profile in a zone of decomposed basalt, which is very common in the interior of Southern Brazil. There is, under a 2.5 m thick fill, a "porous clay" layer of 5 m thickness; underlying that layer there is a stiff clay layer and finally a desintegrated basalt layer overlying sound rock. The figure shows also results of grain size analyses of the several layers. By these analyses we can see that the clay content decreases with depth, in accordance with

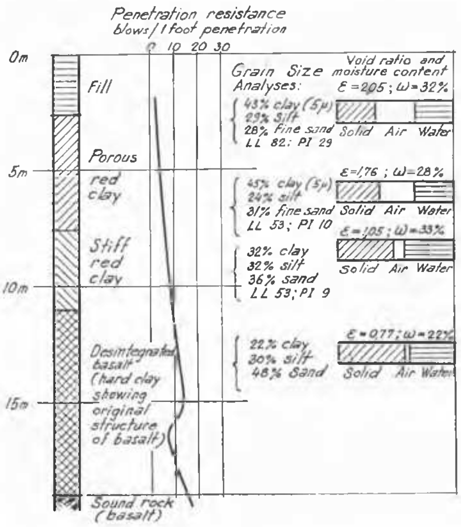

Fig. 2 Soil Profiles in Desintegrated Basalt
Profils du sol en terrain de basalte décomposé

what was previously said. It shows also graphs indicating the relative volumes occuppied by solid grains, water and air, in the several layers. The voids are larger at the surface of the soil and decrease with depth, but the saturation increases with depth.

Grain-Size Distribution, Atterberg Limits, and Porosity of Residual Clays

Fig. 3 shows grain size distribution curves of soils for the decomposition of ten different parent rocks. The coarser grains were observed to be fragments of intact or incipiently weathered rock; the sand fraction was constituted, in all cases, by intact crystals of the mineral constituents of the parent rock as indicated in Fig. 3.

Fig. 4 shows a plasticity-chart where 589 liquid-limit and plasticity index pairs of values obtained from Atterberg tests on residual clays from Southern Brazil were plotted. Each point was classified according to the nature of the parent rock in zones limited by two inclined parallel lines and two vertical lines. Each of these zones covers the total range of occurrence for soils originated by decomposition of four types of rock. In each of these zones the regions where the most frequent

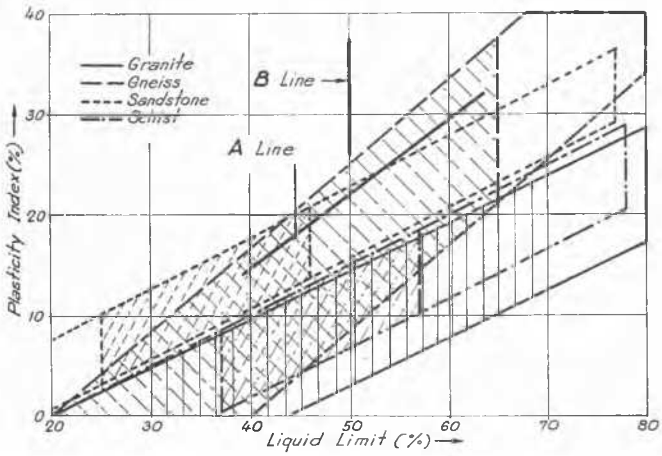

Fig. 4 Residual Porous Clays—Plasticity Chart
Argiles résiduelles poreuses – Diagramme de plasticité

values fall are indicated by dashed lines. It is interesting to notice that almost all soils plot below the A-line and show a low plasticity. This fact can be understood by remembering that, in all the studied soils, the clay fraction was of the kaolin group.

Fig. 5 presents the variation with depth of the Atterberg limits, moisture content, grain-size distribution and porosity of a residual clay from the decomposition of a clayey-sandstone, from Campinas (State of S. Paulo). The superficial layer of porous sandy-clay, with a constant and low water content, over a layer of stiff clay is clearly shown. The grain-size distribution is almost uniform but the porosity varies with

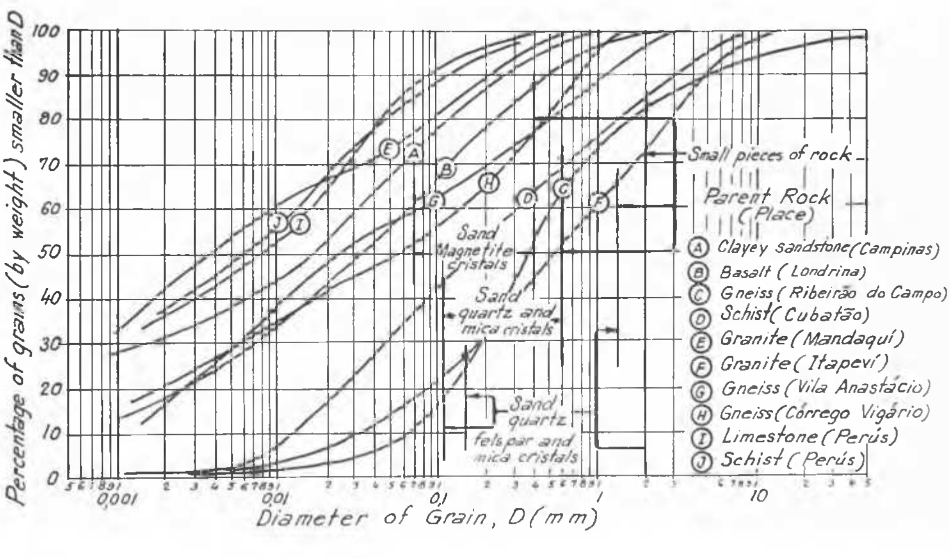

Fig. 3 Grain Size Distribution of Residual Clays
Distribution granulométrique d'argiles résiduelles

depth. It has an average value of 55% in the upper layer and only 40% in the lower one. Also, as the water content is almost constant, the air content is high in the upper layer and almost absent in the lower layer.

High porosity and non-saturation of residual clay only occur

Virtual Pre-Consolidation Load in Residual Clays

The concept of pre-consolidation load, introduced by *A. Casagrande*, is plainly defined and explainable in the particular case of sedimentary clays. It has no meaning on residual

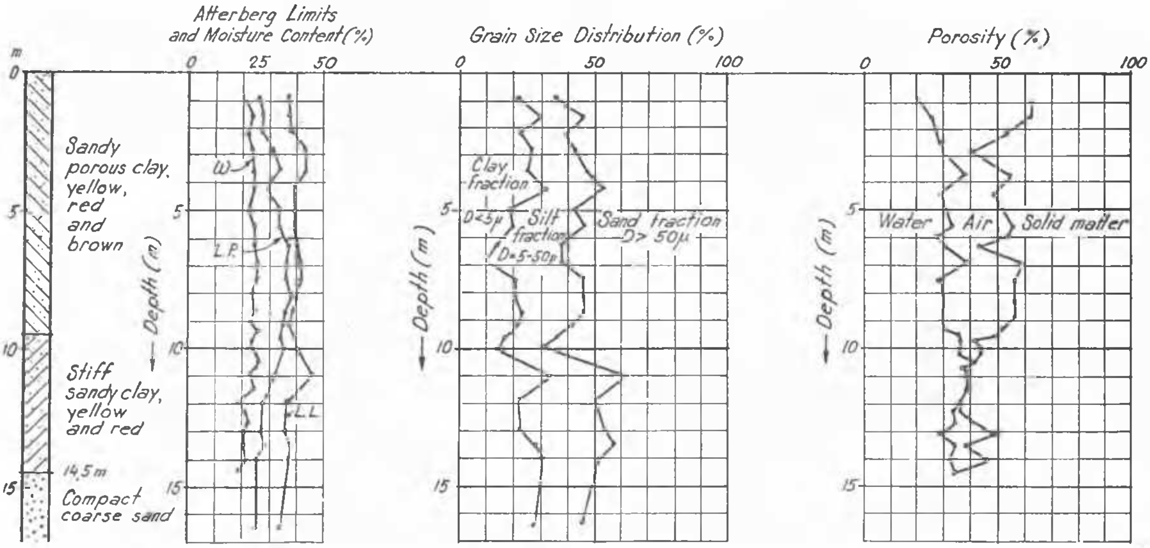

Fig. 5 Porous Residual Clay (Campinas) from Decomposition of a Clayey Sandstone. Variation of Consistance, Grain-Size Distribution and Porosity with Depth
Argile résiduelle poreuse (Campinas) provenant de la décomposition d'un grès argileux. Variation de la consistance, distribution granulométrique et porosité selon la profondeur

in superficial layers. Fig. 6 shows the same variation of Atterberg limits, grain-size distribution and porosity with depth for a layer of residual clay from the decomposition of gneiss, never exposed to the atmosphere. In that case the evolution which brings the residual soil to the porous state could not progress and the porosity is almost constant with depth.

Similar distribution of Atterberg limits and grain-size distribution was observed in several borings where such observations were made. The occurrence of the porous state was observed in superficial layers of granite, gneiss, schist, sandstones, claystones and basalt. Also the superficial layers of tertiary clays suffer the same phenomenon and the result is a porous clay whose properties are very similar to those originated from igneous and sedimentary rocks.

Consolidation and Shearing Resistance of Residual Clay

Experience has shown that the decrease of void-ratio with applied normal pressure in residual clays follows the same law which governs the consolidation phenomenon for sedimentary clays. That is, there is a minor decrease of void-ratio when the applied loads are smaller than a certain value and when they exceed this value the decrease of void-ratio is proportional to the logaritm of the relation between the final and the initial pressure.

Experience has shown also that the shearing resistance of a sample of residual clay is a function only of the void-ratio in the moment of rupture, whatever the type of test, provided that the samples submitted to the test had all the same degree of saturation at the moment of rupture.

Shearing resistance of residual clays was treated with some detail by the author in another paper submitted to the 3rd Conference on Soil Mechanics and Foundation Engineering.

clays. However, consolidation tests show that there is, for the latter clays, something similar to the pre-consolidation pressures. That is, up to a certain load the decrease in void-ratio by consolidation is very small; after the applied load exceeds that limit, the relation between void-ratio and applied pressures follows the consolidation law. This critical load which limits both behaviours of clays can be determined by *Casagrande*'s

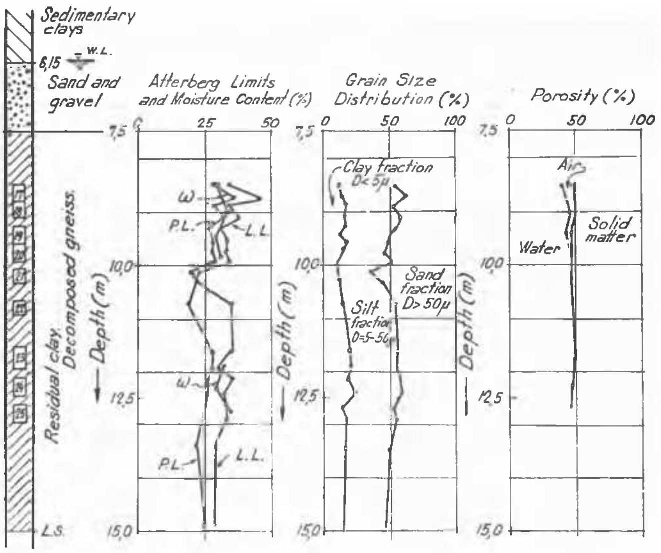

Fig. 6 Residual Clay (Belo Horizonte) from Decomposition of Gneiss. Variation of Consistance, Grain-Size Distribution and Porosity with Depth
Argile résiduelle provenant de la décomposition du gneiss. Variation de la consistance, distribution granulométrique et porosité selon la profondeur

empirical method in the same way as for the sedimentary clays.

Under such consideration we decided to call this limit load, "virtual pre-consolidation pressure". The explanation of the existence of such value can be made as follows: Let us suppose a certain superficial portion of a rock decomposes and transforms into a uniform and homogeneous soil. Such a soil will have a certain void-ratio, ε_0, which depends entirely on the nature and structure of the parent rock. If we remould this soil, increasing its water-content until slightly above the liquid limit we, certainly, will obtain a sample with a void-ratio ε_{LL} superior to ε_0. If we run a consolidation test on this sample we shall obtain a consolidation curve similar to $A'B'$ (see Fig. 7). If we compact the soil in its optimum moisture and maximum density and then carry out a consolidation test we will obtain a curve like $A''B''$. Finally if we remould the clay at its natural water content, we shall have a consolidation curve, intermediate between $A'B'$ and $A''B''$ (see curve $A'''B'''$ in Fig. 7).

If, however, we run a consolidation test on an undisturbed sample of the residual clay soil we will see that the resulting

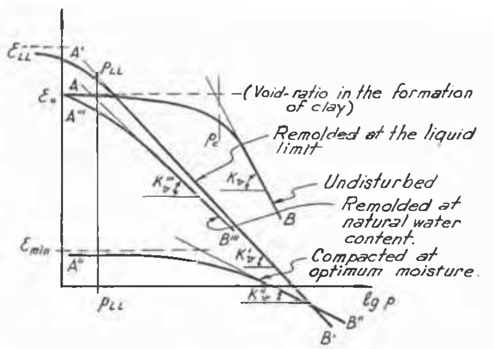

Fig. 7 Consolidation Curves for Residual Clays
Courbes de consolidation pour argiles résiduelles

curve AB cannot coincide with any of the three above mentioned curves (except in extreme cases with $A'''B'''$). The only possibility is a curve like AB, which we shall call "basic consolidation curves"; in connection with it we can observe a "virtual pre-consolidation pressure" defined as above.

For a shallow sample of a residual clay, when the earth pressure above the sample is less than the "virtual pre-

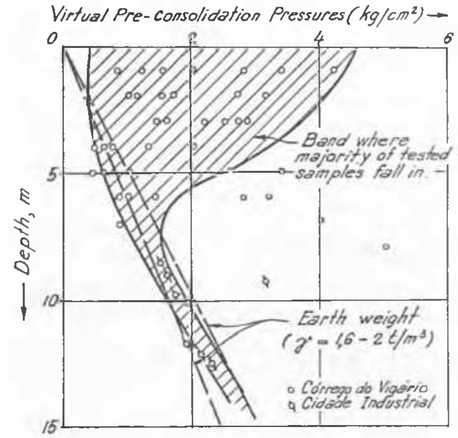

Fig. 8 Virtual Pre-Consolidation Pressures Against Depth of Samples
Pressions virtuelles de préconsolidation dans le sens contraire à la profondeur des échantillons

consolidation load", the consolidation test will show the real "virtual pre-consolidation pressures" of the residual soil. But for deep samples, when the earth pressure is bigger than the "virtual pre-consolidation pressure", the pre-consolidation pressures observed in the test will constitute a real pre-consolidation load equal to the earth pressure above the sample.

In the majority of cases residual soils cannot be represented by only one "basic consolidation curve". There will be at least a basic curve for each layer of parent rock of different kind. So there will be no correlation between the depth of sample and the "virtual pre-consolidation pressure" above a certain elevation. Under such an elevation there will be observed a pre-consolidation pressure similar to the classical one, regardless of the soil nature and properties (see Fig. 8).