43. *Colloids and Seismology.*

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1. Seismology is a special branch of applied science and owes its essential advancement to the application of our knowledges in almost every department of pure science, i. e., not only of physical, but also of chemical and even of biological sciences. Introduction of any new source of knowledges in the domain of seismology will not fail to shed some new light under which some problems may obtain a further elucidation than might be otherwise possible.

2. Among the fundamental knowledges upon which the investigation of earthquake phenomena are based, the most important are those related to the mechanical properties of materials constituting the different layers of the earth's crust, such as elasticity, plasticity, viscosity, visco-elasticity, etc. In want of exact knowledges about these properties, any reliable theory of seismic phenomena can scarcely be propounded.

3. The materials constituting the earth's crust are mostly colloidal, if we use this word in its widest sense, i. e., in the same sense as we may call any polycrystalline metallic alloy as such. Especially, among the materials constituting alluvial deposits there are many which must be regarded as colloids in the ordinary sense of the word. As regards such a substance, other mechanical properties come into play than are usually taken into consideration in dealing with problems concerning the mechanical behaviour of the surface crust.

4. An example near at hand is the alluvial sedimentation deposited as a river delta. The problems of colloidal sedimentation in such a case was already investigated from many sides. As regards, however, to those very problems which are most closely related to seismology, due attention seems to have not yet been paid. From the seismological point of view, the gradual volume change of the deposited materials subsequents to sedimentation, due to the gradual change in

1) For example see Pierre URBAIN, "Les science géologiques et la notion d' état colloidal", (1933).

colloidal states of materials, i. e., change in degree of coagulation, swelling, etc., cannot be carelessly put out of consideration, especially in cases when we are to deal with the mode of vertical movements of the earth's crust such as revealed by the results of repeated precise levelling survey. For instance, if there may occur a linear contraction or expansion of only 1/10,000 in a layer of 100 m thickness, it will be observed as a subsidence or upheaval of 10 mm of a bench-mark situated on such a layer, an amount which may easily be detected by means of precise levelling, provided that there exists a point of reference or datum station which is not very far from the above said bench-mark and which is situated upon a substratum not much affected by such a colloidal change of volume.

5. In considering the physical significance of the vertical displacement of bench-mark situated upon a layer consisting of mud, sand and gravels, the following factors must necessarily be considered:

(a) Effect of the change in mode of packing of granular mass, an effect which was fully treated in O. Reynolds's classical investigation.

(b) Effect of electrolytes on the apparent volume of fine sand as was recently investigated by Freundlich and Juliusburger[2] with powdered slate from Solnhofen.

(c) Effect of the change in degree of swelling due to any change in electrolytes content of water circulating in the sedimentary layer.

(d) Effect of volume change connected with the change in content of capillary water due to the capillary force.

6. According to (a), various modes of change in level of the ground surface may be brought about. If a layer of the substratum consisting of granular mass in state of closest packing be violently disturbed by severe shocks of such an intensity as is observed in the epicentral region of destructive earthquake, a sensible dilatation of apparent volume may be produced. The amount of volume change due to this cause is known to be quite sensible, as is demonstrated by sudden drying up of the surface of fine sand layer on a sea shore when trodden upon. Hence, in the case when the thickness of the layer disturbed be of several hundred metres or more as is usual with sedimentary deposit, the total amount of upheaval of the surface may become quite sensible. The upheaval due to this cause may tend afterwards to gradually subside and the subsidence may be accelerated by suitable shocks or vibrations, as may also be demonstrated by laboratory experiment.

2) *Trans. Farady Soc.*, **30** (1934), 333; see also *ibid.*, **31** (1935), 769, in which thixotropic property of "quick sand" is discussed.

In actual cases, therefore, in which a sudden upheaval is observed in the epicentral region of severe earthquake, accompanied with subsequent gradual subsidence, it will be reasonable to inquire whether the above effect may not be involved, at least partly, in the mechanism of the change observed. The following alternative is also conceivable: i. e., the constituent granular matters which were initially in equilibrium in state of closest packing may undergo gradual chemical and physical change and, on account of it, the grains may acquire mechanical and colloidal properties somewhat different from those formerly possessed. This may lead to a deformation in the geometrical shape of grain and consequently to a new mode of closest packing throughout the layer containing these grains. The transition to the new state of packing may be facilitated by seismic shocks or vibrations. It may also be remarked that what is considered above may apply not only to a loose granular mass but to some kinds of rock mass, though in comparatively less degree, if we consider that the subterranean rock layers are run through with numerous joints and fissures.

7. Next, according to (b) and (c), we may consider the following points. Alluvial sedimentations, especially those in the case of the delta of a river discharging into sea, took place in water with a certain concentration of the constituent electrolytes. Afterwards, the upper surface of the sedimentation layer had been exposed to atmosphere. The constant percolation of meteoric precipitation water may have resulted in some change in electrolyte contents of the colloidal matters contained in the layer by a process similar to dialysis, and thence may have led to a change in degree of coagulation and swelling. The latter change may sometimes contribute something to the apparent change in the level of the ground surface, as it is well known that the mechanical stress caused by such a colloidal process may attain enormous amount under favourable circumstances.

8. As regard to the factor (d) above mentioned, we way point out a case in which, the increase of plastered area as well as the development of sewage system in a city, have brought about a considerable lowering of the ground water level. In this case, if the substratum be of such a nature that its apparent volume is sensitive to its content of capillary water, we may expect some sensible change in the height of benchmarks situated on such a ground.[3]. It is well known that some kinds of soil are subjected to very conspicuous contraction

3) Mr. N. Miyabe is at present engaged in the investigation regarding this point and his result will appear in this Bull. in a near future.

by loss of water content.

9. The actual vertical displacement of the surface of the ground revealed by the method of repeated precise levelling may be regarded as the resultant of the displacement of the underlying earth's crust proper due to geotectonic causes plus the elastic and plastic deformation due to some change in surface loading both natural and artificial, and the displacement due to the colloidal volume changes above considered. It is therefore of serious importance to carefully discriminate in what degree the above enumerated colloidal factors are participated in producing the observed change in the heights of bench-marks, especially in the case when the substratum consists of loose alluvial deposits as in the cases of Osaka and some quarters of Tôkyô. Without such a discrimination of complicated causes it is difficult to say anything definitive about the geodynamic process going on in the deeper part of the crust such as is closely connected with the origin of earthquake.

10. In view of the above considerations, the rapid subsidence observed in the course of the last few years in a certain limited area in the city of Tôkyô[4] and also of Osaka[5] may be suspected to be connected at least partly with the causes mentioned above. The areas with the remarkable annual rates of depression are situated on alluvial formations of rather recent origin. Moreover, in the last ten years the plastered areas of streets have been rapidly increasing and in some places a remarkable lowering of underground water level is reported. It is, therefore, premature to conclude from the apparent depression of levelling routes in these areas that the earth's crust proper under these areas are undergoing corresponding rapid deformations and it is too far fetched to anticipate a coming severe earthquake in these regions, before a careful analysis of the observed data into their various components due to the respective causes has been effected.

11. On the other hand, the change in colloidal state is often connected with a change in mechanical stress prevailing in colloidal medium. An example is afforded by enormous pressure exerted by a swelling gel. A change in state of a colloidal alluvial deposit may sometimes give rise to an additional stress upon the surface crust and may eventually play a role as one of the secondary causes of earthquake, in the case when the linear dimension of the area covered with such a layer be comparable with the thickness of the crust in which the potential energy of earthquake is stored up.

4) N. Miyabe, *Proc. Imp. Acad.*, **8** (1932), 417.
5) A. Imamura, *Proc. Imp. Acad.*, **8** (1932), 378; **11** (1935), 186.

12. Among the other mechanical propoperties of colloids which may be of special interest for seismologists, we may especially mention the *thixotropic* property of some class of colloids. An interesting example was recently studied by Freundlich and Juliusburger in the paper already cited. The present author experimented with a kind of sand called "aosuna (blue sand)" which is an artificial mixture of sand with some organic colloid pigment and commonly used for wall plastering of Japanese houses. A conspicuous stage of thixotropy could be observed, when the sand is made to deposit slowly in water contained in a cylindrical glass vessel. The sand is first thoroughly shook with water and made to deposit. When the sedimentation is ended a slight shock is given to the vessel. The head of the sand column shrinks down by a certain sensible amount. A second shock causes the second shrinkage and so on. When the shocks are thus repeated, a stage is attained when the sand layer is apparently solidified so that by tilting the vessel no flow or deformation of the surface of the sand is observed. By giving, however, a violent shock to the vessel, the solid sand mass is at once transformed into liquid as may be seen from the oscillating motion of its surface. The surface then falls down slightly and again solidified. The thixotropic state may be once more or twice observed by repeating strong shocks. Finally, the whole mass is solidified as far as the present kind of demonstration experiment is concerned.

13. There seems to exist some class of geophysical phenomena which may be rightly explained by taking account of the thixotropic property of earth materials. On the occasion of the Kwantô Earthquake of 1923, a striking case was reported of sudden emergence of buried wooden pillars above the surface of a rice field near the River Sagami. The pillars once formed the piers of an ancient wooden bridge and remained long under the soil, being forgotten even by the inhabitants of the locality. It is probable that the severe shocks of the earthquake, having its epicentre near this locality, momentarily turned the earthy materials surrounding the pillars into a state comparable to a fluid and the wooden pillars were upheaved on account of their own bouyancy, which is large due to the large density of the ambient "fluid".

14. In the case of landslides which are most frequently induced by severe earthquakes this very thixotropic property of earthy substratum may also play some important part, provided that the substratum to be traversed by the "slip-plane" is especially endowed with such property. This consideration will suggest some modification in the usual theory of landslide phenomena.

15. The present note is written with the mere purpose of drawing the attention of seismologists especially those interested with the secular movement of the earth's crust, to those colloidal properties of some crust materials as are here considered, as these properties seem to have not yet been duly taken account of, inspite of their probable importance in connection with many urgent problems of modern seismology.

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43. コロイドと地震學

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地震學の基礎として地殼を構成する物質の物理的性質に關する詳細な知識が必要であるが，從來の地震學では地殼を普通の固體と見做し，それの彈性，粘撓性，粘性，粘彈性等を考慮してゐるに過ぎない．多くの場合にはそれで一應十分であらうが，必しもさうでない場合がある．例へば地殼上層が膠狀物質と考へられるもので成立つてゐる場合がさうである．

普通岩石の如きものも廣義に於けるコロイドと見られないこともないが，それよりも，普通沖積層と稱する地層中には普通の意味でコロイドと稱すべきものを含有するものが多い．

從來でもこれ等膠質物の沈積に關する研究は多いが，一旦沈積した後に於けるそれの體積變化に關する膠質物理學的研究は比較的少なく，特に地震學に連關してのさうした研究は甚稀である．然るに近來地震學上から地殼の垂直變動に關する水準測量成果の研究が盛になつて來て，水準線路の昇降から地殼の運動が推定されるやうになつたので，此際に於て膠質的地層の體積がその含水量や電解質含有量の長期變化によつて如何なる程度に變化し得るかを研究し，それを地殼深層までも參與するやうな正當な意味での地殼變動と區別して考へることが必要であると思はれる．

細砂や粘土が水と混合したものは，その水中の電解質含量の多少により著しい體積變化を示すことが知られてゐるので，河口三角洲に堆積した此種の層が水面に露出して後多年降水の滲透を受けて電解質含量を變じ，その爲に起る可逆的或は不可逆的な見掛け上の體積變化を生ずる事も可能である．

又土壤の如きものゝ見掛けの體積は含水量の變化により著しい變化を示すこともよく知られて居る．

此等の變化は數プロセントより時には數十プロセントに達する．假に 100 m の層の厚さが 1% 變れば表面の標高變化は 1 m に達するのである．それで精密水準測量の結果で數粍又は數糎の昇降を論ずる場合にはどうしてもこの因子を度外視することは出來ない．

近年東京の本所，深川，又大阪市の一部が年々著しい沈降を示し，一見地殼の大變動を豫想せしめるものがあるが，此等の地はいづれも比較的新時代の冲積層より成るものであるから上記の如き膠質的變化による體積變化も無視する事が出來ないし，又一方此等地方では最近數年間市街

の舗裝工事並びに下水工事の進捗の結果として地下水の系統に可也著しい變化が起つたであらうと考へられるから，この爲にも表層土壤の體積變化が若干起り得るものと考へなければならない．兎に角此等の諸點を考慮しこれ等に因る水準變化の部分を除去した後でなければ容易に地殼運動等の問題を論ずることは困難であらう．

なほ，膠質の膨潤等により強大な器械的歪力の發生することも知られてゐるから，表面沖積層等の體積變化に伴ふ歪力が地震發生の第二次的誘因として作用する場合もないとは云はれない．

なほ又或種の膠質物に特有な所謂 Thixotropy の現象も地震學と連關して時に考慮を要することがある．例へば地震によつて地下に埋沒してゐた橋脚が浮上がつたりする現象はこれで說明される．又地辷りの場合にもこの性質が重要因子となり得る．

土砂層の見掛けの體積にはレーノルヅの研究した粒子充塡度の影響もあるので，大地震の激動で地盤が擾亂を受けた際この效果で表面が隆起し，その後徐々に落着く場合もあり得るから此點も考慮を要する．又相當深い地層でも多數の裂罅を有する場合には地震の爲に各岩片が平衡位置から移動して見掛けの體積を增す場合があるかも知れない．

此等の諸點を十分考慮に入れた上で地殼變動を論じなければならないので，その爲には將來地震學の範圍內に一般膠質に關する物理化學上の知識を十分に取入れることが望ましいと思はれる．
