Reports

Possible Quick-Clay Motion in Turbidity Currents

Abstract. Sensitive clay masses that lie dormant for years but, as the result of a sudden shock, become turbulent, flowing mud, have been called quick clays. Such masses may move in quantity over almost flat terrain, and they exhibit the power to transport buildings and other heavy objects considerable distances. On theoretical grounds it is proposed that one of the elements in the flowage of turbidity currents on the ocean floor may be comparable to quick-clay flowage on land. Both types of flowage cover considerable areas, may move on a comparatively flat base, exhibit fairly rapid motion, involve masses of colloidal-size clay and detritus, exhibit powerful transporting power, involve porous material of high water content, and are initiated by some form of trigger action. While experimental data are inadequate for proof, the parallelism in these two forms of erosional movement warrants the suggestion that the mobile mechanisms responsible for mass transport may be similar in the two cases.

The work of a number of investigators has led to the conclusion that large earth movements occur on the floor of the ocean (*1*). Such slides not only form on the continental shelves but travel at times for many miles on almost flat ocean bottom. It has been postulated that these flows behave like turbid mobile masses or "turbidity currents."

The cause of turbidity currents appears not to have been well established. A landslide mechanism similar to the mechanism of landslides on land was first proposed (*2*). However, a normal landslide would hardly account for a submarine movement 400 miles long such as occurred on the Grand Banks of Newfoundland at an average slope of less than 0.5 percent. It would appear that some additional mechanism must be involved, to cause such powerful movements for long distances over essentially flat ocean bottom.

It is suggested that movement of marine clays, as established in Norway (*3*), in Sweden (*4*), and along the St. Lawrence River valley in Canada (*5*), may indicate such a mechanism. In Norway these clays, which undergo abrupt mass transformation, have long been referred to as quick clays. Such clays are of marine glacial origin, were deposited during the Pleistocene, and have since been elevated, forming benches, terraces, and flat uplands now as much as 650 feet above sea level. On occasion, areas of such clays, hundreds or even thousands of feet in diameter, may change from a flat stable field to a turbulent mass of moving clay. In such instances the change in shear resistance between the original clay and the remoulded mass—that is, the sensitivity—is high. Such clays with high sensitivity are locally called "quick."

The quick-clay slide which occurred at Surte, Sweden, in 1950 is one of the most carefully studied clay movements on record (*6*). The velocity of movement was 2 to 3 mi/hr, the slope was 4° in part but largely less than 1°, and much clay was involved in the movement, while 31 houses, a railroad, and a highway were displaced. An estimated volume of 106 million cubic feet of clay formed a slide 2200 feet long and 1200 feet across in less than 3 minutes. The material involved was largely clay and silt, although portions of pebble beds were rafted along with the fluid mass. The investigating commission considered the possibility that a pile driver operating in the area may have provided a trigger action which initiated the slide. Once initiated, the conversion of clay to mud spread rapidly throughout a large area of clay strata, and an almost negligible slope was adequate to cause flowage. The spread and change in physical state have been compared to the behavior of a thixotropic gel. However, the physical change in the clay is not reversible.

A great slide occurred along the Grand Banks south of Newfoundland in 1929 (*7*). The slide caused the breakage of 12 transatlantic cables; involved an area 400 miles long and 230 miles wide; lasted for 13 hours, 17 minutes; had a velocity up to 14 mi/hr; moved on a slope of 1°50′, about half of it less than 1°; involved clay, sharp sand, and gravel; and was initiated by a severe earthquake (of magnitude 7.2).

There are many unknown factors in such a movement. However, the presence of a fine clay mass, the high water content of the clay pores, and the trigger action of a shock suggest the possibility that sensitive submarine clay masses, similar in general to quick-clay masses on land, are involved.

A critical factor in a comparison of quick-clay flows with turbidity deposits is the nature of the materials involved. Gravels, sands, and siltstones are transported in turbidity movement; while such coarse materials are frequently included in slides, it seems more relevant to attribute mobility to the clay constituent.

Submarine cores from areas of turbidity deposits have been studied in several laboratories. Likewise, a considerable amount of investigation has been devoted to quick clays. Turbidity deposits from the Mindanao Trough (*8*) and from the Puerto Rico Trench (*9*) may serve as examples. The Mindanao sample contains a considerable fraction of fine clay (grain size, $< 2\ \mu$) with illite abundant and montmorillonite common, while kaolinite, quartz, and feldspar are present but rare. The fine-clay content of the Puerto Rico submarine cores ranges from 5 to 75 percent, with illite the most prominent constituent. Montmorillonite and chlorite are also reported. Fine aragonite is abundant in place of clay in some cores. Cores from the North Atlantic continental slope (*10*) and the basin floor north of Bermuda contain illite and chlorite and small amounts of kaolinite and montmorillonite, although not known to be from turbidity deposits. In similar studies of sediments (*11*) on the Pacific floor or the California shelf, abundant illite, with montmorillonite

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Type manuscripts double-spaced and submit one ribbon copy and two carbon copies.

Limit the report proper to the equivalent of 1200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to *one* 2-column figure (that is, a figure whose width equals two columns of text) or to *one* 2-column table or to *two* 1-column illustrations, which may consist of two figures or two tables or one of each. Submit three copies of illustrative material.

For further details see "Suggestions to contributors" [*Science* **125**, 16 (1957)].

and some kaolinite, has been reported. The sediment on the floor of the Gulf of Mexico (*12*) is reported to contain illite, montmorillonite, kaolinite, chlorite, and mixed layer material. In general, it would appear (*13*) that illite (or hydromica), montmorillonite (or vermiculite), and chlorite, are prominent in submarine clays.

Terrestrial quick clays of marine origin might be expected to resemble submarine clays. Results of studies of the Norwegian (*14*), Swedish (*15*), and Canadian (*16*) clay types, confirmed by observations in the Columbia University mineralogical laboratory, indicate that illite in fine sizes is a prominent constituent of quick clays, while montmorillonite, chlorite, and kaolinite are present. Such fine clay (largely of grain size less than 2 μ) with flaky texture and layer lattice structure, tends to develop unusual physical properties in large masses, behaving in what seems to be a somewhat thixotropic manner.

In quick-clay masses the loss of the natural electrolyte sodium chloride by fresh-water leaching (*16*), or the addition of a natural organic dispersant, such as tannic acid, or of calcium and magnesium ions (*17*) also acting as dispersants, increases the sensitivity of the clays. Clays in such a sensitive condition, or with such a high water content that the electrolytic factor is outweighed, appear susceptible to mass movement. Such clays, whether they are sensitive quick clays or sensitive submarine clays, are all similar in nature and appear susceptible to sliding action with an accompanying rafting action which moves associated heavy materials (*18*).

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18. This study was conducted with the cooperation of the Cambridge Air Force Research Laboratories.

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Toxicity of Blood Clotting Factors

Abstract. Pure bovine thrombin was separated from autoprothrombin C, and the lethal intravenous dose for mice weighing 25 g was 0.4 ml of a solution containing 50 units of thrombin per milliliter. Autoprothrombin C was not toxic alone, but with crude cephalin it was fatal. The clotting time of human plasma was only slightly accelerated by autoprothrombin C alone; the clotting time was as short as 5 seconds with a combination of autoprothrombin C and cephalin.

When thrombin was first obtained in concentrated form, its intravenous infusion was found to be lethal when the dose was high (*1*). When the dose was smaller, a disseminated intravascular coagulation syndrome resulted, from direct clotting of the fibrinogen by thrombin. No other blood-clotting substance besides tissue extracts has been found to be toxic when infused intravenously. For instance, platelets and platelet degradation products were infused and clotting did not follow (*2*). Moreover, almost every conceivable concentrate of a procoagulant we have had in this laboratory has been tried (*3*). None has produced intravascular coagulation when given as a single substance or in combinations.

Recently autoprothrombin C was discovered in certain thrombin preparations (*4*), and we have separated it from thrombin so that purified thrombin and purified autoprothrombin C are available for intravenous infusion (*5*). Purified thrombin (*6*), shown to be homogeneous by several criteria, was assayed for its toxicity. Mice weighing an average of 25 g were given ether anesthesia, and the test material was injected into the tail vein rapidly by a technique previously described (*7*). The minimum lethal dose was 0.4 ml of a solution containing 50 units of thrombin per milliliter. Autoprothrombin C was not toxic in any of the concentrations tested. However, when it was combined with lipid material extracted from brain tissue, autoprothrombin C was found to be fully as toxic as tissue extracts.

Autoprothrombin C was added to a saline suspension of crude cephalin, and 0.3 ml of the mixture was injected. The autoprothrombin C was purified, as previously described (*5, 6*), and crude cephalin was obtained from bovine brain by drying the macerated tissue with acetone, extracting with ether, evaporating the solvent, and suspending the lipid in saline. The minimum lethal dose of autoprothrombin C was about 300 units. Without cephalin, 3500 units of autoprothrombin C were tolerated well, and we suppose that even much larger quantities could be given without toxic manifestations. Evidently the lipid mixture normally in the plasma is not of sufficient potency to be of consequence as a procoagulant to function with autoprothrombin C. Platelet factor 3 functions as a procoagulant with autoprothrombin C, but when it is in the living circulating platelets it is not free to react.

We have emphasized that the autoprothrombin C functions with lipids to convert plasma prothrombin to thrombin. To evaluate this procoagulant power in test tubes, we used crude cephalin suspension, added autoprothrombin C, and then combined this with calcium and oxalated plasma. With excess lipid the rate of clotting was proportional to the concentration of autoprothrombin C (Fig. 1). By itself

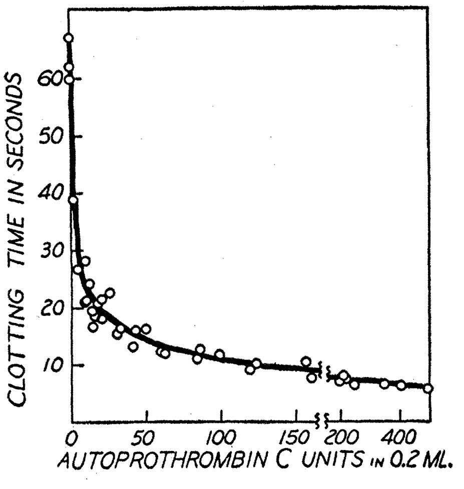

Fig. 1. Clotting time of normal human plasma in the presence of a constant quantity of calcium and lipid and of variable amounts of autoprothrombin C (at 37°C). The unit of autoprothrombin C has been previously described (*5*) in terms of kinetics of purified prothrombin activation. The reaction mixture consisted of normal plasma, 0.2 ml; crude cephalin (0.1 percent wt/vol), 0.2 ml; and autoprothrombin C (in $CaCl_2$, 0.025*M*), 0.2 ml.