THE GLARUS OVERTHRUST

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In June of 1970 it was my privilege to spend several days studying the classical Lochseite of the Glarus overthrust near Schwanden, Switzerland. Before going there I had an interview with Dr. K. I. Hsu of Zurich, who recently published a study of his interpretation of how this overthrust of Jurassic limestone on Eocene rock occurred. In this article a resumé of Hsu's observations and conclusions will be given first, followed by my own observations and experiments. A discussion of how this series of stratified rocks may be interpreted in terms of flood geology will then be given. A comparison of this overthrust with the far more extensive wrong order formation known as the Lewis overthrust, and recently observed small overthrusts resulting from the earthquake in the Newhall area described by Dr. George Howe in this issue will also be made.

Resumé of K. J. Hsu's Observations and Conclusions

K. J. Hsu[1] reported on his studies of the Glarus over-thrust in 1969. He concluded that the overthrust has a dimension of 35 kilometers (or about 21 miles) in length by about five to six kilometers in thickness. It lies upon an Eocene formation and consists of Jurassic limestone at the base and Verrucano conglomerate above. The limestone above the fault line is classified as Malm, and below as probably Vanlangien (L and L-2 in Figure 1).

The overthrust took place in two phases at least. The earlier phase of main movement was related to the flowage of the Lochseitenkalk (limestone) within the thrust zone. The later phase of frictional sliding produced the thin film of fault gouge within the Lochseitenkalk.

The later movement was probably related to an uplift of the autochthonous (sediment deposited in place) massif, which caused the present 10° to 12° northerly dip of the Glarus overthrust. If the pore pressure (in the rock) had remained abnormally high, the block would have to slide under its own weight. If the pore pressure had dropped to normal, then a push from behind would be necessary.

The earlier movement was related to a push from behind along a nearly horizontal thrust plane where the pore pressure was equal, or nearly equal to the overburden pressure.

The rate of the earlier displacement through the flowage of the Lochseitenkalk was estimated as ranging from .2 to 10 cm / year at a temperature of 300-400°C. at the base of the thrust, which is at about six kilometers of depth. The heat generated by overthrusting may have contributed to the steep geothermal gradient then prevailing in the Glarus region.

The rate of later displacement by frictional sliding was governed by either the rate of stress built up as a result of the push from behind by an advancing nappe, or by the rate of erosion of the toe which obstructed gravity sliding. In either case the displacement would be a jerky sliding resulting in a series of shallow earthquakes.

More precise study of strain rate; stress, and temperature, based upon experimental creep studies or tests of the Lochseitenkalk are planned.

Critique of Earlier Studies

K. J. Hsu believes that earlier studies of overthrusting erred in that only the friction at the base was considered in estimating minimum resistance. Thus Smoluchowski[2] concluded that the friction factor alone would restrict maximum length of an over-thrust to eight kilometers (about five miles). Oldham[3] suggested large overthrusts move like the crawl of a caterpillar which advances one part of its body at a time, and all parts in succession.

Hubbert and Ruby[4] substituted for the term "caterpillar crawl," the terminology "dislocation mechanism," which purportedly eliminated the cohesion strength in succession so that resistance to overthrusting was by friction only. This faulty analysis led them to greatly underestimate the shearing resistance at the base of overthrusts, and greatly overestimated their length and the ease of gravitational sliding along very gentle slopes. Hsu shows that their analysis is not applicable to those overthrusts whose movement is related to flowage of ductile materials within the thrust zone, and proposes a new treatment of the mechanism of such thrusts.

Hsu's Proposed Explanation

By a rather complicated mathematical analysis Hsu shows that brittle fracture depends on the initial shear strength or cohesive strength, and a variable friction term directly proportional to the effective normal stress. He maintains that Hubbert and Ruby erred in that they considered only the variable friction. Thrust faults as long as the Glarus cannot therefore be explained by their proposed mechanism.

Between the upper Verrucano and lower Eocene is the Lochseitenkalk, less than one meter

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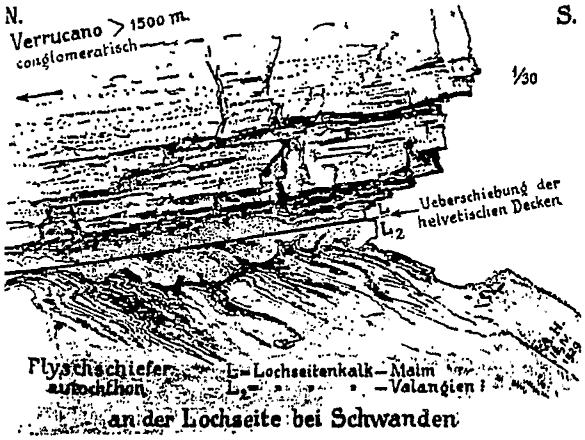

Figure 1. The thrust contact of the Glarus overthrust at Lochseite near Schwanden (Glarus), reproduced from Albert Heim, 1929, Naturforschende gesellschaft, Zurich, Viertel Jahrschrift, pp. 213-233.

thick. This smeared out limestone shows signs of flowage and is present practically everywhere as the lowest layer of the Glarus thrust (labeled L and L-2 in Figure 1). This Hsu considers as evidence that the upper thrust plate moved forward as the limestone *flowed.* There is in addition a fault gouge zone or a clay film, a few millimeters thick present as a planar system within the limestone.

Now fault gouge has been produced experimentally when one block slid past another along a pre-existing fracture surface as noted by Byerlee.[5] This gouge is then considered as evidence that the thrust later moved along a cohesionless plane by frictional sliding after the limestone had fractured with a loss of cohesion.

The main thrust was followed by uplift of the autochthonous massifs, which resulted in arching of the thrust plane and produced its present northerly dip of 10° to 12°. During the main phase the thrust plane was more nearly horizontal, and northerly dip not more than 5°. Since the plane was originally dipping only about 5°, the main movement could not have been due to gravity sliding. A push from behind must be assumed. Because of obstructions in front of such a thrust producing the so-called toe effect, the minimum angle would have to be at least 11.6° and more probably 20° to cause gravity sliding.

The rocks of the Glarus are re-crystallized in part. Sericite and Chlorite are present in the Verrucano formation. But there is no evidence of amphibolite facies metamorphism which starts at 540°C. and 2 Kilobars pressure at K-1. Hence the average temperature at the time of deformation and flow of the limestone could not have been more than 500°C.

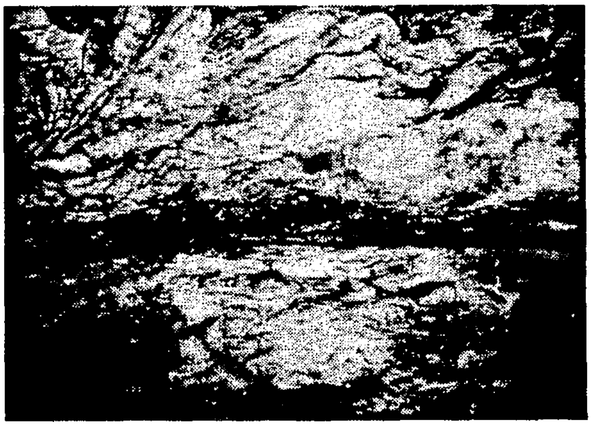

Figure 2. Almost straight line of contact L and L2.

A temperature of 400°C. seems to be higher than expected judging from the largely unmetamorphosed nature of the Flysch (Eocene) under the thrust. In the later phase of frictional sliding resulting in the gouge, a "stick-slip" jerky movement occurred. The stress built up and was then relieved by small slips such as those now causing earthquakes along the San Andreas fault.

Observations June, 1970

I left for Schwanden, Switzerland, by train from Zurich at 9:20 A.M. June 3, 1970. It was surprising how much open land and forests still remain. We arrived at 1:30, and after checking in at the Adler Hotel, immediately went up the Sernf river road, and after one wrong turn, soon found the little steps described by Dr. Hsu. A rather well worn pathway led to the outcrop shown in Figure 1. Unfortunately it was cloudy so pictures could not be taken.

The following day was clearer so some pictures of the contact line were quite clear cut. The following notes are most pertinent:

(1) The broken up clay at the contact line separating L and L-2 varies from 1/8 to one inch in thickness and is mostly 1/8 to 1/4 inch thick. This layer is almost horizontal and a very straight line. (Figure 2).

(2) The limestone is about six inches thick above and six to seven inches thick below the broken up clay layer.

(3) The limestone both above and below the contact is mostly very hard, though some is quite soft and does not seem metamorphosed.

(4) The contact of the limestone with the Verrucano above is very irregular.

(5) Also the contact with the Eocene below is even more irregular.

(6) The Eocene is very hard and a type of slate formation.

(7) Toward the north end of the exposure the contact line separating L and L-2 is lying

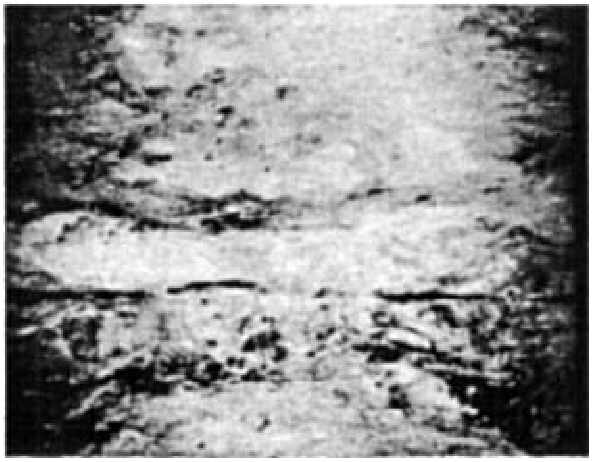

Figure 3. Shows black streaks of clay particles in L2.

directly on the Eocene rock in places with very little of the L-2 part below it anywhere.

(8) Soft areas like the gouge layer extend down as streaks for about 4 inches into the lower Jurassic (L-2). (Figure 3).

One of the most difficult facts as regards accepting Hsu's concept of flowage of the limestone, followed by a secondary movement of frictional sliding after its fracture between L and L-2, is that the gouge layer is mostly clay instead of ground up limestone particles. If the gouge layer is actually the result of the grinding action of the upper layer L sliding over the lower layer L-2. it would seem that a chalky, powdery type of layer would be formed. Chemical tests of this clay layer show that only about 5 to 10% of it is $CaCO_3$, the rest remaining insoluble in hydrochloric acid.

Even more important is the present order of the formations. In order to have the Verrucano, a Permian formation, on top of the Jurassic, Hsu postulates a recumbent fold of these formations, or overturning of them. They were then according to his concept thrust over the Eocene by the flow type of mechanism he postulates.

Now the usual order of these formations is of course Permian, Jurassic, and then much later the Eocene. An assumed overturning would have to occur after the Eocene above the Permian and Jurassic had been eroded away in the area they *were located* before the overthrusting, but *not in the present location at the overthrust.*

The fact that the Eocene rock is very hard and slaty makes it difficult to see how this differential localized erosion could have occurred. Besides the contact line of the Jurassic with the Eocene below is very irregular. Hsu's flow concept would allow for this but as noted above some of the limestone is quite soft and does not seem to have flowed. Though there is no question as to the fact of metamorphosis it seems strange this was not complete if heated to 300-400°C. long enough to make it flow for over 21 miles.

Also as indicated the contact of the limestone with the Verrucano now above it is also very irregular. This indicates that considerable erosion of the Verrucano took place before the Jurassic was deposited on it. Though in itself not conflicting with the concept of overturning and then thrusting over the Eocene, this evidence of large scale erosion would seem to fit in much better with a flood geology interpretation.

Flood Geology Interpretation

If one looks at this famous exposure of wrong order rock formations without any bias in favor of the authenticity of the geologic time table, a much simpler explanation of it can be given in terms of flood geology concepts. According to this view point the various formations have no time value in the sense of millions or even thousands of years of time, but were all deposited rather rapidly during or relatively soon after the world wide flood action.

The Eocene formation at the bottom of L-2 was deposited, hardened or rather consolidated to some extent and then eroded into its present irregular surface. Then the Jurassic L-2 layer of almost pure limestone was deposited but not in a completely uniform manner, the amount being greater in the south end than toward the north end.

After this a change of current and a quieter deposition period led to the formation of the 1/8 to one inch deposit of mostly clay particles, though some limestone particles were still in the water. That the transition was an uneven one may be supported by the fact that the streaks of black clay particles extend down into the L-2 layer of limestone.

This was followed by a renewed current carrying limestone particles resulting in the deposition of the Jurassic L layer above the clay. No erosion took place between the deposition of L-2, the clay layer, and L, hence these layers form an almost straight line. Following the deposition of L, considerable erosion took place causing the irregular surface. This erosion was followed by a long period of deposition from a different source, thus causing the very thick Permian or Verrucano conglomerate to be formed.

Most of the deposits have been more or less metamorphosed into partly crystalline rock. This is particularly true of the Jurassic formation and it may well be, as Hsu suggests, that they were heated to a temperature of 300-400°C. and flowed into their present position. The remarkable continuity of the Jurassic into the Verrucano above and Eocene below would then be accounted for.

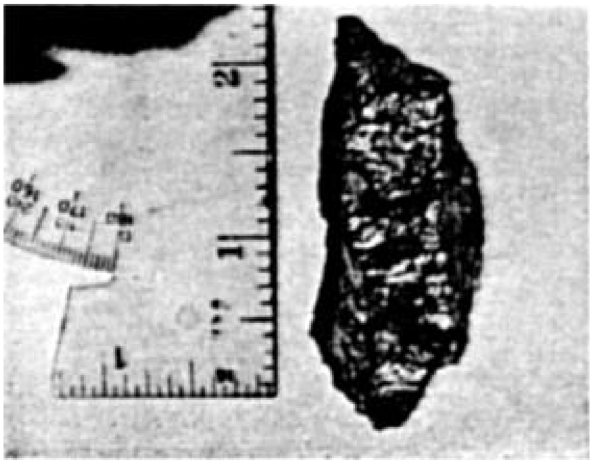

Figure 4. Sample from upper surface of thrust plane. Jurassic L just above the layer of clay. The limestone is noticeably metamorphosed. (Scale is in inches.)

As may be seen by a careful study of Figure 2 these contacts are no longer depositional but the rock is actually so intimately united that it is difficult to obtain samples of one without some of the other. (Note irregular black Eocene in very close contact with the Jurassic at bottom of Figure 2.) The Eocene formation was also much hardened and as Figure 1 shows is now inclined and much distorted. The Verrucano above is also a very hard rock formation, though relatively unaltered as compared to the Jurassic and Eocene.

The flow postulated by Hsu could hardly have resulted in a movement of over 21 miles since some of the Jurassic limestone has not been metamorphosed. This part is a rather loosely compacted material which can be broken off and pulverized with one's fingers. It is mostly found in the lower or L-2 layer. Both it and the crystalline metamorphic parts consist of almost pure limestone dissolving rapidly in hydrochloric acid. About 1% or even less consists of magnesium carbonate since part of it dissolves in hot hydrochloric acid, and the rest is made up of dark almost black particles and some undetermined mineral.

It is interesting to note that the upper or L layer contains no black streaks of clay particles, and is a remarkably pure limestone, dissolving completely in hydrochloric acid. Microscopic study of both L and L-2 particles indicated that they are of inorganic origin. No evidence of any even minute fossils was found.

The flow mechanism suggested by Hsu could hardly apply to such large scale wrong order formations as the so-called Lewis overthrust. As described by Burdick the contact line shows no evidence of any gouge layer, breccia, or striation.

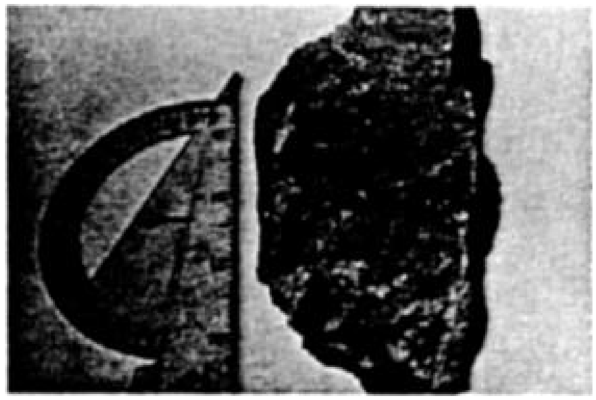

Figure 5. Sample from lower surface of thrust plane. L 2 surface just below the layer of clay. Some of the limestone was quite soft. (Scale is in inches.)

Also the Altyn limestone above unlike the Jurassic of the Glarus overthrust shows no evidence of flowing and resultant metamorphosis. It is a relatively soft, sandy dolomite of light buff color.

As regards the later phase of movement, there is no question as to its occurrence leading to the thrust plane now visible. Any stress built up would be most readily relieved at this comparatively thin weak layer of clay. It is however, difficult to see how this movement *caused* the clay layer as postulated by Hsu since movement of two surfaces of limestone against each other would result in a gouge of limestone particles.

Clay or kaolin results from the breakdown of feldspar. As mentioned above only 5 to 10% of this layer is calcium carbonate. Furthermore the upper L and lower L-2 contact surfaces of the very hard Jurassic with this clay layer are very glossy, black, and uneven. Not the slightest trace of even a striation can be seen (Figures 4 and 5).

Undoubtedly many small movements each accompanied by an earthquake have occurred. This resulted in the highly polished look of both surfaces as they moved along the comparatively soft black clay layer separating them. These "stick-slip" jerky movements are the same as those now occurring along the famous San Andreas fault.

As shown by Howe[7] these result in very bad breakage and gouging when hard surfaces slide against each other, but relatively little damage if one surface is soft. Certainly phenomena such as these could never result in any major 21 mile movement such as is postulated at the Glarus overthrust. This part of Hsu's able analysis is undoubtedly correct.

Conclusions

In conclusion the following has been established:

(1) The Glarus "overthrust" is a complex one in which the formations instead of being in their correct order according to the commonly accepted geologic time table (i.e. Permian, Jurassic, Eocene) are actually Eocene, Jurassic, Permian.

(2) In order to explain this order, Hsu postulates a recumbent fold placing the Jurassic under the Permian followed by a 21 miles thrust over the Eocene formation.

(3) This thrust resulted from a push from behind, heating the Jurassic rock to from 300-400°C. so that they flowed into their present position.

(4) A secondary series of small movements is also postulated resulting in the gouge layer of clay from 1/4 to one inch thick.

(5) As opposed to Hsu's conclusions it is shown that the so-called gouge layer is only 5 to 10% limestone, the rest being clay particles. Also the surfaces of both L and L-2 in contact with this clay layer are shiny and black, show no striations, and even their irregularities have not been worn away.

(6) The small "stick-slip" movements resulting from stress were thus rather easily made against the relatively soft clay layer.

(7) Undoubtedly a major movement such as postulated by Hsu also occurred which initiated the almost level fault line. The stress may very well have heated this rock to 300-400°C. so that it flowed into its present position physically united with the uneven Verrucano or Permian above and irregular Eocene surface below.

(8) The evidence for a *flow* of 21 miles is lacking since only the major part of the Jurassic limestone was metamorphosed into its present crystalline structure. Much of the limestone is quite soft and shows no evidence of metamorphoses and movement.

(9) From the view point of a world wide flood and later resultant settling stresses there is no need to postulate a flow of 21 miles. It is more likely that this limestone flowed only as far as necessary to relieve stress.

(10) An outline is given as to how these deposits may have been laid down in their present order, and later subjected to pressures and vulcanism resulting in their partial metamorphoses.

(11) It is shown that the flow type of mechanism postulated by Hsu will not explain such vast wrong order formations as the so-called Lewis overthrust since no large scale flow type of metamorphosis is found in the Altyn limestone lying immediately above the Cretareous shales.

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