DIAGENETIC ORIGIN OF CHERT LENSES IN LIMESTONE AT SOYATIAL, STATE OF QUERETARO, MEXICO.1

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EVIDENCE concerning the diagenetic origin of chert was obtained as a by-product of an investigation, by the U. S. Geological Survey, of antimony deposits in Mexico. The Soyatal district is in the north-central part of the state of Querétaro, about 120 kilometers by dirt road north of Bernal, the nearest shipping point on the Mexican National Railroad.

The sedimentary rocks of the district have been divided into three formations. In accord with the custom of the Geological Survey for local strategic mineral investigations, these rocks were distinguished merely as the lower, middle, and upper formations. The lower formation is a thick sequence of limestone, with some shale and limestone conglomerate. The middle formation generally consists of about 30 meters of limestone containing numerous lenses of chert, whose origin is discussed in detail. A few beds contain poorly-preserved fossils that indicate a lower Cretaceous age. The basal beds of the upper formation, separated from the middle formation by a disconformity, generally consist of limestone conglomerate that grades upward through impure limestone into shale.

The rocks were folded and faulted, and in a few places were intruded by dikes of basalt and altered andesite.2

The limestone of the middle formation is light gray when weathered, but dark gray to blue-gray on fresh surfaces. Individual beds are 5 to 50 centimeters thick and are commonly separated by thin shaly partings, which are mostly red or reddish-purple. Upon close examination each limestone bed is found to be laminated to a degree that is unusual in limestone. The lamination is generally parallel to the beds, but deviations due to local channeling are not uncommon. These

1 Published by permission of the Director, U. S. Geological Survey.
2 For further details concerning the general stratigraphy and structure, the reader is referred to a forthcoming bulletin of the U. S. Geological Survey, entitled "The antimony deposits of the Soyatal District, State of Querétaro, Mexico," by Donald E. White.

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internal structures are believed to be caused by an original accumulation of calcareous sediments consisting of clastic grains up to 1 or 2 millimeters in diameter.

The chert lenses are varied in color and form. They are black, dark to light gray, and tan, and lenses differing in color are found within a few meters of each other in the same bed. The dark lenses are generally uniform in color, and are lacking in relict structures such as would indicate the original character of the material. The light-colored lenses, on the other hand, commonly contain dark streaks and bands that correlate with the bedding in the adjacent limestone. Why the chert varies in color is not known.

Individual lenses range in thickness from less than 1 centimeter to more than 30 centimeters, and average about 10 centimeters. A limestone bed that contains a large proportion of chert in one place is likely to contain a similar proportion of chert along the strike for at least 100 meters and possibly farther; that is, about the greatest distance for which a bed has been traced. A bed that is free from chert in one place is likely to contain little or no chert at any place nearby, and a bed that contains lenses of a particular size or shape is likely to contain lenses of comparable size and shape and spaced at regular intervals for some distance along the bed. In short, the character of a given bed seems to remain uniform for a considerable distance.

The lens in the upper left part of Fig. 1 is unusual because of its almost knife-edged terminations. The rounded terminations of the other lenses in the same figure predominate throughout the formation. These lenses are also typical in definitely cutting across the bedding at their rounded ends. All the lenses appear to be elongated parallel to the bedding. The shapes cannot often be observed in plan, but the few that have been observed are irregularly rounded or oval. The current bedding in the lower right-hand part of Fig. 1 indicates that the beds may have been deposited at relatively shallow depth, possibly near shore.

Fig. 2 shows irregular masses of chert that have definitely replaced limestone. Two thin beds of light-colored, fine-grained limestone show some selective replacement as compared with a thicker intervening bed of medium-grained limestone that originally consisted of clastic particles of carbonate up to 2 millimeters in diameter. The chert lenses contain two bands of
Fig. 1 - Small lenses of chert in current-bedded limestone. (Traced from photograph.)

Fig. 2 - Chert lenses that have replaced limestone, and that show relict structures of the original limestone. (Traced from photograph.)

lighter-colored chert that merge horizontally with adjacent thin beds of light-colored limestone, whose color they evidently have inherited. The beds above and below the chert are warped into parallelism with the thickest part of each lens, and this warping is believed to indicate either a slight increase in volume
Fig. 3 - Chert lens indicating volume-for-volume replacement of limestone. *(Field sketch)*

Fig. 4 - Chert lens indicating an increase in volume during placement. *(Traced from photograph.)*
during the replacement of limestone by chert or a greater compaction of the limestone after the chert lenses had formed. The cross-cutting relations of the irregular chert lens of Fig. 3, as well as the relict bedding, constitute evidence that the limestone was replaced by chert. Here the replacement has not resulted in any change in volume. The thick lens in Fig. 4, however, shows a marked warping of the beds adjacent to the thickest part of the largest lens. This warping, as well as the curvature of the relict structures within the chert, is believed to indicate a gradual swelling during its emplacement.

Several of the chert lenses in Fig. 5 are particularly significant, because they and the adjacent beds provide critical evidence concerning the time at which the chert was emplaced. The lenses were formed in part by replacement of loose clastic grains of limestone, but a more important factor for these particular lenses was the raising of the overlying beds. Outstanding features are the local unconformities that overlie chert units 1 and 8. The extent of each unconformity is directly related to the underlying chert. Lens 1 is believed to have
been emplaced after limestone units 2 and 3 were deposited. The wedging out of the basal part of limestone unit 4 is evidence that this unit was being deposited contemporaneously with the emplacement of the chert. Limestone unit 5, on the other hand, was deposited after the chert.

Limestone unit 10, consisting of three isolated segments, is light gray in color and is made up of clastic grains that are larger than the grains in adjacent beds. The wedging out of the individual segments of this unit, and the local erosion of unit 9 over the thickest part of chert unit 8, indicate that this chert was emplaced during the deposition of unit 10 or immediately thereafter.

The curious phenomenon of the swelling of a chert lens during its emplacement may be possible only in loose unindurated sediments, at a depth of no more than a few centimeters below the sea floor. No swelling is to be expected if the chert is deposited directly on the sea bottom, or at such a depth that the load of overlying sediments will counteract the tendency of the siliceous matter to swell.

Chert unit 12 in Fig. 5 has almost a knife-edge termination over the thickest part of the underlying lens. The lens above may have been deposited directly on the sea floor while the lower lens was still being formed. The knife-edged lens in the upper left part of Fig. 1 may also have been deposited on the sea floor, but the evidence as to either lens is not conclusive.

The nature of the siliceous matter and the chemistry of its emplacement are largely beyond the scope of the present discussion. But if the material was a siliceous ooze or a water-rich colloidal solution, the silica must have separated almost immediately from the associated water. If the water had been drawn off at a considerably later time, the loss in volume should have resulted either in a slumping of the overlying beds or in the formation of a honeycomb texture in the chert. Neither condition however, has been observed in connection with any of the chert lenses of the middle formation.

The detailed relations of the chert lenses and the containing limestone of the middle formation appear to justify the following conclusions:

1. The lenses formed largely through the direct replacement of clastic grains of limestone.
2. The emplacement of chert was a diagenetic process, having taken place soon after the sediments were deposited and
while the clastic grains were still loose and unindurated. In some instances at least, the emplacement occurred at a depth of no more than a few centimeters below limestone beds that were being deposited at the same time.

(3) In some places where the action took place under very slight load and at a depth of several centimeters to possibly a meter or more below the prevailing ocean floor, the emplacement of siliceous material was accompanied by an increase in volume, accomplished by raising the overlying beds.

(4) In other places, where the action may have taken place at a depth of a few meters, the replacement was volume-for-volume.

(5) A small amount of the chert may have been deposited directly on the ocean floor.

(6) If the introduced material was a siliceous ooze or a water-rich colloidal solution, the silica must have separated almost immediately from the associated water.

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