The theories may be enumerated as follows: 1) organic theory (Eaton 1824); 2) crystallization theory (Bonnycastle 1831); 3) erosion theory (Plieninger 1852); 4) gas theory (Zelger 1870); 5) bitumen theory (Alberti 1858); 6) pressure theory (Quenstedt 1837); 7) solution theory (Fuchs 1894); 8) contraction-pressure theory (Shaub 1939), and 9) subaqueous-solution theory (Prosko and rift 1952).

The earliest theories were quite hypothetical and presented little evidence for their support. The solution idea was first suggested by Fuchs (1894) and was strengthened soon by Reis (1902). It was extensively reviewed and studied by Wagner, in 1913, and further developed and crystallized by Stockdale. Stockdale published, in 1922, a comprehensive paper on the nature and origin of Stylolites, in which he gave an excellent resume of the previous theories and descriptions of the Stylolites from the limestone areas of Southern Indiana. He also included a bibliography of 88 titles on Stylolites and related subjects. While he is not the originator of the solution theory, Stockdale presented evidence to substantiate this theory.

Two theories of the origin of Stylolites have a divided following among today's geologists: the solution and the contraction-pressure theories.

The solution theory. The solution theory contends that Stylolites result from differential chemical solution in hardened rock, under some pressure, on the two sides of a parting of some sort (such as a bedding plane, lamination plane, suture or crevice), the individual portions of the one side fitting into the dissolved out parts of the opposite, the interfitting taking place slowly and gradually as solution continues. According to this idea, Stylolites are a strictly secondary phenomenon developed after consolidation and hardening of rock material. The films of clay which cap the Stylolites are regarded as largely, if not entirely, residual - the insoluble constituents left from the dissolving of the stone. Accumulation of this residue along the stylolitic surface, in greatest amounts at the ends of the columns, is best evidence of the solution origin of this feature. (Pettijohn 1949, p. 157). The striated slickensided-appearing sides of Stylolites are attributed in part to the slippage of one solid rock column past another. According to this theory, most commonplace development of Stylolites would be expected in calcareous, soluble rocks, such as limestone and marble. However, the theory does not preclude the less frequent existence of the feature in other kinds of strata (Stockdale 1936).

The contraction-pressure theory. The contraction-pressure theory of Shaub (1939, pp. 53-54) holds that Stylolites originate while sediments are in the unconsolidated state from differential pressure and compaction which has compelled "transfer of material by plastic flow". Accordingly, Stylolites are a primary structure. To account for differential stresses necessary, the theory emphasizes the removal of pore water from sediments on top of an original thin, clay band to bring about volume contraction. "The proximity of plastic material on one side of a soft clay band and less plastic material under differential horizontal stresses on the opposite side establishes conditions where the more plastic material will flow into the places where the pressure is reduced. The process of compaction is under gravitational control, hence the normal direction of the transfer of material by plastic flow will be approximately at right angles to the bedding. Where the more and less plastic materials are strongly influenced by dynamic forces, the flow may be in any direction. At the beginning of plastic flow from one side of a clay band to the other, the clay is sheared and carried
ahead of the penetrating plastic material. The transfer of material by plastic flow under very low differential pressure between the adjoining beds is believed to be slow, orderly and usually non-turbulent. The transfer is accomplished in such a manner that little evidence of dragging is developed, except at the contacts. The gradual removal of pore water, and consequent gradual and continued volume contraction, provides the necessary differential stresses for a prolonged transfer of material, which will continue until the stress differences become too low to overcome the resistance to plastic flow.

Shaun (1949, p. 35, fig 4) reproduced an interesting occurrence of stylolites illustrated and described by Logan (1863, p. 633, fig. 437) apud Shaun. It shows the manner in which the limestone stylolites penetrate a mass of chert in the Conemaugh formation, near Port Dover, Canada. Criticizing the solution theory, Shaun asks: "...how, by all fair and unbiased deductions based on known facts, can one claim that the limestone columns in the chert were more resistant to solution than the chert?"

The subaqueous-solution theory In December of 1952 Prokopovich presented a new approach to the solution of the origin of stylolites. The writer based his conclusions in field observations in Southwestern Germany, where he studied about 95 outcrops of the Muschelkalk and the Malm limestone, which are well known for their stylolites. He illustrated some curved columns with curved striations, and observed that "more often the stylolites cut fossils." Against the solution theory he presents seven arguments. He states that "is often impossible" to explain the origin of columns which are curved or corroded, and narrowed at the bottom, by "partial resistance of solid rock." About the curved striations he adds: "The development of a partially curved striation in solid rock is impossible." (p. 218).

The contraction-pressure theory is likewise unsatisfactory to explain the facts observed by Prokopovich. He points out six arguments against this theory. The two more important facts are that the contraction-pressure idea fails to explain the origin of clay layers belonging to vertical seams, and that the cutting of fossils, the branching of seams, and the like, are all hard to explain by this hypothesis.

He concludes, "neither the pressure-solution nor the contraction-pressure hypothesis can be used alone" to explain the origin of the stylolites. And states: "The stylolites were formed by solution in soft sediments." (Prokopovich 1952, p. 219).

Certain peculiarities noted in the stylolites investigated by Prokopovich are in accordance with the ideas expressed by various oceanographers. The solution of limestone, according to oceanographic studies, may be caused by changes of pH, temperature, water salinity, and other factors. To explain the cutting of fossils Prokopovich states: "The small turbulent currents in such a dynamic medium as water are very irregular. Such irregularities produce changes either in the form or location and size of columns or they may produce the solution of walls, movement of water, and the force of gravity."

Discussing the mechanism of this subaqueous-solution theory, Prokopovich emphasizes the influence of the pH of seawater in the development of stylolitic seams, and states that stylolites "could take place two or three times during the sedimentation of one bed." According to this idea, stylolites are not a post-depositional structure.

Accepting the solution origin of the stylolites, without any further details in such mechanism, the author tried to add some statistical data about this peculiar geological structure.

OBSERVATIONS Calculations of rock loss by solution Stockdale (1926) emphasizing the stratigraphic significance of solution, made some calculations of rock loss by solution. To secure quantitative data on the thinning of strata, he made a series of measurements in stylolitic rocks. Using all criteria in evidence for determining the amount of rock loss, such as number of prominent stylolitic seams, average length of stylolites, uncutting stylolitic seams and the necessary amount and distribution of solution to produce such, he got the quantitative results as shown in Table 3.

Detrital residue as a measure of rock loss Stockdale mentions, very often, the clay-like residual seams, as an important feature encountered in all stylolites, but he does not mention the detrital insoluble grains of silt size, that accumulate together with the clay-like materials, within the stylolitic surface. He states that "the residue from this type of rock solution... offers another means of measurement or rock loss through solution." (Stockdale 1926, p. 409). The procedure suggested by him, for such measurement, is based entirely in chemical analyses. He converts the percentages by weight of CaO, and "impurities" to percentages by volume of limestone and shale, obtaining, this way, a figure for the thickness of the residual cap.

Dr. Pettijohn, in one of his lectures, suggested that by knowing the concentration of insoluble grains in the rock body and in the stylolitic seam, a measure of rock loss could be established. Following his suggestion, and dealing with only one thin section available (SR-64), from the Warrior limestone of Pennsylvania, the Author attempted to get some quantitative data on the thinning of strata of that rock. The stylolites are very conspicuous, cutting calcareous oolites and with a great amount of residual detritus.

The thin section was divided in half-centimeter squares and counted quartz and plagioclase grains both in the rock body and accumulated in the stylolitic seams. Muscovite detritus can also be seen, but they were disregarded because of their minor importance.

Figure 1 shows the quartz-plagioclase ratio as obtained from the direct microscopic observation. Since the conclusions are raised without distinction between quartz and plagioclase. Figure 2 shows the added amount of these two kinds of grains in the observed areas.

CONCLUSION We can assume that solution dissolved the same amount of rock in both sides of the stylolitic surface. We can assume, also, that, in extreme cases, the solution took place only in one side of the stylolitic seam. The amount of rock dissolved in all these cases are shown in Table 1. Calculating a hypothetical average concentration of insoluble grains, for the entire thin section, we would have 98 grains per square centimeter. It was included in the same table.
the amount of solution of such average rock. Several other cases may be considered in order to establish a gradational variation of detrital grain concentration through all the section, and consequent different dissolved portions. Taking the values that rise to extreme possibilities, and calculating the percentage of rock loss, we would have the results of Table 2. Comparing (see Table 3) the percentage of minimum loss, obtained by macroscopic observations (Ramos), with Stockdale's figures (Stockdale 1926, pp. 405-407), obtained by macroscopic measurements, also referred to a minimum possible loss testified by the evidence, it seems reasonable Stockdale's statement that "some horizons may have been thinned as much as 40 to 50 per cent." (p. 406).
References


Quenstedt A. 1837. Die Stylolithen sind anorganische Absonderungen. Wiegmann's Arch., 137-142.


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