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Alpena Limestone, Alpena, Michigan

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ABSTRACT

LITHOLOGIC CONTROL OF PRESSURE SOLUTION;
ALPENA LIMESTONE, ALPENA, MICHIGAN

By

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Three distinct types of pressure solution features are found in the Alpena limestone (Devonian, Michigan): Stylolites, solution seams, and fitted fabric or intergranular pressure solution. Cementation is the fundamental control on the type of features which develop during pressure solution. Well cemented crinoidal grainstones typically have stylolites, whereas solution seams and fitted fabric texture are more common in poorly cemented grainstones, packstones, wackestones, and mudstones.

Pressure solution occurs preferentially at lithologic transitions between rock types, due to competency contrasts of the units, rather than within homogeneous units. Material dissolved at pressure solution features does not appear to be locally reprecipitated, probably because the rate of fluid flow in the sediment exceeded the solute diffusion rate during pressure solution.

The style of pressure solution in the Alpena limestone, and its relationship to cementation, is also observed in sandstones.

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INTRODUCTION

The purpose of this study is to determine the relationship between lithology and style of pressure solution in a shallow water carbonate sequence. Because grain size and the presence of clay along grain boundaries will enhance the rate of pressure solution (Weyl, 1959), one could expect these variables to be important in determining the nature of pressure solution in sedimentary rocks. Also, thorough cementation during early diagenesis has been emphasised as the principal variable controlling the distribution of stylolites (in well-lithified units) and solution seams (in less well-lithified units) in chalks (Garrison and Kennedy, 1977). Although one would expect to observe predictable interrelations between lithology, cementation, and the style of pressure solution in limestones, such relationships have not previously been defined. This paper is an attempt to define the relationships between lithologic variation, which is expressed by variations in texture and cementation, and pressure solution. This has been done by a quantitative analysis of stylolites, solution seams, and intergranular pressure solution in the various lithologies of the Alpena limestone (Devonian, Michigan). The Alpena limestone was chosen for this study because of its abundant pressure solution features, lithologic variability, and lack of deformation. Maximum depth of burial of the Alpena is 1500 meters (Hathon, 1979).

PREVIOUS WORK ON PRESSURE SOLUTION

Pressure solution of well lithified rocks has been generally accepted as the mechanism responsible for formation of stylolites and solution seams since the early work of Stockdale (1926, 1943). Kerrich (1978) has recently comprehensively reviewed the subject. Pressure solution has been noted in many rock types, but is most commonly found in carbonates. Weyl (1959) suggested the most accepted view of the mechanism of pressure solution: solute ions migrate down chemical potential gradients, through a thin, quasi-liquid "solution film", capable of supporting a shear stress. Variations in chemical potential, and, therefore, chemical potential gradients, may be created by variations in contact pressure, structural state, impurity distribution, and crystallographic orientation. Rutter (1976), DeBoer (1977), DeBoer, et al (1977), and Robin (1978) strongly support Weyl's solution film hypothesis on thermodynamic and experimental grounds.

Pressure solution has often been suggested as a cement-generating mechanism in sands and limestones (Waldschmidt, 1941; Dunnington, 1954, 1967; Oldershaw and Scoffin, 1967; Trurnit, 1968; Durney, 1972; Scholle, 1977).

Many workers have stated that clay minerals may promote pressure solution by serving as avenues for diffusion (Heald, 1956; Weyl, 1959; Sibley and Blatt, 1976; DeBoer, 1977; Garrison and Kennedy, 1977), or by inhibiting cementation (Sibley and Blatt, 1976). Wanless (1979) attempted to relate pressure solution features to structural resistance (competentcy) and presence of clays in carbonates. He found that structurally resistant units with little clay content develop sutured pressure solution features, whereas structurally responsive units with high clay contents develop solution seams and intergranular pressure solution.

PROCEDURE

All samples studied in this investigation were collected from the Middle Devonian Alpena limestone, exposed in the Huron Portland Cement quarry, located in R31N, T8E, section 31 in Alpena County, Michigan.

A vertical sequence of samples was collected at one location and supplemental samples from the entire quarry were selected to obtain specimens of all lithologies at the site. Thin sections and acetate peels were prepared. Acetate peels were used because preliminary investigations revealed that thin sections were often too small a sample of the rock to be useful in the analyses undertaken. Acetate peel procedures are outlined in Bouma (1969). Ferroan calcite was known to occur in the Alpena materials and was differentiated by the application of a potassium ferricyanide stain (Lindholm and Finkleman, 1972) to thin sections and polished slabs before peels were taken. Methods of data collection and analysis are described in a latter section.

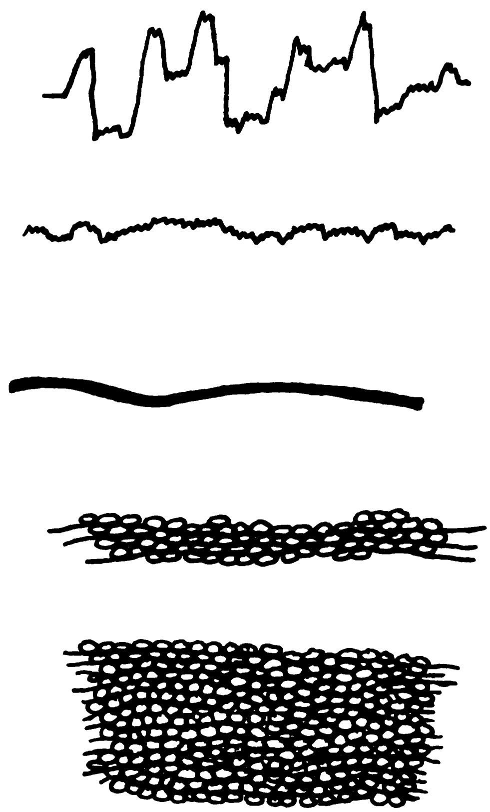
PRESSURE SOLUTION IN THE ALPENA LIMESTONE

There are three fundamental styles of pressure solution in the Alpena limestone: stylolites, solution seams, and pervasive grain-to-grain solution. Stylolites are serrated boundaries between units; the boundary usually has an accumulation of clay, oxides, and/or organic matter. The boundary between two grains may be serrated, but is not considered to be a stylolite unless the feature extends beyond the individual grains. Solution seams are smooth, undulating boundaries between units, lacking the sutured form of stylolites; they also have an accumulation of clay or other material. These two major types of pressure solution features are recognized by Wanless (1979) in his classification.

A third type of pressure solution feature, called "fitted fabric" pressure solution in this paper, consists of zones of intense intergranular pressure solution. Wanless (1979) includes this type in the solution seam group. The importance of "fitted fabric" textures as a major category of pressure solution features was recognized by Logan and Semeniuk (1976).

Fitted fabric pressure solution differs from pressure solution along stylolites and solution seams in that fitted fabric dissolution occurs pervasively throughout a zone, effecting all grains, whereas stylolites and solution seams are planar features. At stylolites and solution seams, only grains at the pressure solution surface are removed or presolved, while adjacent grains are uneffected.

For the purposes of data collection, it was convenient to further subdivide the major categories (see Figure 1). There are two types of stylolites: type 1A and 1B. Type 1B features are sutured, as are type 1A features, but the serrations are of higher frequency and lower amplitude. Fitted fabric pressure solution texture classification has also been subdivided into two types. Intergranular pressure solution within a zone on the order of a few grains thick, and surrounded by material not showing fitted fabric textures, is classified as a "limited fitted fabric" feature. "Unlimited fitted fabric" features are similar to the above, but are not constrained to a vertical dimension of a few grain diameters. Fitted fabric pressure solution is analogous to intergranular pressure solution and Trurnit's (1968) "network fabric".



TYPE 1A STYLOLITE

TYPE 1B STYLOLITE

SOLUTION SEAM

"LIMITED FITTED FABRIC"

"UNLIMITED FITTED FABRIC"

Figure 1: Classification of pressure solution features used in this paper. See text for discussion.

LITHOLOGIES IN THE ALPENA LIMESTONE

Alpena limestone deposition occurred in a shallow, normal marine environment (Ehlers and Kesline, 1970), during generally transgressive Traverse Group deposition (Gardner, 1974). Field work and examination of hand samples from the quarry indicate a generally shallowing subtidal environment with possible tidal channel and minor reef development. The major lithologies sampled for this study are discussed below. Dunham's (1962) classification of limestone has been used in this paper in a slightly revised form. Dunham's (1962) classification is shown in Appendix A.

Grainstones consist primarily of clean, sand-sized skeletal material, dominantly crinoidal, with varying percentages of brachiopods, bryozoans, corals, and other allochems. Two general types of grainstones can be distinguished within the Alpena materials; crinoid-dominated zones, with abundant syntaxial overgrowth cements and few pressure solution features, and pervasively presolved, less crinoid-rich units lacking evidence of substantial cementation. In the first type of grainstones, cementation by syntaxial overgrowths on crinoids is evident and abundant, while minor sparry cements are seen on multicrystalline substrates (see Figure 2). In the second type of grainstone, cementation is minor, and both crinoidal and other allochem grains are fitted in an interlocking pressure solution mosaic (see Figure 3).

Packstones contain a similar fossil assemblage in the sand-size fraction to the grainstones, although the percentage of crinoidal grains is lower. These sediments are poorly sorted, and commonly contain coarse

Figure 2: Dominant syntaxial overgrowth cements on crinoid fragments and minor sparry cement on brachiopods. 80X scale = 150 μ

Figure 3: Fitted fabric grainstone. Note fitted texture and lack of cementation. 80X scale = 100 μ

sand to pebble size bryozoan and coral fragments. The packstones contain 5 to 25% or more fine-grained matrix which reduces visible pore space. Where mud is locally absent, cementation appears well developed. Sparry cements are the dominant cement type in the packstones. Syntaxial overgrowth cements occur on crinoid grains, but are less well-developed than in clean grainstones. Intergranular pressure solution and solution seams are common features in packstones, generally found in zones apparently lacking cement. Well-cemented areas lack most pressure solution features.

The wackestones in the Alpena limestone characteristically contain 10 to 50% coarse fossil fragments in a fine-grained carbonate matrix. Bryozoans, brachiopods, stromatoporoids, and corals are the major fossils present, and generally show no sign of transport. Cementation features cannot be seen in the matrix of the wackestones, although intragranular cementation of the fossil fragments is commonly observed. Relict structures from partially obliterated allochems and zones of increased grain size, due to recrystallization, are not uncommon in the wackestones (see Figures 4 and 5). For the purposes of this paper, recrystallization is considered to be a form of cementation, whether or not sediment volume has been increased.

Stylolites are virtually absent in the wackestones, and fitted fabric textures and solution seams are the most common pressure solution features. Recrystallized wackestones show little development of pressure solution features, whereas recrystallization textures cannot be distinguished in highly presolved zones.

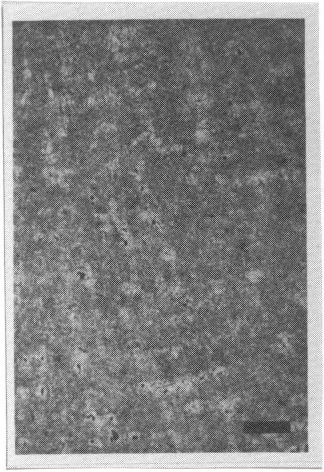


Figure 4: Relict structure of partially obliterated stromatoporoid boundstone. 25X. Scale = 500 μ

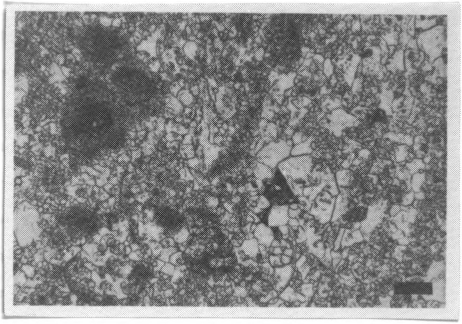


Figure 5: Recrystallized wackestone unit. 100X scale = 100 μ

The mudstones from the Alpena contain few allochems (less than 10%); these are ostracods. Two distinctly different mudstones are found at the Alpena quarry and are not associated on the outcrop. The first is a clean, porous, pelletal mudstone in which the ostracods are found, and the second is a shaley member of the Alpena which contains small horizontal burrows, giving the rock a mottled, slightly nodular appearance. In thin section, fine, sparry cement can be seen in the pelletal rocks; cementation cannot be distinguished in the shaley unit. Fitted fabric, solution seams, and limited fitted fabric pressure solution features are pervasive in the shaley member, although burrow-filling material lacks these pressure solution features. Burrows are accentuated by dissolution in the surrounding rock. Where pressure solution is seen in the pelletal unit, it commonly occurs in well-defined planes or thin zones between porous, well-cemented areas.

Units which can be classified as boundstones are common throughout the other lithologies. Boundstone units consist of intergrown skeletal matter. In the Alpena, these units are bryozoans, corals, and stromatoporoids. Sparry, intragranular cement is common in the interstices of the fragments. Pressure solution features develop around boundstone units in the surrounding sediments. Pressure solution features developed within boundstones, although very rare, have been observed in the rocks; in these cases, porous boundstones have been crushed by overburden, and pressure solution has occurred between fragments.

CEMENTATION OF THE ALPENA LIMESTONE

Most visible cement in the Alpena is rim cement on crinoid fragments in clean, well-sorted crinoidal grainstones (see Figure 6). Rim cements on crinoid fragments in other lithologies are less well developed, presumably because of inhibition of overgrowths by mud (Lucia, 1962) or other impurities. Intraparticle porosity in fossil fragments is often filled with sparry calcite.

No evidence of vadose marine cements was found; i.e., no meniscus or gravitational cements, no vadose silt, no acicular or bladed spar, no micritic cements. Potassium ferricyanide staining revealed ferrous iron-rich zonation in both the rim and sparry cements. Cement, therefore, was probably formed in a fresh water, phreatic environment subject to fluctuating Eh/pH conditions. Where pressure solution features are in contact with cement, the features truncate, and, therefore, postdate the cement (see Figures 7a, 7b, and 7c).

DATA

A comparison of the distribution of pressure solution features in various lithologies from the Alpena quarry has been undertaken. Data were collected by traversing acetate peels of grainstones, packstones, and wackestones, normal to bedding, and counting the transitions from one lithotype to another lithotype, or to a pressure solution feature. Mudstones were not included in the data collection due to difficulties in distinguishing individual pressure solution features in the pervasively presolved rocks, and lack of resolution in acetate peels. Thin sections were too

Figure 6: Syntaxial cement on echinoderm fragments. Note dominance of this type of cement over sparry cements developed on multi-crystalline substrates. Typical of clean crinoidal grainstones. 20X scale = 500 μ

Figure 7a: Cementation was essentially complete before development of pressure solution features. Note type 1A pressure solution feature cutting both allochem and cement, and note cement supporting allochem undergoing dissolution. 45X scale = 100 μ

Figure 7b: Note pressure solution removing both cement and allochem in this photograph. 150X scale = 30 μ

Figure 7c: Note pressure solution removing both cement and allochem in this photograph. Note fitted fabric texture developed above and beneath central pressure solution feature. Pressure solution of a distinctly different style than Figures 7a and 7b. 25X scale = 500 μ

small as samples of the rock for this quantitative evaluation. Type 1A, 1B solution seams and limited fitted fabric pressure solution features were recorded as separate variables, while the unlimited fitted fabric type features were listed with reference to the lithology in which they occured; e.g., fitted fabric grainstone (FFG). Unlike the other four pressure solution features, unlimited fitted fabric textures are units within which stylolites and/or solution seams may occur; hence, they were essentially recorded as a lithologic type. Lithologies lacking fitted fabric type textures were simply referred to as grainstones, packstones, or wackestones. During data collection, each feature or lithotype was defined at the point of intersection of the feature or lithotype with the traverse line, regardless of lateral changes in the form of pressure solution or the lithologic variables.

An example of a traverse line is shown in Table 1. This traverse has three 1A grainstone transitions, two 1A boundstone transitions, one 1B grainstone transition, and one 1B fitted fabric grainstone transition as well as four transitions between various lithotypes. Two hundred transitions were counted for each of four wackestones, 100 transitions for each of ten packstones, and 100 transitions for each of six grainstones. The raw data are found in the appendices.

The data were analyzed by constructing 2 by 4 contingency tables such as Table 2. This table shows the number of transitions between the four pressure solution features and unlimited fitted versus nonfitted fabric grainstones. The chi-square statistic demonstrates that the solution

Table 1: Sample traverse line data. This traverse has three grainstone to type 1A pressure solution feature transitions, two boundstone to 1A transitions, one unlimited fitted fabric grainstone to type 1B stylolite transition, one grainstone to 1B transition, and four transitions from one lithotype into another.

1A	(type 1A stylolite)
GRN	(grainstone)
FFG	(unlimited fitted fabric grainstone)
GRN	
1A	
BND	(boundstone)
1A	
GRN	
FFG	
1B	(type 1B stylolite)
GRN	
FFG	

Table 2: Comparison of distributions of pressure solution features in fitted and nonfitted fabric grainstones. Sum of chi-square components = 40.20; critical value = 7.81. Chi-Square component values for transitions with expected values less than 5 not included (*).

Feature	Nonfitted fabric grainstone	Unlimited fitted fabric grainstone	Total observed
1A Stylolite	75 (observed) 57.94 (expected) 4.73 (chi-square component)	3 20.06 13.67	78
1B	147 167.87 2.47	79 58.13 7.14	226
Solution seam	0 5.95 4.98	8 2.06 14.37*	8
Limited fitted fabric	61 51.25 1.85	8 17.75 5.36	69
Total	283	98	381

features are not randomly distributed between the two types of grainstone. It is obvious by inspection of the table that most (96%) of the type 1A transitions are with nonfitted fabric grainstones. Statistically significant differences (at the 95% confidence level) were also detected for unlimited fitted and nonfitted fabric packstones and wackestones (see appendices for contingency tables). In addition, all grainstone transitions (unlimited fitted and nonfitted fabric) were compared with all packstone transitions in a similar fashion (see Table 3). A chi-square test shows the difference between the two lithologies is significant at the 95% confidence level. In fact, several individual components have chi-square values which exceed the critical value. All combinations of lithologies were found to be significantly different at the $\alpha = .05$ level. All of the following pairs are significantly different: grainstone - packstone, grainstone - wackestone, and packstone - wackestone. The largest chi-square value was for the grainstone - wackestone comparison, and the smallest was for the packstone - wackestone comparison (see contingency tables in appendices).

Differences in the portion of pressure solution features between lithologies were also statistically examined. For example, 20.5% of the solution features in grainstones are type 1A, whereas only 4.9% of features in packstones are type 1A. Assuming random samples and a binomial distribution, there is a significantly higher proportion (at $\alpha = .05$) of 1A features in grainstones (see Van Der Plas and Tobi, 1965, for confidence limits on binomial approximations). Test results are shown in Table 4. Type 1A and limited fitted fabric features are difference in each lithology,

Table 3: Comparison of distributions of pressure solution features in grainstones versus packstones. Sum of chi-square components = 171.07; critical value = 7.81, significant difference is, therefore, detected between the distributions of pressure solution features in the two lithologies.

Feature	All grainstones	All packstones	Total
1A Stylolite	78 (observed)	34	112
	39.18 (expected	72.81	
	37.48 (chi-square component)	20.16	
1B	226	334	560
	195.92	364.08	
	4.47	2.40	
Solution seam	8	114	122
	42.68	79.32	
	27.37	14.73	
Limited fitted fabric	69	226	295
	103.21	191.79	
	11.01	5.93	
Total	381	708	1089

Table 4: Statistical comparison of the percentage of each type of pressure solution feature within each lithology. Comparing grainstones and packstones, for example, there is a statistically significantly greater percentage of type 1A stylolites in grainstones than packstones (GRN $>$ PAK), a significantly smaller percentage of solution seams in grainstones than packstones (GRN $<$ PAK), etc. $\alpha = .05$. (See Van Der Plas and Tobi, 1965.)

Feature	Grainstones (GRN) - Packstones (PAK)	Grainstones - Wackestones (WAK)	Packstones - Wackestones
1A Stylolite	GRN $>$ PAK	GRN $>$ WAK	PAK $>$ WAK
1B	GRN $>$ PAK	GRN $>$ WAK	No significant difference
Solution seam	GRN $<$ PAK	GRN $<$ WAK	No significant difference
Limited fitted fabric	GRN $<$ PAK	GRN $<$ WAK	PAK $<$ WAK

while the percentage of type 1B and solution seams in grainstones is significantly different from that in packstones or wackestones. In addition, the combined percentages of type 1A and 1B stylolites are significantly different in each lithology. Type 1A and 1B stylolites account for nearly 80% of pressure solution features in grainstones, 52% in packstones, and less than 40% of features in wackestones.

The percentage of lithologic transitions; i.e., grainstone to packstone lithotype transition within a lithology, that had pressure solution features present at the transition, was also determined. In packstones and grainstones, 81% and 75% of lithologic transitions have pressure solution features, whereas only 39% of the transitions in wackestones have these features. If, however, boundstone to wackestone transitions are removed from the wackestones, then 84% of the lithologic transitions have pressure solution features. The rationale for removing boundstone to wackestone transitions from consideration is that in a wackestone any disproportionately large fragment must be classified as a boundstone. This is not the case with grainstones or packstones which are better sorted and in which the original definition of the term "boundstone" (Dunham, 1962) is more meaningful.

Although not quantitatively examined, shaley mudstones show pervasive solution seams and unlimited fitted fabric texture development. They show no type 1A features. In the pelletal mudstones, anastomatising, sutured pressure solution features are well developed between clean, cement-rich zones.

In summary, statistical analysis of the data shows that the various lithologies do respond differently to pressure solution. The greatest difference in response is between grainstones and wackestones, and the least different in response are packstones and wackestones. In addition, most lithologic transitions have associated pressure solution features.

INTERPRETATION

Data analysis shows that there is a clear difference between various lithologies and the style of pressure solution. Type 1A stylolite seams are common only in nonfitted fabric grainstones. Solution seams are common in the other lithologies: unlimited fitted fabric grainstones, all packstones, and all wackestones. The fact that type 1A features did not occur in fitted fabric grainstones indicates that grain size is not the fundamental property which determines whether stylolites or solution seams develop. There is a clear difference between unlimited fitted and nonfitted fabric grainstones which explains the difference in pressure solution features. Fitted fabric grainstones have very little cement, whereas the nonfitted fabric grainstones are well cemented. The cement in the nonfitted fabric grainstones is substrate controlled; most of the cement is rim cement on crinoidal fragments. Sparry calcite cement is found on scattered brachiopods, but is much less abundant than rim cement due to a slower growth rate (Lucia, 1962), and the relative paucity of non-crinoid fragments. Whereas all the crinoid fragments in the nonfitted fabric grainstones have overgrowths, most crinoids in the fitted fabric grainstones do not have significant overgrowths (see Figures 6 and 8). Therefore, it is concluded that the most important difference between fitted and nonfitted fabric grainstones is the lack of cement in the fitted fabric.

In an uncemented sediment, the maximum amplitude of a pressure solution feature is one grain diameter and, in most instances, amplitude will be much less. Type 1A stylolites are, therefore, absent from unlimited fitted fabric zones because such units are not well cemented. Two grains within the fitted fabric zone may be structurally competent, and, therefore, have a sutured contact, but larger scale features (solution seams) will not. This is consistent with Wanless' (1979) classification, wherein he points out that stylolites are found in clean, structurally competent units. Obviously, competence is determined by cementation.

It is reasonable to assume that cementation history is important to the response of packstones, wackestones, and mudstones, also. However, it is more difficult to determine the degree of cementation of these rocks. These rocks contain scattered crinoid fragments, but they seldom have prominent overgrowths. Some fossils have an intraparticle sparry calcite cement, but the matrix is not displaced or replaced by cement crystals. Therefore, it is presumed that these rocks were not well cemented. Some samples were neomorphosed, and this can be considered a form of cementation regardless of whether or not material has been added to the rock. Only one wackestone had a type 1A pressure solution feature and it occurred between a brachiopod fragment and neomorphosed mud (Figure 9). Neomorphism is inferred from the observation that the neomorphosed micrite (microspar) was more coarsely crystalline than the majority of the micrite in the rock. Areas of neomorphism (microspar) in wackestones lack pressure solution features; where solution features are abundant, micrite, rather than microspar, is found. The only area where a type 1A feature was found in a wackestone was as a boundary between two structurally competent units.

The inference that cementation controls pressure solution may seem unlikely at first because many have suggested that much of the cement found in sedimentary rocks may have been derived from pressure solution (Weyl, 1959; Renton, Heald, and Cecil, 1969; Durney, 1972; DeBoer, 1977; etc.). The evidence indicates, however, that the material derived from pressure solution of the Alpena limestone was not locally reprecipitated. The grounds for this contention are the incomplete intragranular cementation of still-porous allochems along stylolites and solution seams, and lack of cement in fitted fabric lithologies (see Figure 8). One explanation for a lack of cementation associated with pressure solution is that pressure solution occurs in nonhydrostatically stressed sediments, often early in diagenesis (Friedman, 1975; Bathurst, 1975, p. 473). Under these conditions, the rate of fluid flow in the sediment will usually exceed the rate of solute diffusion along grain boundaries. Therefore, solute concentrations will not build up in the pore fluids; because supersaturation is not achieved, precipitation does not occur. A fundamental difference between sedimentary and metamorphic rocks is that in metamorphic rocks, solute material is precipitated in pressure shadows (Ramsey, 1967; Kerrich, 1977), whereas

Figure 8: Pressure solution in fitted fabric texture. Note lack of apparent reprecipitation of dissolved carbonate. 20X scale = 500 μ

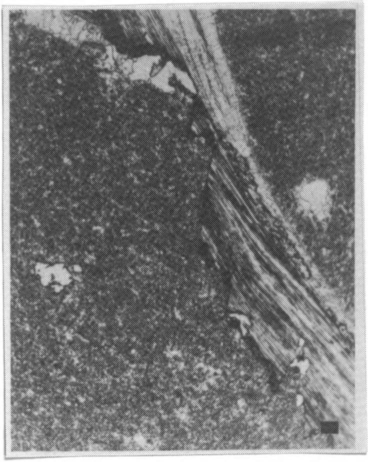


Figure 9: Neomorphosed wackestone. Note type 1A pressure solution feature which becomes a solution seam outside the field of view. This feature is developed between two well-lithified, structurally competent units, a neomorphosed wackestone and a boundstone. 1A features not seen elsewhere in the wackestone. 185X scale = 25 μ

solute material is not locally reprecipitated in sedimentary rocks. This can be directly attributed to fluid flow exceeding the rate of diffusion in sedimentary rocks, whereas in metamorphic rocks, diffusion is the major mechanism of transport.

Thorough cementation was observed only in crinoidal grainstones. Rim cementation on crinoid fragments is not well developed in the other rocks where pores contain micrite (Lucia, 1962). This may be analogous to inhibition of quartz overgrowths by clays (Pittman and Lumsden, 1968; Heald and Larese, 1974). It is reasonable that sparry calcite growth and neomorphic grain enlargement are also inhibited by impurities.

The greatest difference in response to pressure solution (as shown by the chi-square tests) is between grainstones and packstones. This difference is interpreted to be due to well developed cementation in the grainstones. The least different units are the wackestones and packstones. If texture is the fundamental property which controls the style of pressure solution, the grainstones and packstones should be more similar (lower chi-square value). The relative similarity between packstones and wackestones is due to the presence of cement-inhibiting mud.

A second fundamental relationship which can be shown with the data is that lithologic transitions commonly (80%) have pressure solution features. The following model is suggested. Two adjacent layers will respond to stress differently due to the differences in packing, cementation, etc. As a result of these differences, nonhydrostatic stress will be different in each unit. Pressure solution is driven by this nonhydrostatic stress, and the

rate of pressure solution in each unit will be proportional to sigma 1 minus sigma 3. Under normal stress, sigma 1 will be the same in all units, but sigma 3 will be less in the more competent unit (Robin, 1979). At the boundary between the two units, therefore, nonhydrostatic stress in the less competent unit is at a maximum, and a gradient for diffusion of solute from the less competent to the more competent unit is established. Lithologic boundaries, therefore, have a greater potential for pressure solution than intralithologic discontinuities. The same tendency for material to flow from less competent to more competent units is the cause of banding in metamorphic rocks (Robin, 1979).

COMPARISON TO A SANDSTONE

The same fundamental styles of pressure solution that occur in the Alpena limestone are also present in the Tuscarora sandstone (Silurian). The Tuscarora is a silica cemented, very clean quartz arenite. A few samples contain up to 17% clay, but the vast majority contain no more than 2%. The Tuscarora samples were studied as part of a previous investigation of intergranular pressure solution (Sibley and Blatt, 1976). Pressure solution features are not as common in the Tuscarora as in the Alpena, although the same types of features are observed. Figure 10 shows a type 1A stylolite from the Tuscarora. Above and below the seam, the rock is well lithified with quartz overgrowth cement, which can be deduced by the dust rings on many of the detrital grains. This rock is texturally analogous to the well-cemented grainstones in the Alpena. Unlimited fitted

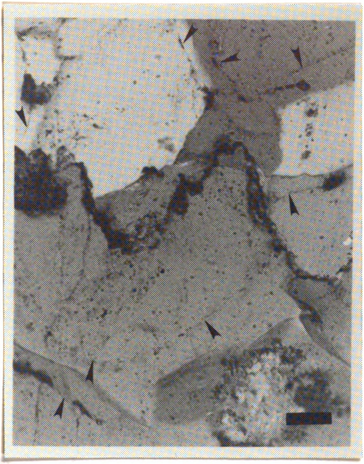


Figure 10: Type 1A stylolite in the Tuscarora sandstone. Note cementation by well-developed quartz overgrowths. Arrows point to dust rings on detrital grains. This sample is texturally analogous to well-cemented grainstones in the Alpena limestone. 240X scale = 50 μ

fabric pressure solution is seen in the Tuscarora in Figure 11. This figure includes a plane light and a luminescence view of the same area. The luminescence photograph is used to distinguish luminescing detrital cores from nonluminescing authigenic overgrowths and fracture fillings. The dark areas in the luminescence photograph are voids (some due to plucking in sample preparation), not authigenic silica. In Figure 12, a solution seam is overlain by a well-cemented zone and underlain by a fitted fabric sand, lacking cementation. This is analogous to the presence of solution seams in the fitted fabric grainstones from the Alpena. Note the clay material in the fitted fabric zone. The fitted fabric texture has developed because the clays have inhibited quartz overgrowth cementation.

The three examples from the Tuscarora clearly demonstrate a relationship between style of pressure solution and cementation similar to that proposed for the Alpena limestone. Type 1A stylolites are found in well-cemented rocks, and solution seams and fitted fabric features are found in uncemented units.

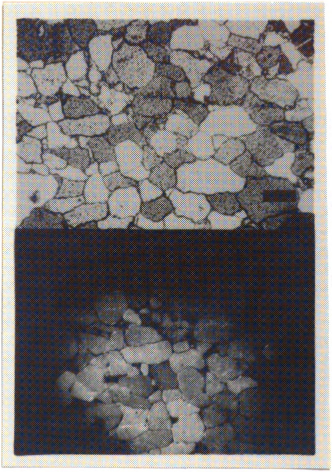


Figure 11: Zone of fitted fabric pressure solution in the Tuscarora sandstone. Note the lack of cementation. 17X scale = 500 μ

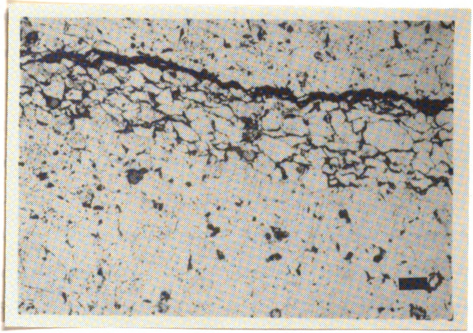


Figure 12: Fitted fabric and solution seam pressure solution features in the Tuscarora sandstone. Note the clay present in the fitted fabric zone. Clay has inhibited cementation, leading to fitted texture. Solution seam has formed as clay minerals have accumulated during dissolution of grains in fitted fabric zone. 37.5X scale = 200 μ

CONCLUSIONS

1) Pressure solution features in the Alpena limestones have been classified on the basis of morphology, and statistically significant relationships between different lithologies and pressure solution types have been delineated.

2) Type 1A pressure solution features (stylolites) are found in well-lithified, nonfitted fabric materials, whereas solution seams are strongly associated with fitted fabric textures, developed in less well-lithified, poorly cemented sediments.

3) Clays and/or mud may be responsible for inhibiting cementation of crinoid fragments where present and may, therefore, influence the mode of pressure solution developed and the type of pressure solution features observed.

4) Mud-free sediments will be most easily lithified. Later in diagenesis, pressure solution will produce type 1A pressure solution features.

5) Sediments which are less well-lithified will undergo essentially intergranular pressure solution throughout the section and will develop a characteristic fitted fabric texture. Solution seams develop within fitted fabric zones as insoluble material accumulates.

6) Material dissolved by pressure solution does not appear to reprecipitate in the immediate vicinity of its origin as would be expected. This implies that the rate of fluid flow in the rocks undergoing dissolution is greater than the rate of solute diffusion away from areas of dissolution. This

is distinctly different from similar metamorphic reactions where, without benefit of adequate permeability and fluid flow, diffusion is local and reprecipitation is immediate on the sides of grains normal to sigma 3.

7) Pressure solution features are developed preferentially along transition between lithotypes and, in general, develop along inhomogeneities within otherwise homogeneous rocks.

8) The style of pressure solution in carbonates and its relationship to previous cementation, is also found in sandstones.

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BIBLIOGRAPHY

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APPENDICES

APPENDIX A

APPENDIX A

DUNHAM'S CLASSIFICATION ACCORDING TO DEPOSITIONAL TEXTURE

<table>
<tr><th colspan="4">Original components not bound together during deposition</th><th rowspan="4">Original components were bound together during deposition... as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices.

Boundstone</th></tr>
<tr><td colspan="3">Contains mud
(Particles of clay and fine silt size)</td><td>Lacks mud</td></tr>
<tr><td colspan="2">Mud supported</td><td colspan="2">Grain supported</td></tr>
<tr><td>Less than
10% grains

Mudstone</td><td>More than
10% grains

Wackestone</td><td>Packstone</td><td>Grainstone</td></tr>
</table>

APPENDIX B

APPENDIX B

RAW DATA AND RAW DATA SUMMARY TABLES

GRAINSTONES: SUMMARY

	WLG	WLP	WLW	FFG	FFP	FFW	BND	UNK	TOT
1A	71	1	1	3	0	0	2	0	78
1B	115	8	0	76	3	0	24	0	226
2A	0	0	0	8	0	0	0	0	8
2B	55	1	0	8	0	0	5	0	69
SUB-TOTAL	241	10	1	95	3	0	31	0	381
WLG	X	11	0	65	5	0	16	2	99
WLP	12	X	0	0	2	0	3	0	17
WLW	0	0	X	0	0	0	0	0	0
FFG	73	0	0	X	1	0	3	0	77
FFP	6	1	0	0	X	0	0	0	7
FFW	0	0	0	0	0	X	0	0	0
BND	11	1	1	5	0	0	X	0	18
UNK	0	0	0	1	0	0	0	X	1
SUB-TOTAL	102	13	1	71	8	0	22	2	219
GRAND TOTAL	343	23	2	166	11	0	53	2	600

Sample 21A (6) - Grainstones: Raw Data

FFG
1B
FFG
WLG
FFG
WLG
2B
WLG
FFG
1B
BND
WLG
FFG
WLG
2B
FFG
WLG
1B
WLG
FFG
WLG
FFG
WLG
1B
WLG
FFG
WLG
2B
WLG
WLP
WLG
WLP

FFG
2A
FFG

1B
FFG
1B
FFG
WLG
BND
WLG
BND
FFG
WLG
2B
WLG
2B
BND
WLG
1B
WLG
1B
FFG
2A
FFG
WLG
2B
WLG
1A
WLG
WLP
BND
WLP

FFG
2A
FFG
1B
FFG
WLG

BND
WLG
FFG
1B
FFG
WLG
2B
WLG
2B
WLG
2B
WLG
2B
WLG
1A
WLG
1B
BND
2B
WLG
BND
WLG
BND
WLG
1A
FFG

FFG
2A
FFG
WLG
BND
2B
BND
WLG

Sample 1B - Grainstones: Raw Data

BND
1B
WLG
1B
FFG
WLG
UNK
WLG
BND
1B
WLG
1B
FFG
WLG
BND
1B
WLG
2B
WLG
2B
WLG
1B
WLG
FFG
1B
FFG
1B
FFG
1B
FFG
BND

WLG
2B
WLG
BND

1B
WLG
1B
WLG
1B
WLG
1B
WLG
1B
FFG
WLG
1B
WLG
FFG
1B
FFG
1B
FFG
1B
FFG

WLG
1B
WLG
2B
WLG
1B
WLG
2B
WLG
2B
FFG
2B
FFG
2B

WLG
BND
FFG
WLG
BND
FFG
WLG
FFG
WLG
2B
WLG
2B
WLG
2B
WLG
1B
WLG
1B
WLG
FFG

WLG
2B
WLG
2B
WLG
2B
WLG
2B
WLG
1B
WLG
1B
WLG
1B
WLG

Sample M^2 - 19 - Grainstones: Raw Data

FFG	FFG	2B
WLG		WLG
1B		FFG
WLG	FFG	WLG
FFG	1B	FFG
WLG	FFG	WLG
FFG	1B	FFG
WLG	WLG	1B
FFG	1B	FFG
WLG	FFG	WLG
FFG	WLG	FFG
1B	FFG	WLG
FFG	WLG	FFG
BND	FFG	1B
WLG	WLG	FFG
	FFG	WLG
	WLG	
FFG	FFG	
1B	WLG	FFG
FFG	FFG	1B
1B	WLG	FFG
WLG		WLG
FFG		FFG
1B	WLG	WLG
FFG	FFG	FFG
WLG	1B	WLG
FFG	FFG	FFG
WLG	WLG	WLG
FFG	FFG	FFG
WLG	WLG	WLG
FFG	FFG	FFG
WLG	WLG	
FFG	FFG	
WLG	WLG	1B
FFG	FFG	FFG
1B	WLG	1B
BND	FFG	FFG
FFG	WLG	1B
1B	FFG	

Sample 18B - Grainstones: Raw Data

FFG
WLG
FFP
WLG
FFP
WLG
1B
WLG
WLP
WLG
1B
WLG
1A
WLG
WLP
WLG
1B
WLG
1A
WLG
1B
WLG
WLP
WLG
1A
WLG
1A
WLG
1B
WLG

WLG
FFG
WLG
1A
WLG

FFP
WLG
1A
WLG
FFP
WLG
FFG
WLG
1B
WLG
1B
WLG
1A
WLG
1B
WLG
WLP
WLG
FFG
WLG
1A
WLG
1B
WLP
WLG
1A
WLG
1A
WLG
FFG
WLG
1A
WLG
BND
WLG

WLG
FFG
WLG
FFG
WLG
1A
WLG
1A
WLG
1B
WLG
FFG
WLG
2B
WLG
1A
WLG
1A
WLG
1A
WLG
1B
WLG
1B
WLG
1B
WLG
1A
WLG
1B
WLG
1A
WLG

Sample 16E - Grainstones: Raw Data

BND	1B	WLG
FFG	WLP	WLP
1B	FFP	1B
FFG	WLP	WLP
FFP	BND	WLG
WLG	1B	1B
2B	BND	FFG
WLG	1B	WLG
FFG	BND	
1B	1B	
BND	WLG	WLG
1B	WLP	1B
FFP	WLG	WLG
WLG	1A	BND
2B	BND	1B
WLG	WLW	FFG
BND	1A	1B
1B	BND	WLP
WLG	WLG	FFP
1B	1A	1B
WLG	WLP	WLG
FFG	1B	WLP
1B	WLP	BND
WLG	WLG	1B
1B	1B	BND
WLG	WLG	2B
1A	FFG	WLP
FFG	1B	WLG
2B	BND	WLP
FFG	WLG	WLG
WLG	FFP	2B
1A	1B	WLG
WLG	WLP	2B
1B	WLG	WLG
BND	1B	

Sample 18A - Grainstones: Raw Data

WLG
FFG
1B
FFG
WLG
FFG
WLG
FFG
WLG
1A
WLG
1B
WLG
1A
WLG
1A
WLG
1A
WLG
1A
WLG
FFG
WLG
1A
WLG

FFG
1B
FFG
1B
FFG
1B
FFG
1B
FFG
1B

WLG
1B
WLG
1B
WLG
1A
WLG
1A
FFG
WLG
FFG
WLG
1B
WLG
1B
WLG
1B
WLG

UNK
FFG
BND
1B
FFG
1B
FFG
WLG
FFG
WLG
1A
WLG
1B
WLG
1B
WLG
1A

WLG
1A
WLG
1B
WLG
1B
WLG
FFG
WLG
1A
WLG
FFG
WLG
1B
WLG
FFG
WLG
FFG
WLG
BND
1B
WLG
1A
WLG

FFG
1B
WLG
BND
1B
WLG
FFG
WLG
1B
WLG

PACKSTONES: SUMMARY

	WLG	WLP	WLW	FFG	FFP	FFW	BND	UNK	TOT
1A	0	31	0	0	2	0	1	0	34
1B	1	113	2	0	166	0	50	2	334
2A	0	6	0	0	89	0	19	0	114
2B	0	85	0	0	120	0	20	1	226
SUB-TOTAL	1	235	2	0	377	0	90	3	708
WLG	X	1	0	0	0	0	0	0	1
WLP	0	X	0	0	56	0	23	0	79
WLW	0	0	X	0	4	1	4	0	9
FFG	0	0	0	X	0	0	0	0	0
FFP	0	51	4	0	X	0	54	2	111
FFW	0	0	1	0	0	X	0	0	1
BND	0	22	5	0	61	0	X	0	88
UNK	0	0	1	0	0	0	2	0	3
SUB-TOTAL	0	74	11	0	121	1	83	2	292
GRAND TOTAL	1	309	13	0	498	1	173	5	1000

Sample 8A - Packstones: Raw Data

FFP	FFP	FFP
BND	1B	2A
FFP	BND	FFP
BND	1B	2B
FFP	BND	FFP
1B	FFP	BND
BND	BND	2B
1B	FFP	BND
BND	BND	2B
FFP	FFP	FFP
2A	BND	BND
FFP	FFP	FFP
BND	BND	BND
FFP	FFP	2A
BND	BND	FFP
2B	FFP	2A
BND	2A	FFP
FFP	FFP	BND
BND	2A	FFP
FFP	FFP	BND
BND	BND	FFP
FFP	FFP	
2A	2A	
FFP	FFP	FFP
WLP	2A	BND
BND	FFP	FFP
FFP	BND	BND
BND	FFP	FFP
FFP	2B	BND
BND	FFP	FFP
FFP		BND
		FFP
	2B	2B
FFP	BND	FFP
BND	2A	BND
FFP	BND	2B
BND	2A	

<u>Sample 19B - (16) - Packstones: Raw Data</u>

UNK	1B	2B
1B	WLP	WLP
WLP	1B	FFP
1B	WLP	1B
WLP	2B	FFP
2B	WLP	WLP
WLP	1B	FFP
1B	<u>WLP</u>	2B
WLP		FFP
1B		2B
WLP	WLP	FFP
1B	1B	WLP
WLP	WLP	FFP
FFP	1B	WLP
2B	WLP	1B
WLP	1B	WLP
1B	FFP	2B
WLP	WLP	WLP
2B	1B	FFP
WLP	WLP	2B
2B	1B	WLP
WLP	WLP	2B
1B	1B	WLP
WLP	WLP	1B
2B	1B	WLP
WLP	WLP	1B
2B	2B	WLP
FFP	WLP	1B
1B	1B	WLP
WLP	WLP	1B
2B	2B	<u>WLP</u>
WLP	WLP	
FFP	1B	
WLP	WLP	WLP
2B	1B	1B
WLP	WLP	

Sample M^2 - 7 - Packstones: Raw Data

FFP	FFP	FFP
WLP	WLP	2B
FFP	FFP	FFP
BND	2A	2A
FFP	FFP	FFP
2B	WLP	1B
FFP	1B	FFP
BND	FFP	BND
FFP	2A	WLW
1B	BND	FFP
FFP	FFP	1B
2A	2B	FFP
FFP	BND	WLP
2A	2B	FFP
FFP	FFP	WLP
2B	BND	2B
WLP	1B	WLP
2B	FFP	FFP
WLP	1B	UNK
2A	FFP	
WLP		
1B		BND
WLP	WLP	FFP
FFP	1B	2B
1B	FFP	FFP
FFP	2B	BND
2B	FFP	WLW
FFP	1B	BND
WLP	FFP	FFP
FFP	2B	
2A	FFP	
FFP	1B	FFP
WLP	FFP	WLP
FFP	1B	FFP
1B	WLP	BND
FFP	FFP	FFP
2B	2A	

Sample 16D (2) - Packstones: Raw Data

2B	1B	1A
WLP	FFP	WLP
FFP	WLP	2B
2A	1B	WLP
BND	WLP	2B
WLP	1B	FFP
BND	BND	2A
WLP	2B	FFP
FFP	BND	1B
2B	2B	FFP
WLP	FFP	BND
1B	2A	2B
FFP	BND	BND
1B	1B	WLP
BND	FFP	2B
FFP	1B	WLP
1B	FFP	FFP
FFP	1B	2A
2A	FFP	FFP
BND	1B	2A
FFP	WLP	FFP
WLP	1B	1B
FFP	BND	FFP
1B	FFP	2A
FFP		FFP
1B		WLP
FFP	FFP	1B
2A	WLP	BND
BND	BND	WLP
2A	1B	FFP
FFP	BND	2B
BND	1B	UNK
1B	WLP	1B
WLP	1A	BND
BND	WLP	

Sample 19A - (9) - Packstones: Raw Data

FFP
2A
FFP
2B
FFP
WLP
FFP
2B
FFP
WLP
2B
WLP
FFP
1B
FFP
1B
FFP
1B
FFP
1B
FFP
2B
FFP
2B
FFP
2B
FFP
2B
FFP

FFP
2B
FFP
2B
FFP
WLP
2B
WLP

FFP
1B
FFP
WLP
2B
WLP
FFP
WLP
BND
WLP
FFP
2B
FFP
2B
FFP
2B
FFP
1B
FFP
1B
FFP

FFP
1B
FFP
WLP
FFP
1B
FFP

WLP
2B
WLP
FFP
2B
WLP
2B

WLP
FFP
1B
FFP
WLP
1A
WLP
1A
WLP
1A
WLP
FFP
2B
FFP

FFP
1B
FFP
1B
FFP
1B
FFP
2B
FFP
WLP
FFP
2B
FFP
1B
FFP

FFP
BND
FFP
1B
FFP

Sample M^2 - 15 - Packstones: Raw Data

FFP
1B
FFP
1B
FFP
BND
FFP
1B
BND
WLW
BND
1B
FFP
2A
FFP
WLW
1B
BND
FFP
WLW
FFP
2A
FFP
2A
FFP
1B
BND
FFP
BND
1B
FFP
2A
FFP
2A
FFP

WLW

FFP
BND
1B
BND
WLP
1B
BND
FFP
BND
FFP
WLW
FFP
1B
FFP
BND
FFP
1B
FFP
BND
FFP
BND
1B
FFP
1B
FFP
2N
FFP
2A
FFP
1B
FFP
1B
FFP
WLP
FFP
UNK
WLW

UNK
BND
FFP
1B
FFP
1B
BND
FFP
1B
FFP
WLW
FFW
WLW
1B
BND
2A
FFP
1B
BND

FFP
BND
2B
FFP
BND
FFP
1B
FFP
1B
BND
1B
FFP

Sample 14B - Packstones: Raw Data

UNK	BND	2A
BND	1B	FFP
FFP	BND	2B
1B	FFP	FFP
FFP	2B	BND
BND	FFP	FFP
1B	2B	2A
WLP	FFP	FFP
BND	2B	2A
FFP	FFP	FFP
2B	2A	2A
BND	FFP	FFP
WLP	2A	
BND	BND	
WLW	1B	WLP
BND	BND	1B
WLP	2B	WLP
2A	BND	FFP
FFP	FFP	WLP
WLP	1B	FFP
1B	WLP	BND
FFP	BND	WLP
2B	WLP	2B
FFP	BND	WLP
2A	WLP	FFP
BND	BND	BND
FFP	WLP	WLW
BND	BND	BND
1B	WLP	2B
FFP	BND	FFP
1B	WLP	2B
BND	2B	FFP
2A	FFP	BND
BND	2B	FFP
2A	FFP	

Sample 3A - Packstones: Raw Data

WLP	2B	WLP
1B	BND	1B
WLP	FFP	WLP
2B	2A	FFP
WLP	WLP	1B
2A	2B	FFP
FFP	WLP	1B
1A	2B	FFP
WLP	WLP	WLP
2B	FFP	1B
FFP	2A	WLP
WLP	FFP	1B
2B	1B	WLP
WLP	FFP	1B
1A	WLP	WLP
WLP	BND	1B
BND	WLP	WLG
WLP	1B	WLP
2B	BND	1B
WLP	1B	WLP
2B	WLP	1A
WLP	1B	WLP
1A	WLP	1B
WLP	2B	WLP
1B	WLP	1B
WLP	1A	WLP
FFP	WLP	2B
1A	1A	WLP
WLP	WLP	1A
1B	1B	WLP
BND	WLP	1A
FFP	1B	BND
2A	WLP	WLP
FFP	1B	

Sample 9L - Packstones: Raw Data

BND	FFP	FFP
FFP	2A	WLP
1B	FFP	FFP
FFP	1B	2B
WLP	WLP	FFP
2A	BND	WLP
BND		FFP
FFP		WLP
1B	FFP	BND
FFP	1B	1B
1B	FFP	FFP
FFP	2A	WLP
1B	BND	FFP
FFP	FFP	1B
2B	WLP	FFP
WLP	FFP	WLP
2B	2B	FFP
FFP	FFP	2A
WLP	2B	FFP
2B	FFP	2B
FFP	2B	FFP
2B	FFP	2B
WLP	1B	FFP
2B	FFP	WLP
FFP	1B	BND
1B	FFP	WLP
FFP	2B	1B
WLP	WLP	WLP
FFP	2B	FFP
2B	WLP	2B
FFP	1B	WLP
1B	FFP	FFP
WLP	WLP	1B
FFP	2B	FFP
1B	WLP	

Sample 14A - Packstones: Raw Data

W LP	W LP	BND
BND	BND	W LP
W LP	FFP	FFP
1A	1B	BND
W LP	FFP	1B
1B	1B	FFP
W LP	FFP	1B
1A	BND	BND
W LP		
2B		
FFP	FFP	W LP
1B	W LP	FFP
FFP	1A	1B
2A	W LP	FFP
FFP	FFP	1B
W LP	1B	FFP
1B	FFP	W LP
WLP	2A	FFP
1B	FFP	W LP
W LP	2B	FFP
	FFP	2A
	W LP	FFP
2B	FFP	1B
FFP	2B	FFP
W LP	W LP	1B
BND	FFP	FFP
W LP	2B	2B
BND	FFP	FFP
FFP	2B	W LP
W LP	FFP	FFP
2B	1B	2B
FFP	BND	W LP
1B	1B	BND
FFP	W LP	1B
1B	FFP	BND
FFP	1B	1B
BND	W LP	

WACKESTONES: SUMMARY

	WLG	WLP	WLW	FFG	FFP	FFW	BND	UNK	TOT
1A	0	0	1	0	0	0	1	0	2
1B	0	1	75	0	0	29	22	0	127
2A	0	0	5	0	0	57	2	0	64
2B	0	1	64	0	0	68	7	0	140
SUB-TOTAL	0	2	145	0	0	154	32	0	333
WLG	X	0	0	0	0	0	0	0	0
WLP	0	X	13	0	0	1	4	0	18
WLW	0	15	X	0	0	43	142	0	200
FFG	0	0	0	X	0	0	0	0	0
FFP	0	0	0	0	X	0	0	0	0
FFW	0	1	42	0	0	X	32	0	75
BND	0	3	139	0	0	32	X	0	174
UNK	0	0	0	0	0	0	0	X	0
SUB-TOTAL	0	19	194	0	0	76	178	0	467
GRAND TOTAL	0	21	339	0	0	230	210	0	800

Sample 10B (4) - Wackestone: Raw Data

WLW	2A	FFW	WLW	1B
FFW	FFW	2A	2B	BND
2B	BND	FFW	WLW	1B
FFW	1B	BND	BND	BND
2A	FFW	WLW	WLW	FFW
FFW	2B	FFW	BND	WLW
BND	WLW	2B	FFW	FFW
FFW	1B	WLW	BND	BND
2B	WLW	BND	1B	FFW
FFW	BND	WLW	WLW	BND
1B	FFW	FFW	FFW	1B
FFW	1B	2A	2B	WLW
2A	FFW	FFW	FFW	1B
FFW	WLW	WLW	BND	WLW
1B	2B	1B	FFW	BND
BND	WLW	BND	2A	WLW
1B	FFW	FFW	FFW	1B
FFW	BND	2A	WLW	WLW
WLW	WLW	FFW	FFW	BND
FFW	1B		2B	WLW
2A	WLW		FFW	BND
FFW	1B	WLW	2B	FFW
WLW	BND	1B	BND	BND
BND	FFW	WLW		1B
WLW	BND	FFW		BND
2B	WLW	BND	FFW	1B
WLW	FFW	WLW	WLW	FFW
2B	2A	BND	1B	WLW
BND	FFW	WLW	WLW	1B
WLW	WLW	FFW	BND	WLW
2B	FFW	WLP	WLW	2B
WLW	2A	FFW	BND	WLW
BND	FFW	WLW	WLW	2B
FFW	BND	1B	WLP	FFW
WLW	WLW	WLW	WLW	WLW
BND	2B	BND	2B	FFW
WLW	FFW	FFW	WLW	2A
1B	WLW	BND	2B	FFW
BND	2B	FFW	WLP	BND
WLW	WLW	WLW	1B	FFW
FFW	1B	BND	BND	BND
			WLW	WLW

Sample 15A - Wackestone: Raw Data

FFA	BND	WLW	BND	2B
2A	FFW	FFW	2B	FFW
FFW	BND	1B	FFW	BND
2A	FFW	BND	1B	WLW
FFW	BND	WLW	FFW	BND
BND	WLW	BND	2B	FFW
WLW	BND	1B	WLW	2B
BND	FFW	FFW	BND	FFW
1A	WLW	2B	WLW	WLW
WLW	FFW	FFW	2B	FFW
2A	2B	2A	WLW	1B
FFW	FFW	FFW	FFW	WLW
BND	BND	WLW	WLW	2B
2B	WLW	1B	2B	FFW
FFW	1B	WLW	WLW	2B
2A	WLW	FFW	FFW	WLW
FFW	FFW	2B	2B	FFW
BND	2A	FFW	WLW	1B
FFW	FFW	2A	FFW	FFW
2B	2A	FFW	2B	2A
FFW	FFW		FFW	FFW
2B	BND		2A	1B
BND	WLW	FFW	FFW	WLW
WLW	BND	2B	2B	1B
BND	2A	FFW	FFW	FFW
FFW	FFW	WLW	2B	WLW
2A	BND	2B	WLW	FFW
FFW	WLW	WLW	BND	1B
2B	BND	2B	FFW	WLW
FFW	FFW	WLW	2A	FFW
2A	2B	BND	FFW	1B
FFW	FFW	WLW	2A	FFW
BND		BND	FFW	2B
FFW		FFW	2B	WLW
2B	FFW	2A	WLW	FFW
FFW	2B	FFW	1B	2A
2B	FFW	1B	WLW	FFW
FFW	WLW	FFW	2B	2B
WLW	BND	2B	WLW	FFW
2B	FFW	WLW	2B	WLW
BND	1B	2B	WLW	FFW
WLW	FFW			

Sample 4A (14) - Wackestone: Raw Data

WLW	BND	BND	1B	BND	WLW
1B	WLW	WLP	WLW		
WLW	BND	BND	BND		
BND	WLW	WLP	WLW	WLW	WLW
1B	BND	BND	BND	BND	BND
WLW	WLW	WLW	WLW	WLW	WLW
1B	FFW	WLP	BND	1B	BND
WLW	WLW	WLW	WLW	WLW	WLW
1B	BND	WLP	BND	BND	BND
WLW	WLW	WLW	WLW	WLW	WLW
BND	BND	WLP	BND	BND	BND
FFW	WLW	BND	WLW	WLW	WLW
WLW	BND	WLW	BND	BND	
BND		BND	WLW	WLP	
WLW		WLW	BND	WLW	BND
BND	WLW	WLP		BND	WLW
WLW	BND	WLW		WLW	1B
BND	WLW	WLP	BND	BND	WLW
WLW	BND	WLW	WLW	WLW	1B
BND	WLW	WLP	1B	BND	WLW
WLW	BND	WLW	WLW	WLW	BND
BND	WLW	WLP	BND	BND	WLW
WLW	BND		WLW	WLW	BND
BND	WLW		1B	BND	WLW
WLW		WLW	WLW	WLW	BND
		WLP	BND	BND	WLW
	WLW	WLW	WLW	WLW	BND
BND	FFW	WLP	BND	BND	WLW
1B	WLW	WLW	WLW		BND
WLW	BND	WLP	BND		WLW
1B	WLW	BND	WLW	WLW	BND
BND	WLP	WLW	BND	BND	WLW
WLW	WLW	BND	WLW	WLW	BND
1B	WLP	WLW	BND	BND	WLW
WLW	WLW	BND	WLW	WLW	BND
BND	WLP		BND	BND	WLW
WLW	WLW		WLW	WLW	BND
BND	WLP	BND	BND	BND	
WLW	WLW	WLW	WLW		

Sample 8B (12) - Wackestone: Raw Data

FFW	WLW	BND	2B	BND
BND	BND	WLW	FFW	WLW
FFW	WLW	2A	2B	FFW
WLW	BND	WLW	FFW	WLW
BND	WLW	2A	2B	BND
WLW	BND	WLW	FFW	FFW
FFW	WLW	BND	BND	WLW
1B	BND	WLW	WLW	BND
FFW	WLW	FFW	BND	WLW
1B	BND	2A	WLW	FFW
FFW	1B	BND	1B	2B
BND	WLW	WLW	WLW	FFW
FFW	BND	BND	FFW	WLW
WLW	WLW	FFW	WLW	BND
BND	1B	WLW	1B	WLW
WLW	WLW	BND	WLW	BND
BND	BND	WLW	2B	WLW
WLW	WLW		WLW	
1B	BND		FFW	
WLW	WLW	WLW	BND	FFW
BND	1B	BND	WLW	2B
WLW	WLW	2B	BND	WLW
BND	1B	WLW	WLW	FFW
WLW	WLW	FFW	BND	BND
BND	2B	WLW	WLW	FFW
WLW	WLW	2B	BND	WLW
BND	1B	WLW	WLW	FFW
1B	WLW	BND	2B	WLW
WLW	2B	WLW	WLW	BND
1B	WLW	BND	2B	FFW
WLW	2B	WLW	WLW	BND
1B	WLW	BND	BND	FFW
WLW	2B	WLW	WLW	WLW
BND	WLW	FFW	FFW	FFW
WLW	BND	2A	WLW	2B
BND	WLW	FFW	BND	FFW
WLW	BND	2B	WLW	2B
BND	WLW	FFW	FFW	FFW
WLW	BND	WLW	WLW	WLW
BND	WLW	BND	2B	FFW
WLW	BND	WLW	WLW	BND
BND	WLW			

APPENDIX C

APPENDIX C

Comparison of distributions of pressure solution features in fitted fabric and non-fitted fabric lithotypes of the major lithologies in the Alpena limestone. Chi-square tests reveal that the distribution of pressure solution features is different in fitted fabric and non-fitted fabric lithotypes in all lithologies. Data from raw data tables in appendix B.

GRAINSTONES

	NON-FITTED FABRIC	FITTED FABRIC	TOTAL
1A	75 57.94 4.73	3 20.06 13.67	78
1B	147 167.87 2.47	79 58.13 7.14	226
2A	0 5.94 4.98	8 not significant	8
2B	61 51.25 1.85	8 17.75 5.36	69
TOTAL	283	98	381

Sum of chi-square components = 40.20; critical value = 7.81.

Comparison of distributions of pressure solution features in fitted fabric and non-fitted fabric grainstones. No significance can be attached to those transitions which have expected values of less than five.

PACKSTONES

	NON-FITTED FABRIC	FITTED FABRIC	TOTAL
1A	32	2	34
	15.90	18.10	
	15.31	13.45	
1B	168	166	334
	156.15	177.85	
	.82	.72	
2A	25	83	114
	53.30	60.70	
	14.50	12.73	
2B	106	120	226
	105.66	120.34	
	0.0	0.0	
TOTAL	331	377	708

Sum of chi-square components = 57.53; critical value = 7.81

Comparison of distributions of pressure solution features in fitted fabric and non-fitted fabric packstones.

WACKESTONES

	NON-FITTED FABRIC	FITTED FABRIC	TOTAL
1A	2 not significant	0 not significant	2
1B	98 68.27 12.53	29 58.73 14.55	127
2A	7 34.40 21.04	57 29.60 24.45	64
2B	72 75.26 .10	68 64.74 .11	140
TOTAL	179	154	333

Sum of chi-square components = 72.78; critical value = 7.81.

Comparison of distributions of pressure solution features in fitted fabric and non-fitted fabric wackestones. No significance can be attached to those transitions which have expected values of less than five.

APPENDIX D

APPENDIX D

Comparison of distributions of pressure solution features in all lithotypes of grainstones, packstones, and wackestones in the Alpena limestone. Chi-square tests reveal that the distribution of pressure solution features is different in each of the lithologies. Data from raw data tables in appendix B.

	GRAINSTONES	PACKSTONES	TOTAL
1A	78	34	112
	39.18	72.82	
	37.48	20.16	
1B	226	334	560
	195.92	364.08	
	4.47	2.40	
2A	8	114	122
	42.68	79.32	
	27.37	14.73	
2B	69	226	295
	103.21	191.79	
	11.01	5.93	
TOTAL	381	708	1089

Sum of chi-square components = 123.55; critical value = 7.81.

Comparison of distributions of pressure solution features in all grainstones and all packstones.

	GRAINSTONES	WACKESTONES	TOTAL
1A	78	2	80
	42.69	37.31	
	28.38	32.48	
1B	226	127	353
	188.37	164.63	
	7.32	8.37	
2A	8	64	72
	38.42	33.58	
	23.30	26.66	
2B	69	140	209
	111.53	97.47	
	15.83	18.12	
TOTAL	381	333	714

Sum of chi-square components = 160.46; critical value = 7.81.

Comparison of distributions of pressure solution features in all grainstones and all wackestones.

	PACKSTONES	WACKESTONES	TOTAL
1A	34	2	36
	24.48	11.52	
	3.32	7.06	
1B	334	127	461
	313.53	147.47	
	1.27	2.70	
2A	114	64	178
	121.06	56.94	
	.36	.76	
2B	226	140	366
	248.92	117.08	
	2.02	4.29	
TOTAL	708	333	1041

Sum of chi-square components = 21.78; critical value = 7.81.

Comparison of distributions of pressure solution features in all packstones and all wackestones.