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# Lithologic Control of Alkali-Induced Expansion in Carbonate Rock From Decorah, Iowa

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*Abstract.* A study of the overall linear expansion of carbonate rock cores in an alkaline environment was extended to include the distribution of expansion along the length of the core. For the material tested, it was found that the fracture pattern, radial expansion and overall linear expansion were associated with bedding planes and stylolitic seams. The formation of voids and the constant association of iron stains both with pyrite and expansion zones places pyrite under suspicion as an indicator of a type of expansive lithology. The radial expansion distribution provides a basis for separating expansive and non-expansive lengths of core. The analyses of the chemical and physical properties of the differential lengths of core might then be used to describe the nature of changes found in differential expansion.

## INTRODUCTION

The poor service record of Decorah carbonate rock as highway aggregate and the problem of detecting other detrimental aggregate of this type has recently been described by Welp and De Young (1). The present alkali-induced expansion study is part of the Iowa State Highway Commission sponsored program to investigate the nature of this carbonate rock. For the purpose of quality control, carbonate materials have been identified by local source and stratigraphic horizon. Material herein identified as Decorah carbonate rock was deposited as part of the Prosser and Stewartville members of the Ordovician Galena formation. The description and evaluation of the differential behavior of this material under laboratory test conditions is the purpose of this study.

## BULK BEHAVIOR

Methods of sampling and procedures used in alkali-induced expansion tests both at room temperature and in the autoclave were those described by Lemish and Moore (2). The results are reported as percent change in the original length of a core after a specified time in the test environment. On the basis of their tests expansive carbonate rocks were placed in four categories:

Category I samples which expanded in excess of 0.5 percent.

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Category II samples which expanded between 0.0 and 0.5 percent.

Category III samples which contracted prior to expanding.

Category IV samples which contracted steadily.

In the present study cores were obtained from rock samples previously evaluated by the Iowa State Highway Commission. Data consisting of chemical analyses and freezing and thawing results obtained by the water-alcohol method "A" are shown in Table I under the heading "Rocks Samples." In Table I the specimens tested are identified by core number. In general, two core numbers are related to the corresponding Highway Commission sample number and the quarry bed unit so that the material represented by the samples can be completely specified. Both I.H.C. 4D and I.H.C. 7D rock samples fail the freezing and thawing test while the others are well within the six per-

Table 1. Rock and Core Properties

| Core No. | Bed | I.H.C. | CaO | MgO | $Al_2O_3$ | $SiO_2$ | F&T "A" |
|---|---|---|---|---|---|---|---|
| 1<br>2 | S3 | 16 | 44.28 | 8.6 | 0.63 | 1.87 | 3.9 |
| 7<br>8 | S6-9 | 18 | 45.50 | 7.88 | 0.63 | 1.78 | 2.7 |
| 16<br>17 | S 11 | 20 | 44.66 | 7.63 | 0.46 | 2.73 | 2.9 |
| 34<br>35 | E 8 | 26 | 34.09 | 17.45 | 0.85 | 2.14 | |
| 22<br>23 | D12-14 | 4D | 48.51 | 2.41 | 1.29 | 6.95 | 20.0 |
| 25<br>26<br>27 | D 6&7 | 7D | | | | | 20.0 |

CORE SAMPLES

| Core No. | LTP NaOH | Auto NaOH | Auto $H^2O$ | 17 day Percent | 106 day Percent | Identity | Condition |
|---|---|---|---|---|---|---|---|
| 1 | x | | | -0.0879 | -0.1154 | St | Brown |
| 2 | | x | | 0.0455 | | | satisfactory |
| 7 | x | | | -0.0714 | -0.0766 | St | Brown |
| 8 | | x | | 0.1008 | | | Expanded |
| 16 | x | | | | | St | Broken |
| 17 | | x | | 0.0532 | | | |
| 34 | x | | | -0.0457 | -0.0366 | St | Gray |
| 35 | | x | | 0.0259 | | | Satisfactory |
| 22 | x | | | 0.0366 | 0.1969 | P | Uniformly |
| 23 | | x | | 0.2088 | | | Expanded |
| 25 | x | | | 0.0000 | 0.0598 | P | Locally |
| 26 | | x | | 0.8230 | | | Expanded |
| 27 | | | x | 0.0276 | | | |

Symbols
S — Kulhmans Schrader Quarry
E — Elkader Quarry
D — Decorah Road Cut HW 52 one mile due west of Decorah Quarry
# — Cores obtained from I.H.C. rock samples.
I.H.C. — Rock Sample Data furnished by Iowa State Highway Commission
LTP — Laboratory temperature and pressure
St — Stewartville member

cent loss allowed by the Highway Commission. It should be noted that I.H.C. 4D is relatively low in magnesia and high in silica and alumina.

The results of alkali-induced expansion tests at room temperature and in the autoclave are also shown in Table 1. At the seventeen day stage when the autoclave test was terminated cores of highly reactive carbonate rock as defined by curves of Lemish and Moore have shown overall expansions of O.1 percent or more. if a 0.1 percent expansion in 17 days is accepted as a reasonable threshold for the identification of expansive lithology, then sample numbers 8, 23, and 26 are suspect. With the exception of number 7, which still indicates contraction, the 106 day room temperature alkali-induced expansion tests also identify the same lithologies as expansive. It should be noted that the autoclave test and the freezing and thawing test identify the same Prosser lithology as having different behavior than the other samples tested.

## Differential Behavior

Information as presented in Table I allows evaluation of the bulk behavior of the material sampled. The nature of the expansion and its related reaction may be better described in terms of the changes evident in a single core. These changes call attention to the differential nature of the expansive behavior in those parts of the core that are texturally varied. Heretofore expansion data represented only the overall or net growth of a core.

The need to study differential behavior is developed in figurs 1, 2, 3, and 4. Starting with the fracture surface where core 16 has failed along a styolitic seam shown in figure 1, the degree of differential behavior is reduced as partially reacted seams of core number 8 and the apparently unreacted core 2 are compared with the pieces of core 16 in figure 2. It seems obvious from these pictures that styolitic seams, being zones of weakness have different behavior than carbonate material. In figure 3 failure along the seams of core 35 is contrasted with core 26 showing local expansion and core 23 showing uniform expansion. It may be noted that bands, identified as bedding planes, are present in the top part of core 26 and the entire length of core 23. Figure 4 shows another view of cores 26 and 27. These cores represent the same lithology subjected to the same treatment in the autoclave; core 26 was reacted in sodium hydroxide whereas core 27 was placed in distilled water to act as a treatment control. The cracks which are present in core 26 but absent in core 27 are attributed to the different solution environments under autoclave conditions.

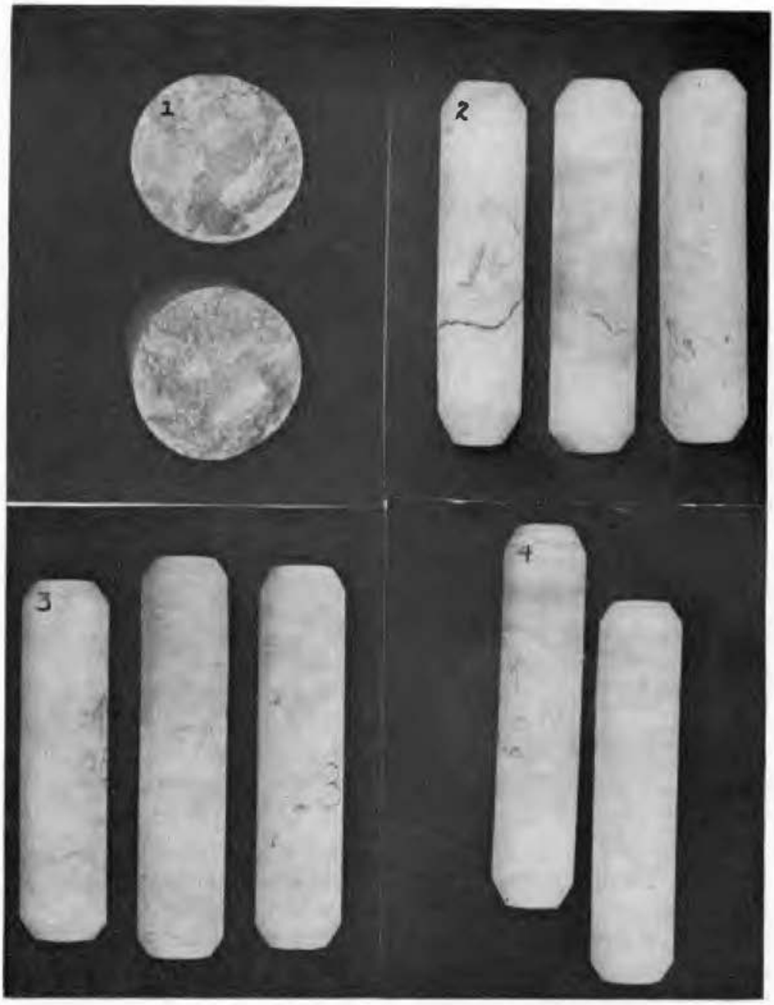


Figure 1. Fracture surfaces of broken styolitic seam of core number 16. This core fractured under its own weight when it was removed from sodium hydroxide.

Figure 2. Variation of behavior along styotitic seams. Discolored zones surrounding the seams and fracture surface are contrasted with the uniform coloration of the matrix where the seams are absent.

Figure 3. Variation in lithology of expansive cores. Cores which have styolitic seams or are partly to uniformly laminated were the only lithologic types indentified as expansive.

Figure 4. Alkali-induced expansion of core number 26 and control core number 27 taken from the same rock sample after treatment in the autoclave.

## Distribution of Expansion

The lithology represented by number 26 was selected for further study to determine if expansion as well as cracking failure was non-homogenous. Distributions of radical expansion were obtained by placing the core horizontally and measuring the variations in core diameter at intervals along its length with a feeler gage. Measurement are shown in figure 5 for the unreacted core, the core reacted in distilled water in the autoclave, number 27, and the core reacted in sodium hydroxide, number 26. The color change from brown to gray was used to index the spacing of sample points along the length of the core. The change in radial expansion shown for the reacted samples is associated with the change in color from gray to brown.

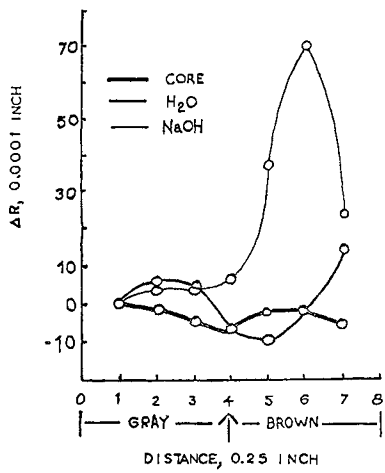


Figure 5. Axial distribution of radial expansion. Curves for untreated and autoclave treated cores from the same rock are presented with the change from gray to brown color to show the dependence of the magnitude of expansion on color.

An estimate of the axial distribution of linear expansion is shown in figure 6. This distribution was determined from depth gage measurements using surface features to orient the core and cored rock. The measurements are only approximate since the outer diameter of the core approximates the inner diameter of the cored rock. Within the limits of measurement, expansion is associated with the fine laminations which from failure planes rather that the change in color from gray to brown. This is consistent with the radial expansion data since the differential changes measured with the depth gage are more sensitive to change. The expansive zone is now identified as the fine laminations within the brown zone. By means of the distribution of radial and linear expansion, the overall linear expansion measured can be associated with discontinuities and the material associated with the discontinuities rather than the continuous material of the core.

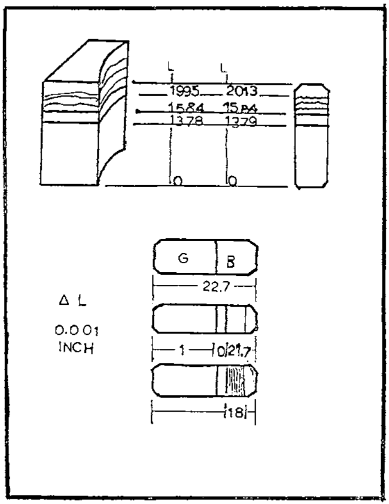


Figure 6. Axial Distribution of Linear expansion. Core number 26 after treatment in the autoclave is compared with the untreated rock sample using surface features to index the core within the hole.

## Expanded Zones

Petrographic examination of finely laminated bedding planes of core number 26 indicated a brown material associated with pyrite and void fillings of former pyrite sites. This brown material is interpreted as limonite after pyrite. The pyrite in this material is very fine-grained as shown by the black cluster and inclusions in figure 7. Figure of the area near the styolitic seams in core 35 shows brown material within the seam and the cubic shape of the empty and filled voids near the seam. In core 26 the major and minor cracks shown in figure 9 appear to be controlled by voids which resemble the pyrite surfaces in figure 8 and the cubic voids shown in figure 9. A cross section of the major crack is shown in figure 10. It should be noted that the central area of this fracture surface is gray while the outer area is brown and bleached. Because the circular symmetry of the brown zone is controlled by the round shape of the core and has the same center, this color change is associated with the autoclave treatment and the alkali-induced expansion.

Bulk chemical analyses of the brown and gray areas of the lithology represented by core number 26 indicated considerable difference between zones. Two cores about 2.5 inches long and 0.25 inches apart were separated into zones for chemical analyses. The results in the brown areas were more consistant than the results in the gray areas but when the results are shown as ratios of weight percentages in the different zones the general

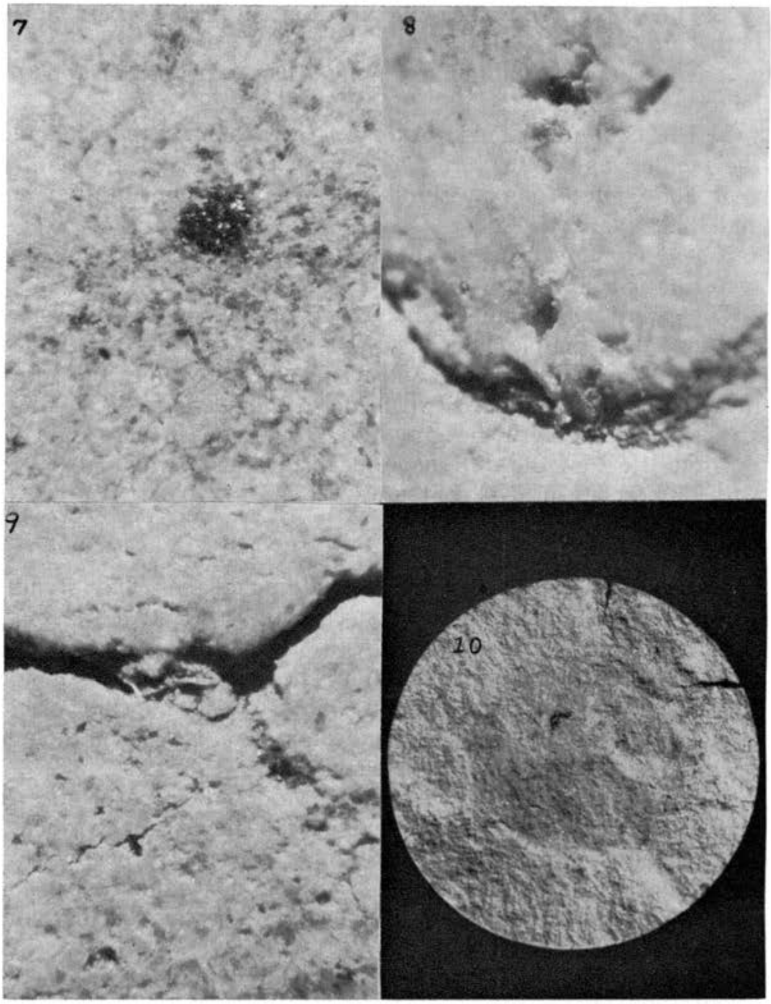


Figure 7. Clustering in the pyrite distribution. Small particles are shown in the opaque cluster as well as numberous single particles.

Figure 8. Seams and vugs of core number 35. Surface showing evidence of chemical attack and brown material.

Figure 9. Fractures and vugs of core number 26. Large and small fractures developed during autoclave treatment in sodium hydroxide indicate the extent of differential chemical attack.

Figure 10. Fracture surface of core number 26 showing reaction ring. The black center area contrasts with the brown outer ring to show the degree of penetration during the autoclave test.

trend is the same in both core samples. The factor which the weight percent of the material in the gray zone must be multiplied to equal the weight percent of the material in the brown one of the same core is shown below.

1. The content of silica averaged about twelve percent in both zones.
2. The content of alumina was less than two percent and the factor was 3.3.
3. The content of ferric oxide was less than 0.7 percent and the factor was 2.87.
4. The content of potassium oxide was less than one percent and the factor was 4.86.
5. The content of magnesia was less than 9.1 percent and the factor about 6.0.

The results of chemical analysis reported for different zones within a rock sample associate lower values of CaO and higher values of MgO, $Fe_2O_3$, $K_2O$ and $Al_2O_3$ with the zones subject to the greater alkali induced expansion. Although high $SiO_2$ values are reported for both the gray and brown zones, these data do not indicate that the difference in alkali reactivity is correlated with differences in $SiO_2$ content.

## Summary

Former pyrite–rich laminated bedding planes and styolite seams expand and fail under test conditions. Most of the measurable expansion is associated with the discontinuities rather than the carbonate matrix material. The formation of voids and the constant association of iron stains with expansion places pyrite under suspicion as in indicator of a type of lithology suceptible to alkali-induced expansion.

Radial expansion is more sensitive and indicative of the reactivity of Decorah carbonate than overall linear growth since it can be shown as an axial distribution. A testing procedure redefining reactive carbonate in terms of the radial expansion distribution may be useful in detecting and evaluating nonhomogeneous behavior.

Lithologic control in the form of bedding planes localize the alkali-induced expansion in Decorah carbonate.

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