

# THE GREEN COMPRESSION STRENGTH OF NATURAL BENTONITES<sup>1</sup>

*By*

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## ABSTRACT

Cored specimens of several commercial bentonite beds were preserved at field moisture levels for laboratory examination. Green strength, water content, and x-ray diffraction character of undisturbed material were found to conform substantially to the relation that strength is proportional to the solid fraction.

The remarkable unidimensional swelling properties of bentonites have led to many extended studies of their water sorption characteristics as laboratory processes. In general these procedures are applied to prepared commercial products or to indefinitely aged mineralogical specimens.

Several years ago a unique opportunity was presented the author, through the offices of Dr. R. E. Grim, to study a set of ten specimens from bentonite beds being exploited by the Baroid Division of the National Lead Company. Care was taken to preserve the field water content, and the specimens were delivered sealed and undisturbed for laboratory analysis. They were received at the peak of the characteristic high relative humidity of midsummer, permitting testing under conditions of least possible deterioration.

From each specimen, when unsealed, one lump was weighed and reserved for oven drying, one lump was put into a closed camera with saturated atmosphere for x-ray diffraction analysis, and as many pieces as possible were whittled to more-or-less regular dimensions for determination of their green compression strength in a standard Dietert loading machine. Reasonable care was exercised to insure that all test pieces were representative and undisturbed. With the possible exception of no. W4, no specimen gave any visual indication of deterioration during handling. The longest operation was the three-hour x-ray diffraction exposure. Any water loss in this interval was probably of less consequence than the latitude of error inherent in the strength tests. The breaking of test pieces was conducted rapidly (within about one-half hour) with attention concentrated on the quality of the test pieces rather than on an exactly uniform size and shape.

The various analytical data are summarized in Table I. The observation of first importance is that total water contents vary by a factor of two, whereas the hydration states indicated by x-ray diffraction are relatively constant. This is of particular interest because both Na- and Ca-bentonites are represented.

The thicknesses of interlayer hydration-water packets are notably greater than the common one- and two-layer configurations that normally obtain for laboratory conditions. In his comprehensive studies of the associations of montmorillonites with organic liquids, MacEwan (1951, p. 112) has noted that the num-

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TABLE 1. — THE COMPOSITION AND GREEN COMPRESSION STRENGTH OF NATURAL BENTONITES

Sample no.	Oven-dry moisture (180° C) : g per 100 g of dry clay	X-ray diffraction measure of dominant layer thickness, in Å	Accessory minerals; g per 100 g of dry clay	Water excess above x-ray estimate of that associated with the solid	Fraction of volume occupied by solids; $\phi$	Green compression strength; P.S.I.
T <sub>1</sub>	53	19.9	20 (quartz)	26	0.72	27
T <sub>2</sub>	65	19.3*		33	.68	16
T <sub>3</sub>	69	19.6	2 (quartz)	38	.65	20
T <sub>4</sub>	68	19.8		35	.67	22
W <sub>L</sub>	38	18.5*	13 (quartz)	14	.82	30
W <sub>1</sub>	40	18.8*		10	.88	39
W <sub>2</sub>	55	18.6*	30 (feldspar and cristobalite)	34	.64	8
W <sub>3</sub>	81	19.5	5 (cristobalite and quartz)	51	.58	5
W <sub>4</sub>	43	18.7*		12	.85	19
H	50	19.1		19	0.79	40

\* Higher orders well developed.

ber of liquid layers in a complex in contact with excess liquid increases with the ratio of the molecular dipole moment to the molecular volume of the liquid. On this basis he estimated that 4 layers of water should be a stable complex for bentonites in the presence of excess water. The present data indicate an actual range of from 3 to 3.5 layers. Integral or near-integral higher orders appear in the diffraction diagrams of the specimens near 3 layers; the more hydrous specimens show only mixed-layer diffuse scattering sequences.

The actual density of hydration-water layers in association with montmorillonite has not been amenable to an authoritative determination. An early study in our laboratories (Bradley, Grim, and Clark, 1937) indicated a dubiously high value substantially greater than 1. Later consensus has favored a figure slightly less than 0.9. In seeking a proper partition of determined field water contents between the hydration water and liquid water categories in order to arrive at the data of Table 1, the density of hydration water was taken to be four molecules per unit cell per layer. The low density of this interlayer water may be a factor leading to the association of fewer layers than would be anticipated from the magnitude of the dipole moment alone. In this sense, the observation is evidence that the bound-water density is low.

The data of Table 1 are cast arbitrarily on an assumption that green compression strength should be proportional to the fraction of the bulk volume of the rock which is actually occupied by solids. In Figure 1 this fraction ( $\phi$ ), cal-

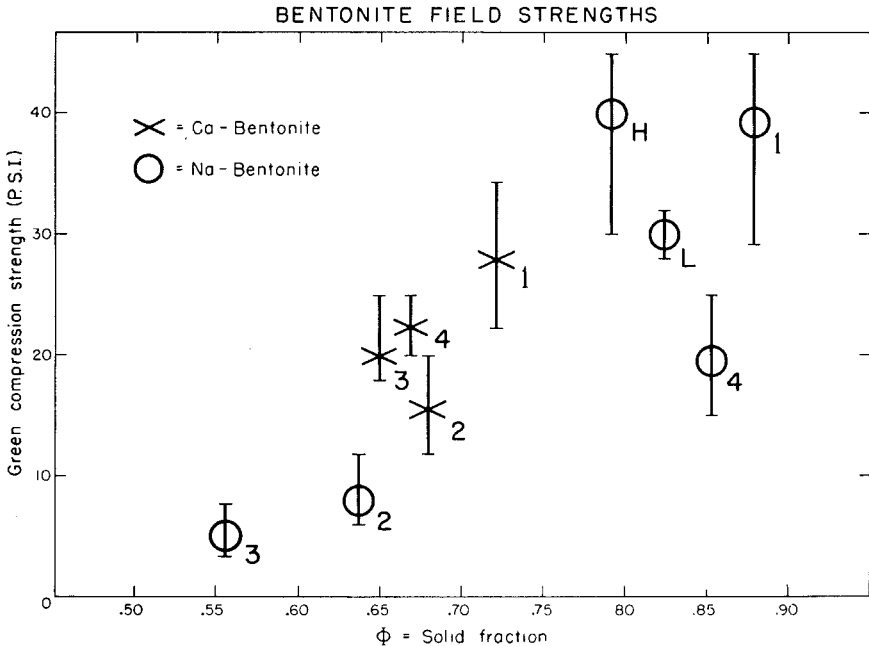


FIGURE 1. — Average green compression strengths of natural bentonites. Circles are Na-bentonites and crosses are Ca-bentonites. Vertical lines indicate the latitude of deviation from averages.

culated from x-ray diffraction estimates of the bentonite compositions, is plotted against the average green compression strengths. The latitude of deviation of individual breaks from their average is indicated by an appropriate vertical line.

With the exception of specimen W4, the green strengths conform in a vague way to a relation expressible in round numbers as: green strength (P.S.I.) =  $100\phi - 50$ . There was some evidence that the specimen W4 had lost water to its container in transit, leading to a fictitiously high  $\phi$  value. This specimen was ignored in estimating the trend of the other data.

It is of interest to orient the field of the present plot with respect to more familiar magnitudes. The strengths are of about the same order of magnitude as the load of overburden the deposits bear in the field. Maximum green compression strengths of synthetic molding sands are of the order of 30 or 40 P.S.I. and have  $\phi$  fractions of the order of 0.9. The initial apparent relative viscosities of dilute thixotropic suspensions relate to shearing stresses of the order of only  $10^{-3}$  times the strengths of these concentrated systems.

I am indebted to the Baroid personnel for the careful collection of the undisturbed specimens, and for their kind permission to present the results.

## REFERENCES

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