EFFECTS OF INTERPARTICLE AND INTRAPARTICLE MATERIAL ON THE GEOMECHANICAL PROPERTIES OF LIMESTONE

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SUMMARY

Interparticle and intraparticle material within limestone is that material deposited between skeletal (and other) grains and within the cavities of skeletal grains, respectively. Combinations of the distribution and quantity of these carbonate materials, and whether they are sparite cement (>0.02mm) or fine micrite matrix, form important controls on the geomechanical behaviour of limestone.

Interparticle material is correlated with durability/abrasion and dissolution rate parameters. Geomechanically, these involve surficial processes, suggesting that surface degradation is influenced most significantly by the material deposited between grains in limestone. Micrite (muddy) materials are more durable than sparite materials, and intersparite is also responsible for higher rates of dissolution.

Intraparticle material is correlated especially with sonic velocity and various strength properties. These areas of geomechanics are concerned primarily with the body of the rock, suggesting that internal breakdown of limestone under stress is controlled particularly by the amount and type of material infilling pore spaces in skeletal grains. An increase in intraparticle material improves the geomechanical performance of limestone. Intramicrite appears to be particularly conducive to higher limestone strengths.

INTRODUCTION

Little published information exists about the geotechnical properties of limestones. This paper contributes to this short-coming, and suggests some likely compositional controls on limestone behaviour under different physical and chemical test environments. Eight texturally diverse limestones were collected from quarries in the North Island, New Zealand (Appendix Table 1). The compositions of the limestones were determined by petrographic (microscopic) analysis, and a wide range of field and laboratory geotechnical measurements were made on the specimens. We report here a subset of the statistical correlations that link the petrographic features of the limestones to their geomechanical properties. We recognise the limitations of using only eight cases in the statistical evaluation, but trust the results will encourage further research into the relationships postulated.

TEST PARAMETERS

Limestones are sedimentary rocks, normally comprising more than 50% $CaCO_3$. A special feature of limestones compared to terrigenous rocks, such as mudstones or sandstones, is that their particles consist mainly of the carbonate fossils or skeletons of various organisms involved in the sedimentation process, and that many of these skeletons include internal cavities and pores. Thus, during conversion of an unconsolidated carbonate sediment into a limestone, precipitated carbonate and other material is deposited both *within* and *between* the skeletal grains, here referred to as *intraparticle* and *interparticle* material, respectively (Fig. 1). This material may include calcite spar cement (or sparite >0.02mm) or an infiltered very fine matrix of calcite material, known as micrite (sometimes including terrigenous silt and clay) [11]. The abundance of each of these materials, and of the skeletal and terrigenous framework grains, was determined by point-counting under a petrographic microscope, identification of the limestone constituents being aided by the photographic plates in Adams et al. [1] and Scholle [12].

The following geomechanical tests were undertaken on the limestones: sonic velocity - a measure of the velocity of high frequency soundwaves passing through cored specimens; unconfined compressive strength (UCS) - a measure of compressive strength characteristics of cored specimens; pointload strength - a measure of (largely) tensile strength characteristics of small irregular blocks of limestone in the field; slake durability and Los

Angeles abrasion - measuring the effects of surface degradation of rock aggregate under alternate wetting and drying cycles, and under purely dry conditions, respectively; dissolution rate - an index measure of the rate at which small limestone disks undergo dissolution over a two hour period in distilled water. Apart from the dissolution rate test, which was designed specifically for the project [10], all geomechanical tests follow standard methods [2, 3, 5, 6].

The abundances of skeletal (and other) grains and of the interparticle and intraparticle material in the limestones are summarised in Appendix Table 2, along with the geomechanical properties of the specimens.

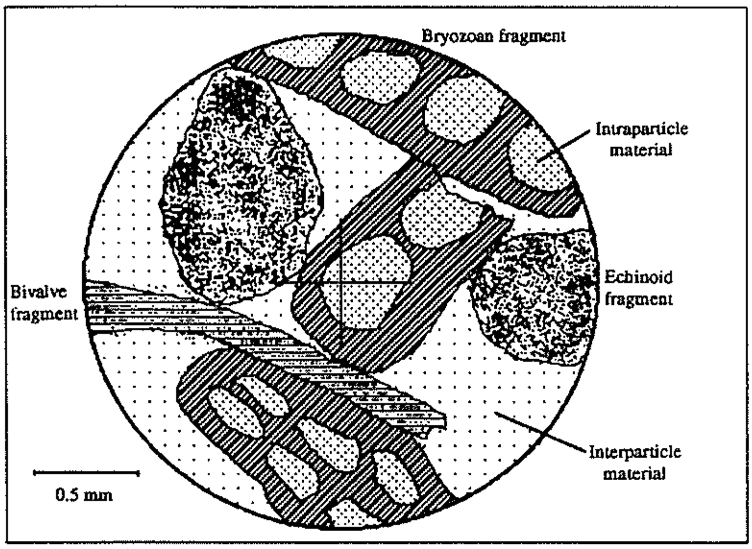


Figure 1: Sketch of a portion of a thin-section of a limestone under a petrographic microscope showing three common types of skeletal fragments and the distribution of interparticle and intraparticle material.

GEOMECHANICAL CORRELATIONS WITH INTERPARTICLE MATERIAL

Interparticle material influences the behaviour of limestone aggregate tested in the Los Angeles abrasion machine. Abrasion loss is more substantial with larger amounts of intersparite (Fig. 2), whereas considerable resistance to abrasion loss is demonstrated with intermicrite materials (Fig. 3). Knill [8] discovered that the surface polishing of roadstones was significant in material containing sparite, and that materials comprising mainly a fine matrix were most resistant to polishing. The results of the Los Angeles abrasion test (involving similar processes) on the limestone support these observations.

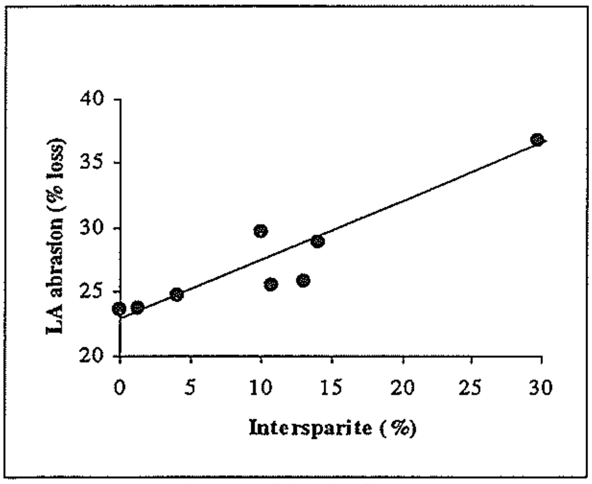
Lees and Kennedy [9] and Collis and Fox [4] attributed higher amounts of surface degradation associated with spar cemented materials to the softness and cleavage typical of large calcite sparite crystals.

Interparticle material also shows correlation with slake durability, despite the small range of recorded values (Appendix Table 2). Durability of the limestones is reduced by increasing amounts of interparticle material (Fig. 4), and correspondingly increased with larger numbers of grains, suggesting cement-rich limestones may be more prone to degradation than grain-rich materials.

The alternate wetting and drying cycles associated with the slake durability test may be partially responsible for lower durability observed in materials with more interparticle material (see the dissolution rate correlation below). Note that the outlier in Fig. 4 is the very sandy, lower carbonate limestone (D), perhaps contributing to the more significant degradation.

The proportion of interparticle material and grains in the limestones influences their rate of dissolution. Larger amounts of interparticle material (and correspondingly fewer grains) produce greater rates of dissolution (Fig. 5) and suggest that cement-rich limestones are more prone to (relatively) more rapid chemical degradation.

Intersparite materials in particular show good correlation with higher dissolution rate. This is supported by the work of Jakucs [7], who determined that dissolution of sparite textures was more evident than dissolution involving dense, uniform textures.



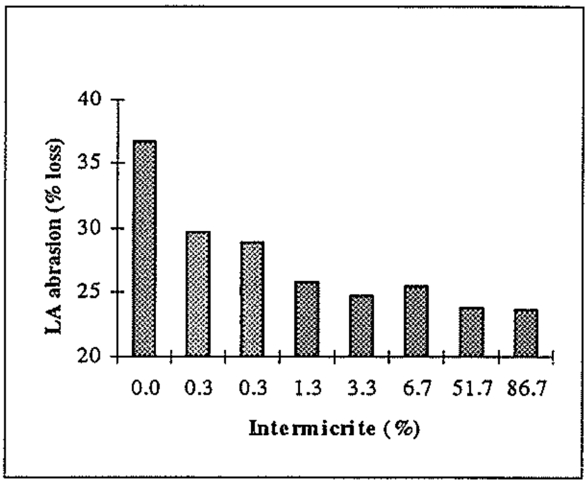
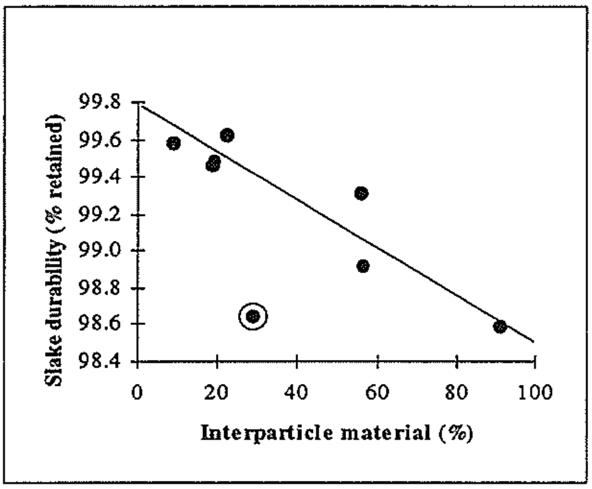


Figure 2 (left): Correlation between LA abrasion and intersparite. $R^2 = 84.6\%$.
Figure 3 (right): Histogram relating LA abrasion and intermicrite content.



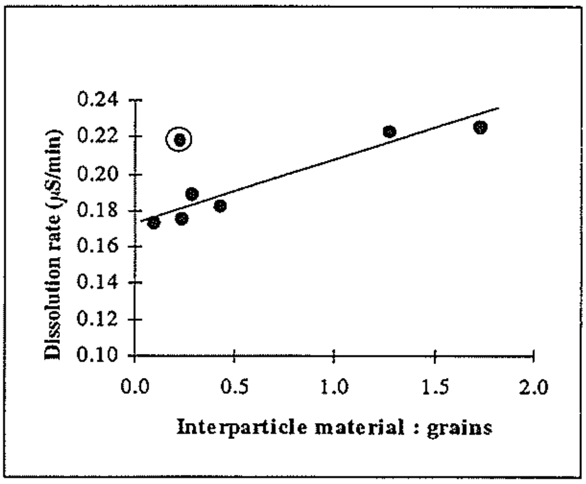


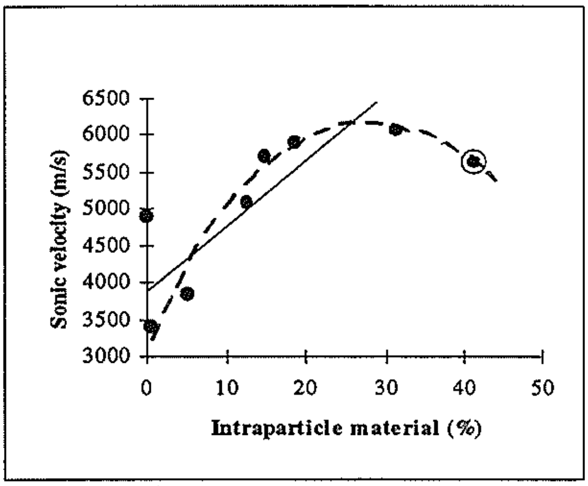
Figure 4 (left): Correlation between slake durability and interparticle material. The outlier is circled and omitted from the regression analysis. $R^2 = 91.2\%$.
Figure 5 (right): Correlation between dissolution rate and interparticle material:grains ratio. The outlier is circled and omitted from the regression analysis. $R^2 = 93.5\%$.

GEOMECHANICAL CORRELATIONS WITH INTRAPARTICLE MATERIAL

The sonic velocity parameter is influenced by the presence of intraparticle material. Higher soundwave velocities occur with larger quantities of intraparticle material (Fig. 6), and notably with larger amounts of intramicrite (Fig. 7). An explanation for these observations is the increase in grain 'rigidity' produced by the infilling material, as well as a simple reduction in porosity, both of which are likely to improve soundwave propagation through the material. Scanning electron microscopy (SEM) has shown the boundary between intraparticle material and the associated cavity wall to be extremely secure [10], further promoting rigidity of the grain and infilling material as a whole.

Intraparticle material correlates with pointload strength of the limestones. Larger amounts of intraparticle material produce higher pointload strengths (Fig. 8), and again intramicrite appears particularly conducive to producing more competent specimens (Fig. 9). Pointload testing involves 'splitting' the specimen (a measure of tensile strength), and intraparticle material appears to provide effective resistance to the splitting of individual grains as the specimen fails. As mentioned earlier, SEM has highlighted the secure bond between intraparticle material and the cavity walls [10].

UCS values also correlate with intraparticle material, and again an increase in intraparticle material (particularly intramicrite) produces higher compressive strengths (Figs. 10 and 11). The positive influence of intraparticle material on limestone under tension (above) is likely also to be important during compression of the specimens.



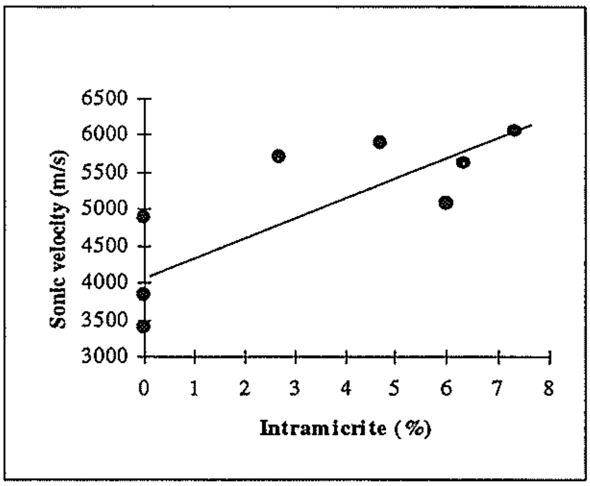
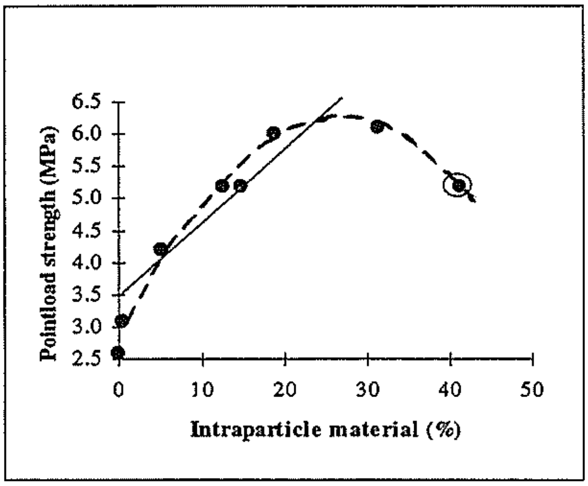


Figure 6 (left): Correlation between sonic velocity and intraparticle material. The outlier is circled and omitted from the regression analysis. R^2 = 69.2%. The dashed line is discussed below.

Figure 7 (right): Correlation between sonic velocity and intramicrite. R^2 = 62.7%.



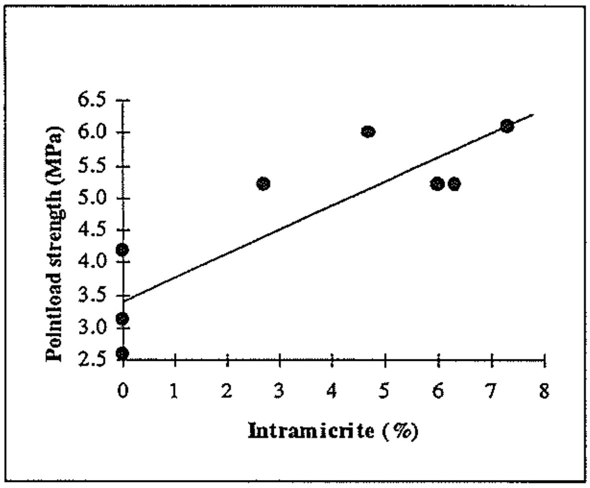
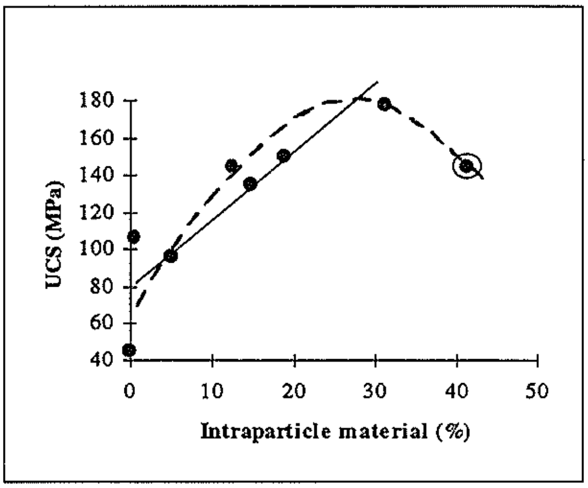


Figure 8 (left): Correlation between pointload strength and intraparticle material. The outlier is circled and omitted from the regression analysis. R^2 = 83.5%. The dashed line is discussed below.

Figure 9 (right): Correlation between pointload strength and intramicrite. R^2 = 72.4%.



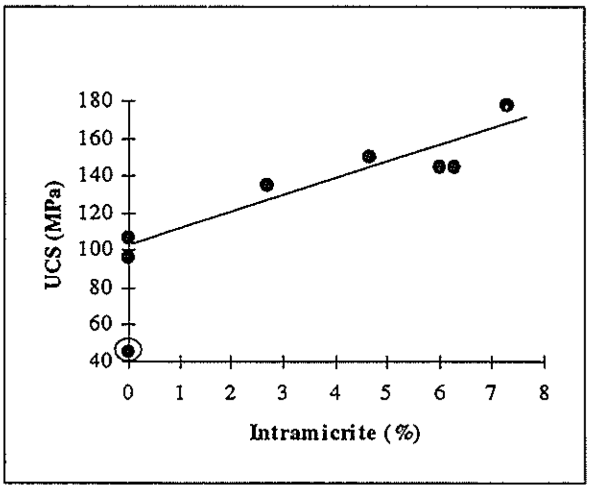


Figure 10 (left): Correlation between UCS and intraparticle material. R^2 = 79.5%. The dashed line is discussed below.

Figure 11 (right): Correlation between UCS and intramicrite. The outlier is circled and omitted from the regression analysis. R^2 = 86.8%.

The alternative (curved/dashed) best fit lines shown in Figs. 6, 8 and 10 suggest that the respective geomechanical parameters may approach a maximum at about 25 - 30% intraparticle material, after which velocities or strengths reduce. Although more data are needed to confirm this relationship, it is a recognised phenomenon in other geomechanical applications (e.g. the optimum quantity of lime added to road foundations to maximise consolidation and stability, above which additional added lime is detrimental to the overall product).

CONCLUSIONS

The content of interparticle and intraparticle material in a variety of New Zealand limestone types appears to correlate with the results of a number of geomechanical tests, suggesting that the presence (or absence) of the materials, and their types, influence the behaviour of the limestones during testing. The proportion of these materials to grains within the limestones is also shown to be important.

Interparticle material affects the geomechanical behaviour of the *surface* of the limestone, as is shown by correlations with Los Angeles abrasion, slake durability and dissolution rate tests. Intersparite materials are responsible for higher amounts of physical degradation and higher rates of dissolution, whereas intermicrite materials show significant resistance to physical degradation. Conversely, intraparticle material affects the geomechanical behaviour of the *body* of the limestone, demonstrated by correlations with sonic velocity, pointload strength and UCS tests, which impose forces through the specimens (not just at their surface). Intraparticle material, and particularly intramicrite, is conducive to higher strengths and sonic velocities. No significant correlations were observed between interparticle material and strength or sonic velocity tests. Similarly, no significant correlations were observed between intraparticle material and abrasion, durability or dissolution rate tests. This reinforces the conclusion that different types of material influence the behaviour of the limestones during different physical processes.

The correlations described are useful where limestone is to be considered for a particular geotechnical application. During the earliest stages of an investigation, where only simple field textural observations or perhaps published textural information are available, some appreciation of the likely behaviour of the materials may be gauged, prior to rigorous geomechanical laboratory appraisal. Applications involving surface degradation and weathering, such as roading, may best utilise intermicrite-rich limestones, whereas foundation materials, in which structural soundness is more important, might better utilise limestones with an abundance of skeletal grains infilled with intraparticle material. In many applications combinations of both these requirements are essential; the selection of an intermicrite, grain/intraparticle material-rich limestone, or perhaps blends of intermicrite-rich and intraparticle material-rich aggregates, may then be appropriate.

ACKNOWLEDGMENTS

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Appendix Table 1: Field and textural information for the studied limestones.

Limestone	Name	Locality	$CaCO_3$ (%)	Textural description
A	Onerahi Formation	Whangarei	70	argillaceous, slightly fossiliferous
B	Whangarei Limestone	Whangarei	98	crystalline, fine grained, very fossiliferous
C	Whangarei Limestone	Whangarei	97	crystalline, fine grained, very fossiliferous
D	Ruatangata 'Sandstone'	Whangarei	80	sandy/terrigenous, slightly fossiliferous
E	Otorohanga Limestone	Otorohanga	99	crystalline, coarse grained, very fossiliferous
F	Otorohanga Limestone	Otorohanga	99	crystalline, coarse grained, very fossiliferous
G	Patutahi Limestone	Gisborne	90	argillaceous, very coarse grained, fossiliferous
H	Tangoio Limestone	Napier	95	shelly, very porous, very fossiliferous

Appendix Table 2: General petrographic properties and geomechanical performance of the studied limestones. Interparticle material and grains total 100% in the table, except where limestone porosity is significant. Intraparticle material is counted along with porous grains where appropriate (e.g. Limestone F comprises about 81% grains, the volume of which is made up of approximately half intraparticle material). Not all inter/intraparticle materials are tabulated. Abridged terms are used for interparticle sparite (intersparite), intraparticle micrite (intramicrite), etc. Note that *larger* LA abrasion values and *smaller* slake durability values reflect *less competent* materials.[1]Only one core was tested, hence no standard error. [2]Empirical estimates were used for these values as suitable test specimens were not available. [3]Suitable specimens were not available.

	Petrographic Parameters							*Geomechanical Parameters*					
Limestone	**Interparticle material (%)**	**Intersparite (%)**	**Intermicrite (%)**	**Intraparticle material (%)**	**Intramicrite (%)**	**Skeletal (and other) grains (%)**	**Interparticle material : grains**	**Sonic velocity (m/s)**	**UCS (MPa)**	**Pointload strength (MPa)**	**Slake durability (% retained)**	**LA abrasion (% lost)**	**Dissolution rate (μS/minute)**
A	91.4	0.0	86.7	0.6	0.0	8.6	10.63	3400±190	107[2]	3.1±0.2	98.58	23.6	-[3]
B	22.7	10.7	6.7	18.7	4.7	77.3	0.29	5900±60	150±10	6.0±0.1	99.62	25.5	0.189
C	9.3	4.0	3.3	14.7	2.7	90.6	0.10	5700±110	135±6	5.2±0.1	99.57	24.6	0.173
D	29.3	10.0	0.3	5.0	0.0	67.8	0.43	3840±40	96±2	4.2±0.1	98.64	29.6	0.182
E	19.3	13.0	1.3	31.3	7.3	80.7	0.24	6060±60	178±9	6.1±0.3	99.48	25.7	0.175
F	19.0	14.0	0.3	41.3	6.3	81.1	0.23	5642[1]	144[2]	5.2±0.3	99.46	28.8	0.218
G	56.3	1.3	51.7	12.4	6.0	43.9	1.28	5080±50	145[2]	5.2±0.2	99.31	23.7	0.222
H	56.7	29.7	0.0	0.0	0.0	32.7	1.73	4900±150	45±4	2.6±0.2	98.92	36.8	0.225