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TESTING OF SLATE FOR SUITABILITY AS NATURAL BUILDING STONE

by

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SUMMARY

During the last eighteen months tests of the properties of samples of slate as building stone have been carried out by the Bureau of Mineral Resources.

The properties considered desirable in slate used as building stone include attractive appearance, ease of quarrying and working the stone, adequate strength and durability, chemical inertness, and uniformity of product.

There are four main ways of evaluating the properties of samples - each complementary to the others - but in this Record only one method is considered: the laboratory determinations of physical and chemical properties.

There are two types of tests, (i) for quantitative data and (ii) for qualitative comparison. The first covers physical parameter such as bulk specific gravity, strength and porosity; and the second resistance to abrasion, resistance to weathering and similar tests.

The reasons for using the tests selected and for rejecting others are discussed and a tentative grading of results is suggested.

Ten slates from New South Wales, South Australia, Victoria, and Norway have been tested. Descriptions of the slates, the results of tests and an evaluation of the usefulness of the slates as building stones are included, firstly to show how the gradings are applied and secondly to provide data for later comparison.

In Appendix 1 details of the tests are set out together with the equipment and type of samples needed. Appendix 2 contains petrographic descriptions of some of the slates tested.

INTRODUCTION

The interest in recent years in the use of natural stone on large buildings has increased the need for standardized testing procedures. Requests are made to the Bureau from time to time, by both planning authorities and suppliers of stone for information regarding the strength and durability of stone from new and reopened deposits. Standard tests have been adapted to apply to building stones or new tests devised, but generally there is little information to correlate the results of the tests with the performance of the stone in use. To make the correlation, tests have been carried out on stone whose performance in use is known, and the results obtained have been used to grade stone from unproven sources. Probably the most common use for slate, both indoors and outdoors, is as paving material, either in random paving or as regular sawn tiles. Slate is rarely used nowadays as roofing material, but is widely used for exterior cladding window sills, doorsteps, and other purposes to which its flaggy nature is suited. It is also used in purely decorative situations as feature walls and fireplace surrounds.

PROPERTIES CONSIDERED DESIRABLE IN A BUILDING STONE

The properties thought desirable in a particular slate depend, to some extent, on the use intended for the stone; the following would be expected for most slate intended for functional use.

Appearance: the stone should be attractive, free from blemishes, stains, cavities or large grains that may pluck out, or any irregularities that will adversely affect the surface of the stone. A deposit should be able to supply large quantities of uniform material.

Workability and Production: the stone should be easy to quarry, cleave and shape; the cleavage parting should be smooth but not slippery, and the stone should break cleanly across the cleavage, or be sawn readily to required dimensions.

Structural Qualities: adequate compressive strength normal to the cleavage and high transverse strength both parallel and normal to the cleavage are required; the slate should have sufficient cohesion to prevent flaking in use.

Durability: the slate should be resistant to abrasion, weathering, and in some districts, frost action. It should have low porosity, and low permeability both across and along the cleavage planes, particularly to water but also to any possible staining agents.

<u>Chemical inertness:</u> the stone should be largely free of soluble salts, or minerals that are subject to hydration or oxidation in the atmosphere, particularly if the stone is to be used in an atmosphere that is polluted by industrial fumes.

Slate required for sawn and shaped paving stone should be uniformly fine-grained, compact, siliceous, and unweathered. It should have a well developed cleavage, spaced so as to yield slabs of the thickness required for the project. The cleavage plane should be smooth and should not flake; it should be free of any coating which might make it slippery.

There are four main ways of evaluating these properties; these methods are complementary, not alternative:

(i) Inspection of the source of the material by a geologist and a stonemason, with geological mapping where necessary.

(ii) Practical workability test - that is cleaving and dressing.

(iii) Petrological examination of selected specimens.

(iv) Laboratory determinations of physical and chemical properties.

The tests used in (iv) and the reasons for their selection are discussed below. Examples of (iii) are included in Appendix 2.

SELECTION OF TESTS FOR PHYSICAL AND CHEMICAL PROPERTIES

The tests can be divided into two groups:

1. The first group of tests provides <u>quantitative information</u> about the physical properties of the stone.

2. The second group of tests may provide quantitative information but this is used for <u>qualitative comparison</u> in order to estimate the stone's response to weathering and usage.

DETERMINATION OF PHYSICAL PROPERTIES

Bulk Specific Gravity

Examination of thin sections of the slates tested, showed that there was a very small percentage of pore space per volume of rock. The bulk specific gravity is therefore a close approximation to the true specific gravity of the rock material, and possibly more useful to the consumer.

The true specific gravity is determined from a crushed sample but the bulk specific gravity is determined from the weight of a slab, aquarter of an inch thick, measured first in air and then in water.

Strength Testing

Two kinds of test can be made - transverse strength, and unjacketed uniaxial commpression. The latter method uses both wet and dry samples. At present the type of the test performed is largely determined by size and characteristics of the samples supplied to the Bureau.

The determination of transverse strength requires six bars, each 12 inches long, with a one-inch-square cross-section and exactly plane and parallel sides. The bars must be cut to the approximate width and exact length by the suppliers, as the large saw facilities needed, are not available in Canberra. Preparation of the cubes required for compressive strength determinations can be carried out at the Bureau so this test is more generally used. The transverse strength should be determined if the stone is to be used for lintels, window-sills, steps, or in other situations where the stone will be under transverse stress. It can be inferred from data supplied by Parks (1912-1914) that there is not always a direct correlation between transverse and compressive strength.

The detailed methods for testing are set out in the appendix, but briefly the determination of transverse strength employs a bar supported at each end by knife edges and centrally loaded, normal to the cleavage. The load at failure is noted, together with the type of fracture, and the modulus and average modulus of rupture are calculated; any figure 25% less than the average, (where the material has failed along an obvious plane of weakness) is discarded and the average is recalculated.

In determining compressive strength, wet samples (saturated with water in a partial vacuum), and oven-dried samples are used. Each is placed in turn in the compression machine and loaded normal to the cleavage until failure. The load at failure is recorded, together with the type of fracture; the compressive strength, corrected for the dimensions of the specimen, is then calculated.

Both the test for transverse strength and that for unjacketed uniaxial compression follow much the same methods as set out in the 1965 Book of ASTM Standards for Natural Building Stone (Amer. Soc. test. materials 1965a Pt 12), but there is little information on which to evaluate the results of the tests. In the Standard Specifications for Roofing Slate (ASTM Designation C406-58) there is a requirement for a modulus of rupture across the grain of 9 (i.e. a pressure of 9,000 pounds per square inch (psi)). This has proved to be a reasonable estimate in the tests completed so far. Bray (1948) quotes a London County Council regulation which states that stone used in walls or piers "shall have a resistance to crushing of at least 1,500 lbs. per square inch". This seems rather low for reasonable discrimination between the different quality stones. No other tests for strength have been considered yet.

Water Absorption

This test is usually carried out in conjunction with the determination of specific gravity. It measures the amount of water absorbed by a dry specimen in 48 hours under conditions of room temperature and pressure.

The Building Research Station at Garston, England, suggests that an attempt should be made to establish the natural water content of the stone in the area in which it is to be used at the wettest time of the year. An approximation for the climate at Garston, in Hertfordshire, is to soak the specimen for 24 hours at a pressure of 40 cm of mercury. The natural water content of rocks in Canberra has not been established since the climate is not a particularly wet one and frost damage is not usually a problem in rocks shown to be sound in other tests.

Another parameter more often applied to sandstone than to slate, is the coefficient of saturation measured under various conditions of time and pressure. It is the ratio of the amount of water the stone is theoretically capable of absorbing as determined from the porosity, to the amount absorbed under the particular conditions of time and pressure. As no direct porosity measurements are made on the slate samples this parameter has not been applied.

ESTIMATION OF THE RESPONSE TO WEATHERING AND USE

These tests attempt to provide conditions of accelerated weathering and use which will answer the question "How well and how long will this stone last?". Most of the tests are still experimental and no sand basis exists for the evaluation of results. Some are merely expedient and only indicate the possible performance of the stone.

Resistance to abrasion

The main abrasion to which slate is subjected in use is that by foot-wear. A machine, a wearometer, specifically designed by industrial concerns to evaluate resistance has not been used by the Bureau of Mineral Resources. Instead, the Los Angeles machine, used normally to measure the resistance of concrete or road aggregate to abrasion, is used to evaluate resistance of the stone to abrasion by foot traffic. The results have no specific correlation with those produced by the wearometer or with the amount of wear in use but they are useful for comparison of the various slates.

From the results of the standard test (ASTM designation C535-65) a Los Angeles value is calculated, high numbers indicating a low resistance to abrasion.

Sodium Sulphate Weathering Test

This test aims at evaluating the durability of the stone with particular reference to frost action. It is thought to be, "the best single test for assessing the relative durability of limestones exposed to general weathering agencies, and the relative resistance of sandstones to damage by the forces associated with the crystallization of soluble salts" (Honeyborne, 1964). The sandstone may fail however through the weakening of the cement by reaction with sodium sulphate or by the wedging action of growing crystals of salts formed in the reaction, more rapidly than it would by the forces of crystallization of sodium sulphate in the pore spaces. Thus the stone may evince an apparently lower resistance to frost action than is actually the case. In a polluted atmosphere however, reactions may take place which weaken the bonding in the stone and in that case the results are a fair estimation of the resistance of the stone to the effects of chemical weathering. The same case can be made for the performance of slate in this test.

The test consists of soaking slabs (½" x 2" x 4") in a 14% solution of sodium sulphate then drying them. This cycle is repeated fifteen times; samples which do not deteriorate during the fifteen cycles are of excellent quality, but of those that deteriorate some will probably be sufficiently durable and resistant to frost for all uses as a building stone, at least in Canberra's climate.

A similar test was tried, using a solution of calcium sulphate, but problems were met first in maintaining a saturated solution, and secondly in keeping the samples free from the coating of calcium sulphate which developed in each cycle, and prevented the free access of dissolved calcium sulphate. The results of this test were ambiguous and samples which failed other tests did not deteriorate in this one. The test is not now used.

The results of the sodium sulphate test are assessed in two ways;

(1) by noting the number of cycles which produced the first noticeable deterioration e.g., flaking or pitting

and (2) by calculating the percentage loss of weight of the sample during the tests.

Handscraping

In this test slabs, similar to those used in water absorption determination, are scraped using a flat blade weighted to apply a constant pressure of 3 lbs, soaked in a dilute solution of sulphuric acid for a week, and then rescraped. The increase in depth of scraping is supposed to indicate the degree of softening by weathering. The results from samples tested so far are not enlightening. The samples tested apparently developed a "skin" on soaking in the acid and the second scraping was less effective than the first. Samples of Goulburn and Forbes slate gave very similar results but it is known that these slates differ greatly in durability. The results are not considered plausible and therefore the test has been discontinued.

This test simulates the reaction undergone by slate containing pyrite, calcite, and carbon in an atmosphere polluted by industrial waste. The calcite particles are converted to gypsum with an increase in volume causing softening and disintegration. (ASTM, 1965, p. 274) The reaction that occurs in this test is duplicated in the test using sodium sulphate, so the handscraping test is no longer used.

DESCRIPTIONS OF THE SLATES TESTED

CASTLEMAINE SLATE

This slate was supplied by the Victorian Department of Mines, and is in use in Victoria and other States as a building stone.

The sample pieces were small, and most were superficially weathered, with a powdery surface which flaked easily. Wiping produced a matte to silky lustre on a slippery surface. The unweathered surface was greenish-grey or purplish-grey, while the weathered surfaces were mostly light coloured, green-yellow, or pink with some dark red-brown. Cut surfaces showed a colour banding, probably due to leaching, and a secondary banding of parallel elongate holes from which a flaky mineral had weathered out.

The rock is very fine-grained and soft enough to be scratched with a finger nail.

FORBES SLATE

The samples were supplied from a recently-developed deposit seven miles north-west of Forbes, New South Wales.

Some samples are yellowish-cream with brown banding, while others are whitish-cream with purple banding (Leisegang banding). The grains are coarser than in the Castlemaine Slate and vary in size between laminae. The rock is jointed in handspecimen and many of the joint planes are iron-stained, reddish or purplish-brown. The rock splits cleanly into slabs along a plane parallel to both bedding and cleavage. The surfaces have a matte lustre and do not feel slippery, even when the rock is sawn.

GOULBURN SLATE

The samples tested are from a quarry, belonging to Windmill Stone and Slate Industries Pty Ltd, situated at Middle Arm, 17 miles northwest of Goulburn (Grid reference 275734, Goulburn 1:250,000 Sheet) New South Wales.

Two varieties of slate were submitted; one purplish-brown to purplish-grey (trade name Blue Slate), and the other greenish-grey (trade name Green Slate). The two varieties are not significantly different in physical characteristics, either in hand specimen or under testing, so they are described together. The texture is compact and the individual grains are scarcely visible to the unaided eye; the lustre is matte to silky sheen; the cleavage is good but not perfect. Large crystals of pyrite (maximum size 3-4 mm) were visible in some specimens of green slate.

The material is gaining popularity as rough cladding and random paving stone in the A.C.T. since introduction to the market here in recent years. It was a source of roofing slate in the last century.

GUNDAGAI SLATE

Samples were supplied by Mr. O. Gardner from quarries near Gundagai (Grid references Gundagai 1:50,000 Sheet 144638 - black and banded slate - and between 114637 and 123641 - silver slate). Three types of slate were submitted for testing.

One is a black slate which contains some bands of lighter material. It is massive, and is free of minerals that would tend to affect its durability adversely. It can be readily cleaved but yields mostly thick slabs with surfaces which are generally smooth and lack lustre. Polished surfaces have a silky lustre and do not flake readily. Many joint and cleavage planes are stained.

The second is a banded slate, slightly coarser grained than the black slate; it contains layers of poorly compacted, vuggy, and silty material. These layers are not parallel to the cleavage and are zones of poor cohesion, thus when split the slate has an uneven surface which has a tendency to flake. The surface has a dull lustre and is commonly iron-stained.

The third type is a silver slate, the most coarse-grained of the three slates. It parts very readily along cleavage planes yielding thin slabs whose surface is not in all cases smooth but is generally free of staining. Some cleavage planes are coated in talc; most are flaky or lack lustre but the stone is capable of taking a good polish.

These slates were marketed in the early part of this century and at present their reintroduction is being considered.

MINTARO SLATE

The sample tested was supplied through the South Australian Department of Mines; the slate is in use in that State and interstate as a building stone.

It is medium-grey in colour, fine-grained and compact and has well-developed cleavage. On splitting, the stone gives a plane surface with a dull lustre. The colour is uniform and the slate is not distinguished by colour banding or other marking.

NORWEGIAN "SLATE"

This stone was supplied by the National Capital Development Commission and was part of a shipment from Norway for use in Canberra. Although the stone is sold as a "slate" it is a quartz-chlorite-mica schist. It is a greyish green, has a glossy lustre and is medium to coarse grained. At least two lineations are apparent on the slab, giving a "rippling" plane surface, but slabs have a uniform thickness. The stone is hard. The cleavability of the stone was not tested; the samples provided were slabs approx. $\frac{1}{4}$ inch thick.

WILLUNGA SLATE

This slate is grey to grey-green, very fine-grained with a dull lustre; the cleavage is good, and the rock parts easily and evenly. On weathered faces the rock ranges from cream through light brown to black. The slate is slightly harder than Goulburn Slate.

This stone was supplied by the South Australian Department of Mines and is in common use in that State.

WISTOW "SLATE"

The sample was supplied by the South Australian Mine Department; this slate has only entered the market in recent years.

The stone is a quartz-mica-schist but is described commercially as Wistow Slate. It is green and gold in colour and the surface shows one distinct lineation, a very fine crenulation parallel to the aligned mica flakes. On unweathered surfaces the mica grains give the rock a twinkling appearance, on weathered surfaces the mica has a tendency to flake off and the rock assumes a yellow-brown powdery surface. The rock is hard; the cleavage is good although widely spaced in the sample. Some large, thick blocks were present; the minimum thickness was approximately ¼ inch. The mica flakes lie in a plane which intersects the cleavage plane at a very low angle. The onlapping flakes cause the cleavage plane to be slippery in one direction normal to the intersection of the cleavage plane and the plane of micas. The opposite direction, that is the direction of off-lap of mica flakes, is not slippery, nor is any other direction on the cleavage plane.

EVALUATION OF RESULTS

CRITERIA USED TO GRADE THE RESULTS

(a) Bulk Specific Gravity - greater than 2.6

Slates with a bulk specific gravity less than 2.6 have performed poorly in other tests. Values greater than 2.8 suggest that the slate should be examined to find why the value is so high. If it is due to the presence of ore minerals these may adversely affect the performance of the stone in use. An error in procedure may also produce abnormal results.

(b) Water Absorption - less than 2%

This value has been arrived at from consideration of the results carried out so far. It is much higher than the Standard Specification for all grades of roofing slate. (ASTM Designaton C406-58: for a service period of 20-40 years the maximum absorption shall be 0.45%, for 40-75 years, 0.36%, and for 75-100 years a maximum absorption of 0.25%. These values seem unduly rigorous in the light of the known good performance of slates such as Goulburn wich was a water absorption of 1.85%).

(c) Modulus of Rupture - greater than 9 or able to withstand a pressure or more than 9,000 pounds per square inch (psi).

This is the value required in ASTM Standard Specification for Roofing Slate Designation C406-58.

(d) Crushing Strength - Dry - able to support a load of more than 20,000 psi.

This is a very arbitary figure as poor slates do not even approach this value and good material yields values considerably in excess of this.

Wet - able to support a load not less than 70% of that borne by the sample when dry.

The loss of strength which a stone suffers in consequence of being saturated with water is regarded as a good measure of its general durability (Parks, 1914). This loss should not be more than about 30%.

(e) Hand scraping test - the reduced depth of softening should not exceed 0.002 inches for highest grade slate and not more than 0.008 inches for the medium grade slate.

These values are taken from the Standard Specifications for Roofing Slate. The hand scraping test is no longer used.

(f) Los Angeles Value for abrasion - less than 40%

No specification for this value could be found so this figure was arrived at by inspection of the results of all the tests. Forty percent appears to provide a reasonable boundary.

(g) Sodium Sulphate Test - the samples are graded for durability according to the number of cycles completed before deterioration is discerned.

10 cycles or less	-	poor
11-14 cycles	-	good
all 15 cycles	-	very good

Weight lost - no discrimination has been made on the basis of these figures yet.

These figures have been arrived at from suggestions made by the Building Research Station England and from consideration of our own results.

EVALUATION OF THE SAMPLES PROVIDED

All remarks apply to the samples as submitted only, and in most cases no inspection has been carried out to find out how representative the samples are.

Castlemaine Slate

This stone is in satisfactory use as a building stone but the sample provided yielded very poor results.

Bulk specific gravity is low, water absorption is high. The material provided did not allow the preparation of samples for strength testing. The Los Angeles Value indicates a very soft stone, not suitable for paving. The low number of cycles survived in the sodium sulphate test indicates a poor stone. This stone represented by the sample could not be recommended for paving stone or exterior cladding stone.

Forbes Slate

This stone has a low specific gravity and a high water absorption. Its durability, as indicated by the sodium sulphate test and the loss of crushing strength where saturated, is poor. It cannot be recommended for use as external facing stone. Its softness and susceptibility to abrasion indicate that it is not suitable as a paving stone for either interior or exterior use.

Goulburn Slate

The bulk specific gravity is normal and the water absorption low. The modulus of rupture exceeds the minimum requirement indicating sufficient strength under transverse load. The Los Angeles value indicates that the slate is very resistant to abrasion and the results of the sodium sulphate test show that it is resistant to the action of frost, and to weathering by chemical agents.

The slate would be suitable for use as interior or exterior paving stone or for cladding stone.

Gundagai Black Slate

The bulk specific gravity is high, probably due to the pyrite present; the water absorption is very low. The transverse strenth is less than the acceptable limit but the results showed a very wide range and further testing may give a higher average value; compressive strength testing indicates a very strong and durable stone. The Los Angeles value indicates that this slate is fairly resistant to abrasion and the sodium sulphate test indicates a durable stone resistant to the action of frost and the action of chemical weathering agents.

This slate is suitable for use as an exterior cladding stone or as interior or exterior paving stone.

Gundagai Silver Slate

The bulk specific gravity is normal and the water absorption is within limits for good slate (retest gave a very low water absorption). The modulus of rupture is high indicating high transverse strength, but the slate did not have sufficient cohesion in thick slabs to prepare samples for compressive strength testing. The Los Angeles value indicates that the slate is fairly resistant to abrasion; the sodium sulphate test shows that it is a moderately durable stone.

This slate is suitable for use as cladding stone but cannot be recommended as paving stone. In spite of satisfactory performances in the physical tests talc coatings on cleavage planes would tend to make the stone too slippery for paving material.

Gundagai Banded Slate

The bulk specific gravity is lower than normal; the water absorption is satisfactory. The slate did not have sufficient cohesion to enable samples to be prepared for strength testing. The Los Angeles value is high indicating low resistance to abrasion. The sodium sulphate test showed the stone to lack durability and resistance to chemical attack.

This stone cannot be recommended for internal or external paving or external cladding.

Mintaro Slate

This slate has been used as a standard for comparison with stones newly introduced to the market. It has a high bulk specific gravity and low water absorption. The compressive strength is adequate and the loss on saturation is less than 30%. The Los Angeles value is very low indicating that the stone is very resistant to abrasion, and the sodium sulphate test shows that the stone is durable and resistant to the action of frost and weathering by chemical agents.

The slate is suitable for interior and exterior use as paving stone and for use as exterior cladding stone.

Norwegian "Slate"

There was insufficient sample to test this stone properly but the bulk specific gravity is within the range given and the water absorption is very low. The durability is good as expressed in the sodium sulphate test.

The stone is known to be an extremely good paving stone. It would also be suitable as cladding stone.

Willunga Slate

The bulk specific gravity is normal and the water absorption is low. The stone has more than adequate strength and the loss of strength on saturation is not more than 30%. The sodium sulphate test shows it to be a fairly durable slate and the Los Angeles value indicates that it is fairly resistant to abrasion.

The slate would be useful as internal or external paving stone or as external cladding stone.

Wistow "Slate"

The bulk specific gravity is within the acceptable range and the water absorption is very low. The strength of the slate in compression is more than adequate although there was a 40% loss of strength on saturation. The Los Angeles value is very low indicating high resistance to abrasion and the sodium sulphate test shows that the slate is resistant to chemical attack by the weather.

The stone is suitable for use as external cladding stone and internal or external paving stone. The slipperiness of surface in one direction may impose some restriction on the usefulness of the stone for paving.

CONCLUSION

The work carried out so far has shown that an evaluation of the usefulness and durability of the slate, based on the results of the physical and chemical tests described, is generally in agreement with what is known of the performance of the several slates in use.

The evaluation cannot yet be quantitative, nor are the recommendations very definite. Refinement of the conclusions will come when the parameters and limiting factors of use, the conditions of weathering, and the stresses operating in use, are known quantitatively and applied to the design of the experiments and the evaluation of the results. This will mean consideration, in detail, of chemical analyses of the agents of pollution and the chemical reaction these agents promote, the quantitative effect of climate patterns on rock, and perhaps the forces associated with physical weathering. The recommendations contained in this report are for a climate similar to that of Canberra but with allowance for more severe chemical weathering than can be expected at present. The level of performance expected of a stone will vary under different climate conditions, a fact to be considered when evaluating a stone for a particular project.

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APPENDIX 1

METHODS OF TESTING

I <u>To calculate the BULK SPECIFIC GRAVITY of Slate</u>

This test may be carried out at the same time as the test for water.

ABSORPTION (Test II)

SAMPLE: Six sawn samples, each 4 inches by 2 inches by approximately ¼ inch, with the 4" x 2" face parallel to the cleavage plane; label the samples 1 to 6.

EQUIPMENT: A balance, capable of weighing 500 g $\pm$ 0.01 g.
Aluminium wire bracket to support the specimen (other light weight material may be used but this was found most satisfactory).
Beaker, approximately 800 ml. but large enough to contain the sample completely immersed in water, and fit the balance.
Container in which to immerse the samples overnight.
Oven with temperature range 105° $\pm$ 5°C.
Dessicator.
Distilled water.
Thermometer with a range 0° to 30°C $\pm$ 0.5°C.

METHOD: (i) Dry the samples in the oven for 24 hours at 105°C $\pm$ 5°C.

(ii) Cool the samples in the dessicator.

(iii) Weigh each sample (weight should be accurate to 0.01g).

<u>Record</u> W_1 (Fig. 1)

(iv) Immerse the slabs in filtered or distilled water for 48 hours. Note the temperature of the water before and after immersion.

<u>Record</u> T_1 and T_2

(v) Surface dry the samples with a damp towel (not a wet one).

(vi) Weigh the sample immediately (accuracy 0.01g).

<u>Record</u> W_2

(vii) Weigh the sample while it is completely immersed in water.

<u>Record</u> W_3

Ensure that the balance is in equilibrium before the samples are weighed and that allowance is made for the weight of the bracket.

(viii) Calculate the BULK SPECIFIC GRAVITY as follows:

$$\text{Bulk S.G.} = W_1/(W_2-W_3)$$

II <u>To determine the WATER ABSORPTION of Slate</u>

Based on Standard Method of Test ASTM Designation C121-48. The SAMPLES, and EQUIPMENT are the same as those of the test above (Test I).

METHOD: Steps (i) to (vi) of the calculation of Bulk Specific Gravity are also used to determine the Water Absorption of slate. It is not necessary to record the temperature of the water if this test is done without Test I.
Using the values obtained for W_1 and W_2 calculate the WATER ABSORPTION as follows

$$\text{Absorption \%} = \frac{(W_2 - W_1)\ 100}{W_2}$$

Record the results on the same card as the data for Bulk Specific Gravity (see Figure 1 - pro forma index' card).

III <u>To determine the MODULUS OF RUPTURE OF SLATE</u>

This test is based in part on Standard Method ASTM Designation C120-52.

SAMPLE: Six specimes cut from a slab approximately 1½ inches thick. Each specimen is 12 inches long, 1½ inches wide and ground to 1 inch thick so that the 12 inches by 1 inch faces are plane and parallel. Samples are labelled 1 to 6.

EQUIPMENT: Oven-temperature range $105^{\circ}C \pm 5^{\circ}C$.
Dessicator
Vernier caliper and steel rule measuring in 1/10 inch.

METHOD: Testing is at the moment done at the Department of Works' Testing Laboratories at Fyshwick; the following is the procedure used.

(i) Samples are measured and the following values are recorded. (see figure 2)

l length along the centre line

b width

d thickness, average of three readings

values are to be accurate to 0.01 inch.

(ii) The samples are dried in the oven at 105°C ± 5°C for 24 hours. Cool in a dessicator.

(iii) The samples are taken to the Department of Works' Laboratories where they are loaded in the machine by the C.D.W. operator. Load is applied at a rate not exceeding 1000 lbs. per minute.

(iv) Record the breaking load - W - to the nearest 5 lbs. If the results are supplied in a report by the Deparment of Works they should be attached to the file card with the rest of the data, otherwise they are entered in the table as usual. The modulus of rupture - R - is calculated as follows:

$R = 3Wl/2bd^2$ R is expressed in lb./sq. in. (psi)

Values for R are averaged but any specimen whose value is 25% less than the mean is discarded and the average recalculated.

IV To calculate the WET and DRY COMPRESSIVE STRENGTHS of Slate

This test is based on Standard Method of Test ASTM C170-50.

SAMPLE: Two samples, each a two-inch cube; the loadbearing faces, usually parallel to the clevage plane, must be exactly plane and parallel. Label one sample D and the other W.

EQUIPMENT: Oven-temperature range 105°C ± 5°C.
Dessicator.
Equipment for saturation of samples under a partial vacumm (see Figure 6).
Blotting paper.
Vernier calipers.
Avery Hydraulic Compression unit (NATA classification A) or equivalent machine.

METHOD: Preparation of the samples.
Dry Test.
Dry samples in oven for 24 hours, then cool in the dessicator.
Wet Test.
Saturate the samples as follows:

(a) place the sample on the tray in the bowl as shows in Figure 6;

(b) seal the bowl and push the long glass tube below the level of the tray;

(c) connect the tubing as shown in the diagram and close clips A and B;

(d) evacuate the bowl for half an hour with an efficient pump;

(e) with the pump still running open clip A and allow water to flow in until it reaches the level of the tray. By partly closing the clip regulate the flow so that a two-inch cube would be covered in about twenty minutes;

(f) when the cube is covered close clip A and allow the cube to stand until no further bubbles rise from its surface;

(g) open clip C or disconnect the vacuum pump to admit air;

(h) withdraw the cube and wipe lightly with a damp cloth.

(NOTE: If testing is not to take place immediately keep the sample under water).

Testing is the same for both wet and dry samples. At present it is done on the Department of Works machine in their laboratories at Fyshwick.

(i) Remove the wet sample from water.

(ii) Measure both samples and record the following data from the upper and lower faces:

Lu	length upper face
Bu	breadth upper face
Ll	length lower face
Bl	breadth lower face
d	height

Note measurements on record cards (for sample see Figure 3).

The cubes are crushed between hardened, polished steel plates, and a layer of blotting paper. Detailed procedure depends to some extent on the type of machine used but the following is the procedure followed at present.

(iii) Place the block in the crushing machine and centre it with the steel plates above and below the cube; lower the upper head and adjust it until a hair's breadth is visible between the upper steel plate and the upper head. Raise the head and insert sheets of blotting paper between the faces of the cube and the steel plates.

Apply the load at a rate such that the speed of the loading head is not more than 0.05 inches per minute. Record the maximum load - F lbs.

(iv) Calculate the compressive strength:

C = F/A where A is the calculated load bearing surface

$$A = \frac{(Lu + Ll)\ (Bu + Bl)}{4}$$

For specimens with height to width ratio of less than 0.75 the following correction is to be applied:

$$C_c = \frac{C_p}{0.778 + 0.222b/d}$$

b is the average width of the cube; $= \dfrac{Lu + Ll + Bu + Bl}{4}$

C_c = corrected compressive strength.

C_p = measured compressive strength.

It is necessary to test more than one sample of slate for each test to obtain reliable results. Two or three samples should provide significant results.

If cylindrical samples are used, such as core samples, the amount of time required to grind the samples is reduced considerably.

V. To estimate the DURABILITY and RESISTANCE TO WEATHERING of a Slate by immersion in 14% SODIUM SULPHATE SOLUTION

This test is based in part on the British Building Research Station, Note No. IN 23 (1964) Part I, Test 1.

SAMPLE: Six samples, 4 inches by 2 inches by approximately ¼ inch, are required. Label 1 to 6.

The samples used for Water Absorption and Bulk Specific Gravity determinations may be used for this test.

EQUIPMENT: Oven-temperature range $105^{o}C \pm 5^{o}C$.
Balance to weigh samples up to 500g accurate to ± 0.01g
Anhydrous sodium sulphate.
Mineral-free water.
Containers with covers, for samples and solution.
Supports for samples to allow free circulation of the solution in the dish, e.g., match sticks.

METHOD: (i) Dry the samples in the oven for 24 hours at $105^{o}C \pm 5^{o}C$.

(ii) Weigh and <u>Record</u> dry weight W_1 (Figure 4).

(iii) Prepare a 14% solution of sodium sulphate decahydrate. It is useful to prepare this in bulk. 61.7g of anhydrous sodium sulphate are required to make 1 litre of solution.

(iv) Support the samples in the dishes so that the solution has free access to both 4 inch x 2 inch faces.

(v) Cover the samples with solution, and cover the container to prevent evaporation. Allow the sample to soak for 2 hours.

(vi) Remove the samples and ppace in an oven in which initial high relative humidity has been achieved. This can be done by placing a dish of water (about 300 mls. for an oven capable of holding about 40 samples), in the oven for half an hour before putting in the samples.
Remove the water from the oven after 8-10 hours and allow the samples to remain in the oven not less than sixteen hours, nor more than twenty hours.

(vii) Cool to room temperature; inspect samples for signs of deterioration and re-soak.
Steps (iv) to (vii) represent one cycle. This cycle is repeated fifteen times.

(viii) <u>Record</u> the changes in the samples and the number of cycles completed when disintegration commences.

(ix) Dry the sample in the oven and weigh. <u>Record</u> W_2.

(x) Calculate the percentage loss of weight as follows:

$$\% \text{ loss} = \frac{100\ (W_1 - W_2)}{W_1}$$

A photographic record may extremely useful.

VI. Standard Method of test for RESISTANCE TO ABRASION of large size coarse aggregate by use of the LOS ANGELES MACHINE. ASTM Designation C 535-65.

The procedure followed in this test is that set out in the ASTM standards Pt. 10, 1965. The machine used belongs to the Department of Works, and is at the laboratories at Fyshwick.

The results may be recorded on the forms provided by the Department of Works but the original weight of the sample, the Los Angeles values, and the average Los Angeles value must be entered into the table on the file card. If the forms are not used the file card may be used in its entirety (see Figure 5).

APPENDIX 2

PETROGRAPHIC DESCRIPTIONS

GOULBURN SLATE

The two varieties of slate submitted, one purplish-brown to purplish-grey, the other greenish-grey, have similar physical characteristics in hand specimen except that the greenish-grey slate is apparently slightly harder. The texture of both is compact with individual grains scarcely visible to the naked eye; the lustre ranges from matte to a silky sheen; and the cleavage is good but not perfect. Large crystals of pyrite (maximum 3-4mm; average 0.5-1mm) are visible in some specimens of green slate.

Thin section examination shows that the colour-difference is related to the hematite content. The slates consist of quartz (25-35%) with minor feldspar grains, in a network of sericite and chlorite shreds. In the green slate chlorite constitutes about 30%, and opaque material less than 1%, hence the green colour. In the purple slate chlorite constitutes 20-25% and opaque material - hematite, pyrite, and magnetite - 10-15%.

Finely-divided hematite is disseminated through the rock and also recurs in small lenticular aggregates; its colour masks the chloritic colouring. Carbonates are absent. Grain size ranges from 0.02mm to 0.08mm; most of the green slate may be a little finer grained than the purple slate.

FORBES SLATE

The samples submitted by Mr. A. Lea were whitish to yellowish cream with purple or, less numerous, red-brown to orange banding. The banding varies from stripes to irregular concentric rings. The bands range from ⅛ to 1½ inches in width, with some larger patches of colour (maximum dimensions in sample 3" x 8"). The samples have a dull lustre; cleavage planes are powdery and slightly rough to touch. The cleavage is distinct. Bedding is parallel to the cleavage, and there appears to be a joint system normal to the cleavage.

Thin section examination shows that the slate consists of quartz and altered feldspar grains set in a fine-grained matrix. The matrix is composed of finely divided sericite with some minor clay minerals; it contains dispersed hematite and secondary limonite. The quartz grains (average 0.02 mm) are irregular in shape and are cracked. Some feldspars are sericitised, others are altered to, and in some places entirely replaced by clay. A very few are partially replaced by carbonate minerals.

The percentage of quartz and feldspar ranges, in different laminae, from 15% to 30% but relict structures, which may represent completely altered feldspar, make up a further 10% of the rock. Sericite and minor clay minerals (av. less than 0.01 mm) constitute from 60% to 80% of the rock. Hematite is concentrated in bands and appears to be responsible for the banding visible in hand specimens.

Specimens swelled visibly when saturated with water. This indicates that some of the clays present are of the smectite (montmorillonitic) group.

GUNDAGAI SLATE

The dark/grey slate (black slate) contains some bands of lighter colour but appears massive, without layers of poorly-compacted or coarse-grained material. The black slate yields mostly thick slabs, and the cleavage planes are generally smooth, although many are stained. Naturally-broken surfaces and cleavage planes lack lustre, but the stone appears to take a good polish giving a silky surface that does not flake readily. Under the microscope the rock was found to be uniformily very fine grained without blebs of coarse-grained material. It consists of white mica, quartz, a minor amount of green chlorite, and carbonaceous material. Pyrite, which forms about 1% of the rock, is aligned in bleb-like grains along the cleavage planes. The rock appears to be free of voids, is well compacted, and lacks large grains of hard minerals which would prevent the material from polishing well.

The banded slate is not as fine-grained as the black slate; it contains layers of poorly compacted and coarse-grained sediment. The coarse-grained layers have poor cohesion, consequently the slate tends to split along them and this prevented the preparation of the cubes and bars required for strength tests. As the bands are not parallel to the cleavage, the rock, when split has an uneven surface which tends to flake. The surface so formed has a dull lustre, is darker than sawn surfaces, and is commonly iron-stained. In hand specimen, numerous vugs can be seen, mostly in the coarse bands. Under the microscope the slate was seen to consist of quartz and white mica, with minor amounts of a brown mica and very little chlorite; it also contains about 1% pyrite. The brown mica is concentrated in bands and around blebs; the blebs contain finely crystalline quartz but much of this was plucked out during preparation of the slide. The blebs may also have contained some opaque mineral which was plucked out with the quartz. The layers in which brown mica are concentrated seem to represent zones of poor cohesion and probably contain some unsuitable clay material.

The silver slate is the most coarse-grained of the three slates - it has an average grain size of 0.03 mm. It is generally even-grained but contains sparse layers of coarse material. The cleavage planes part more readily than in the other slates and thinner slabs are available. The plane of parting is not everywhere smooth. Some of the surfaces are flaky and lack lustre, but most are relatively free of staining. While the other slates break cleanly across the cleavage this slate tends to part in a jagged fashion, separating along the cleavage planes rather than through them. This would result in a lot of wastage in dressing. Under the microscope the silver slate can be seen to consist of chlorite, white mica, quartz, and about 10% opaque minerals, mostly secondary leucoxene and some pyrite. There are a few blebs of calcite aligned parallel to the cleavage. The coarser-grained layers contain a brown mica, quartz, and very finely divided chlorite in the interstices. The slate contains no voids or void-filling minerals other than calcite; there are no large crystals of minerals which would prevent a good polish being achieved.

TABLE 1 – RESULTS OF TESTS

	Victoria	New South Wales		New South Wales				South Aust.	Norway	South Aust.	
				Gundagai							
	Castlemaine Slate	Forbes Slate	Goulburn Slate	Black Slate	Silver Slate Sample 1	Silver Slate Sample 2	Banded Slate	Mintaro Slate	Norwegian "Slate"	Willunga Slate	Wistow "Slate"
PHYSICAL TESTS											
Bulk specific gravity	2.53	2.17	2.61	2.71	2.67	2.72	2.58	2.76	2.69	2.70	2.66
Water absorption	3.71%	5.99%	1.85%	~~8.36%~~ 0.36%	1.72%	0.40%	1.34%	0.49%	0.12%	0.68%	0.31%
Modulus of rupture			10.91	7.67	14.34						
Crushing strength Dry		6300psi		35,000psi				33,100psi		40,150psi	33,600psi
Wet		2450psi		34,700psi				27,600psi		31,400psi	20,000psi
QUALITY TESTS											
Hand scraping Reduced depth of softening		-0.001in.	-0.001in.								
Los Angeles Value for abrasion	57%	46%	37%	38%	37%		45%	32%		38%	30%
Sodium sulphate Number of cycles	10/15	8/15	15/15	15/15	13/15		9/15	15/15	15/15	13/15	15/15
% Weight lost	1%	9.7%	negligible	negligible	0.66%		0.7%	0.2%	negligible	negligible	negligible

GOULBURN SLATE

WATER ABSORPTION and BULK SPECIFIC GRAVITY

weight dry W_1						
weight after immersion W_2						
$W_2 - W_1$						
weight in water W_3						
$W_2 - W_3$						
temperature T						
Absorption % $\frac{(W_2 - W_1)100}{W_1}$						
Bulk specific gravity $\frac{W_1}{W_2 - W_3}$						

Average Absorption %

Average Bulk specific gravity

Average Temperature

Fig.1

To accompany Record 1967/145
M(Pf) 102

MODULUS OF RUPTURE

GOULBURN SLATE

dimensions b in. d in. l in.						
total load W lbs.						
state of sample before testing						
type of fracture						
Modulus of Rupture $R = \frac{3Wl}{2bd^2}$						
average Modulus						

Fig. 2

To accompany Record 1967/145
M(Pf) 103

CRUSHING STRENGTH

GOULBURN SLATE

		WET			DRY	
dimensions Lu in.						
Bu in.						
Ll in.						
Bl in.						
d in						
breaking load L lbs						
nature of break						
av. area $\frac{Lu \times Bu + Ll \times Bl}{2}$						
crushing strength lb/sq.in. $= \frac{L}{av.A}$						
corrected crushing strength						

percentage loss of strength

$$= \frac{\text{dry strength} - \text{wet strength}}{\text{dry strength}} \times 100$$

Fig. 3

To accompany Record 1967/145
M(Pf)106

WEATHERING TEST

GOULBURN SLATE

dry weight W_1						
no. of cycles to sample's deterioration						
state of sample after 15 cycles						
dry weight after 15 cycles W_2						
percentage loss of weight $\frac{W_1 - W_2}{W_1} \times 100$						
average loss of weight(%)						
average no. of cycles to sample's deterioration						

Fig 4

To accompany Record 1967/145
M(Pf)105

GOULBURN SLATE	LOS ANGELES ABRASION TEST	
original weight of sample W		
weight of sample after abrasion		
weight retained on no. 10 B.S. sieve after dry sieving		
weight passing no 10 B.S. sieve after dry sieving		
weight of sample after dry sieving Wd		
loss in weight W–Wd		
weight retained on no 10 B.S. sieve after wet sieving X		
fraction of sample retained after wet sieving X/W		
Los Angeles value 100(1–X/W)		
average LOS ANGELES value		

Fig. 5

To accompany Record 1967/145
M(Pf) 104

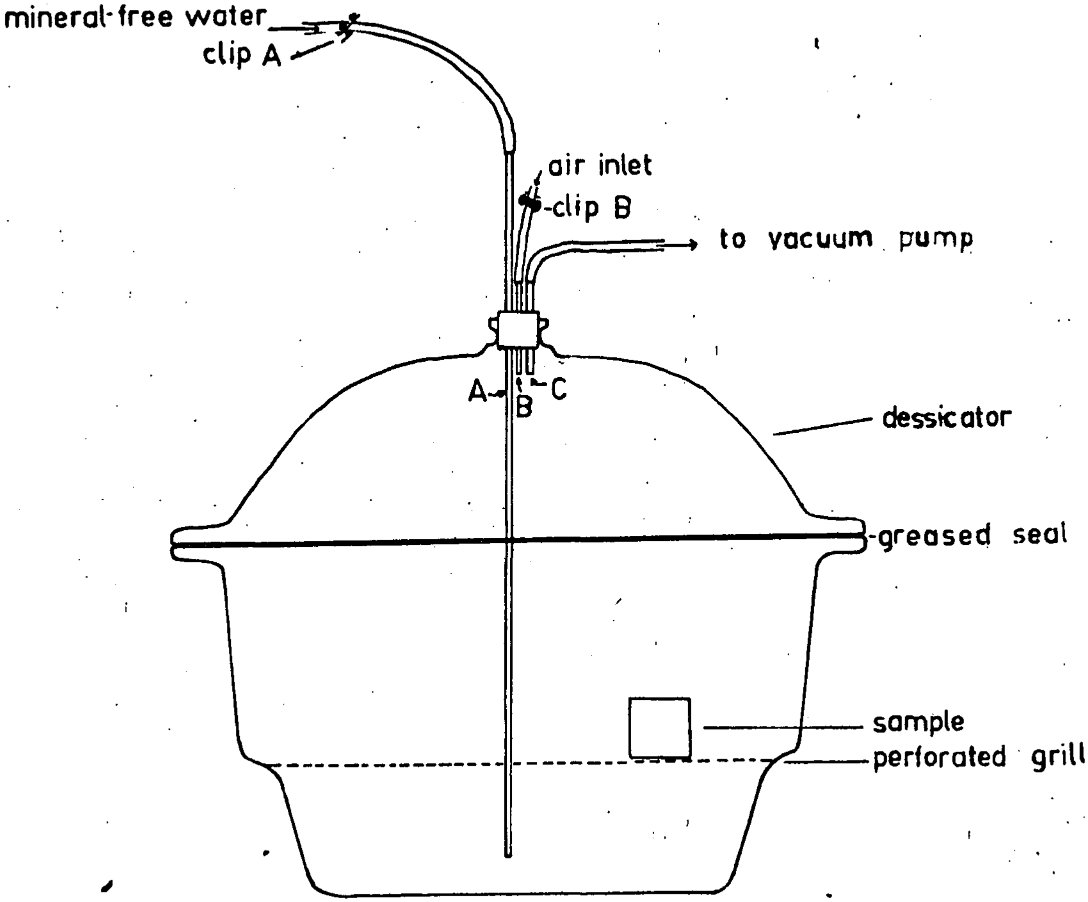

Fig.6 EQUIPMENT FOR SATURATING SAMPLES IN A PARTIAL VACUUM

To accompany Record 1967/145

M(E)98