The limestones of Scotland v.1 — Chapter 5 Chemical characteristics

Introduction

For most economic purposes the value of a limestone depends largely upon the total quantity of calcium carbonate contained in it. The amounts of magnesium carbonate, alumina, silica, iron, phosphorus, sulphur, etc., are also important because of their effect, either in giving the stone some particularly desired quality or in affecting it adversely for the special purpose to which it is put. Chemical analysis is therefore necessary, and nearly all the chief limestones in Scotland have been analysed in connection with this investigation. In the preliminary stages use had sometimes to be made of analytical data based on old work and on samples of limestone selected for particular purposes and thus not truly representative of the bulk of the stone available. The figures used in this memoir, however, are from material selected as typical of the bulk of the limestone to which they apply, and in many cases refer to samples taken across the whole thickness of the bed and so representing the average character of the limestone composing it.

Complete analyses were made of the chief limestones in each district but, in addition, many partial analyses were carried out with a view to ascertaining the value for agricultural use of limestone in particular outcrops. These partial analyses were confined in most cases to estimates of lime, magnesia, carbon dioxide and residue insoluble in acid.

For general purposes the composition of the limestones is best expressed in percentages of calcium carbonate and magnesium carbonate rather than in percentages of the oxides. The carbonate percentages have therefore been calculated from the analytical figures and are used in all cases except where the percentages of carbon dioxide, iron oxide and other constituents make it clear that some appreciable proportion of the lime and magnesia is present in other than carbonate form. The conversion factors used were as follows: $CaCO_3$ = CaO × 1.784 and $MgCO_3$ = MgO × 2.091. In no case have the results been recalculated to bring the total to 100 per cent.

Where any appreciable proportion of the lime or magnesia (or both) is not present as carbonate but is contained in calc-silicate minerals, the percentages of calcium carbonate and magnesium carbonate cannot be calculated from the ultimate analysis, but require special estimation. This is done on that portion of the rock which is soluble in acetic acid and which normally contains only the lime and magnesia which were present in the rock in carbonate form. For economic purposes such special estimatiops are seldom necessary, but for this investigation they were made where calc-silicate minerals were known to be present in amounts exceeding one or two units per cent. In some cases, however, the calculated figures for calcium and magnesium carbonates given below may exceed slightly the figure that would have been obtained by the use of acetic acid as a solvent.

In a large number of instances estimates were made of the amounts of elements other than those normally included in a standard complete analysis, and information was thus obtained regarding the distribution of such trace elements. Full discussion of chemical and petrographical questions would, however, require a separate volume.

Dolomitization

The analyses have an important bearing on the question of dolomitization. The problem of dolomitization in sedimentary limestones is fully discussed by F. M. Van Tuyl (Van Tuyl, 1916, pp. 251–422) and by F. W. Clarke (Clarke, 1924, pp. 565–580). From their critical reviews, it is clear that dolomite has been produced in a number of different ways, but that the only important method from the normal stratigraphical point of view is that of marine alteration of deposits of calcium carbonate. The accounts of the process of dolomitization by marine alteration vary somewhat in detail as expressed by different authors (Cullis, 1904; Skeats, 1905; Dixon, 1907; Daly, 1909; Blackwelder, 1913), but in general they amount to the same thing. According to this view the calcareous material, whether chemically or organically deposited, was originally composed of calcium carbonate containing a percentage of magnesium carbonate not greater than that found in the skeletons and shells of living organisms. The original magnesiuth carbonate is probably not in the form of dolomite but is contained in solid solution or otherwise in the calcium carbonate. It seldom exceeds 16 per cent. except in certain algae, and is usually less than 10 per cent. If, after its original formation, the deposit of calcium carbonate remains in contact with sea water, then under favourable conditions, interaction between the calcium carbonate and the magnesium salts in the water may cause progressive replacement of calcite by dolomite. The favourable conditions include a somewhat warm temperature, a pressure not in excess of that due to comparatively shallow water, and a period of time long enough to allow the action to take place before the calcareous material either sinks to deeper and colder levels or is covered up by succeeding deposits of calcareous or non-calcareous materials and so insulated from the sea water. Another factor in dolomitization of this type, and perhaps the most important one, is the degree of carbonation of the water; for the solution of calcium and magnesium carbonates in natural waters depends upon the presence of carbon dioxide in the water, and when this gas is driven off the carbonates are precipitated. Thus the presence or absence of organic matter in the water associated with the originally deposited calcium carbonate is likely to influence its sensitiveness to the action of magnesia in the sea water with which it is in contact (Peach and Horne, 1907, pp. 370–371).

If the calcareous deposit is in the form of an ooze or mud, then complete dolomitization may take place comparatively quickly under favourable conditions of temperature and pressure; it might even take place during the settlement of the ooze on the sea foor. If burial and consolidation take place quickly thereafter the result will be a fine-grained compact dolomite such as those in Group IT of the Durness Limestone (pp. 38 and 182) and some of the dolomites in the Lower Limestone Group of the Carboniferous (p. 42). Should consolidation take longer, there would be the opportunity for coarser crystallization of the mineral, and the result — might be a more granular dolomite, like some of those in Groups III and VI of the Durness Limestone (p. 181).

Where the calcareous deposit consists of solid calcareous grains or masses, such as shells, corals, crinoids, ooliths, or the like, embedded in calcareous mud, the dolomitization may take place selectively, the solid grains and the matrix being dolomitized at different rates or the one before the other. Thus if the process of dolomitization is stopped before it is completed, the result may be a mottled rock consisting partly of dolomite and partly of limestone as is the case in some beds in Group VI of the Durness Limestone (p. 181). If such a process of dolomitization is completed, however, a mottled dolomite may be produced, such as the leopard stone in Group III of the Durness Limestone (p. 181).

In the above cases it is assumed that the reduction in volume of 12.1 per cent. due to conversion of the calcite molecule to the dolomite molecule is not evident in the final product because the deposit as a whole was not consolidated until after conversion.

A further possible case is that in which a partly or completely consolidated but porous limestone, such as a coral-reef deposit, remains in contact with sea water under conditions conducive to dolomitization. Under such circumstances the final result may be a porous dolomite. The Funafuti results seem to show that there may, however, be secondary deposition of dolomite in addition to the replacement of calcite (Cullis, 1904, pp. 404–415). There was an unfortunate gap in the evidence, however, in that it was not possible to ascertain the character of the water in the porous portions of the reef at depth (Judd, 1904, pp. 366–367); nor is there any way of judging whether the porous portions of the rock were still undergoing secondary changes of any sort.

Apart from the normal sedimentary, usually marine, dolomite the only other type commonly occurring in Scottish limestones is that found in the vicinity of faults, broken ground and planes of jointing. Such dolomite has obviously been formed after final consolidation, when water containing magnesia has regained access to the limestone. In cases where the dolomitization is associated with fractures known to have occurred long after deposition of the limestone, it is clear that groundwater has been the medium through which the change has been effected. In other cases, however, the dolomite veins in the limestone do not appear to be in direct communication with veins or fissures extending for any great distance into the surrounding strata; and it seems probable in some instances that the limestone, after having solidified on the sea floor, was broken or developed jointing whilst still uncovered by other sediment or so lightly covered that it was still within reach of sea water, and so under the influence of dolomitizing agencies.

When the Macaulay Institute analyses were scrutinized with a view to ascertaining the incidence of dolomitization upon Scottish limestones it was immediately obvious that certain samples were *prima facie* open to suspicion in this connection. These included mixed samples taken over a thickness of limestone known to contain definite separate beds of limestone and dolomite, grab samples from broken rock, samples from the vicinity of faults, samples not taken under the supervision of a fully qualified geologist, samples found on analysis to contain 25 per cent. or more of insoluble residue, samples in which an appreciable proportion of the lime or magnesia, or both, were not present as carbonate, and samples in which iron replaces part of the magnesia in the dolomite molecule. Leaving aside all samples known to be of such a character, but no others, this gives a total of 175 analyses. In addition there are seven Geological Survey analyses of the Durness dolomites which can be taken as of equivalent authenticity to those of the Macaulay Institute, and 27 analyses by the British Oxygen Co., Ltd., of limestones selected and sampled by the Geological Survey during an investigation of some of the purer Scottish limestones. In the latter case particular attention was given to the magnesia content. Altogether, therefore, there is a total of 209 analyses available on which to base conclusions.

The percentages of $MgCO_3$ on a pure $CaCO_3$+$MgCO_3$ basis show the following distribution (Figure 1):

Percentage Range of $MgCO_3$	No. of Analyses	Percentage of Total Analyses
0 to 5	137	65.6
0 to 10	161	77.0
0 to 16	169	80.9
16 to 41	10	4.8
41 to 46	30	14.3

The figure of 16 per cent. is taken as being about the maximum of $MgCO_3$ found in living organisms apart from some highly magnesian alga (Clarke, 1924, pp. 571–574). The 41 to 46 per cent. range includes all the sedimentary dolomites.

The. analyses in the 0 to 16 per cent. $MgCO_3$ group consist of limestones from the Lower Limestone Group of the Carboniferous, from the Dalradian, Moine and Shetland Metamorphic series, and from Groups V and VI of the Durness Limestone; together with a few from the Upper Old Red Sandstone. The relative proportions in the metamorphic and non-metamorphic limestones are shown in the upper histograms in (Figure 1). In each of these two subdivisions the distribution of figures is similar, nearly all lying between 0 and 10 per cent. and the great majority between 0 and 5 per cent. Taking all the analyses within the group, 65.7 per cent. show between 0 and 3 per cent. $MgCO_3$.

The analyses in the 16 to 41 per cent. $MgCO_3$ group include the following:

Lewisian	4	all the available analyses, except one which is a high-grade dolomite.
Middle Old Red Sandstone	2}	probably chemical precipitates or
Cementstone Group	2}	evaporation deposits.
Lower Limestone Group	2	both of them from limestones affected by intrusive sills of quartz-dolerite.

The analyses in the 41 to 46 per cent. $MgCO_3$ group include as follows: Lewisian, 1; Dalradian, 1; Durness, 17; Cementstones from the Cement-stone Group and the highest portion of the Upper Old Red Sandstone, 8; Lower Limestone Group, 3.

There are very marked concentrations both at the calcite and the dolomite ends of the scale in the series of analyses as a whole; and, if only normal sedimentary beds of organic or almost certainly organic origin are considered, this concentration is so decided that there are no analyses of limestone unaffected by subsequent metamorphic action within the range of 16 to 41 per cent. $MgCO_3$. In the Dalradian, Moine and Shetland Metamorphic limestones a similar concentration at the calcite end of the scale is found; there is nothing between 16 and 41 per cent. $MgCO_3$; and the rarity of magnesia in these rocks as a whole is indicated by the fact that only one dolomite, the Appin one, appears amongst the analysed samples.

In the case of the Durness Limestone we have no analyses of the limestone beds as distinct from the dolomites, either in the Macaulay Institute or Geological Survey data; but a reliable series of analytical figures for samples collected from the limestone as distinct from the dolomite beds and examined by the British Oxygen Co., Ltd., with special attention to their magnesia content, is available. This shows a range of from 0.08 to 11.9 per cent. $MgCO_3$, a result consistent with that indicated above for the sedimentary limestones as a whole. A similar tendency to concentration at each end of the calcite-dolomite range is one of the chief features of the analytical results of the, Funafuti coral-reef boring investigations (Judd, 1904, pp. 363–366).

Under the depositional conditions of Scottish limestones of post-Lewisian metamorphic, Cambro-Ordovician and Carboniferous Limestone age, therefore, it seems that there was a very definite tendency either towards preservation of the original calcareous composition of the deposited material of any given bed, or towards the complete conversion of the whole bed into dolomite. The influence upon dolomitization exercised by the depth of the water, the temperature of the water, the original character and degree of porosity of the deposited material, the presence or absence of decaying organic matter and the consequent amount of carbon dioxide present, or any combination of or variation in these, may be conjectured in some cases, but not in all. Any suggestion regarding the cause of the dolomitization, however, must take into account this further factor of the great scarcity of intermediate stages in the process. It seems difficult to avoid the conclusion that the rate of dolomitization was so rapid in comparison with other processes connected with the formation of the limestones that there was little chance of its being interrupted in the middle of the transformation once this had commenced.

It should be noted, however, that there are some examples of bedded limestones which, on analysis of a bulk sample of any one bed, may be judged to be partly dolomitized. The mottled beds in Groups VI and VII of the Durness Limestone (Peach and Horne, 1907, pp. 379–380) and the irregularly dolomitized beds in the Lower Limestone Group at St. Monans. are instances in point. They were not selected for analysis because they are not macroscopically homogeneous and so could not give a $CaCO_3$–$MgCO_3$ ratio from which any reasonable deduction could be made. Beds of these types, however, are extremely rare in Scotland, and it is safe to say that the analyses on which this discussion is based represent the facts fairly.

In most cases in which percentages of $MgCO_3$ between 16 and 41 occur later dolomitization of the vein type is concerned. For example, a bulk sample of the Burdiehouse Limestone from one bed in the Newbigging Mine, Burntisland, 'would in some areas include dolomite from definite veins or veinlets traversing the limestone. Precautions have been taken to avoid this in the samples selected for analysis as representative of the various limestones.

The magnesian content of sedimentary limestones of the non-dolomitic type is not usually contained in crystalline dolomite observable under the microscope. The magnesia may be mainly within the calcite or may be disseminated through the matrix in a very fine state of subdivision. Crystals of dolomite, nevertheless, are found in some instances in the sections of such rocks. In default of further evidence it is best to assume that such crystalline dolomite may have been derived from the original magnesia in the limestone, since it does not exceed the amount that could easily have been present in the original shells, corals, etc.

In the Dalradian and other post-Lewisian metamorphic limestones, apart from those few which are high-grade dolomites, the occurrence of dolomite crystals is very rare.

Turning now to the other limestones represented, by the analyses, we find that the Lewisian and Cementstone types both contain a considerable percentage of magnesia. In the Lewisian of the Loch Maree district the range is from 21 to 44 per cent. $MgCO_3$, and in every case dolomite crystals are seen under the microscope. The Lewisian rocks of this area were originally a sedimentary series containing much basic igneous material, probably chiefly intrusive; and they have been subjected to intense metamorphic action, probably more than once. A discussion of the problem of their magnesian content would be purely speculative in the present state of our knowledge.

With the cementstones we are on firmer ground, for they show definite evidence of having been deposited from mineralized water in confined basins, possibly through evaporation. The similarly produced cornstones of the Old Red Sandstone were derived from water containing only calcium carbonate in solution and the result was a limestone low in magnesia. The water from which the cementstones were derived contained a large proportion of magnesia, and sometimes some iron also; and the resulting rock is therefore dolomitic with, in addition, a considerable amount of ferrous carbonate in some cases.

Characteristics of stratigraphical formations

As a result of the chemical work some interesting general statements can be made regarding the character of the limestones in the various stratigraphical groups.

Lewisian

In bulk sample nearly all the Lewisian limestones are of poor quality, with a calcium carbonate percentage round about 60; and in at least one case (Glen Urquhart, (SL 106) [NH 485 314]) some of the lime is contained in calc-silicate minerals. The percentage of magnesia is usually high, some of it being present in dolomite and some in magnesian silicates. The Lewisian limestone from the North-West Highlands which on analysis proved highest in calcium carbonate was obtained from Letterewe (SL 258) [NG 952 719]: $CaCO_3$ 91.52; $MgCO_3$ 3.03; Insol. Res. 3.65. The range in other samples from Wester Ross ((SL 259) [NG 951 720], (SL 260) [NG 902 770], (SL 261) [NG 811 724], (SL 262) [NG 8556 7223], (SL 263) [NG 829 710]) was $CaCO_3$ 51.33 to 62.27; $MgCO_3$ 17.44 to 39.97; Insol. Res. 3.59 to 19.41.

In contrast with the above, the Glen Dessafry limestone of western Inverness-shire, which is believed to be Lewisian, is very low in magnesia. An analysis (Geol. Surv Lab. No. 1401) showed as follows: $CaCO_3$ 92.62; $MgCO_3$ 4.60; SiO_2 2.0; Al_2O_3 1.0.

Moine Series

The Moine limestones, of which those at Shiness (SL 169) [NC 47156 14307] and Rebeg (SL 107) [NH 563 422] are the only noteworthy examples, are low in magnesia according to the analyses available, except for one band at Shiness which gave MgO 7.45 per cent. in an old determination (Anderson 1853, pp. 275–276). The grade of the Shiness limestone as a whole, however, is not high over any great width of face owing to a considerable development of calc-silicate minerals. Three representative samples across the beds exposed in the old quarry showed as follows:

Top 8½. ft.	about 42 per cent. $CaCO_3$
Middle 3 ft.	about 50 per cent. $CaCO_3$
Bottom 7½ ft.	about 81 per cent. $CaCO_3$

Old analyses of the Rebeg Limestone when it was being worked (Johnston, 1845, p. 487) gave as follows: $CaCO_3$ 93.82 and 94.10; $MgCO_3$ 1.64 and 1.09; Insol. Res. 3.55 and 2.74. A recent analysis of selected rock shows a similar result. It is typical of the best material in the lenses of limestone of which the occurrence is composed.

Shetland Metamorphic Series

The Shetland limestones resemble those of the Moine and Dalradian series (see below) in being distinctly low in magnesia.

The range of composition in the analysed samples ((SL 184) [HU 437 324]–191) is as follows:-

$CaCO_3$	60.61 to 89.73 per cent., but in most cases over 80
$MgCO_3$	1.53 to 4.01 per cent.
Insol. Res.	6.37 to 30.85 per cent., but in most cases under 20

There is an appreciable amount of calc-silicate mineral in some cases, but the main impurity is usually silica.

Dalradian Series

The Dalradian Series consists of a thick group of highly altered sedimentary rocks in which several different kinds of limestones are included. It is therefore not to be expected that even when altered they will, as a group, necessarily show any diagnostic chemical character. It can nevertheless be said that on the whole they are non-dolomitic, the only outstanding exception being the Appin Limestone which is a high-grade dolomite in at least one area. The characters of the individual limestones are noted below.

The Ballachulish Limestone is excellent between Fort William and Spean Bridge ((SL 85) [NN 1800 7763], (SL 229) [NN 2492 8244], (SL 230) [NN 2418 8157]): $CaCO_3$ 95.09 to 97.03; $MgCO_3$ 1.01 to 1.41; Insol. Res. 2.38 to 4.15.

To the south it is poorer, at Ballachulish, for example. The following analysis is from Allt Socaich, 2■ miles S.S.W. of Bridge of Coe (Lightfoot, 1916, p. 189): $CaCO_3$ 75.39; $MgCO_3$ 4.16; SiO_2, Al_2O_3, Fe_2O_3 and FeO 19.24.

The Appin Limestone is dolomitic in most outcrops. Some earlier analyses from the Ballachulish area show a very high grade of dolomite, but as they are of rock selected for petrographic purposes they cannot be looked upon as truly typical of its bulk composition. Later analyses, however, by the Steetley Lime and Basic Co., from Dalnatrat and Ballachulish indicate a good bulk composition, as shown below:

Dalnatrat	$CaCO_3$	51.97	$MgCO_3$	45.67	SiO_2	3.30
Duror (SL 87) [NM 9832 5421]	$CaCO_3$	47.63	$MgCO_3$	38.60	Insol. Res.	13.11
Ballachulish	$CaCO_3$	51.62	$MgCO_3$	43.78	SiO_2	3.70

The Lismore Limestone is a stone of good quality. Limestone from Port Ramsay Quarry (SL 88) [NM 8844 4558] gave: $CaCO_3$ 87.17; $MgCO_3$ 0.25; Insol. Res. 11.25.

An analysis of limestone from Eilean na Caorach (Lightfoot, 1916, p. 189) shows 4.63 per cent. $MgCO_3$.

Analyses by the British Oxygen Co. of representative samples collected by Dr. I. G. C. Anderson showed as follows:

	Width	$CaCO_3$	$MgCO_3$	SiO_2, Al_2O_3 & Fe_2O_3
Achadun Castle, 100 yds. W. of,	20 ft.	95.0	0.13	4.01
Port Salen Quarry	50 ft.	90.7	Nil	8.57

The Islay Limestone is a stone of considerable purity in many places. The following range refers to Lower Cragabus and Leorin quarries near Port Ellen, Islay Estates Quarry near Bridgend, and Persabus Quarry near Port Askaig ((SL 129) [NR 354 485]–132): $CaCO_3$ 91.59 to 94.60; $MgCO_3$ 2.16 to 6.51; Insol. Res. 1.63 to 4.41.

A number of single lump samples from exposures in the Ballygrant area showed as follows: $CaCO_3$ 95.17 to 97.30; $MgCO_3$ 1.74 to 3.10.

The Tayvallich Limestone is poor at the Crinan Canal and Kilmartin, as shown by the following figures:

Crinan Canal (SL 133) [NR 8397 9086]	$CaCO_3$	58.86	$MgCO_3$	0.90	Insol. Res.	38.84
Kilmartin (SL 125) [NR 8336 9685]	$CaCO_3$	66.44	$MgCO_3$	0.55	Insol. Res.	32.05

It is of better quality farther north, near the head of Loch Awe:

Eurach Quarry (SL 127) [NM 8523 0085]	$CaCO_3$	83.84	$MgCO_3$	7.81	Insol. Res.	5.29
Finch Quarry (SL 126) [NM 8988 0380]	$CaCO_3$	90.09	$MgCO_3$	0.61	Insol. Res.	8.21
Kilchrenan Quarry (SL 123) [NN 0384 2447]	$CaCO_3$	82.39	$MgCO_3$	0.88	Insol. Res.	13.54

The Loch Tay Limestone is poor to moderate in Kintyre and Cowal ((SL 128) [NR 734 211], (SL 134) [NS 0926 9944], (SL 147) [NR 7553 5499]): $CaCO_3$ 66.89 to 83.87; $MgCO_3$ 0.69 to 3.26; Insol. Res. 14.83 to 28.18.

In Perthshire the quality is rather better on the whole. The following range refers to outcrops in the Loch Earn, Loch Tay, Pitlochry and Kirkmichael areas ((SL 1) [NN 609 202], (SL 2) [NN 559 321], (SL 3) [NN 569 334], (SL 5) [NN 921 581], SL137, (SL 138) [NO 111 588]): $CaCO_3$ 66.40 to 90.39; $MgCO_3$ 0.55 to 2.20; Insol. Res. 7.66 to 30.00.

The magnesia content of the Loch Tay Limestone is everywhere low.

The Blair Atholl Limestones are of high grade in many places. The range of analyses given below is based on samples from White Bridge, Blair Atholl, and Gleann Beag near the Devil's Elbow ((SL 4) [NN 776 541], (SL 11) [NN 891 665], (SL 12) [NN 880 642], (SL 139) [NO 139 756]): $CaCO_3$ 87.65 to 92.19; $MgCO_3$ 0.76 to 1.87; Insol. Res. 6.28 to 10.74.

The chief impurity is silica which occurs mainly as quartz. Calc-silicates are not common. A white dolomitic band occurs in this limestone N.E. of Blair Atholl.

Limestones in the Sandend Group (Banffshire): There are several different bands of limestone in the Sandend Group. The stone analysed from the various quarries proved to be somewhat variable in character, but is in most cases of moderate to high grade. The following figures refer to samples from Tomintoul, Keith and Dufftown ((SL 68) [NJ 439 482], (SL 70) [NJ 3325 4078] (SL 71) [NJ 4591 4482], SL72 [NJ 3915 4989], (SL 73) [NJ 3895 4625], (SL 74) [NJ 4965 5915], (SL 76) [NJ 153 193], (SL 238) [NJ 426 503]): $CaCO_3$ 79.60 to 95.62; $MgCO_3$ 0.65 to 3.30; Insol. Res. 3.48 to 19.45.

The rocks at Rinaitin, Glen Rinnes (SL 75) [NJ 263 328] and Richmond Quarry, Dufftown (SL 239) [NJ 3315 3965] are the only ones in this series showing any considerable percentages of magnesia: $CaCO_3$ 74.62 and 82.75; $MgCO_3$ 12.56 and 8.33; Insol. Res. 12.72 and 7.98.

Limestones in the Portsoy Group: Two analyses of the Portsoy limestones are available, both good:

Limehillock Quarry, Grange (SL 67) [NJ 5150 5181]	$CaCO_3$	90.49	$MgCO_3$	1.25	Insol. Res.	8.02
Broadland, near Huntly Boyne (SL 240) [NJ 4797 4167]	$CaCO_3$	89.39	$MgCO_3$	2.22	Insol. Res.	7.12

The Boyne Limestone (SL 69) [NJ 6140 6610] gave as follows: $CaCO_3$ 89.25; $MgCO_3$ 2.81; Insol. Res. 9.30.

Deeside Limestones: All analyses show an impure limestone containing a considerable amount of calc-silicate minerals. The insoluble residue in samples from Deecastle, Aboyne and Banchory ((SL 77) [NO 4402 9692], (SL 78) [NO 5890 9520], (SL 79) [NO 5757 9607], SL 80) ranged from 30.92 to 66.85.

Metamorphic limestones of doubtful age

The unclassified metamorphic limestones vary greatly in quality. Two of the best, Kinlochlaggan (SL 14) [NN 55143 89751] and Aviemore (SL 15) [NH 937 082], gave as follows:

Kinlochlaggan (SL 14) [NN 55143 89751]	$CaCO_3$	91.37	$MgCO_3$	5.00	Insol. Res.	2.64

Aviemore (SL 15) [NH 937 082]:Aviemore (SL 15) [NH 937 082]	$CaCO_3$	86.64	$MgCO_3$	0.88	Insol. Res.	10.03

Cambrian and Ordovician (N. W. Scotland)

The analyses available for the various subdivisions of the Durness Limestone are from several different sources and have been made on material selected for a number of different reasons. Hence they cannot be compared strictly with one another. Both pure dolomite and almost completely non-magnesian limestone are to be found, some of the groups being mainly dolomite and some containing a large proportion of limestone.

Group I: Dolomite, in most places impure.

Dolomite, Inchnadamph (SL 269) [NC 24267 23635]	$CaCO_3$	52.6	$MgCO_3$	40.2		
Dolomite, Kishorn	$CaCO_3$	60.3	$MgCO_3$	26.4	Insol. Res.	13.1

Grown II: Dolomite. often high in grade: marmorized in Ledbeg area.

Dolomite, Kishorn (SL 255) [NG 836 415]	$CaCO_3$	47.76	$MgCO_3$	40.32	Insol. Res.	10.45
Dolomite, Kishorn (SL 256) [NG 833 401]	$CaCO_3$	49.91	$MgCO_3$	39.74	Insol. Res.	8.39
Dolomite, Elphin ((SL 272) [NC 21843 10376] [NC 21673 10634], (SL 273) [NC 21735 10559], (SL 274) [NC 21763 10539])	$CaCO_3$	52.40	$MgCO_3$	38.48	Insol. Res.	3.04
Dolomite, Durness (SL 175) [NC 384 649]	$CaCO_3$	51.79	$MgCO_3$	41.08	Insol. Res.	6.29
Dolomite, Durness (SL 177) [NC 436 572]	$CaCO_3$	52.23	$MgCO_3$	43.11	Insol. Res.	5.61

Group III: Dolomite, often high in grade.

Dolomite, Durness (SL 176) [NC 372 626]: $CaCO_3$ 53.71; $MgCO_3$ 43.83; Insol. Res. 1.85

Group IV: Alternating beds of limestone and dolomite at Durness. An old analysis (Pollard, in Peach and Horne, 1907, p. 637) gave $CaCO_3$ 67.9; $MgCO_2$ 9.2; Insol. Res. 19.9; indicating a somewhat magnesian limestone.

Group V: Mainly limestone at Durness. The following range was found in an investigation of the principal limestone beds by the British Oxygen Co., Ltd. based on representative samples taken by Mr. J. Knox from measured outcrops at Balnakiel: $CaCO_3$ 71.6 to 96.5; $MgCO_3$ 1.4 to 11.9; SiO_3 2.09 to 8.33; Al_2O_3+ Fe_2O_3 0.22 to 1.25.

In Skye some of the limestone is marmorized, as shown by the following analyses:

Brucite-marble, N.W. of Broadford (SL 245) [NG 623 248]	CaO	31.63	MgO	17.66	CO_2	30.83	Insol. Res.	12.28
Brucite-marble, Cill Chriosd (SL 248) [NG 621 201]	CaO	31.09	MgO	19.43	CO_2	37.43	Insol. Res.	6.78

The CaO is mainly in calcite and the MgO mainly in brucite (magnesium hydroxide). An analysis of non-marmorized material from near Loch Lonachan, Skye (Pollard, in Peach and Horne, 1907, p. 637), showed the composition of a high-grade dolomite: $CaCO_3$ 54.52; $MgCO_3$ 43.70; Insol. Res. 1.72.

Group VI: Alternating beds of limestone and dolomite at Durness. Two analyses by the British Oxygen Co. Ltd., of limestone from this Group at Balnakiel, sampled by Mr. J. Knox, showed as follows: $CaCO_3$ 90.4 and 87.7; $MgCO_3$ 6.27 and 8.03; SiO_2 4.07 and 4.10; Al_2O_3+Fe_2O_3 0.92 and 1.65.

In Skye there are also high-grade limestones in this group:

Limestone, Torran (SL 246) [NG 576 203]	$CaCO_3$	93.01	$MgCO_3$	2.28	Insol. Res.	2.55
Limestone, Dun Beag, Torran (SL 247) [NG 575 198]	$CaCO_3$	90.53	$MgCO_3$	1.00	Insol. Res.	5.50

Other samples from this area, analysed by the British Oxygen Co., Ltd., showed up to 7.53 per cent. $MgCO_3$.

Another analysis, of material from the same group a mile or two distant, at Suardal (Pollard, in Peach and Horne, 1907, p. 637) showed a high-grade dolomite.

Group VII: No analysis available; the limestones of this group are much sheared.

Ordovician (S.W. Scotland)

The Stinchar Limestone of the Girvan district is, in general, a rather poor limestone, but is low in magnesia. It is very variable in composition, as the following range of percentages will show ((SL 152) [NS 234 012], (SL 153) [NX 23 94], (SL 154) [NX 23 94], (SL 266) [NX 197 897], (SL 267) [NX 251 929]): $CaCO_3$ 75.58 to 95.54; $MgCO_3$ 0.82 to 2.80; Insol. Res. 2.73 to 20.49.

Old Red Sandstone

Nearly all the cornstones that have been worked in Scotland belong to the Upper Old Red Sandstone Series. They are very irregular in development, and in consequence the analyses available show extreme variability in lime content. Where they are thick enough to make it possible to obtain clean stone the grade is high, often over 90 per cent. $CaCO_3$. A noteworthy feature is the low magnesia content in nearly every case ((SL 24) [NO 742 635], (SL 26) [NO 699 608], (SL

27) [NO 622 634], (SL 94) [NS 663 153], (SL 104) [NT 1645 9850], (SL 155) [NS 313 017], (SL 156) [NS 313 017], (SL 170) [NS 6945 3006], (SL 180) [NT 0842 6608], (SL 208) [NT 538 013], (SL 257) [NS 700 201]), ranging from nil to 2.47 per cent. $MgCO_3$.

In exceptional cases, namely, at Toward Taynuill in Argyll (SL 283) [NS 134 685], Kilchattan in Bute (SL 228) [NS 106 542] and at Gargunnock, W. of Stirling (SL 160) [NS 7067 9330] the cornstone is highly dolomitic:

(SL 283) [NS 134 685]	$CaCO_3$	49.95	$MgCO_3$	38.90	Insol. Res.	6.30
(SL 228) [NS 106 542]	$CaCO_3$	47.29	$MgCO_3$	30.85	Insol. Res.	20.83
(SL 160) [NS 7067 9330]	$CaCO_3$	49.89	$MgCO_3$	36.21	Insol. Res.	11.76

In these places the bed is practically at the top of the Upper Old Red Sands stone sequence and not far removed in the succession from the cementstone of the lowest part of the Calciferous Sandstone Series, which are also in most cases magnesian.

Two analyses of calcareous flagstones from the Middle Old Red Sandstone of Caithness show a poor content of lime and some magnesia:

Halkirk (SL 163) [ND 13917 58274]	$CaCO_3$	28.93	$MgCO_3$	12.15	Insol. Res.	53.32
Robbery Head (SL 167) [ND 222 333]	$CaCO_3$	52.41	$MgCO_3$	12.15	Insol. Res.	32.93

A limestone near the base of the Middle Old Red Sandstone at Achvarasdal, Reay (SL 282) [NC 993 613] gave 79.82 per cent. $CaCO_3$ and 15.10 per cent. of insoluble residue.

Calciferous Sandstone Series

These beds contain several different types of limestone.

Cementstones

The typical cementstones of the Midland Valley are argil-laceous dolomites with some iron carbonate, grading into manly cements and manly clays with increase in such constituents as SiO_2, Fe_2O_3, Al_2O_3, and K_2O. Analyses from the best known occurrences, namely, Ballagan (Stirlingshire), Devonshaw (Kinross-shire) and Randerstone (Fifeshire), show the following range ((SL 28) [NO 6113 1133], (SL 29) [NO 6099 1147], (SL 30) [NO 6125 1131], (SL 31) [NO 6133 1128], (SL 32) [NO 5641 0707], (SL 40) [NO 4914 1140], (SL 91) [NS 4083 7782], (SL 181) [NT 0758 6486], (SL 192) [NS 5221 8014], (SL 193) [NS 5221 8014]): $CaCO_3$ 43.20 to 53.95; $MgCO_3$ 22.66 to 37.48; $FeCO_3$ up to 17.23; Insol. Res. 1.29 to 25.65. The cementstones of Liddesdale are probably similar in composition.

Limestones in the Calciferous Sandstone Series of Roxburgh

The limestones near the base of the Carboniferous in Roxburghshire are not all of cementstone type, and many of them resemble more closely the shelly limestones of the Lower Limestone Group. The following range is shown in analysed specimens of these beds ((SL 143) [NY 26 76], (SL 144) [NY 22 73], (SL 201) [NY 552 937], (SL 202) [NY 481 864], (SL 203) [NY 453 802], (SL 204) [NY 427 789], (SL 206) [NY 442 784], (SL 264) [NY 24 75], (SL 265) [NY 24 75]): $CaCO_3$ 82.69 to 95.74; $MgCO_3$ 0.69 to 6.48, but mostly less than 4 per cent.; Insol. Res. 0.74 to 8.54.

Some of the thicker limestones of the Border counties are very highly dolomitic: for example. those at Bari are and Carham:

Barjarg, Closeburn (SL 142) [NX 880 904]	$CaCO_3$	53.57	$MgCO_3$	43.12	Insol. Res.	2.65
Nottylees, Carham (SL 220) [NT 795 368]	$CaCO_3$	53.15	$MgCO_3$	42.31	Insol. Res.	3.30
Carham Station (SL 221) [NT 790 368]	$CaCO_3$	55.33	$MgCO_3$	38.95	Insol. Res.	5.20

Limestones in the Oil Shale Group

The three chief limestone horizons of the Oil Shale Group of the Lothians and Fife, namely, the Burdiehouse, the Barracks and the Fells, are all of freshwater origin. The Burdiehouse Limestone is the only one of economic importance, and it is of good quality even when compared with some of the best limestones of the more calcareous groups in the Scottish Carboniferous. It maintains a calcium carbonate content of over 90 per cent. in all the representative analyses available. The range of composition is as follows ((SL 16) [NT 2787 6727], (SL 17) [NT 2787 6727], (SL 18) [NT 2787 6727], (SL 54) [NT 0348 5973], (SL 198) [NT 0348 5793], (SL 216) [NT 2155 8637], (SL 217) [NT 2155 8637], (SL 218) [NT 2155 8637], (SL 219) [NT 2155 8637]): $CaCO_3$ 90.09 to 96.50; $MgCO_3$ 0.50 to 4.66, but under 2 per cent. in all except (SL 219) [NT 2155 8637]; Insol. Res. 1.11 to 6.08. Iron (calculated as Fe_2O_3) is less than 1 per cent. except in (SL 219) [NT 2155 8637], which is the top bed at Burntisland.

The following comparative figures for different beds at Burntisland and Straiton are of interest:

	Newbigging Mine, Burntisland, Carron Co.				Straiton Mine, Midlothian. Shotts, Iron Co., Ltd.		
	Top	Middle	Bottom	Flooring	Top	Middle	Bottom
Thickness in ft.	4½	4	5	1 to l½	11½	7	8½
$CaCO_3$ per cent.	90.09	96.20	95.48	96.50	91.39	91.87	96.02
$MgCO_3$ per cent.	4.66	1.62	1.66	1.32	1.32	1.15	0.50
Insol. Res. per cent.	1.70	1.11	1.74	1.27	1.62	2.50	1.37

The Sunnyside and Rhodes Quarry limestones of East Lothian lie in predominantly volcanic strata which are contemporaneous with the Oil Shale Group. Their character may be judged by the following:

Sunnyside Quarry, E. Linton (SL 178) [NT 6019 7669]	$CaCO_3$	92.68	$MgCO_3$	2.16	Insol. Res	5.53
Rhodes Quarry, N. Berwick (SL 199) [NT 569 849]	$CaCO_3$	87.55	$MgCO_3$	8.00	Insol. Res	0.58

Several analyses more representative of the Rhodes Quarry limestone were obtained from a borehole which was drilled through the full thickness of the bed. It gave as follows:

Thickness in ft.	$CaCO_3$	MgO (approx.)	SrO
5 (top)	89.3		0.33
6	99.2	}0.5 to 1	0.05
4	91.9		0.03
12 (bottom)	81.8	5	0.03

In a sample from one face of Rhodes Quarry a considerable percentage of celestite (strontium sulphate) was found on petrographic examination; and in the bulk sample analysed ((SL 199) [NT 569 849], above) 2.68 per cent, of strontium sulphate was present. The figures given in the bore are much less, and from this it would appear that the distribution of the strontium-bearing mineral is very sporadic.

Limestones in the Upper Sedimentary Group

The limestones in the highest part of the Calciferous Sandstone Series in the area west of the ground in which the Oil Shale Group is developed are similar in character to those of the immediately overlying Lower Limestone Group. They are of good quality, showing figures round about 90 per cent. for $CaCO_3$ content. The range in analysed specimens of the Broadstone and Wee Post limestones from north Ayrshire is as follows ((SL 108) [NS 3690 5365], (SL 122) [NS 3645 5057], (SL 135) [NS 3380 4855], (SL 136) [NS 3380 4855]): $CaCO_3$ 89.37 to 91.96; $MgCO_3$ 0.94 to 2.05; Insol. Res. 4.67 to 6.92.

The Long Craig Lower Limestone of East Lothian, which is considered to be just below the top of the Calciferous Sandstone sequence, gives the following at Lennoxlove, Haddington (SL 197) [NT 5142 7222]: $CaCO_3$ 85.16; $MgCO_3$ 2.48; Insol. Res. 9.69.

Carboniferous Limestone Series

In this division of the Carboniferous valuable limestone seams are present in the basal Lower Limestone Group, and in the higher Upper Limestone Group. No limestones of economic worth occur in the intermediate Limestone Coal Group.

Lower Limestone Group. The lowest limestone of this group, namely, the *Hurlet, is* to be found in many parts of the Midland Valley and in most areas is of good quality and low in magnesia. In the Muirkirk and New Cumnock district of Ayrshire, where it is known as the Hawthorn Limestone, two analyses show as follows:

Muirkirk (SL 114) [NS 720 276]	$CaCO_3$	92.62	$MgCO_3$	1.19	Insol. Res.	4.96
Glenmuir. Cumnock (SL 93) [NS 630 211]	$CaCO_3$	85.72	$MgCO_3$	217	Insol. Res.	9.23

In Buteshire, North Ayrshire and Lanarkshire it shows the following range in samples from Corrie (Arran), Patna, Beith, East Kilbride, Hairmyres and Coalburn ((SL 82) [NS 024 434], (SL 109) [NS 3770 5325], (SL 149) [NS 408 100], (SL 174) [NS 8014 3302], (SL 222) [NS 5953 5480], (SL 223) [NS 6066 5190]): $CaCO_3$ 87.41 to 97.25; $MgCO_3$ 0.99 to 3.28, but mainly between 1 and 2 per cent.; Insol. Res. 2.37 to 10.29.

In the Stirling area the Hurlet (or Murrayshall) gives the following analysis at Cambusbarron (SL 159) [NS 7712 9217]: $CaCO_3$ 86.56; $MgCO_3$ 2.28; Insol. Res. 8.18.

The Gilmerton Limestone of Midlothian is taken as the equivalent of the Hurlet. It is of variable composition according to available analytical figures from quarries at Whitfield and Whim in Peeblesshire, and at Gilmerton and Middleton in Midlothian ((SL 19) [NT 2957 6920], (SL 20) [NT 2957 6920], (SL 21) [NT 171 543], (SL 46) [NT 3578 5765], (SL 183) [NT 172 542]). The following are typical:

Whitfield (top) (SL 21) [NT 171 543]	$CaCO_3$	62.45	$MgCO_3$	5.80	Insol. Res.	27.64
Gilmerton (bottom) (SL 20) [NT 2957 6920]	$CaCO_3$	94.78	$MgCO_3$	1.81	Insol. Res.	2.98

In East Lothian the Long Craig Upper Limestone is thought to be the equivalent of the Hurlet (Macgregor, 1930, p. 523). At Longniddry, Saltoun and Dunbar it gives a good analysis, the range being as follows ((SL 63) [NT 4857 6797], (SL 65) [NT 4490 7625], SL 83): $CaCO_3$ 90.30 to 96.43; $MgCO_3$ 1.41 to 3.19; Insol. Res. 2.01 to 5.47.

The limestone in this position in the Aberlady shore section, however, is a ferro-dolomite (SL 64) [NT 4497 8029]: $CaCO_3$ 60.37; $MgCO_3$ 25.60; FeCO, 10.55; Insol. Res. 1.55.

In Fife the Charlestown Station Limestone is taken as the Hurlet. It is usually too thin to be of use, and the only analysis is one from Easter Glasslie in the Lomond Hills. In this area it is highly dolomitic (SL 97) [NO 2371 0524]: $CaCO_3$ 51.48; $MgCO_3$ 37.08; Insol. Res. 3.57.

The Charlestown Green Limestone of Fife and the *Skateraw Middle Limestone* of East Lothian both lie a short distance above the Hurlet position. Analysis shows them to be. in some places at least, of good quality:

Skateraw Middle Limestone, Dunbar (SL 84) [NT 7466 7540]	$CaCO_3$	94.12	$MgCO_3$	2.33	Insol. Res.	2.65
Charlestown Green Limestone, W. Lomond Hill (SL 100) [NO 2007 0677]	$CaCO_3$	98.17	$MgCO_3$	1.44	Insol. Res.	0.51

A sample of the 'Charlestown Green Limestone from Bishop Hill, however, was dolomitic.

The Blackhall Limestone, and its equivalent, the *Petershill* of Bathgate, the *North Greens* of Mid and East Lothian and the *Charlestown Main* of Fife, constitute a well marked calcareous horizon.

The Petershill Limestone is not of outstanding quality. An analysis gave as follows: $CaCO_3$ 85.20; $MgCO_3$ 1.92; SiO_2 10.45; Al_2O_3 0.95; Fe_2O_3 0.77.

The North Greens Limestone seems from the available analyses to be good in many places. The following range is given by samples from Macbiehill in Peeblesshire and from Cousland, D'Arcy, Middleton and Temple in Midlothian ((SL 23) [NT 184 519], (SL 41) [NT 356 583], (SL 42) [NT 353 575], (SL 55) [NT 3799 6236], (SL 59) [NT 3761 6865], (SL 61), (SL 62) [NT 4702 6766], SL 81): $CaCO_3$ 86.95 to 95.36; $MgCO_3$ 1.26 to 4.14, but nearly always under 2 per cent.; Insol. Res. 2.53 to 8.72. Some other analyses, from particular bands in the North Greens, show much inferior material.

The Charlestown Main Limestone, which has been largely worked both in central and east Fife, shows a variable analysis. The following range is typical ((SL 9) [NT 0926 9286], (SL 10) [NT 252 939], (SL 48) [NO 344 086], (SL 49) [NO 344 080], SL 98, (SL 225) [NT 0633 8385], (SL 226) [NT 091 932], (SL 231) [NO 1854 0370]): $CaCO_3$ 69.32 to 96.61; $MgCO_3$ 0.79 to 7.41; Insol. Res. 1.14 to 30.02.

On the other hand, where account has been taken of the variations in composition between different beds of the limestone, it is found that the lowest post of the Charlestown Main in the Kirkcaldy and Cupar areas is dolomite and that the higher posts are limestone. Again, in the Charlestown area there is extensive dolomitization near faulting. The following analyses illustrate these points:

N. end of face, Charlestown (SL 224) [NT 0656 8423]	$CaCO_3$	54.03	$MgCO_3$	41.10	Insol. Res.	2.19
Bottom 3 ft., Seafield Tower (SL 280) [NT 2794 8853]	$CaCO_3$	49.95	$MgCO_3$	37.85	Insol. Res.	2.50

The lowest 1½ ft. of the limestone at Cults is a high-grade dolomite, showing 53.8 per cent. $CaCO_3$, whilst the average of the rest of the stone shows 97.55 per cent. $CaCO_3$.

Petrographic examination of the Charlestown Main Limestone at Chapel Quarries (SL 10) [NT 252 939] disclosed the presence of a considerable amount of boron in the form of datolite (calcium boro-silicate), particularly in the lowest 10 to 15 ft. of the limestone. Analysis showed percentages of B_2O_3 varying from 0.0015 to 2.00. This compares with an average of about 0.001 per cent. B_2O_3 in estimations made on a dozen other limestones from various parts of the country. A thick quartz-dolerite sill lies immediately below the limestone, and there appears little doubt that the boron mineral has been derived from the intrusion.

The Bilston Burn Limestone of Midlothian is worked at Esperston, where it shows high quality throughout its main thickness of 20 ft. An analysis (SL 43) [NT 345 573] gave $CaCO_3$ 95.14; $MgCO_3$ 1.83; Insol. Res. 2.69. The top 3 ft., however, are ferro-dolomitic, showing as follows (SL 44) [NT 345 573]: $CaCO_3$ 50.78; $MgCO_3$ 32.17; $FeCO_2$ 7.62; Insol. Res. 5.97. The Bilston Burn is also dolomitic in a sample from Deepsykehead, near Carlops, in Peeblesshire (SL 22) [NT 182 541]: $CaCO_3$ 40.18; $MgCO_3$ 25.30; $FeCO_3$ 6.44; Insol. Res. 24.70.

Upper Limestone Group: The Index Limestone shows the following very variable figures in analyses from Ayrshire:

New Cumnock (SL 95) [NS 633 125]	$CaCO_3$	51.83	$MgCO_3$	29.42	Insol. Res.	6.98		
Patna (SL 150) [NS 431 081]	$CaCO_3$	54.34	$MgCO_3$	5.02	Insol. Res.	26.20	$FeCO_3$	9.97
Kilwinning(SL 196) [NS 3190 4477]	$CaCO_3$	84.77	$MgCO_3$	4.20	Insol. Res.	6.55		

The Lyoncross (Keirs) and the *Orchard (Lower Linn)* are not of good quality in the single analysis of each available:

Keirs Limestone, Patna (SL 151) [NS 435 078]	$CaCO_3$	73.73	$MgCO_3$	2.79	Insol. Res.	20.20
Lower Linn Limestone, Dalry (SL 112) [NS 2869 4863]	$CaCO_3$	31.75	$MgCO_3$	1.03	Insol. Res.	57.80

The Calmy Limestone is not usually of great purity. The following range is shown in analyses from Dalry, Cumnock and Muirkirk in Ayrshire and Nitshill in Renfrewshire ((SL 92) [NS 5820 1600], (SL 111) [NS 2842 4855], (SL 113) [NS 686 258], (SL 140) [NS 524 586], (SL 141) [NS 524 586]): $CaCO_3$ 69.05 to 89.48; $MgCO_3$ 1.26 to 5.02; Insol. Res. 8.29 to 23.99.

Where worked at Darnley (Nitshill) it is found to be a good cement limestone. Two analyses showed as follows:

Top Post (SL 140) [NS 524 586]	$CaCO_3$	69.05	$MgCO_3$	5.02	SiO_2	19.17	Al_2O_3	2.55	$FeO+Fe_2O_3$	1.49
Middle and Bottom Posts (SL 141) [NS 524 586]	$CaCO_3$	72.30	$MgCO_3$	3.11	SiO_2	22.34	Al_2O_3	1.64	$FeO+Fe_2O_3$	1.14

The equivalent of the Calmy in Lanarkshire (the Gair) and in Fife (the Jenny Pate) is magnesian. The analysis of this limestone from Auchenheath is provided by Messrs. Colvilles, Ltd. The insoluble residue in this case is a summation of the figures for SiO_2, Al_2O_3, FeO and Fe_2O_3.

Gair Limestone, Auchenheath	$CaCO_3$	50.36	$MgCO_3$	32.63	Insol. Res.	14.80
Jenny Pate Limestone, Saline (SL 117) [NT 0046 9340]	$CaCO_3$	41.38	$MgCO_3$	25.23	Insol. Res.	20.10
Jenny Pate Limestone, Culross (SL 119) [NS 9840 8585]	$CaCO_3$	48.56	$MgCO_3$	24.61	Insol. Res.	13.35

The Castlecary Limestone at Castlecary is represented by an old analysis (Hinxman, 1917, p. 25): $CaCO_3$ 87.36; $MgCO_3$ 3.35; SiO_2 4.53; Al_2O_3 1.74; Fe_2O_3 1.35; MnO 0.10. Analyses from old workings in Fife and Clackmannan show it to be a highly magnesian limestone in these areas. Samples from Dollar (SL 7) [NS 9879 9829], Culross (SL 120) [NS 9722 8572] and Largo (SL 36) [NO 4008 0437] show the following range: $CaCO_3$ 47.13 to 51.76; $MgCO_3$ 32.16 to 37.45; Insol. Res. 4.92 to 11.95. The sample from Dollar was calculated to contain 9.02 per cent. $FeCO_3$.

Jurassic

In east Sutherland the Jurassic limestones are sandy:

Brora (SL 161) [NC 915 041]	$CaCO_3$	69.10	$MgCO_3$	1.83	Insol. Res.	25.68
Portgower (SL 162) [ND 004 127]	$CaCO_3$	60.87	$MgCO_3$	0.78	Insol. Res.	36.64

In north-west Argyll, Skye and Wester Ross samples selected from promising outcrops are of better quality, though the beds as a whole are sandy. The following may be considered typical:

Lias:						
Loch Aline (SL 89) [NM 6928 4597]	$CaCO_3$	90.05	$MgCO_3$	1.53	Insol. Res.	6.10
Sconser (SL 242) [NG 512 315]	$CaCO_3$	91.31	$MgCO_3$	1.42	Insol. Res.	6.15

Broadford-Heast (SL 250) [NG 645 210]	$CaCO_3$	89.06	$MgCO_3$	1.40	Insol. Res.	8.33
Applecross (SL 253) [NG 727 447]	$CaCO_3$	93.96	$MgCO_3$	2.09	Insol. Res.	2.89

Great Estuarine Series:

Paludina Limestone, Elgol (SL 251) [NG 516 144]: $CaCO_3$ 74.64; $MgCO_3$ 1.95; Insol. Res. 20.69

Strollamus (SL 243): CaO 40.57; MgO 0.30; CO, 11.22; Insol. Res. 40.55 This latter is a contact-altered limestone, high in calc-silicate content.

Cretaceous

The only Cretaceous limestone analysed is marble near a granite intrusion at Strollamus in Skye (SL 244) [NG 5975 2620]. It showed $CaCO_3$ 93.33; $MgCO_3$ 0.50; Insol. Res. 5.03.

Recent

Shell sand and lake marl are mainly low in magnesia. The John o' Groat's sand ((SL 164) [ND 385 735], (SL 165) [ND 38939 73810]) showed as follows:

(SL 164) [ND 385 735]	$CaCO_3$	93.11	$MgCO_3$	1.80	Insol. Res.	2.53
(SL 165) [ND 38939 73810]	$CaCO_3$	95.45	$MgCO_3$	0.86	Insol. Res.	1.03

A shell sand from a recently opened working for agricultural needs at Chesterhill, East Fife (SL 268), gave 69.7 per cent. $CaCO_3$.

Lake marl is very variable in composition. One from Loch Watten in Caithness (SL 168) [ND 07 64] gave, on an oven-dry sample,. $CaCO_3$ 59.41; $MgCO_3$ 0.61; Insol. Res. 33.90. Analyses from other deposits show much higher percentages of calcium carbonate, up to an average of 89.94 in the case of marl from a drained loch at Westfield near Thurso.

The following figures were obtained from a sample of calcareous tufa at Tornapress, Wester Ross (SL 254) [NG 836 415]: $CaCO_3$ 90.63; $MgCO_3$ 3.22; Insol. Res. 3.00.

Dolomitic Fault-Breccia

Dolomitic fault-breccia is found in the zone of the Highland Boundary Fault at Balmaha (Loch Lomond), Aberfoyle and Stonehaven; it is on the whole of poor quality. The Balmaha analysis is by Mr. C. O. Harvey (Geol. Surv. Lab. No. 1343). That of the Aberfoyle material has been provided by Messrs. Colvilles, Ltd.

Balmaha	$CaCO_3$	5.0	MgO	12.4	SiO_2 Al_2O_3 & FeO	46.3
Aberfoyle	$CaCO_3$	17.56	MgO	10.60	SiO_2 Al_2O_3 & FeO	48.04
Stonehaven (SL 25) [NO 8896 8757]	$CaCO_3$	15.03	MgO	7.00	Insol. Res.	46.61

Calcite Veins

In the one case for which analyses are available the quality is high, but the material is in general rather high in iron as seen in the field. It is a vein-calcite from the Ochil Hills, Menstrie, and shows as follows: $CaCO_3$ 98.20 and 96.34; $MgCO_3$ 1.26 and 0.76; SiO_2 0.40 and 0.20; Al_2O_3 0·34 and 0.60; FeO 0.36 and trace. The analyses are by Messrs. Colvilles, Ltd.

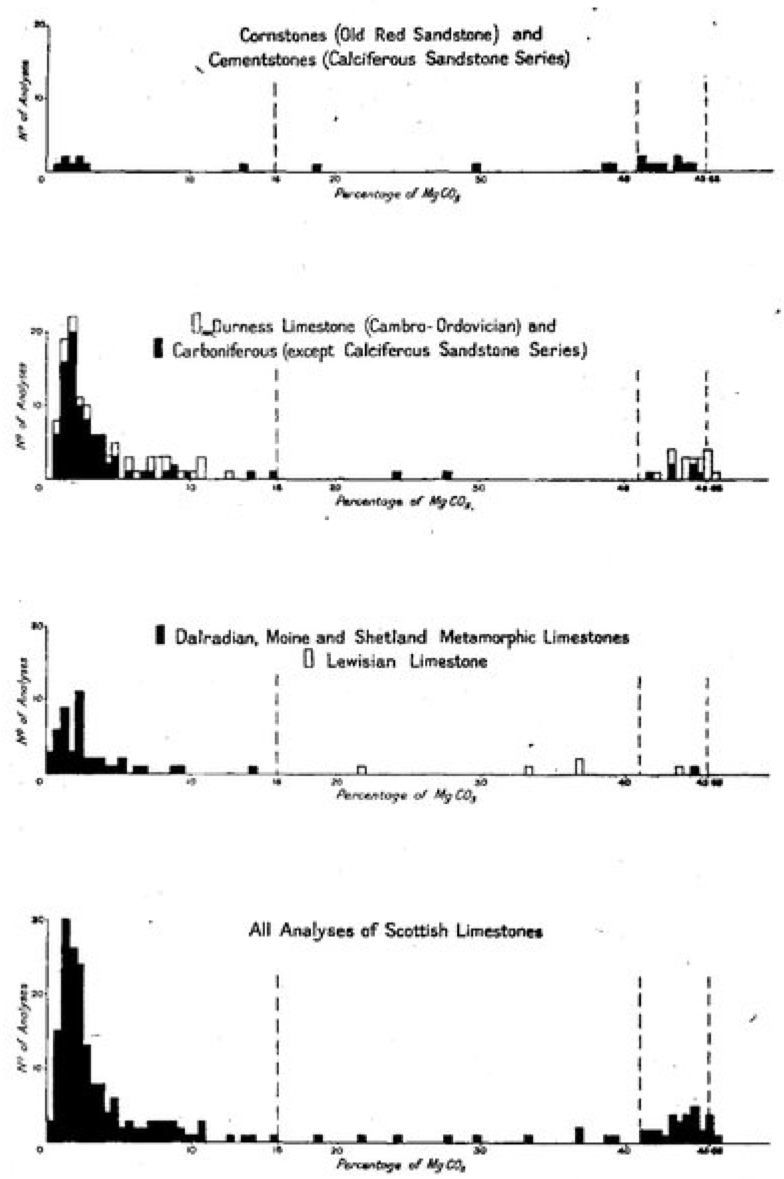

Figure 1 Histograms showing percentages of magnesium carbonate in analysed Scottish limestones.