schungskorrosion, die beim Vermischen verschieden temperierter Wässer auftritt. Beim Abkühlen wird weiterhin CO_2 frei, was zur Korrosion führt: Abkühlungskorrosion. Durch diese vier Korrosionsmöglichkeiten wird der ganze verkarstungsfähige Raum in Karbonatgesteinen in seinem Werden zu einer Ganzheit zusammengeschlossen.

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SOME FACTORS IN THE ABSOLUTE DENUDATION OF LIMESTONE TERRAINS

With 1 photo and 6 figures

M. M. SWEETING

We are indebted to CORBEL for bringing our attention to the mean rates of erosion of limestone areas and particularly for stressing the variations dependent upon temperature differences (1). It is quite clear however that solution rates in limestones are dependent upon many factors, of which temperature is only one. Hence CORBEL's figures though useful are not a true guide to the real rates of solution which may be occurring in a given area. This contribution seeks to point out some of the other factors.

If the rates for the mean, maximum and minimum rates of chemical erosion for various rivers are examined it will be seen that these figures are extremely variable.

Table (Figures supplied by I. DOUGLAS,
Ballioc College, Oxford [2])
Rates of chemical denudation m³/km²/year

River	Mean	Maximum	Minimum
Thames (Teddington)	104,0	288,0	12,87
Derwent (Matlock Bath)		197,4	65,92
Kentucky (U. S. A.)	63,75	297,0	3,44
Lee (Essex)	63,36	155,0	23,05
Kissimmee (Florida)	26,94	63,04	15,90

Such values are therefore probably only a rough guide to the range of intensity of chemical denudation. It is also difficult to be sure that the mean figures give a realistic picture of chemical denudation in a limestone area. There is therefore a need for the systematic observation and analysis of limestone waters and springs in order to isolate the factors which may be causing the variations. With this aim in mind a series of observations of springs and waters in many parts of the British Isles has been started. The preliminary results show that in a small region such as the British Isles, quite significant variations in solution rates may be observed.

In N. W. England, the area best known to the writer, the figures given for the Malham Tarn waters in fig. 1 are fairly typical for the limestone solubility of the springs and waters of the district. The calcium content in general varies inversely with the discharge. The average calcium content of waters varies from about 140-180 p. p. m. The figures when plotted on to the curves of TROMBE, show that the waters are more or less in equilibrium or only slightly aggressive (fig. 2). The values for a dry period and for the summer months
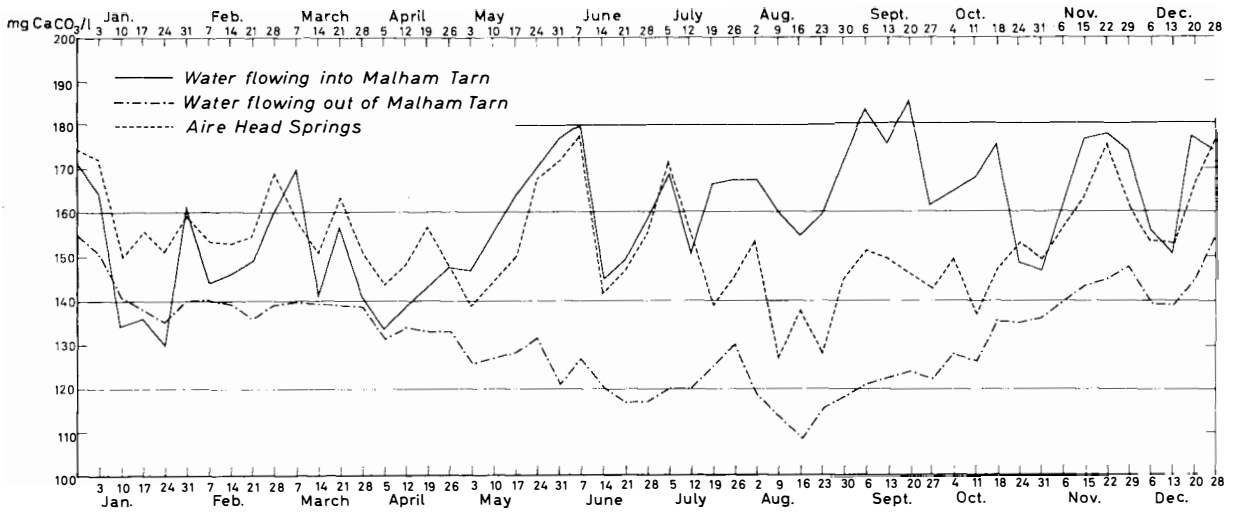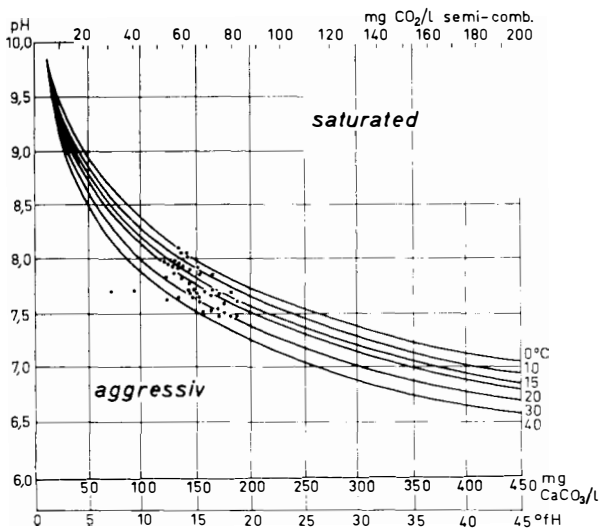
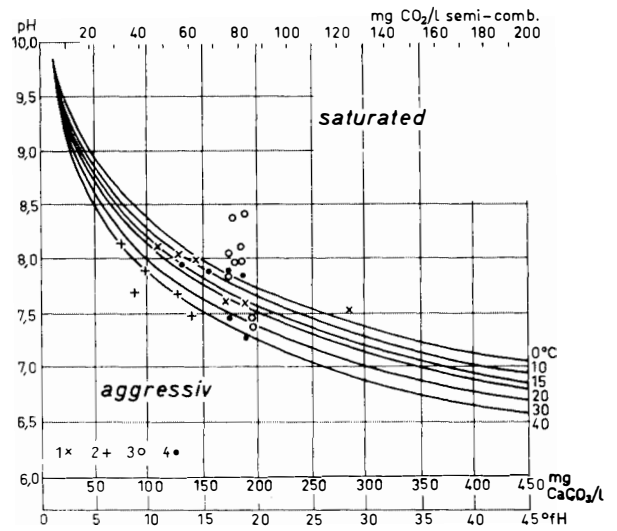Fig. 1: Calcium content of the Malham Tarn waters

Fig. 2: Malham Tarn System

Fig. 3: N. W. England

1 Limestone waters in summer
2 Limestone waters in winter
3 Inflow to Malham Tarn (N. W. Yorks.)
4 Great Close Springe (N. W. Yorks.)

are relatively saturated, those for a wet period and for winter being more aggressive (fig. 3).

Examination of the calcium content of pools and pans at selected periods after rain shows that the calcium is taken up relatively quickly after rain: the waters contain 120-140 p. p. m. after a short interval of time or after having flowed for only a few metres upon the bare rock. Subsequently relatively little calcium is picked up. Figure 4 shows the relationship of dissolved total hardness ($MgCO_3 + CaCO_3$) to the dissolved $CaCO_3$, and shows that this is a straight-forward connection.

If these figures for N. W. England are used in conjunction with CORBEL's formula, then the average lowering of the surface by chemical denudation per kilometre square is of the order of 0.04 mm. per year (1). The amount of lowering since the end of the last phase of the Quaternary Ice Age should then be of the order of 40–50 cm. The pedestals of the well-known Norber boulders in N.W. Yorkshire fit in very well with this type of calculation (photo), and support the idea of a general lowering of this amount in Northern England, since the Quaternary (3). In several other
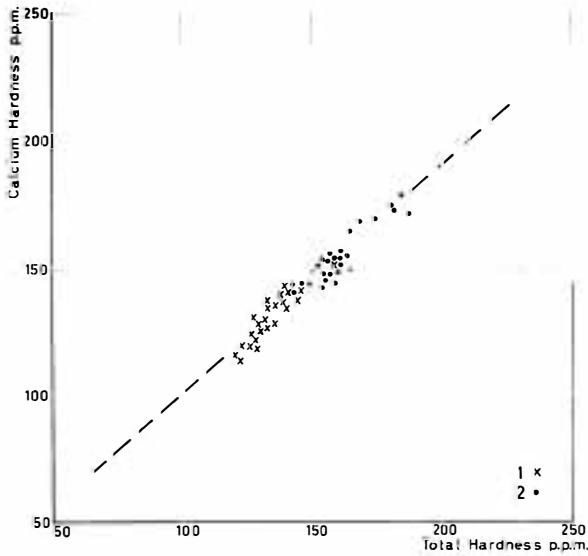
Fig. 4: Malham Area (N. W. Yorks.)

Photo 1: Pedestal of the Norber boulders
in N. W. Yorkshire

localities in Northern England similar limestone pedestals can be found. Locally, solution rates, may be relatively greater, particularly where favourable conditions occur.

In the Southern Pennines, only a 100 kilometres or so south of the areas just considered, PIGGOTT has produced evidence for a very similar rate of lowering of the limestone surface since the end of the Quaternary (4). In N. W. England the limestone was glaciated during the period of the Newer Drift, whereas the limestone of the Southern Pennines is believed to have remained ice free. As a result much of the limestone of N. W. England is made up of bare pavements, while that in the Southern area is grass covered. This fact may in part explain the much higher figures for the amount of calcium in the waters of the Southern Pennines, about 230-250 p. p. m.; such figures if plotted on TROMBE's curves show that the waters are saturated (fig. 5).

The Mendip Hills in South West England also form limestone terrain and many thousands of measurements of the calcium content of the waters have been made by members of Bristol University (5). The figures for the springs in the Mendip area are in general very consistent, averaging about 220-240 p. p. m. These results are explained by SMITH and MEAD as due to the great concentration of soil CO_2 consequent upon a complete grass cover. A further point made by these two authors concerns the importance of the length of time the limestone has been in contact with the waters and the depth of penetration of those waters; the greatest concentrations of calcium seem to occur in those springs and waters which have been in contact longest with the limestones (5). Hence the lower and deeper the percolation, the greater the solution and the actual chemical denudation, a result which might be inverse to the rates of mechanical denudation.

Other observations in the British Isles are given below:

	Calcium content
Cambrian Limestones, Durness, N. Scotland	60- 80 p. p. m.
Carboniferous Limestones, S. Wales	80-100 p. p. m.
Carboniferous Limestones, Clare, W. Ireland	120-134 p. p. m.
Jurassic Limestones, Cotswolds	290 p. p. m.
Chalk of Southern England	280-300 p. p. m.

These results thus indicate that amounts of calcium picked up by percolating waters are not dependent upon temperature variations and that lithology and nature of the vegetation must also be taken into account.

Returning to CORBEL's graphs in his 1959 paper, it would seem that they refer to potential agressivity and saturation of the waters rather than to actual solution rates. Individual variations in the calcium content of waters occur from place to place but no systematic variation on a world scale such as suggested by CORBEL can be shown to exist. This can be seen from the following figures:

	Calcium content
Cockpit Country, Jamaica	214 p. p. m.
Cyrenaica, North Africa	139-200 p. p. m.
Yugoslavia, Dinaric Coast	140-150 p. p. m.
N. W. Australia, Fitzroy Area	200 p. p. m.

These figures should be compared with those obtained from areas in the British Isles. Figure 6, compares the results of two districts in southern Australia, (New South Wales), this shows that while the aggressivity of the waters may be greater in the cooler region, the rate of actual limestone solution is greater in the warmer region.
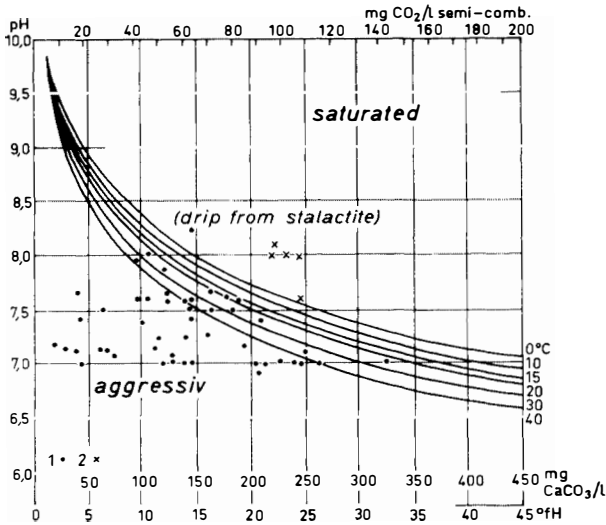
Fig. 5: 1 Mendips: Runding streams and risings
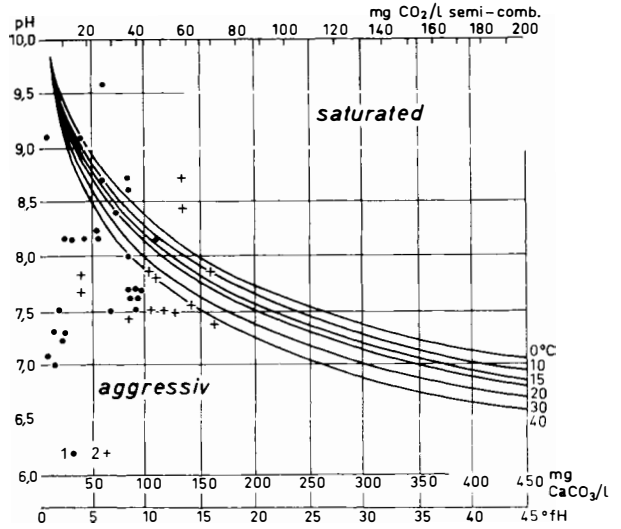2 Central Peak District, S. Pennines

Fig. 6: New South Wales (Australia)
1 Coolaman Plain (1330 m. above S. L., 1200 mm rainfall, 12° C. mean annual temp.)
2 Jenolan (800 m. above S. L., 800 mm rainfall, 16° C. mean annual temp.)
(from observations by J. N. Jennings)

Thus a brief review of the results now coming to light suggest that temperature is not a major factor in the dissolution of limestones. There is almost invariably a correlation between the log. of the discharge and the calcium hardness of waters; despite this maximum chemical denudation is most likely to occur at or near maximum discharge, due to the large volumes of water involved. Recent work suggests that non-climatic factors (lithology and structure of the limestones, depth and length of time of percolation) more than compensate for any variation due to temperature. Furthermore, the importance of soil CO_2 as a result of a vegetation cover has been completely ignored in hypotheses based solely on temperature variations. Such a situation has been for many years recognized by geographers and geologists — long before the somewhat misleading attempts which have been made recently to over-simplify a very complex problem. It also illustrated the need to tackle the problem in a completely different manner.

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KALKABTRAGUNGSMESSUNGEN IN DEN ÖSTERREICHISCHEN KALKHOCHALPEN

Mit 4 Abbildungen und 2 Tabellen

FRIDTJOF BAUER

Eines der wesentlichsten Merkmale eines Karstgebietes ist die dauernde Umgestaltung seiner Oberfläche durch die karbonatlösende Wirkung CO_2-haltiger Niederschlagswässer. Diese kontinuierliche, auch unter Bodenbedeckung vor sich gehende Veränderung der Gesteinsoberfläche schafft laufend neue Voraussetzungen für die Entwicklung der überlagernden Böden und der Struktur der Vegetation, wie auch für Mikroklima und Oberflächenwasserhaushalt. Die Frage nach der Geschwindigkeit des Karbonatgesteinsabtrages muß daher im Rahmen eines Karstforschungspro-