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A GEOCHEMICAL CYCLING STUDY IN AN UPLAND GRASSLAND CATCHMENT: AN INTRODUCTION TO THE PROJECT

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PREFACE

As work has progressed on the project outlined in the following pages it has become apparent that it would be useful if we circulated short papers on methods, sampling devices, developmental studies and interim assessments of data to colleagues in ITE and to collaborators in other NERC institutes and in universities. We have therefore decided to issue a series of such papers/reports as part of the Bangor Research Station Occasional Paper series and the first five are now in preparation and will appear shortly. The following note is intended to provide a general introduction to the project as a background to these papers.

INTRODUCTION

In 1978, as a result of recommendations from the Advisory Board for Research Councils (ABRC), the Natural Environment Research Council (NERC) initiated special programmes of research in four areas with particular emphasis on collaborative work between NERC Institutes and Universities. The areas of research were (i) geochemical cycling, (ii) environmental radio-activity, (iii) ecology of viruses in relation to their hosts, and (iv) deep geology. ITE Project 594 covers the ITE input to a group of projects funded under the geochemical cycling programme and involving ITE, the Institute of Geological Sciences (IGS), the Institute of Hydrology (IH) and the University College of North Wales (UCNW), Bangor.

DEVELOPMENT OF THE PROJECT

Following the recommendations of the ABRC, working groups were set up by NERC to consider research proposals under each of the four special programmes. Preliminary discussions between staff from ITE and IGS identified mineral weathering as an area with opportunities for increased research input and with considerable overlap of interest between the two Institutes. As a result of meetings of the Geochemical Cycling working group IGS and ITE staff were asked to formulate a joint programme of work covering some aspects of mineral weathering and the link between bedrock, soil and freshwater in the geochemical cycle.

There is a voluminous literature covering this broad field which utilises a variety of techniques and approaches. Thus there are investigations on the mechanisms of weathering of individual mineral species, e.g. albite feldspar (Holdren and Berner 1979), potassium micas (e.g. Norish 1973), the release of ions during decomposition of single minerals by mineral and organic acids (e.g. Ross 1969, Huang and Keller 1972, and Tan 1980); the rate of weight loss of rock specimens

exposed at the soil surface (Caine 1978) or buried within the soil (Trudgill 1975); the weathering of exposed in situ rock faces (Pearce 1976, Abrahamsen et al 1979), the laboratory weathering of rock material (Henin and Pedro 1965), the experimental attack of bulk soil samples using sequential extraction (McLaren and Crawford 1973), reflux systems (Singleton and Lavkulich 1978) or progressive leaching (Thompson et al 1977), the study of the secondary mineral products of weathering (Basham 1974, Harrison 1934, Hatton 1978), pedogenetic studies of individual soil types (Adams, Evans and Abdulla 1971, Nørnberg 1980), the experimental simulation of pedogenic processes (Adams and Boyle 1979 Bower 1970), the investigation of solution chemistry of soils using lysimeters (Singer et al 1978, Upchurch et al 1973), the study of drainage waters and catchment studies (Perrin 1965, Routson et al 1977, Johnson et al 1978, Waylen 1979) and the investigation of geochemical and biogeochemical cycles (Likens et al 1977, Fredriksen 1972).

Examination of this literature reveals few studies in which several of these alternative approaches and techniques have been linked in the investigation of the minerals, rocks, soils and drainage waters of a given area or experimental site. There is also a paucity of data on rates of weathering in the soil environment and the subsequent rates of release of major nutrient ions and the extent to which this release through weathering contributes to the nutrient budget of the related vegetation and to elemental export from soils into freshwaters.

It was decided therefore to initiate a group of projects which would, (a) utilise a number of the approaches noted above in parallel but linked investigations of a particular area and (b) place a high priority on the determination of rates of weathering, release and transfers. The projects would aim to link catchment scale work with studies on single soil profiles, samples from individual horizons and

mineral separates; field based work with laboratory studies; and observational investigations with experimentation and manipulation.

A first or second order stream catchment with uniform underlying bedrock and a limited range of soils was seen as an ideal focus and unifying link for the projects. It was further considered that the work would have wider relevance if the catchment was on a widespread rock type, preferably within the uplands. Secondary catchments on differing parent materials could be usefully examined on a less intensive basis to test and expand principles developed on the main site.

The overall objectives of the study were eventually formulated as follows:-

1 To determine the rate of breakdown of bedrock and of selected minerals and the consequent release of major nutrient elements and iron, manganese and aluminium into the soils and to determine the major factors controlling release.

2 To determine the rate of movement of elements, released by weathering within the soil profiles and into surface and sub-surface drainage waters and to define the relationships between rate of movement and controlling environmental factors.

3 To determine (a) the relationship between the major and trace element content of bedrock, drift and soil materials and that of stream sediments; (b) the seasonal variations in the chemistry of stream sediments and the factors controlling these variations.

While some overlap was seen as inevitable and desirable, investigations of the three objectives would be divided between UCNW, ITE and IGS respectively.

SITE SELECTION

Main site

The Institute of Hydrology's experimental catchments at the headwaters of the River Wye in mid-Wales (usually referred to as the Plynlimon catchments) were chosen as the main site for the project. The catchments are underlain by Lower Palaeozoic mudstones and shales, rocks which are widespread in the uplands of Britain (occurring in Wales, the Southern Uplands of Scotland and the margins of the Lake District) and are free from extraneous drift deposits. The catchments are the most intensively instrumented in Britain and have been studied for the past twelve years; as a result there is a large volume of meteorological and hydrological data plus some information on geology, soils, vegetation and land use history (Newson 1976). The catchments are close enough to the ITE Research Station at Bangor to make regular sampling feasible on a day visit basis. The Institute of Hydrology maintains a permanent laboratory adjacent to the site and the resident staff provide an enormous fund of expertise and experience. NERC has access/sampling agreements with the landowner which ensure security of sites. Previous pedological and mineralogical research at UCNW and University College, Aberystwyth, on soils and parent materials similar to those occurring in the catchments, also provided a basis for the proposed mineralogical studies. Together these various factors make the Plynlimon catchments an excellent focus for the projects.

Secondary sites

The Lake District was selected as the most suitable area for secondary catchments as it offered a variety of bedrock types, was accessible to the ITE Merlewood Research Station at Grange-Over-Sands and offered the possibility of joint work with the Freshwater Biological Association (FBA).

Specific catchments would be selected following visits to the area. A preliminary short list of six catchments has been identified to date, two on granophyre, two on slate and two on rocks of the Borrowdale Volcanic Series.

Selection of sites within the Wye experimental catchment

The Wye experimental catchment has three gauged tributaries, the Cyff (3.13 km^2), the Gwy (3.98 km^2) and the Nant Iago (1.02 km^2). Examination of the available information on geology, soils and land management, plus reconnaissance surveys soon indicated that these catchments were much too complex as the base for the planned investigation. A subsequent examination of the first and second order streams in each of these catchments indicated that although most of them were also complex a few relatively uniform ones were available. However, the preliminary surveys also revealed interesting variations in land management and bedrock geology between catchments. These variations offered potential additional dimensions to the study and it was decided to alter the emphasis of the work to exploit the variations. Therefore a number of first and second order catchments were included in the study to determine the influence of land improvement and limited variation in geology on weathering and on element release and transfers.

To facilitate selection of the catchments to be studied all the first and second order were categorized on the basis of geology and land management. Three geological formations, of Ordovician and Silurian age dominate the solid geology of the Wye experimental catchments:

1 Frongoch formation - shales and mudstones with some thin sandstone or siltstone bands.

2 Gwestyn formation - shale and mudstones with some siltstones and impure limestone bands.

3 Van formation, Upper - soft blue shales and bronze weathering mudstones.
Lower - massive grits, mudstones and conglomerates.

In addition, mineral veins occur discontinuously in all three formations with the location of the major veins marked by evidence of past mining activity.

The catchments were allocated on the basis of their formation, their lithology (if possible) and the presence or absence of known mineralization. Catchments crossing known boundaries between formations and/or lithologies or with known mineral veins were rejected.

The remaining catchments were then separated on the basis of land management. Although there have been several phases of land improvement using a variety of techniques, the only practical division at this stage was into catchments which had been improved and those which had not.

A subdivision of catchments on the basis of soils was not used at this stage as preliminary examinations indicated a similar range of soils and comparable complexity in most catchments.

Five catchments were eventually selected, three on mudstones of the Frongoch formation - two unimproved and one improved and two on the shales of the Gwestyn formation - one improved and one unimproved. Although each contained a variety of soil types the dominant soil in all five catchments is a stagnopodzol and it was decided that the soil studies would initially be concentrated on this soil type in each catchment. Two unimproved catchments were selected on the Frongoch formation in the hope that areas of one of them could be experimentally manipulated at some future date.

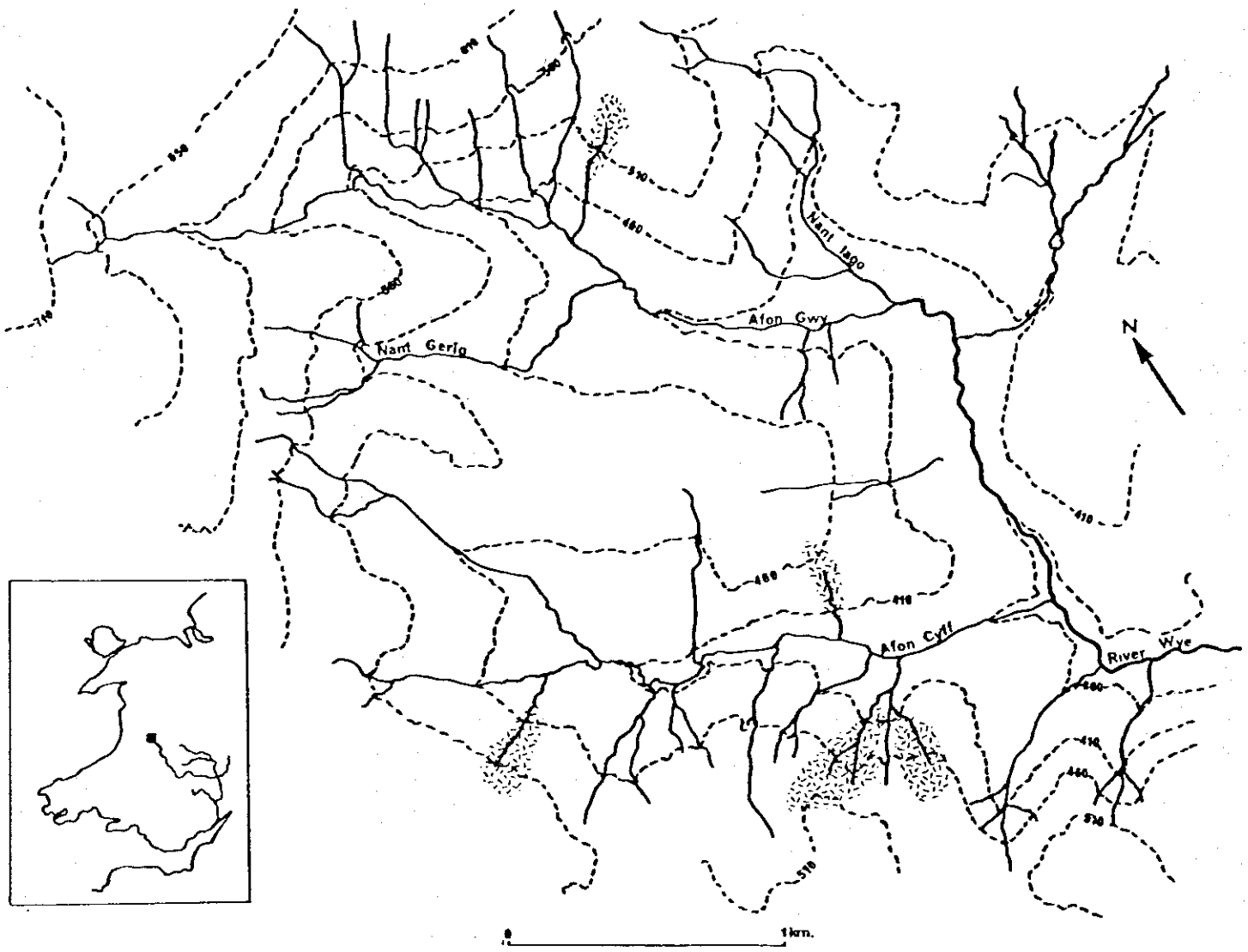

Figure 1 The location of the study areas (hatched) within the Wye experimental catchments. Inset shows the location of the Plynlimon experimental catchments within Wales.
(Contour heights are in metres).

The experimental streams and catchments are not named but their location is indicated on figure 1.

THE ITE PROJECT

Structure and Objectives

The ITE section of the investigation comprised three parts from a relatively early stage in the development of the project:

1 Determination of overall rates of weathering as indicated by elemental budgets for the study catchments.
2 Investigation of element release and transfers within in situ soil profiles and into surface waters.
3 Simulation of the above releases and transfers in the laboratory followed by determination of the response of release and transfer to experimental manipulation of the conditions.

The objectives of the investigation have now been detailed as follows:

a To monitor seasonal and annual inputs, of the elements being studied to each experimental catchment.
b To define the seasonal and annual export of the elements being studied from each catchment.
c To derive annual and seasonal nutrient budget for each catchment.
d To assess the influence of land management and the variations in bedrock geology on nutrient budgets.
e To develop techniques in the use of various types of soil solution samplers/simple lysimeters.
f To measure the rates and patterns of movement of the elements being studied within in situ profiles of the dominant soils in each catchment.
g To assess the influence of land management on the rates and patterns of movement of elements within soil profiles.

h To determine the major variations in the rate of the movement of the elements being studied from the dominant soils into the streams of each catchment.

i To assess the influence of land management on the transfers into surface water.

j To develop laboratory techniques for simulating nutrient release and transfers within soil profiles.

k To determine, by experimental manipulation, the effect of factors which control rates and patterns of movement of the elements in soils.

l To develop a model for the pedogenesis of the dominant stagnopodzols of the catchments.

Instrumentation, sampling and data collection

(i) Atmospheric inputs of elements to the catchments

Six rainfall collectors have been installed in the Wye catchments with at least one in, or adjacent to, each study catchment. The collectors are located alongside IOH monthly rain-gauges which provide quantitative data on rainfall; data on snowfall in the catchments is obtained from IOH records. Each rainfall collector is emptied weekly while snow samples are collected on an ad hoc basis. Chemical analysis of the samples plus data on precipitation will enable elemental inputs to the catchments in precipitation to be calculated.

(ii) Export of elements from the catchments in streamwaters

Each of the five streams being studied is sampled weekly. Samples are collected at the outlet of each catchment, at one or two points upstream and, if the streams rise in an area of peat, from the peat source. V-notch weirs with linked chart recorders have been installed (by IH staff) on four of the five streams and a flow measuring system is being developed

for the fifth - the stream channel geometry on this stream precludes the use of the weir design used on the other streams. The flow data plus the analytical data from the weekly samples from the catchment outflow will allow us to calculate element export from the catchments. The sampling at points along the stream will provide data on the change in stream water chemistry from source to confluence.

(iii) Bedrock geology influences

Samples of bedrock have been collected from outcrops in each catchment and rock fragments are being separated from C - horizon material of soil samples from stagnopodzols in each catchment. Analytical data from these samples will define the bedrock chemistry of each catchment and the variation between catchments.

(iv) Land management influences

To provide a basis for estimating element transfers due to stock movements from paddock to paddock sheep and cattle numbers are counted in each catchment at the time of the weekly sampling. More intensive counting over short (12 to 24 hours) periods is also beind carried out seasonally.

Inputs (if any) of nutrients to each catchment as winter feed are being monitored during the weekly sampling visits.

In co-operation with the farmer, data is being accumulated on the timing and method of land improvement, including quantifying any fertilizer inputs to the 'improved catchments'.

(v) Soil distribution, chemistry, mineralogy and micromorphology.

Detailed, large scale soil maps are being prepared for each of the experimental catchments. The mapping is based on a grid sampling approach with a spacing of 30 m between observation points. The resulting maps will provide an essential comparison between the catchments but they are also being used as the basis for all subsequent soil sampling.

Horizon based sampling is being carried out from a sample of profiles of each soil type represented in the catchments and will be used for physical and extractable chemical analysis. This will characterize the soils and will provide an assessment of the influence of the variations in land management on the soil chemistry. Sampling of surface horizons will be repeated seasonally for extractable chemical analysis. The resulting data will be examined with seasonal changes in soil solution chemistry.

Bulk samples and undisturbed samples collected in Kubiena tins are being taken from a small subsample of stagnopodzols in each catchment. Extractable and total chemical, physical and mineralogical analyses are being carried out on the bulk samples and thin sections will be prepared from the undisturbed samples. Together these analyses will form the basis of a pedogenetic study.

(vi) Solution chemistry and transfers in <u>in situ</u> profiles

As noted above, the studies on element transfers within soil profiles are at present centred on the stagnopodzols occurring in the study catchments. Two porous cup soil solution samplers have been installed in the Ea, Bs and

C horizon of stagnopodzols in each catchment. These are providing comparative data on the influence of the bedrock and land management variations on soil chemistry. (Additonal sets of porous cup samplers have been installed in two areas of stagnopodzols outside the study catchments but which have been improved at different times to those within the study catchments). Tensionless solution collectors (crude lysimeters) are being placed below each horizon and two different designs are being used. A simple tray like device which will intercept both lateral and vertical water movement, and a pipe based device which will only collect vertically moving water. These samplers are designed to provide quantitative data on the solution transfers. Each sampler is examined weekly and a sample collected weekly if available.

Laboratory investigations of release and transfers

Two approaches are being used in parallel, (a) leaching of soil columns; (b) progressive extraction of soil materials

a Soil Columns

Several alternative designs and sizes of columns have been investigated as the first stage of this work and a system based on 50 mm diameter piping has been developed. At present the columns are being packed with disturbed soil materials but comparative studies with undisturbed cores are planned. Material from each horizon is leached both separately and as part of a complete simulated profile. As a first stage the columns are leached with distilled water, rain-water from Plynlimon and drainage from O horizon. Future planned experiments include the use of complexing agents, increased activity, addition of lime and basic slag to the surface layers and simulation

b Progressive Extraction

Several systems for progressive extraction of soil materials have been reported in the literature and a number of these are being evaluated at present. Early work is being concentrated on a method based on leaching and developed by Mandzak et al (1976).

Sample handling and analysis

The pH of all the stream waters, rainfall, snow and soil water samples is measured at the ITE Bangor Research Station prior to filtering. Following filtering samples are split with analyses for Ca, Mg, Na, K, and NCO_3^- being carried out at Bangor and for Fe, Al, Si, Mn, So_4^-, Cl^-, NO_3^-, P and dissolved organic carbon at the ITE Central Chemical Service and the Merlewood Research Station. Solutions obtained from the laboratory studies on release and transfers are at present being analysed for Na, K, Mg, Ca, Fe, Mn, Al and Si at Bangor.

Extractions of the soil samples are carried out on air dried soil at Bangor; analyses of the extracts for cations are carried out at Bangor and anions at Merlewood. Total soil chemical and bedrock analyses are being carried out by IGS, Grays Inn Road. Mineralogical analyses (microscopic and XRD) and micromorphological work is based in Bangor using facilities at both ITE and UCNW.

(A detailed account of the analytical methods being used will form the basis of a separate Occasional Paper).

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