LANDFORM REPLICATION RESEARCH IN TWO ENGLISH LIMESTONE QUARRIES[1]

by

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Abstract. This paper describes a novel method for the reclamation of quarried limestone rock slopes by 'Landform Replication' which aims to construct a landform/vegetation assemblage which resembles that in the unexcavated landscape around the quarry. The first stage of the technique involves Restoration Blasting, the application of drilling and blasting designs which aim to construct a suite of landforms which replicate the outward form of those on natural limestone slopes and which can be predicted to evolve through the operation of natural processes. The second phase is 'Habitat Reconstruction', which is the application of ecological techniques to establish semi-natural vegetation communities. The technique has been developed in the White Peak of Derbyshire, England, where the limestone outcrop is dissected by valleys (dales) in which the dominant landform assemblage consists of bare and vegetated scree slopes, buttresses and headwalls. The vegetation includes various proportions of grassland/wildflower and woodland community types. The research programme aimed to construct landform/vegetation assemblages which visually resemble and function in a similar way to their semi-natural counterpart.

Introduction

Limestones are an important natural resource. They are exploited extensively and are used mainly for construction purposes as aggregate and for cement but also in significant amounts in the chemical, steel, glass and agricultural industries. As a result, limestone is probably more heavily exploited than any other type of deposit, particularly in highly developed countries (Bradshaw & Chadwick, 1980). For example, during the 1980's annual limestone production in England and Wales rose from c. 80 million tonnes to over 110 million tonnes.

Limestone areas often give rise to very attractive scenery and many National Parks and Areas of Outstanding Natural Beauty owe their designation, at least in part, to their attractive limestone landscapes. Although the mineral wealth of these areas cannot be ignored, there is an

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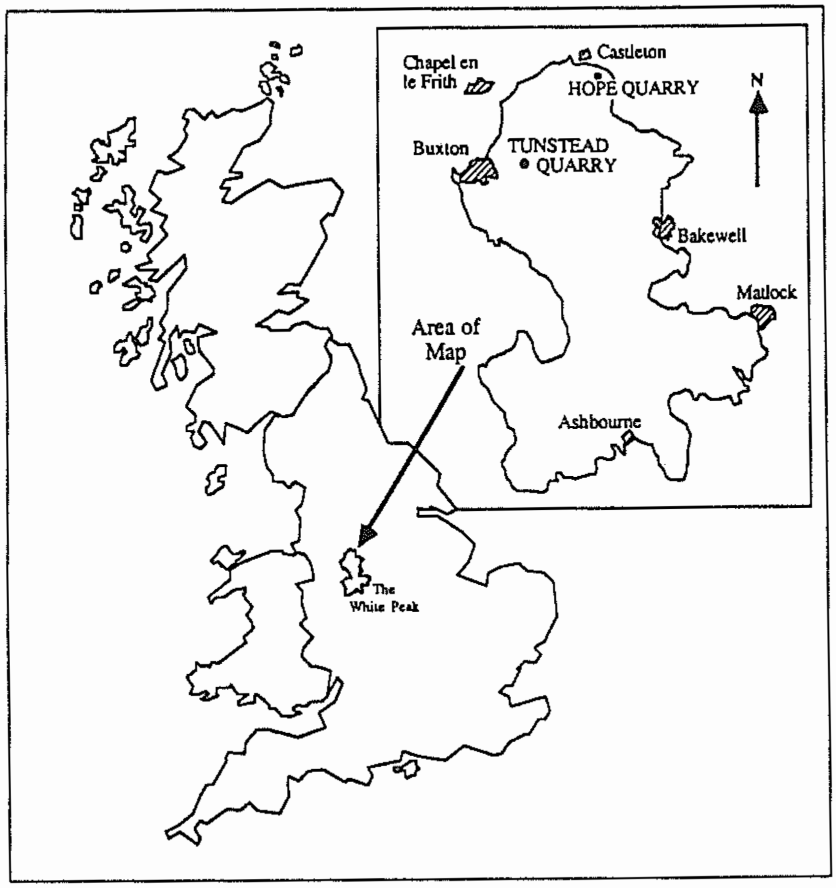

Figure 1 : Location of the research trials which were undertaken at ICI Tunstead Quarry and BCI Hope Quarry in the Derbyshire White Peak, England.

obvious need to balance the demand for, and extraction of, limestone resources with the need to protect and conserve the natural beauty of the countryside.

The open pit mining method commonly used by the limestone extractive industry has often led to a number of environmental impacts (Down & Stocks, 1977). Paramount among these are habitat destruction, visual intrusion and general disturbance to the area. Near vertical quarry faces stand in particularly stark contrast to the surrounding landscape. Other impacts include noise, vibration, air and water pollution and post abandonment dereliction.

The high faces of limestone extractions present some of the most difficult reclamation problems in quarries and existing methods for their rehabilitation are limited (Coppin & Bradshaw, 1982). Methods currently used for their restoration include complete infill of slopes, backfilling slopes, selectively placing fill along lengths of quarry face and 'selectively blasting' the upper portions of the quarry face to produce minor landscape features and create a more shattered and fissured rock face for natural colonisation or deliberate vegetation establishment (Coppin & Bradshaw, 1982; Bailey & Gunn, 1991).

In response to the need for practical, visually and technically acceptable and economic technique's for the reclamation and long-term stability of large-scale quarry faces, the Minerals and Land Reclamation Division of the Department of the Environment commissioned a research programme entitled 'Landform Replication as a Technique for the Reclamation of Limestone Quarries' in the Spring of 1988. The research project, is to continue until March 1993 and forms part of the DOE's Geological and Minerals Planning Research Programme.

The research is being undertaken in the Derbyshire White Peak, England, which is the largest limestone producing region in the United Kingdom. Choice of region was partly logistical because of easy access from Manchester and partly because of the active encouragement received from the mineral planning authorities (Derbyshire County Council and Peak Park Joint Planning Board). Suitable quarry sites for blasting and revegetation trials together with technical and financial support was provided by ICI Chemicals and Polymers Limited and Blue Circle Industries Plc. The trials were undertaken at ICI's Tunstead Quarry and BCI's Hope Quarry (Figure 1).

Landform Replication

Landform Replication aims to construct, on the margins of abandoned limestone quarries, a landform/vegetation assemblage which resembles that in the unexcavated landscape around the quarry. The technique requires the application of a series of geo-engineering and ecological restoration strategies. The first stage involves Restoration Blasting, the application of drilling and blasting designs which aim to construct a suite of landforms which replicate the outward form of those on natural limestone slopes and which can be predicted to evolve through the operation of natural processes (Gagen & Gunn, 1988, Gagen et al, 1992). In the White Peak of Derbyshire, England, the limestone outcrop is dissected by valleys (dales) in which the dominant landform assemblage consists of bare and vegetated scree slopes, buttresses and headwalls (Figure 2). It is these landforms that the research trials aimed to replicate (Bailey et al, 1992[a]). It is believed that the development of a fully functioning ecosystem through natural colonisation on the landforms produced by restoration blasting would take many hundreds of years so the second phase of Landform Replication is 'Habitat Reconstruction', which is the application of ecological techniques to 'establish semi-natural vegetation communities which in some way resemble the semi-natural original' (Buckley, 1989, page 1). The daleside grasslands of conservation value in the White Peak comprise a rich and intimate mixture of grasses and herbs in a continuous closed sward and are generally classified as Festuca ovina (Sheeps Fescue) - Avenula pratensis (Meadow Oat Grass) grasslands with a sub-community which includes the moss Dicranum scoparium. The daleside woodlands are mainly uneven aged Fraxinus excelsior (Ash) woods which grow on shallow, well and excessively drained soil directly over bedrock. Acer pseudoplatanus (the English Sycamore) has also become increasingly common in the Derbyshire Dales. It was the aim of the research programme to reconstruct a limestone grassland/woodland community similar to the original habitat type (Bailey et al, 1992[b]).

Landform Replication is an inter-disciplinary approach to the reclamation of limestone quarries. In order for the technique to be effective it requires an informed understanding of both natural and excavated limestone rock slopes and the ecosystems which they support. The approach adopted in this project was to examine both the geomorphology and ecology of the unexcavated landscape surrounding the quarry and the geology, geomorphology and the effects of previous production blasting on the quarry margins to be reclaimed. Laboratory and field planting trials supported by physical and chemical analyses were then undertaken on a number of crushed limestone materials which were considered to be potential seed bed mediums (Bailey et al, 1992[b]; Gagen et al, 1992).

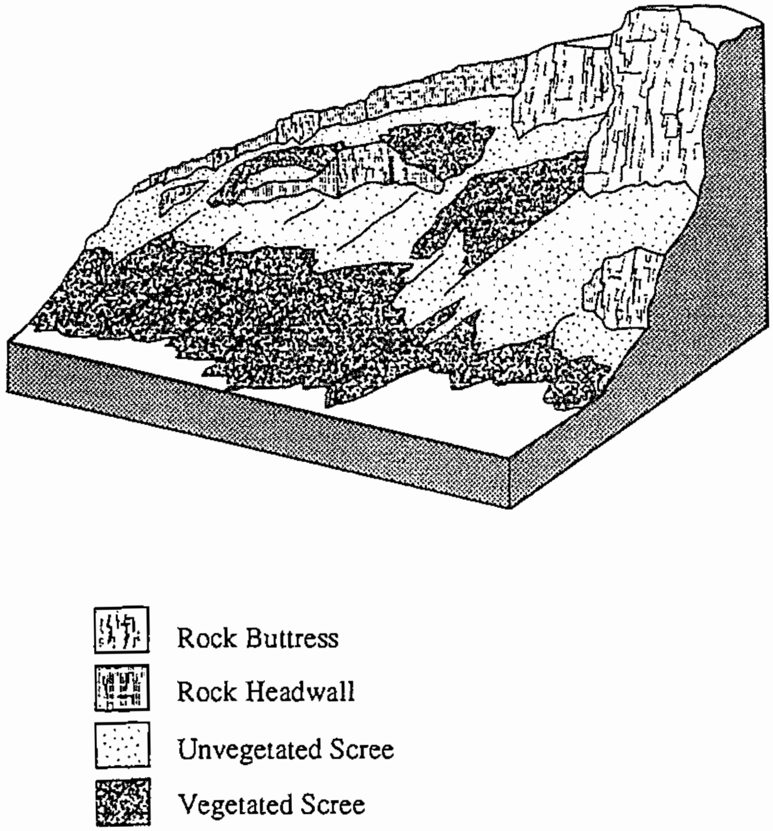

Figure 2 : Principal macro-scale daleside landforms of the Derbyshire White Peak, England.

Restoration Blasting

Initial research on the geomorphological evolution of quarried limestone rock slopes led to the development of a theory for the construction of rock landforms by restoration blasting (Gagen,1988). Restoration blasting is a controlled blasting technique which aims to minimise overbreak and excavate a stable rock face within the confines of a defined excavation area. Blasting technology and engineering practice are used to re-profile the quarried rock face in response to geological conditions, the effects of previous production blasting and changes arising from weathering and erosion. Attention is focused upon achieving a balance between the safe and effective construction of appropriate and stable landforms, whilst control is exercised over the form and character of the rock pile through the combined effect of blast geometry, explosives loading and the sequencing and timing of the restoration blast (Gagen et al, 1992, Figure 3).

A major objective of restoration blasting is to reduce the final face heights by the construction of scree blast piles. Variation in the height of the scree blast pile, achieved through alteration of the piles' fragmentation, heave and swell will reduce the amount of face available to liberate rock fall. It is anticipated that the stability of the scree blast pile will be maintained through the provision of a rock step or steps at the base of the face (Gagen

Figure 3 : A typical suite of landforms which may be constructed by restoration blasting

et al, 1992). Careful design of the blast geometry, explosive loading, sequencing and timing of the restoration blast should enable rock fragmentation to be controlled both laterally and vertically through the scree blast pile to produce an increasingly inter-locking and layered pile upon which a seed bed medium may be applied (Figure 4). Restoration blasting also aims to produce more natural landform features by indenting the face with a series of cut-backs which mimic the collapsed sinkholes of natural dalesides and by the production of rock headwalls and buttresses of varying height and lateral extent. The restoration blasting technique sterilise's the stone out of which the scree blast pile is constructed and all the stone beneath the pile. In order to reduce this sterilisation of stone, the technique aims to limit the throw of the scree blast pile out from the foot of the quarry face to within 1½ times the face height.

Fourteen restoration blasting trials have been undertaken in ICI Tunstead Quarry and BCI Hope Quarry. The first three trials were undertaken as part of a doctoral research project at Manchester Polytechnic (Gagen, 1988) and the remainder as part of the five year research programme. The trials were carried out on single limestone benches ranging in height from 10-25 m. The limestones are largely of late Dinantian age and are pale grey, well jointed, thickly bedded (0.3 - 3.0 m) with shallow dips. Prior to the commencement of the restoration blasting trials a review of current practice in production blasting at limestone

Figure 4 : Cross section of a scree blast pile to demonstrate the inter-locking and layered nature of the landform.

quarries was undertaken (Gagen et al, 1992). This identified the physical and operational parameters, and legislative controls, which guide the production blasting of limestone quarries. This enabled the restoration blasting trials to be developed using the same methods and parameters used for production blasting, namely rock face laser profiling, blast geometry, explosives loading, sequence and timing of detonation, to achieve the innovative aim of constructing new landforms. Details of the restoration blasting trials together with an initial assessment of the results are given in Gagen et al, 1992.

Habitat Reconstruction

The surface of the scree blast pile constructed by restoration blasting is extremely hostile to plant establishment as it contains little indigenous soil and has a minimum fragmentation size of 30cm A-axis. Hence, a seed bed material applied to the surface of the scree blast pile is required to achieve plant establishment, growth and survival. In the Peak District the shallow nature of the daleside soil often means it is not available for reclamation and that soil which exists on the plateau surface prior to the excavation of rock possesses different physical, chemical and biological characteristics. Any attempt to establish a daleside limestone flora on such a medium would fail as a result of competitive exclusion and invasion of inappropriate species. The only alternatives to the use of top soil as a seed bed which are readily available in most quarries are materials produced during the quarrying process. These include both wastes produced during mineral extraction and processing and also some grades of stone which would otherwise be sold but which would be cheaper than imported top soil. For the present research programme, ICI made available five grades of crushed limestone ranging from 0.06mm - 10mm in diameter, all of which were marketable products. BCI provided a waste material manufactured during processing which ranged in size from 0.06mm - 6.5mm. In common with other raw mineral materials, these mediums did not have the physical and chemical properties of naturally evolved soils. Generally the materials were of a regular and homogeneous size fraction greater than 2mm in diameter and chemical analysis demonstrated a severe nutrient deficiency and a pH >=9. Hence, the limitations of the materials were poor water retention as a result of physical structure and texture, and a high pH and low content of essential nutrients as a result of chemical structure. A series of laboratory and field planting trials were undertaken to determine what amelioration treatments would be necessary to assist the development of a limestone ecosystem. The trials demonstrated that plant establishment, growth and survival is improved through the incorporation of organic matter into the seed bed medium, the application of a mulch during seed establishment, careful application of fertiliser at the initial phase of establishment and as a series of after-care treatments, and the use of legumes in the seed mixture. The physical, chemical and biological trials enabled a quarry material and treatment regime to be selected for the re-construction of a limestone grassland. Details of these trials together with an initial assessment of the results are given in Bailey et al, 1992[b].

Large Scale Landform Replication

Three daleside landfrom sequences were constructed by restoration blasting. A dragline was then used to apply seed bed material to selected areas of the constructed scree blast piles in accordance with a landscape design (Bailey et al, 1992[b]). The landscape design aimed to reproduce the position of grasslands on natural limestone dalesides and was drawn up following geo-ecological mapping of a number of dales in the White Peak. Geomorphological mapping of the scree blast piles prior to the dragline operation identified areas which were considered either to be more receptive to the seed bed material or less receptive and the landscape design was modified accordingly. Following the application of the seed bed material peat was incorporated by the dragline to improve the water retention of the medium. A more homogenous mixture could probably have been achieved if the peat had been incorporated into the seed bed material by mechanical shovels prior to being spread over the scree blast piles by dragline but this was not possible in the present trials. The scree blast piles were then hydraulically sown. At Tunstead Quarry the hydraulic slurry contained seed, fertiliser, a binding agent and a mulch of peat, and at Hope Quarry a wood cellulose/coconut fibre mulch was tested. The seed mixture was selected following surveys of natural limestone dalesides and abandoned quarries. The legumes Lotus corniculatus and Anthyllis vulneraria were a major component of the seed mixture due to their ability to fix atmospheric nitrogen (Bailey et al, 1992[b]).

Bradshaw (1987) considers that the reason for failure of many habitat reconstruction schemes is due to inadequate nutrient aftercare, particularly nitrogen and phosphorous. He believes that the early phases of ecosystem development rely on nitrogen fixing species until there is an accumulation of at least 1000kg/ha of nitrogen in the total system. Hence, whilst the legume component of the grassland has been establishing, the other grass and herb components, including Poa pratensis, Festuca rubra, Cynosurus cristatus; Centurea scabiosa, Knautia arvensis, and Primula veris, have been maintained by a series of fertiliser aftercare treatments (Bailey et al, 1992[b]). The initial establishment of the grassland vegetation has been encouraging and monitoring of the density of sown herbs and percentage

Figure 5 : A revegetated Daleside Landform Sequence at ICI Tunstead Quarry (July 1991). The sequence was hydraulically sown with a limestone grassland seed mixture in April 1990.

vegetation cover is to continue in order to assess the revegetation technique (Figure 5).

Trees have also been established on the scree blast piles. The fragmentation of the scree blast piles and lack of indigenous soil material has meant that all trees have had to be planted in pits containing imported materials. At Tunstead Quarry the pits were excavated directly into the bare rock screes which were filled with a peat/limestone mixture prior to planting. The pits at Hope Quarry were excavated directly into the seed bed material. At Hope quarry an experiment was established at the time of planting which aims to determine the type of amelioration required to improve the water relations of the pit. The tree species established were selected following surveys of the woodland vegetation in the surrounding dales. Species planted included Fraxinus excelsior (Ash), Acer pseudoplatanus (the English Sycamore), Salix caprea (Goat Willow) and Sorbus aucuparia (Rowan). The trees at both sites were protected from rabbit predation by the use of tree guards. At Tunstead Quarry a trial to examine the rate of nitrogen necessary for tree establishment has been established (nitrogen is particularly important for the stimulation of root growth). Initial establishment of the trees at both sites has been successful, with only 2-3% failing to break bud. The trees are to be monitored throughout the project with root and shoot development receiving particular attention (Bailey et al, 1992[b]).

Conclusion

The high quarry faces of limestone extractions present some of the most difficult reclamation problems in quarries and existing methods for their rehabilitation are limited. Landform Replication may provide an alternative strategy which is practical, visually and technically acceptable and economic for the reclamation and long-term stability of large-scale quarry faces. Although the research is still in the devolpment and appraisal phase progress so far is encouraging. Further monitoring and assessment of the general applicabilty of the technique is to be undertaken. It is envisaged that the landform replication approach could form part of an overall reclamation strategy for the whole of a quarry with a variety of different face treatments.

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