Uplift, Erosion and Stability:
Perspectives on Long-term Landscape Development

Geological Society Special Publications
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It is recommended that reference to all or part of this book should be made in one of the following ways:

Smith, B. J., Whalley, W. B. & Warke, P. A. (eds) 1999. *Uplift, Erosion and Stability: Perspectives on Long-term Landscape Development.* Geological Society, London, Special Publications, **162**.

Puura, V., Vaher, R. & Tuuling, I. 1999. Pre-Devonian landscape of the Baltic Oil-Shale Basin, NW of the Russian platform. *In:* Smith, B. J., Whalley, W. B. & Warke, P. A. (eds) *Uplift, Erosion and Stability: Perspectives on Long-term Landscape Development.* Geological Society, London, Special Publications, **162,** 75–83.

GEOLOGICAL SOCIETY SPECIAL PUBLICATION NO. 162

Uplift, Erosion and Stability: Perspectives on Long-term Landscape Development

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1999

Published by

The Geological Society

London

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Published by The Geological Society from:
The Geological Society Publishing House
Unit 7, Brassmill Enterprise Centre
Brassmill Lane
Bath BA1 3JN, UK
(*Orders*: Tel. +44 (0)1225 445046
Fax +44 (0)1225 442836)
Online bookshop: http://bookshop.geolsoc.org.uk

First published 1999

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British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library.

ISBN 1-86239-047-9
ISSN 0305-8719

Typeset by Wyvern 21 Ltd, Bristol, UK

Printed by Anthony Rowe Ltd, Chippenham, UK

Distributors

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Introduction and background: interpretations of landscape change

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Research into the origins of landscape has a long and distinguished tradition. In America, landscape studies form the core of physical geology while elsewhere the study of landscape development has spread beyond the confines of geology to develop a firmer foothold in the geographical tradition, particularly in geomorphology. The development of ideas in landscape study has, however, been neither steady nor sequential. It has been characterized instead by several major conceptual shifts interspersed with periods of reinforcement or neglect. Within geomorphology, and certainly within the English-speaking world, the most important of these shifts occurred in the early 1960s with the move from denudation chronology of landscapes as a core activity to an emphasis on process-based investigation of individual landforms.

In geology, the 1960s also marked an important change in perspective. Publication of plate tectonic theories (sea-floor spreading, continental drift, subduction and mountain building) had far-reaching consequences for all earth science. In particular, plate tectonics made the study of apparently ancient processes (billions of years old) applicable to the present-day with, for example, application to earthquake studies.

Whilst the initial shift towards process studies was a response to the desire for a better understanding of the mechanisms driving landscape change, it was not long before this goal became relegated in the eyes of many of its practitioners. As a consequence, process study became an end in itself, rather than a means to an end. This movement has been reinforced in recent years by a demand for greater 'relevance' from, for example, research funding bodies resulting in an emphasis on problem solving and wealth generation that has moved away from studies at the landscape scale. Consequently, within geomorphology, process studies and applied geomorphology have come to dominate the literature – a dominance reinforced by the increasing division and separation of the discipline into process domains such as fluvial and glacial studies. This has reached the point where many researchers would now naturally identify themselves as specialists in a particular process rather than as geomorphologists.

A similar trend can be identified within geology, whereby studies of uplift, erosion and stability clearly fall into pre-plate tectonics and post-plate tectonics generations. In the 1920s, studies of denudation were popular, as evidenced by the volume of work conducted in southern England and based largely on observations of palaeovalleys, tilted strata and unconformities. Sediment provenance became important in the 1920s and 1930s and early works on the use of heavy minerals in studies of past erosion were developed. By the 1960s geologists were standing back and viewing many processes in terms of their global plate tectonic significance. However, this emphasis on processes inevitably led to the development of more labour-intensive analytical methods, as a consequence of which, the wider perspective began to be neglected. Through the 1970s and 1980s, therefore, studies of uplift developed using methods that determine heating or pressurization of the uplifted rocks. Thermal estimates of uplift, including spore or conodont alteration indexes, fluid inclusion studies and diagenetic models were developed, together with estimates of pressurization including studies of mineralogy and sonic borehole logs. However, perhaps the most significant advance in the determination of uplift rates and amounts has been in the field of apatite fission track analysis (AFTA) (Carter 1999). The widespread use of AFTA in the oil industry has provided large datasets that encompass the offshore basins formerly ignored by those concerned with land erosion (Buchanan & Buchanan 1995). Studies of erosion and palaeoerosion have also developed from the study of derived clasts to clay minerals and heavy minerals, requiring increasingly labour-intensive, and hence specialist, methods to derive local or even regional perspectives.

Specialization clearly has many advantages. If, however, it is allowed to proceed unchecked, these advantages eventually come to be outweighed by the effects of an increasingly reductionist approach whereby concentration on small-scale studies and the pursuit of ever greater detail detracts from appreciation of the large-scale picture and ultimately fragmentation and loss of the subject core. Clearly, the longer this reductionist/segregationist approach persists the more difficult it is to define and to justify the existence of the original parent discipline.

From: SMITH, B. J., WHALLEY, W. B. & WARKE, P. A. (eds) 1999. *Uplift, Erosion and Stability: Perspectives on Long-term Landscape Development*. Geological Society, London, Special Publications, **162**, vii–xi. 1-86239-030-4/99/
$15.00 © The Geological Society of London 1999.

The case for integration and collaboration

Calls for the integration of process studies and their application to the original question of landscape characterization and change are not new (Summerfield 1981; Douglas 1982). In general these calls have been hindered by problems of scale, whereby there is still an incomplete understanding of the multiplier effects of extrapolating small-scale, spatially and temporally confined process studies to larger scales of investigation. There is, however, an increasing awareness that such extrapolation is essential and that present-day landscape cannot be explained solely in terms of current processes or even those that operated in the geologically recent past.

This view has been fuelled by a growing understanding that many of the world's landscapes are much older than the Quaternary and thus require explanations involving long-term and large-scale consideration of both climatic change and tectonics. This has been emphasized by geomorphological and geological investigations over the last 20–30 years in low-latitude environments not directly affected by Quaternary glacial activity, especially in Australia and South Africa (Young 1983; Fried & Smith 1992; Gale 1992). This in turn, has been supported by an increasing number of studies in western Europe where evidence has accumulated to support the survival of pre-glacial landforms (Mitchell 1980), extensive deeply weathered Tertiary material (Fitzpatrick 1963; Hall & Sugden 1987) and pre-Quaternary weathering and associated land surfaces (Lidmar-Bergström & Åse 1988; Lidmar-Bergström 1995; Whalley *et al.* 1997).

One factor that has facilitated this renewed interest in long-term landscape change has been the beginning of collaboration between geologists and geomorphologists, which has greatly enhanced our ability to interpret landscape development. Central to this have been improvements in the elucidation of tectonic and erosional histories and the use of dating techniques such as apatite fission track and cosmogenics that have significantly contributed to characterization and landscape interpretation (e.g. Morisawa & Hack 1985; Thomas 1995; Widdowson 1997). In addition, a greater concern of structural geologists with questions of landscape change has fostered a much less dogmatic and simplistic view of 'uplift, erosion and subsequent deposition' within geomorphological thinking. In particular, the role of geosynclinal deposition in promoting the deformation and uplift of sediment supply areas and the possibilities for using rates and patterns of basin deposition for better understanding of continental erosion (e.g. Partridge & Maude 1987; Lidmar-Bergström 1995). Similarly, it is significant that the current motivation for linking erosion rates, structural geology and dating methodologies has not come solely from geomorphologists, but has been matched by a comparable desire within geology to integrate these components, largely driven by the demands of petroleum exploration and a consequent burgeoning of interest in sequence stratigraphy. Thus, there is clear evidence for the emergence of collaborative, interdisciplinary investigations.

The present volume

It was recognition of a need for interdisciplinary research that provided the stimulus for the meeting, jointly sponsored by The Geological Society of London, The British Geomorphological Research Group and IGCP 317 (Palaeoweathering Records and Palaeosurfaces), that led to this publication. The contributors were encouraged to examine large-scale earth surface change – as a contribution towards the setting of an agenda for the integration of process and landscape studies. However, the aim extended beyond a desire to chronicle and understand individual landscape histories. Instead, it was hoped that, by demonstrating the benefits of interdisciplinary discourse, a widening of interest in landscape studies would be encouraged. It was also hoped that the presentations would demonstrate that studies of present-day processes can be successfully placed within an evolutionary framework and geological setting, the necessity for which increases as appreciation of the antiquity of many landscapes grows.

The material in this volume represents work from both the geological and geomorphological traditions, and encompasses a wide geographical spread and many geological interests. Most importantly, however, the papers highlight the significance of recent advances in analytical technology for improving interpretation of both geologically 'ancient' and 'young' landscapes.

To set these developments in context, **Jones** revisits the 'classic' landscape studies of SE England by Wooldridge & Linton (1938, 1955) in the first two papers. In these, recent advances in understanding of the Tertiary evolutionary geomorphology of this region are supported by developments in, for example, apatite fission track dating and the establishment of inversion tectonics. However, while acknowledging that substantial progress has been made towards establishing a much clearer evolutionary geomorphology for SE England, **Jones** recognizes that uncertainties persist especially with regard to the temporal and spatial dimensions of uplift, the significance of palaeoenvironmental conditions and the lack of widespread dating of surfaces. **Walsh *et al.*** and **Battiau-Queney** continue the theme of revisiting traditional models of landscape development. **Walsh *et al.*** use a combination of sedimentological, palaeokarstic and palaeobotanical evidence to suggest a greater antiquity for surfaces previously thought to be of late Pliocene or Pleistocene age. **Battiau-Queney** highlights the importance of such factors as continuous energy input associated with plate tectonics and inherited crustal discontinuities in the long-term landscape development of the British Isles.

The study by **Puura *et al.*** of the pre-Devonian landscape of the Baltic Oil-Shale Basin provides a timely reminder that investigations of complex present-day landscapes may have implications for interpretation of similar periods of continental dominance within the geological record. The value of traditional landform interpretation in the provision of a relative chronology of landscape development is also demonstrated by **Lidmar-Bergström** in her study of Scandinavia which highlights the increasingly significant role of apatite fission track analysis in interpreting denudational histories and in identifying the relative antiquity of many present-day landscapes. From Central Europe, **Migon** demonstrates the complexity and antiquity of previously glaciated areas and suggests that much of the upland topography of the region may be inherited from the Early Cenozoic.

The theme of continuing tectonic control on the development of individual landscapes and landforms is followed in a series of papers which extend from Tunisia (**Baird & Russell**) to the Lebanon (**Butler & Spencer**), Italy (**Basili *et al.***), Tanzania (**Eriksson**) and to extremely active landscapes dominated by neotectonics in Taiwan (**Petley & Reid**), the Tibetan Plateau (**Fothergill & Ma**), Argentina (**Costa *et al.***), Ecuadorian Andes (**Coltorti & Ollier**) and the Gobi Desert (**Owen *et al.***). The close links between geomorphological processes, specific landforms and uplift in the formation of contemporary landscapes in tectonically active regions of Asia are also clearly illustrated by **Petley & Reid**, **Fothergill & Ma** and **Owen *et al.*** **Eriksson** further exemplifies these interactions with specific regard to soil erosion in Tanzania with removal of soil occurring as part of the natural long-term stripping of regolith associated with crustal uplift and tilting of tectonic blocks. These examples of relatively rapid landscape development are contrasted with the data presented by **Butler & Spencer** who suggest that even in tectonically active areas large-scale tectonic landforms may be preserved for many millions of years with only minor surface modification because of low denudation rates (e.g. in arid regions).

In all of these studies, the integration of structural, sedimentological and geomorphological data have contributed to large-scale landscape interpretation and identification of the spatial and temporal complexity of landscape development. The consequence of continued uplift for regional erosion and offshore sedimentation is explored by **Bartolini** with specific reference to Italy and the Adriatic whereby sedimentological data have been used to identify variability of uplift rates since the Upper Oligocene. These issues are given a North American perspective by a quantitative analysis of historic erosion and deposition rates along the northeastern seaboard of the USA by **Conrad & Saunderson** – an analysis that recommends caution regarding the extrapolation of modern sediment yields to longer-term landscape development.

The possibility of fixing absolute time-scales to landscape development through the use of cosmogenic dating is explored in detail by **Summerfield *et al.*** in a study of the Dry Valleys region of Antarctica. Cosmogenic dating has identified very slow rates of denudation and landscape modification in the hyper-arid conditions of Antarctica. It is sufficiently sensitive to identify differences between upland and coastal sites where slightly higher denudation rates in the latter possibly reflect the seasonal availability of liquid water and hence more active weathering. The ability to date surfaces is perhaps one of the most important technological advances in landscape interpretation. It has enabled recognition of the antiquity of many landsurfaces and has thus necessitated reassessment of former interpretations especially with regard to climate change and tectonics.

Conclusions

There is a growing awareness that the explanation of long-term landscape change remains a core objective of geomorphology and physical geology. This realization has been prompted by the coincidence of a number of factors:

- a much improved knowledge of geomorphological processes over the last 40 years, with a recognition that applied and process geomorphology alone cannot provide a conceptual framework for a discipline and that there is a need for a purpose to these studies

- the growing acknowledgement, demonstrated by some of the contributions to this volume, that many of the world's landscapes pre-date the Quaternary and Tertiary – even those that were subject to extensive glaciation
- a much improved understanding of tectonic processes, coupled with a willingness on the part of geomorphologists and structural geologists to exchange ideas and undertake collaborative work
- the advent of new techniques amenable to the dating of land surfaces and estimation of erosion rates
- the need to review concepts and practicalities of long-term landscape evolution, before first-hand experience and expertise in denudation chronology is lost

However, if long-term landscape change is to be revisited, it is clear that there must be certain prerequisites. First, earth surface studies at the landscape scale, especially within geomorphology, must avoid interpretation of the history of landscape based solely upon morphological evidence or the efficacy of proprietary models of landscape evolution. Second, given the breadth of relevant knowledge and range of analytical techniques now available, it is evident that, if landscape change is to be understood, it must be through an interdisciplinary approach.

Plate tectonics, in particular, has had a major impact on studies of land stability. The realization that these essentially geological processes were occurring in the present day brought geomorphology into perspective for many structural geologists (especially in North America), resulting in the birth of the new science of neotectonics. Improved analytical techniques such as real-time satellite imagery and seismic monitoring were the result of the obvious social and economic requirements for understanding Earth movements. Until now, the more advanced analytical methods (AFTA, heavy minerals) have been labour intensive and thus confined to local studies. Technological advances and an ever-increasing database suggest that we are now in a position to bring the detail of local studies into their regional context, using all the skills of geology and geomorphology.

By their very nature, interdisciplinary volumes place great strains on the expertise of a limited number of editors. As a consequence, publication would not have been possible if we had not been able to draw upon the experience of a large number of reviewers from a wide range of backgrounds. In addition Dr Bob Holdsworth has provided unstinting guidance and support. To all of these individuals we extend our sincerest thanks.

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