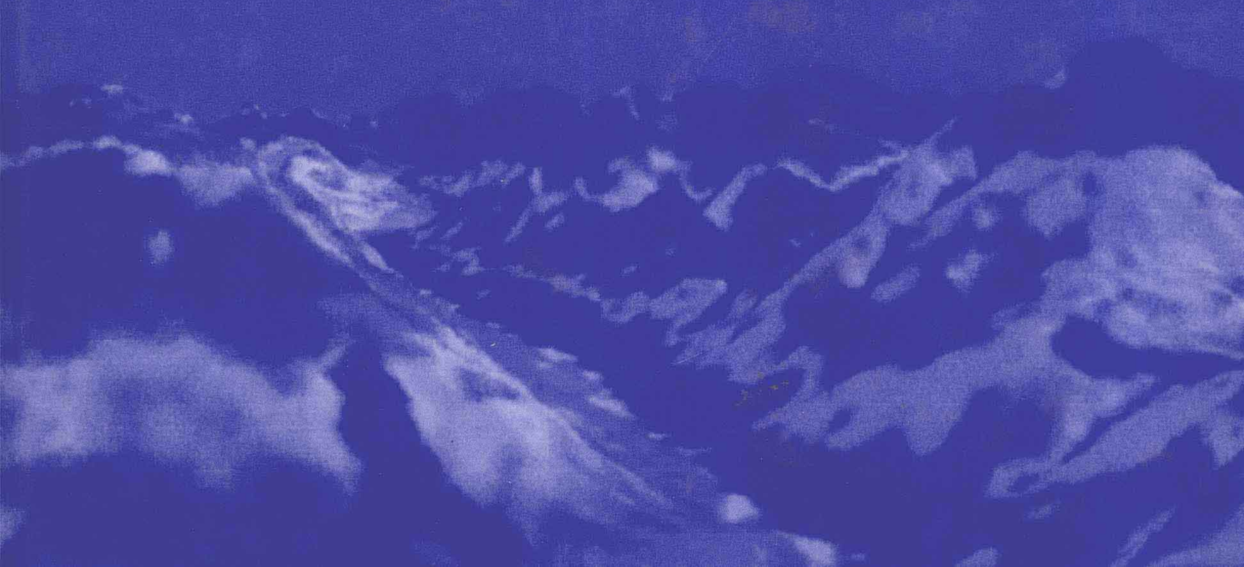
GEOENVIRONMENTAL MAPPING

Methods, Theory and Practice

Peter T. Bobrowsky *Editor*



GEOENVIRONMENTAL MAPPING
METHODS, THEORY AND PRACTICE

PETER T. BOBROWSKY
School of Earth and Ocean Sciences, University of Victoria, Victoria, British Columbia, Canada

A.A. BALKEMA PUBLISHERS LEIDEN / LONDON / NEW YORK / PHILADELPHIA / SINGAPORE

Library of Congress Cataloging-in-Publication Data

Bobrowsky, Peter T.
Geoenvironmental mapping : methods, theory, and practice / Peter T. Bobrowsky.
p. cm.
Includes bibliographical references and index.
ISBN 90 5410 487 2
1. Geological mapping. 2. Environmental mapping. I. Title.

QE36 .B56 2002
550'.022'3–dc21

2001052525

First print: 2002
Second print: 2005

Cover design: Studio Jan de Boer, Amsterdam, The Netherlands.
Typesetting: Charon Tec Pvt. Ltd, Chennai, India.

Published by: Taylor & Francis/Balkema
P.O. Box 447, 2300 AK Leiden, The Netherlands
e-mail: Pub.NL@tandf.co.uk
www.balkema.nl, www.tandf.co.uk, www.crcpress.com

ISBN 90 5410 487 2 (hardback)

Printed in Great Britain

Contents

Introduction

PETER T. BOBROWSKY
School of Earth and Ocean Sciences, University of Victoria, Victoria, British Columbia, Canada

The purpose of this text is to reaffirm the relevance of geoenvironmental mapping as a key component to both fundamental and applied geoscience research in the 21st century. Here, geoenvironment follows the simple and broad definition of Aswathanarayana (1995) as referring 'to the uppermost parts of the lithosphere which is affected by human activities'. As a result, the topical coverage of this text is diverse and ranges from geophysics and geochemistry to geohazards and Geographic Information System (GIS). As geoscientists we often devote considerable energy, time and finances towards observing and documenting, either directly or indirectly, various attributes and features about the planet we inhabit. Geoscientists map everything from mineral micro-fabrics in outcrop to subsurface contaminants in groundwater to plate tectonics. We photograph, sketch and write detailed field notes to capture 'location-dependent' data before we intellectually digest the information collected. Eventually, such collected data appear in published form as an abbreviated testament to an individual's hard work. Few would argue that many parts of the data capture, analysis and reporting continuum require a reliance on the use of various forms of maps. Maps provide an ideal medium to manage data, visually assess and comprehend spatial relationships and transmit this information to others. Maps used in research may or may not appear in the published record, but they are used nonetheless. Regrettably, in the eyes of non-geoscientists, the importance of geoscience mapping has gradually diminished. Often, funding sources (e.g. granting agencies, employers, governments, clients, etc.) routinely question the need for mapping, and more recently, question the very need for geosciences (cf. Nowell 2001).

The presentation of mapped data is without boundaries, but the goal is always the same, to understand, portray and communicate spatially constrained phenomena. Simple black and white stratigraphic cross-sections are still common in publications, but these may also complement colourful three-dimensional fence diagrams in the same paper. In fact, one can find three-dimensional shaded relief, digital elevation models, draped with all types of geological data in modern geological literature instead of actual photographs! For some, the digital capture of data is immediate, since laptop computers, palm held computers and other sophisticated hardware often loaded with Global Positioning System and GIS applications, graphic and database capabilities, now accompany the mapper in their field work (cf. Walker & Black 2000). For others, the advent of full, computerized geological mapping is not yet a routine procedure.

This book is not intended to review basic mapping (see Dorling & Fairbairn [1997] for an excellent review), nor does it try to address the properties and characteristics of maps themselves, that is scales, projections, protocols, cartography, etc. (see Campbell [1998] for a comprehensive discussion). Instead, I have attempted to compile a number of chapters on a suite of topics relevant to geoenvironmental studies in a format best recognized as 'case studies'. My intent is to have this book complement senior undergraduate instruction in engineering geology, Quaternary geology and environmental geology. Further, my intent is to illustrate to the professional geoscientist that both fundamental and applied research of all types can be framed within a geoenvironmental perspective; a perspective that somehow benefits society. It is hoped that practising geologists not familiar with the subject of geoenvironmental research will also benefit from this compilation of case studies when dealing with their own efforts to justify geoscience mapping. Given the breadth of this field of study and realistic space limitations when publishing, I have not been able to include examples of all aspects of geoenvironmental mapping.

For those interested in the interdisciplinary nature of geoenvironmental research, there are many examples that clearly show the importance of integrating basic geoenvironmental map information for the good of society. For instance, one well-illustrated study is that of Thompson et al. (1998) who indicate how hydrologic, hydrogeologic, geologic, geomorphic, geotechnical, landform, soil and engineering geology map data are successfully combined to address conservation, resource and hazard land-use concerns in Great Britain. Such multi-faceted reports are informative and serve their intended use for a particular question. This volume does not try to replicate such focused reports. Instead, this compilation of chapters addresses a suite of technical subjects ranging from the methods of mapping specific hazards to the practice of land-use zonation. All subjects in this volume fall under the rubric of geoenvironmental mapping.

As each contribution in this volume is unique, my attempt to order the chapters has provided an organizational challenge. Chapters have been grouped into eight sets where there are some shared attributes: (1) distinct methods of mapping; (2) physical-based mapping methods; (3) shallow subsurface mapping; (4) resource management issues; (5) water–land relationships; (6) urban geology; (7) health and the environment; and (8) natural and geological hazards.

The first set of chapters consists of three contributions, which address distinct methods of mapping. Keaton and Rinne provide an excellent start to the collection as they summarize the basic tenants of engineering-geology mapping where slope stability may be a concern. Their chapter provides a good discussion of such elements as age classification, landslide classification, the engineering-geology mapping, and rock classification systems used in the production of slope stability mapping. Pain and colleagues skillfully examine all aspects of the methodology of regolith mapping in Australia, a method that could easily be applied in numerous other areas around the world. The authors provide examples of different landscape-based mapping components (geomorphic, soil and land systems), models, methods of regolith mapping and presentation of information. The difference between regolith mapping and basic geologic mapping is clearly presented and important to those not familiar with the ubiquitous nature and formation of regolith deposits. The final chapter on methodology is that of Jordán and Szücs who address the concept of mapping geochemical systems from a global perspective. This is a unique twist to geoenvironmental mapping, since geochemistry plays a prominent role in many aspects of the discipline. Jordán and Szücs provide a good overview to a complex system that affects most geoenvironmental studies.

Two chapters follow on physical-based mapping methods now in use in the United States. Haneberg and others review the mapping of multi-hazards in the Rio Grande area of New Mexico using the Unified Engineering Geologic Mapping System. The three-level approach to geologic hazard assessment presented by the authors is a proven, cost-effective method for dealing with hazardous terrain. Another specific case study by Real follows, in his examination of seismic hazard mapping in California. The high seismic risk in this region and the lengthy but established history for addressing the threat provides the perfect location for this important type of mapping to be explained. In this chapter, Real details several aspects to seismic microzonation mapping from zone designation, to data requirements, to types of products. Both contributions provide sufficient guidance that users globally can adapt these methodologies to their own needs.

The next two chapters deal specifically with the shallow subsurface of Quaternary deposits. Smith reviews the method and theory behind data acquisition and processing of borehole geophysics. He supplements the methods of data interpretation with several case studies, and follows up with an essential summary of why such information is relevant to geoenvironmental research. Straffin addresses the theoretical paradigms of subsurface mapping. The concept of allostratigraphic mapping is examined within the framework of his own work in the alluvial landscapes of southern France. This chapter is a welcome addition to frequently overlooked aspects of basic mapping philosophy.

Four practical chapters dealing with geochemistry, aggregate resources, remote sensing and erosion follow. The first chapter in this set, by Cook, focuses on the use of lake-sediment geochemical mapping in the Canadian Cordillera for both mineral exploration and environmental applications. Cook clearly discusses methods of sample collection, preparation, analysis, quality control study and map production. He then expands this discussion by addressing three applications: mapping lithological variations, exploration for mineral deposits, and environmental assessment. Kelly and Bobrowsky review the methods of aggregate potential mapping from around the world. They centre the chapter on the economic importance of aggregate resources, collecting information and map production. Their discussion is supplemented with an actual case-study product generated for Canadian data users. Khawlie briefly highlights the essential contribution of remote sensing to geoenvironmental mapping. Khawlie relies on his expertise in Lebanon to summarize the types and methods of data used, as well as the presentation and interpretation of resultant data for this part of the world. He concludes his chapter by suggesting applications for decision-making for which such information can prove invaluable. Finally, a chapter by Sauchyn on mapping rainfall erosion in the prairies of Canada emphasizes the applied relevance of geoenvironmental mapping for societal needs. The problem of rainfall erosion is not unique to this area, but the advances in modelling and mapping developed by Sauchyn and his collaborators provides a useful introduction to solutions that can be applied elsewhere when dealing with this type of hazard.

The next five chapters in this volume deal with water–land relationships. The first chapter, by Muir and colleagues, describes and presents the methodology for a mapping technique which allows one to take available bathymetric data matrices and convert them into 2D and 3D topology maps. As a twist on this new technique, the authors provide a case-study application dealing with population genetics and presumed paleomigrations. This type of fundamental research has links to many historical aspects of geosciences. Berg provides a concise examination of groundwater mapping using his own experience from the United States. Berg's review relies on a series of map-scale dependent examples to illustrate his thesis. The benefits and pitfalls of aquifer sensitivity mapping are also examined in this chapter. The third chapter in this set of contributions deals with mapping watersheds, which are easily threatened by multiple pollution sources. Rogers successfully illustrates the importance of mapping hydrogeology and near-surface geology in the development of geologic sensitivity mapping for the Rouge River watershed in Michigan. He supports his arguments with two unique case-study examples from the watershed. Cluer describes the geodetic and geophysical data collected to map large river channels and the three-dimensional flow field in rivers. After detailing the methods of data collection, Cluer provides a well-documented case study from the Colorado River in Arizona to solidify his points. Schwab and others deal with floodplain hazard assessment. The successful management of this common landform is crucial, given the frequent exploitation of floodplains by people around the world. The authors first carefully compare manual to computer-assisted mapping methods, then outline methods of interpretation using real data from two rivers (Skeena and Symoetz) in western Canada.

The next selection of manuscripts all deal with urban geology issues. The first chapter in this set, by Valiunas, reviews the state of the art of environmental geology mapping in Lithuania. The author clearly shows how different types of maps have helped in urban planning by closely examining two separate urban centres: Vilnius City and Kaunas City, where different problems require different geological solutions. Hoyos and Hermelin present an analysis of natural hazard mapping in several urban centres in Antioqua, Colombia. The diversity in hazards and the relevance of historic geologic information are important factors in the success stories of urban hazard mapping in this region. Their chapter serves as a superb standard for managing similar geoenvironmental issues elsewhere in South America. Lugo and associates provide a general review of the geoenvironmental conditions of Mexico City by focusing on natural-anthropogenic risks. The authors illustrate the risks and relationships through three different municipal case studies: ground cracking in Iztapalapa, volcanic risks at Cerro del Peñon, and terrain in Cuajimalpa. The importance of managing geology correctly is readily apparent given Mexico City's incredible population of about 30 million people. Marker uses four case studies to illustrate the lessons learned from using geological data for land-use planning and development in Great Britain. Marker provides an educational awakening for geoscientists in their quest to satisfy the needs of others not familiar with geological concepts. The final chapter, by Villota and colleagues, is an interesting study of urban geology in Alicante, Spain. The authors examine the importance of basic geoenvironmental mapping to the safe management and preservation of architectural features; a unique focus for applied geological studies.

The next three chapters are variants on the theme of health. Selinus provides a superb overview and introduction to the field of medical geology. The author discusses specific diseases and ailments related to geology and the use of biogeochemical monitoring for health studies. This chapter serves an essential service to promote a significant and timely emerging new discipline in earth sciences. A chapter by Foster follows, which focuses on diseases associated with selenium. Foster provides convincing arguments why the collection and analysis of health data and selenium in the geological environment has crucial implications for the health of mankind. This geographic analysis of health complements the geologic review by Selinus. The final chapter in this set, by Limpitlaw and Fabbri, is actually a case study on the use of GIS and geoindicators of mining impacts in Zambia. The health implications of mine-related environmental degradation are clear and hae far-reaching relevance. Their treatment of the benefits of environmental maps is well presented.

All the remaining chapters deal with aspects related to natural and geological hazards. Chesnokova and colleagues provide the first chapter with a review of the basic concept of hazard-risk assessment as currently practised in Russia. The authors creatively integrate the threat of hazards with the necessity to manage risk-assessment policy and zonation of hazards in a country whose economic losses due to hazards has amounted to some US $300 billion over the last two decades. Hickson provides an exemplary review of the problems associated with volcanoes. Hickson clearly examines the history of hazard maps, types of volcanic hazard maps, zonation maps, volcanic forecast and prediction maps, as well as the quite important aspect of map limitations. Her chapter can be used as a template for volcano-related research around the world. Appleton and Ball focus their chapter on an extensive examination of geological radon potential mapping. The authors rely on their own extensive experience in the subject to outline the procedures of data collection, interpretation and map production. Case studies from the UK, Sweden, Czech Republic, USA and Canada clarify the importance of properly mapping this hazard. They also examine the role of the map users in dealing with the information. Two separate chapters on tsunami hazards follow. Prasetya and others define the characteristics of the tsunamigenic area of the Makassar Strait based on an analysis of geological, geophysical and historic tsunami event data. The implications and risk for coastal development in this part of Indonesia are also examined and discussed. Fiedorowicz and Peterson illustrate the importance of mapping historic and prehistoric tsunami deposits on the coast of Oregon, USA, as a valuable tool in dealing with future events. Collection of geological data in this region was used to focus on tsunami run-up elevations, which prove critical in the development of evacuation routes for populated areas. The only chapter on subsidence in this volume is by Simón-Gómez and Soriano, who focus their discussion on doline subsidence in the Ebro basin of Spain. The authors successfully summarize the general methodology of mapping dolines, presenting the actual subsidence map, and discussing the potential subsidence hazard map. The final two contributions in this volume deal specifically with landslides. Carson and Geertsema provide a cogent review of the many aspects related to flowslides. The authors explore the parameters of regional mapping vs. individual landslide mapping and illustrate how engineering and geology can be successfully merged. Citing key international references, the authors highlight their points with case studies from Canada. The final chapter in this volume, by Chung and colleagues, outlines a new quantitative method for landslide hazard mapping. A strong reliance on GIS in this chapter illustrates the importance of new graphical methods of representation to facilitate visualization of such phenomena for the non-specialist.

The ability to successfully process the many chapters submitted for publication stems from the collected efforts of the conscientious and professional manuscript reviewers who devoted their time and expertise as a courtesy to ensure a better product. As the editor of this volume, I greatly appreciate and acknowledge the combined contributions of all the reviewers listed below. I reviewed each of the chapters in this volume with the assistance of two external reviewers. For the information of the reader, I note that several chapters originally submitted for inclusion in this volume were eventually rejected by reviewers. The list of reviewers in alphabetical order includes: B. Atwater, D. Baker, V. Barrie, A. Berger, M. Best, W. Blake, M. Bovis, A. Boydell, G. Brooks, B. Broster, M. Brunengo, N. Catto, A. Cendrero, J. Clague, K. Conway, S. Cook, P. David, A. Duk Rodkin, C. Dunn, D. Elliott, K. Fletcher, H. Foster, R. Fulton, M. Geertsema, R. Gerath, T. Hickin, O. Hungr, J. Hunter, D. Huntley, I. Hutchinson, L. Jackson, P. Karrow, R. Kelly, R. Lett, T. Little, D. Liverman, L. Martz, N. Massey, J. Matthews, J. McCall, B. McClenaghan, P. Monahan, J. Monger, G. Morgan, D. Mosher, E. de Mulder,

O. Niemann, C. Peterson, P. Pringle, T. Pronk, A. Roberts, M. Roberts, J. Rose, D. Sauchyn, R. Schuster, C. Simpson, O. Selinus, D. Smith, I. Spooner, R. Stea, R. Turner, D. VanDine, T. Walsh, B. Ward and M. Wei. My thanks again to all of these colleagues.

I wish to thank the positive, inspiring and invaluable support of my colleagues, friends and family who inspired me to pursue and complete this initiative. In particular, I acknowledge my close friends, collaborators and mentors, Drs Nat Rutter, John Clague and Ed de Mulder who during the years have instilled in me a greater appreciation for geoenvironmental research. My graduate students Ahren Bichler, Charlotte Bowman, Adrian Hickin, Gloria Lopez and Roger Paulen are thanked for keeping me busy, exhausted and focused on geoenvironmental research as they pursue their own studies on the subject. Thanks to the BC Geological Survey Branch for providing a favourable environment to pursue this research. A special appreciation goes to my family Mary, Jeannine, Kate, Talya, David and Theresa. Finally, I acknowledge and express my gratitude to my two best critics and companions Oreana and Killian.

REFERENCES

Aswathanarayana, U. 1995. *Geoenvironment, an introduction*. Rotterdam: A.A. Balkema. 270 pp.

Campbell, J. 1998. *Map use and analysis*, 3rd edition. WCB McGraw-Hill. 422 pp.

Dorling, D. & Fairbairn, D. 1997. *Mapping: ways of representing the world*. Addison-Wesley-Longman. 184 pp.

Nowell, D. 2001. Who pays the piper? Costs and benefits in Quaternary research. *Geoscientist* 11(1): 14.

Thompson, A., Hine, P.D., Poole, J.S. & Greig, J.R. 1998. *Environmental geology in land use planning: a guide to good practice*. Report to the Department of the Environment, Transport and the Regions by Symonds Travers Morgan, East Grinstead. 80 pp.

Walker, J.D. & Black, R.A. 2000. Mapping the outcrop. *Geotimes*, November: 28–31.

Engineering-geology mapping of slopes and landslides

JEFFREY R. KEATON & RICHARD RINNE
AGRA Earth & Environmental, Inc., Sedona, Arizona, USA

1 INTRODUCTION

Assessing risks of future movements of slopes is based on the engineering-geology corollary to the Geologic Principle of Uniformitarianism: The recent past is the key to the near future (Keaton 1994, p. 220). Slopes have different levels of risk of future movement. Natural slopes that are currently moving (i.e. landslides) clearly have a high risk of movement in the future, whereas natural slopes that have no evidence of movement probably have little risk of future movement, unless they are modified by works of man. Other natural slopes have intermediate risk of future movements. The purpose of this chapter is to describe the elements of engineering-geology mapping of slopes and to discuss a stability classification of slopes and landslides that is useful in assessing risks of future movements. Many constructed slopes (excavations as well as embankments) can be evaluated using the procedures described in this chapter. However, the emphasis of the chapter is on natural slopes. A brief discussion is presented below to describe geologic maps and historical development of landslide classifications and mapping.

2 HISTORICAL PERSPECTIVE OF LANDSLIDE MAPPING

To provide a basis for the recommended system for engineering-geology mapping of slopes and landslides, a brief historical perspective is presented using selected references.

Brabb et al. (1972) used the following seven-level classification for mapping landslide susceptibility in San Mateo County, California:

Classification I. Areas least susceptible to landsliding. Very few small landslides have formed in these areas. Formation of large landslides is possible but unlikely, except during earthquakes. Slopes generally less than 15%, but may include small areas of steep slopes that could have higher susceptibility. Includes some areas with 30% to more than 70% slopes that seem to be underlain by stable rock units.

Classification II. Low susceptibility to landsliding. Several small landslides have formed in these areas and some of these have caused damage to homes and roads. A few large landslides may occur. Slopes vary from 5–15% for unstable rock units to more than 70% for rock units that seem to be stable.

Classification III. Moderate susceptibility to landsliding. Many small landslides have formed in these areas and several of these have caused extensive damage to homes and roads. Some large landslides are likely. Slopes generally greater than 30% but includes some slopes 15–30% in areas underlain by unstable rock units.

Classification IV. Moderately high susceptibility to landsliding. Slopes all greater than 30%. These areas are mostly in undeveloped parts of the county. Several large landslides are likely.

Classification V. High susceptibility to landsliding. Slopes all greater than 30%. Many large and small landslides may form. These areas are mostly in undeveloped parts of the county.

Classification VI. Very high susceptibility to landsliding. Slopes all greater than 30%. Development of many large and small landslides is likely. The areas are mainly in undeveloped parts of the county.

Classification L. Highest susceptibility to landsliding. Consists of landslide and possible landslide deposits. No small landslide deposits are shown. Some of these areas may be relatively stable and suitable for development, whereas others are active and causing damage to roads, houses, and other cultural features.

It should be noted that Brabb et al. (1972) considered landslide and possible landslide deposits to be indicators of the highest susceptibility to landsliding regardless of the age of most recent movement, although some relatively stable areas were allowed to exist within Classification L.

Varnes (1974, p. 45) notes that a 'geologic map is a synthesis; it is not information in its most fundamental and versatile form. It is a generalization that is a geologist's interpretation of the geology for a particular purpose.'

IAEG Commission on Engineering Geological Maps (1976, p. 11) states that 'A map provides the best impression of a geological environment, including the character and variety of engineering-geological conditions, their individual components and their interrelationships. But it is a simplified model of the facts and the complexity of various dynamic geological factors can never be entirely represented. The degree of simplification depends mainly on the purpose and scale of the map, the relative importance of specific engineering-geological factors or relationships, the accuracy of the information and on the techniques of representation used.'

Barnes (1981, pp. 45–46) provides simple guidance on mapping landslides in the context of basic geologic maps, and notes that 'Landslides can be recognized by the scar where the slide starts, and by the material that has slid. If the slide is old the scar may be eroded and overgrown. The debris, however, may show several recognizable features. Its average gradient is gentler than the rest of the hillside and its surface different. There may be small parallel ridges or hummocks caused by "earth flow". Drainage is small scale, often dendritic, and there may be small ponds and pools. In heavily-wooded areas the slide may support only scrubby bush, or dead trees with new growth between them. Where sliding is imminent, trees may be "kneed". Some slides are indicated by massive unweathered blocks poking through the hillside colluvium and they can cover huge areas. Map a slide as a distinctive geological unit, indicating both the scar and the spread of the debris.'

Verstappen (1983, p. 256) provides a systematic description of the content and preparation of geomorphological maps: 'The specific aim of geomorphological mapping is the representation of terrain configuration, landforms being the main subject matter. The cartographical elaboration of the map should allow for the identification and exact description of the landforms and landform complexes and should indicate their position and arrangement as well as their genesis. The spatial relationships with adjacent forms and the temporal or chronological relationship with features of other form generations should be emphasized. To fulfil this aim, an analytical approach was devised distinguishing between four different types of information about landforms:

1. *Morphographical information*. The forms should be identified from a geomorphological point of view, for example, a river terrace and erosion surface, which is not the case on a topographic map.

2. *Morphogenetic information*. The forms should be represented in such a way that their origin and development is immediately clear. In the legend accompanying the map, descriptive indications such as "sandy plain" should be avoided; instead, genetic descriptions ("sandy alluvial plain", "sandy pro-glacial plain") should be used. Since form is the outcome of the combined effect of exogenous geomorphological processes of the past and present, as well as endogenous neotectonic processes, it should be properly mapped. Lithology and geological structure, forming the morphostructural framework of landform development, merit full attention, also. These factors have a profound effect on forms and processes occurring to date.

3. *Morphometrical information*. Topographical (contour) maps give much essential information in this respect therefore, the geomorphological map can best be printed on an orohydrographical base, but certain geomorphologically important data, such as height of trough shoulders or river terraces, must be added. Slope steepness is another important element contributing to an understanding of the geomorphological situation.

4. *Morphochronological information*. Since every form is characterized by the period of its formation and further development, it is essential to make a distinction between forms of different ages, in particular between recent forms and those inherited from earlier periods when different climatic conditions prevailed. It is essential to keep age indications flexible since it is this part of the map that is most apt to need revision with the advance of geomorphological knowledge.'

Fleisher (1984, p. 174) notes that maps showing the locations of past slope movements commonly are used as the basis for depicting the potential for future