



**Computer-Based Modelling and Analysis in
Engineering Geology**

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**A thesis submitted in partial fulfilment of the
requirements for the degree of Doctor of Philosophy**

PhD by Publication Supporting Statement

**School of Earth and Environmental Sciences
University of Portsmouth**

2014

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Abstract

This body of work presents the research and publications undertaken under a general theme of computer-based modelling and analysis in engineering geology. Papers are presented on geotechnical data management, data interchange, Geographical Information Systems, surface modelling, geostatistical methods, risk-based modelling, knowledge-based systems, remote sensing in engineering geology and on the integration of computer applications into applied geoscience teaching.

The work highlights my own personal contributions and publications under this theme as well as collaborations and output emanating from PhD co-supervisions which have included the following projects: *A geotechnical and geochemical characterisation of dry oil lake contaminated soil in Kuwait; Dust dispersion monitoring and modelling; Geotechnical properties of chalk putties; The application of airborne multispectral remote sensing and digital terrain modelling to the detection and delineation of landslides on clay dominated slopes of the Cotswolds Escarpment; Domestic property insurance risks associated with brickearth deposits; Development of a knowledge-based system methodology for designing solid waste disposal sites in arid and semi-arid environments; GIS Techniques as an aid to the assessment of earthquake triggered landslide hazards; The application of GIS as a data integrator of pre-ground investigation desk studies for terrain evaluation and investigation planning; The influence of clay mineralogy pore water composition and pre-consolidation pressure on the magnitude of ground surface heave due to rises in groundwater level.*

My publication record comprises; Pathfinder and seminal papers; Papers from co-supervised PhD programmes; Pedagogic contributions; Encyclopaedia entries; International collaborations; Technical authorship and support; Other published contributions; Confidential development and technical reports and Internal briefing papers.

Declaration

Whilst registered as a candidate for the above degree, I have not been registered for any other research award. The results and conclusions embodied in this thesis are the work of the named candidate and have not been submitted for any other academic award.

23,563 Words (including list of publications and citations)

Document History

Ver. 1.0	March 2014	Initial submission.
Ver. 1.1	October 2014	Final submission with corrections.

Acknowledgments

For Christine, Holly and Milly

The presentation of this work, representing a 29 year period of my career in Engineering Geology and Geotechnics, has been made possible by the continual support and encouragement from Christine, Holly and Milly who have made sure that I did not deviate from the task.

I would also like to pay tribute to my early employers, Scott Pickford Associates, NERC Computer Services, the British Geological Survey and Mott MacDonald where many of these computer applications described in my publications were first developed and supported. These were companies and organisations that were ahead of their time in recognising the significance and applicability of computer-based modelling in the geosciences.

My thanks also to Professor John Vail who also recognised the need for developing undergraduate geoscience courses in computing and recruited me to the then Department of Geology to initiate and develop such courses at Portsmouth. My early collaborations with John Whalley firmly established computer-based methods in geology as a core part of the Portsmouth curriculum.

Finally my thanks to Dr Dave Martill for his support, as my Academic Mentor, throughout the formal submission process.

David Giles February 2014

I would additionally like to thank my three External and Internal Examiners; Professor Rory Mortimore, Professor Paul Nathanail and Professor Jim Smith for a thoroughly rigorous and testing *viva voce*.

David Giles October 2014

1.0 Introduction

Throughout my career I have been actively involved in the research, development, publication and dissemination of work in the field of computer-based modelling and analysis engineering geology. This submission includes a series of published papers, abstracts, data interchange standards and formats together with a selection of other technical reports, manuals and briefing notes to demonstrate my leading and significant contribution to this field and to the innovative developments that I have made within it.

My early pathfinder research work involved the development of data management systems for geotechnical data within the ground engineering industry. This work culminated in the creation of a commercial product for geotechnical data management and analysis which was marketed by Mott MacDonald Ltd. In turn this led to the definition of a digital data interchange format for the electronic transfer of geotechnical data. This was published via the then Association of Geotechnical Specialists and is now a global industry standard for the interchange of geotechnical data. At the time this work was at the cutting edge of such developments in ground engineering and geotechnics.

Subsequent research considered the spatial modelling of geotechnical and geological data specifically utilising geostatistical techniques. Again new and innovative work on major construction projects such as the London Water Ring Main and the Channel Tunnel Rail Link led to several technical publications on these, as then new to ground engineering, modelling techniques, many of which have now become industry standard practices.

On joining the University of Portsmouth in 1991 I further developed and published my research in the outlined theme with significant work in the areas of Geographical Information Systems (GIS) in engineering geology together with the use and application of remotely sensed imagery for the applied geosciences. This work has extended into the use of LiDAR techniques for engineering geological applications as well as the use of Knowledge-Based Systems (KBS).

Throughout my academic career I have published widely with my co-supervised MPhil and PhD students together with other international collaborations. This work has included the

following projects: *A geotechnical and geochemical characterisation of dry oil lake contaminated soil in Kuwait; Dust dispersion monitoring and modelling; geotechnical properties of chalk putties; The application of airborne multispectral remote sensing and digital terrain modelling to the detection and delineation of landslides on clay dominated slopes of the Cotswolds Escarpment; Domestic property insurance risks associated with brickearth deposits; Development of a knowledge-based system methodology for designing solid waste disposal sites in arid and semi-arid environments; GIS techniques as an aid to the assessment of earthquake triggered landslide hazards; The Application of GIS as a data integrator of pre-ground investigation desk studies for terrain evaluation and investigation planning; The influence of clay mineralogy pore water composition and pre-consolidation pressure on the magnitude of ground surface heave due to rises in groundwater level.* This submission outlines my contributions to the publications emanating from this research.

My publication record can be considered as comprising Pathfinder and seminal papers; Papers from co-supervised PhD programmes; Pedagogic contributions; Encyclopaedia entries; International collaborations; Technical authorship and support; Other published contributions; Confidential development and technical reports and Internal briefing papers.

In summary my work to be submitted for consideration for the award of PhD by Publication includes research and publication in geotechnical data management and data transfer, geostatistics and spatial data modelling, hazard and risk analysis, Knowledge-Based Systems, Geographical Information Systems and remote sensing, all within the themed framework of Computer-Based Modelling and Analysis in Engineering Geology. Much of this work when undertaken and published was at the leading edge of such research and developments in the field of engineering geology.

1.1 Co-Supervised PhD and MPhil Research Programmes

Humoud Helfi Zayed Al-Daihani PhD. *A geotechnical and geochemical characterisation of dry oil lake contaminated soil in Kuwait*. Self-funded. 2010 – Current (Paul Watson & David Giles)

Provided specific support for spatial modelling, risk modelling, ground model development and contaminated land characterisation.

Ben Williams PhD. *Dust dispersion monitoring and modelling*. Funded by Grundon Plc. 2008 – Current (Mike Fowler & David Giles)

Provided specific support for spatial visualisation and geostatistical analysis.

Stephen Bundy PhD. *Geotechnical properties of chalk putties*. Funded by University of Portsmouth. 2006 – 2013 (Paul Watson, Steven Mitchell & David Giles)

Provided specific support for Chalk stratigraphy, lithology and engineering geology.

Malcolm Whitworth PhD. *The application of airborne multi-spectral remote sensing and digital terrain modelling to the detection and delineation of landslides on clay dominated slopes of the Cotswolds Escarpment, Worcestershire, United Kingdom*. Self-funded. 1995 – 2006 (Bill Murphy & David Giles)

Provided specific support for landslide geomorphology, remote sensing and image analysis techniques, ground model development.

David Fall PhD. *Domestic property insurance risks associated with brickearth deposits of Southern Britain*. Association of British Insurers Studentship. 1995 – 2004 (Nick Langdon & David Giles)

Provided specific support for GIS, spatial modelling and Quaternary Ground Models.

Sindila Mwiya PhD. *Development of a knowledge-based system methodology for designing solid waste disposal sites in arid and semi-arid environments*. Funded by BGR Germany. 2000 – 2003 (David Hughes & David Giles)

Provided specific support for Computer modelling, risk assessment and contaminated land characterisation.

Joe Mankelow PhD. *GIS techniques as an aid to the assessment of earthquake triggered landslide hazards*. RAE Funded. 1994 – 1998 (Bill Murphy & David Giles)

Provided specific support for GIS development and probabilistic modelling.

Robert Barnes MPhil. *The application of GIS as a data integrator of pre-ground investigation desk studies for terrain evaluation and investigation planning*. HEFCE Funded. 1993 – 1996 (Nick Langdon & David Giles)

Provided specific support for GIS development.

Jason Drake MPhil. *The influence of clay mineralogy pore water composition and pre-consolidation pressure on the magnitude of ground surface heave due to rises in groundwater level*. PCFC Funded. 1991 – 1996 (Nick Walton & David Giles)

Provided specific support for engineering geological aspects.

2.0 Published Journal and Conference Papers

Input Levels: *Sole author, Minor, Significant, Extensive*

Giles, D.P. (1992). The geotechnical computer workstation: The link between the geotechnical database and the geographical information system. *Proceedings of the Colloque International: Géotechnique et Infomatique* (pp. 685-690). Presses de l'Ecole Nationale des Ponts et Chaussées, Paris, France.

Sole author.

Association of Geotechnical Specialists (1992). *Electronic transfer of geotechnical data from ground investigations*, (1st Edition). Association of Geotechnical Specialists, London, UK. Working Party Members: Duncumb, R., **Giles, D.**, Holehouse, R., Hutchinson, R., Perry, J., Threadgold, L., Walthall, S. & Zytynski, M.

Extensive contribution to text; Extensive conceptual input. Extensive editing of text.

Giles, D.P. (1993). Geostatistical interpolation techniques for geotechnical data modelling and ground condition risk and reliability assessment. In B.O. Skipp (Ed.), *Risk and reliability in ground engineering* (pp. 202-214). Thomas Telford, London, UK.

Sole author.

Giles, D.P. (1994a). A digital data standard for the electronic transfer of geotechnical data from ground investigations. In R. Oliveira, L.F. Rodrigues, A.G. Coelho & A.P. Cunha, A.P. (Eds.), *Proceedings of the 7th Congress of the International Association of Engineering Geology*, VI, (pp. 4563-4568). Lisbon, Portugal.

Sole author.

Giles, D.P. (1994b). Geological surface modelling utilising geostatistical algorithms for tunnelling window delineation - a case study from the London Water Ring Main. In R. Oliveira, L.F. Rodrigues, A.G. Coelho & A.P. Cunha, A.P. (Eds.), *Proceedings of the 7th Congress of the International Association of Engineering Geology*, VI, (pp. 4581-4589). Lisbon, Portugal.

Sole author.

Giles, D.P. (1994c). A geographical information system for geotechnical and ground investigation data management and analysis. *Proceedings of the 5th European Conference and Exhibition on Geographical Information Systems, EGIS*, (pp. 766-778). Paris, France.

Sole author.

Giles, D.P. & Whalley, J.S. (1994). Computer-based activities in engineering geology training. In R. Oliveira, L.F. Rodrigues, A.G. Coelho & A.P. Cunha, A.P. (Eds.), *Proceedings of the 7th Congress of the International Association of Engineering Geology*, VI, (pp. 4845-4851). Lisbon, Portugal.

Extensive contribution to text; Extensive conceptual input.

Association of Geotechnical Specialists (1994). *Electronic transfer of geotechnical data from ground investigations*, (2nd Edition). Association of Geotechnical Specialists, London, UK. Working Party Members: Duncumb, R., **Giles, D.**, Holehouse, R., Hutchinson, R., Perry, J., Swales, J., Threadgold, L., Walthall, S. & Zytynski, M.

Extensive contribution to text; Extensive conceptual input. Extensive editing of text.

Drake, J.J., Giles, D.P., Murphy, W. & Walton, N.R.G. (1994). Rising groundwater levels at Fawley, Hants. In R. Oliveira, L.F. Rodrigues, A.G. Coelho & A.P. Cunha, A.P. (Eds.), *Proceedings of the 7th Congress of the International Association of Engineering Geology*, IV, (pp. 2895-2903). Lisbon, Portugal.

Minor editing of text.

Giles, D.P. (1995). The integration of GIS and geostatistical modelling for a tunnelling geohazard study. *Proceedings of the 1st Joint European Conference on Geographical Information, JEC-GI*, Vol. 1. (pp. 421-426). Basel, Switzerland.

Sole author.

Barnes, R.C., Giles, D.P., Johnson, P.B. & Langdon, N.J. (1995). Geographical information systems as data integrators for pre-ground investigation studies in the urban environment. *Euroconference GIS*, University of Karlsruhe, Union Europeenne, Projet Capital Humain et Mobilite, DG XII, ENSG, St. Mandé, France.

Extensive editing of text; Significant conceptual input.

Morgan, A., Giles, D.P. & Walton, N.R.G. (1995). Topsoil thickness modelling using GIS for the purpose of assessing risks from underlying contaminated material on Hope Cottage Allotments, Portsmouth. *Euroconference GIS*, University of Karlsruhe, Union Europeenne, Projet Capital Humain et Mobilite, DG XII, ENSG, St. Mande, France.

Extensive contribution to text; Extensive conceptual input.

Giles, D.P., Morgan, A. & Darlow, P. (1996, December). On contaminated ground. *GIS Europe*, 20-22.

Extensive contribution to text; Extensive conceptual input.

Fall, D., Giles, D.P. & Langdon, N.J. (1996). GIS for the modelling and analysis of domestic property insurance risk associated with potentially collapsible soils of southern Britain. *Proceedings of the 2nd Joint European Conference on Geographical Information, JEC*, (pp. 338-341). IOS Press, Netherlands.

Extensive editing of text; Significant conceptual input.

Whalley, J.S. & Giles, D.P. (1996). A spreadsheet-based, problem-orientated approach to computing for earth scientists. In D.A.V. Stow & G.J.H. McCall (Eds.). *Geoscience education and training in schools and universities, for industry and public awareness*. Joint Special Publication of the Commission on Geoscience Education and Training of the International Union of Geological Sciences and the Association of Geoscientists for International Development, AGID Special Publication Series, 19, (pp. 537-542).

Significant contribution to text; Extensive conceptual input.

Moran, J., Langdon, N.J. & Giles, D.P. (1996). *Geotechnical computer assisted learning, Strand 3, Site investigation*. Teaching and Learning Technology Programme. Higher Education Funding Council.

Significant conceptual input.

Moran, J.A., Langdon, N.J. & Giles, D.P. (1997a). Computer aided learning for realistic undergraduate professional experience in site investigation. *Proceedings of the 2nd Working Conference on Engineering Education: Professional Standards and Quality in Engineering Education*, (pp. 257-262), Sheffield Hallam University, Sheffield, UK.

Minor editing of text; Significant conceptual input.

Moran, J.A., Langdon, N.J. & Giles, D.P. (1997b, November). Can site investigation be taught? *New Civil Engineer International*, 29-36.

Minor editing of text; Significant conceptual input.

Moran, J.A., Langdon, N.J. & Giles, D.P. (1997c). Can site Investigation be taught? *Proceedings of the Institution of Civil Engineers, Civil Engineering*, 120, (Paper 11118), 111-118.

Minor editing of text; Significant conceptual input.

Giles, D.P. (1998). A digital data standard for the interchange of geotechnical and geoenviromental data. In A. Buccianti, G. Nardi & R. Potenza (Eds.), *Proceedings of the 4th Annual Conference of the International Association for Mathematical Geology*, (pp. 683-687). Ischia, Italy.

Sole author.

Plunkett, J.S., Giles, D.P. & Langdon, N.J. (1998). A brief review of the use of risk assessment software for the characterization of contaminated land. *Proceedings of the 6th International TNO/BMFT Conference on Contaminated Soil: Consoil 98*, (pp. 1027-1028). Thomas Telford, London, UK.

Significant editing of text; Significant conceptual input.

Mankelaw, J., Giles, D.P. & Murphy, W. (1998). Probability density function modelling for earthquake-triggered landslide hazard assessments. In A. Buccianti, G. Nardi & R. Potenza (Eds.), *Proceedings of the 4th Annual Conference of the International Association for Mathematical Geology*, (pp. 241-246). Ischia, Italy.

Significant editing of text; Significant conceptual input. Assisted with data interpretation.

Association of Geotechnical Specialists (1999). *Electronic transfer of geotechnical data from ground investigations*, (3rd Edition). Association of Geotechnical Specialists, London, UK. Working Party Members: Duncumb, R., **Giles, D.**, Holehouse, R., Hutchinson, R., Perry, J., Threadgold, L., Walthall, S. & Zytynski, M.

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Plunkett, J.S., Walton, N., Giles, D.P. & Langdon, N.J. (1999). Risk assessment revisited: A review of contaminated land risk assessment using data from a known contaminated site in Portsmouth, UK. In Goossens, L.H.J. (Ed.) *Proceedings of the 9th Annual Conference on Risk Analysis: Facing the New Millennium*, Rotterdam, (pp. 227-230). Delft University Press, Netherlands.

Significant editing of text; Significant conceptual input.

Whitworth, M., Murphy, W., Giles, D.P. & Petley D.N. (2000). Historical constraints on slope movement age: a case study at Broadway, United Kingdom. *The Geographical Journal*, 166(2), 139-155.

Significant editing of text; Significant conceptual input; Assisted with data collection and data interpretation.

Whitworth, M.C.Z., Giles, D.P., Murphy, W. & Petley, D.N. (2000). Spectral properties of active, suspended and relict landslides derived from Airborne Thematic Mapper imagery. In E. Bromhead, N. Dixon & M-L. Ibsen, (Eds.), *Landslides in research, theory and practice, Proceedings of the 8th International Symposium on Landslides*, (pp. 1569-1574). Thomas Telford, London, UK.

Significant editing of text; Significant conceptual input; Assisted with data collection and data interpretation.

Whitworth, M.C.Z., Giles, D.P., & Murphy, W. (2001). Identification of landslides in clay terrains using Airborne Thematic Mapper (ATM) multispectral imagery. *Proceedings of the 8th International Symposium on Remote Sensing*, 4545 (pp. 216-224). SPIE, Toulouse, France.

Significant editing of text; Significant conceptual input; Assisted with data collection and data interpretation.

Mrabet, Z. & Giles, D. (2001). Modelling uncertainties in the stationary seepage problem. In C.A. Brebbia, P. Anagnostopoulos & K.L. Katsifarakis (Eds.), *Water Resources Management, Progress in Water Resources*, (Vol 4, pp. 311-320). Wessex Institute of Technology Press, Ashurst, UK.

Major technical editing of text.

Mrabet, Z. & Giles, D. (2002a). Probabilistic risk assessment: The tool for uncertainty reduction in geotechnical engineering. In C.A. Brebbia (Ed.), *Risk Analysis III, Transactions of the Wessex Institute of Technology, Ecology and the Environment*, (Vol 100, pp. 3-13). Wessex Institute of Technology Press, Ashurst, UK.

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Mrabet, Z. & Giles, D. (2002b). Reliability analysis of earth fills using stochastic methods. *Proceedings of the 3rd International Conference on Mathematical Methods in Reliability: Methodology and Practice*, (pp. 469-472). Trondheim, Norway.

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Whitworth, M., Giles, D., & Murphy, W. (2002). Landslides of the Cotswolds escarpment, Broadway, Worcestershire, UK. *Proceedings of the Cotteswold Naturalists' Field Club*, XLII(2), 118-127.

Significant editing of text; Significant conceptual input; Assisted with data collection and data interpretation.

Giles, D.P. (2004). Geotechnical engineering. In R.C. Selley, L.R.M. Cocks & I.R. Plimer, (Eds.), *The Encyclopaedia of Geology*, (Vol. 3, pp. 100-105). Elsevier.

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Mwiya, S. & Giles, D. (2004). A knowledge-based approach to municipal solid waste disposal site development in the Kartsified Dolomitic terrain around the town of Tsumeb in North Central Namibia. *Communications Geological Survey of Namibia*, 13, 9-21.

Major editing of text; Significant conceptual input.

Mwiya, S., Hughes, D.J. & Giles, D. (2004). Strategies for identifying and designing safe, economic municipal solid waste disposal sites in the arid zones of Southern Africa. *Proceedings of Waste 2004: Integrated Waste Management and Pollution Control: Policy and Practice, Research and Solutions*, (pp. 253-264). Warwick, UK.

Major editing of text; Significant conceptual input.

Whitworth, M.C.Z., Giles, D.P. & Murphy, W. (2005). Airborne remote sensing for landslide hazard assessment: a case study on the Jurassic escarpment slopes of

Worcestershire, United Kingdom. *Quarterly Journal of Engineering Geology and Hydrogeology*, 38(3), 285-300.

Extensive editing of text; Extensive conceptual input; Assisted with data collection and data interpretation.

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Minor editing of text; Assisted in data collection and interpretation.

Whitworth, M.C.Z., Giles, D.P. & Anderson, I. (2006). Landslide imaging techniques for urban geoscience reconnaissance. *Engineering Geology for Tomorrow's Cities*. The 10th IAEG Congress, Nottingham, UK. Paper No. 245.

Minor editing of text.

Giles, D.P. & Whitworth, M.C.Z. (2006). Training and education of engineering geologists for the new urban challenges in applied geosciences. *Engineering Geology for Tomorrow's Cities*. The 10th IAEG Congress, Nottingham, UK. Paper No. 244.

Extensive contribution to text; Extensive conceptual input.

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Minor contribution to text.

Giles, D.P. (2008). Digimap Case Study: *The Engineering geology and geological hazards of Ironbridge Gorge*. Retrieved from the Edina Digimap Website: <http://edina.ac.uk/digimap/casestudies/ironbridge/>

Sole author.

Wheeler, S., Chilton, S., Hodgson, I., Giles, D. & Whitworth, M. (2008). *The Geological Society's training guide for engineering geologists*. Retrieved from the Engineering Group of the Geological Society London Website:

<http://www.geolsoc.org.uk/gsl/site/GSL/lang/en/cgeol>

Extensive contribution to text; Extensive conceptual input.

Giles, D.P., Whitworth, M.C.Z. & Poulson, A.J. (2008). The development of fieldwork problem-based exercises in the Applied Geosciences. *Planet*, 20, 37-40.

Extensive contribution to text; Extensive conceptual input.

Giles, D.P. & Whitworth, M.C.Z. (2009). Training and education of engineering geologists for the new urban challenges in applied geosciences. In M. G. Culshaw, H. J. Reeves, I. Jefferson & T. W. Spink, (Eds.), *Engineering Geology for Tomorrow's Cities*. Geological Society London Engineering Geology Special Publication, 22, CD Paper No. 244.

Extensive contribution to text; Extensive conceptual input.

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5.0 Background and Context

5.1 The Development of Computers and Computer Applications in the Applied Geosciences over the last 30 Years (1983 – Present)

To put this body of work into context it is worthwhile considering the development of computing, computer applications and computer software over the last 30 years. Processing power and software applications that we take for granted today were very different in the mid 1980's and early 1990's when much of my pathfinder work was published. Analyses that would normally take seconds to run today would require many hours of processing time even on the latest and highest specification computers that were generally available.

Software applications, especially in the ground engineering industries, were in their infancy with only a limited number of often crude and cumbersome applications available. Microsoft Windows was a relatively new phenomenon with many programs still running in an MS-DOS environment. Software such as spreadsheets and databases were novel and often with disk space on hardware to store these packages and associated data extremely limited, with as little as 20 MBytes on a standard PC.

Much data was still plotted by hand and engineering calculations being undertaken with hand held calculators or even with slide rules. The culture of computing and utilising computer-based methods was also new, with much resistance to its uptake in many parts of the more traditional engineering disciplines such as geotechnics.

The Personal Computer itself was also a relatively new innovation, taking on the old cumbersome mainframes which did not lend themselves to the type of desk top analyses undertaken on a daily basis by geologists, engineering geologists and geotechnical engineers working in the geoscience industries.

The transfer of computer-based data was also very much in its early developmental stage. There was no Internet widely available, with JANET (Joint Academic Network) solely for the academic community and no World Wide Web and no common, uniformly used, file

transfer protocols with data often being delivered or transferred on complex formatted reel to reel tapes requiring specialist inputting and outputting. The floppy disk was a new phenomenon albeit with a very small storage capacity. Data was still transferred in a paper format with a typical site investigation taking up many volumes of material.

Table 5.1 outlines the key events and dates in the development of personal computing from 1976 to 2002 with Table 5.2 highlighting the significant software releases during this period (Computer History Museum, 2006; Zimmerman, 2012; La Morte & Lilly, 2013, Intel, n.d.).

Table 5.1 The development of personal computing (1976 – 2006) (Computer History Museum, 2006; Zimmerman, 2012; La Morte & Lilly, 2013, Intel, n.d.)

Date	Event	Significant Giles Publications and Work
1975	Microsoft founded IBM 5100 first available portable computer	
1976	Apple founded and release the Apple I	
1980	Microsoft DOS released	
1981	IBM release the first personal computer with the Intel 8088 microprocessor	
1982	Lotus Development Corporation release the Lotus 1-2-3 spreadsheet	
1983	IBM establishes the IBM Format PC with Intel microprocessors and Microsoft DOS	
1984	Apple introduces the Macintosh with the first GUI (Graphical User Interface)	
1985	Intel introduces the 386™ microprocessor, a 32-bit chip that allowed multitasking for the first time. Microsoft release the Windows operating system with a Graphical User Interface	<i>Geo-Graphics</i> : Seismic data management system (Giles, 1985, Papers Vol. 5)
1987	Toshiba introduces the T1000 Laptop PC	
1988	Recordable CD discs become available	
1990	The proto World Wide Web in development	<i>GDMS</i> : Geotechnical data management system (Giles, 1990b, Papers Vol. 5)
1991		London Water Ring Main geostatistical modelling (Giles, 1991a, Papers Vol. 4) Electronic transfer of geotechnical data from ground investigations: Geotechnical Data Interchange Format, (Giles, 1991c, Papers Vol. 3)
1992		Geotechnical computer workstation, (Giles, 1992, Papers Vol. 1)
1993	Intel introduces the Pentium™ microprocessor. Microsoft release Windows 3.1	
1994	Adobe founded	Computer-based activities in engineering geology, (Giles & Whalley, 1994, Papers Vol. 1)
1995	Microsoft launches Windows 95 and Internet Explorer	Raster-based GIS for contaminated land applications, (Morgan et al, 1995, Papers Vol. 1) Integration of GIS and geostatistics, (Giles, 1995, Papers Vol. 1)

1996	First DVD in circulation	Computer Assisted Learning (CAL) for engineering geologists and civil engineers, (Moran et al., 1996, Papers Vol. 1)
1997	Intel Pentium™ II released. Recordable and rewritable DVD discs become available	
1998		Risk assessment for contaminated land, (Plunkett et al., 1998, Papers Vol. 1) Probabilistic modelling for seismic hazard assessment, (Mankelow et al., 1998, Papers Vol. 1)
1999	Intel Pentium™ III released	
2000	Intel Pentium™ 4 released	Remote sensing for landslide geohazard assessment, (Whitworth et al., 2000, Papers Vol. 2)
2001	Microsoft release Windows XP	
2002	I billionth PC sold	
2004	Mozilla release Firefox 1.0	Knowledge-based systems for landfill site assessment, (Mwiya et al., 2004, Papers Vol. 2)
2006	Microsoft Windows 7 released to manufacturers	LiDAR for landslide geohazard assessment, (Whitworth et al., 2006, Papers Vol. 2)

Table 5.2 Significant software releases and events (1979 – 2010) (Computer History Museum, 2006; Zimmerman, 2012; La Morte & Lilly, 2013, Intel, n.d., Howland & Podolski, 1985; Howland, 1989; Rosenbaum & Warren, 1986, Deans et al., 1992; Howland, 2001)

Date	Event	Significant Giles Publications and Work
1972	Greater London Council develop a geological database of London boreholes via punched cards	
1979	VisiCalc for the Apple II released	
1981	MS-DOS for the IBM PC released	
1982	Lotus 1-2-3 spreadsheet released ESRI Arc/Info GIS for PC released ERDAS (Earth Resource Data Analysis System) image analysis and processing system released for PC released	
1983	Microsoft Word word processor released	
1984	Ashton Tate dBase III released	
1985	Aldus PageMaker Desk Top Publisher released C++ programming language released First computer generated borehole logs	<i>Geo-Graphics</i> : Seismic data management system (Giles, 1985, Papers Vol. 5)
1986	MIDAS (Mapping Display and Analysis System) released, first desktop GIS product for the MS-DOS operating system GINT borehole log plotting system developed in US	
1987	Apple Hypercard user interface released Microsoft Excel spreadsheet released	
1989	London Docklands Development Corporation develop PC based geotechnical database GEODASY	
1990	Microsoft Windows 3.0 released ER Mapper 1 image analysis and processing system for PC released Mapinfo for Windows mapping system released HTML first developed at CERN	<i>GDMS</i> : Geotechnical data management system (Giles, 1990b, Papers Vol. 5)
1991	Linux operating system released	London Water Ring Main geostatistical modelling (Giles, 1991a, Papers Vol. 4) Electronic transfer of geotechnical data from

		ground investigations: Geotechnical Data Interchange Format, (Giles, 1991c, Papers Vol. 3)
1992	AGS 1 st Edition Geotechnical Data Interchange File format published	Geotechnical computer workstation, (Giles, 1992, Papers Vol. 1)
1994	Adobe founded First PC based computer games	Computer-based activities in engineering geology, (Giles & Whalley, 1994, Papers Vol. 1)
1995	Microsoft launches Windows 95 and Internet Explorer AGS 2 nd Edition Geotechnical Data Interchange File format published	Raster-based GIS for contaminated land applications, (Morgan et al, 1995, Papers Vol. 1) Integration of GIS and geostatistics, (Giles, 1995, Papers Vol. 1)
1996		Computer Assisted Learning (CAL) for engineering geologists and civil engineers, (Moran et al., 1996, Papers Vol. 1)
1998		Risk assessment for contaminated land, (Plunkett et al., 1998, Papers Vol. 1) Probabilistic modelling for seismic hazard assessment, (Mankelow et al., 1998, Papers Vol. 1)
1999	AGS 3 rd Edition Geotechnical Data Interchange File format published	
2000	Sony release the PlayStation 2	Remote sensing for landslide geohazard assessment, (Whitworth et al., 2000, Papers Vol. 2)
2001	Microsoft release Windows XP	
2004	AGS 3.1 Edition Geotechnical Data Interchange File format published	
2009	Microsoft release Windows 7	
2010	AGS 4 th Edition Geotechnical Data Interchange File format published	

6.0 Geotechnical Data Management and Interchange

Databases and Data Interchange Formats

As part of my early career and publication history I made a significant contribution to the development of databases, data management systems and data transfer protocols for the storage and interchange of geological and geotechnical data. In the late 1980's and early 1990's development of these systems in geotechnics and ground engineering were in their infancy with systems mainly being developed to produce borehole logs rather than create relational databases for information retrieval (Howland 1989, 1992, 2001; Rosenbaum & Warren 1986; Deans et al. 1992). My contribution was novel and made significant advances in the management, retrieval, presentation and interpretation of such geotechnical data.

Whilst working at Scott Pickford Associates Ltd. I documented the company's seismic data management system, *<Geo-Graphics>* (Giles, 1985, Papers Vol. 5). This experience was extended on my employment by Mott MacDonald where I produced a commercial data management product, developed entirely by myself, namely *GDMS - Geotechnical Data Management System* (Giles, 1990b, 1990c, Papers Vol. 5) and was closely involved in the development and definition of a data interchange format for the electronic transfer of ground investigation data *Electronic transfer of geotechnical data from ground investigations, Association of Geotechnical Specialists* (AGS 1992, 1994, 1999, Papers Vol. 1). *GDMS* was one of the very first geotechnical data management systems commercially marketed in the UK. This work was formally described in papers presented at one of the first conferences on computers and geotechnics held in Paris; *The geotechnical computer workstation: The link between the geotechnical database and the geographical information system* (Giles, 1992, Papers Vol. 1) and at the 7th *International Association of Engineering Geology Conference* of 1994 in Lisbon; *A digital data standard for the electronic transfer of geotechnical data from ground investigations* (Giles, 1994a, Papers Vol. 1) as well as at the 4th *Annual Conference of the International Association for Mathematical Geology* in Italy; *A digital data standard for the interchange of geotechnical and geoenvironmental data* (Giles, 1998, Papers Vol. 1).

This pathfinder work has ultimately led to the publication of several updated versions of the format and current ground industry wide usage of these protocols (Association of Geotechnical and Geoenvironmental Specialists, 2005, 2010). This developmental work with the AGS is now currently being formalised into a British Standard Code of Practice BS 8574:2014 *Code of practice for the management of geotechnical data for ground engineering projects* (British Standards Institution, 2014).

In the late 1980's many major ground investigations were still being presented solely in a paper format, often running to many volumes, and not in a format which could easily and quickly be processed, analysed and presented further. Whilst at Mott MacDonald Ltd. two key projects were identified as having the potential to firstly generate a significant volume of descriptive and geotechnical data and secondly as having a need to much more effectively manage, present, interpret and share that data. These two projects, the Barking Reach Redevelopment and Jubilee Line Extension investigations in London were chosen to be the research and development test bed for the design and development of a database and data management system for the geotechnical data produced by the site investigations. Internal briefing and review papers such as *Mott MacDonald Geotechnical Database – an overview* (Giles, 1990a, Papers Vol. 3), *A review of the Mott MacDonald Geotechnical Data Management System* (Giles, 1990d, Papers Vol. 3), *Relational databases and geotechnical data management* (Cann and Giles, 1991, Papers Vol. 3) were prepared and have been included to demonstrate this research, its nature, innovation and contribution to knowledge that this work was part of. Subsequently the *Mott MacDonald Geotechnical Data Management System* was produced written in *dBase IV* and a very early version of *Grapher* (Giles, 1990b, Papers Vol. 3, 1990c, Papers Vol. 5) which was commercially marketed by Mott MacDonald Ltd. Figs. 6.1, 6.2 and 6.3 show the database control and data input screens from the developed program with Fig. 6.4 showing a typical graphical output from *Grapher*. Table 6.1 details some of the major site investigation projects which utilised the *Geotechnical Data Management System* developed by myself.

In order to receive data into the database from the ground investigation contractors an electronic geotechnical data interchange format was required. The impetus from the Jubilee Line Extension along with other major projects on the horizon such as HS1, or as was then the Channel Tunnel Rail Link (Riordan, 2003), led to the Association of Geotechnical Specialists (AGS) establishing a working party to formulate, design and implement such a

system for geotechnical data transfer (Anon, 1991 June; Anon, 1991, July / August; Giles, 1991b, Papers Vol. 3, 1991c, Papers Vol. 3). The product of this working party was the Association of Geotechnical Specialists (1992, Papers Vol. 1) *Electronic transfer of geotechnical data from ground investigations*, (1st Edition). Association of Geotechnical Specialists, London, UK. *Working party members Duncumb, R., Giles, D., Holehouse, R., Hutchinson, R., Perry, J., Threadgold, L., Walthall, S. & Zytynski, M.* This work was followed by second and third editions with modifications added after a period of industry testing (Association of Geotechnical Specialists, 1994, 1999). This work became the definitive set of protocols, rules and format for the interchange of geotechnical data both in the UK (Toll et al., 2001; Waltham and Palmer, 2006) and internationally (Chadwick et al., 2006; Chandler, 2011) being adopted in the USA by Bectel Inc. (Walthall & Waterman, 2006), China (Li et al., 2012), New Zealand (New Zealand Geotechnical Society (2012), Hong Kong (Plant et al., 1998; Swales et al., 2010), Abu Dhabi (Municipality of Abu Dhabi City, n.d.), Malaysia (Gue & Tan, 2003) and Australia (Roads and Traffic Authority of New South Wales, 2007) for example. Currently the format is at Version 4 being released in May 2010 (Association of Geotechnical and Geoenvironmental Specialists, 2010).

My direct involvement with the working party was significant in the development of these protocols and I was instrumental and a key individual in their overall definition and production (Pers. Comm. L. Threadgold, AGS, 1992, Fig 6.5).

Fig. 6.6 demonstrates the original work undertaken by myself in defining the first data structures for the AGS Geotechnical Data Interchange Format. Figs. 6.7, 6.8 and 6.9 detail the subsequently developed format and associated data structures.

The format has been adopted for the British Geological Survey's National Geotechnical Properties Database (British Geological Survey, n.d.) as well as by the National Laboratory Service (2009) and the Highways Agency (Power et al., 2012; Highways Agency 2003a; 2003b). It has been used on such major projects as HS1 (Riordan, 2003) and CrossRail (Torp-Petersen & Black, 2001; Chmelina et al., 2013). Today no significant ground investigation is undertaken in the UK without data being generated and transferred between all interested parties in the AGS Geotechnical Data Interchange Format.

This work has ultimately led to the Association of Geotechnical and Geoenvironmental Specialists internationalizing its initiative to create a universal data transfer format (DIGGS; Data Interchange for Geotechnical and Geoenvironmental Specialists) (AGS, 2007). *DIGGS* is intended to extend the data transfer format not only to other countries, but also to other parts of the geotechnical industry, such as piling and infrastructure management. It has been based on the AGS Geotechnical Data Interchange Format, which, according to the AGS, is the only truly international data transfer format in use (AGS, 2007).

Other database research involved the scoping and establishment of a geological database for the London Water Ring Main tunnelling project (Giles, 1990e, Papers Vol. 3). This resource was used further for aspects of the high speed Channel Tunnel Rail Link ground investigation and ground modelling (Giles, 1994d, Papers Vol. 4).

Table 6.1 Examples of major engineering projects utilising the Geotechnical Data Management System (Giles, 1990b, 1990c)

Project	Client	Site	Holes	Notes
Barking Reach Redevelopment	Barking Reach Accord	Barking Reach, East London	296	Geotechnical study of a proposed redevelopment of a 200 hectare site for light industrial use and housing. Database used for the management of the large amounts of geotechnical data arising out of the project both from existing information on the site and data from new investigations. Database used for analysis of all relevant data and for the production of appropriate interpretive plots for the final report. Database latterly used for efficient distribution of data to prospective developers of the site.
Heathrow Express Rail Link	Heathrow Airport Ltd	Heathrow Airport, London	274	Geotechnical study for a high speed rail link between Paddington Station and the Central Terminal Area at Heathrow Airport. The geotechnical database was used for general ground investigation data management and for data analysis and interpretation for the final report. Database also extensively used for a rapid and detailed production for a range of geotechnical properties to be included in a prequalification document issued to contractors for budget construction estimates.

The Lunt Junction Interchange	Department of Transport	Lunt Junction, Bilston, West Midlands	131	Assessment of the geotechnical properties and contamination of an area previously used for heavy industry, coal extraction and sewage treatment. The database was used to manage the ground investigation data and to determine the distribution and types of fill (made ground) on the site. The analytical aspects of the data management system were used to determine the geotechnical properties and nature of the fill types, to assess contamination levels, and to provide data for assessment of quantities of unsuitable material that will have to be removed from the site. Extensive use of the cross-sectioning capabilities of the software were made.
A10 Wadesmill, High Cross & Colliers End	Department of Transport	Ware to Puckeridge, Hertfordshire	124	Geotechnical and geological study for a proposed 7.5 km dual carriageway replacement of the existing A10 between Ware and Puckeridge. The database was used for general ground investigation management and to aid the engineer in the clarification of the geology along the route and to delineate the extent of the various soil types encountered, in this case a variety of glacial deposits. The system was used to classify the acceptability of the materials encountered within cuttings for use in embankments. All interpretive graphs for the final report were produced by the data management system.
River Calder Diversion	West Yorkshire Metropolitan County Council	Welbeck, West Yorkshire	N/A	A major land reclamation project which involved the diversion of the River Calder. Database being used for general data analysis and interpretation.

London Water Ring Main Stages 4/5	Thames Water Authority	Barren Hill to Ashford Common	N/A	Geotechnical and geological study of the proposed tunnel alignment for Stage 4 and 5 of the London Water Ring Main. The database used for general stratigraphic data management, geological interpretation for a regional structural analysis and for a geological risk analysis study.
Dhaka Regional Subsidence Study	Water & Sewerage Authority of Dhaka	Dhaka, Bangladesh	N/A	Major geotechnical investigation forming part of a regional subsidence study of the city of Dhaka covering 14000km ² .
Jubilee Line Extension	London Underground Ltd	Green Park to Canada Water, London	491	Geotechnical investigations for the extension of the Jubilee Line. Database established from ground investigation for data management and the production of the interpretive report with appropriate data analysis and plotting.
A34 Newbury Bypass	Highways Agency	Newbury, Berks	N/A	Geotechnical investigation for the A34 Newbury Bypass ground investigation incorporating new boreholes from the project.
West Kowloon Airport Extension	Airport Authority, Honk Kong	Hong Kong	N/A	Database structure established for the new Hong Kong Airport.
Trafford Park Development, Irlam, Manchester	Trafford Park Development Corporation	Trafford Park, Manchester	N/A	Database established to incorporate and manage the large number of available historic borehole logs to be integrated with new investigation data.

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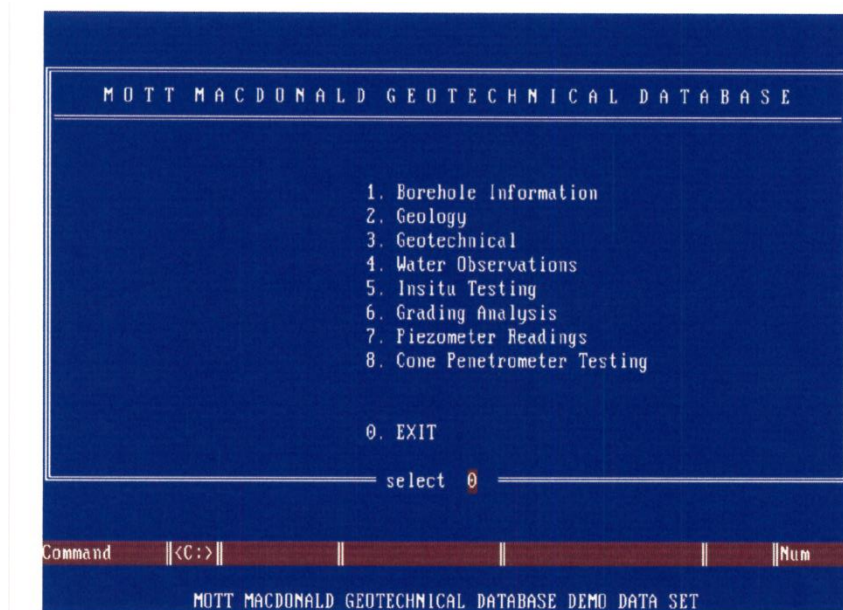


Figure 6.1. Mott MacDonald Geotechnical Data Management System Start-up screen (Giles, 1990c)

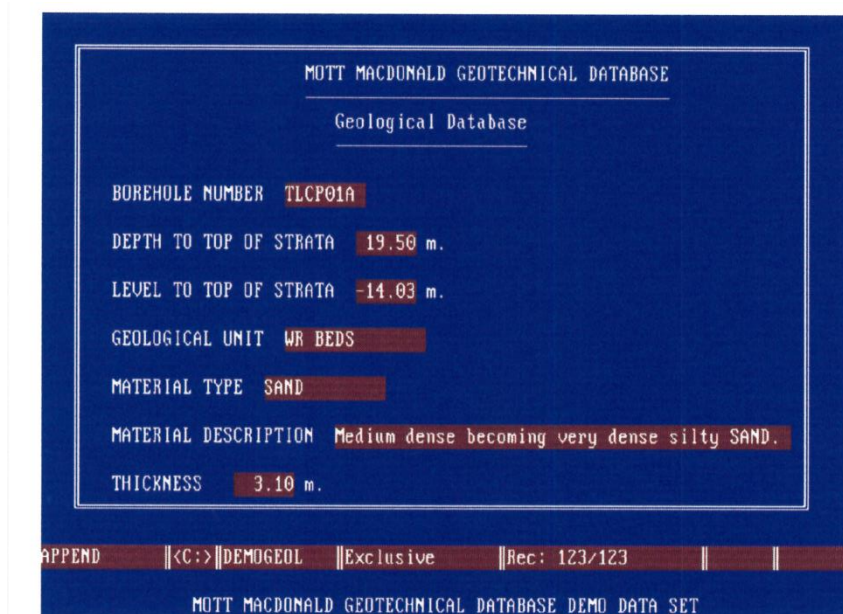


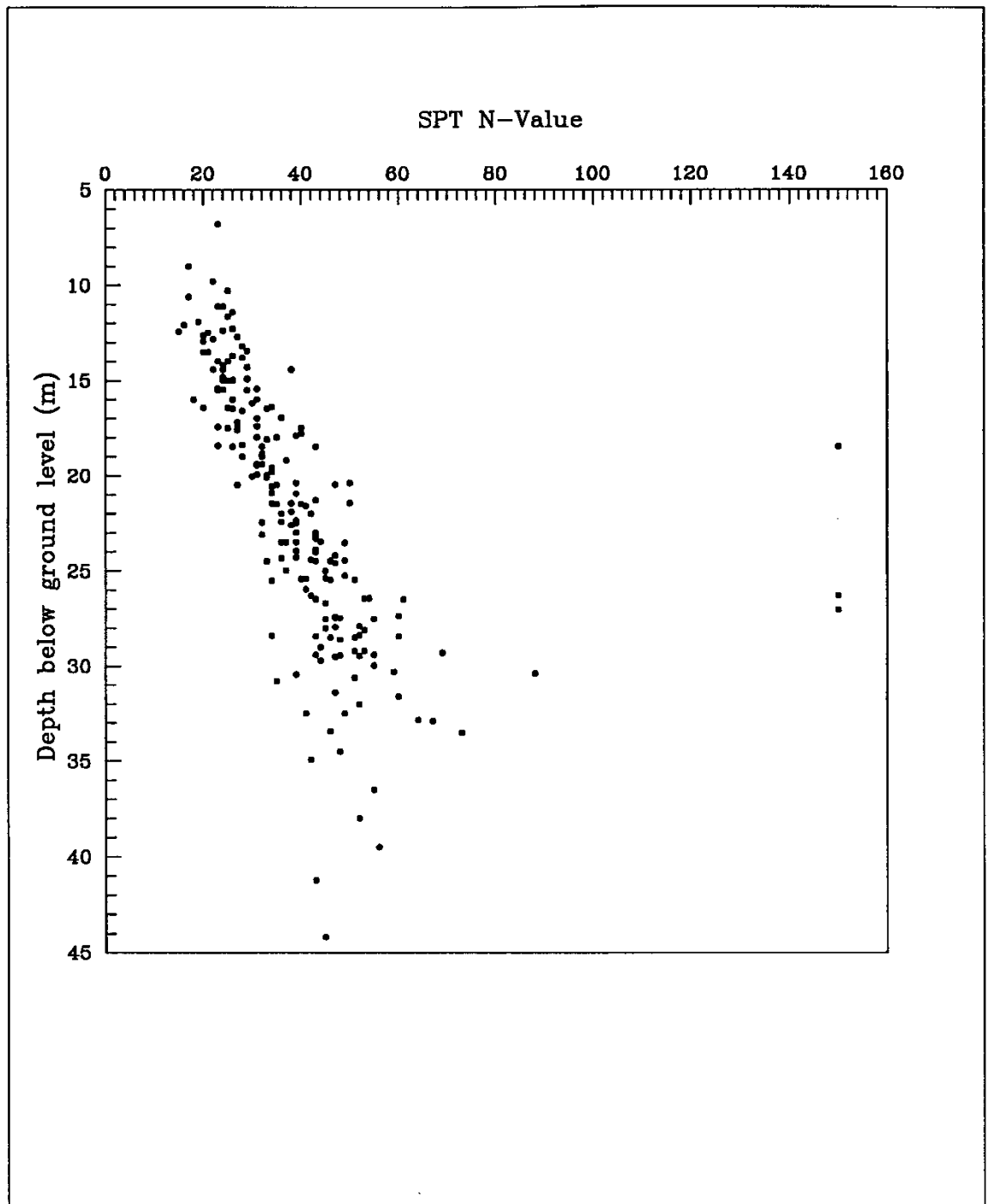
Figure 6.2. Mott MacDonald Geotechnical Data Management System Geological Database data input screen (Giles, 1990c)

MOTT MACDONALD GEOTECHNICAL DATABASE			
Laboratory Test Results			
BOREHOLE NAME	GE18	SAMPLE DEPTH	12.00
		SAMPLE LEVEL	-11.51
INDEX TESTS	MC 31.0 %	LL 66.0 %	PL 23.0 %
		PI 43.0 %	
	BULK UNIT WT.	19.9 kN/m ³	DRY UNIT WT.
		15.2 kN/m ³	
	SPECIFIC GRAVITY	0.00	
STRESS TESTING	TEST TYPE CU38T	C 182 kPa	PHI 0 Degrees
SOIL CHEMICAL TESTS	PH 0.0	TOT. S03 0.000 %	AQ. S03 0.000 g/l
OEDOMETER TESTS	Mv 0.0000	m ² /MN @100kPa Above Overburden Pressure	
	Cv 0.0000	m ² /YEAR	

APPEND <<C:> DEMOGEOT Exclusive Rec: 67/68

MOTT MACDONALD GEOTECHNICAL DATABASE DEMO DATA SET

Figure 6.3. Mott MacDonald Geotechnical Data Management System Laboratory Test Results data input screen (Giles, 1990c)




Title An Example of SPT N-Value Against Depth					 Mott MacDonald Mott MacDonald Civil Limited St Anne House, 20-22 Wallasey Road Croydon CR9 2UL Telephone 081-686 5041 Fax 081-681 5706 / 656 1814 Telex 917241 MOTTAY G
Date 16/05/90	Drawn DPG	Checked	Approved	Scale	Figure no. Fig 1

Figure 6.4. Mott MacDonald Geotechnical Data Management System example of a data output plot (Giles, 1990c)

AGS ASSOCIATION OF GEOTECHNICAL SPECIALISTS

Please reply to:

The Geotechnical Centre
203 Torrington Avenue
Tile Hill
Coventry CV4 9AP

Our Ref : LT/ALB
Date : 18th June 1992

Mr D Giles
Portsmouth Polytechnic
Faculty of Science
Department of Geology
Burnaby Building
Burnaby Road
Portsmouth
PO1 3QL

Dear David

Electronic Transfer of Geotechnical Data from Ground Investigations

At long last I can write to you confirming that the above document, complete with disk, is now available.

Quite a number have been ordered and copies sent out although the disk and wallet is being sent separately to those who placed initial orders and have only received the printed document. An article is appearing in the latest edition of the AGS newsletter together with an advertisement. It is hoped that similar items will appear in the technical press over the next few months. It has already been widely welcomed.

A paper based on the document has been prepared by myself and Rodney and submitted to the Paris Conference on behalf of the Working Party. We have not yet heard whether it has finally been accepted, although our synopsis was accepted earlier; if it is, I hope to be going to wave the flag.

I would like to take this opportunity to thank you most sincerely both personally and on behalf of the AGS for all your efforts and enthusiasm whilst serving on the Working Party. Without it, the production of any document, let alone such a comprehensive one in such a short time scale would have been impossible. The committee of the AGS have been full of praise. It sets a high standard for others to follow and reflects well on all those involved.

I have been asked to set up a Review Group to take on the role of clarifying, improving or extending the format. I hope that you will be able to be a member of this group so that the good work may be continued into the future. Time will tell how often it will need to meet but I don't expect too much activity before Autumn when, no doubt, some experience in its application will have been gained by the industry.

I am enclosing two copies of the document, one for yourself and one for your library at Portsmouth. One is also due to Motts for supporting your work on the committee. Please let me know who this should be sent to.

Thank you again for your efforts. I hope that we will be able to arrange a get together of all those involved in the Working Party and document production in the not-too-distant future.

Kind Regards



L Threadgold
for THE ASSOCIATION OF GEOTECHNICAL SPECIALISTS

**Figure 6.5. Letter of Thanks regarding Working Party involvement and contribution
(Pers. Comm. L. Threadgold, AGS, 1992)**

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Geotechnical Data Interchange Format Data Dictionary

Common Data Set

Note: what the PRO contains
data set is.

Project Information : PROJ

PROJ_ID	Project Identifier	ie. 6421/A
PROJ_NAME	Project Title	ie. Acme Gas Works Redevelopment
PROJ_LOC	Location of Site	ie. London Road, Croydon
PROJ_CLIENT	Client Name	ie. Acme Enterprises
PROJ_CON	Contractors Name	ie. Acme Piling Ltd

Hole Information : HOLE

HOLE_ID	Exploratory hole name/number	ie. 327/16A
HOLE_TYPE	Type of exploratory hole	ie. SA ¹
HOLE_NATE	O.S. National Grid 6 figure Easting	ie. 523145
HOLE_NATN	O.S. National Grid 6 figure Northing	ie. 178456
HOLE_DAT	Hole datum level relative to Ordnance Datum	ie. 16.23 m OD
HOLE_FDEP	Final depth of hole	ie. 32.60 m
HOLE_STAR	Date of start of excavation	ie. 16/03/1991
HOLE_LOG	The definitive person responsible for logging the hole.	ie. DPG (MN)

Figure 6.6. The original definitions for what eventually became the AGS Geotechnical Data Interchange Format (Giles, 1991b, GEO2418)

```

***PROJ
**PROJ_ID","**PROJ_NAME","**PROJ_LOC","**PROJ_CLNT","**PROJ_CONT","**PROJ_ENG"
"6421/A","Acme Gas Works","London Road Croydon","Acme Enterprises","Acme Drilling
Ltd","Acme Consulting",""

***HOLE
**HOLE_ID","**HOLE_STAR","**HOLE_GL","**HOLE_FDEP","**HOLE_NATE","**HOLE_NATN
","**HOLE_DIAM","**HOLE_CASG","**HOLE_LOG","**HOLE_EXC","**HOLE_REM"
"136","","62.36","","12345E","12345N","","","AIB","","1. Standpipe installed at 20.00m. 2.
Undisturbed samples 16 & 19 extruded. 3. CHALK GRADE I based upon spt. "
"198","","89.49","","54321E","54325N","","","AIB","","1. Borehole grouted up on completion. 2.
Subv = subvertical. 3. No water encountered during boring and drilling. 4. If max: >75 ;
18.00-20.00m. "

***GEOL
**HOLE_ID","**GEOL_TOP","**GEOL_BASE","**GEOL_STAT","**GEOL_DESC"
"136","0",".55","1","Clayey earth with flints. (Driller's description). "
"136",".55","1.5","52","Structureless CHALK, composed of a matrix of yellowish white sandy silt
size fragments with some to much subangular fine to medium gravel size white moderately
weathered weak fragments. (CHALK GRADE VI) "
"136","1.5","2.6","52","Structureless CHALK, composed of subangular fine to coarse gravel size
white moderately weathered weak fragments with a matrix of sandy silt size fragments. (CHALK
GRADE V) "
"136","2.6","6.5","52","White moderately to slightly weathered CHALK, weak. Fractures
extremely closely to very closely spaced infilled up to 2mm with yellowish white comminuted
chalk. (CHALK GRADE IV) "

***DETL
**HOLE_ID","**DETL_TOP","**DETL_BASE","**DETL_DESC"
"198","0","3.45","Firm orangish brown and yellow banded very sandy CLAY with a little
subangular medium flint gravel. "
"198","3.45","6.05","No recovery "

***SAMP
**HOLE_ID","**SAMP_REF","**SAMP_TOP","**SAMP_BASE","**GEOL_STAT","**SAMP_TYPE"
"136","",".6","1.05","","B"
"136","","1.1","1.1","","B"
"136","S","1.1","1.55","","B"
"136","","1.6","2.05","","B"

***CORE
**HOLE_ID","**CORE_TOP","**CORE_BOT","**CORE_SREC","**CORE_PREC","**CORE_RQD"
"198","5","13.5","-1","-1","-1"
"198","6.5","8","9","29","9"
"198","8","10","0","15","0"
"198","12","14","0","38","0"
"198","13.5","18","-1","-1","-1"

```

Figure 6.7. An example of an AGS Geotechnical Data Interchange Format file (Giles, 1994a)

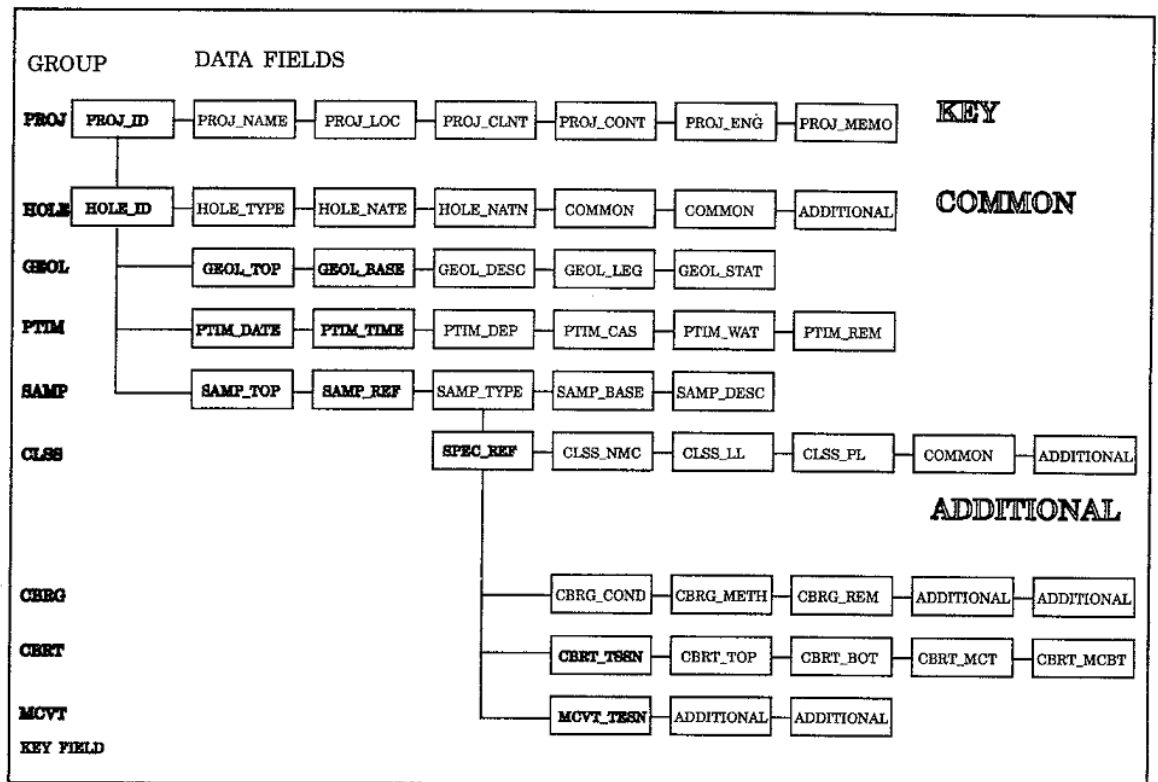


Figure 6.8. Part of a GDIF data file showing the structural relationships, the significance of the data groups and the key, common and additional data fields within them (Giles, 1994a)

GROUP	STORED DATA	GROUP	STORED DATA	GROUP	STORED DATA
HOLE	Hole information	TRIG	Triaxial test - general	CMPG	Compaction tests - general
GEOL	Stratum descriptions	TRIX	Triaxial test - results	CMPT	Compaction tests - results
DETL	Stratum detail descriptions	CONG	Consolidation test - general	RELD	Relative density test results
DREM	Depth related remarks	CONS	Consolidation test - results	MCVG	MCV test - general
PTIM	Hole progress by time	ROCK	Rock index testing - results	MCVT	MCV test - results
WSTK	Water strike details	STCN	Static cone penetration test	CBRG	CBR test - general
SAMP	Sample reference information	CONC	Cone calibrations	CBRT	CBR test - results
CORE	Rotary core information	DPRB	Dynamic probe test results	PTST	Lab permeability test results
FRAC	Fracture spacing	IDEN	In-situ density test results	SHBG	Shear box testing - general
ISPT	Standard penetration test	ICBR	In-situ CBR test results	SHBT	Shear box testing - results
PREF	Piezometer installation details	IVAN	In-situ vane test results	TNPL	Ten per cent fines
POBS	Piezometer readings	IRES	In-situ resistivity test results	FRST	Frost susceptibility
CLSS	Classification test results	IRDX	In-situ redox test results	CHLK	Chalk crushing value results
GRAD	Particle size distribution data	IPRM	In-situ permeability test	CMNT	Contaminant test results
CHEM	Chemical test results	PUMP	Pumping test results	AMAL	Amalgated sample data

Figure 6.9. Selection of the geotechnical data and associated data group names as defined in the interchange format (Giles, 1998)

7.0 Geographical Information Systems

In the late 1980's and early 1990's Geographical Information Systems (GIS) were just beginning to become established and more widely available as a computer-based tool to collect, manage, display, analyse and interpret spatially referenced data sets (Coppock & Rhind, 1991).

Increasingly more disciplines were realising the potential of GIS for their specific data sets and the new possibilities presented in visualising and interpreting these data. The fields of engineering geology and ground investigation were initially slow to adopt these new possibilities mainly due to their heavy investment and reliance on CAD (Computer Aided Design) for engineering design coupled with the high data acquisition costs.

The potential of these systems for geotechnical assessment was initially set out in Giles 1992 (Papers Vol. 1) *The geotechnical computer workstation: The link between the geotechnical database and the geographical information system* published in the proceedings of the *Colloque International: Géotechnique et Informatique*, held in Paris where the concept of a *geotechnical workstation* was developed, linking the geotechnical database with the Geographical Information System. The paper considered how a GIS for geotechnical engineers could be established and the type of data sets that could be brought together under the GIS for subsequent analysis, visualisation and interpretation. This concept was further developed in Giles 1994c (Papers Vol. 1) (cited by Obergrießer et al., 2009; Kaâniche et al., 2000; Fei, 2001; Suwanwiwattana et al., 2001 and Tudeş, 2011) with a paper *A geographical information system for geotechnical and ground investigation data management and analysis* published in the proceedings of the *5th European Conference and Exhibition on Geographical Information Systems, EGIS*, also held in Paris. These contributions were some of the very first papers in engineering geology to explore and demonstrate these new concepts. Work with Robert Barnes, a co-supervised MPhil student, considered ground investigation data and its interpretation and presentation via a GIS in more detail (Barnes, Giles, Johnson & Langdon, 1995, Papers Vol. 1). The use of GIS along with geostatistical modelling for a tunnelling geohazard study was described in Giles 1995 (Papers Vol. 1) with a paper *The integration of GIS and geostatistical modelling for a tunnelling geohazard study* published in the proceedings of the *1st Joint European*

Conference on Geographical Information, cited in Rodriguez-Bachiller (2000) and Rodriguez-Bachiller and Glasson (2004).

Further application of these new methodologies using GIS for brownfield site and contaminated land assessment were developed with co-workers from Portsmouth City Council and were described in a short paper published by *GIS Europe* (Giles, Morgan & Darlow, 1996, Papers Vol. 1) along with a paper *Topsoil thickness modelling using GIS for the purpose of assessing risks from underlying contaminated material on Hope Cottage Allotments, Portsmouth*, (Morgan, Giles & Walton, 1995, Papers Vol. 1) presented at the *Euroconference GIS*, University of Karlsruhe, Germany. These papers described the use of GIS for contaminated land remediation and the partnership with Portsmouth City Council in developing these applications.

Working with another co-supervised PhD student (David Fall) the application of GIS to the insurance industry investigating problematic ground conditions was also considered. In *GIS for the modelling and analysis of domestic property insurance risk associated with potentially collapsible soils of southern Britain* (Fall, Giles & Langdon, 1996, Papers Vol. 1) we set out to define how a tool could be developed to provide insurers and loss adjusters with the ability to assess the risk posed to insured structures by potentially collapsible aeolian soils (loess and brickearth). An example of the thematic data coverages outlined in the paper is shown in Fig. 7.1.

The novelty and timeliness of this work can be seen with the research being presented and published at some of the very first European wide conferences on GIS and its application, namely the *1st and 2nd Joint European Conferences on GIS* for example and at the *Colloque International: Géotechnique et Infomatique* Paris which was the first conference of its kind considering computers and their application in geotechnics.

More recent work in GIS has been in an international collaboration with Dr Şule Tüdeş from the Faculty of Architecture of Gazi University, Ankara, Turkey who visited Portsmouth on a Post-Doctoral Research Fellowship Programme where an all-encompassing GIS was established for Portsmouth which included geological, geotechnical, geochemical and historic map data sets (Tüdeş, 2011).

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Fall, D., Giles, D.P. & Langdon, N.J. (1996). GIS for the modelling and analysis of domestic property insurance risk associated with potentially collapsible soils of southern Britain. *Proceedings of the 2nd Joint European Conference on Geographical Information, JEC*, (pp. 338-341). IOS Press, Netherlands.

Giles, D.P., Morgan, A. & Darlow, P. (1996, December). On contaminated ground. *GIS Europe*, 20-22.

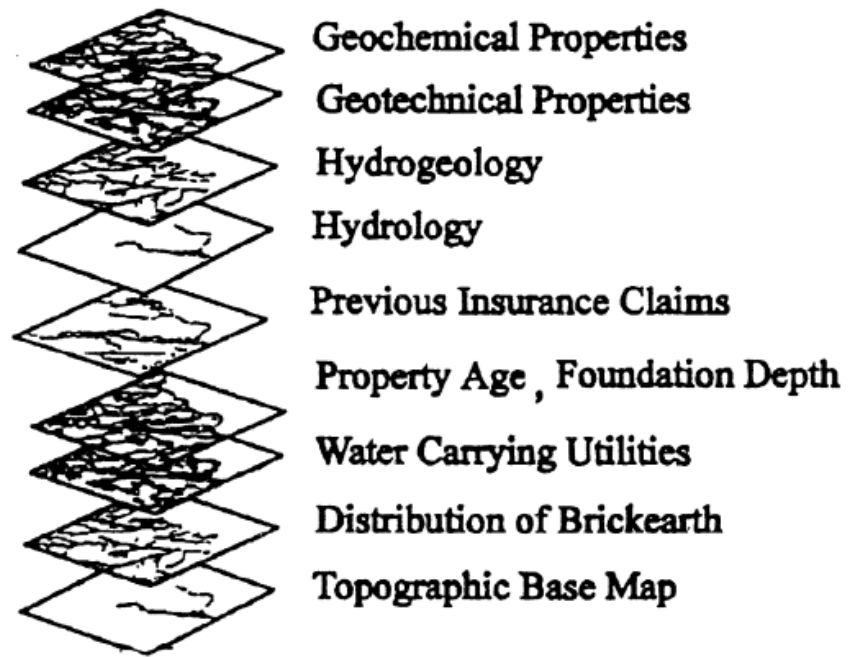


Figure 7.1. Suggested thematic data coverages for a domestic insurance GIS for potentially collapsible soils in southern Britain (Fall, Giles & Langdon, 1996)

8.0 Surface Modelling and Geostatistical Methods

Key components of my research and certainly significant aspects of my pathfinder work have been the investigation and application of surface modelling techniques and geostatistical methods for the interpolation and visualisation of geological and geotechnical data. Again I was one of the very first to undertake and explore these methodologies in engineering geology. Early work was focused in the oil exploration industry where I was involved in experimental research and development work for oil field equity studies and volumetric modelling whilst working at Scott Pickford Associates Ltd. I documented and wrote the manual for the company's database management and spatial modelling software <Geo-Graphics> *Seismic Data Management System User's Manual* (Giles, 1985, Papers Vol. 5). This early surface modelling work utilised the then state-of-the-art gridding and software package CPS-1 (Radian Corporation), an expensive mainframe-based batch command led program. It was here that my research interest in gridding algorithms and surface modelling developed, specifically whilst working in partnership with Shell UK on a pathfinder research project for the North Sea Dunlin Field Equity Study and the subsequent spatial modelling of the key reservoir horizons and isopachs, finally calculating STOIP (stock tank oil initially in place) volumes. At the time this work was in the infancy of volumetric modelling and was very much cutting-edge predating the full fault modelling techniques used today.

On moving to Mott MacDonald Ltd. in 1989 I was, as discussed previously, extensively involved in the research, development and assimilation of computer-based modelling into the company's engineering geology and geotechnical work. I extended my experience from oil reservoir modelling into the modelling of geological surface horizons for tunnelling purposes.

In 1988 Thames Water, whilst constructing the initial stages of the new London Water Ring Main, inadvertently *lost* two tunnel boring machines during the construction of Phase I of the project where a variety of difficult ground conditions were encountered which drastically affected the tunnelling operations (Clarke & MacKenzie, 1994; Newman, 2009). Mott MacDonald Ltd. were subsequently commissioned to undertake what was then termed a *geological risk analysis* to investigate the geological hazards posed to the tunnel

along the alignment for Phase II of the project, the sections between Ashford Common to Barrow Hill and Brixton to Honor Oak in London (Fig. 8.1). This work involved the development of a major geological database – London Basin Stratigraphic Database, which I established (Giles, 1990e, Papers Vol. 3) and the production of surface models to delineate tunnelling windows with appropriate confidence limits for the route alignment. Geostatistical techniques were chosen to develop these surface models as they offered robust and defensible interpolation algorithms and allowed the surface spatial continuity to be explored as well as producing a measure of the error associated with the interpolation process. Fig. 8.2 shows the geostatistical modelling procedure adopted for this work with the spatial continuity of the various key geological horizons being defined by semi-variograms which then fed into the generation of gridded surfaces using Kriging algorithms. Figs. 8.3 and 8.4 show the calculated and modelled semi-variograms with Fig. 8.5 giving an example of the contoured Kriged surface along with the contoured map of the generated Standard Errors associated with the Kriging interpolation. Fig. 8.6 demonstrates the type of subsurface profile that can be generated with the output Kriged surface and the associated Standard Error, enabling 95% confidence intervals to be displayed along with the proposed tunnel level. Areas of potential geohazard and/or uncertainty could then be identified. This work was initially externally presented in 1991 at the 3rd *Geostatistics in the UK Meeting* at the University of Leeds with an abstract *Geostatistics as an aid to geological risk analysis* (Giles, 1991d, Papers Vol. 3) and subsequently at the 7th *Congress of the International Association of Engineering Geology* in Lisbon 1994 with a paper entitled *Geological surface modelling utilising geostatistical algorithms for tunnelling window delineation - a case study from the London Water Ring Main*, (Giles, 1994b, Papers Vol. 1). The geostatistical methodology was published in 1993 in a themed Thomas Telford publication on *Risk and Reliability in Ground Engineering* (Skipp, Ed., 1993) with a paper *Geostatistical interpolation techniques for geotechnical data modelling and ground condition risk and reliability assessment*, (Giles, 1993, Papers Vol. 1). This work was cited by Culshaw in the Geological Society Engineering Group 7th Glossop Lecture (Culshaw, 2005) as well as by Ho et al., 2000 and Nicholls and Pycroft, 1996. The work fully described the geostatistical methodology namely the construction of semi-variograms of lithology levels from borehole data (Fig. 8.3, 8.4), the interpolation via Kriging of surface levels with associated Standard Errors (Fig. 8.5) and the creation of geological cross sections with confidence intervals (Fig. 8.6)

The London Water Ring Main modelling work undertaken at Mott MacDonald Ltd. was presented as two confidential reports: *London Water Ring Main Stage 5 geological risk analysis* (Giles, 1991a, Papers Vol. 4) and *London Water Ring Main Brixton to Honor Oak tunnel desk study and geological risk analysis* (Giles & Bennett, 1993, Papers Vol. 4). This significant ground breaking work was reported by *Ground Engineering* in an article *Geostatistical analysis gains in popularity*, (Anon, 1997, August). Fig. 8.7 demonstrates the typical semi-variograms calculated from the stratigraphic database as presented in the final Brixton to Honor Oak report.

In 1994 further work was undertaken for Union Railways Ltd utilising these methodologies on the Channel Tunnel Rail Link with a project on the Thames Crossing and Approaches (Giles, 1994d, Papers Vol. 4), although with slightly less success than with the London Water Ring Main modelling mainly due to a poor quality input data set.

In 1995 these concepts were further described in a paper *The integration of GIS and geostatistical modelling for a tunnelling geohazard study* submitted to the 1st Joint European Conference on Geographical Information, in Basel, Switzerland, (Giles, 1995, Papers Vol. 1), cited by Rodriguez-Bachiller, (2000) and Rodriguez-Bachiller and Glasson, (2004). This paper highlighted the emerging technology of Geographical Information Systems and the powerful tool that it offered when linked to geostatistical modelling. Fig. 8.8 detailed a potential methodology for such studies.

The importance of geostatistics, geostatistical techniques and surface modelling was such that I introduced these key subjects into the undergraduate curriculum at the University of Portsmouth on the Engineering Geology and Geotechnics and Geological Hazards pathways. This work was reported at the 7th Congress of the International Association of Engineering Geology, Lisbon with a paper on *Computer-based activities in engineering geology training*, (Giles & Whalley, 1994, Papers Vol. 1). These techniques are now widely adopted in the ground engineering industry as a standard practice for the development of ground models (Reeves & West, 2009). Current research work is focusing on the use of geostatistics for the spatial modelling of the wind borne dusts emanating from the land filling of APC (Air Pollution Control) residues from power station ash with the co-supervision of Ben Williams in his PhD investigating dust dispersion monitoring and modelling.

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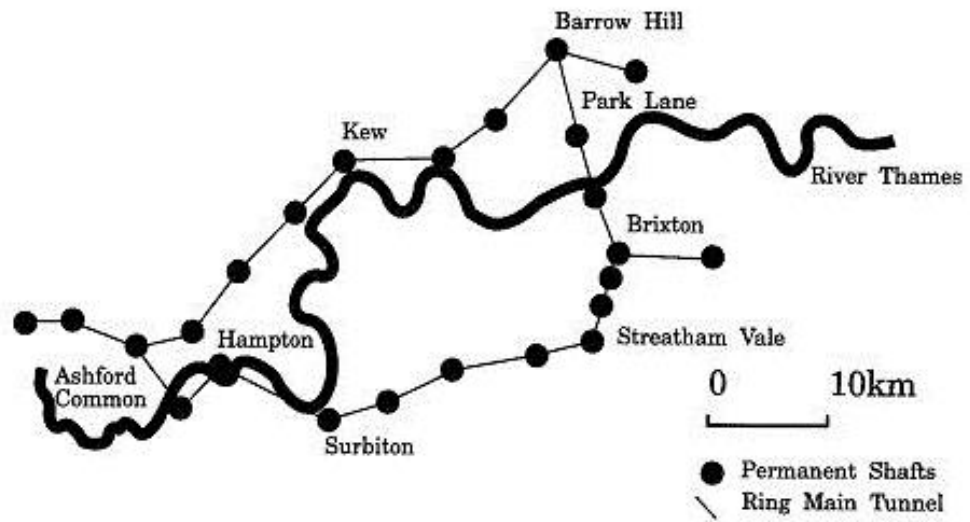


Figure 8.1. London Water Ring Main tunnels and major shaft locations (Giles, 1994b)

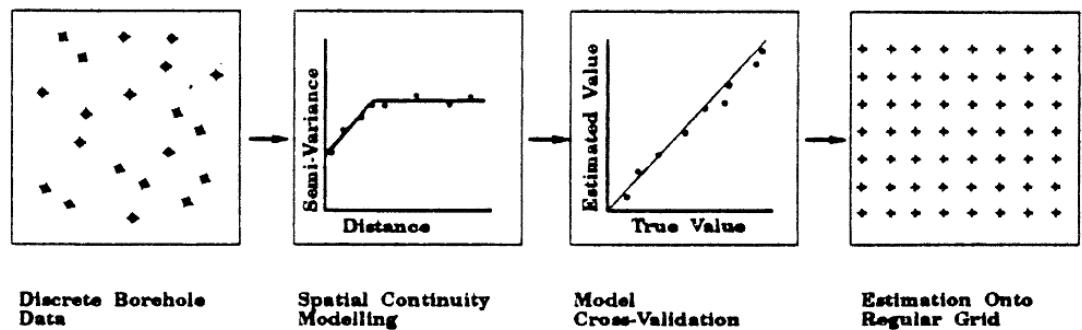


Figure 8.2. Geostatistical modelling procedure (Giles, 1995)

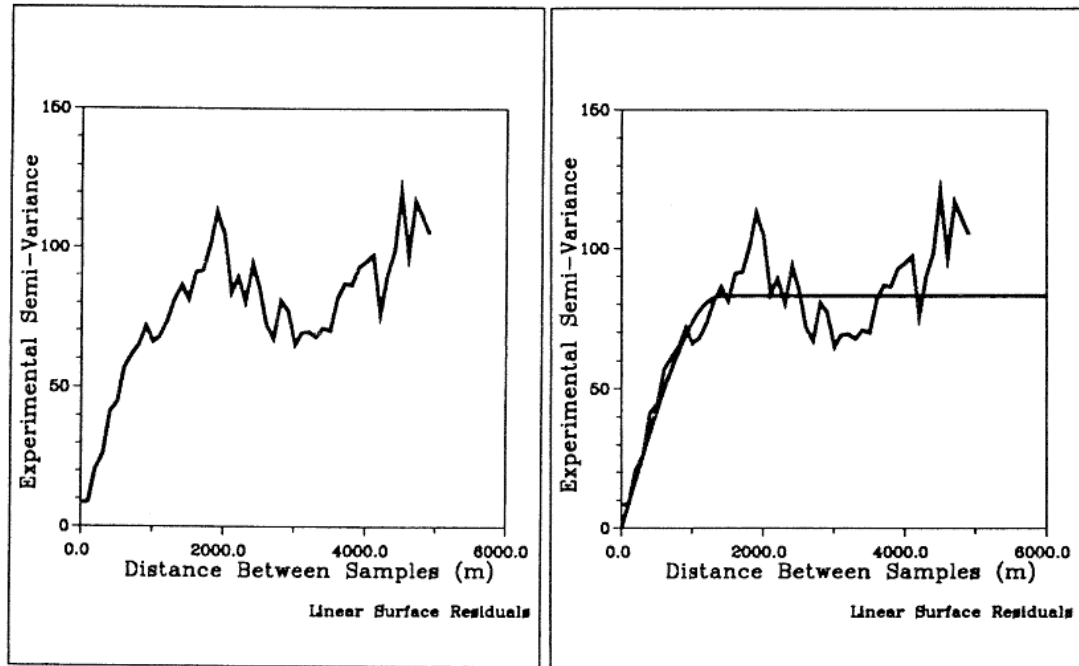


Figure 8.3. Experimental semi-variogram and Experimental semi-variogram with a fitted spherical model (Giles, 1993)

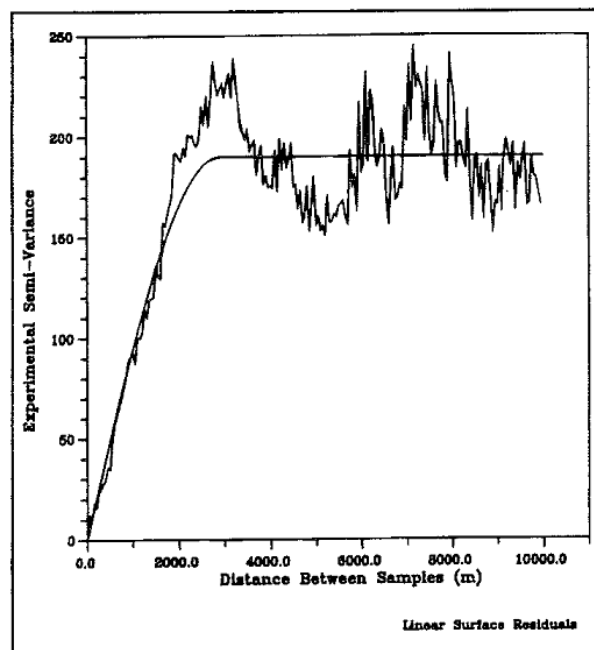


Figure 8.4. Semi-variogram with a fitted spherical model for the top of the Woolwich and Reading Beds (Lambeth Group) surface as generated for the London Water Ring Main study (Giles, 1994b)

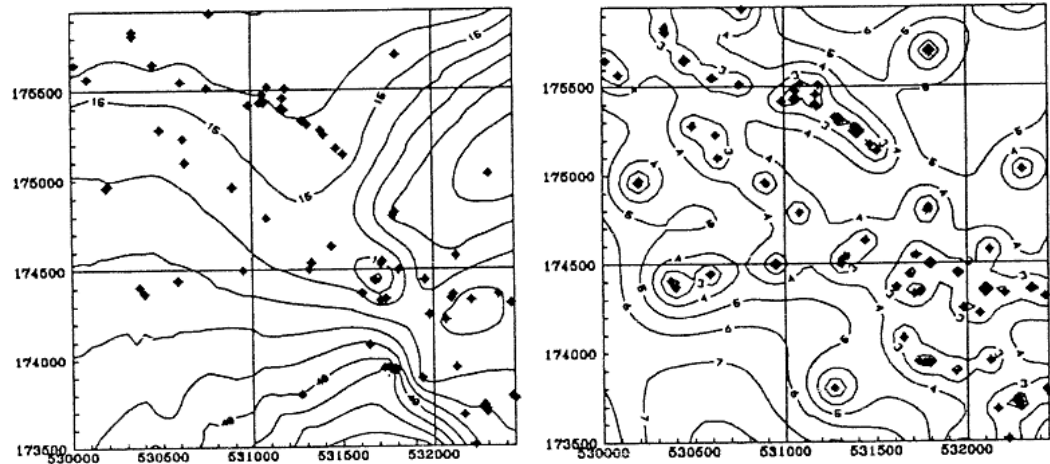


Figure 8.5. Contoured surface with associated standard error as generated from the London Basin Geological Database (Giles, 1993)

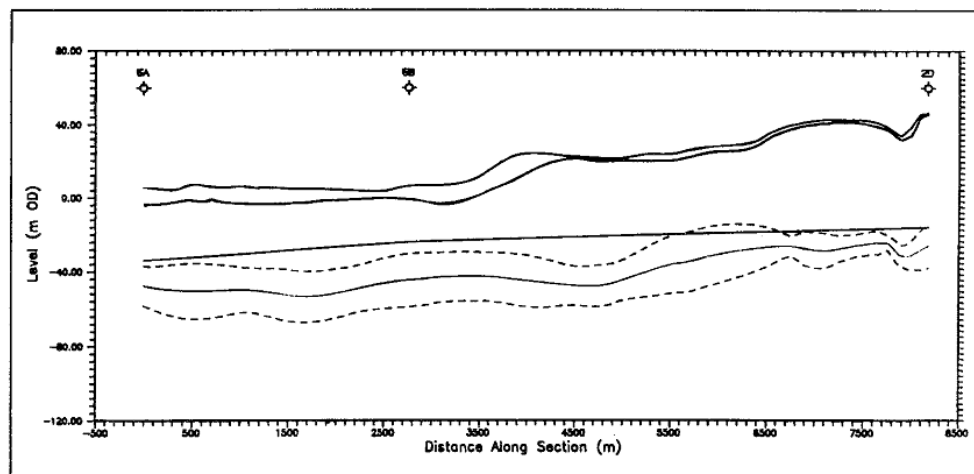


Figure 8.6. Surface profiles along alignment with 95% confidence interval for the top of Woolwich and Reading Beds (Lambeth Group) surface (Giles, 1994b)

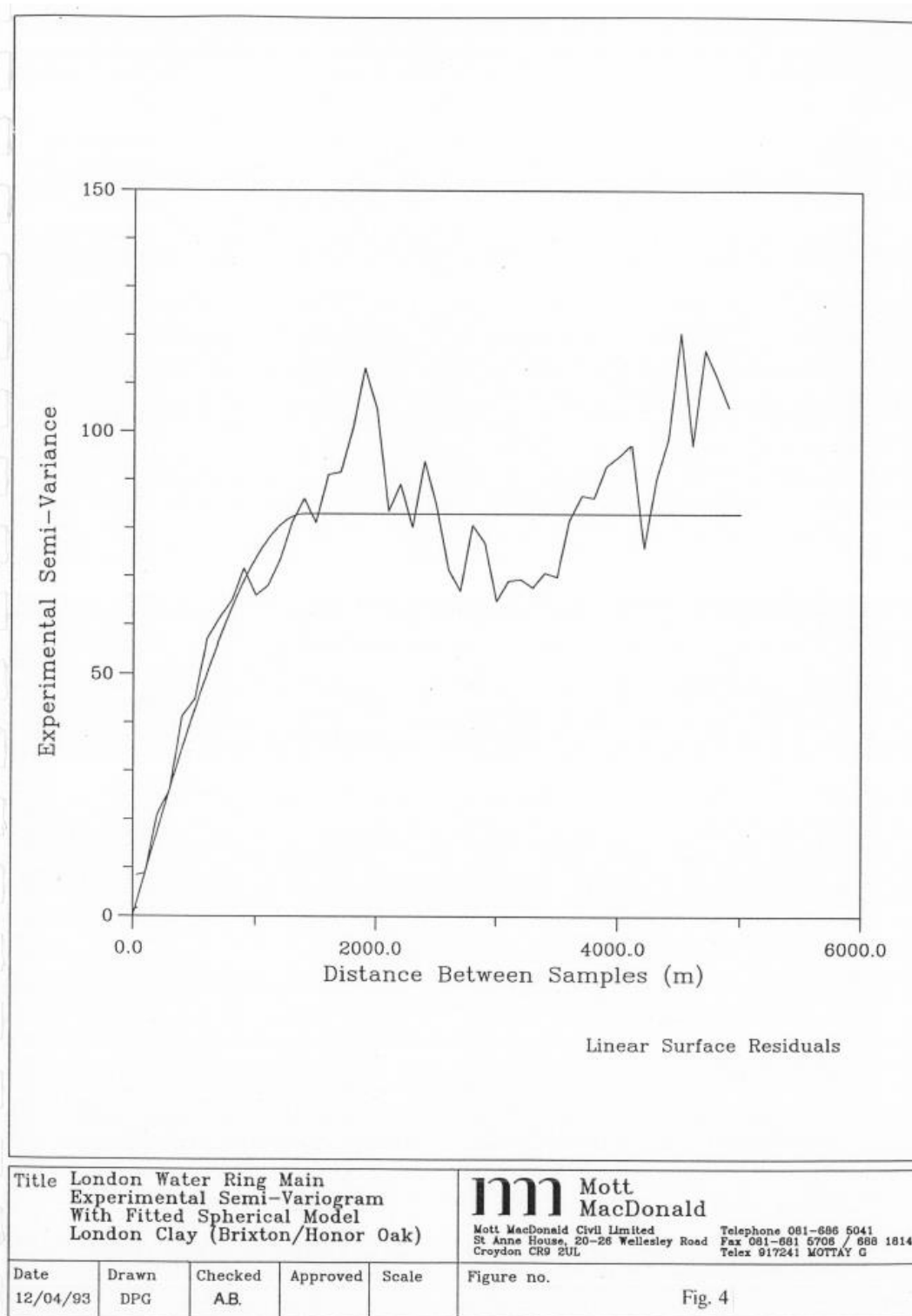


Figure 8.7. Modelled semi-variograms on linear surface residuals for the London Clay Formation surface, London Water Ring Main, Brixton to Honor Oak (Giles & Bennett, 1993)

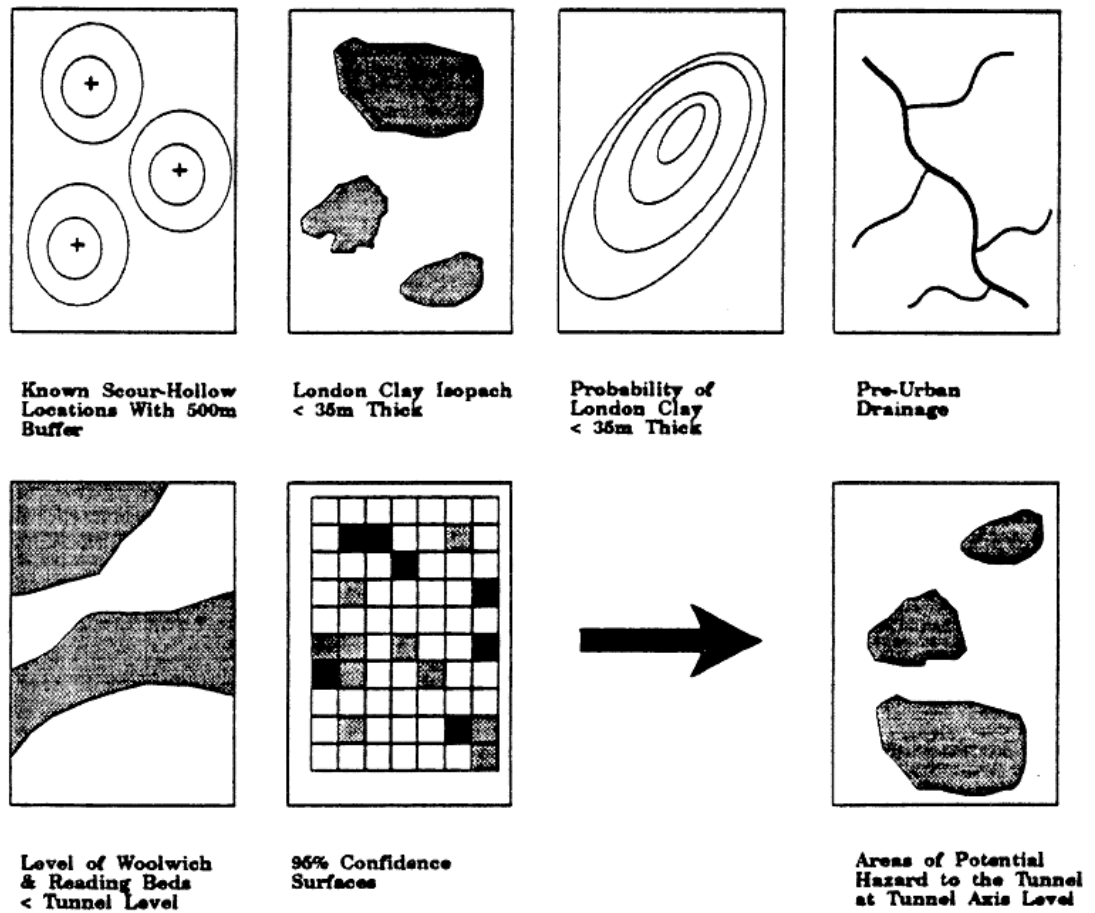


Figure 8.8. Geohazard overlay creation and spatial analysis in the integration of geostatistical modelling into a Geographic Information System (Giles, 1995)

9.0 Risk Modelling and Knowledge-Based Systems

My early work on databases, data interchange, GIS and geostatistical modelling extended into other new areas of computer-based modelling with research developing the fields of risk modelling and knowledge-based systems in engineering geology. Through two studentships sponsored by the Association of British Insurers together with another fully sponsored by the BGR (Geological Survey of Germany) projects were developed considering the risks posed by Quaternary brickearths to insured properties in southern Britain (David Fall), spatial risk assessment of contaminated land in an urban environment (Jenny Plunkett) and the development of a knowledge-based system methodology for designing waste disposal sites in arid and semi-arid environments in Namibia (Sindila Mwiya).

Publications from the contaminated land themed Association of British Insurers project included *A brief review of the use of risk assessment software for the characterization of contaminated land*, published in the proceedings and presented at the 6th *International Conference on Contaminated Soil, Consoil 98*, Edinburgh (Plunkett, Giles & Langdon, 1998) and *Risk assessment revisited: A review of contaminated land risk assessment using data from a known contaminated site in Portsmouth, UK*, published in the proceedings and presented at the 9th *Annual Conference on Risk Analysis: Facing the New Millennium* in Rotterdam (Plunkett, Walton, Giles & Langdon, 1999, Papers Vol. 1). Fig. 9.1 outlines the procedure adopted for the estimation of human health risk used in the risk assessment approach.

Research on the theme of risk-based contaminated land assessment and characterisation was included in a publication on *Topsoil thickness modelling using GIS for the purpose of assessing risks from underlying contaminated material on Hope Cottage Allotments, Portsmouth* (Morgan, Giles & Walton, 1995, Papers Vol. 1).

Research with David Fall (as previously discussed) generated *GIS for the modelling and analysis of domestic property insurance risk associated with potentially collapsible soils of southern Britain* (Fall, Giles & Langdon, 1996, Papers Vol. 1).

Again the use of Geographical Information Systems was also presented in both the Morgan et al. (1995, Papers Vol. 1) and Fall et al. (1996, Papers Vol. 1) work.

Sindila Mwiya's project considered the development of knowledge-based systems principally as a potential siting and design tool for landfill sites in Namibia. *A knowledge-based approach to municipal solid waste disposal site development in the karstified dolomitic terrain around the town of Tsumeb in North Central Namibia* was published in the *Communications of the Geological Survey of Namibia* (Mwiya & Giles, 2004, Papers Vol. 2) complimented by *Strategies for identifying and designing safe, economic municipal solid waste disposal sites in the arid zones of Southern Africa* published in the proceedings of *Waste 2004: Integrated Waste Management and Pollution Control: Policy and Practice, Research and Solutions* conference at Warwick (Mwiya, Hughes & Giles, 2004, Papers Vol. 2). Again this was pioneering work in the development of these techniques and applications in the field of engineering geology. The research developed a knowledge-based system methodology as a decision support tool to assist an engineer in data collection and evaluation strategies in order to develop safer and more economic municipal solid waste disposal sites in arid and semi-arid environments as found in Namibia. Fig. 9.2 details the study area within Namibia, with Fig. 9.3 and Fig. 9.4 outlining the methodology adopted in the project.

Other publications and confidential reports under this theme which has been previously discussed includes *The integration of GIS and geostatistical modelling for a tunnelling geohazard study* (Giles, 1995, Papers Vol. 1), *Geostatistical interpolation techniques for geotechnical data modelling and ground condition risk and reliability assessment* (Giles, 1993, Papers Vol. 1), *London Water Ring Main Stage 5 geological risk analysis* (Giles, 1991a, Papers Vol. 4), *London Water Ring Main Brixton to Honor Oak tunnel desk study and geological risk analysis* (Giles & Bennett, 1993, Papers Vol. 4). Fig. 9.5 demonstrates the risk delineation window generated by the geostatistical methods used in the tunnel study.

An international collaboration with Dr Zouhair Mrabet from Tunisia working on aspects of probabilistic modelling in geotechnics considering earth fills and seepage analysis produced three papers where I acted as a technical editor with a large editing input to the work produced by Dr Mrabet, namely *Modelling uncertainties in the stationary seepage*

problem (Mrabet & Giles, 2001, Papers Vol. 2), *Probabilistic risk assessment: The tool for uncertainty reduction in geotechnical engineering* (Mrabet & Giles, 2002a, Papers Vol. 2) and *Reliability analysis of earth fills using stochastic methods* (Mrabet & Giles, 2002b, Papers Vol. 2).

Other aspects of probabilistic modelling included research with another co-supervised PhD student (Joseph Mankelow) which considered the use of probability density functions for the modelling of earthquake-triggered landslides (Mankelow, Giles & Murphy, 1998, Papers Vol. 1) presented at and published in the proceedings of the 4th *Annual Conference of the International Association for Mathematical Geology* in Ischia, Italy, work which was cited by Refice and Capolongo (2002) and Capolongo et al. (2002).

All of this work on risk modelling and knowledge-based systems was undertaken in the very early stages of the development and usage of these tools and methodologies in engineering geology and geotechnics. What we now consider as mature and tested technologies and methods were very much in their infancy and my research work and associated authored and co-authored publications contributed to the development of these practices in engineering geology. These papers made an early contribution to the development, progress and acceptance of this work especially with the integration of databases, GIS, spatial modelling and geostatistics, probabilistic modelling, risk and hazard assessment.

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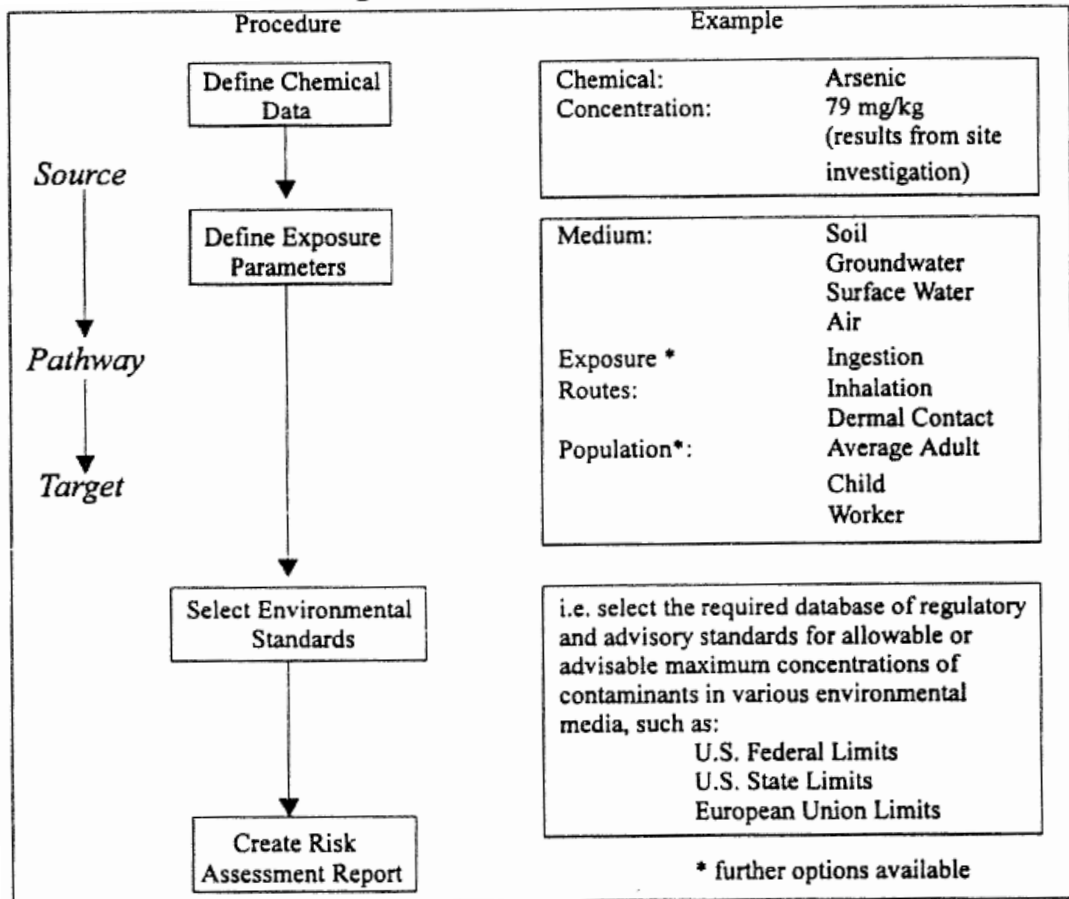


Figure 9.1. Procedure for estimating human health risks using risk assessment software (Plunkett, Giles & Langdon, 1998)

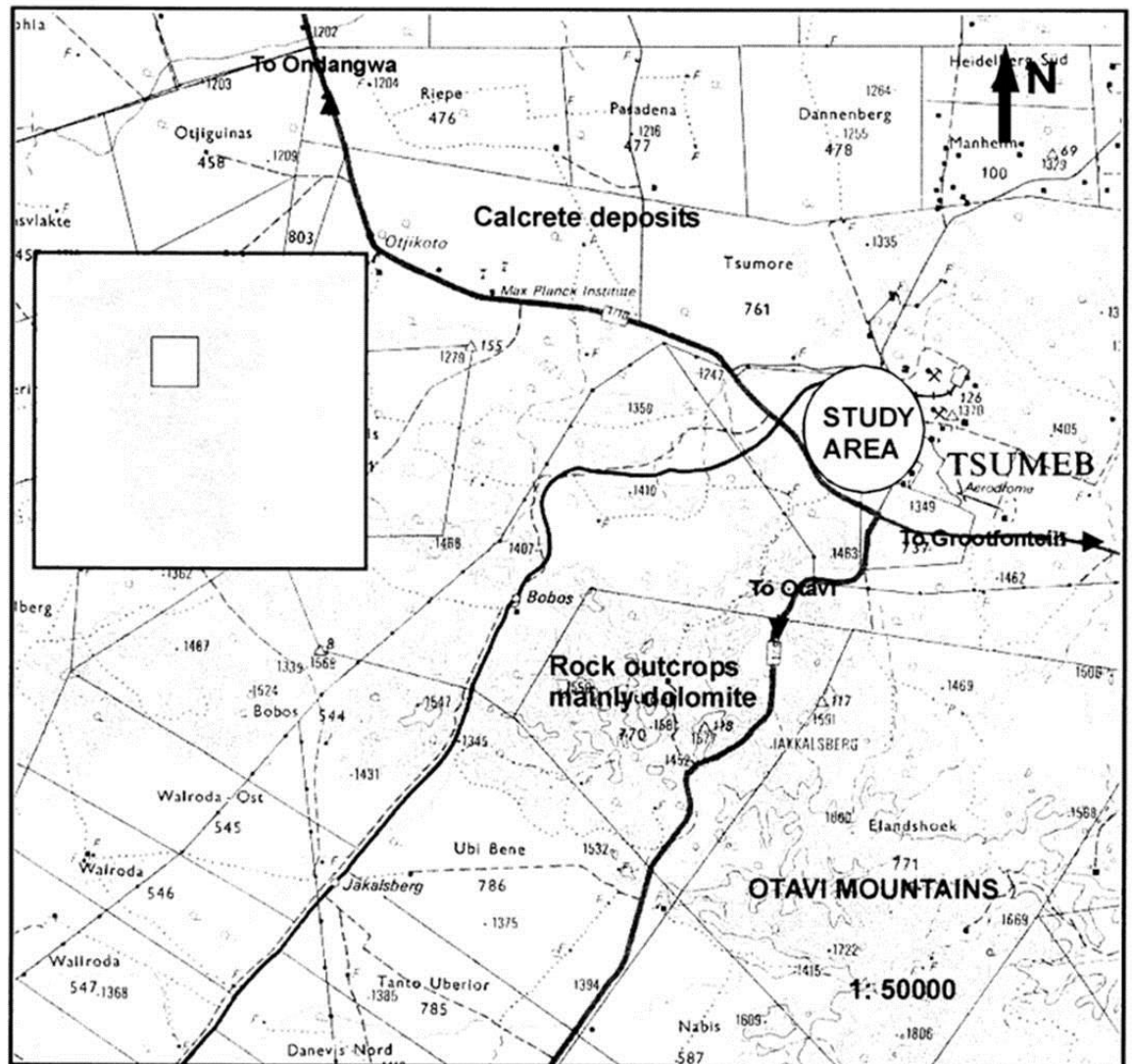


Figure 9.2. Location of the study area (Namibia) (Mwiya & Giles, 2004)

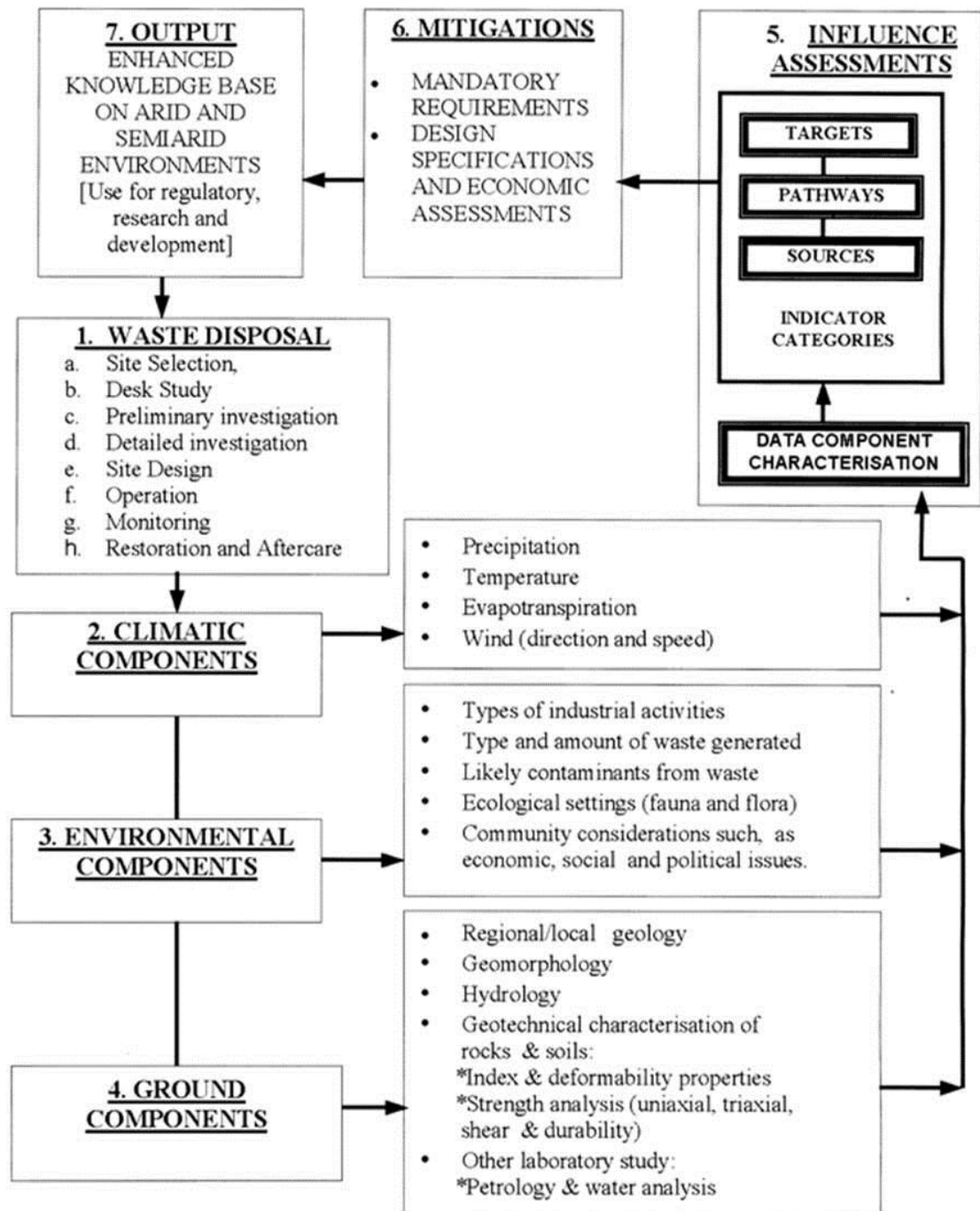


Figure 9.3. Complete cycle of the conceptual knowledge-based model used in the study (Mwiya & Giles, 2004)

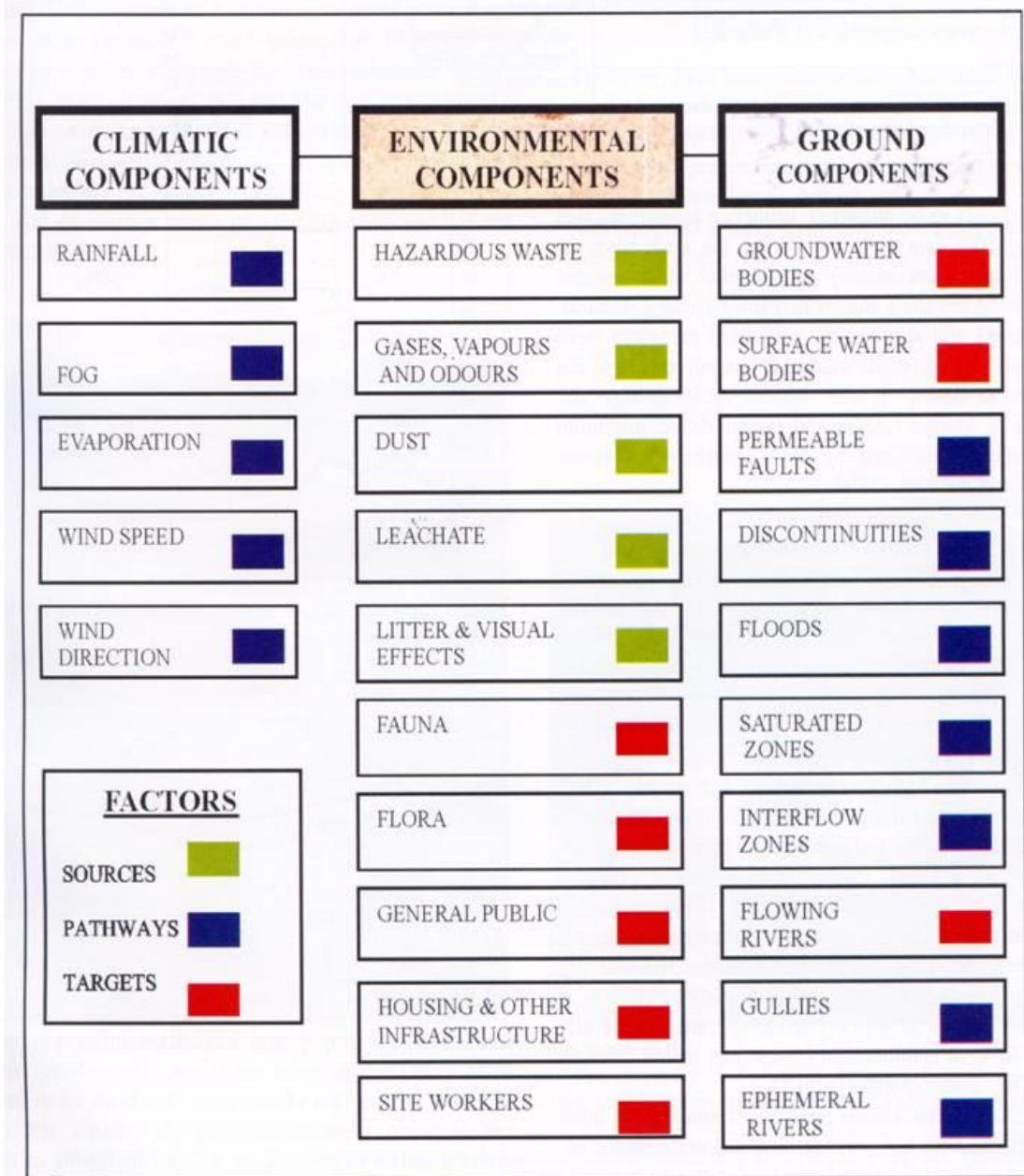


Figure 9.4. Characterised factors associated with the climatic, environmental and ground components utilised in the knowledge-based system (Mwiya & Giles, 2004)

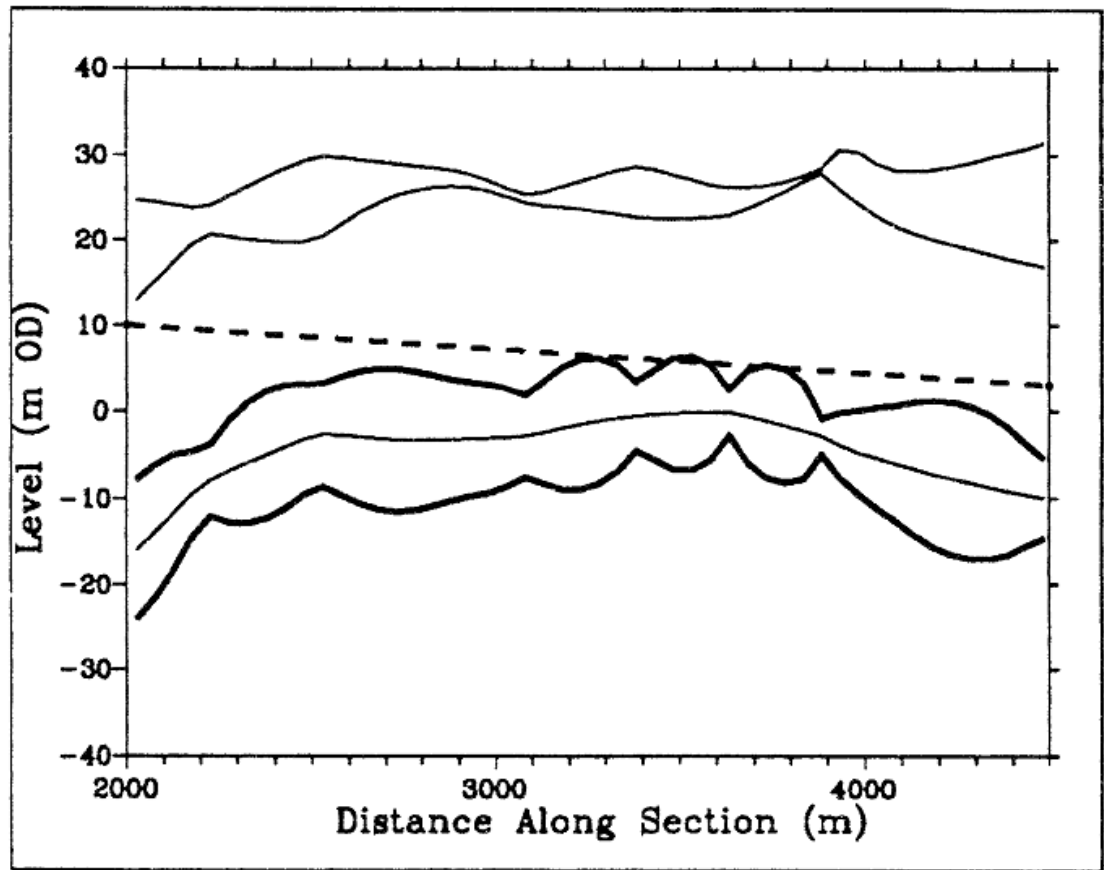


Figure 9.5. The 95% Confidence interval highlighting tunnel chainages at potential risk from adverse ground conditions (Giles, 1993)

Table 2. Calculated static factors of safety and associated aseismic instability probability estimates given the variability in the geotechnical parameters.

Distribution	F_{STAT}	$P(F_{STAT} \leq 1.0)$ %
Triangular	3.02	3.73
Trigen 2, 98	8.40	7.87
BetaPERT	3.07	2.67
Truncated Normal	3.87	6.82
Truncated Lognormal	4.71	2.59

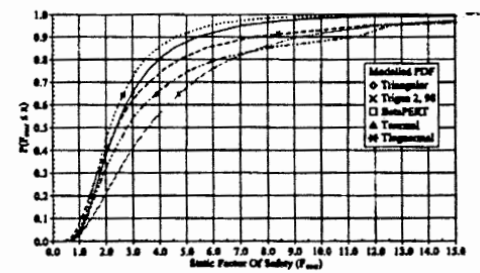


Figure 2. Cumulative PDF showing the probability of landsliding under ambient stress conditions.

Figure 9.6. Probability Density Functions utilised in the Factor of Safety calculations for the assessment of seismically triggered landslides (Mankelow, Giles & Murphy, 1998)

10.0 Remote Sensing in Engineering Geology

Another major component of my research contribution and publication output has been work on remote sensing and image analysis and its application in engineering geology and geohazards, specifically for the study of landslides and slope instability.

Today we take many remotely sensed images for granted. For example our use of *Google Earth*, the everyday download of digital data, even our acquisition of remotely sensed images via a digital camera or mobile phone. In the early 1990's remote sensing and the associated digital imagery was a relatively new science and the available data was technically difficult to download and process. The data itself was very expensive, available only in complex computer formats and delivered on cumbersome media such as reel-to-reel tapes. The advent of optical discs, CD's then DVD's allowed for this data to become more readily available and accessible.

Early usage of these data was mainly for land use studies and broader geographical applications. Very little work had been undertaken in the field of engineering geology mainly due to the resolution of the remotely sensed imagery. Table 10.1 highlights the resolution issues presented by the data sets and how over time they became more relevant to the scales of engineering geology and engineering geomorphology. With the arrival of Landsat MSS, Landsat TM, SPOT and Airborne Thematic Mapper Data imagery possibilities were developing for the analysis and interpretation of these data sets at these scales. Very little work at this time had been done with respect to the spectral response of clays, ground moisture conditions and vegetation cover with respect to landslides and slope instability.

Around 1991 I was aware of a ground investigation project being undertaken by Mott MacDonald Ltd., my employer at the time, for the proposed A44 Broadway bypass in the Cotswolds. This site was dominated by relict periglacial solifluction landforms along with large rotational and translational landslides with an underlying bedrock lithology alternating between oolitic limestones and clay / mudrock strata. The site presented an ideal testing location for research into the potential of remotely sensed data sets and associated image processing techniques for the engineering geomorphological assessment

of the slopes and in particular the delineation of landslides and other relict slope geohazards such as the solifluction lobes. The site allowed the digital data sets to be calibrated against the detailed field setting.

After a series of field visits a PhD programme was defined by myself and Bill Murphy (then at the University of Portsmouth) to investigate these issues. Malcolm Whitworth was recruited in 1995 onto this project under our co-supervision to undertake a programme of research investigating the *application of airborne multi-spectral remote sensing and digital terrain modelling to the detection and delineation of landslides on clay dominated slopes of the Cotswolds Escarpment*. This partnership was very fruitful with the work producing a significant number of co-authored papers considering the spectral response of clays and the incipient ground conditions at the site along with its geomorphological interpretation. The seminal paper produced from this work, which had a significant input from myself, was published in 2005 in the *Quarterly Journal of Engineering Geology and Hydrogeology*, namely *Airborne remote sensing for landslide hazard assessment: a case study on the Jurassic escarpment slopes of Worcestershire, United Kingdom* (Whitworth, Giles & Murphy, 2005, Papers Vol. 2). This paper has been cited by 26 other works (Table 10.2) demonstrating its significance and impact as a landslide study. Daedalus Airborne Thematic Mapper (ATM) imagery (11 bands, 2m resolution) was acquired for this project from a successful bid to the NERC Airborne Remote Sensing Facility (ARSF) which was flown in February 1997. Fig. 10.1 details the geomorphological significance of the area detailing the numerous landslides and solifluction landforms that are present at the study site. Fig. 10.2 gives an example of the photographic imagery acquired from the NERC Airborne Remote Sensing Facility flight.

Publications from this research commenced in 1996 with abstracts and posters outlining the proposed investigations and analysis being presented at the Geological Society's *Applied Geoscience* conference at the University of Warwick, namely *GIS integration of remotely sensed imagery, geomorphological maps and piezometric data for periglacial geohazard assessment* (Whitworth, Giles & Murphy, 1996, Papers Vol. 3) and at the 4th *International Conference on Geomorphology* in Bologna, Italy *Periglacial geohazard prediction utilising remotely sensed imagery, geomorphology and piezometry* (Giles & Whitworth, 1997, Papers Vol. 3).

Initially the work utilised high resolution aerial photos acquired from the NERC ARSF campaign to geomorphologically evaluate the site with regards to dating the relict slope movements. A paper *Historical constraints on slope movement age: a case study at Broadway, United Kingdom* was published in *The Geographical Journal* (Whitworth, Murphy, Giles & Petley, 2000, Papers Vol. 2) detailing the historical development of the site and the influence of the Little Ice Age on slope stability conditions. This work was cited by Lane et al. (2008) in the *Journal of the Geological Society*. Another geomorphological commentary was published in *Proceedings of the Cotteswold Naturalists' Field Club* with a paper *Landslides of the Cotswolds escarpment, Broadway, Worcestershire, UK* (Whitworth, Giles & Murphy, 2002, Papers Vol. 2) cited by Foster et al. (2007).

The spectral and image classification aspects of the research with the Airborne Thematic Mapper imagery were presented at the 8th *International Symposium on Landslides* with a paper *Spectral properties of active, suspended and relict landslides derived from Airborne Thematic Mapper imagery* (Whitworth, Giles, Murphy & Petley, 2000, Papers Vol. 2), cited by Santacana Quintas (2001) and Glade and Crozier (2005). This spectral theme continued with a paper presented at the 8th *International Symposium on Remote Sensing* in Toulouse, France *Identification of landslides in clay terrains using Airborne Thematic Mapper (ATM) multispectral imagery* (Whitworth, Giles & Murphy, 2001, Papers Vol. 2), again with several citations; Pack (2005), Lira et al. (2013) and Fernández et al. (2010). This work was also presented at the European Geophysical Society XXVII General Assembly, Nice, France with an abstract *A combined texture-principal component image classification technique for landslide identification using airborne multispectral imagery* (Whitworth, Giles & Murphy, 2002, Papers Vol. 3). Fig. 10.3 shows an example of the spectral variation across the identified landslides at the site. The thermal infrared variation across the features was also explored. Fig. 10.4 highlights the thermal infrared imagery utilised, with Fig. 10.5 demonstrating some of the derivative images produced using colour composites and Principal Component Analysis.

More recent research addressing remote sensing techniques has concentrated on the use of laser scanning (LiDAR) in engineering geology. Exploratory work on this technique has been published in the proceedings and associated Geological Society Engineering Geology Special Publication for the 10th *International Association for Engineering Geology*

Congress in Nottingham with a paper on *Terrestrial laser scanning for applied geoscience and landslide studies in the urban environment* (Whitworth, Giles, Anderson & Clewett, 2006, 2009, Papers Vol. 2) cited by Green and Hellings (2009). The extension of the Broadway work with LiDAR techniques was presented in another paper at the same conference *Landslide imaging techniques for urban geoscience reconnaissance* (Whitworth, Giles & Anderson 2006, 2009, Papers Vol. 2). Fig. 10.6 shows the Reigl LMS-Z420i scanner being used in a study of Gore Cliff on the Isle of Wight. Fig. 10.7 presents some of the imagery derived using *NextMap* digital elevation model data with various aspects of the presentation of that data for interpretive studies.

Table 10.1. Some typical characteristics of various remote sensing satellites, platforms and sensors (Richards & Richards, 1999; Barnsley, 1999; Sandau, 2009)

Satellite / Platform	First Launch	Sensor	Data Resolutions – Pixel Size
LANDSAT	1972	MSS, TM, ETM, ETM+	15m, 30m, 60m, 80m, 120m
NOAA	1978	AVHRR	1100m
SPOT	1986	PAN, HRV	5m, 10m, 20m, 25m
IRS	1988	PAN, LISS, WIFS	2.5m, 23m, 70m
NERC	1990	CASI	1m
NERC	1993	ATM	2m
ORBVVIEW	1997	OHRIS	1m, 4m
TERRA	1999	MODIS	250m, 500m, 1000m
IKONOS	1999	OSA	1m, 4m
ARIRANG	1999	MSC, EOC	1m, 4m
FORMOSAT	1999	RSI	2m, 8m
CBERS	1999	HRPC, HRC	2.5m, 20m, 25m
EROS	2000	PIC	1.8m, 2.8m
QUICKBIRD	2001	PAN, BGIS	0.6m, 2.5m
ENVISAT	2002	MERIS	300m, 1200m
DMC	2002	ESIS	4m, 12m, 32m
TOPSAT	2005	RALCAM	2.5m, 5.6m
ALOS	2006	PRISM, AVNIR	2.5m, 10m
WORLDVIEW	2007	PAN	0.5m
GEOEYE	2008	PAN, MSS	0.5m, 1.65m
RAPIDEYE	2008	REIS	5m

Table 10.2. Authors citing *Airborne remote sensing for landslide hazard assessment: a case study on the Jurassic escarpment slopes of Worcestershire, United Kingdom* (Whitworth, Giles & Murphy, 2005), February 2014.

Authors	Date	Publication
Lira et al.	2013	Natural Hazards and Earth System Sciences
Griffiths et al.	2012	Bulletin of Engineering Geology and the Environment
Miller & Degg	2012	Geomatics Natural Hazards & Risk
Joshly & Senthilkumar	2012	International Journal of Emerging Trends in Engineering and Development
Stumpf & Kerle	2011	Remote Sensing of Environment
Hearn	2011	Slope Engineering for Mountain Roads, Engineering Geology Special Publication Series
Yang & Chen	2010	International Journal of Applied Earth Observation and Geoinformation
Yang & Chen	2010	International Journal of Applied Earth Observation and Geoinformation
Yang	2010	Advances in Earth Observation of Global Change
Fernández et al.	2010	Tecnologías de la Información Geográfica
Tang & Dai	2010	Power and Energy Engineering Conference (APPEEC), Asia-Pacific
Tang & Dai	2010	Computational Science and its Applications–ICCSA 2010
Tang & Dai	2010	Intelligent Information and Database Systems.
Khairunniza-Bejo, Petrou & Ganas	2010	International Journal of Remote Sensing
Joyce, Belliss & Samsonov	2009	Progress in Physical Geography
Jiao et al.	2009	Proceedings of the 2 nd International Conference on Earth Observation for Global Changes
Jaksa, Ho & Woodward	2009	Proceedings of the 17 th International Conference on Soil Mechanics and Geotechnical Engineering

Van Westen, Castellanos & Sekhar	2008	Engineering Geology
Joyce, Dellow & Glassey	2008	Geoscience and Remote Sensing Symposium, IGARSS 2008
Kääb	2008	Permafrost and Periglacial Processes
Fell et al.	2008	Engineering Geology
Zequn & Shen	2008	Proceedings of the International Conference on Earth Observation Data Processing and Analysis
Fernández et al.	2008	International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences
Morgan et al.	2007	Offshore Technology Conference, Houston, Texas
Foster, Jenkins & Gibson	2007	British Geological Survey Open Report, OR/07/004
Van Westen	2007	Proceedings 1 st North American Landslide Conference, Vail, Colorado

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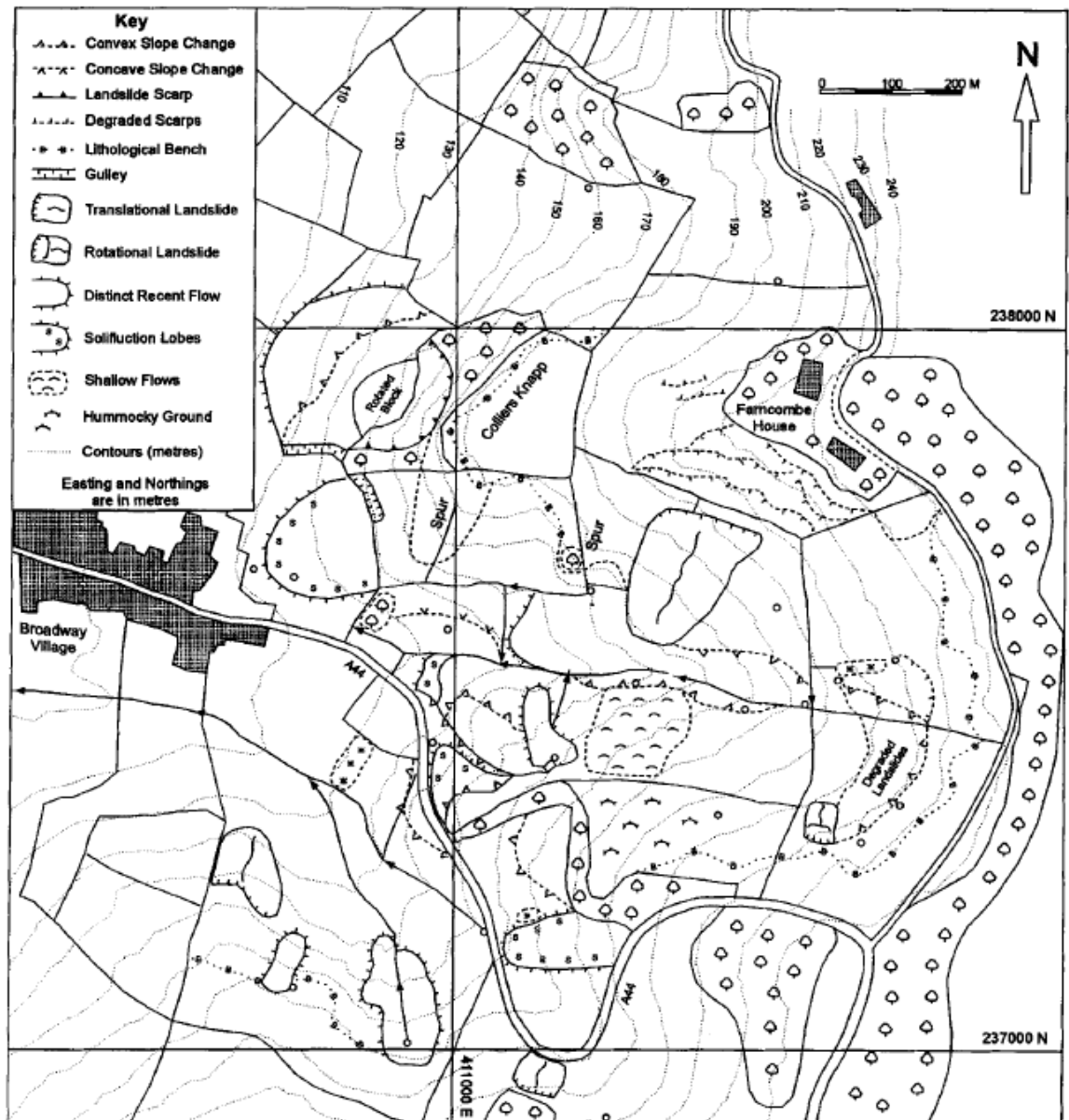


Figure 10.1. Engineering geomorphology of the Broadway, Worcestershire study area showing areas of slope instability with major landslide and solifluction features (Whitworth, Murphy, Giles & Petley, 2000)



**Figure 10.2. Aerial photography of the south-west part of the Broadway study area.
(Reproduced with permission of NERC Airborne Remote Sensing Facility (ARSF)
(Whitworth, Murphy, Giles & Petley, 2000)**

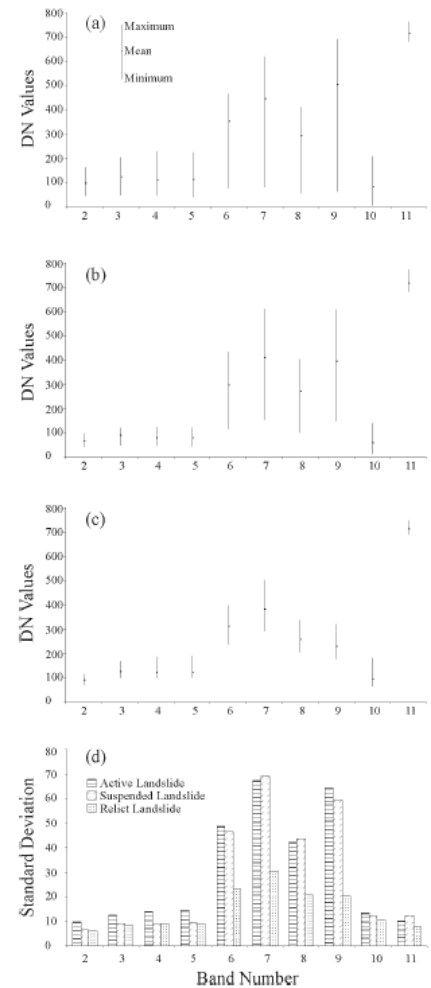
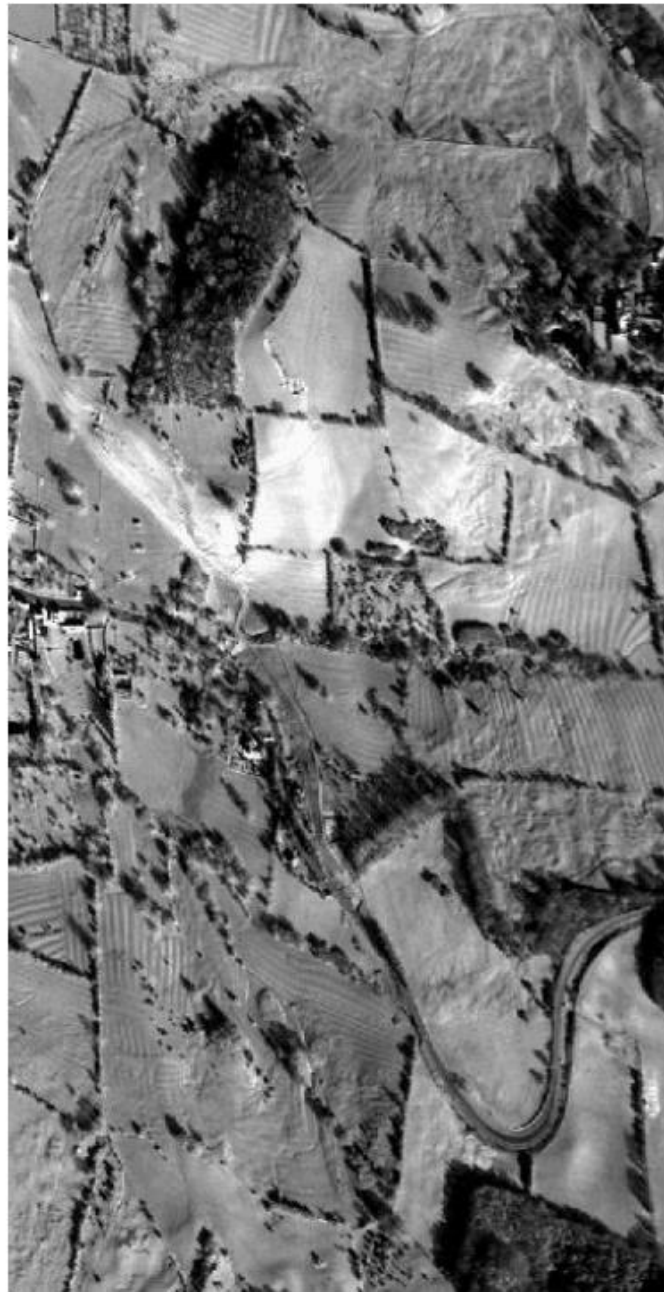


Figure 10.3. Broadway ATM (Airbourne Thematic Mapper) image (Band 9) with DN (Digital Number) Profiles for (a) Active Landslide (b) Suspended Landslide and (c) Relict Landslide with (d) Standard Deviations for all landslide categories (Re-scaled DN Values) (Whitworth, Giles, Murphy & Petley, 2000)

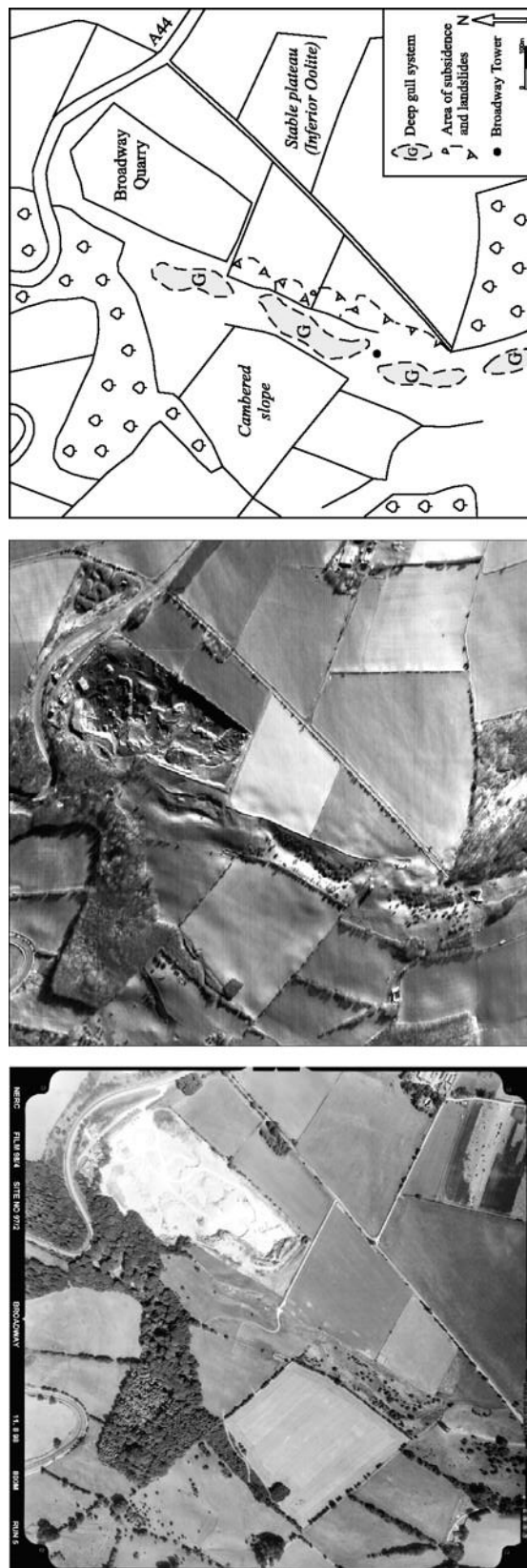


Figure 10.4. Thermal image analysis of the cambered slope at the top of the escarpment in the vicinity of Broadway Tower. (a) Greyscale aerial photograph; (b) Thermal infrared ATM band 11; and (c) Map showing the main geomorphological features. (Whitworth, Giles & Murphy, 2005)

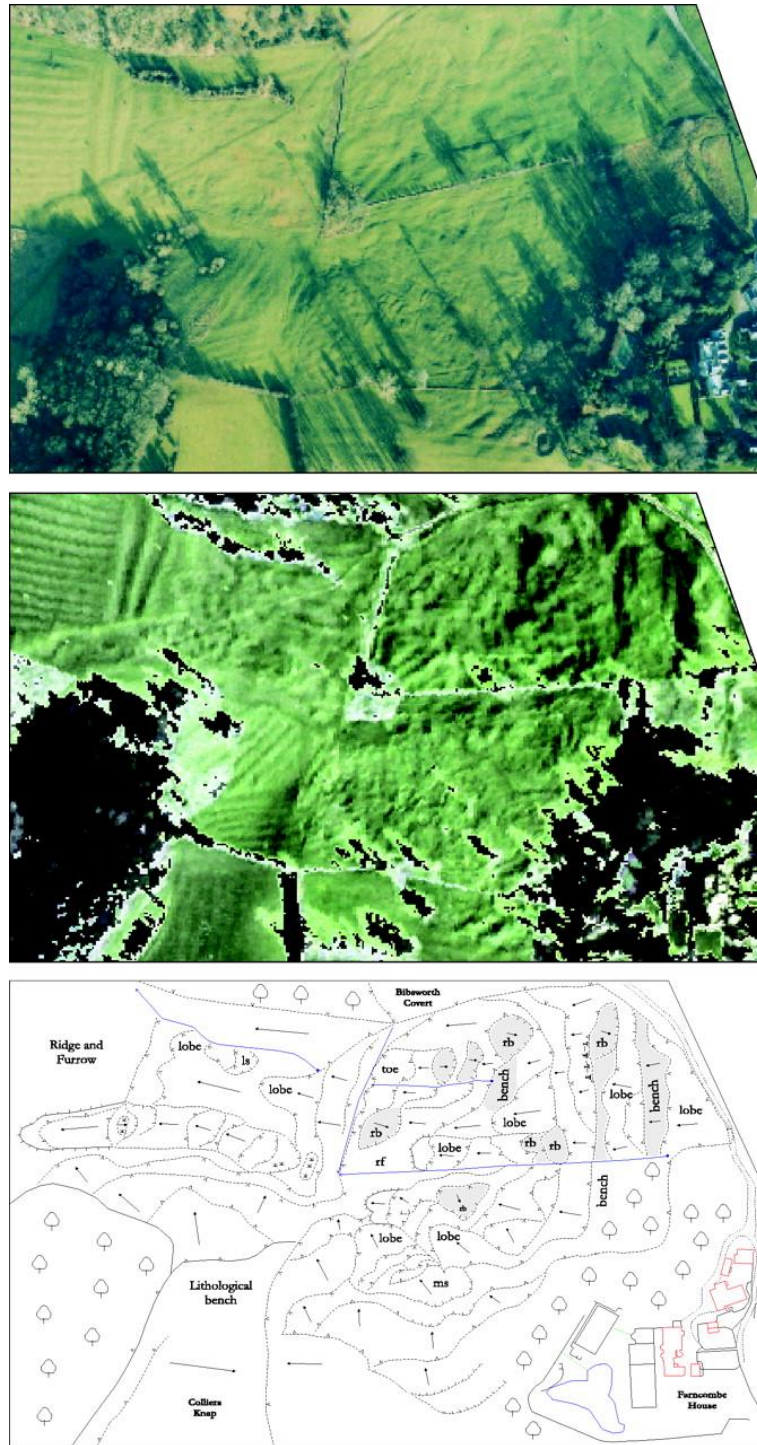


Figure 10.5. Landslide morphological mapping of Farncombe Valley, Broadway, Worcestershire using ATM colour composite and Principal Component Analysis. (a) NERC colour aerial photo (b) RGB colour composite produced by combination of a true colour composite of ATM bands 4–3–5 with PCA image; (c) Geomorphological map showing location of benches, lobes and rotated blocks (Whitworth, Giles & Murphy, 2005)

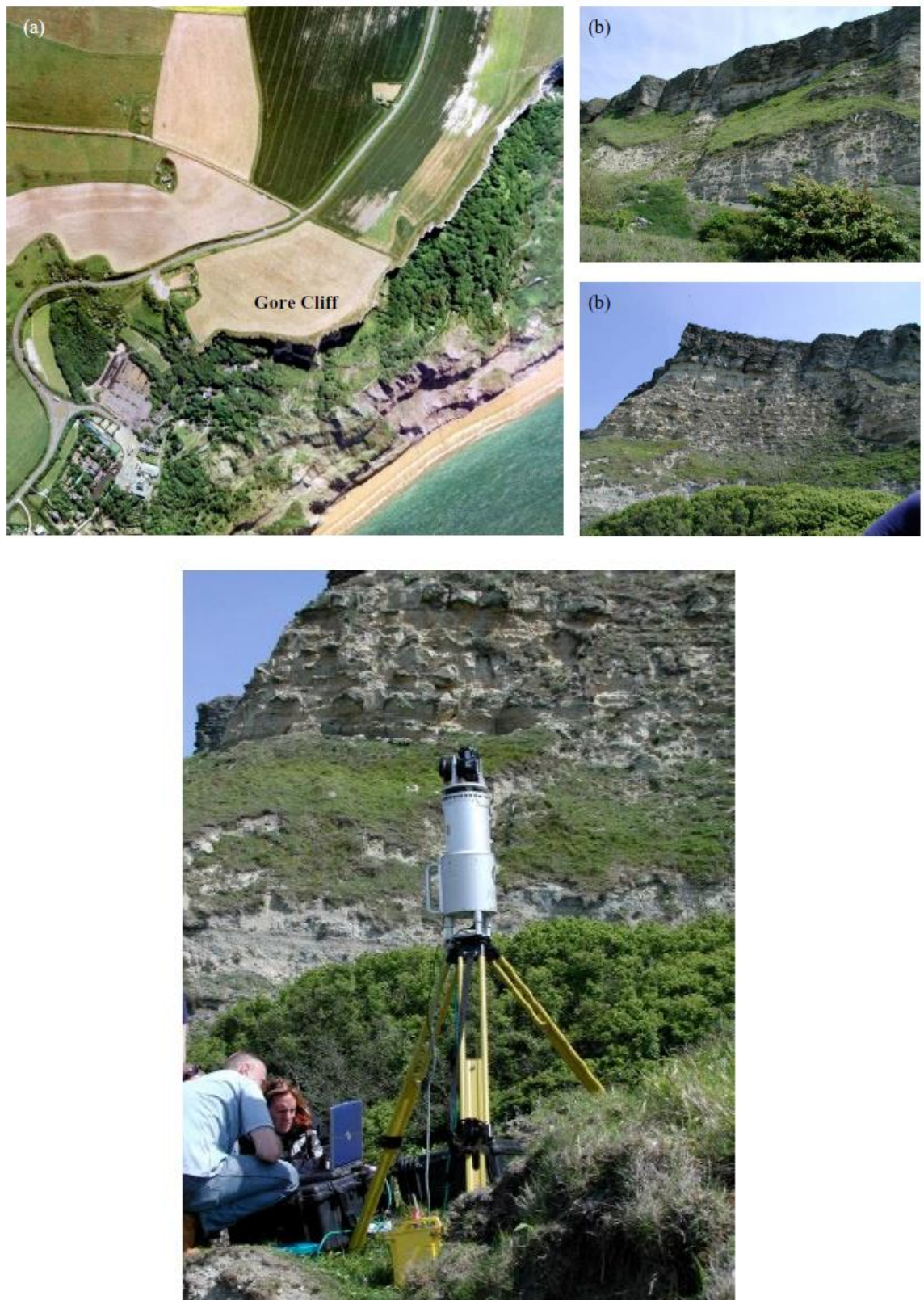


Figure 10.6. Reigl LMS-Z420i scanner with top mounted digital camera. Study area : (a) Gore Cliff and (b) Blackgang Upper Greensand cliffs, Isle of Wight (Whitworth, Giles & Anderson, 2009)

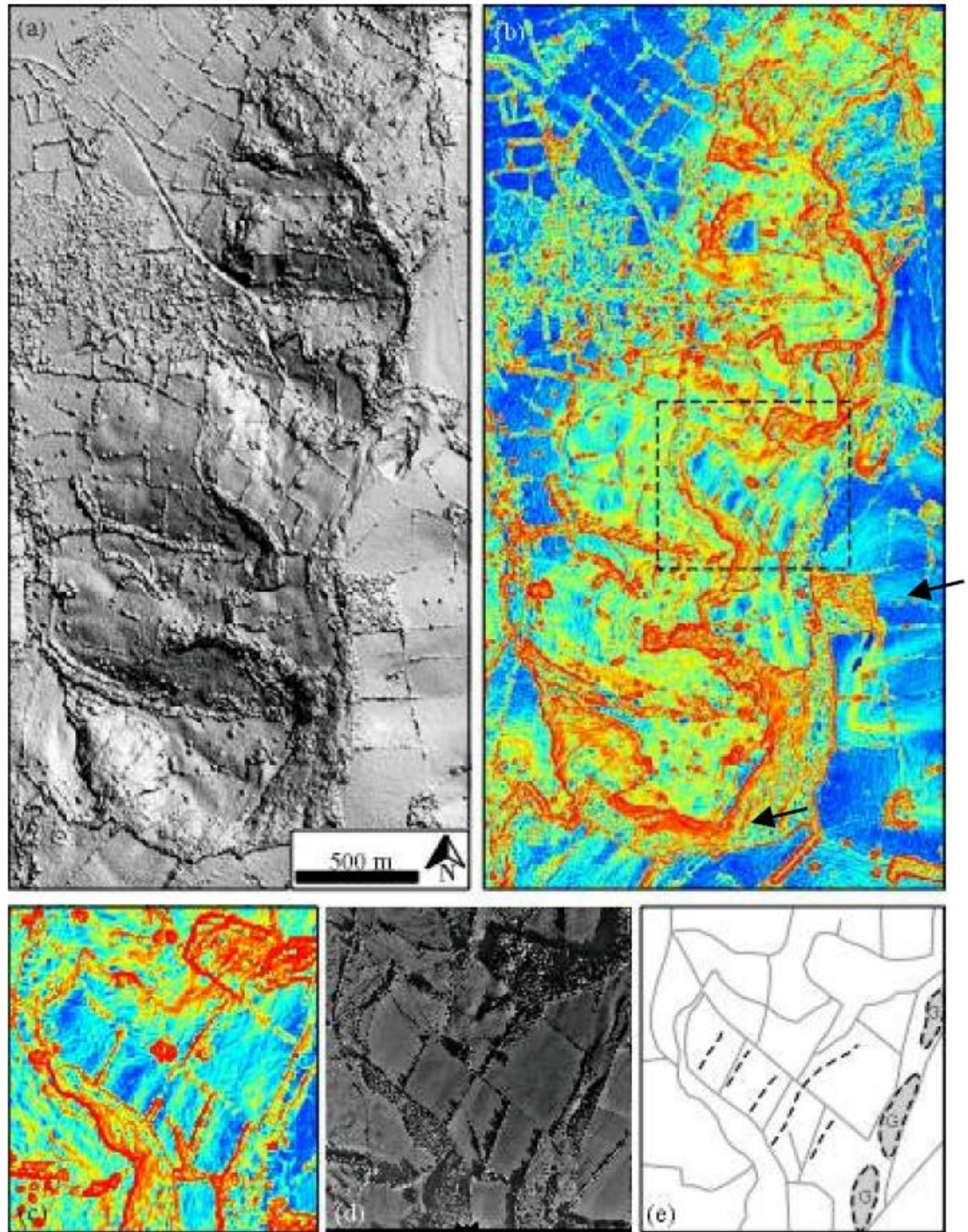


Figure 10.7. Mapping surface expression of cambering using *NextMap* digital elevation data (a) Sun shaded surface map of Broadway study area (b) Pseudocolour slope angle map (c) Slope map showing cambered slope in vicinity of Broadway Tower (d) Black and white aerial photograph of area (e) Location of main cambered gullies and linear surface depressions identified in the slope map. Arrows indicate locations of other slopes which show topographic signatures indicative of cambering (Whitworth, Giles & Anderson, 2009)

11.0 Integration of Computer Applications into the Applied Geoscience Teaching Programme

A key and high impact aspect of my research into and the development of computer-based modelling and analysis in engineering geology has been the incorporation of this work into the undergraduate and postgraduate teaching programmes at the University of Portsmouth. From very early work on the use of spreadsheets (which now would be considered very mundane but at the time was very ambitious, advanced and cutting edge for a geoscience curriculum) to advanced image processing, GIS, surface modelling and risk analysis, this research now forms the basis of many student exercises and practical labs.

The early pedagogic contributions, in collaboration with John Whalley, have been reported in several papers and conferences commencing in 1994 with *Computer-based activities in engineering geology training* (Giles & Whalley, 1994, Papers Vol. 1) published in the proceedings of the 7th Congress of the International Association of Engineering Geology along with *The integration of spatial analysis software into undergraduate earth science teaching* (Whalley & Giles, 1994, Papers Vol. 3) presented at the *Mineralogical Association of Canada Annual Meeting* in Waterloo, Ontario. This early work was also published in an expanded form in the proceedings of a joint meeting of the *International Union of Geological Sciences and the Association of Geoscientists for International Development* which considered *Geoscience Education and Training*. The paper, *A spreadsheet-based, problem-orientated approach to computing for earth scientists* (Whalley & Giles, 1996, Papers Vol. 1) demonstrated our work in the development of spreadsheet based exercises for undergraduates.

A paper prepared with Malcolm Whitworth for the 10th International Association of Engineering Geology Congress in Nottingham and later republished in the Engineering Geology Special Publication *Engineering Geology for Tomorrow's Cities* (Culshaw et al., 2009) entitled *Training and education of engineering geologists for the new urban challenges in applied geosciences* (Giles & Whitworth, 2006, 2009, Papers Vol. 2) outlined further developments in the applied geoscience curriculum in risk-based modelling, remote sensing, image analysis and GIS applications. This work was cited by Kaczyński (2007) and Baynes et al. (2009).

Another significant and perhaps *avant-garde* collaborative pedagogic contribution was with Civil Engineering colleagues at South Bank University and the University of Portsmouth (John Moran and Nick Langdon) in a HEFCE funded project as part of their Teaching and Learning Programme. The work focused on the development of Geotechnical Computer Assisted Learning materials (CAL) for use by undergraduate civil engineering and engineering geology students (Moran, Langdon & Giles, 1996, Papers Vol. 1). We were engaged on Strand 3 of the project which developed a suite of Computer Assisted Learning exercises for Site Investigation training (Fig. 11.1).

The pedagogy and critical assessment behind this work was first published in the proceedings of the 2nd *Working Conference on Engineering Education: Professional Standards and Quality in Engineering Education* held at the Sheffield Hallam University in 1997 with a paper *Computer Aided Learning for realistic undergraduate professional experience in site investigation* (Moran, Langdon & Giles, 1997c, Papers Vol. 1). The themes were developed further in a paper *Can Site Investigation be taught?* published in the *Proceedings of the Institution of Civil Engineers, Civil Engineering* and reprinted in *New Civil Engineer International* (Moran, Langdon & Giles, 1997a, 1997b, Papers Vol. 1). The paper discussed the relative merits of the approach and commented on its place and relevance in the then modern day curriculum. This work has been cited by numerous other authors; Davison and Porritt (1999), Maskall et al. (2005), Chegenizadeh and Nikraz (2012), Jaksa et al. (2009), Jaksa et al. (2000), Jaksa, Davison and Toll (2000) and Toll (2000).

The Computer Assisted Learning exercises developed involved an interactive site investigation game (simulation and role playing software long before the Xbox and PS4). The student was given a brief by a virtual client to undertake a site investigation involving a desk study, walkover survey and planned borehole excavations. Moran, Langdon and Giles prepared the general concepts which were then programmed by the project's Research Assistants. Fig. 11.2 shows the start-up screen for the developed program. The software was widely adopted at the time by Civil Engineering departments and other members of the consortium.

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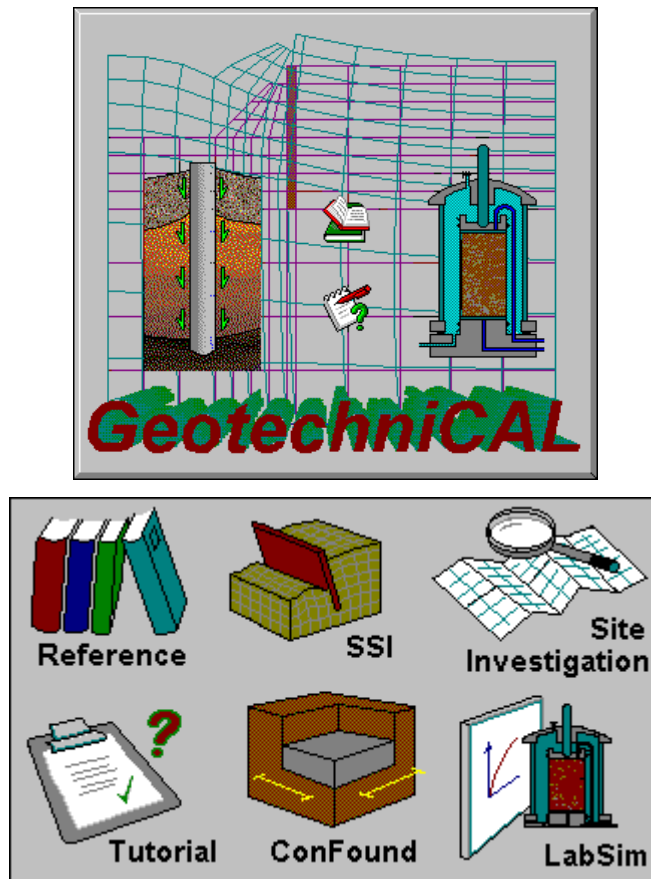


Figure 11.1. The developed *GeotechniCAL* program (Moran, Langdon & Giles, 1996)

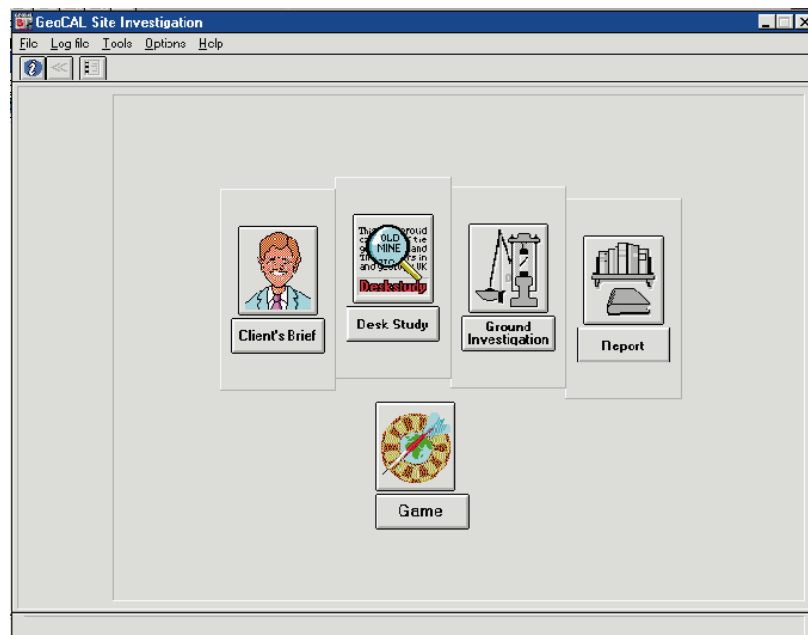


Figure 11.2. Start-up screens for the developed computer simulation game (Moran, Langdon & Giles, 1996)

12.0 Other Research and Publications

This section of the commentary briefly describes my other research publications and output that does not fall under the general thematic heading of *Computer-Based Modelling and Analysis in Engineering Geology*. This work has included encyclopaedia entries, field guides, work on the International Association for Engineering Geology Commission 22 (*Landscape evolution in engineering geomorphology*) as well as being a principal author in the production of a training guide for engineering geologists for the Geological Society.

I have published three encyclopaedia contributions, firstly on *Geotechnical engineering*, (Giles, 2004, Papers Vol. 2) in *The Encyclopaedia of Geology* (Selley et al., 2004) and secondly two entries in *The Encyclopaedia of Natural Hazards* (Bobrowsky, 2013). These were focussed on seismic measurement scales; *Intensity scales* (Giles, 2013a, Papers Vol. 3) and *Magnitude measures* (Giles, 2013b, Papers Vol. 3).

My academic fieldwork experience has been published via a paper in *Planet; The development of fieldwork problem-based exercises in the Applied Geosciences* (Giles, Whitworth & Poulsom, 2008, Papers Vol. 2) resulting from a GEES Subject Centre funded project in 2005 *Bringing the 'Real World' into the GEES Student Learning Experience: The Development of Fieldwork Problem-Based Learning in the Applied Geosciences*. This work was cited by Brabham (2009).

In 2009 I led an Engineering Group of the Geological Society Field Meeting to the Grenoble area of the French Alps. A field guide was produced for this excursion which I subsequently published in the *Quarterly Journal of Engineering Geology and Hydrogeology; A Field Guide to the Engineering Geology of the French Alps, Grenoble* (Giles, 2012, Papers Vol. 3). Figure 12.1 details the site localities visited and described in the paper.

Other collaborative projects have been with work on the International Association for Engineering Geology Commission 22: *Landscape evolution in engineering geomorphology* with Professor Jim Griffiths and Dr Martin Stokes of Plymouth University and Dr Doug Stead of Simon Fraser University, Canada, a project where I acted as the Commission

Secretary. Two papers were produced from this work, the initial on the intentions of the Commission presented at the 11th *International Association for Engineering Geology Congress: Geologically Active*, in Auckland, New Zealand, *Report on IAEG Commission 22: Landscape evolution and engineering geology* (Griffiths, Stokes, Stead & Giles, 2010, Papers Vol. 3) and the final results from the Commission published in the *Bulletin of Engineering Geology and the Environment, Landscape Evolution and Engineering Geology: Results from IAEG Commission 22* (Griffiths, Stokes, Stead & Giles, 2012, Papers Vol. 3) cited by Merritt et al. (2013). Work on this geomorphological theme was also presented via a poster at the 8th *IAG International Conference on Geomorphology*, Paris (Giles, 2013c, Papers Vol. 3).

As part of my active membership of the Committee of the Engineering Group of the Geological Society I was a key contributor to the *Geological Society's Training guide for engineering geologists* (Wheeler, Chilton, Hodgson, Giles & Whitworth, 2008, Papers Vol. 2), a document now widely adopted in the applied geoscience industry as the benchmark for graduate engineering geology training.

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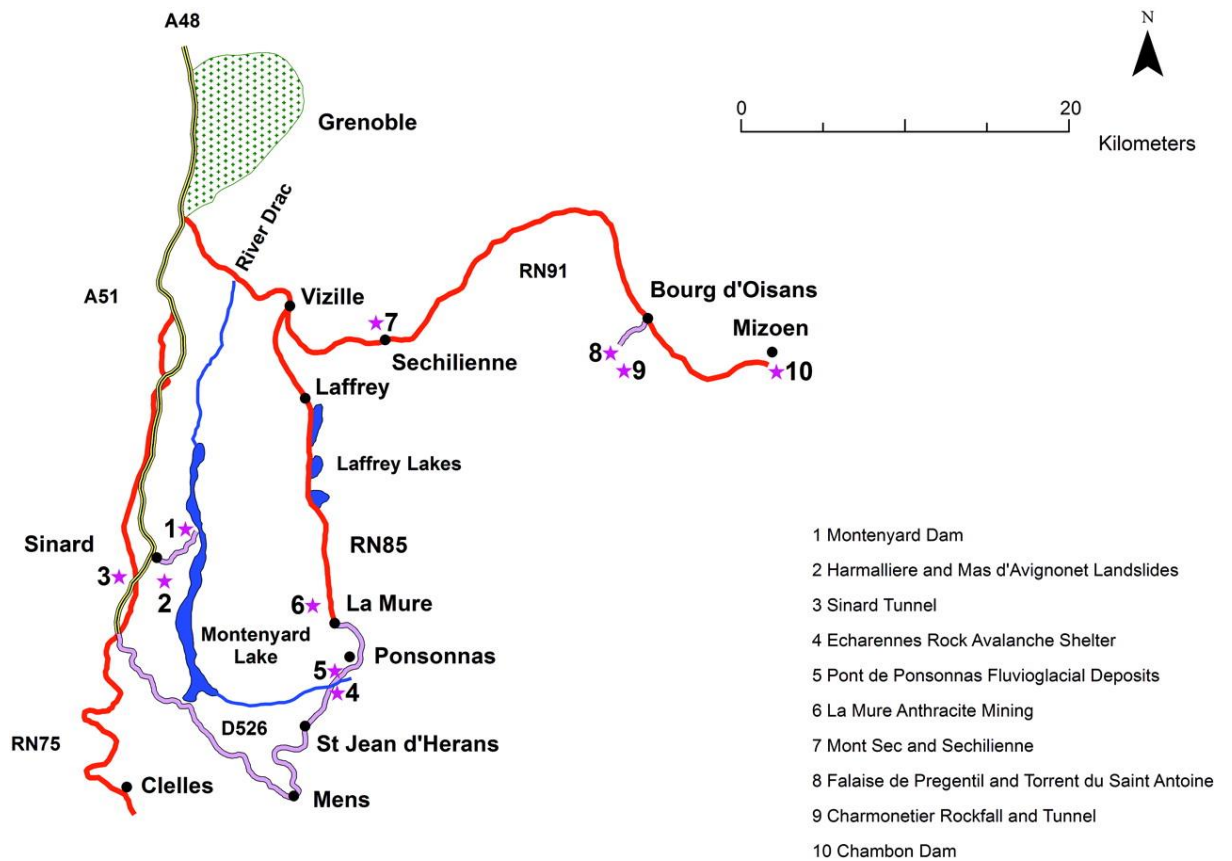


Figure 12.1. Site localities from a field guide to the engineering geology of the French Alps, Grenoble (Giles, 2012)

13.0 Work in Progress

I am currently heavily involved in two working parties for the Geological Society of London. Firstly with the Working Party on Geological Hazards in the UK (which I chair) and secondly with the Working Party on Periglacial and Glacial Engineering Geology.

I am the joint editor of the proposed Engineering Geology Special Publication on *Geological Hazards in the UK: Their occurrence, monitoring and mitigation*, as well as contributing a paper on *Quick Clays* to this volume.

For the second project I am the lead author for a chapter on the *Geomorphological Framework* to be published in the Engineering Geology Special Publication *Periglacial and Glacial Engineering Geology*. I am also a named contributor to the chapter on *Engineering materials and hazards*. Overview papers on this work are due to be published in the proceedings of the IAEG XII Congress, *Engineering Geology for Society and Territory* in Turin, Italy, 2014 (Giles et al., 2014, Papers Vol. 3) and in the proceedings of the 4th *European Conference on Permafrost*, Évora, Portugal, 2014 as well as in the proceedings of the 16th *European Conference on Soil Mechanics and Geotechnical Engineering*, Edinburgh. A poster with abstract on this work was also presented at the 8th *IAG International Conference on Geomorphology*, Paris (Giles et al., 2013).

Another paper accepted for publication at IAEG XII is work from one of my current PhD co-supervisions on *Geotechnical and Geochemical Characterisation of Oil Fire Contaminated Soils in Kuwait* (Al-Daihani, Watson & Giles, 2014, Papers Vol. 3).

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14.0 Summary

My work presented here for consideration for the award of PhD by Publication includes research and publications in geotechnical data management and data transfer, geostatistics and spatial data modelling, hazard and risk analysis, Knowledge-Based Systems, Geographical Information Systems and remote sensing, all within the themed framework of *Computer-Based Modelling and Analysis in Engineering Geology*.

Throughout my career I have sought to design, develop and test a variety of computer-based modelling and analytical techniques within the discipline of engineering geology. My work has significantly contributed to the development of geotechnical database systems and data interchange, spatial modelling and the use of GIS within engineering geology. I have also made a major contribution to the education and training of both undergraduates and postgraduates in the use of computer-based modelling tools in engineering geology and ground assessment.

My original work is now applied on a daily basis within the ground engineering industry with the use of the AGS data format for geotechnical data interchange together with spatial modelling and visualisation techniques now being used routinely for site assessment, characterisation and interpretation. My work has been significant in the advancement of these techniques and in their wide acceptance within the UK engineering geology community for their use and application.

In summary my publication record comprises of; Pathfinder and seminal papers; Papers from supervised PhD programmes; Pedagogic contributions; Encyclopaedia entries; International collaborations; Technical authorship and support; Other published contributions; Confidential development and technical reports and Internal briefing papers. Listed below is a summary of these publications under these themes.

14.1 Key

Papers submitted for consideration under the theme of Computer-Based Modelling and Analysis in Engineering Geology

Other published papers

14.2 Pathfinder and Seminal Papers

- The geotechnical computer workstation: The link between the geotechnical database and the geographical information system.
- A digital data standard for the interchange of geotechnical and geoenvironmental data.
- The integration of GIS and geostatistical modelling for a tunnelling geohazard study.
- Electronic transfer of geotechnical data from ground investigations.
- A digital data standard for the electronic transfer of geotechnical data from ground investigations.
- Geological surface modelling utilising geostatistical algorithms for tunnelling window delineation - a case study from the London Water Ring Main.
- A geographical information system for geotechnical and ground investigation data management and analysis.
- Geostatistical interpolation techniques for geotechnical data modelling and ground condition risk and reliability assessment.

14.3 Publications from Co-supervised PhD's

- A geotechnical and geochemical characterisation of oil fire contaminated soils in Kuwait.
- Landslide imaging techniques for urban geoscience reconnaissance.
- Terrestrial laser scanning for applied geoscience and landslide studies in the urban environment.
- Airborne remote sensing for landslide hazard assessment: a case study on the Jurassic escarpment slopes of Worcestershire, United Kingdom.
- Strategies for identifying and designing safe, economic municipal solid waste disposal sites in the arid zones of Southern Africa.
- A knowledge-based approach to municipal solid waste disposal site development in the Karstified Dolomitic terrain around the town of Tsumeb in North Central Namibia.
- Landslides of the Cotswolds escarpment, Broadway, Worcestershire, UK.
- Identification of landslides in clay terrains using Airborne Thematic Mapper (ATM) multispectral imagery.
- Spectral properties of active, suspended and relict landslides derived from Airborne Thematic Mapper imagery.
- Historical constraints on slope movement age: a case study at Broadway, United Kingdom.
- Risk assessment revisited: A review of contaminated land risk assessment using data from a known contaminated site in Portsmouth, UK.

- Probability density function modelling for earthquake-triggered landslide hazard assessments.
- A brief review of the use of risk assessment software for the characterization of contaminated land.
- GIS for the modelling and analysis of domestic property insurance risk associated with potentially collapsible soils of southern Britain.
- Topsoil thickness modelling using GIS for the purpose of assessing risks from underlying contaminated material on Hope Cottage Allotments, Portsmouth.
- On contaminated ground.
- Geographical information systems as data integrators for pre-ground investigation studies in the urban environment.
- Rising groundwater levels at Fawley, Hants.

14.4 Pedagogic Contributions

- A field guide to the engineering geology of the French Alps, Grenoble.
- Training and education of engineering geologists for the new urban challenges in applied geosciences.
- The development of fieldwork problem-based exercises in the Applied Geosciences.
- The Geological Society's Training guide for engineering geologists.
- Digimap Case Study: The engineering geology and geological hazards of Ironbridge Gorge.
- Engineering Geology and Geotechnics at Portsmouth – The First 40 Years.
- Can Site Investigation be taught?
- Computer Aided Learning for realistic undergraduate professional experience in site investigation.
- Geotechnical Computer Assisted Learning, Strand 3, Site Investigation.
- A spreadsheet-based, problem-orientated approach to computing for earth scientists.
- Computer-based activities in engineering geology training.

14.5 Encyclopaedia Entries

- Intensity scales.
- Magnitude measures.
- Geotechnical engineering.

14.6 International Collaborations, Technical Authorship and Support

- Probabilistic risk assessment: The tool for uncertainty reduction in geotechnical engineering.
- Reliability analysis of earth fills using stochastic methods.
- Modelling uncertainties in the stationary seepage problem.

14.7 Other Published Contributions

- The Geological Society of London Engineering Group Working Party on Periglacial and Glacial Engineering Geology.
 - Geomorphological framework.
 - Engineering materials and hazards.
- Quick clays - Geological hazards in the UK: Their occurrence, monitoring and mitigation.
- Landscape evolution and engineering Geology: Results from IAEG Commission 22.
- Report on IAEG Commission 22: Landscape evolution and engineering geology.

14.8 Abstracts

- The Geological Society of London Engineering Group Working Party on periglacial and glacial engineering geology.
- A geotechnical and geochemical characterisation of oil fire contaminated soils in Kuwait.
- The use of ground models for the integration of geomorphological, geoenvironmental and engineering geological data.
- A combined texture-principal component image classification technique for landslide identification using airborne multispectral imagery.
- Geotechnical characterisation of some brickearths of Southern Britain.
- Periglacial geohazard prediction utilising remotely sensed imagery, geomorphology and piezometry.
- GIS integration of remotely sensed imagery, geomorphological maps and piezometric data for periglacial geohazard assessment.
- The integration of spatial analysis software into undergraduate earth science teaching.
- Geostatistics as an aid to geological risk analysis.

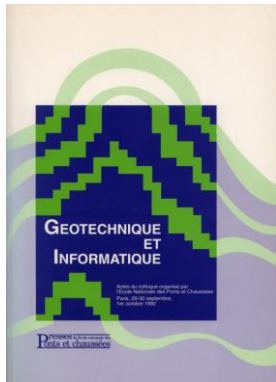
14.9 Confidential Development and Technical Reports

- Channel Tunnel Rail Link Thames Crossing and Approaches Geostatistical Analysis.
- London Water Ring Main Brixton to Honor Oak Tunnel Desk Study and Geological Risk Analysis.
- London Water Ring Main Stage 5 Geological Risk Analysis.
- GDMS - Geotechnical Data Management System.
- GDMS: Geotechnical Data Management System User's Manual.
- <Geo-Graphics> Seismic Data Management System User's Manual.

14.10 Confidential Internal Briefing Papers

- Use of a raster based geographic information system by Portsmouth City Council for contaminated land assessment and modelling.
- Relational databases and geotechnical data management.
- The interchange of geotechnical data by electronic means – Towards a common key.
- Geotechnical data interchange: Format Data Dictionary.
- Mott MacDonald Geotechnical Database – an overview.
- A review of the Mott MacDonald Geotechnical Data Management System.

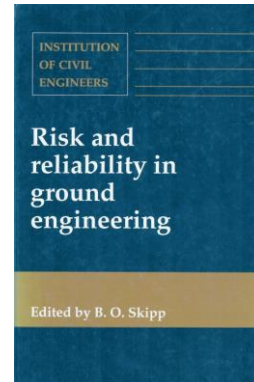
- The revised London Basin Geological Database – Preliminary discussion document.
- Current computer software within the Foundations and Geotechnics Division, Mott MacDonald.



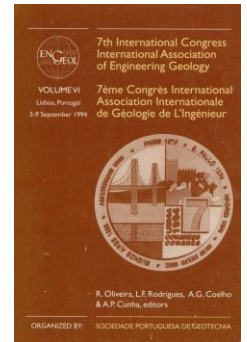
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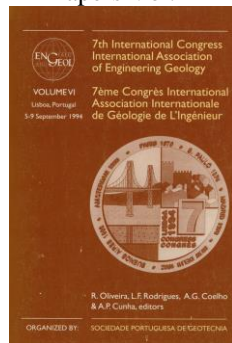
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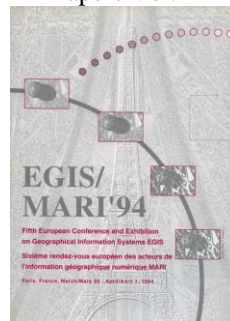
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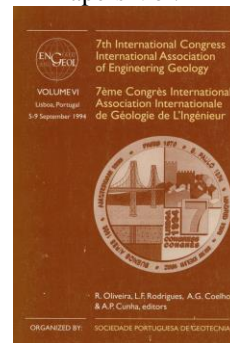
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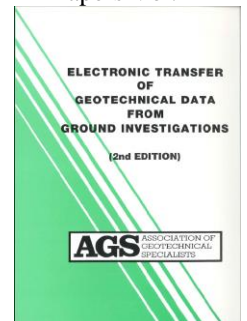
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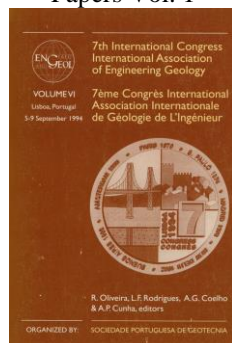
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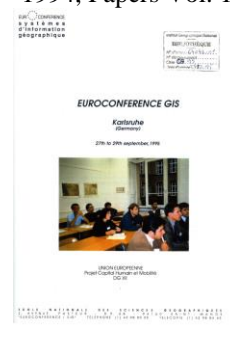
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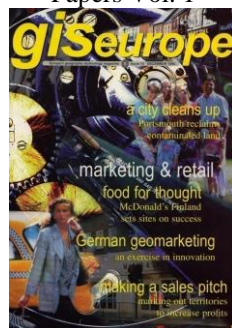
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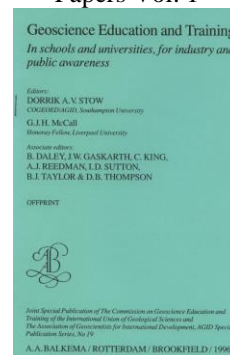
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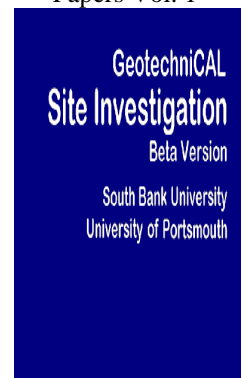
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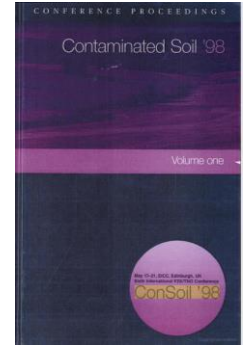
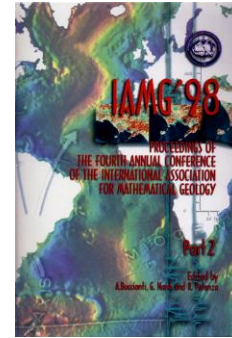
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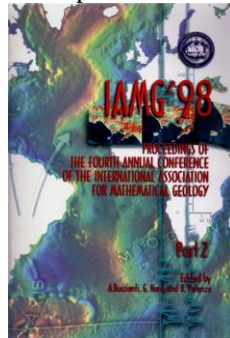
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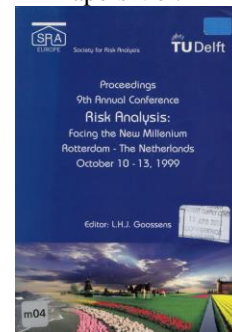
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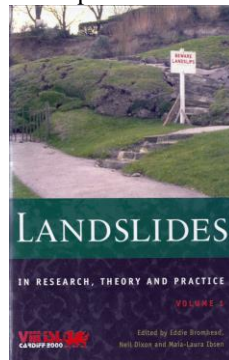
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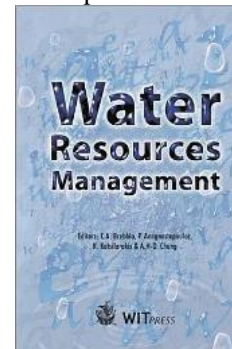
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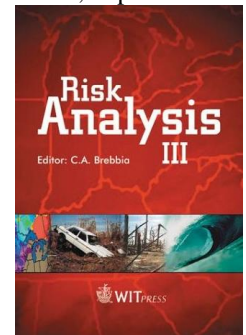
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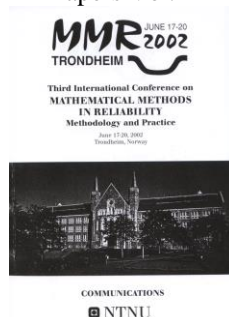
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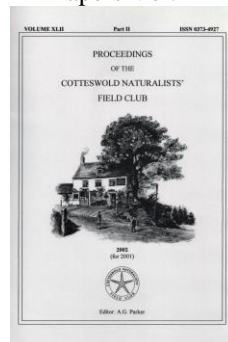
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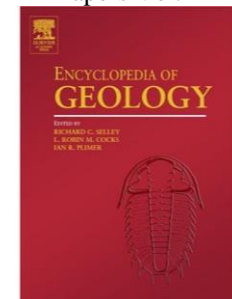
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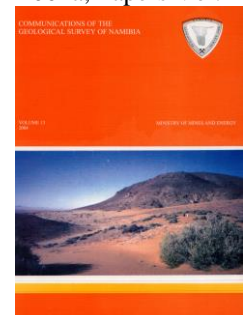
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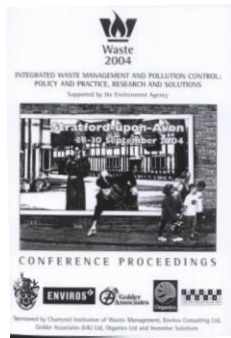


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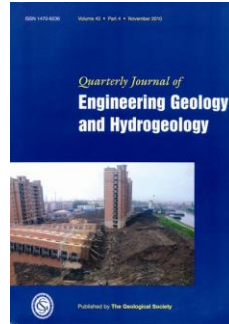
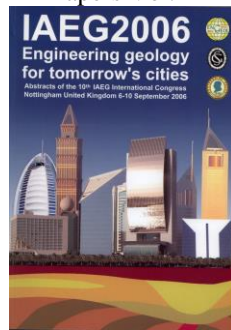
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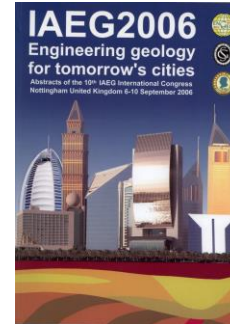
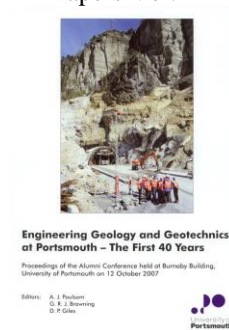
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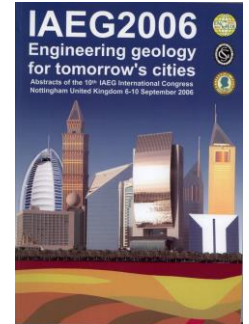
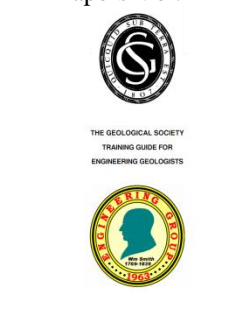
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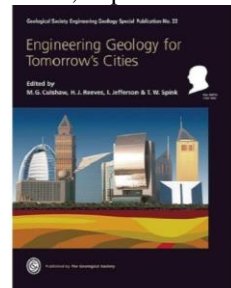
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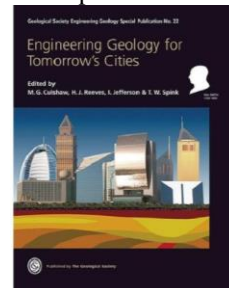
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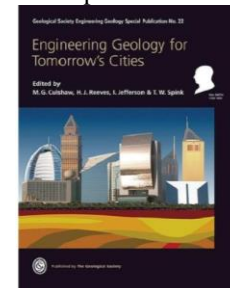
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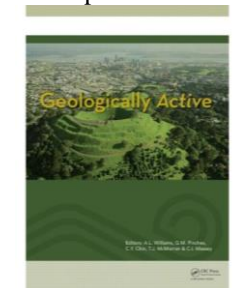
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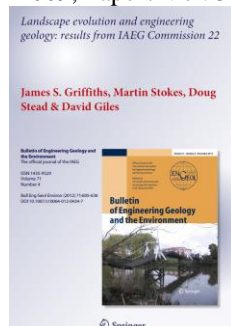
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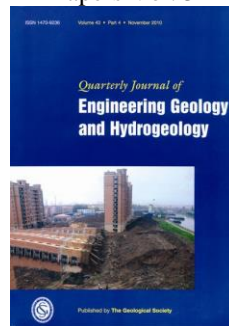
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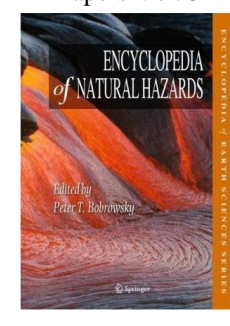
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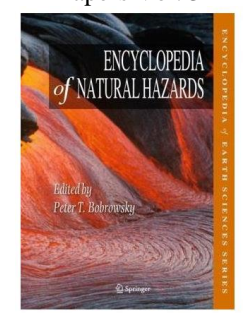
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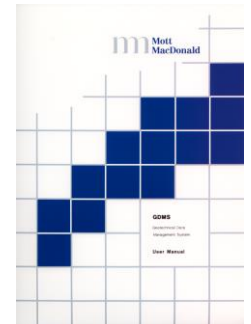
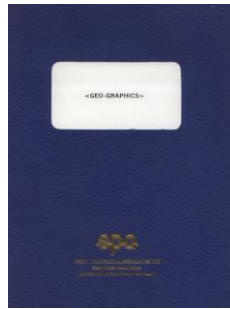


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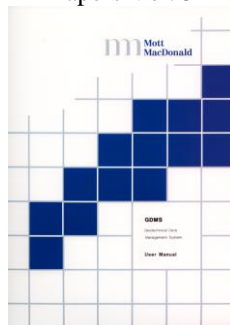
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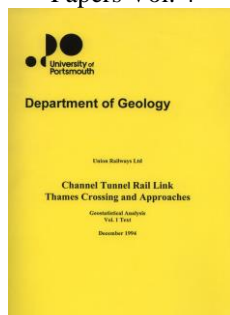
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15.0 Concluding Remarks

As all of the computer-based techniques and associated software have developed over the years the sophistication of the models generated has perhaps started to depart from the field and ground experience of the end-user.

Complex models are being developed to replicate the natural world without the user of those models having the field-based experience of such environments.

It is imperative for future work that due attention be paid to field knowledge and field calibration of the computer-based models so that they don't just become a dangerous "black-box" phenomena.

It is ironic that in the most *computerate* of ages that we should need to go back to our first field principles as engineering geologists to fully appreciate our developed computer models. Future research must seek to benchmark and calibrate the developed computer models with real field settings and situations. Failure to do so will result in a potentially visually stunning piece of software and associated output that fails to accurately replicate the very setting that it is trying to model.

The best geologist remains the one who has seen the most rocks, not the one who can run the most sophisticated of computer models.

David Giles October 2014

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