An Evolution of Near Surface Geophysical Imaging:

Directionality, Physical Properties and Challenging Conventional Wisdom

A collection of papers submitted for consideration for the degree of
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Table of Contents

Introduction

The fundamental changes in applied geophysics in the last few decades have to a great extent been in the development of near-surface geophysics (NSG) – what used to be called environmental and engineering geophysics. In some locations and for some purposes, it still is. The developments in my publications have, to some extent, paralleled and sometimes foreshadowed some significant developments.

My earliest papers were on marine electromagnetic (EM) sounding, and some of those papers are still cited. The work from my PhD and my post-doctoral fellowship laid the groundwork for what was to become controlled source EM (CSEM), a technique of growing importance in marine oil and gas exploration. Because the depths involved were less than 1 km, it can still perhaps be called "near surface", but that was not the original intention.

However, a theme central to that early work has carried on, explicitly or implicitly, through much of my research – anisotropy and the directionality of the geophysical response. One of my early theoretical papers was on the inclusion of anisotropy in Maxwell's equations, and recent papers have used the directionality of the EM response as a tool in archaeological imaging.

Another pair of linked themes that have recurred almost from the beginning are the influence of physical properties on the geophysical response, and the inter-relationships of physical properties. It allowed me to determine the physical property variations at depth in Middle Valley, on the northern Juan de Fuca Ridge. Those predictions were confirmed by the results from Ocean Drilling Program (ODP) Leg 139, which drilled those Middle Valley sites.

While the marine research was interesting and rewarding, I was also moving more and more onshore, and began doing archaeological imaging in the late 1980's. Much of that work was focussed around student projects, but then expanded into forensic geoscience, and ultimately to the non-invasive imaging of burial sites. That work continues today.

The onshore research also allowed me to move from EM induction methods into ground penetrating radar (GPR), which involved the propagation of high-frequency EM waves. There are many hypotheses and approaches to GPR that were based on incorrect assumptions. For example, it was often assumed that rocky debris in debris-covered and debris-laden glaciers would not prevent the propagation of significant GPR energy at depth, an assumption that we proved wrong. The publication from 1994 on GPR imaging of the debris-covered lower Tasman Glacier was not followed by a paper by other researchers on GPR imaging of debris-laden glaciers until 1997, and GPR is now a common technique for imaging of all types of glaciers.

Thus glacier imaging has been an ongoing application, and has expanded to include imaging of permafrost, including 4-dimensional (4D) imaging, i.e. time lapse 3-dimensional (3D) imaging, of permafrost polygonal patterned ground (PPG) in the Dry Valleys of Antarctica. The utility of near-surface geophysics in Antarctica has expanded greatly over the years.

Similarly, surface water was assumed to degrade GPR signal penetration. Again, this was based on an incorrect assumption – that water was inherently conductive. While the presence of water does increase the electrical conductivity, if the water is fresh then the conductivity still remains quite low, and the attenuation of the GPR signal is minimal.

Thus the applications for EM and GPR have expanded, and the principles and applications are better understood now, ranging from archaeological and forensic geoscience, through non-destructive testing (NDT) and other geotechnical projects, to neotectonics and the imaging of active faults. Recently, I and my students have combined GPR more and more with electrical imaging. The two complement each other nicely.

Finally, I have included two review papers, each in the section of greatest relevance. I recognise that this is not standard practice, but one from 1996 was used as a benchmark and a starting point for the later reviews of the environmental applications of EM, and the other from 2011 provides what I hope will be a paper used to help glacier imaging surveys to be better designed and completed. Both also include recent research results that had yet to be published, and thus represented the state of the art.

I would note that I have included a number of papers from conference proceedings. In applied geophysics, the conference papers are normally peer reviewed, just as in engineering. Sometimes those papers are then expanded and augmented and subsequently published in peer-reviewed journals. If the peer-reviewed conference papers were later published as peer-reviewed journal articles, then the journal article is included here.

There are papers I decided not to include because they did not fit into the overall theme of this collection of papers – the evolution of my work in near-surface geophysics, which I took very broadly to embrace my work in marine geophysics as well. The papers not included here were two papers on paleoclimatology, for which I did the crucial spectral analysis, and three papers on social science and philosophy of science. I also excluded a few papers that were superseded by later work.

There appears to be no set configuration to the form of a DSc, beyond collecting the papers together into some sort of coherent form that reflects the themes the work represents. In principle, a collection of papers submitted for the DSc represents the best of a lifetime of work. However, I hope that my best work is still to come. Only time will tell if that is true. For the papers submitted here, I have done a significant amount of the work, if not the majority of the work. In the case of papers based on student projects that I supervised, if the student wrote the first draft, then I made them first author, regardless of how much additional work was required to get the paper to its published form. A complete list of publications is appended to this Introduction. The papers included here have been highlighted.

Structure and Layout

This collections of papers submitted for the DSc is arranged approximately thematically, and within each section, the papers are arranged approximately chronologically. The internal chronological order is not strictly followed to keep closely allied papers together. There are papers that can be in more grouped under more than one thematic section; they will be identified individually.

Section 1, Anisotropy and Directionality, includes all of the marine EM papers, because that underlying theme was present in all of them. The directionality of the response can give rise to applications of that property, to enable us to highlight subsurface features more accurately.

Section 2, Physical Properties, brings together the papers on the factors influencing physical properties, physical property inter-relationships, and the application of those relationships to modelling of the sea floor physical properties as a function of depth.

Section 3, GPR Properties and Methodologies, presents the papers that explore the properties and processes that govern GPR and its applications. Many of those papers challenged existing preconceived notions about when GPR would work and not work, as discussed in the Introduction.

Section 4, Glacier and Permafrost GPR, originated as a result of a question from Manfred Hochstein in 1992: Can we do geophysics on a debris-covered and debris-laden glacier? My initial reaction was that it was not viable, but we decided to try it anyway on the terminus of the Tasman Glacier. It was a resounding success and triggered a wave of GPR on glaciers of all types, not just polar and "clean" temperate glaciers. Again, we successfully challenged the prevailing pre-conceived notions of the day.

Section 5 brings together papers that focussed on environmental aspects, specifically Groundwater and Soil Contamination, including contamination in Antarctica. Of particular interest is that hydrocarbon contaminants in polar regions behave like young contaminants in temperate regions, due to the slow rate at which degradation of the contaminants occurs. This result was not unexpected, but needed confirmation.

Section 6, Structure and Stratigraphy, represents the tip of an iceberg. The three papers that are focussed on stratigraphy and the two papers on structure (or the term "neotectonics" could also be used) represent only a small portion of the work in which I have been involved, especially in neotectonics and structure. However, those are the ones for which I have made a significant enough contribution that I felt justified in including them here. As with all collaborative work, sometimes the proportion of the contribution is difficult to judge. Thus I have erred on the conservative side and included only a few of the more than a dozen papers that have arisen in my collaborations with colleagues from the US and Switzerland, that have involved geophysical imaging of active subsurface structures and stratigraphy.

Section 7, Geoarchaeology and Forensic Geoscience, reflects an ongoing interest of mine that has also inspired a number of students over the years. Again, some of the results are counter-intuitive. For example, higher frequency – and thus greater detail – often obscures the targets rather than showing them more clearly.

Section 8, Non-destructive Testing (NDT), is a short section that has the few papers on geotechnical applications that could be published. Often, such work goes unreported because of its proprietary nature, but it is an important application of NSG nonetheless.

My specific contribution is outlined in each of the section introductions, which in any case is at least 1/3 of the published work, and is ½ or more for most papers here. In the case of the papers for which students were lead authors, I was the primary, co- or associate supervisor, and was involved in the design, implementation, processing and interpretation of the geophysical imaging, and was also a major contributor to the writing of the papers.

Addendum: List of Peer-Reviewed Papers

The list of publications here is accurate up to January 2014. Other papers in the review process or nearing completion are not included. The 44 papers included for the DSc are highlighted (| and *). Co-authors who were students at the time the work was done are indicated by *italics*. The papers are listed in reverse chronological order, but are, in general, presented in the body of the DSc in the chronological order in which they were published. Those papers for which citation numbers are available are indicated. Citation numbers are not available for all papers. The numbers of citations are from Google Scholar as at 24 January 2014.

Peer-Reviewed Journal Papers:

61. *Stahl, T., Bilderback, E.*, Quigley, M., **Nobes, D.** and Massey, C. 2014. Coseismic landsliding during the Mw 7.1 Darfield (Canterbury) Earthquake: Implications for paleoseismic studies of landslides. *Geomorphology*, in press.

60. **Nobes, David C.**, *Bastin, Sarah, Charlton, Gemma, Cook, Rowan, Gallagher, Max, Graham, Hamish, Grose, Daniel, Hedley, Joanne*, Sharp-Heward, Scott & *Templeton, Sean*, 2013. Geophysical imaging of subsurface earthquake-induced liquefaction features at Christchurch Boys High School, Christchurch, New Zealand. *Journal of Environmental and Engineering Geophysics*, Special Issue on Geotechnical Assessment and Geoenvironmental Engineering, **18**(4): 255-267. doi: 10.2113/JEEG18.4.255.

59. Xie, Xiongyao, *Pan, Li*, Qin, Hui, Liu, Lanbo & **Nobes, David C.**, 2013. GPR identification of voids inside concrete based on support vector machine algorithm. *Journal of Geophysics and Engineering*, **10**(3): 034002. doi:10.1088/1742-2132/10/3/034002.

58. *Amos, C. B., Lapwood, J. J.*, **Nobes, D. C.**, Burbank, D. W., Rieser, U., & *Wade, A.*, 2011. Paleoseismic constraints on Holocene surface ruptures along the Ostler Fault, southern New Zealand. *New Zealand Journal of Geology and Geophysics*, **54**(4): 367–378, doi:10.1080/00288306.2011.601746.

57. Almond, P., Wilson, T. M., Shanhun, F., *Whitman, Z.*, Eger, A., Moot, D., Cockcroft, M., & **Nobes, D. C.**, 2010. Agricultual land rehabilitation following the 4 September 2010 Canterbury earthquake: A preliminary report. *Bulletin of the New Zealand Society of Earthquake Engineering*, **43**(4): 432-438. Cited 7 times.

56. *Campbell, F.M., Kaiser, A.*, Horstmeyer, H., Green, A.G., Ghisetti, F., Gorman, A.R., Finnemore, M., & **Nobes, D. C.**, 2010. Processing and preliminary interpretation of noisy high-resolution seismic reflection/refraction data across the active Ostler Fault zone, South Island, New Zealand. *Journal of Applied Geophysics*, **70**(4): 332-342, doi:10.1016/j.jappgeo.2009.05.001. Cited 8 times.

55. *Dorn, C., Carpentier, S., Kaiser, A.E.*, Green, A. G., Horstmeyer, H., Campbell., F., Campbell, J., Jongens, R., Finnemore, M., & **Nobes, D. C.**, 2010. First seismic imaging results of tectonically complex structures at shallow depths beneath the northwest Canterbury Plains, New Zealand. *Journal of Applied Geophysics*, **70**(4): 317-331, doi:10.1016/j.jappgeo.2009.06.003. Cited 12 times.

54.* *Wallace , Shamus C.*, **Nobes, David C.**, *Davis, Kenneth J.*, Burbank, Douglas W., & White, Antony, 2010. Three-dimensional GPR imaging of the Benmore Anticline and step-over of the Ostler Fault, South Island, New Zealand. *Geophysical Journal International*, **184**: 465-474, doi: 10.1111/j.1365-246X.2009.04400.x. Cited 9 times.

53. *Kaiser, A. E.*, Green, A. G., *Campbell, F. M.*, Horstmeyer, H., Manukyan, E., Langridge, R. M., *McClymont, A. F.*, Mancktelow, N., Finnemore, M., & **Nobes, D. C.**, 2009. Ultra-high-resolution seismic reflection imaging of the Alpine Fault, New Zealand, *Journal of Geophysical Research*, **114**: B11306, doi:10.1029/2009JB006338. Cited 14 times.

52. *McClymont, A. F.*, Green, A. G., Villamor, P., Horstmeyer, H., Grass, C., & **Nobes, D. C.** 2008. Characterization of the shallow structures of active fault zones using 3-D GPR data. *Journal of Geophysical Research*, **113**: B10315, doi:10.1029/2007JB005402. Cited 28 times.

51. *McClymont, Alastair F.*, Green, Alan G., *Streich, Rita*, Horstmeyer, Heinrich, Tronicke, Jens, **Nobes, David C.**, Pettinga, Jarg, Campbell, Jocelyn & Langridge, Robert. 2008. Visualization of active faults using geometric attributes of 3D GPR data: an example from the Alpine Fault Zone, New Zealand. *Geophysics*, **73** (2): B11-B23. Cited 55 times.

50. *Amos, Colin B.*, Burbank, Douglas W., **Nobes, David C.** & Read, Stuart A.L. 2007. Geomorphic constraints on listric faulting: Implications for active deformation in the Mackenzie Basin, South Island, New Zealand. *Journal of Geophysical Research*, **112**(B03S11): doi:10.1029/2006JB004291. Cited 45 times.

49. Alloway, Brent V., Lowe, David J., Barrell, David J. A., Newnham, Rewi M., Almond, Peter C., Augustinus, Paul C., Bertler, Nancy A. N., Carter, Lionel, Litchfield, Nicola J., McGlone, Matt S., Shulmeister, Jamie, Vandergoes, Marcus J., Williams, Paul W., Anderson, Brian, Brackley, Hannah, Burge, Phil, Carter, John, Cochran, Ursula, Cooke, Penny, Crampton, James, Crouch, Erica, Crundwell, Martin, Deng, Yanbin, Drost, Frank, Graham, Ian, Harper, Margaret, Hayward, Bruce, Hendy, Chris, Hollis, Chris, Hughes, Matthew, Kennedy, David, Kennedy, Liz, King, Darren, Mackintosh, Andrew, Manighetti, Barbara, Marra, Maureen, Mildenhall, Dallas, Morgenstern, Uwe, Naish, Tim, Neil, Helen, **Nobes, David**, Page, Mike, Palmer, Alan, Prior, Chris, Rieser, Uwe, Rother, Henrik, Shane, Phil, Strong, Percy, Suggate, Pat, Thomson, Julian, Tonkin, Phil, Trustum, Noel, Van Dissen, Russell, Vucetich, Colin, Wilmhurst, Janet, Woodward, Craig & Zondervan, Albert, 2007. Towards a climate event stratigraphy for New Zealand over the past 30 000 years (NZ-INTIMATE project). *Journal of Quaternary Science*, **22** (1): 9-35.

48.* **Nobes, David C.**, *Rother, Henrik*, van der Kruk, Jan & Jol, Harry M. 2006. Radar "lensing" by a small river: Can a layer of surface water improve the signal? *Near Surface Geophysics*, GPR 2004 Special Issue, **4**: 69-74.

47. *Davis, Kenneth*, Burbank, Douglas W., Fisher, Donald, *Wallace, Shamus* & **Nobes, David**, 2005. Thrust fault growth and segment linkage in the active Ostler fault zone, New Zealand. *Journal of Structural Geology*, **27**: 1528-1546. Cited 53 times.

46.* **Nobes, David C.**, *Davis, Emma F.* & Arcone, Steven A., 2005. "Mirror-image" multiples in ground penetrating radar. *Geophysics*, **70**(1): K20-K22. Cited 25 times.

45. *Pepper, Andrea C.*, Shulmeister, James, **Nobes, David C.** & Augustinus, Paul C., 2004. Possible ENSO signals prior to the Last Glacial Maximum, during the last deglaciation and the early Holocene, from New Zealand. *Geophysical Research Letters*, **31**(15): L15206 10.1029/2004GL020236. http://www.agu.org/journals/gl/gl0415/2004GL020236/ Cited 21 times.

44.* Bassett, Kari N., *Gordon, Hamish W.*, **Nobes, David C.** & Jacomb, Chris, 2004. Gardening at the edge: documenting the limits of tropical Polynesian kumara horticulture in southern New Zealand. *Geoarchaeology*, **19**(1): 185-218. http://www3.interscience.wiley.com/cgi-bin/ abstract/107614459/. Cited 6 times.

43.* *Pettersson, J. K.* & **Nobes, D. C.**, 2003. Environmental geophysics at Scott Base: Ground penetrating radar and electromagnetic induction as tools for mapping contaminated ground at Antarctic research bases. *Cold Regions Science and Technology*, Special Issue on Contaminants in Cold Regions, **37**: 187-195. Cited 18 times.

42. Hesse, P. P., Humphreys, G. S., Selkirk, P., Adamson, D., Gore, D., **Nobes, D. C.**, Price, D., Schwenninger, J.-L., Smith, B. & Tulau, M., 2003. Late quaternary aeolian dunes on the presently humid Blue Mountains, Eastern Australia. *Quaternary International*, **108**: 13-32. Cited 37 times.

41. **Nobes, David C.**, 2002. Building on the foundations: Environmental Science at the University of Canterbury, Christchurch, New Zealand. *International Journal of Sustainability in Higher Education*, **3**(4): 371-379. doi: 10.1108/14676370210442409.

40. Noon, David A. & **Nobes, David C.**, 2001. Preface to the GPR 2000 Special Issue. *Journal of Applied Geophysics*, **47**(3-4): 171-173.

39.* **Nobes, D. C.**, *Ferguson, R. J.* & Brierley, G. J., 2001. Ground-penetrating radar and sedimentological analysis of Holocene floodplains: insight from the Tuross valley, New South Wales. *Australian Journal of Earth Sciences*, **48**: 347-355. Cited 40 times.

38.* **Nobes, David C.**, *Armstrong, Mark J.*, & Close, Murray E., 2000. Delineation of a landfill leachate plume and flow channels in coastal sands near Christchurch, New Zealand, using a shallow electromagnetic survey method, *Hydrogeology Journal*, **8**(3): 328-336. Cited 20 times.

37. **Nobes, D. C.**, 2000. The search for "Yvonne": A case example of the delineation of a grave using near-surface geophysical methods, *Journal of Forensic Sciences*, **45**(3): 715-721. Cited 54 times.

36.* **Nobes, David C.** & McCahon, Ian F., 1999. Buried channels and refuse pits: shallow electromagnetic mapping for characterization of a proposed construction site, *The Leading Edge*, **18**(12): 1378-1383.

35.* **Nobes, David C.**, 1999. The directional dependence of the ground penetrating radar response on the accumulation zones of temperate alpine glaciers, *First Break*, **17**(7): 249-259. Cited 30 times.

34.* **Nobes, David C.**, 1999. How important is the orientation of a horizontal loop EM system? Examples from a leachate plume and a fault zone, *Journal of Environmental and Engineering Geophysics*, **4**: 81-85. Cited 11 times.

33.* **Nobes, David C.**, 1999. Geophysical surveys of burial sites: a case study of the Oaro urupa, *Geophysics*, **64**(2): 357-367. Cited 49 times.

32.* *Yetton, Mark D.* & **Nobes, David C.**, 1998. Recent vertical offset and near-surface structure of the Alpine Fault in Westland, New Zealand, from ground penetrating radar profiling. *New Zealand Journal of Geology and Geophysics*, **41**: 485-492. Cited 20 times.

31. Hochstein, M. P., *Watson, M. I.*, Malengreau, B., **Nobes, D. C.** & Owens, I. F., 1998. Rapid melting of the terminal section of the Hooker Glacier (Mt Cook National Park, New Zealand). *New Zealand Journal of Geology and Geophysics*, **41**: 203-218. Cited 12 times.

30. **Nobes, David C.** The half-lives of past lives. *Annals of Improbable Research*, **III** (6), 1997: 14-15.

29.* **Nobes, David C.**, 1996. Troubled Waters: Environmental applications of electrical and electromagnetic methods. *Surveys in Geophysics*, **17**: 393-454. Cited 53 times.

28. **Nobes, David C.** & Tyndall, Arthur, 1995. Searching for avalanche victims: Lessons from Broken River. *The Leading Edge*, **14**(4): 265-268. Cited 5 times.

27. Hochstein, M. P., Claridge, David, Henrys, S. A., Pyne, A., **Nobes, D. C.** & *Leary, S. F.*, 1995. Downwasting of the Tasman Glacier (South Island, NZ): Changes in the terminus region between 1971 and 1993. *New Zealand Journal of Geology and Geophysics*, **38**: 1-16. Cited 55 times.

26.* *Lei, Hong* & **Nobes, David C.**, 1994. Resistivity structure of the underconsolidated sediments of the Cascadia Basin. *Geophysical Journal International*, **118**: 717-729. doi: 10.1111/j.1365-246X.1994.tb03996.x

25. *Narayan, S.*, Dusseault, M. B. & **Nobes, D. C.**, 1994. Resistivity inversion applied to resistivity inverse problems. *Inverse Problems*, **10**: 669-686. Cited 20 times.

24. *Schneider, G. W.*, **Nobes, D. C.**, *Lockhard, M. A.* & Greenhouse, J. P., 1994. Urban geophysics in the Kitchener-Waterloo region. *Geoscience Canada*, **20**: 149-156.

23.* *Theimer, Brian D.*, **Nobes, David C.** & Warner, Barry G., 1994. A study of geoelectric properties of peatlands and their influence on ground penetrating radar surveying. *Geophysical Prospecting*, **42**: 179-209. Cited 69 times.

22.* **Nobes, D. C.**, Langseth, M. G., Kuramoto, S., Holler, P. & Hirata, N., 1992. Comparison and correlation of physical properties from Japan Sea basin and rise sites, Legs 127 and 128. *Proceedings of the Ocean Drilling Program, Scientific Results*, **127/128**, Pt. 2: 1275-1296. doi:10.2973/odp.proc.sr.127128-2.219.1992. Cited 25 times.

21. Kuramoto, S., Tamaki, K., Pisciotto, K., Langseth, M. G., **Nobes, D. C.**, Tokuyama, H. & Taira, A., 1992. Opal-A/CT BSR can be an indicator of the thermal structure of the Yamato Basin, Japan Sea? *Proceedings of the Ocean Drilling Program, Scientific Results*, **127/128**, Pt. 2: 1145-1156. doi:10.2973/odp.proc.sr.127128-2.235.1992. Cited 22 times.

20.* **Nobes, D. C.**, Langseth, M. G., Kuramoto, S. & Holler, P., 1992. Identification and correction of a systematic error in the index property measurements. *Proceedings of the Ocean Drilling Program, Scientific Results*, **127/128**, Pt. 2: 985-1005. doi:10.2973/odp.proc.sr.127128-2.218.1992.

19. Föllmi, Karl B., Cramp, Adrian, Alexandrovich, Joanne M., Brunner, Charlotte, Burckle, Lloyd H., Casey, Martin, DeMenocal, Peter, Dunbar, Robert B., Grimm, Kurt A., Holler, Peter, Ingle, James C., Jr., Kheradyar, Tara, McEvoy, James, **Nobes, David C.**, Stein, Ruediger, Tada, Ryuji, Von Breymann, Marta T. & White, Lisa D., 1992. Dark-light rhythms in the sediments of the Japan Sea: Preliminary results from Site 798, with some additional results from Sites 797 and 799. *Proceedings of the Ocean Drilling Program, Scientific Results*, **127/128**, Pt. 1: 559-576. doi:10.2973/odp.proc.sr.127128-1.159.1992. Cited 15 times.

18.* **Nobes, David C.**, Murray, Richard W., Holler, Peter, Kuramoto, Shin'ichi & Pisciotto, Kenneth A., 1992. Impact of silica diagnesis on physical property variations. *Proceedings of the Ocean Drilling Program, Scientific Results*, **127/128**, Pt. 1: 3-31. doi:10.2973/odp.proc.sr.127128-1.111.1992. Cited 27 times.

17.* **Nobes, D. C.**, Law, L. K. & Edwards, R. N., 1992. Results of a sea floor electromagnetic survey near a hydrothermal vent field. *Geophysical Journal International*, **110**: 333-346. Cited 17 times.

16.* **Nobes, David C.**, Mienert, Jürgen & Mwenifumbo, C. Jonathon, 1991. An estimate of the heat flow on Meteor Rise, subantarctic South Atlantic. *Journal of Geophysical Research*, **96**: 5947-5953.

15.* **Nobes, D. C.**, Mwenifumbo, C. J., Mienert, J. & Blangy, J. P., 1991. The problem of porosity rebound in deep-sea sediment cores: a comparison of laboratory and in-situ physical-property measurements, Site 704, Meteor Rise. *Proceedings of the Ocean Drilling Program, Scientific Results*, **114**: 711-716. doi:10.2973/odp.proc.sr.114.160.1991. Cited 5 times.

14.* Mienert, J. & **Nobes, D. C.**, 1991. Physical properties of sediments beneath Polar Front upwelling regions of the subantarctic South Atlantic (Hole 704A). *Proceedings of the Ocean Drilling Program, Scientific Results*, **114**: 671-684. doi:10.2973/odp.proc.sr.114.158.1991. Cited 3 times.

13.* **Nobes, D. C.**, Mienert, J. & *Dirksen, G. J.*, 1991. Lithologic control of physical property interrelationships. *Proceedings of the Ocean Drilling Program, Scientific Results,* **114**: 657-670. doi:10.2973/odp.proc.sr.114.162.1991. Cited 10 times.

12. **Nobes, D. C.**, *Bloomer, S. F.*, Mienert, J. & Westall, F., 1991. Milankovitch cycles and nonlinear response in the Quaternary record in the Atlantic sector of the southern oceans. *Proceedings of the Ocean Drilling Program, Scientific Results,* **114**: 551-576. doi:10.2973/odp.proc.sr.114.161.1991. Cited 12 times.

11. Froelich, P. N., Malone, P. N., Hodell, D. A., Ciesielski, P. F., Warnke, D. A., Westall, F., Hailwood, E. A., **Nobes, D. C.**, Fenner, J., Mienert, J., Mwenifumbo, C. J. & Muller, D. W., 1991. Biogenic opal and carbonate accumulation rates in the subantarctic South Atlantic: the late Neogene of Meteor Rise Site 704. *Proceedings of the Ocean Drilling Program, Scientific Results,* **114**: 515-550. doi:10.2973/odp.proc.sr.114.149.1991. Cited 62 times.

10. **Nobes, D. C.**, Mwenifumbo, C. J., Mienert, J. & Blangy, J. P., 1991. An estimate of heat flow on the Meteor Rise, Site 704. *Proceedings of the Ocean Drilling Program, Scientific Results,* **114**: 39-46. doi:10.2973/odp.proc.sr.114.164.1991.

9. Warner, Barry G., **Nobes, David C.** & *Theimer, Brian D.*, 1990. An application of ground penetrating radar to peat stratigraphy of Ellice Swamp, southwestern Ontario. *Canadian Journal of Earth Sciences,* **27**: 932-938. Cited 40 times.

8. **Nobes, D. C.**, Hamilton, T. S. & Cartwright, P., 1990. Structure of the southwestern Fraser River delta as determined from geoelectric sounding. *Geophysical Prospecting,* **38**: 525-544.

7.* **Nobes, David C.**, 1989. A test of a simple model of the acoustic velocity in marine sediments. *The Journal of the Acoustical Society of America,* **86**: 290-294. Cited 11 times.

6. Cieselski, P. F., Kristoffersen, Y., Clement, B. M., Blangy, J. P., Bourrouilh, R., Crux, J. A., Fenner, J. M., Froelich, P. N., Hailwood, E., Hodell, D., Katz, M. E., Ling, H. Y., Mienert, J., Müller, D., Mwenifumbo, C. J., **Nobes, D. C.**, Nocchi, M., Warnke, D. A. & Westall, F., 1987. Late Cretaceous to Quaternary Paleoceanography of the Stormy Sub-Antarctic South Atlantic. *Nature,* **328**: 671-672.

5.* **Nobes, D. C.**, Villinger, H., Law, L. K. & Davis, E. E., 1986. Estimation of marine sediment bulk physical properties at depth from sea floor geophysical measurements. *Journal of Geophysical Research,* **91**: 14033-14043. Cited 62 times.

4.* **Nobes, D. C.**, Law, L. K. & Edwards, R. N., 1986. The determination of resistivity and porosity of the sediment and fractured basalt layers near the Juan de Fuca Ridge. *Geophysical Journal of the Royal Astronomical Society,* **86**: 289-317. Cited 31 times.

3.* **Nobes, D. C.**, 1986. The inclusion of anistropy in Maxwell's equations *Geophysical Journal of the Royal Astronomical Society,* **85**: 655-662. Cited 4 times.

2. Edwards, R. N., Law, L. K., Wolfgram, P. A., **Nobes, D. C.,** Bone, M. N., Trigg, D. F. & Delaurier, J. M., 1985. First results of the MOSES experiment: Sea sediment conductivity and thickness determination, Bute Inlet, British Columbia, by magnetometric off-shore electrical sounding. *Geophysics,* **50**: 153-161. Cited 67 times.

1.* Edwards, R. N., **Nobes, D. C.** & Gómez-Treviño, E., 1984. Offshore electrical exploration of sedimentary basins: The effects of anisotropy in horizontally isotropic, layered media. *Geophysics,* **49**: 566-576. Cited 45 times.

Books and Special Volumes Edited:

1. Noon, D. A. & **Nobes, D. C.** (Guest Editors), 2001. *Journal of Applied Geophysics,* **47**(3-4): Ground Penetrating Radar 2000 – Special Issue.

Chapters in Peer-Reviewed Monographs:

5.* **Nobes, David C.**, 2011. Ground penetrating radar measurements over glaciers. *In* Singh, V. P., Singh, P., and Haritashya, U. K. (eds.), *Encyclopedia of Snow, Ice and Glaciers*, Springer Verlag, Heidelberg: 490-504.

4.* Close, Murray E., **Nobes, David C.** & Pang, Liping, 2004. Presence of preferential flow paths in shallow groundwater systems as indicated by tracer experiments and geophysical surveys. *In* Bridge, John S. & Hyndman, David W. (eds), *Aquifer Characterization*, SEPM Special Publication, **80**: 79-91. Cited 4 times.

3.* *Field, Garrick*, *Leonard, Graham* & **Nobes, David C.**, 2001. Where is Percy Rutherford's grave? *In* Jones, Martin & Sheppard, Peter (eds.), *Australasian Connections and New Directions: Proceedings of the 7th Australasian Archœometry Conference*, Research in Anthropology and Linguistics, University of Auckland, **5**: 123-140. Cited 9 times.

2.* **Nobes, David C.** & Schneider, George W., 1996. Results of downhole geophysical measurements and vertical seismic profile from the Canandaigua borehole of New York state Finger Lakes. *In* Mullins, Henry T. & Eyles, Nicholas (eds.), *Subsurface Geologic Investigations of New York Finger Lakes: Implications for Late Quaternary Deglaciation and Environmental Change*, Geological Society of America Special Paper 311: 51-63. Cited 21 times.

1. **Nobes, David C.**, 1994. Geophysics and archaeology: Non-destructive survey techniques. *In* Macdonald, R. (ed.), *Proceedings of the Symposium on Great Lakes Archaeology and Paleoecology*: 367-411.

Papers in Peer-Reviewed Conference Proceedings:

34. **Nobes, David C.** & Beeching, Andrew J., 2013. Ground penetrating radar in ironsands: A case study of the Taharoa deposit, New Zealand. *In* Xia, Jianghai and Lin, Chih-Ping (eds), *Proceedings of the First Near Surface Geophysics Asia-Pacific Conference*, Beijing, China. Paper H-9.

33.* **Nobes, David C.**, Horstmeyer, H. & Milana, Juan-Pablo, 2013. The importance of topographic migration in ground penetrating radar imaging: A salutary example from GPR imaging of the Horcones Superior Glacier, Aconcagua, Argentina. *In* Xia, Jianghai and Lin, Chih-Ping (eds), *Proceedings of the First Near Surface Geophysics Asia-Pacific Conference*, Beijing, China. Paper H-8.

32.* **Nobes, David C.** & *Pettersson, Jared K.*, 2012. Non-invasive imaging of hydrocarbon contamination in permafrost soils at Marble Point, McMurdo Sound region, Antarctica. *In* Liu, Jianxin, Xu, Yixian and Dai, Qianwei (eds), *Near-Surface Geophysics and Environment Protection: ICEEG2012, Proceedings of the 5th International Conference on Environmental and Engineering Geophysics*, Science Press USA, Monmouth, NJ, ISBN 978-1-933100-42-5: 350-356.

31. **Nobes, David C.**, Wilson, Thomas M., Cockcroft, Matt, Almond, Peter & *Whitman, Zachary*, 2012. Agricultural ground penetrating radar response to deep cultivation across a fault scarp after the 4 September 2010 Darfield earthquake, Canterbury, New Zealand. *In* Liu, Lanbo, Sato, Motoyuki, Xie, Xionyao, Kong, Fannian and Zhao, Yonghui (eds.), *GPR2012, Proceedings of the 14th International Conference on Ground Penetrating Radar*, Shanghai, China, Vol. III: 775-779.

30. **Nobes, David C.**, Gravley, Darren M., Brand, Brittany D., *Bloomberg, Simon H.*, *Garden, Thomas O.* & Lindsay, Jan M., 2012. Ground penetrating radar imaging of Auckland volcanic surge deposits. *In* Liu, Lanbo, Sato, Motoyuki, Xie, Xionyao, Kong, Fannian and Zhao, Yonghui (eds.), *GPR2012, Proceedings of the 14th International Conference on Ground Penetrating Radar*, Shanghai, China, Vol. III: 659-664.

29. **Nobes, David C.**, *Johnston, Alison G.*, Holdaway, Richard N. & Horton, Travis W., 2012. Ground penetrating radar imaging of the late Quaternary Pyramid Valley lake deposit, North Canterbury, New Zealand: correlation with paleoclimatic records and the stratigraphic sequence. *In* Liu, Lanbo, Sato, Motoyuki, Xie, Xionyao, Kong, Fannian and Zhao, Yonghui (eds.), *GPR2012, Proceedings of the 14th International Conference on Ground Penetrating Radar,* Shanghai, China, Vol. II: 595-598.

28.* **Nobes, David C.**, *Hornblow, Sharon M.* & *Lapwood, Jonathan J.*, 2010. A radar interpretation pitfall: Velocity push-down due to a footwall loess wedge in the ground penetrating radar imaging of the Ostler Fault, New Zealand. *In Technical Program: Expanded Abstracts and Authors' Biographies, SEG International Exposition and Eightieth Annual Meeting,* Denver, Colorado, USA.: 1955-1959.

27. Green, A.G., *Campbell, F.M.*, *Kaiser, A.E.*, *Dorn, C.*, *Carpentier, S.*, *Doetsch, J.,* Horstmeyer, H., **Nobes, D.**, Campbell, J., Finnemore, M., Jongens, R., Ghisetti, F., Gorman, A.R., Langridge, R.M. & *McClymont, A.F.*, 2010. Seismic reflection images of active faults in New Zealand. *In ICEEG2010: Proceedings of the 4th International Conference on Environmental and Engineering Geophysics*, Chengdu, China.

26. *Carpentier, S. F. A.*, *Dorn, C.*, *Doetsch, J. A.*, *Campbell, F. M.*, Horstmeyer, H., Green, A. G., *Kaiser, A. E.*, Campbell, J., Pettinga, J., **Nobes, D. C.** & Jongens, R., 2010. Recent deformation of Quaternary sediments in the northwestern Canterbury Plains, New Zealand, as inferred from GPR and seismic data. *In Proceedings of GPR2010: 13th International Conference on Ground Penetrating Radar*, Lecce, Italy.

25.* *Godfrey, Myfanwy J.*, *Bannister, Michele T.*, **Nobes, David C.** & Sletten, Ronald S., 2008. 3D Time-Lapse Imaging of Polygonal Patterned Ground in the McMurdo Dry Valleys of Antarctica, *In Proceedings of GPR2008: 12th International Conference on Ground Penetrating Radar*, Birmingham, UK. Cited 18 times.

24.* **Nobes, David C.**, Ruffell, Alastair & Macdonald, Philip, 2008. Migrating and merging polarised GPR profiles: Does it matter if migration is before or after merger? *In Proceedings of GPR2008: 12th International Conference on Ground Penetrating Radar*, Birmingham, UK.

23.* **Nobes, David C.**, 2007. Effect of grain size on the geophysical responses of indigenous burial sites. *In Proceedings of Near Surface 2007: 13th European Meeting of Environmental and Engineering Geophysics*, Istanbul, Turkey: Paper P33.

22.* **Nobes, David C.**, 2007. Detecting Linear Features Using the Directionality of the HLEM Response. *In Proceedings of Near Surface 2007: 13th European Meeting of Environmental and Engineering Geophysics*, Istanbul, Turkey: Paper A23.

21.* **Nobes, David C.** & Wallace, Lynda R., 2007. Geophysical Imaging of an Early 19th Century Colonial Defensive Blockhouse. *In Proceedings of Near Surface 2007: 13th European Meeting of Environmental and Engineering Geophysics*, Istanbul, Turkey: Paper B10.

20. **Nobes, David C.**, 2007. Effect of soil grain size on the geophysical response of graves: Clay vs silt vs sand. *In Proceedings of the International Crime Science Conference,* London, UK.

19. *McClymont, Alastair, Streich, Rita, Heincke, Bjorn*, Green, Alan & **Nobes, David**. 2006. Visualization of active faulting using 3-D GPR data recorded across the Alpine Fault, New Zealand. *In GPR 2006: Proceedings of the 11th International Conference on Ground Penetrating Radar*, Columbus, Ohio, USA.

18. *Corboz, P.*, Horstmeyer, H., Tronicke, J., **Nobes, D.**, Campbell, J. & Green, A., 2005. High-resolution geophysical surveying at the Springfield Fault, New Zealand. *In Near Surface 2005: Proceedings of the 11th European Meeting of Environmental and Engineering Geophysics*, Palermo, Italy.

17. Jol, Harry M., Goodsell, Becky, **Nobes, David C.**, Finnemore, Michael, *Cussins, Tim, de Passille, Bruno* & Tealby, Julian, 2004. Preliminary results from high frequency GPR surveys and a 3D grid: Davis Snowfield, Franz Josef Glacier, New Zealand. *In* Slob, Evert, Yarovoy, Alex & Rhebergen, Jan (eds), *GPR 2004: Proceedings of the 10th International Conference on Ground Penetrating Radar*: 773-776. Cited 20 times.

16. **Nobes, David C.**, Jol, Harry M. & *Rother, Henrik*, 2004. Radar "lensing" by a small river: Can a layer of surface water improve the signal? *In* Slob, Evert, Yarovoy, Alex & Rhebergen, Jan (eds), *GPR 2004: Proceedings of the 10th International Conference on Ground Penetrating Radar*: 539-542.

15. *Streich, Rita*, van der Kruk, Jan, Green, Alan G. & **Nobes, David C.**, 2004. Three-dimensional multicomponent georadar surveying near the Alpine Fault, New Zealand. *In* Slob, Evert, Yarovoy, Alex & Rhebergen, Jan (eds), *GPR 2004: Proceedings of the 10th International Conference on Ground Penetrating Radar*: 349-352.

14.* King, Martin L., Wu, Dany & **Nobes, David C.**, 2003. Non-invasive ground penetrating radar investigation of a failing concrete floor slab. *In Proceedings of NDT-CE 2003, the International Conference on Non-Destructive Testing in Civil Engineering*, Deutsche Gesellschaft für Zerstörungsfreie Prüfung, Berlin, Proceedings BB85-CD, http://www.ndt.net/article/ndtce03/papers/p043/p043.htm.

13.* **Nobes, David C.** & *Sikma, Timothy J.*, 2003. Non-invasive ground penetrating radar in the NDT of the foundations of the Cathedral of the Blessed Sacrament, Christchurch, New Zealand. *In Proceedings of NDT-CE 2003, the International Conference on Non-Destructive Testing in Civil Engineering*, Deutsche Gesellschaft für Zerstörungsfreie Prüfung, Berlin, Proceedings BB85-CD, http://www.ndt.net/article/ndtce03/papers/v077/v077.htm

12. **Nobes, David C.**, 2001. Building on the Foundations: Environmental Science at the University of Canterbury, Christchurch, New Zealand, *Bridging Minds and Markets: Proceedings of the 6th International auDes Conference*: 104-109. Revised and published in *IJSHE* (item 40 above), by request of *IJSHE* Editorial Board.

11.* **Nobes, David C.** & Lintott, Bryan, 2000. Rutherford's "Old Tin Shed": Mapping the foundations of a Victorian-age lecture hall. *In* Noon, David A., Stickley, Glen F. & Longstaff, Dennis (eds.), *GPR 2000: Proceedings of the 8th International Conference on Ground Penetrating Radar*, Society of Photo-Optical Instrumentation Engineers (SPIE), **4084**: 887-892.

10.* **Nobes, David C.** & Annan, A. Peter, 2000. "Broadside" versus "End-fire" Radar Response: Some simple illustrative examples. *In* Noon, David A., Stickley, Glen F. & Longstaff, Dennis (eds.), *GPR 2000: Proceedings of the 8th International Conference on Ground Penetrating Radar*, Society of Photo-Optical Instrumentation Engineers (SPIE), **4084**: 696-701. Cited 28 times.

9.* *Francké, Jan* & **Nobes, David C.**, 2000. A preliminary evaluation of GPR for nickel laterite exploration. *In* Noon, David A., Stickley, Glen F. & Longstaff, Dennis (eds.), *GPR 2000: Proceedings of the 8th International Conference on Ground Penetrating Radar*, Society of Photo-Optical Instrumentation Engineers (SPIE), **4084**: 7-12. Cited 3 times.

8. **Nobes, David C.** & Bright, John C., 1998. The Artificial Aquifer: Radar under a steel roof, *Proceedings of the 7th International Conference on Ground Penetrating Radar*: 245-249.

7. **Nobes, David C.**, 1998. How important is the orientation of a horizontal loop EM system? Examples from a leachate plume and a fault zone, *Proceedings of the Symposium on Applications of Geophysics to Environmental and Engineering Problems (SAGEEP)*, **11**: 453-458. Revised and published in *JEEG* (item 34 above), by invitiation of member of *JEEG* Editorial Board.

6.* **Nobes, D. C.**, *Leary, S. F.*, Hochstein, M. P. & Henrys, S. A., 1994. Ground penetrating radar profiles of debris-covered glaciers: Results from the Tasman and Mueller Glaciers of the Southern Alps of New Zealand. *Society of Exploration Geophysicists Annual Meeting, Expanded Abstracts*, **64**: 826-829. doi: 10.1190/1.1932012. Cited 27 times.

5. **Nobes, David C.**, *Armstrong, Mark J.* & Broadbent, Michael, 1994. Delineation of a leachate plume using shallow electromagnetic and ground penetrating radar surveys. *Society of Exploration Geophysicists Annual Meeting, Expanded Abstracts*, **64**: 566-568.

4. **Nobes, David C.**, 1994. Using non-invasive, non-destructive geophysical methods to map and to monitor the source and extent of contamination. *Proceedings of the Symposium on Geotechnical Aspects of Waste Management*, *IPENZ Proceedings of Technical Groups*, **20**(1G): 89-98.

3. **Nobes, D. C.** & Warner, B. G., 1992. Application of ground penetrating radar to a study of peat stratigraphy: preliminary results. *In* Pilon, J. (ed.), *Ground Penetrating Radar*, Geological Survey of Canada, Paper 90-4: 133-138.

2. Greenhouse, John P., **Nobes, David C.** & Schneider, George W., 1990. Groundwater beneath the city: A geophysical study. *Ground Water Management*, **2**: 1179-1191. Proceedings of the Fourth Annual Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods, Las Vegas, Nevada, U.S.A.

1. Edwards, R. N., **Nobes, D. C.**, Wolfgram, P. A., Gómez-Treviño, E., Law, L. K., Bone, M. N. & Trigg, D. F., 1983. Electrical exploration of the sea floor: The effects of interbedding in a sedimentary basin. *Society of Exploration Geophysicists Annual Meeting, Expanded Abstracts*, **53**: 76-80.

Discussions:

4. **Nobes, D. C.**, 2002. Comment on “Intelligent design”, by A. L. Melott and M. Singham. *Physics Today*, **55**(11): 95-96.

3. **Nobes, D. C.**, 1998. Comment on “Nibbling the bullet”, by D. Kleppner. *Physics Today*, **51**(10): 13-15.

2. **Nobes, D. C.**, 1992. Comment on "The utility of conductivity surveying and resistivity sounding in evaluating sand and gravel deposits and mapping drift sequences in northeast Scotland", by C. A. Auton. *Engineering Geology*, **33**: 151-152.

1. **Nobes, D. C.**, Schneider, G. & *Hodgson, S.*, 1987. Discussion on "Effects of porosity and clay content on wave velocities in sandstones". *Geophysics*, **52**: 1439.

Book and Conference Reviews in Refereed Journals:

2. **Nobes, David C.**, 2005. The Role of Science in the Information Society (RSIS): Scientists on the margins at the World Summit on the Information Society (WSIS). *ebr – electronic book review*, http://www.electronicbookreview.com/thread/internetnation/myopic

1. **Nobes, D. C.**, 1994. "Effects of Scale on Archaeological and Geoscientific Perspectives", Stein, J. K. & Linse, A. R. (eds), Geological Society of America Special Paper 283, *Journal of Hydrology*: *New Zealand*, **32** (1): 44-45.

Section 1

Anisotropy and Directionality

1. Anisotropy and Directionality

The papers in this first section all have some major element of the theme of anisotropy and directionality. The first paper, Edwards, Nobes and Gomez-Treviño (1984, GEOPHYSICS), was based to a large extent on the theory chapter in my PhD thesis. R. N. Edwards, my supervisor, placed himself as first author and submitted the paper to the journal, and E. Gomez-Treviño, the post-doctoral fellow who did much of the work on the Fréchet kernels, was made the third author. This paper extended the theory behind the sea floor electromagnetic method developed by Edwards, Law and de Laurier, to include transverse isotropy. That is, the vertical and horizontal electrical properties differ. The system has azimuthal symmetry. The theory is valid for layered media, and became a focal point for later work in Middle Valley on the northern Juan de Fuca Ridge (Nobes, Law and Edwards, 1992).

The second paper, Nobes (1986, the forerunner to Geophysical Journal International – GJI), laid the groundwork for how full anisotropy could be incorporated into Maxwell's equations, by using decomposition of the vector fields into poloidal and toroidal modes.

The next two papers, Nobes, Law and Edwards (1986 and 1992, GJI), used the theory developed in Edwards, Nobes and Gomez-Treviño, plus additional work from my PhD, to model and interpret data from the northern Juan de Fuca Ridge. They also have a sub-theme of physical properties and so overlap with Section 2. They are still two of my more satisfying papers. In Nobes et al. (1992), I predicted that there would be 100 – 150 m of massive sulphides. One reviewer claimed that this was ridiculous, that no such thickness of massive sulphide could possibly exist at that location, and that I should go away and do a lot of Monte Carlo modelling with many layers. I have always felt that one should begin from the simplest model and add what complexity is required to fit the data, rather than starting from the other extreme. While the paper was in review, Leg 139 of the Ocean Drilling Program drilled the site of the anomalous EM response. Sadly, Leg 139 could not fully confirm the predicted thickness of massive sulphide – they reached 95 m before they had to stop because the sulphides were so massive that the drill bit was in danger of getting stuck. So I was able to add a "Note Added in Proof".

Lei and Nobes (1994) is based on a part of Lei's MSc thesis, which I supervised. It built in a natural way on my work on transverse isotropy, extending it to many thin layers. By using a computer algebra system called Maple, developed at the University of Waterloo, we were able to obtain a closed form recursive solution, a big step forward.

Nobes (1999, First Break) illustrated the directionality of the ground penetrating radar response in a temperate glacier, in this case the nevé (the accumulation zone) of the Franz Josef glacier. Previous research had shown velocity anisotropy in some glacier ice. However, while no velocity anisotropy was observed in this case, but there was a strong amplitude change from one orientation to another. These field observations were the motivation for Nobes and Annan (2000, GPR2000), which showed how the difference in amplitude response as a function of antenna orientation could provide additional information about the geometry of the structures within the ice that were giving rise to the directionality. Nobes and Annan is put slightly out of chronological order because it follows naturally from Nobes (1999, FB).

Nobes (1999, Journal of Environmental and Engineering Geophysics) is a slight change of pace, showing from field measurements that the directionality of a horizontal loop EM (HLEM) system only clearly shows a directionality of response for discrete sharp boundaries. For diffuse boundaries, such as a leachate plume from a landfill site, there is no directionality to the HLEM response. This paper is deliberately out of chronological order because to a large extent it inspired Nobes (2007, NSG2007), which takes the HLEM directionality discussed in the JEEG 2000 paper, and shows how it can be used to highlight subsurface features that have relatively distinct edges, but which are hard to distinguish in the raw HLEM data. The process was used to great effect in an archaeological survey (Nobes & Wallace, 2007), which is presented in Section 7, Geoarchaeology.

References

Nobes, David C., 2007. Detecting Linear Features Using the Directionality of the HLEM Response. *In Proceedings of Near Surface 2007: 13th European Meeting of Environmental and Engineering Geophysics*, Istanbul, Turkey: Paper A23.

Nobes, David C. & Annan, A. Peter, 2000. “Broadside” versus “End-fire” Radar Response: Some simple illustrative examples. *In* Noon, David A., Stickley, Glen F. & Longstaff, Dennis (eds.), *GPR 2000: Proceedings of the 8th International Conference on Ground Penetrating Radar*, Society of Photo-Optical Instrumentation Engineers (SPIE), **4084**: 696-701.

Nobes, David C., 1999. The directional dependence of the ground penetrating radar response on the accumulation zones of temperate alpine glaciers, *First Break*, **17**(7): 249-259.

Nobes, David C., 1999. How important is the orientation of a horizontal loop EM system? Examples from a leachate plume and a fault zone, *Journal of Environmental and Engineering Geophysics*, **4**: 81-85.

Lei, Hong & **Nobes, David C.**, 1994. Resistivity structure of the underconsolidated sediments of the Cascadia Basin. *Geophysical Journal International*, **118**: 717-729. doi: 10.1111/j.1365-246X.1994.tb03996.x

Nobes, D. C., Law, L. K. & Edwards, R. N., 1992. Results of a sea floor electromagnetic survey near a hydrothermal vent field. *Geophysical Journal International*, **110**: 333-346.

Nobes, D. C., Law, L. K. & Edwards, R. N., 1986. The determination of resistivity and porosity of the sediment and fractured basalt layers near the Juan de Fuca Ridge. *Geophysical Journal of the Royal Astronomical Society*, **86**: 289-317.

Nobes, D. C., 1986. The inclusion of anistropy in Maxwell's equations *Geophysical Journal of the Royal Astronomical Society*, **85**: 655-662.

Edwards, R. N., **Nobes, D. C.** & Gómez-Treviño, E., 1984. Offshore electrical exploration of sedimentary basins: The effects of anisotropy in horizontally isotropic, layered media. *Geophysics*, **49**: 566-576.

Section 2

Physical Properties

2. Physical Properties

The papers in this second section are all concerned with physical property inter-relationships and their applications. Aside from the first two papers, results from Legs 114, 127 and 128 of the Ocean Drilling Program (ODP) are the focus of the publications. Even the first paper was indirectly linked to ODP site surveys and the subsequent ODP Leg 139.

Nobes, Villinger, Law and Davis (Journal of Geophysical Research B, 1986), combined results from geophysical surveys across the northern Juan de Fuca Ridge to calculate the changes in physical properties, such as the porosity, as a function of depth. The predictions were confirmed by Leg 139 of the ODP.

Nobes (Journal of Acoustical Society of America, 1989) was based on a database of physical property results compiled from Deep Sea Drilling Project (DSDP) and ODP volumes. The large database had 1000’s of entries, from which almost 2,000 entries allowed a systematic examination of the velocity versus porosity in marine sediments. The model proposed, the weighted Wood-Wyllie model, worked very well for carbonate-rich sediments, but later work on siliceous sediments from Leg 127 (Nobes et al., 1992a, noted below) showed that the model was limited in its applicability.

The next two papers – Nobes, Mienert and Dirksen (1991a), and Nobes, Mwenifumbo, Mienert and Blangy (1991b) – are from the Subantarctic South Atlantic ODP Leg 114 Scientific Results (1991), and highlight both the utility of physical property variations and the limitations of physical property measurements. Nobes et al. (1991a) explored the lithologic controls on physical property inter-relationships. Because physical properties measured in the laboratory have undergone decompression, there can be effects due to “porosity rebound”, which is explored in Nobes et al. (1991b) by comparing laboratory physical properties with downhole logging results.

Nobes, Mienert and Mwenifumbo (JGR-B, 1991) discuss the determination of the heat flow on the Meteor Rise estimated by using physical property inter-relationships and a calibrated temperature reading, both obtained during ODP Leg 114. They show that, even when limited data are available, valid estimates of heat flow can still be made using our knowledge of physical property inter-relationships.

The final set of two papers – Nobes, Murray, Kuramoto, Pisciotto and Holler (1992a), and Nobes, Langseth, Kuramoto and Holler (1992b) – are all from the Japan Sea ODP Legs 127 and 128 Combined Scientific Results (1992). Nobes et al. (1992a) discuss the influence of silica diagenesis on the physical property variations, and show how the transitions from opal-A (amorphous silica) to opal-CT (cristobalite and tridymite) and from opal-CT to quartz are reflected in the physical properties. These then can be used to calibrate seismic surveys, and in particular the strong reflective horizons that arise from the diagenetic transitions. These transitions occur within relatively small ranges of temperature and depth, and thus can be used to estimate heat flows remotely. Nobes et al. (1992b) explore the systematic errors that can arise in the way physical property measurements were done, and the corrected values can be more effectively used. Because of their length and unnecessary detail, Tables 2 and 3 are not presented.

References

Nobes, D. C., Langseth, M. G., Kuramoto, S. & Holler, P., 1992b. Identification and correction of a systematic error in the index property measurements. *Proceedings of the Ocean Drilling Program, Scientific Results*, **127/128**, Pt. 2: 985-1005. doi:10.2973/odp.proc.sr.127128-2.218.1992.

Nobes, David C., Murray, Richard W., Holler, Peter, Kuramoto, Shin'ichi & Pisciotto, Kenneth A., 1992a. Impact of silica diagnesis on physical property variations. *Proceedings of the Ocean Drilling Program, Scientific Results*, **127/128**, Pt. 1: 3-31. doi:10.2973/odp.proc.sr.127128-1.111.1992.

Nobes, David C., Mienert, Jürgen & Mwenifumbo, C. Jonathon, 1991. An estimate of the heat flow on Meteor Rise, subantarctic South Atlantic. *Journal of Geophysical Research*, **96**: 5947-5953.

Nobes, D. C., Mwenifumbo, C. J., Mienert, J. & Blangy, J. P., 1991b. The problem of porosity rebound in deep-sea sediment cores: a comparison of laboratory and in-situ physical-property measurements, Site 704, Meteor Rise. *Proceedings of the Ocean Drilling Program, Scientific Results*, **114**: 711-716. doi:10.2973/odp.proc.sr.114.160.1991.

Nobes, D. C., Mienert, J. & *Dirksen, G. J.*, 1991a. Lithologic control of physical property interrelationships. *Proceedings of the Ocean Drilling Program, Scientific Results*, **114**: 657-670. doi:10.2973/odp.proc.sr.114.162.1991.

Nobes, David C., 1989. A test of a simple model of the acoustic velocity in marine sediments. *The Journal of the Acoustical Society of America*, **86**: 290-294.

Nobes, D. C., Villinger, H., Law, L. K. & Davis, E. E., 1986. Estimation of marine sediment bulk physical properties at depth from sea floor geophysical measurements. *Journal of Geophysical Research*, **91**: 14033-14043.

Section 3

Ground Penetrating Radar Properties and Methodologies

3. Ground Penetrating Radar Properties and Methodologies

I became involved in using ground penetrating radar (GPR) in January 1987, and have been involved in understanding its principles and expanding its range of applications since then. It is a natural extension of EM, since GPR involves the propagation of high-frequency EM waves, whereas traditional EM methods, involving as they do EM induction, work at low frequencies. My earliest GPR papers are not presented here, largely because they were superseded by the later work, and partly because they were using GPR at the simplest level. Other GPR papers are more focussed on specific applications, and so are placed in the relevant sections, whereas the ones here deal primarily with the underlying GPR properties and some of the (incorrect) assumptions.

The first paper included here is Theimer, Nobes and Warner (Geophysical Prospecting, 1994), which clearly sets out the importance of the electrical properties in GPR surveys. It does so by considering three peatlands as case studies, but its relevance extends well beyond peatlands. It was also a test of how well the radar range equation works in real situations, and in the case of Mer Bleue, it worked perfectly. This paper was based to a large extent on Theimer's MSc thesis, co-supervised by me and Warner. The final form of the paper is about a third of the length of Theimer's first draft. I was the corresponding author.

The next two papers deal with some enigmatic GPR responses that both highlight the GPR properties (Nobes, Davis and Arcone, 2005, Geophysics) and also challenge what had been a common assumption (Nobes, Rother, van der Kruk and Jol, 2006, Near Surface Geophysics) – that when doing GPR imaging, we should avoid surface water. That assumption was based on the misunderstanding of the properties of water. Yes, it enhances the electrical conductivity of the soil, but if the water is very fresh, it only changes the formation properties from very resistive to moderately resistive. The conductivity is still so low as to have little or no attenuation of the GPR signal. The results of the GPR survey carried out by Rother and Jol across a stream were at first surprising, and we had to convince ourselves first what we were seeing. I did a careful step by step analysis of what could be causing the results that we saw, and once we had done that, it was easy to convince the broader GPR community.

The Nobes, Davis and Arcone (2005) paper, on the other hand, shows that interesting effects occur when extreme changes in physical properties are present. On the Ross Ice Shelf, salt water from the Ross Sea can infiltrate at a certain depth, where the hydrostatic pressures just compensate for the overlying mass of ice. This percolation can extend 10's of km in from the edge of the ice shelf. As the sea water freezes, the salt remains behind, creating a salt-saturated brine with very high electrical conductivity. The physical property contrasts are so high, that the brine layer behaves like a mirror, making the folds due to the overlying pressure ridges in the ice shelf appear in mirror-image form at later travel times. This work grew out of the preliminary GPR imaging that was done for Davis' MSc thesis.

The last paper in this section, by Nobes, Hornblow and Lapwood (2010, SEG2010), dealt with a potential pitfall in the interpretation of GPR profiles, which can occur in seismic profiles as well. This is the problem of a zone of anomalous material with a propagation velocity that is different from the surroundings. The anomalous travel times that result can lead to, in this case, what is called velocity “push down”. The effect makes layered stratigraphy look either folded or as if there is a buried channel, when in fact none may exist. The GPR profiles in the paper were a subset of the data sets acquired for Hornblow’s and Lapwood’s Honours projects, which I supervised.

References

Nobes, David C., *Hornblow, Sharon M.* & *Lapwood, Jonathan J.*, 2010. A radar interpretation pitfall: Velocity push-down due to a footwall loess wedge in the ground penetrating radar imaging of the Ostler Fault, New Zealand. *In Technical Program: Expanded Abstracts and Authors’ Biographies, SEG International Exposition and Eightieth Annual Meeting,* Denver, Colorado, USA.: 1955-1959.

Nobes, David C., *Rother, Henrik*, van der Kruk, Jan & Jol, Harry M. 2006. Radar “lensing” by a small river: Can a layer of surface water improve the signal? *Near Surface Geophysics,* GPR 2004 Special Issue, **4**: 69-74.

Nobes, David C., *Davis, Emma F.* & Arcone, Steven A., 2005. “Mirror-image” multiples in ground penetrating radar. *Geophysics,* **70**(1): K20-K22.

Theimer, Brian D., **Nobes, David C.** & Warner, Barry G., 1994. A study of geoelectric properties of peatlands and their influence on ground penetrating radar surveying. *Geophysical Prospecting,* **42**: 179-209.

Section 4

Glacier and Permafrost Ground Penetrating Radar

4. Glacier and Permafrost Ground Penetrating Radar

One of the themes in the applications for many years has been use of ground penetrating radar, supplemented by other near-surface geophysical methods, for imaging the thickness and internal structure of glaciers and permafrost. Much of that work has been combined with other results, such as in Hochstein et al. (New Zealand Journal of Geology and Geophysics, 1995 and 1998). In addition, a number of the glacier and permafrost papers involve other themes. For example, Nobes (1999, First Break) and the associated paper by Nobes and Annan (2000, GPR2000), deal more with the directionality of GPR, within the context of glacier GPR imaging, and thus are in Section 1, Anisotropy and Directionality. Similarly, the papers by Pettersson and Nobes (2003, Cold Regions Science and Technology) and Nobes and Pettersson (2012, ICEEG2012) deal more with the detection and imaging of the extent of contaminants in Antarctic permafrost soils (Section 5, Groundwater and Contaminated Soils), than in permafrost per se.

Hence this section is short, but is representative of a broader, and ongoing, body of research. The first paper, Nobes, Leary, Hochstein and Henrys (1994, SEG 1994) represents the first paper on GPR imaging of a debris-covered or debris-laden glacier, so far as I can know. The next published paper in any of the standard search engines for scientific literature shows the next published paper by another group occurs in 1997. As noted in the Introduction, it challenged the prevailing notion at the time that GPR on a debris-covered glacier was not possible, because the debris would scatter the radar energy too much to get any significant penetration. The prevailing notion was incorrect, as we showed.

The next paper, by Godfrey, Bannister, Nobes and Sletten (2008, GPR2008), was based on Godfrey’s MSc thesis, which I supervised, and in which Bannister was involved as an Honours project student. It represents one of the first attempts to do four dimensional (4D) imagine, that is time-lapse 3D (three dimensional) imaging of the permafrost in Antarctica. Indeed, few groups around the world are doing 4D GPR, but there is growing interest. The results suggest that the permafrost in Antarctica is active, even over just one thaw season, which begs the question – what do the old cosmogenic dates mean then, if the upper permafrost layers are active? It suggests that the dates represent the armouring and the upper surface only, not the age of the permafrost below.

The next-to-last paper is not a research paper, as such, but it does include what at the time were unpublished research results. Nobes (2011, Springer Encyclopedia of Snow, Ice and Glaciers) was written as a review paper, rather than just as an encyclopedia chapter on glacier GPR, and includes some original research results. It also gives a relatively comprehensive introduction to glacier GPR that hopefully will be useful as a guide for future researchers. Thus, I have included it here.

Finally, Nobes, Horstmeyer and Milana (2013, Proceedings of the First Near Surface Geophysics Asia-Pacific Conference) used the results of imaging of the Horcones Superior on Aconcagua to illustrate the importance of taking into account topography when it is of the same order of magnitude as the thickness of the glacier.

References

Nobes, David C., Horstmeyer, H. & Milana, Juan-Pablo, 2013. The importance of topographic migration in ground penetrating radar imaging: A salutary example from GPR imaging of the Horcones Superior Glacier, Aconcagua, Argentina. *In* Xia, Jianghai and Lin, Chih-Ping (eds), *Proceedings of the First Near Surface Geophysics Asia-Pacific Conference*, Beijing, China. Paper H-8.

Nobes, David C., 2011. Ground penetrating radar measurements over glaciers. *In* Singh, V. P., Singh, P., and Haritashya, U. K. (eds.), *Encyclopedia of Snow, Ice and Glaciers*, Springer Verlag, Heidelberg: 490-504.

Godfrey, Myfanwy J., *Bannister, Michele T.*, **Nobes, David C.** & Sletten, Ronald S., 2008. 3D Time-Lapse Imaging of Polygonal Patterned Ground in the McMurdo Dry Valleys of Antarctica, *In Proceedings of GPR2008: 12th International Conference on Ground Penetrating Radar*, Birmingham, UK.

Nobes, D. C., *Leary, S. F.*, Hochstein, M. P. & Henrys, S. A., 1994. Ground penetrating radar profiles of debris-covered glaciers: Results from the Tasman and Mueller Glaciers of the Southern Alps of New Zealand. *Society of Exploration Geophysicists Annual Meeting, Expanded Abstracts*, **64**: 826-829.

Section 5

Groundwater and Soil Contamination

5. Groundwater and Soil Contamination

Near surface geophysics has almost always had an association with looking for groundwater resources and groundwater contamination, so it is no surprise that I have a number of papers related to the delineation of groundwater and soil contamination. NSG started off being called environmental geophysics, then environmental and engineering geophysics (hence SAGEEP, JEEG, etc.), before the broader term “near surface geophysics” was devised to encompass all of the NSG applications. NSG applied to groundwater resources and groundwater contamination is now called hydrogeophysics, a growing sub-discipline of its own.

The papers in this section are a selection of those on the mapping of groundwater and soil contamination. The last paper of the previous section was a review paper written as an encyclopedia chapter. The first paper in this section was a review paper published in 1996 in Surveys in Geophysics. I include it for a few reasons: Firstly, it included recently published or unpublished research results and so represented the state of the art. Secondly, it was the first comprehensive review of the topic, and subsequent reviews on the subject have cited this paper and then discussed the advances that had occurred in the intervening years. Lastly, it puts electrical, EM and GPR imaging into the broader context of hydrogeology and physical properties. It was required reading for some graduate programmes for the first few years after its publication (Green, pers. comm., 2001), and is one of my most cited papers.

Nobes, Armstrong and Close (2000, Hydrogeology Journal) delineated a leachate plume from a landfill site using horizontal loop EM (HLEM) to guide the placement of calibration sampling wells. The results also showed the effects of the tides on the coastal responses. This paper is, to some extent, a companion paper to Nobes (1999, JEEG), that showed that there was no directionality to the HLEM response across the diffusive boundary of a leachate plume. One reviewer of an early version of the HJ paper suggested that the results did not account for directionality; the Nobes (1999) paper was written to counter their incorrect comments.

Close, Nobes and Pang (2004, SEPM Special Publication SP80) is placed slightly out of chronological order because the final two papers are closely linked. Close et al. dealt with the use of GPR to locate buried channels, and the results clearly showed that the flow paths of the tracers on the experimental test site followed those paths. The well data were too sparse to properly delineate the channels, and the GPR was a central part of the final experiment.

Finally, Pettersson and Nobes (2003, Cold Regions Science & Technology) and Nobes and Pettersson (2012, ICEEG2012) examined the utility of HLEM and GPR to delineate the extent of hydrocarbon contaminants in the permafrost soils of the McMurdo Sound region of Antarctica. The results of the Borden experiment (Greenhouse et al., 1983, The Leading Edge) and from Wurtsmith Air Force Base in Michigan (Sauck et al., 1998, JEEG) gave contrasting results of geophysical imaging of hydrocarbon contamination. The Borden experiment found that fresh young contaminants were electrically resistive and enhanced the GPR response, whereas at Wurtsmith, the old contaminants were electrically conductive and thus attenuated the GPR response. Thus: (1) Could we “see” the hydrocarbon contamination in the permafrost soils of Antarctica? (2) If so, was the contaminant response in the polar permafrost soils of Antarctica “fresh” or “old”, i.e. electrically resistive or conductive? (3) Was there a seasonality to the geophysical response? (4) Finally, did the response vary with the age of the contamination? The answers to questions (1) and (3) were “Yes”, but question (4) could not be answered. Even the oldest contamination had a “fresh” resistive response, thus answering question (2).

References

Nobes, David C. & *Pettersson, Jared K.*, 2012. Non-invasive imaging of hydrocarbon contamination in permafrost soils at Marble Point, McMurdo Sound region, Antarctica. *In* Liu, Jianxin, Xu, Yixian and Dai, Qianwei (eds), *Near-Surface Geophysics and Environment Protection: ICEEG2012, Proceedings of the 5th International Conference on Environmental and Engineering Geophysics,* Science Press USA, Monmouth, NJ, ISBN 978-1-933100-42-5: 350-356.

Close, Murray E., **Nobes, David C.** & Pang, Liping, 2004. Presence of preferential flow paths in shallow groundwater systems as indicated by tracer experiments and geophysical surveys. *In* Bridge, John S. & Hyndman, David W. (eds), *Aquifer Characterization*, SEPM Special Publication, **80**: 79-91.

Pettersson, J. K. & **Nobes, D. C.**, 2003. Environmental geophysics at Scott Base: Ground penetrating radar and electromagnetic induction as tools for mapping contaminated ground at Antarctic research bases. *Cold Regions Science and Technology*, Special Issue on Contaminants in Cold Regions, **37**: 187-195.

Nobes, David C., *Armstrong, Mark J.*, & Close, Murray E., 2000. Delineation of a landfill leachate plume and flow channels in coastal sands near Christchurch, New Zealand, using a shallow electromagnetic survey method, *Hydrogeology Journal*, **8**(3): 328-336.

Nobes, David C., 1996. Troubled Waters: Environmental applications of electrical and electromagnetic methods. *Surveys in Geophysics*, **17**: 393-454.

Section 6

Structure and Stratigraphy

6. Structure and Stratigraphy

This section, which includes papers that could be broadly said to be concerned primarily with NSG imaging of structure and stratigraphy, is really just the tip of a big iceberg. Some of the relevant papers on GPR, for example, may be found in other sections, such as Godfrey et al. (2001) in Section 4, Glacier and Permafrost . Many other papers have arisen out of many collaborative efforts. The ones here are ones where I played either the lead role or a major role. There are other papers where it could be argued that I also played a major role, but I decided to be conservative in the papers I selected.

Nobes and Schneider (1996, GSA Special Paper 311) also has a small component of directionality, but it does play a role in the interpretation. A suite of downhole logs and a vertical seismic profile (VSP) were acquired to complement and supplement some shallow seismic surveys done at one end of Lake Canandaigua, in the Finger Lakes area of New York state. The data provided the information needed to understand why there were so few laterally continuous shallow seismic reflectors. It was because most of the boundaries were gradational, not sharp, and hence the physical property contrasts occurred over a distance larger than the resolution of the seismic signal.

Yetton and Nobes (1998, NZJGG) was one of my early projects using GPR to look at subsurface structure. The surface micro-topography was correlated with subsurface structures, so that the large scale broad topography present at the site in fact masked the small scale topography that was more reflective of the presence of faulting. I also used complex attributes, specifically instantaneous phase, to track the continuity of the fluvial bedding, and was able to isolate the bed truncations that were associated with the subsurface fault “flower” structure.

Francké and Nobes (2000, GPR2000) highlight the importance of using complex attributes, such as instantaneous phase and instantaneous frequency, in GPR. In this case, the attributes were used to show that GPR could distinguish between the different layers present in lateritic mineral deposits. The examples shown are particularly for nickel, and specifically for the deposits on the plateau of New Caledonia. The New Caledonia work formed the core of Francké’s MSc thesis which I supervised, and I was heavily involved with the New Caledonia field work.

Nobes, Ferguson and Brierly (2001, Australian Journal of Earth Sciences) used GPR imaging of fluvial sediments in the Tuross River valley of southern New South Wales to illustrate basic principles of GPR in sediments, the excellent depth of penetration that could be obtained even well below the water table, and how best to present the resulting GPR profiles. In particular, different gain functions (for example, automatic gain control or AGC versus spreading and exponential compensation or SEC) would emphasise different aspects of the stratigraphy, such as all of the layering (AGC) versus massive sand deposits (SEC).

Wallace, Nobes, Davis, Burbank and White (2010, GJI) was another paper that arose from a collaborative project, and also resulted from an Honours project that I supervised, in this case Wallace’s. I was the corresponding author on the paper. The project aims were to determine the 3D subsurface structure in the area around a growing anticline. We were able to trace the main fault coming from the north into an area of deformation distributed across a large number of small fault scarps, one of which then became the new main fault scarp which continued to the south, but offset from the main scarp to the north.

References

Wallace , Shamus C., **Nobes, David C.**, *Davis, Kenneth J.*, Burbank, Douglas W., & White, Antony, 2010. Three-dimensional GPR imaging of the Benmore Anticline and step-over of the Ostler Fault, South Island, New Zealand. *Geophysical Journal International*, **184**: 465-474, doi: 10.1111/j.1365-246X.2009.04400.x.

Nobes, D. C., *Ferguson, R. J.* & Brierley, G. J., 2001. Ground-penetrating radar and sedimentological analysis of Holocene floodplains: insight from the Tuross valley, New South Wales. *Australian Journal of Earth Sciences*, **48**: 347-355.

Francké, Jan & **Nobes, David C.**, 2000. A preliminary evaluation of GPR for nickel laterite exploration. *In* Noon, David A., Stickley, Glen F. & Longstaff, Dennis (eds.), *GPR 2000: Proceedings of the 8th International Conference on Ground Penetrating Radar*, Society of Photo-Optical Instrumentation Engineers (SPIE), **4084**: 7-12.

Yetton, Mark D. & **Nobes, David C.**, 1998. Recent vertical offset and near-surface structure of the Alpine Fault in Westland, New Zealand, from ground penetrating radar profiling. *New Zealand Journal of Geology and Geophysics*, **41**: 485-492.

Nobes, David C. & Schneider, George W., 1996. Results of downhole geophysical measurements and vertical seismic profile from the Canandaigua borehole of New York state Finger Lakes. *In* Mullins, Henry T. & Eyles, Nicholas (eds.), *Subsurface Geologic Investigations of New York Finger Lakes: Implications for Late Quaternary Deglaciation and Environmental Change*, Geological Society of America Special Paper 311: 51-63.

Section 7

Geoarchaeology and Forensic Geoscience

7. Geoarchaeology and Forensic Geoscience

The archaeological applications of near surface geophysics has long been an interest of mine. Most of the work, however, is contained in various Honours and MSc thesis projects, many of which have not been published. This in hindsight was an oversight. We should have been publishing the results in the archaeological journals, both to more publicly display the results, and to alert the archaeological community to the utility of NSG and how to best use the methods and the results. Nonetheless, that broader community knowledge has grown.

Out of the archaeological work has grown the forensic work, and the overlap between the two – the imaging of Maori burial sites. Of course, much of the forensic work cannot be published unless or until any court hearings are complete, and even then one must be careful of the identities of those involved. Similarly, the individual burial sites yield reports to the communities. The results of the burial site work has not been published for each site, but instead summarised in a collection of all of the results in an overview. Thus the papers presented here, as for the other sections, represent a small proportion of the research work that has been done over the years.

The first paper, Nobes (1999, Geophysics), set the tone and the process for subsequent work on burial sites. The Oaro urupa was the first Maori burial site to be surveyed using NSG imaging, and has led to the imaging of many more sites. The Australian park services, in New South Wales, for example, have used the Oaro *urupa* work as a model for indigenous groups to follow in Australia. In the Oaro paper, it was noted that high-frequency data can be so detailed that the main targets are lost amongst the signals generated by the other smaller features, such as the flax bushes along the burial site margins. I also developed a quantitative way to combine different data sets: by normalising the responses and summing the normalised data sets.

Nobes and Lintott (2000, GPR2000) present the results of the combined HLEM and GPR imaging of the north quadrangle of the Arts Centre in Christchurch. The Arts Centre was the first site for the University of Canterbury, and the imaging was done to locate the foundations of what was colloquially called the “Old Tin Shed”, a corrugated iron clad wood frame building that housed the Physics and Chemistry lecture theatres. The historical importance was heightened by the fact that the Nobel-prize winning physicist, Ernest Rutherford, had many of his undergraduate lectures there. We easily located the foundations, and upon analysing the GPR data estimated that the depth to the top of the foundations was between 70 and 75 cm depth. A small excavation was done, and the foundation was hit at 70 cm depth. A full excavation of the quadrangle was carried out the following year, and may have precipitated the resignation of the groundsman that year.

Field, Leonard and Nobes (2001, Proceedings of the 7th Australasian Archaeometry Conference) also had a connection with Rutherford. Field and Leonard carried out a research project as part of the postgraduate course in Environmental and Engineering Geophysics at the University of Canterbury. The goal was to try to locate the grave of Percy Rutherford, Ernest’s younger brother, who died in a pertussis (whooping cough) epidemic shortly after the family had shifted to Havelock, in Nelson. We ran calibration surveys across graves of known ages, and then surveyed an area in the Victorian part of the cemetery where no markers were present. We were able to locate a cluster of three or four small graves, none longer than 1.5 m, and because of the age of the location, the cluster of small graves, and the lack of markers, it was concluded that Percy was in one of the small graves. The family has since erected a marker over top of the cluster of graves.

Basset, Gordon, Nobes and Jacomb (2004) was based on Gordon's Honours project, supervised by Bassett and I. The site was on a north-facing slope on the south side of Banks Peninsula. The remnants of terracing suggested that agricultural cultivation had occurred on the site, and the proximity of "borrow pits", sites where beach pea gravel had been removed, also were an indication that the slope had been modified for cultivation of crops. The combination of the slope aspect, presence of gravel in the made soils of the slope, the slope terracing, and the presence of what appeared to be storage pits at the top of the slope, all indicated that the site had been used for horticulture. However, the central pieces of evidence were the 3D GPR images of the *tapu* storage pits, which showed internal features similar to kumara storage pits found elsewhere, and the presence of kumara phytoliths. Phytoliths are small grains of silica deposited in the roots of the plant. The silica is not a plant nutrient that can be absorbed, and so is excreted from the plant cells and deposited.

Nobes (2007, NSG2007) presented a summary of the burial site work up to 2007. In essence, almost every setting suited one technique or another, except for a burial site located in sands that were influenced by fluvial, dune and beach activity. The complex subsurface background response serves to mask the anomalous response due to graves. While oversimplifying the problem, we could say that the stream creates a hole by erosion and then a combination of the beach, the dunes and the stream act to fill in the hole. It is difficult to distinguish natural features like this from graves.

Finally, Nobes and Wallace (2007, NSG2007) present the results of geophysical surveys carried out to locate the remains of the French naval defensive blockhouse located in Takamatua. The imaging was so successful that the Historic Places Trust would not give permission for any excavations, although calibration is usually desired whenever possible. The HPT responded that the results were excellent and it was clear that these were the remains of the blockhouse. I was most disappointed – I wanted to find a 19th C French coin.

References

Nobes, David C. & Wallace, Lynda R., 2007. Geophysical Imaging of an Early 19th Century Colonial Defensive Blockhouse. *In Proceedings of Near Surface 2007: 13th European Meeting of Environmental and Engineering Geophysics*, Istanbul, Turkey: Paper B10.

Nobes, David C., 2007. Effect of grain size on the geophysical responses of indigenous burial sites. *In Proceedings of Near Surface 2007: 13th European Meeting of Environmental and Engineering Geophysics*, Istanbul, Turkey: Paper P33.

Bassett, Kari N., *Gordon, Hamish W.*, **Nobes, David C.** & Jacomb, Chris, 2004. Gardening at the edge: documenting the limits of tropical Polynesian kumara horticulture in southern New Zealand. *Geoarchaeology*, **19**(1): 185-218. http://www3.interscience.wiley.com/cgi-bin/ abstract/107614459/.

Field, Garrick, *Leonard, Graham* & **Nobes, David C.**, 2001. Where is Percy Rutherford's grave? *In* Jones, Martin & Sheppard, Peter (eds.), *Australasian Connections and New Directions: Proceedings of the 7th Australasian Archæometry Conference*, Research in Anthropology and Linguistics, University of Auckland, **5**: 123-140.

Nobes, David C. & Lintott, Bryan, 2000. Rutherford's "Old Tin Shed": Mapping the foundations of a Victorian-age lecture hall. *In* Noon, David A., Stickley, Glen F. & Longstaff, Dennis (eds.), *GPR 2000: Proceedings of the 8th International Conference on Ground Penetrating Radar*, Society of Photo-Optical Instrumentation Engineers (SPIE), **4084**: 887-892.

Nobes, David C., 1999. Geophysical surveys of burial sites: a case study of the Oaro urupa, *Geophysics*, **64**(2): 357-367.

Section 8

Non-Destructive Testing

8. Non-Destructive Testing

This last, short section on Non-Destructive Testing consists of only 3 papers, largely because so much geotechnical and engineering work occurs as consulting work to companies. Thus most such projects are presented as reports that never subsequently appear in the literature. Sometimes, however, we obtain permission to publish the results, usually after we have removed the names of the clients.

The first of the NDT papers, Nobes and McCahon (1999, The Leading Edge), was an interesting project to determine the locations of old pits where the refuse from a manufacturing process had been disposed, and the locations of stream channels that had been covered and buried. The plan, since abandoned, was to construct an expanded manufacturing facility, and accurate locations of these features were needed so that any adjustments to the foundations could be made in advance.

King, Wu and Nobes (2003, NDT-CE 2003) was one of those instances where a consultant carried out some surveys for a client, but then needed my help and advice to interpret and understand the results. In this case, a waste water treatment pond went out of level soon after it was constructed. The concern was that voids had formed beneath the foundations. The GPR results confirmed this, and grouting was done to fill the voids. Follow-up GPR surveys could then be used as quality control checks, because grout and concrete have similar physical properties, and the disappearance of the anomalous void responses indicated that grouting had been successful.

The final NDT paper, Nobes and Sikma (2003, NDT-CE 2003), reported the results of GPR surveys to determine the nature of the foundation beneath the Roman Catholic basilica in Christchurch. The results clearly suggested that, in fact, there were no foundation, that the basilica had simply been built on compacted earth. There may have been limited foundations beneath individual pillars and walls, but there were no broader, more extensive foundations. This had implications for the seismic strength of the building, sadly subsequently confirmed in the earthquakes in Christchurch during 2011.

References

Nobes, David C. & *Sikma, Timothy J.*, 2003. Non-invasive ground penetrating radar in the NDT of the foundations of the Cathedral of the Blessed Sacrament, Christchurch, New Zealand. *In Proceedings of NDT-CE 2003, the International Conference on Non-Destructive Testing in Civil Engineering, Deutsche Gesellschaft für Zerstörungsfreie Prüfung, Berlin,* Proceedings BB85-CD, http://www.ndt.net/article/ndtce03/papers/v077/v077.htm

King, Martin L., Wu, Dany & **Nobes, David C.**, 2003. Non-invasive ground penetrating radar investigation of a failing concrete floor slab. *In Proceedings of NDT-CE 2003, the International Conference on Non-Destructive Testing in Civil Engineering*, Deutsche Gesellschaft für Zerstörungsfreie Prüfung, Berlin, Proceedings BB85-CD, http://www.ndt.net/article/ndtce03/papers/p043/p043.htm.

Nobes, David C. & McCahon, Ian F., 1999. Buried channels and refuse pits: shallow electromagnetic mapping for characterization of a proposed construction site, *The Leading Edge*, **18**(12): 1378-1383.