A Celebration of Research in Honour of

Professor Colin Ballantyne MA MSc PhD DSc FRSE FRSGS
The Coppock Research Medal

The Coppock Research Medal is the Royal Scottish Geographical Society’s highest research-specific award, for an outstanding contribution to geographical knowledge through research and publication. This Research Medal, named in 2009 after Professor Terry Coppock, has been awarded since 1931 to some of the world’s most leading and inspirational researchers.

Professor Colin Ballantyne is the most recent academic to be awarded this accolade. In a career spanning more than forty years, Colin has published around 150 papers (mostly as single or senior author) plus over 50 chapters in books and field guides containing a remarkable diversity of material, ranging from papers on orientation statistics, clast shape analysis and climatic gradients to experiments on patterned ground generation to recent reassessments of the dimensions and de-glacial chronology of the last British-Irish Ice sheet. Professor Ballantyne has been an active supporter of the RSGS, with regular contributions to the SGJ on the geomorphology of Scotland (more than any other physical geographer) including several papers in the Scottish landforms examples series.

Mike Robinson
Chief Executive, Royal Scottish Geographical Society
A tribute to Professor Colin Ballantyne on the occasion of his retirement from the University of St Andrews on 31st January, 2015 and in support of his nomination as Emeritus Professor, School of Geography and Geosciences

Colin Ballantyne was appointed Lecturer in Geography at the University of St Andrews in January 1980, was subsequently promoted to Senior Lecturer in Geography and Geology in 1987, and appointed Professor in Physical Geography in 1994. Between 1985 and 1995 he was Warden at McIntosh Hall. In 1996 he became Deputy and Acting Head of the School of Geography and Geosciences, taking on the role of Head of School from 1998 to 2000. Between 2007 and 2012, he was Director of Research in the School of Geography and Geosciences. Although based at St Andrews throughout his career, Colin has also been a visiting Lecturer at the University Centre in Svalbard (UNIS) on Svalbard since 2000 and twice an Erskine Fellow at the University of Canterbury in New Zealand, where he continues to be involved in summer school teaching.

Colin Ballantyne first developed his lifelong interest in Quaternary science and geomorphology at the University of Glasgow under the tutelage of the late Rob Price. Attainment of a First Class Honours MA degree enabled him, with Price’s encouragement, to undertake an MSc degree at McMaster University in Canada, where he joined a team led by Brian McCann studying high arctic hydrology and fluvial processes. Two long field seasons in the high arctic stimulated his enduring interest in periglacial environments, and on returning to Scotland to undertake his PhD under the supervision of Brian Sissons he chose to study the periglacial processes and landforms on mountains in NW Scotland.

Three main research interests have dominated a research career that spans 40 years. Throughout that period he has contributed extensively to the literature on periglacial landforms and processes, and has published widely-cited papers on such diverse phenomena as blockfields, protalus ramparts, ploughing boulders and plateau-top aeolian sand deposits. His work on periglacial phenomena led to his collaboration with Charles Harris in writing The Periglaciation of Great Britain (Cambridge University Press, 1994), which set the agenda for periglacial research in the British Isles for the next two decades. A second major interest has been in the reconstruction of former glaciers and their palaeoclimatic implications, particularly with regard to glaciers that formed during the Younger Dryas period in Scotland, work that included singlehanded reconstruction of former glacier limits on all major Hebridean islands between Orkney and Arran. A combination of his periglacial expertise with interest in Late Pleistocene glaciation led to research on the dimensions of the last British Irish Ice Sheet, and in particular the possibility that the former ice sheet surface might be represented by trimlines that mark the upper limit of glacial erosion. Although initial research based on trimline mapping and analysis of clay mineralogy (together with the earliest $^{10}$Be exposure ages reported in the British Isles) appeared promising, this ultimately proved a false dawn; conflicting evidence accumulated and by 2005 Colin and his co-workers had accepted that trimlines represent englacial pressure thermal boundaries within a former ice sheet that overtopped all mountains in Britain and Ireland. This alternative model was elegantly demonstrated in a groundbreaking paper on the exposure age of high-level erratics by Ballantyne and Fabel in 2012.

Colin’s international reputation was augmented by the publication of a long review paper in Quaternary Science Reviews in 2002. Entitled simply Paraglacial Geomorphology, this paper amassed a vast body of evidence to demonstrate that the trajectory of Holocene landscape change in formerly glaciated environments has been modified and often dominated by the influence of the preceding glacial episode, and encapsulated paraglacial landscape change in terms of the reworking of non-renewable sediment stores over timescales ranging from decades to millennia. This paper and its associated concepts ‘went viral’; the paper has received over 500 citations and spawned a remarkable body of work that employed his ideas to evolve a paradigm of paraglacial landscape modification to explain post-deglaciation landscape evolution. Colin continued to investigate the nature and effects of deglacial inheritance, primarily through a remarkable programme that involved exposure dating of 31 catastrophic rockslides in Scotland and Ireland to demonstrate that over 90% occurred within 5ka after deglaciation, and that kinematic release reflected seismic activity associated with glacio-isostatic uplift.

As the above account suggests, Colin’s research interests are difficult to encapsulate. His record of over 150 published papers (mostly as single or senior author) plus over 50 chapters in books and field guides includes a remarkable diversity of material, ranging from papers on orientation statistics, clast shape analysis and climatic gradients to experiments on patterned ground generation to recent reassessments of the dimensions and deglacial chronology of the last British-Irish Ice sheet.

Over many years Colin Ballantyne has loyally served the University of St Andrews and has been one of the key architects of the School’s remarkable climb in the excellence rankings of the UK RAE and REF Geography league tables. He was responsible for the School submission in all but one RAE, and for the Environment Statement in the REF2014. The quality and originality of his research work has been recognized in several awards and prizes, including the Warwick Award of the British Geomorphological Research Group (1987); the President’s Medal (1991), the Newbiggin Prize (1992) and the Coppock Research Medal (2015) of the Royal Scottish Geographical Society; the Wiley Award of the BGRG (1999), the Saltire Science Medal in Earth Sciences (1996) and the Clough Medal in Earth Sciences (2010). Earlier this year, he was named as the recipient of the prestigious Lyell Medal by the Geological Society of London (2015). He was elected Fellow of the Royal Society of Edinburgh in 1996 and awarded the degree of D.Sc. by the University of St Andrews in 2000.
INTIMATE (Integration of ice-core, marine and terrestrial records) 20 years on: retrospect and prospect

Mike Walker  School of Archaeology, History and Anthropology, Trinity Saint David, University of Wales, Lampeter, Wales UK and Department of Geography and Earth Sciences, Aberystwyth University, Aberystwyth, Wales UK

The INTIMATE project was launched at the Berlin INQUA Congress in 1995, and was a successor to the North Atlantic Seaboard Programme of ICP-253 (Termination of the Pleistocene). The aim was the integration of proxy climate records from around the North Atlantic during the Last Glacial-Interglacial Transition (the Last Termination). Subsequently, the INTIMATE remit has expanded geographically to include the whole Atlantic basin and Australasia, while an extended temporal framework now covers the early Holocene and the Last Glacial cycle. In this presentation, I review briefly the principal achievements of the INTIMATE research community, including the formulation of an event stratigraphy for the North Atlantic region; the establishment of protocols for ice-land-ocean correlation; important developments in geochronology, most notably in tephrochronology; and the contribution of the Greenland ice-core record both in advancing our understanding of the pattern, sequence and timing of climatic events during the Last Glacial cycle in the North Atlantic region, and in constituting a global stratotype for the Pleistocene-Holocene boundary. The presentation concludes with a short discussion of possible future directions for INTIMATE-based and INTIMATE-related research.

Tephrostratigraphic sequencing of Late Devensian glacial limits in Scotland

John Lowe  Centre for Quaternary Research, Royal Holloway University of London

In common with our guest of honour, Colin Ballantyne, I completed a PhD programme of studies at Edinburgh University (1970-73) under the supervision of Brian Sissons, where I worked in close collaboration with fellow-postgraduate, Mike Walker. At that time, Sissons ‘commanded’ a thriving postgraduate team dedicated to the study of the evolution of the Scottish landscape, and in particular of the glacial and meltwater features inherited from the last great ice sheet to cover the country, around 20,000 years ago. Two topics dominated the agenda: (1) the rate and pattern of retreat of the ice sheet, and (2) the maximal limits and timing of a subsequent brief resurgence of glacier growth in the Highlands, termed the Loch Lomond (or Younger Dryas) Readvance. Detailed geomorphological mapping provided evidence of these glacial developments but, in the early 1970s, frequently lacked independent and precise chronological underpinning. Mike Walker and I attempted to provide this underpinning through pollen analysis and radiocarbon dating of sedimentary sequences preserved in lake basins located close to proposed glacier margins. The underlying principle of this approach is that lake basins lying within the limits of the Loch Lomond Readvance (what we termed ‘inside’ sites) should contain sediments of Holocene age only, while much older sediments should be found in basins located outside of those limits: the earliest to accumulate should date back to the time when each basin emerged from the waning ice sheet. Our research results helped to firm up the ages of glacial limits and of concomitant regional environmental changes, but were initially confined to around 10 lake basins in the central and SE Grampian Highlands. Today, thanks to the endeavours of a large number of researchers, sediment records relevant to this theme have been obtained from more than 150 former or extant lake basins in Scotland. The collective results are in remarkable accord with the evidence based on geomorphological mapping, so far as the proposed maximal limits of the Loch Lomond Readvance are concerned. In theory, however, this large body of evidence should also provide a template for reconstructing the pattern and rate of retreat of the last ice sheet, since lake basins located near the former maximal limits of the ice sheet should contain older sediments than those located close to the main glacial sources. There are, however, a number of limitations that constrain the use of the existing stratigraphical data-base for this purpose, largely because, in the majority of cases, the lake basin sequences were not investigated with that specific goal in mind. Furthermore, the chronology of events has, until recently, rested heavily on the results of radiocarbon dating, the reliability of which are frequently open to question, for a variety of reasons. There is a need, therefore, to develop a more secure basis for dating the basal sediments preserved within these basins, for the purpose of reconstructing the pattern and rate of ice sheet retreat. The comparatively recent discovery of non-visible volcanic ash layers (cryptotephra layers) in some of these lake basins appears to offer this potential.

Volcanic ash layers originating from Iceland have been detected in Scottish peat deposits since the 1980s, but of an age (mid-to late Holocene) too young to be of relevance to dating glacial limits. In the mid-1990s, however, a discovery was made of tiny volcanic glass particles in much older sediments from a lake basin in NE Scotland, which sparked a wider search. Now we know of around 8 or 9 ash (or tephra) layers that are preserved in a number of lake sediment sequences in Scotland, dating to between c.16,000 and 8,000 years ago. In one place (Loch Ashiik, on the Isle of Skye), one of the ash layers is visible in the field, but in all other cases the tephra layers can only be detected by careful laboratory preparation. The ages of each of the layers is gradually being determined, but their potential regional distributions are not yet well known. In this talk I summarise the current position, in terms of the number and distribution of the tephra layers we currently know about, and outline the actual and potential advantages that this line of enquiry offers for the reconstruction of Scotland’s recent glacial history.
'Chasing Glaciers: from Scotland to the Arctic'

Doug Benn  UNIS/StAndrews

When I first came to St Andrews in 1987, I joined a thriving group of Colin's PhD students. Under his inspired and sometimes stern leadership we were tackling a wide range of problems on past and present environmental change in the Scottish mountains. These included reconstructing the extent and climatic significance of Loch Lomond Readvance glaciers in the northern Highlands, studying debris flow activity on mountain slopes, the earliest work on ice sheet trimlines, and, in my own case, conducting detailed studies of glacial sediments on the Isle of Skye. At the same time, exciting new results and ideas were being produced by a wider network of researchers who, like Colin, had been PhD students of Brian Sissons, including Don Sutherland, John Lowe, Mike Walker, David Smith, Ali Dawson and Jim Rose. In addition, the close proximity of Geoffrey Boulton and his students in Edinburgh added to the mix.

I remained at St Andrews for a further 3 years after receiving my PhD, again under Colin's guidance. This time, I was working on subglacial processes with study sites in Scotland, Iceland and Norway. A highlight of this time was an expedition to Norway in 1992, when Colin led me and a group of mostly female undergraduates on a month-long camping trip in the mountains of Jostedalen and Jotunheimen. For most of the time, the weather was scorching and we worked long days in the field followed by magical evenings round the camp fire. Our work included the first study of modern paraglacial processes, a field that Colin went on to make his own. Between us, Colin and I published 4 papers based on data collected during that trip, which to date have amassed 353 citations between them. This increases to 886 if you include Colin’s monumental review of ‘Paraglacial Geomorphology’ published 10 years after that initial work.

Although our research later diverged into different fields, Colin and I continued to work together when opportunities presented themselves. This included the first quantitative reconstruction of Late-glacial precipitation in Scotland, using a combination of glacial evidence and proxy temperature data from middens. In case anyone should think that the Highland midge proved useful after all, they were not that kind of midge.

In the late 1990s, Colin hosted a sabbatical visit by a Danish couple, Ole Humlum and Hanne Christiansen. This visit proved to be of great importance, because it resulted in an invitation for Colin to be a guest lecturer at the University Centre in Svalbard, where Ole was based at the time. A year or two later, I got the Call, which eventually led to my full-time employment there in 2006. This is just one example of the many, many ways in which Colin has influenced, helped and guided my career. For his willingness to pass on his experience and knowledge, and for his friendship and generosity of spirit, I am deeply grateful.

**Trimline trauma: the wider implications of a paradigm shift**

Danny McCarrol  Swansea University

Periglacial trimlines on mountains mark the boundary between terrain that has been glacially eroded and terrain that has not. They are often abrupt, with glacially scoured and abraded rocks and moraine deposits of debris on the slopes changing to periglacial landscapes dominated by blockfields and tors on higher ground. Colin Ballantyne and I, together with a range of friends, most notably Atle Nesje and Svein Olaf Dahl from Bergen, spent many years wandering the hills and mountains of Norway, Scotland, Ireland, England and Wales mapping them. We used a range of relative-age dating methods, based on the amount of rock weathering, to demonstrate a significant difference in surface age above and below our trimlines, and as methods became available we supplemented those with numerical ages based on cosmogenic isotopes, working mainly with John Stone. When we published the results we always discussed two possible interpretations: that the trimlines marked the upper surface of ice during the last glaciation, or that they represented an englacial thermal boundary between warm-based eroding ice and cold-based ice that is frozen to the rock and does not erode. After a bit of discussion we would plumb for the first interpretation, and on that basis we reconstructed the upper surface of ice sheets for all of the areas in which we worked. However, it is now clear that we were quite wrong. Colin, working with Derek Fabel, used cosmogenic isotopes not to date bedrock, as in our previous work, but to date erratics both above and below the Scottish trimlines. The results were conclusive, the erratics date from the last glaciation so the trimlines, in the mountains of Scotland at least, represent an englacial thermal boundary and our ice sheet reconstructions are wrong.

All that work was not wasted of course, not least because it was good fun. The trimlines really do exist (most of them anyway) and our maps, interpreted in terms of the thermal boundary, are of use to the ice sheet modellers. However, I think there are some wider implications of the change in paradigm. The team who mapped the trimlines comprised geomorphologists, all with many years of experience working in glacial and periglacial landscapes. Our interpretation of the evidence was based on an underlying assumption that when an area is glaciated a good field geomorphologist can see the evidence for that event in the landscape. Although we discussed the thermal boundary idea, we really considered glaciation to be a traumatic event, leaving plenty of evidence for the trained eye to see. It now seems that on mountains that is not the case, glaciation can occur and leave hardly any geomorphological evidence, and the key evidence is actually sedimentological (erratics). This has caused me to reassess the evidence not just for the vertical limits of glaciation but for the lateral limits. The limits of the last glaciation in Britain and Ireland, for example are still based primarily on geomorphological evidence. I am beginning to wonder whether many of them are wrong.
Landscapes at the periphery of glaciation: the case study of Dartmoor

David J A Evans  Durham University

The greatest challenge in palaeoglaciology is the delimitation of the extent of glaciations, a research arena in which Colin Ballantyne has rigorously tested hypotheses on the occurrence of palaeo-nunataks versus ice sheet thermal boundaries. Although the wider challenge is due in no small measure to problems of chronological control, it is more fundamentally related to the recognition of subtle signatures of glaciation where “below average” conditions have prevailed, in contrast to settings where average conditions have produced unequivocal glacial signatures. Additionally, the efficacy of glacial erosion in settings where ice was cold based and/or thin has been brought into question; landforms once traditionally regarded as evidence of extreme age and long term periglacial climates (e.g. tors) are now often viewed as survivors of glacier ice cover. In upland landscapes that were peripheral to the Quaternary ice sheets, this problem is compounded by the strong permafrost and periglacial landscape signatures that reflect long periods of non-glacial conditions but do not necessarily preclude the notion of former glacier existence.

One textbook example of an unglaciated, ice sheet-peripheral upland is Dartmoor, traditionally regarded as a relict permafrost and periglacial landscape that lay beyond the limits of Quaternary glaciation. Early views of potential glacial signatures were quickly refuted and only a very recent proposal for the former glaciation of nearby Exmoor has re-opened the Dartmoor glaciation debate, fuelled also by the depiction of glacier ice in SW Britain in numerical ice sheet models. A variety of evidence is presented for the former existence of a plateau ice cap, implying that the area is the location of the southernmost independent glacier mass in the British Isles despite its overwhelmingly clear periglacial legacy. The most prominent evidence comprises arcuate and linear bouldery ridges and hummocky valley floor drift, which are interpreted as latero-frontal moraines deposited by the outlet glacier lobes of a plateau ice cap. A numerical model of ice cap development shows that a predominantly thin plateau icefield type glaciation is required in order to produce significant ice flow into surrounding valleys.

It is proposed that the highest and most extensive plateau areas were occupied by ice for the longest cumulative period of time throughout the Quaternary in order to explain: (1) the lack of tors in such areas as the product of ‘average’ glacial conditions, which preferentially removed tors or dampened their production rates; (2) the survival of high relief tors during glaciation if they occupied summits too narrow to develop thick and erosive glacier ice; and (3) the survival of subdued tors in areas glaciated less regularly during the Quaternary.

Our fresh appreciation of the subtleties of glacial landforms in uplands with strong permafrost and periglacial signatures reflects significant advances in our understanding of the spatial and temporal process-form regimes that have operated at the glacial-periglacial interface over the Quaternary Period; a research arena that has developed due, in no small measure, to the career achievements of Colin Ballantyne.

Stone’s Law and its impact on British-Irish glacial theory

Derek Fabel  University of Glasgow

The first publication containing in situ produced terrestrial cosmogenic nuclide derived exposure ages for samples collected in the UK and Ireland appeared in 1994. The second publication, in 1998, marked the entrance of Colin Ballantyne into the fledgling surface exposure dating field. Very early on Colin realised that sampling for surface exposure dating is not a trivial exercise, and he developed Stone’s Law: “unless you are sure about the history of the surface, don’t sample it” as his personal sampling guide. Adhering to this law is continuing to serve Colin well. Since 1998 some 378 surface exposure ages have been published in 36 peer-reviewed papers. Colin had a direct influence on at least 185 of these published ages.

Colin realised the power of being able to determine landform ages directly from the landforms and in collaboration with surface exposure dating practitioners set about establishing temporal patterns of rock slope failures, reconstructing the dimensions of glaciers and ice caps, and testing the nunatak hypothesis. More recently he has been instrumental in communicating some of the more complex cosmogenic production rate issues to the wider Quaternary community.

Colin is continuing to contribute to the surface exposure data base in the UK and Ireland and as a community we are all looking forward to many more years of his application of Stone’s Law.
The windy periglacial world: from the mountain tops of Scotland to the plains of Beringia

Julian Murton  University of Sussex

Aeolian activity is widespread in certain periglacial environments. During the Holocene these environments have included some mountain tops in Scotland, proglacial outwash regions and the polar deserts of the Arctic and Antarctic. In Pleistocene cold stages, however, aeolian activity was much more extensive, leading to widespread deflation, erosion and deposition. The heartland of the windy periglacial world was in the plains of the Beringia, where syngenetically-frozen silt underlies hundreds of thousands of square kilometres of lowlands in central and northeastern Siberia, significant areas of central and northern Alaska and the Klondike region of Yukon, Canada.

The silt forms a distinctive stratigraphic unit 3–80 m thick that is rich in ground ice and organic carbon, and blankets many Beringian lowlands and foothills. Such yedoma preserves an exceptional terrestrial sedimentary record of Late Pleistocene environmental history. Cold permafrost conditions during yedoma accumulation limited oxidation of organic material, preserving remains of the former steppe-tundra ecosystem, including plant roots, mammal bones and carcasses, pollen, insect remains, plant macrofossils, fossil rodent burrows, soil DNA and microbial communities immobilised on the surface of ancient seeds. Much of the silt accumulated as cold-climate loess, as can be demonstrated sedimentologically at the Russian yedoma type site of Duvanny Yar, in the Lower Kolyma valley of northeastern Yakutia.

The Duvanny Yar loess is consistent with evidence of widespread aeolian activity in the Late Pleistocene of Beringia and Eurasia. In northwestern North America, dunefields, sand sheets, sand wedges and composite wedges, deflation areas and loess characterised much of the unglaciated region, particularly during Marine Isotope Stage (MIS) 2, and extended into deglaciated regions. On the north Alaskan Arctic Coastal Plain a Late Pleistocene sand sea (Ilpiikwik Dunes) grades distally into the loess belt along the foothills of the Brooks Range and proximally into a region with large aeolian sand wedges. Farther east, on the Canadian Arctic Coastal Plain another Late Pleistocene sand sea (Kittigazuit Dunes) developed on the Tuktoyaktuk Coastlands and offshore across the emergent eastern Beaufort Sea Shelf, NWT. Large sand wedges and composite wedges of Late Pleistocene age developed widely in this region, particularly during deglaciation of the Laurentide Ice Sheet. In Asia, deflation deserts covered large regions from Mongolia to the Laptev Sea and were associated with intensive release of sand and silt, and subsequent deposition as aeolian sand and thick accumulations of loess (yedoma). A vast cold desert covered the northern half of West Siberia during the Younger Dryas Stadial and probably the Last Glacial Maximum. Highly arid conditions and intense aeolian processes here led to widespread reworking of sand deposits and deposition of silt particles that contributed to loess deposition in the southern part of the West Siberian Plain.

The Duvanny Yar loess represents part of an extensive cold-climate loess deposit that stretches westwards from northeast Yakutia through central Yakutia to the loess belt of Europe and eastwards to the loess of eastern Beringia. The loess represents a gradation between two end members. One constitutes very ice-rich loess (yedoma) characteristic of continuous permafrost that existed throughout MIS 4 to 2 in much of Beringia and central Yakutia and persists to the present day within continuous to discontinuous permafrost. The other constitutes ice-poor loess characteristic of permafrost that developed episodically in northwest Europe and in western and central Siberia, where permafrost degraded during the last glacial-interglacial transition. The ice-rich loess at Duvanny Yar was deposited in a ‘cold-polar’ (rather than seasonally cold) aeolian environment, and during the last glacial-interglacial transition, the environment there has changed from what might once have been considered as glacially-proximal cold-polar into continental cold-polar. Persistence of cold continuous permafrost conditions during loess deposition at Duvanny Yar led to stacking of ice-rich transition zones and growth of large syngenetic ice wedges characteristic of yedoma. By contrast, episodic permafrost conditions in warmer regions to the south and west led to repeated permafrost thaw and development of small ice wedges now represented by ice-wedge and composite-wedge pseudomorphs in northwest Europe.

Megatides and ice sheet collapse

James Scourse  Bangor University

A number of independent numerical open ocean global palaeotidal model simulations identify that the Last Glacial Maximum North Atlantic was close to resonance. This resulted in extremely high tidal amplitudes in some ice-marginal locations, notably the Hudson Strait. Northwest European shelf sea palaeotidal models, parameterised with shelf break open ocean boundaries forced by these global tidal models and with dynamic palaeotopographies from glacial isostatic adjustment (GIA) models, predict megatides (mean spring tidal range in excess of 10 m) in some key locations along the British-Irish Ice Sheet (BIIS) margin. We present relative sea level and palaeotidal amplitude reconstructions for the major ice streams draining the BIIS based on two independent simulations. The simulations are consistent in indicating large variation in palaeotidal amplitudes between different ice streams during deglaciation with some, notably the Minch Ice Stream, characterised by megatidal amplitudes. We propose that the rapid rates of BIIS deglaciation in some ice stream sectors suggested by geological observations were the product of (1) rapid atmospheric and oceanic warming linked to meridional migration of the North Atlantic Polar Front, (2) relative sea-level change, compounded by (3) megatidal calving margins which forced high iceberg fluxes and consequent ice sheet drawdown. The deglaciation and inundation of Hudson Strait in the early Holocene reduced the resonance of the North Atlantic generating the damped interglacial ocean tide characteristic of the Holocene.