NERC Radiocarbon Facility Science Highlights

2017/18

RADIOCARBON DATING OF THE EARLY NEOLITHIC ON ISLANDS WITHIN THE BRITISH ISLES

The question of the arrival of the Neolithic way of life in Britain has been a subject of major interest amongst archaeologists for decades. The islands of the western seaways (see Figure) have long been seen as crucial to our understanding of the processes which led to the arrival of the Neolithic in Britain from around 4000 cal BC. Sites in these regions have not been formally explored in any of the large recent investigations of the chronology of the Neolithic, however. New radiocarbon dates obtained as part of NRCF projects have produced ~50 new results which have far reaching implications for our understanding of the Mesolithic–Neolithic transition in Britain and Ireland and beyond. The findings suggest that the earliest dated Neolithic in this zone falls into the period c. 3900–3700 cal BC. Interestingly this mirrors broadly the chronology from the mainland, in which a general southeast to northwest process of change occurs during the early Neolithic. The authors suggest there is some evidence at odds with this, however, and more work is needed to focus on these anomalies to the general picture with more targeted dating and archaeological analysis. This research was supported by the AHRC.

REFERENCE: Garrow, D., Griffiths, S., Anderson-Whymark, H., & Sturt, F. (2017). Stepping Stones to the Neolithic? Radiocarbon Dating the Early Neolithic on Islands Within the 'Western Seaways' of Britain. Proceedings of the Prehistoric Society, 83, 97-135. doi:10.1017/ppr.2017.4

HUMAN PRESENCE IN THE RAINFOREST DOCUMENTED IN THE LATE PLEISTOCENE

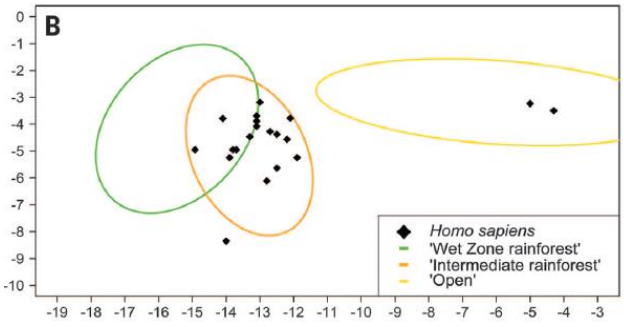


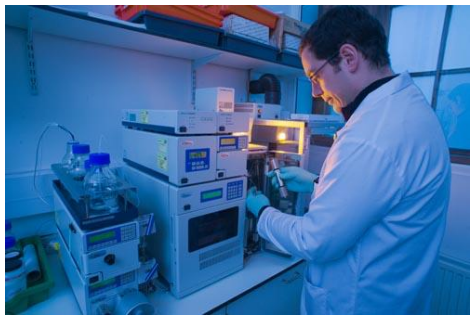
Figure 1: 13C (x-axis) and 18O values (y-axis) for human teeth samples from terminal Pleistocene and Holocene deposits at two sites in Sri Lanka.

Human occupation of tropical rainforest habitats is thought to be a mainly Holocene phenomenon. Although archaeological and palaeoenvironmental data have hinted at pre-Holocene rainforest foraging, earlier human reliance on rainforest resources has not been shown directly. By applying stable carbon and oxygen isotope analysis to dated human and faunal tooth enamel from four late Pleistocene–to–Holocene archaeological sites in Sri Lanka Roberts et al. show that human foragers relied primarily on rainforest resources from at least ~20,000 years ago, with a distinct preference for semi-open rainforest and rain forest edges. Homo sapiens' relationship with the tropical rainforests of South Asia is therefore long-standing, a conclusion that indicates the time-depth of anthropogenic reliance and influence on these habitats.

REFERENCE: Roberts, P. et al. (2015) Direct evidence for human reliance on rainforest resources in late Pleistocene Sri Lanka. *Science*, 347(6227), pp.1246-1249. Roberts, P. et al. (2016) Tropical forests and the genus Homo. *Evol. Anthropol.* 25(6), pp.306-317

DATING SINGLE AMINO ACIDS FROM BONES AND PROTEINACEOUS SAMPLES

In order to be accurate, radiocarbon dates of bone proteins must be free of contaminating carbon. The ORAU has been working on alternatives to routine collagen purification by targetting single amino acids obtained using preparative high performance liquid chromatrography (HPLC). A major focus has been on the amino acid hydroxyproline (HYP) which acts as a virtual biomarker for mammalian type 1 collagen. This paper reports on significant methodological developments to the technique, which faster turnaround times and lower backgrounds, along with better quantification methods for correcting for background carbon. The dating of key Palaeolithic human bones shows that, where the bones have been treated using museum conservation and consolidants that HYP dating is the only method that will produce reliable and accurate determinations. This method holds great promise in enabling 'gold standard' contaminant free AMS dates of bone and other proteinaceous materials. The NRCF-Ox plans to roll out the method for NRCF users in due course.



REFERENCE: Deviese, T., Comeskey, D., McCullagh, J ., Ramsey, .CB., Higham, T. 2018. New protocol for compound specific radiocarbon analysis of archaeological bones. *Rapid Communications in Mass Spectrometry* 32: 373-79.

NEW METHODS FOR SUMMARIZING RADIOCARBON DATASETS

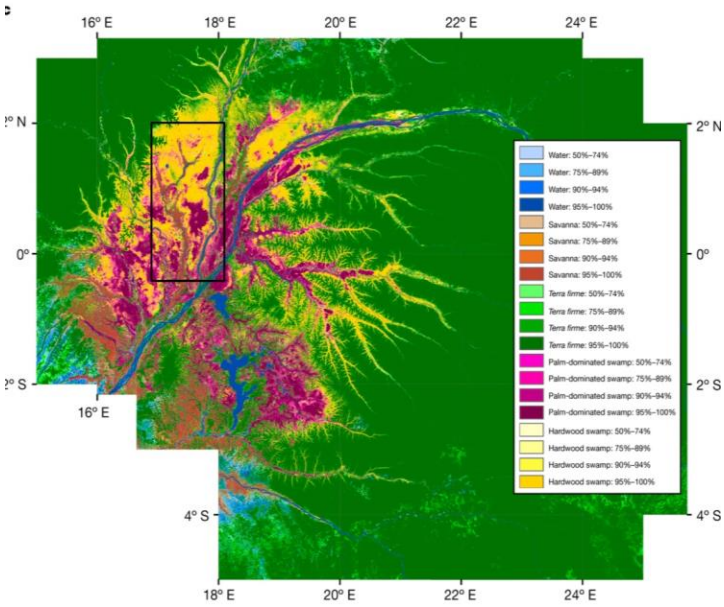
One major issue for environmental scientists and archaeologists using large radiocarbon datasets has been how best to interpret them in terms of underlying processes. A new release of the OxCal statistical analysis software includes new methods based on Kernel Density Estimation associated with Bayesian modelling to address this issue. This enables us to extract frequency distributions from radiocarbon datasets on, for example, magafaunal extinctions or archaeological activity. This development will be inportant for new radiocarbon projects across the NERC portfolio (including for example Hazard Risk). It is also applicable other dating techniques and existing datasets, enabling new forms of analysis to be undertaken. There has already been considerable interest in these new methods and NRCF-Ox is advising researchers on their use in different contexts.

REFERENCE: Bronk Ramsey, C. (2017). Methods for Summarizing Radiocarbon Datasets. Radiocarbon, 59(2), 1809-1833.

AGE, EXTENT AND CARBON STORAGE OF ONE OF THE LARGEST PEATLANDS ON EARTH: THE CONGO BASIN

The central Congo peatlands cover 145,500 square kilometres – an area larger than England. As peat is a highly carbon- rich material, there is the potential for the central Congo region to contain a vast quantity of carbon that is currently not accounted for in global budgets and models for future climate change. This carbon may comprise material that has been 'locked up' for millennia, and hence would be a significant potential carbon source to the atmosphere if released by land use or climate change- an analogy is the release of ancient carbon via peatland burning and drainage in Malaysia.

Radiocarbon is hence the perfect tool to assess the residence time of peat in the Congo basin, and provides a powerful means of characterising this newly-discovered zone of peatland. This research combined radiocarbon measurements across the entire central Congo peatland, with a range of other field and analytical techniques. The results revealed that peat accumulation had been ongoing since c.10,600 years ago, when humid conditions dominated central African climate. The researchers estimate these peatlands store 30.6 petagrams (30.6 × 1015 grams) of carbon belowground, a quantity similar to the above-ground carbon stocks of the entire Congo Basin. This increases the best estimate of global tropical peatland carbon stocks by 36 per cent, meaning the area is a precious store of carbon over the long-term, which is vulnerable to land-use change and any future reduction in precipitation.



REFERENCE: Dargie GC, Lewis SL, Lawson IT, Mitchard ET, Page SE, Bocko YE, Ifo SA. (2017). Age, extent and carbon storage of the central Congo Basin peatland complex.. Nature, 542 (7639), pp. 86-90

VOLCANIC EXPLOSIONS: THE 'SMOKING GUN' FOR VIRTUAL EXTINCTION OF HOLOCENE PENGUIN COLONIES

Penguin populations have expanded across the Antarctic peninsula, becoming established in several island locations over the Holocene. Populations have not been stable however, experiencing periods of 'boom and bust'. Understanding the reasons behind these changes is important for understanding the ecology of Antarctic penguins, and their conservation. Until now these population changes have been primarily linked to environmental factors, but there has been a suspicion that other influences may be in play. This research used radiocarbon dating and other detailed biogeochemical analyses to show that volcanism is the 'smoking gun' for population crashes over the last 8,500 years on Ardley Island, home to one of the Antarctic Peninsula's largest breeding populations of gentoo penguins.

Colonisation of the island by penguins pre-dates Peninsula-wide occupation by c. 1,000 years. For the five identified population maxima, no relationship was found with local-regional atmospheric and ocean temperatures or sea-ice conditions, with only one event linked to temperature increases. Instead, at least three of the five penguin colony expansions were abruptly ended by large eruptions on Deception Island, resulting in near-complete extinction of the colony. On average it took 400–800 years after an eruption for the penguin colony to be sustainable once more.

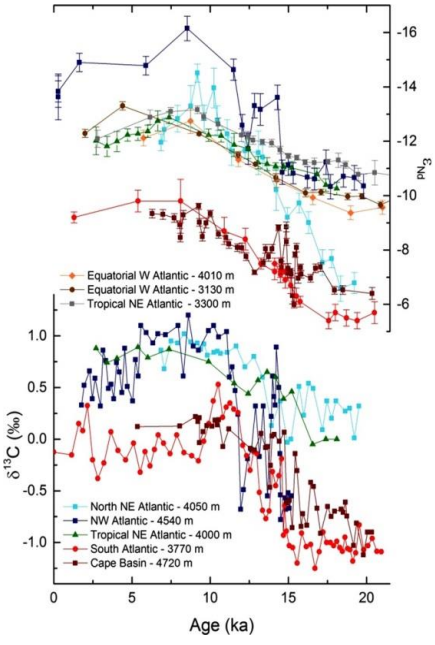
REFERENCE: Roberts S, Monien P, Foster L, Loftfield J, Hocking E, Schnetger B..... Hodgson D, (2017). Past penguin colony responses to explosive volcanism on the Antarctic Peninsula. Nature Communications, Image: By Jason Auch

MELTING PERMAFROST IS NOT THE PRIME CULPRIT FOR METHANE RELEASE AS PEATLANDS THAW

The thaw of permafrost soils is occurring at pace in northern high latitudes. At current estimates, this process will release tens of billions of tonnes of carbon to the atmosphere over the next century, however the effect this has on the Earth's climate depends heavily on which gas is released: CO2 or Methane (CH4). Methane is a much stronger greenhouse gas; for example, even if CH4 emissions represent just 2% of the C release, they would contribute approximately one- quarter of the climate forcing. In the north, permafrost thaw results in subsidence, exposing massive stores of previously preserved organic matter to anaerobic degradation, making ideal conditions for CH4 release from permafrost. This has led to great concern over what this potential methane release will mean for our climate, and a focus on this research question. This paper demonstrates, contrary to what has been expected, that only a small amount (<2 g CH4 m−2 yr−1) of CH4 released from northern Canadian peatlands was due to previously frozen carbon. Instead, the remainder of the substantial CH4 flux (>20 g CH4 m−2 yr−1) was due to anaerobic decomposition of recent carbon inputs. It is therefore thaw- induced changes in surface wetness and wetland area that are most likely to drive the size of the impact that permafrost that has upon CH4 emissions from northern peatlands.

REFERENCE: Cooper M, Estop-Aragonés C, Fisher J, Thierry A, Garnett M, Charman D..... Hartley I, (2017). Limited contribution of permafrost carbon to methane release from thawing peatlands. Nature Climate Change, Image: By Dentren at English Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=8016884. NRCF Allocation 1684.0313

SURPRISING SIMILARITIES BETWEEN THE MODERN AND GLACIAL ATLANTIC OCEAN



The transition of the Atlantic from its Glacial circulation to the modern state has been the subject of intense scrutiny, as it is one of the keys to understanding the mechanics of the most recent major reorganisation of world climate. This research used a suite of isotopic techniques, including radiocarbon to provide the critical chronological framework, to investigate the Glacial-Modern transition across the Atlantic. There were striking similarities between the glacial west to east circulation and the modern ocean, where during the Last Glacial Maximum (LGM), the low latitude deep eastern Atlantic was ventilated from the western Atlantic via advection through fracture zones, identical to today.

This was concluded from identification of a large, homogeneous water mass, sitting in the deepest eastern Atlantic during the LGM. This is confirmed by neodymium isotopes, in conjunction with radiocarbon. In addition, the glacial eastern Atlantic stored more respired carbon than the western Atlantic during the LGM, as is also seen in the modern Atlantic Ocean. Significantly, the

results provide more support for the reduction in the proportion of North Atlantic Deep Water that bathed the study sites during the Last Glacial Maximum (LGM), as has been seen in other high profile papers this year.

REFERENCE: Howe J, Piotrowski A, Hu R, Bory A, (2017). Reconstruction of east–west deep water exchange in the low latitude Atlantic Ocean over the past 25,000 years. Earth and Planetary Science Letters,

2016/17

EYE LENS RADIOCARBON DATING REVEALS CENTURIES OF LONGEVITY IN THE GREENLAND SHARK

Bayesian radiocarbon age modelling at the NRCF of eye lens protein from the Greenland shark (*Somniosus microcephalus*), an iconic species of the Arctic Seas, has shown that this is the world's oldest vertebrate. Dating of these organisms is tricky, because they do not have ear otoliths and generally lack hard body parts that provide sequential growth layers. Scientists therefore focused on dating eye protein because they are metabolically inert and once synthesised in the body, are not renewed any more. The availability of radiocarbon dates from a carefully isolated part of the proteins in growth order meant that Bayesian age modelling could be undertaken. The age ranges of pre-bomb sharks showed that they reached sexual maturity at least by 156 ± 22 years, and the largest animal (502 cm) was 392 ± 120 years old. The results showed that the Greenland shark is the longest-lived vertebrate known. The data raise concerns about the conservation of the Greenland shark, because they are commonly recovered as by-catch in arctic and subarctic groundfish fisheries.

REFERENCE: Nielsen, J., Hedeholm, R. B., Heinemeier, J., Bushnell, P. G., Christiansen, J. S., Olsen, J., Bronk Ramsey, C., Brill, R. W., Simon, M., Steffensen, K. F., & Steffensen, J. F. (2016). Eye lens radiocarbon reveals centuries of longevity in the Greenland shark (Somniosus microcephalus). *Science*, 353(6300), 702-704.

BISON PHYLOGEOGRAPHY AND THE ICE FREE CORRIDOR IN WESTERN CANADA

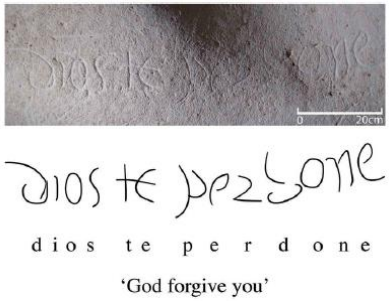
Evidence from bison fossils has been used to determine when an ice-free corridor opened up along the Rocky Mountains during the late Pleistocene. This has long been considered a potential route for human and animal migrations between the far north (Alaska and Yukon) and the rest of North America, but when and how it was used has long been uncertain. Using NRCF radiocarbon dating and DNA analysis to track the movements of bison into the corridor, the data showed that it was fully open by about 13,000 years ago. This suggests that the corridor could not account for the initial dispersal of humans south of the ice sheets, but could have been used for later movements of people and animals, both northward and southward. It appears far more likely that the initial southward movement of people into the Americas more than 15,000 years ago was by a

Pacific coastal route. The Rocky Mountains corridor remains of interest as a potential route for later migrations.

REFERENCE: Heintzman, P. D., Froese, J. W....& Shapiro, B. (2016). Bison phylogeography constrains dispersal and viability of the Ice Free Corridor in western Canada. *PNAS* 113 (29) 8057-8063.

DATING EARLY RELIGIOUS ENCOUNTERS IN THE NEW WORLD

The Carribean island of Mona has been the focus of new archaeological fieldwork led by Jago Cooper of the British Museum. The island was on a key Atlantic route from Europe to the Americas, and central to the 16th C Spanish colonial project. Columbus stopped at the island in 1494 on his second voyage. Island communities were therefore exposed to the earliest wave of European impacts. In 70+ subterranean caves on the island extraordinary evidence for these face-to-face encounters between the two groups has been found, including finger-fluted drawings, historic inscriptions, as well as numerous drawings of Christian symbols and graffiti, in Spanish, asking God to forgive the indigenes for their pagan icons (see figure). NRCF-funded radiocarbon dating (NF/2014/2/7) has been used to provide a context for objects, artefacts and charcoal rock art in the caverns, giving ages for the pre- as well as post-contact archaeology.



REFERENCE: Cooper, J., Samson, A. V. M., Nieves, M. A., Lace, M. J., Caamano-Dones, J., Cartwright, C., Kambesis, P. N., & Olmo Frese, L. D. (2016). The Mona Chronicle: the archaeology of early religious encounter in the New World. *Antiquity*, 90(352), 1054-1071.

CONTINUED NORTH ATLANTIC DEEP WATER FORMATION DURING THE LAST GLACIAL MAXIMUM

At present, the production of deep water in the north Atlantic Ocean forms the northern overturning limb of the global thermohaline circulation system; a mechanism by which heat is transported around the globe in the surface ocean, and by which carbon is stored in the deep ocean. Both of these have fundamental impacts on Earth's climate, and therefore understanding changes in this circulation, particularly during big climate shifts, is imperative to reconstructing past climate and forecasting future changes. The most recent such climate shift was the transition from the maximum of the last Glacial period to the Holocene, but despite its importance, the circulation in the glacial deep Atlantic Ocean and the mechanism by which it may have sequestered carbon remain elusive. In this work, cores were taken across virtually the whole Atlantic Ocean, north to south, to address the problem. Radiocarbon dating at NERC-RCF was central to providing a chronology for these cores, and neodymium isotopes were used to reconstruct the way water masses were moving in the glacial period. The researchers found that there was sustained production of North Atlantic Deep Water during the glacial period, meaning the deep Atlantic contained water sourced from the North. This directly contradicts the notion that the deep Atlantic was dominated by water from Antarctica during the glacial, and supports the idea of a deep, slowly overturning mass of water in the glacial North Atlantic, with longer residence times than in the modern North Atlantic. This stored a large amount of respired carbon in the deep Atlantic during the glacial, something which

resolves problems with understanding how CO_2 was stored in the oceans during this time, and provides a new explanation for the increase in atmospheric CO_2 at the end of the glacial, when carbon was flushed out of the deep ocean.

Supported by NERC-SC Allocation number 1752.1013

REFERENCE: Howe, J. N. W., Piotrowski, A. M., Noble, T. L., Mulitza, S., Chiessi, C. M. and Bayon, G. (2016). North Atlantic Deep Water Production during the Last Glacial Maximum. Nature Communications 7 doi:10.1038/ncomms11765.

GLOBAL SEA LEVEL RISE IS FASTER THAN ANY TIME OVER THE PAST 27OO YEARS

Global Sea Level (GSL) is rising, with potentially catastrophic impacts for the hundreds of millions living on low-lying and coastal land. However, we do not know exactly what the drivers of this rise are, and how much GSL rise we can expect for the different future scenarios of climate change included in the recent IPCC report. This project resulted in the first estimate of GSL change over the last ~3,000 years that is based upon statistical synthesis of a truly global database of regional sea-level reconstructions, the chronology for which was based on radiocarbon dates. The work showed that GSL in the 20th century rose faster than in any preceding century since at least 800 BCE. Temperature seems to have been a driver; for example, GSL decline over 1000–1400 CE coincided with ~0.2 °C of global cooling. Patterns in the western Atlantic were linked to weakening, strengthening, or polar migration of the Gulf Stream. Wind stress also may be an important driver. The estimates of GSL differ markedly from previous reconstructions, and reconcile differences between IPCC and model projections. Without global warming, GSL in the 20th century would have risen by up to 7 cm, rather than the ~14 cm observed. The path we follow in IPCC projections will determine the impacts on environment and society. For 2100 CE, high-end "business-as-usual" greenhouse gas emissions, moderate emissions abatement, and extremely strong emissions abatement give GSL rises of 52–131 cm, 33–85 cm, and 24–61 cm, respectively. Yet a reduction in 21st century sea-level rise of ~30 to 70 cm could be achieved by strong mitigation efforts, even though sea level is a particularly "slow responding" component of the climate system.

Supported by NERC grant NE/G003440/1.

REFERENCE: Kopp, R. E., Kemp, A. C., Bittermann, K., Horton, B. P., Donnelly, J. P., Gehrels, W. R., Hay, C. C., Mitrovica, J. X., Morrow, E. D. and Rahmstorf, S. (2016). Temperature-driven global sea-level variability in the Common Era. Proceedings of the National Academy of Sciences. doi:10.1073/pnas.1517056113

CHANGES IN VEGETATION COVER PROMOTE LOSS OF ANCIENT CARBON 'LOCKED UP' IN PEATLANDS

Northern peatlands are extremely important in the global carbon cycle, containing one third of the Earth's soil carbon stock since the last Ice Age. Now, these stores of ancient carbon 'locked up' in the peat are under threat from global warming, as the rate of peat ecosystem respiration (and hence release of carbon as CO_2) is accelerating. This stands to tip the balance between sequestration of carbon through plant growth versus CO_2 release from the soil, making northern peatlands a source of atmospheric CO_2. Climate warming is expected to increase ecosystem respiration but the magnitude of its impact will depend on additional factors that may themselves be temperature dependent. Ecosystem respiration is the largest land to CO_2 flux, accounting for more than half of all biospheric CO_2 emissions. Understanding the factors influencing ecosystem respiration in peatlands is therefore vital, and one factor about which almost nothing is currently known about is how changes in vegetation composition affect the source and age of respired CO_2. This is despite the fact that changes in plant communities have been observed in response to global warming. This novel project used *in situ* ^{14}C measurements based on technologies developed in the NERC-RCF on a warming and vegetation manipulation experiment. The researchers found that organic inputs from vascular plants can promote ancient peatland carbon release, and that warming of approximately 1 ℃ promotes respiration of ancient peatland carbon (up to 2100 years old). In particular, increases in dwarf-shrubs and graminoids led to decomposition of previously 'locked-up'ancient organic matter, and startlingly, that plant-induced peat respiration could contribute up to 40% of ecosystem CO2 emissions, something not currently factored in to global carbon cycle models. Ultimately, greater contribution of ancient carbon to ecosystem respiration may signal the loss of a previously stable peatland carbon pool, creating potential feedbacks to future climate change.

REFERENCE: Walker, T. N., Garnett, M. H., Ward, S. E., Oakley, S., Bardgett, R. D. and Ostle, N. J. (2016). Vascular plant presence promotes ancient peatland carbon loss under climate warming. Global Change Biology 22: 1880-1889. doi: 10.1111/gcb.13213. Supported by NERC-SC allocation number 1709.0413, a NERC CASE Studentship and NERC award NE/E011594/1

ARSENIC CONTAMINATION OF DRINKING WATER IN ASIA DEPENDS ON ORGANIC MATTER SOURCE

In south and southeast Asia, arsenic contamination of drinking water is a public health catastrophe, causing e.g. 20% of deaths in arsenic impacted areas of Bangladesh. There is an urgent need to predict locations and human activities that risk As contamination, as this is crucial for mitigating the effects of the current crisis, and preventing future As hazards. Our ability to do this is currently limited by our understanding of the As release process. While we know that the As source is in the Himalayas, and what biogeochemical process release As into groundwater from alluvial floodplains, identification of the source of organic matter (OM) that drives these processes remains unresolved, and even controversial. This study examined ground and surface waters at a known arsenic hotspot in Cambodia, in which radiocarbon of aqueous OM was used to determine groundwater residence times and provenance OM. The results show that As mobilization rates are controlled by the age of

dissolved groundwater OM. Arsenic concentrations in shallow groundwaters (<20 m) increase by 1 lg/l for every year increase in OM age compared to only 0.25 lg/l for every year increase in deeper (>20 m) groundwaters. It is shallow aquifers containing young OM that release the most As at present, but As-rich young, surface-derived OM is being naturally transported to depths of 44m in deep aquifers. Thus, both surface and deep aquifers are important in controlling As in Asian groundwaters. Transport of young OM into deep aquifers is exacerbated by the extensive pumping of groundwaters, and any human activities that alter the source and/or rate of groundwater recharge may affect the OM concentration, and therefore the shape and size of the current Asian arsenic hazard.

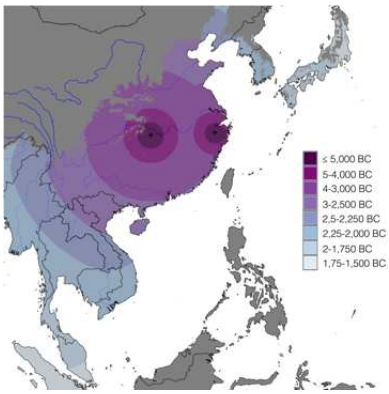
Supported by NERC-SC Allocation numbers 1411.0409, 1029.0403; NERC grants NE/D013291/1, NER/S/A/2006/-14038, KH/Asia-Link/04 142966

REFERENCE: Lawson, M., Polya, D. A., Boyce, A. J., Bryant, C. and Ballentine, C. J. (2016). Tracing organic matter composition and distribution and its role on arsenic release in shallow Cambodian groundwaters. Geochimica et Cosmochimica Acta 178: 160-177. doi:10.1016/j.gca.2016.01.010

2015/16

SPATIAL MODELLING OF THE GEOGRAPHICAL ORIGIN OF RICE CULTIVATION

Rice is a key global crop, feeding the majority of the world's population. Much research has been undertaken to understand the origin and dispersal of rice from its place of domestication in Asia, throughout the rest of the wider region, including southeast Asia and India. Many researchers now agree that the domestication process was protracted and that several thousand years elapsed during which people collected wild rice. Rice was domesticated some time in the middle Holocene. Silva and colleagues (2015) have used a modelling approach and multiple radiocarbon determinations to consider the most probably areas for origins of cultivated rice and its spread. A simple least-cost distance was used to fit to known occurrences of rice in time and space. Different models were built and tested against one another. The model that best fitted the data was a dual origin model, which posited two independent developments of rice in the Yangtze basin (see right). The authors suggest that the most likely scenario involves multiple domestication episodes rather than one or two.



Supported by NERC grant "The impact of evolving rice systems from China to Southeast Asia" (NE/G005540/1).

REFERENCE: Silva, F. et al. (2015). Modelling the geographical origin of rice cultivation in Asia using the Rice Archaeological Database. PLOS One, 10(1).

THE ROMAN AND ISLAMIC SPICE TRADE: NEW EVIDENCE

Tropical spices are of key importance in early trade and exchange networks. During the Roman and later Islamic periods the site of Quseir al-Qadim (on the Red Sea in modern Egypt) was active as a transport hub during both periods (ca. AD 1–250, known as Myos Hormos, and again during ca. AD 1050–1500, known as Kusayr). At least 7 tropical spices were recovered from excavations here directed by Marijke van der Veen of Leicester University and her colleagues. These included black pepper, ginger, cardamom, turmeric, fagara, myrobalan and

betelnut. The only spice employed in cuisine was pepper, the rest were all used in ritual, perfumery and medicine. Radiocarbon of individual identified seeds was undertaken by NRCF-Oxford to provide the chronology for the study. In both periods, spices were accessible only to the elite. This fuelled greater demand for spices from a wider section of society and gave rise to the early modern expansion of the spice trade. In pursuit of this growing trade new relationships were forged, political power struggles occurred and people became entangled in a complex mesh of new relationships. One can see the origins of modern globalisation in this ancient rush to open new trade markets for spices.

Supported by NERC grant NER/A/S/2003/00336.

REFERENCE: Van der Veen, M., & Morales, J. (2015). The Roman and Islamic spice trade: new archaeological evidence. Journal of Ethnopharmacology, 167, 54-63.

UPPER PALAEOLITHIC GENOMES REVEAL DEEP ROOTS OF MODERN EURASIANS

New genetic sequencing of a 13,300 years old and 9,700 years old males from western Georgia has revealed that Caucasus hunter-gatherers (CHG) belong to a distinct ancient clade that split from western hunter-gatherers ~45 kya, shortly after the expansion of anatomically modern humans into Europe. The CHG genomes significantly contributed to the Yamnaya steppe herders DNA who migrated into Europe ~3,000 BC. This data supports a formative Caucasus influence on this important Early Bronze age culture. The Caucasus has left a strong genetic imprint on modern populations from this region and also in central and south Asian populations too. This might well mark the arrival of Indo-Aryan languages. CHG genes represent a fourth ancestral component of the European gene pool (see right) and underscores again the importance of dense geographical sampling for human palaeogenomes.

REFERENCE: Jones, E. P. et al. (2015). Upper Palaeolithic genomes reveal deep roots of modern Eurasians. Nature Communications, 6.

LOCKING AWAY ARCTIC SOIL CARBON

Almost twice as much carbon is stored in Arctic soil, as frozen plant remains, as in the atmosphere. If the soils warm, this carbon can be released as greenhouse gases (carbon dioxide, CO_2, and methane) to the atmosphere, and contribute to warming of Earth's climate. However, some of the soil organic carbon can be eroded and transferred to rivers. If it is not converted to CO_2 during river transport it can eventually reach the sea and become buried in marine sediments. In this case, the carbon can be locked away for millions of years. Knowing the extent to which this happens is important as it is part of the global carbon cycle, and for predicting the possible effects of northern soil warming on climate. Radiocarbon and stable carbon and nitrogen isotopes were measured in sediment samples from one of the largest rivers in the Arctic, the Mackenzie River of Canada to work out that most of the eroded organic carbon ranged from recent to about 8,000 years old, with smaller amounts from very old carbon from rocks. The amount of carbon eroded from soils and transported by the Mackenzie River was calculated to be 2.2 million tonnes of carbon per year. Sediments collected from a core offshore indicated that the terrestrial carbon is rapidly buried in the sediments of the Arctic Ocean. This process will contribute to stabilising the Earth's CO_2 levels over thousands of years, but is not enough to counter CO_2 from burning fossil fuels. It is also about 10-20 times too slow to offset the predicted release of CO_2 if the frozen soils thaw over the next 100 years. The international collaboration was supported by NERC, WHOI Arctic Research Initiative, an Early Career Research Grant by the British Society for Geomorphology, a Royal Society University Fellowship, and a grant from the US National Science Foundation.

REFERENCE: Hilton, R. G., Galy, V., Gaillardet, J., Dellinger, M., Bryant, C., O'Regan, M., Gröcke, D. R., Coxall, H., Bouchez, J. and Calmels, D. (2015). Erosion of organic carbon in the Arctic as a geological carbon dioxide sink. Nature 524(7563): 84-87.

1000 YEARS OF GREAT EARTHQUAKES IN SOUTH CENTRAL CHILE

Earthquakes and tsunamis caused by the release of stress in subduction zones, where a tectonic plate is thrust beneath another plate, pose significant risks to human populations. The potential for great earthquakes in Chile is well known and the 1960 Valdivia, Chile earthquake remains the largest seismically recorded earthquake (magnitude of 9.5) and caused local and trans- Pacific tsunamis. Although historical records provide some understanding of mechanisms and frequency of geohazards in subduction zones, a geological approach to understanding the timing and characteristics of past earthquakes over a longer timescale is essential for assessing future hazards related to subduction zones. Understanding how well the geological records can record past earthquakes and tsunamis is key to this and the Chilean subduction zone is an important area to examine palaeoseismic modelling. A 1000 year sediment record of megathrust earthquakes and tsunamis from the coast at Chucalén south central Chile was compared with historical records. By examining changes in sediment/soil and which types of diatoms occurred (comparing them with those found in modern environments) in coastal marshes, evidence of uplift or subsidence, tsunamis and relative sea-levels were modelled. The results showed net relative sea-level rise over the last millennium. Radiocarbon dates of plant remains were used to determine the timing of changes in the record. Although the geological record from Chucalén did not show as many great earthquakes (magnitude ≥8.0) as the historical record this is consistent with hypothesised spatial variability in earthquake rupture zones. The results demonstrated the potential and possible future refinements of using palaeoseismic modelling in this area.

REFERENCE: Garrett, E., Shennan, I., Woodroffe, S. A., Cisternas, M., Hocking, E. P. and Gulliver, P. (2015). Reconstructing paleoseismic deformation, 2: 1000 years of great earthquakes at Chucalén, south central Chile. Quaternary Science Reviews 113: 112-122.

6,000 YEAR RECORD OF THE NORTH AMERICAN MONSOON

The North American Monsoon (NAM) provides up to 60% of annual precipitation within its core region of Mexico and the southwest USA and is vital to sustaining agriculture, industry and biodiversity. Climate change projections for the NAM region suggest that both increased temperatures and reduced precipitation are likely in the coming century. Understanding past NAM variability and how it is controlled are essential for predicting future changes. In regions affected by the NAM records of lake sediment components which can be linked with precipitation change can be used to identify both the long term evolution of the NAM and its variability under different climatic conditions. Sedimentary titanium concentrations compared with observational, instrumental and historical records through the last 2000 years indicate inwash of sediment to Laguna de Juanacatlan, Mexico are controlled by rainfall amount, mainly due to summer rainfall in the lake's catchment, and so titanium concentrations could be used to reconstruct past NAM rainfall variability. A high resolution timescale was provided combining very fine scale measurements of titanium and using radiocarbon and radiocaesium dating of the lake sediment. The lake records indicated a shift to predominantly Pacific climatic influence of the NAM between 4,000 and 3,000 years ago, giving rise to the present day climatic controls in this region.

REFERENCE: Jones, M. D., Metcalfe, S. E., Davies, S. J. and Noren, A. (2015) Late Holocene climate reorganisation and the North American Monsoon. Quaternary Science Reviews 124: 290-295.

GRASS ROOTS MAGNIFY SOIL CO_2 RELEASE

Soils are the largest store of the world's terrestrial carbon, containing about four times as much carbon as in the atmosphere. Knowing whether higher atmospheric carbon dioxide (CO_2) concentrations increase soil carbon by stimulating plant productivity or decrease soil carbon due to temperature-driven increases in soil organic carbon decomposition rates, is crucial to predictions of future climate. Many studies have investigated microbial mineralisation of soil organic carbon to CO_2 but most of these have been on soil without growing plants, because interpreting results with added CO_2 fluxes from below ground respiration root systems of growing plants is complicated. The NRCF-E designed zeolite molecular sieve field system was used at the Bangor University Henfaes Experimental Station to collect respired CO_2 from plots with growing plants (grass swards) and those with no plants. The effect of a $3^{o}C$ increase in temperature on respiration from soils was examined. Radiocarbon results from sampling intervals over a year helped to estimate the carbon sources and changes in proportion of recent carbon and older soil organic carbon. The presence of plants in grass swards more than doubled the effect of warming on the rate of mineralisation of soil organic carbon, with an estimated mean carbon age of ca. 8 years or older relative to incubated soils without recent plant inputs. These results not only illustrate the complexity of mechanisms controlling carbon fluxes in soils but also suggest that the dual biological and physical effects of CO2 on primary productivity and global temperature have the potential to synergistically increase the mineralisation of existing soil carbon.

REFERENCE: Hill, P. W., Garnett, M. H., Farrar, J., Iqbal, Z., Khalid, M., Soleman, N. and Jones, D. L. (2015). Living roots magnify the response of soil organic carbon decomposition to temperature in temperate grassland. Global Change Biology 21: 1368-1375.

2014/15

SPATIO-TEMPORAL MODELLING OF NEANDERTHAL DISAPPEARANCE

Neanderthals and modern humans were both living in Europe for between 2,600 and 5,400 years. This is the key conclusion of a large NERC-funded study published this past year in the journal *Nature*. For the first time, a robust chronology for when the last Neanderthals died out. Significantly, the data suggest that Neanderthals disappeared at different times across Europe rather than being rapidly replaced by modern humans all at once. The Oxford team, led by Professor Tom Higham, obtained fresh radiocarbon dates from over 400 samples of bone, charcoal and marine shell from 40 key European Palaeolithic archaeological sites. The sites, ranging from Russia in the east to Spain in the west, were either associated with the Neanderthal tool-making industry, known as Mousterian, or were 'transitional' sites containing stone tools also associated with early modern humans. The chronology was pieced together by building mathematical models that combine the new radiocarbon dates with established archaeological evidence. The results showed a 95% probability that both groups were contemporaneously living in Europe for a significant period, giving ample time for interaction and interbreeding. The data suggest some complexity in the ages of the earliest modern human industry known in Europe (the Uluzzian, found in Italy) and the final industries associated with Neanderthals that are found archaeologically suggesting that between 45-40 ka BP there was a mosaic of human populations across Europe.

REFFERENCE: Higham and 49 others. 2014. The timing and spatiotemporal patterning of Neanderthal disappearance. Nature 512(7513): 306-9.

THE OPENING AND CLOSING OF THE BERING STRAIT AND PLEISTOCENE MIGRATION TO THE NEW WORLD

Human colonization of the New World is generally believed to have entailed migrations from Siberia across the Bering isthmus. However, the limited archaeological record of these migrations means that

details of the timing, cause and rate remain cryptic. Work funded by the NRCF based on a combination of ancient DNA, ^{14}C dating, hydrogen and oxygen isotopes, and collagen sequencing has been used to explore the colonization history of one of the few other large mammals to have successfully migrated into the Americas at this time: the North American elk, also known as wapiti. Meiri et al. (2014) identified a long-term occupation of northeast Siberia, far beyond the species's current Old World distribution. Migration into North America occurred at the end of the last glaciation, while the northeast Siberian source population became extinct only within the last 500 years. This finding is congruent with a similar proposed delay in human colonization, inferred from modern human mitochondrial DNA, and suggestions that the Bering isthmus was not traversable during parts of the Late Pleistocene. These new data imply a fundamental constraint in crossing Beringia, placing limits on the age and mode of human settlement in the Americas, and further establish the utility of ancient DNA in palaeontological investigations of species histories. A total of 32 samples were funded by NRCF and these provide an anchor for the DNA Bayesian skyline models and analysis published the paper below.

REFERENCE: Meiri, M. & others. (2014). Faunal record identifies Bering isthmus conditions as constraint to end-Pleistocene migration to the New World. Proceedings of the Royal Society B: Biological Sciences, 281(1776), 20132167.

THE ARCHAEOLOGICAL SEQUENCE OF NIGERIA, FROM 1500 BP

The NRCF has funded several applications for support to work in the archaeology of Nigeria, a region of key importance for African archaeology, but one that has suffered from a dearth of effective archaeological science, post-excavation work and in particular chronology building. Anne Haour and her collaborators have been working to change this, in an area of northern Nigeria that is, in a sense *terra incognita* for this type of work. There are no radiocarbon labs in Nigeria and much excavated material is never properly analysed in post-excavation. This is a great pity because Nigeria boasts a particularly rich archaeological heritage and there is much that needs to be done to place it within its wider political and social framework, particularly over the recent millennia. Trade and exchange across large tracts of western Africa was widely practised since the Iron Age but little definitive is known about it or has been published. A few new radiocarbon dated sites make a huge difference in a region where there are few, if any, reliable chronometric dates. The support of the NRCF for researchers working in Nigeria is a significant help to understanding the prehistoric sequence there.

REFERENCE: Sule Sani, A., & Haour, A. (2014). The archaeology of northern Nigeria: trade, people and polities, 1500 BP onwards. Azania, 50, 1- 24.

DOES PEATLAND DRAINAGE CAUSE CARBON LOSS?

Human impact on peatlands, including drainage, burning, land conversion for agriculture, timber, and biofuel production, cause loss of peat-forming vegetation. Carbon sequestration and storage in peatlands requires high water tables and associated anaerobic conditions leading to slow decomposition. Peatland disturbance can expose previously anaerobic peat to much faster aerobic decomposition, which can shift peatlands from net CO_2 sinks to large CO_2 sources, releasing carbon held for millennia. Peatlands also export significant quantities of carbon via fluvial pathways, mainly as dissolved organic carbon (DOC). In undisturbed peatlands this is largely from recently photosynthesised carbon. Radiocarbon levels in DOC in drainage water from multiple peatlands in Europe and Southeast Asia were used to infer differences in the age of carbon lost from intact and drained systems. In most cases, drainage led to increased release of older carbon from the peat profile but with marked differences related to peat type and a gradient of peatland sensitivity to drainage, with tropical peat>fen>raised bog>blanket bog. Runoff from drained tropical peatlands indicated loss of very old (centuries to millennia) stored peat carbon whereas high-latitude peatlands (eg upland UK blanket bogs) appeared more resilient to drainage. Higher peat surface temperatures, burning of surface peat, loss of natural vegetation cover, and other drainage-related disturbances also appeared to exacerbate carbon loss. The results emphasize the general susceptibility of peatlands to drainage and

other anthropogenic degradation, but also highlight the apparently greater vulnerability of tropical peatlands. Active drainage of northern peatlands is generally decreasing, and in some areas is now being reversed through rewetting and restoration, whereas tropical peatlands remain under severe and ongoing pressure, particularly in Southeast Asia, as demands to drain and clear forest land for agriculture and large-scale plantations intensify.

REFERENCE: Evans, C. D., Page, S. E., Jones, T., Moore, S., Gauci, V., Laiho, R., Hruška, J., Allott, T. E. H., Billett, M. F., Tipping, E., Freeman, C. and Garnett, M. H. (2014). Contrasting vulnerability of drained tropical and high-latitude peatlands to fluvial loss of stored carbon. Global Biogeochemical Cycles 28(11), 1215-1234.

SEA LEVEL CHANGE OVER THE PAST 2000 YEARS

Understanding how sea level has varied in the last few thousand years is important for several Reasons, including 1. Sea-level variability records the net effect of changes in polar ice sheets, mountain glaciers and ocean-atmospheric processes. 2. Long-term trends in sea level provide insights into past climate variability. 3. Past sea-level records can be used to test and develop models of ice-sheet response to climate change and models of glacial isostatic adjustment (rebound of landmasses after glaciations, following depression by ice sheets). There are few precisely dated, continuous records of sea-level change covering the last 2000 years, but those from low energy salt-marsh deposits that fringe mid latitude coastlines are especially useful. Establishing the significance of forcing factors affecting sea level requires additional records from the North Atlantic and beyond. Radiocarbon data from salt marsh deposits in north west Scotland, UK and the eastern North Atlantic provided a timescale for the first continuous 2000 year long records of relative sea level change in these areas. Sea level was reconstructed by comparing the foraminifera and diatoms found at different levels in the salt marsh deposits and assigning these to conditions in which the same organisms are found today. The records showed that relative sea level has been stable (±0.4 m) during the last two millennia**.** The most recent change in the organisms found in the records indicated a regional tendency to marine conditions and that 20th century sea-level acceleration in north west Scotland may have exceeded the rate of background relative sea level fall (0.4 mm yr^{-1}), but the signal was muted and later than in the western North Atlantic**.** These regional differences between sea-level histories on both sides of the North Atlantic provide important clues to identify underlying driving mechanisms.

REFERENCE: Barlow, N. L. M., Long, A. J., Saher, M. H., Gehrels, W. R., Garnett, M. H. and Scaife, R. G. (2014). Salt-marsh reconstructions of relative sea-level change in the North Atlantic during the last 2000 years. Quaternary Science Reviews 9, 1-16.

WESTERN ANTARCTIC ICE SHEET CHANGES

Fully understanding controls on recent ice sheet changes and predicting their future responses requires an assessment of the duration, timing and forcing of past ice sheet retreat. Such assessment is particularly needed for the Amundsen Sea sector of the West Antarctic Ice Sheet (WAIS), where glaciers have thinned and retreated dramatically over the past 20 years and now account for >35% of its total discharge. There are concerns that large-scale glacier collapse is possible on human timescales. Complete collapse of the glaciers in this region would raise global sea level by ~1.5 m and although this remains a possibility, recent estimates suggest that melting of the region's Pine Island Glacier alone would contribute 3.5–10 mm over the next 20 years. Using marine geological data and an extensive new radiocarbon dataset from the eastern Amundsen Sea Embayment this study characterised the retreat of the WAIS since the Last Glacial Maximum and assessed the significance of these changes. Deglaciation of the outer shelf was underway before 20,600 calibrated years before present (cal yr BP), reaching the mid-shelf by 13,575 cal yr BP and the inner shelf to within ca. 150 km of the present grounding line by 10,615 cal yr BP. The timing of retreat is broadly consistent with previous studies in the eastern and western Amundsen Sea Embayment and provides new constraints for ice sheet models. Despite revealing these broad scale trends, the current dataset does not capture

detailed changes in ice flow, such as stillstands and possible readvances as depicted in the geomorphological record and highlights the need for additional marine geological data from the area in order to improve ice sheet models and investigate the mechanisms responsible for forcing ice sheet retreat.

REFERENCE: Smith, J. A., C.-D. Hillenbrand, Kuhn, G, Klages, JP, Graham, AGC, Larter, R D, Ehrmann, W, Moreton, S G, Wiers, S, Frederichs, T (2014). New constraints on the timing of West Antarctic Ice Sheet retreat in the eastern Amundsen Sea since the Last Glacial Maximum. Global and Planetary Change 122 224-237

WATER TREATMENT OF DISSOLVED ORGANIC MATTER

Pressure on water resources has led to the need to utilise water with higher organic matter concentrations. Increased dissolved organic carbon concentrations have been observed in rivers draining peatlands. Evidence from numerous rivers shows riverine DOC as relatively 'young' in radiocarbon age and rivers acting as organic carbon processors, with microbial decomposition of previously unavailable soil carbon. Water treatment involves physico-chemical processes to remove organic matter, which help to minimise the formation of potentially carcinogenic disinfection by-products and microbial regrowth. The energy consumption of treating water (including waste water) has increased significantly in the last 30 years, globally emitting an estimated annual 1.21 Pg CO_2e yr^{-1}, equivalent to approximately 3.6% of annual anthropogenic carbon emissions. Understanding how organic matter is changed through the treatment processes can provide insight into the treatment efficiency. For the first time stable carbon isotopes and radiocarbon measurements of dissolved organic carbon were used to characterise dissolved organic matter through a water treatment works. This showed that new sources of organic carbon were added during the treatment processes, and that treated water is isotopically lighter and typically younger in radiocarbon DOC age than untreated water.

REFERENCE: Bridgeman, J., Gulliver, P., Roe, J. and Baker, A. (2014). Carbon isotopic characterisation of dissolved organic matter during water treatment. Water Research 48(0): 119-125. Carbon isotopes in dissolved organic matter during water treatment are measured for the first time, reveal carbon addition during drinking water treatment, implications for energy use.

MOUNTAINS AS SOURCES OR SINKS OF CARBON

A major source of carbon dioxide (CO_2) to the atmosphere occurs when oxygen reacts with ancient, organic carbon within rocks and may counter sequestration through burial of new organic carbon in sediments. Previous work has suggested the CO_2 release will be significant in mountain belts where erosion exposes rocks rapidly but this 'mountain respiration' has never before been quantified. CO_2 release across the mountain belt of Taiwan was quantified using the element rhenium as a proxy to track organic carbon oxidation from rocks and radiocarbon measurements were used to quantify oxidation of rock- derived organic carbon in soils. Erosion rate sets the pace of CO_2 emissions by mountain respiration but overall Taiwan acts as a CO_2 sink through erosion of organic carbon from the terrestrial biosphere, its fluvial transport and marine burial off-shore. Mountain building in Taiwan presently acts as an organic carbon sink, sequestering atmospheric CO_2 during weathering and erosion.

REFERENCE: Hilton, R. G., J. Gaillardet, et al. (2014). Geological respiration of a mountain belt revealed by the trace element rhenium. Earth and Planetary Science. Letters 403, 27-36.

2013/14

ANCIENT DNA OF THE RED DEER

How different fauna reacted to the intense warm and cold cycles of fluctuating climate in the Pleistocene of Eurasia is a major topic of debate. In Europe, a model of an expansion–contraction has been proposed, wherein temperate species were restricted to southern refugia during glacial times and expanded northwards during interglacials, including the present interglacial (Holocene). Meiri et al. tested this model on the red deer by applying radiocarbon AMS dating, and examining both modern and ancient mitochondrial DNA over the last c. 40 000 years. The results suggested that the species was sensitive to the effects of climate change. Prior to the Last Glacial Maximum (LGM) haplogroups restricted today to South-East Europe and Western Asia reached as far west as the UK. During the LGM, red deer were mainly restricted to southern refugia, in Iberia, the Balkans and possibly in Italy and South-Western Asia. At the end of the LGM, red deer expanded from the Iberian refugium, to Central and Northern Europe, including the UK, Belgium, Scandinavia, Germany, Poland and Belarus. Ancient DNA data cannot rule out refugial survival of red deer in North-West Europe through the LGM. Had such deer survived, though, they were replaced by deer migrating from Iberia at the end of the glacial. The Balkans served as a separate LGM refugium and were probably connected to Western Asia with genetic exchange between the two areas.

REFERENCE: Meiri, M., Lister, A. M., Higham, T. F.G, Stewart, J. R., Straus, L. G., Obermaier, H., Gonzalez Morales, M. R., Marin-Arroyo, A. B., & Barnes, I. (2013). Late-glacial recolonization and phylogeography of European red deer (Cervus elaphus L.). Molecular ecology, 22(18): 4711-4722.

GENETIC STRUCTURE AND RANGE OF MAMMOTHS IN EURASIA

New insights into the history of the wooly mammoth have been obtained in a recent study using mtDNA analysis supported by AMS dating provided through the NRCF. A previously undocumented major mtDNA mammoth lineage dating to 32-34 ka BP was identified for the first time. The research showed strong evidence for major demographic expansions in mammoth populations at 121 ka BP and a very significant population size decline after 20-15 ka BP. Radiocarbon age distributions (right) show the three major clades in different colours, and their spatial distribution through time across Eurasia. The general presence of mammoth fossils in the geoarchaeological record has been taken to represent a fairly stable and abundant species. Palkopoulou et al. suggest that this is not the case, and there is a picture emerging that shows the species was highly dynamic in population terms. Both genetic data and the radiocarbon record indicate a dramatic final demographic decline at the end of the last glaciation.

REFERENCE: Palkopoulou, E., Dalen, L., Lister, A. M., Vartanyan, S., Sablin, M., Sher, A., Edmark, V. N., Brandstrom, M. D., Germonpre, M., Barnes, I., & others. (2013). Holarctic genetic structure and range dynamics in the woolly mammoth. Proceedings of the Royal Society B: Biological Sciences, 280(1770): 20131910.

DATING THE AGE OF NEANDERTHAL DISAPPEARANCE IN IBERIA

One of the major questions in palaeoanthropology is the date of the disappearance of Neanderthals. Southern Iberia has always been considered one of the last refugia of this human species up to around 36 ka calBP. In contrast, to the north of the valley the Mousterian disappears shortly before the Proto-Aurignacian appears at ca. 42 ka calBP. The latter is most likely produced by anatomically modern humans. However, two-thirds of dates from the south are radiocarbon dates, a technique that is particularly sensitive to carbon contaminants of a younger age that can be difficult to remove using routine pretreatment protocols. Wood and colleagues using funding from NERC tested the reliability of chronologies of 11 southern Iberian Middle and early Upper Palaeolithic sites. Only two, Jarama VI and Zafarraya, were found to contain material that could be reliably dated. In both sites, Middle Palaeolithic contexts were previously dated by radiocarbon to less than 42 ka calBP. Using ultrafiltration to purify faunal bone collagen before radiocarbon dating, ages at least 10 ka years older were obtained. The authors concluded that unless rigorous pretreatment protocols have been used, radiocarbon dates should be assumed to be inaccurate until proven otherwise in this region. Evidence for the late survival of Neanderthals in southern Iberia is limited to one possible site, Cueva Antón, and alternative models of human occupation of the region should be considered.

REFERENCE: Wood, R. E., Barroso-Ruiz, C., Caparros, M., Pardo, J. J. F., Santos, B. G., & Higham, T. F. (2013). Radiocarbon dating casts doubt on the late chronology of the Middle to Upper Palaeolithic transition in southern Iberia. PNAS 110(8): 2781-2786.

OLD CARBON RELEASED FROM DISTURBED TROPICAL PEATLANDS

Tropical peatlands contain one of the largest pools of terrestrial organic carbon, amounting to about 89 billion kilograms. Over half of this carbon store is in Indonesia, where human impact in the form of deforestation, drainage and fire result in this terrestrial carbon being a globally significant source of atmospheric carbon dioxide. In this NERC studentship study radiocarbon results and flux measurements of dissolved & particulate organic carbon in rivers draining areas of intact and drained Indonesian peat swamp forest (PSF) revealed that in undisturbed areas carbon leached from the peat into rivers is from recent plant growth, whereas human disturbance of peatlands released old carbon from deep within the peat. An estimated 32% increase in carbon flux in rivers from South East Asia since 1990 has been caused by peatland disturbance. Such carbon losses need to be included within guidelines for the measurement, reporting and verification of carbon emissions and in order to inform land use management (for example regional forest destruction in Indonesia by the oilpalm biofuel industry).

REFERENCE: Moore S., Evans C.D., Page S.E., Garnett M.H., Jones T.G., Freeman C., Hooijer A., Wiltshire A.J., Limin S.H., Gauci V. (2013). Deep instability of deforested tropical peatlands revealed by fluvial organic carbon fluxes. Nature 493: 660-664

MECHANISMS FOR ARSENIC CONTAMINATION OF GROUNDWATERS

Over 100 million people in South and South East Asia drink shallow groundwater containing geogenic arsenic at concentrations hazardous to human health. It is known that arsenic can be released from solid iron oxides to groundwaters under anaerobic conditions. Breakdown of organic carbon by microbes is widely considered to be critical to this process. It remains controversial whether organic carbon can be drawn down from ponds into aquifers by significant pumping of groundwater for irrigation and be involved in the release of arsenic. In this NERC CASE studentship project (M Lawson) radiocarbon in sediment organic matter, dissolved inorganic carbon and organic carbon,

along with other geochemical data, showed that pond-derived organic carbon is transported to depths of up to 50 m even in an arsenic-contaminated aquifer in Cambodia thought to be minimally disturbed by groundwater pumping. In contrast, in the extensively exploited groundwaters of West Bengal, pond-derived organic carbon is transported to over 100 m in the aquifer. Intensive pumping of groundwaters may drive increases in the groundwater arsenic hazard in this region by increasing the contribution of bioavailable pond-derived dissolved organic carbon drawn into these aquifer systems and transporting it to greater depths than would operate under natural flow conditions.

REFERENCE: Lawson, M., Polya, D. A., Boyce, A. J., Bryant, C., Mondal, D., Shantz, A. and Ballentine, C. J. (2013). Pond-Derived Organic Carbon Driving Changes in Arsenic Hazard Found in Asian Groundwaters. Environmental Science and Technology 47(13): 7085-7094.

LANDSLIDE EVENTS FROM THE SOUFRIERE HILLS VOLCANO

The Soufriere Hills volcano in Montserrat has been erupting since 1995, with a lave dome building up and then collapsing, causing avalanches of hot rock and gas (pyroclastic flows). Instability in the volcano's lava dome can also lead to large landslide events, called mass flows, with large amounts of this material being deposited in the surrounding ocean. Such mass flows on volcanic islands can be highly dangerous locally and may generate tsunamis that threaten a wider area. In order to understand their frequency, how they are deposited and the relationship to volcanic eruption cycles, mass flows were identified in sediment cores spanning the past 110ka from the sea around Montserrat. Radiocarbon analysis of foraminifera in the marine sediment enabled the determination of timing and emplacement of the landslide deposits to be determined over the past 44ka and showed that mass flows happened during times of eruption but also when the volcano was thought to be dormant.

REFERENCE: Trofimovs, J., Talling, P. J., Fisher, J. K., Sparks, R. S. J., Watt, S. F. L., Hart, M. B., Smart, C., Le Friant, A., Cassidy, M., Moreton, S. G. and Leng, M. J. (2013). Timing, origin and emplacement dynamics of mass flows offshore of SE Montserrat in the last 110 ka: implications for landslide and tsunami hazards, eruption history, and volcanic island evolution. Gcubed 14(2): 385-406.

VARIATIONS IN EL NINO SOUTHERN OSCILLATION

The El Nino Southern Oscillation (ENSO) refers to the 2-7 year oscillations in temperature of the tropical eastern Pacific Ocean i.e. the coupled warm, oceanic phase (El Nino) and cold phase (La Nina) and in air surface pressure in the tropical western Pacific. After the solar cycle, ENSO is the largest cause of climate variability, causing redistribution of global heat and moisture fluxes. The impacts of ENSO, particularly of strong El Nino events, are wide-ranging and significant for ecosystems, societies and economies, for example reduced agricultural yields, droughts and floods, increased tropical cyclone frequency, fishery collapse and forest fires. The response to anthropogenic increase in atmospheric CO_2 is also largely unknown. Predicting future ENSO behaviour through climate models is made difficult by the lack of clear understanding of the relationship between ENSO variability and long-term changes in Tropical Pacific oceanography. Radiocarbon analysis of foraminifera from a sediment core from the Equatorial Pacific provided a timescale over the past 22,000 years, with which to interpret geochemical data from foraminiferal shells. The geochemical data enabled reconstruction of temperature variations of subsurface waters near the Galapagos Islands, a location central to ENSO activity. The results showed a strong negative correlation between ENSO variability and east to west temperature gradients in the tropical Pacific Ocean. Given the prediction for a decrease in temperature gradients in tropical Pacific in the future this would also suggest enhanced ENSO variability in response to global warming.

REFERENCE: Sadekov, A. Y., Ganeshram, R., Pichevin, L., Berdin, R., McClymont, E., Elderfield, H. and Tudhope, A. W. (2013). Palaeoclimate reconstructions reveal a strong link between El Nino-Southern Oscillation and Tropical Pacific mean state. Nat Commun 4. 1442.1009. 10.1038/ncomms3692