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Vegetation Dynamics of the Rainforests of Vava'u, Kingdom of Tonga

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The objectives of this study are to document the history of the rainforests of the Kingdom of Tonga and to understand the role that prehistoric people have played in the development of Tonga's modern vegetation. Tropical islands are ideal places to study and isolate the effects of human impacts because their ecological systems are particularly vulnerable and the effects are often irreversible. Paleoecological records from Tonga document: (1) changes in lowland rainforests over the past 7000 years; (2) a mid-Holocene sea level highstand from 4600 to 2600 years ago; and (3) the extensive burning of the rainforests of Vava'u beginning about 3000 years ago.

Lowland rainforest surrounded Ngofe Marsh on the island of Uta Vava'u, Vava'u, Tonga between 7000 and 3000 years ago. The most abundant pollen taxa represented in this period are rainforest trees and shrubs, including *Maniltoa*, Elaeocarpaceae, *Alphitonia*, *Melastoma*, Sapotaceae, Mytraceae and Papillionaceae. In addition, small amounts of Anacardiaceae (*Pleiogynium* and *Rhus*), *Dysoxylum*, and *Garuga* pollen are found. Several of these rainforest taxa abundant in the record between 7000 and 3500 years ago, including *Maniltoa*, Sapotaceae, Myrtaceae, Elaeocarpaceae and Papillionaceae, are much less frequent after 2000 years ago. In addition, herbaceous pollen becomes more common after 3500 years ago, suggesting that the forest was more open then. Two coastal forest taxa become more abundant after 3500 (*Cocos*) and 1100 (*Pandanus*) years ago. These changes in the vegetation are most likely related to Polynesian influences.

The coastal wetland of Avai' o 'Vuna on Pangaimotu Island, Vava'u documents a higher sea level between 4600 and 2600 years ago when marine bivavles were deposited between terrestrial sediments. This interpretation is in agreement with the timing for a mid-Holocene sea level highstand between 6000 and 3000 years ago documented for the Ha'apai Group, Tonga.

Changes in tropical rainforest vegetation on the tropical islands of Vava'u, Kingdom of Tonga reflect human alterations following the arrival of Polynesians. Significant increases in microscopic charcoal particles appear in sediments deposited after 3000 years ago, suggesting the rainforests of Vava'u were not burned prior to that time.

Vegetation Changes for the last 14 centuries in Western Equatorial Africa deduced from high-resolution pollen record of Lake Kamalété, Central Gabon

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The past 1410 ^{14}C yrs vegetation changes in western equatorial Africa are reconstructed using a high resolution pollen record collected in the Lake Kamalété located in the mosaic of forest-savanna of Lopé Reserve (0°43'S, 11°46'E), centre of Gabon. Our pollen data indicate that, over the past 14 centuries, the floristic composition of the rainforest has significantly varied, whereas savanna areas show low and uniform fluctuations. Three distinct successive stages of the forest dynamics have been identified. At 1410 yr B.P. the establishment of the mature moist semi-evergreen rainforest, related to forest colonization of savanna areas around the lake is evidenced by high pollen percentages of the mature forest trees. From *ca.* 1360 to 500 yr B.P., a sharp decrease of

pollen percentages of these mature forest trees and a noticeable increase of the shade intolerant plant species indicate an opening of forest cover. The persistence of gap-coloniser species, as *Macaranga*, *Tetrorchidium* and *Musanga* for several centuries in the rainforest is explained by recurring disturbances in the composition of the canopy associated to perturbations of water budget. These hydrological changes may be related to shorter and repeated dry episodes, probably entailing a drier and/or a longer dry season than today, as evidenced by the notable presence of *Celtis* and *Bosqueia angolensis*, both indicators of semi-deciduous forests. At 500 yr B.P., the mature forest increased. This last forest expansion corresponding to new savanna colonization and correlated with lithological evidence of an increase of the water lake-level, indicate the beginning of the modern humid period.

Pollen analysis of dung deposits in a desert and Late Quaternary vegetation and climate in Namibia

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Due to the scarcity of lakes and wetlands in the arid south-west African region palaeoclimatic reconstructions are difficult because conventional pollen analysis is generally not possible. However, shelters in rocky outcrops in the region yielded hyrax and other dung deposits rich in pollen grains ranging as far back as 30 000 yr BP. While several radiocarbon dates are available pollen analyses of these deposits are in progress. At this stage the results promise to provide some potentially high resolution pollen sequences from the Holocene as well as clues about longer-term vegetation changes and climatic conditions in the desert during the Late Pleistocene. Preliminary results indicate that cool shrubby elements spread to the northern Namib during the Last Glacial Maximum. Questions can provisionally be addressed about 1) conditions in the Namib during the last Glacial period, 2) the source and nature of "fynbos" elements recorded previously in offshore sediments along the Northern Namibian coast during this period (Shi et al., 1998), and 3) Holocene climate conditions and human presence in the light of observed settlement history (Kinahan, J., 2000).

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Session h5

LONG CONTINENTAL RECORDS: THE DEVELOPMENT OF "GROUND TRUTH" FOR THE MARINE OXYGEN ISOTOPE CHRONOLOGY

Long pollen records from northern California and southern Oregon, U.S.A.

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Long sedimentary sequences are common in northern California and southern Oregon as a result of regional tectonic extension of the northwestern Great Basin over the past several million years, and in response to

the tectonic development of the northern Coast Ranges driven by the evolving San Andreas Fault System. Long pollen records (>10^5 yr) have been recovered from tectonic depressions in the northern Coast Range, the upper Klamath basin, and the northern Sierra Nevada.

In the northern Coast Range, the pollen record from Clear Lake spans the last full glacial cycle, and shows changes in oak pollen percentages that correlate well with the deep-sea $\delta^{18}O$ record and with the post-Eemian pollen record of northern Europe; abrupt changes in pollen assemblages occur during Oxygen Isotope Stage 5 (Adam, 1988).

Long records in the upper Klamath basin include a nearly continuous record from Tulelake (Siskiyou County, Calif.) from the present back to about 3.2 Ma, a ~3 m.y. record from Butte Valley, about 30 km west of the Tulelake site, a record from Buck Lake in southern Oregon that appear to span isotopic Stages 9-12, a record from Wocus Marsh that extends back about 1 m.y., a 40,000-yr record from Caledonia Marsh in Upper Klamath Lake, and an 80,000-year record from Grass Lake. The upper Klamath Basin cores were collected by the author for the U.S.G.S.; pollen work for the Wocus Marsh core has been done by Cathy Whitlock, and the pollen work for the Grass Lake core has been done by Kathryn Hakala (Adam et al., 1995).

An additional core from Round Lake, also in the Upper Klamath Basin, appears to be broadly coeval with the Wocus Marsh core, but the pollen from that section has not yet been studied.

The remaining long section in the study area is a cliff exposure along the Feather River in the northern Sierra Nevada. Informally known as the "Mohawk Lake Beds", the deposits actually formed in a shallow, marshy basin. The present exposure appears to represent an interval from near the base of the Brunhes Normal to the onset of the penultimate glaciation, based on paleomagnetics, tephra, and glacial outwash deposits.

Correlations between records are based on both paleomagnetics and on extensive tephra work by A. Sarna-Wojcicki. Over two dozen identifiable tephra layers, mostly from eruptions in the Cascade Range, provide firm links between cores.

The potential for recovering other long records in the region is excellent, and the likelihood of establishing links between sites using tephra and paleomagnetics is already well established. Transects of sites are possible both to study latitudinal variations along the Sierra Nevada/Cascades axis and across the northern Sierra Nevada to study elevational and rain shadow effects. Many of the basins are likely to contain records extending back a million years or more.

ADAM, D.P. 1988. Palynology of two upper Quaternary cores from Clear Lake, Lake County, California. U.S. Geological Survey Professional Paper 1363, 88p.

ADAM, D.P., BRADBURY, J.P., DEAN, W.E., GARDNER, J.V., & SARNA-WOJCICKI, A.M. 1995. Report of 1994 Workshop on the Correlation of Marine and Terrestrial Records of Climate Changes in the Western United States. U.S. Geological Survey Open-File Report No. 95-34, 92p.

A 60 ka high-resolution record of paleoecological change at Laguna de las Trancas, California's central coast region, USA

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Laguna de las Trancas is a small wetland presently located within the coast redwood (*Sequoia sempervirens*) – Douglas-fir (*Pseudotsuga menziesii*) forest on an uplifted terrace ca. 170 m above and 1 km inland of the Pacific Ocean in central California. Previous research (ADAM ET AL. 1981) detailed pollen data that spanned the period 5 ka to ca. 30 ka yr BP, making it an unusual site for coastal California. We report here on a new 10m core that spans all of the last ca. 60 ka, based upon a series of AMS dates and the occurrence near the core bottom of the Olema Tephra. These new analyses include high resolution pollen, geochemical and magnetic data, and document a terrestrial record that shows striking parallels to the marine isotope record from the Santa Barbara Basin.

The pollen data closely parallel the geochemical data, which in turn parallel the oxygen isotope records not only from the nearby Santa Barbara Basin but also the GRIP2 sites. The bottom portion of the core (MIS-4; prior to ca. 55 ka yr BP) is dominated by *Pinus* (at least two species), with Cupressaceae and small amounts of *Pseudotsuga*, *Alnus*, *Quercus* and other shrubs. Shallow water conditions are indicated by occurrence of

Botryococcus and *Equisetum*. Pollen spectra from MIS-3 (to ca. 26.5 yr BP) is also dominated by *Pinus*, with greater amounts of Cupressaceae, *Sequoia*, and coastal chaparral elements ca. 55 ka to 43 ka and 33 ka to 26.5 ka, and the highest diploxylon *Pinus* pollen percentages ca. 43 ka to 33 ka. The pond was probably deepest during early MIS-3, as shown by the abundance of *Brasenia*, a floating-leaved aquatic. Spectra from MIS-2 (ca. 26.5 to 10.1 ka yr BP) are again dominated by at least two species of *Pinus*. The occurrence of minor amounts of *Picea* (probably *P. sitchensis*), maximum Pinus and minimum pollen concentrations suggest that the Last Glacial Maximum was centered around ca. 18 ka. *Abies* (perhaps *A. grandis*) becomes important from ca. 15 ka to 10.1 ka. With the opening of MIS-1 at ca. 10.1 ka, *Sequoia*, *Pseudotsuga*, *Alnus*, *Lithocarpus* and *Quercus* dominate the arboreal pollen assemblages, suggesting the development of the modern forest there.

Variations in the geochemical and magnetic data document cyclical variations on the millennial timescale, inferred to be similar to D-O cycles verified from the Santa Barbara Basin (BEHL & KENNETT 1996). Pollen data show considerable millennial-scale variability as well, including increases in *Sequoia* and *Pseudotsuga* pollen that may be linked to interstadial periods. The high-resolution Laguna de las Trancas data are important in connecting periods of terrestrial biotic change with events documented in other high-resolution marine and ice core records, providing additional direct evidence for land – sea coupling and global climatic connections.

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Palynological records of Neogene climate and vegetation from interior western North American sites: an historical overview

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The analysis of long sedimentary records of Quaternary and older sediments began in the North America in 1956, with the publication of Kathryn Clisby's and Paul Sears' (1956) analysis of a series of cores (610 m [2000 ft] 200 samples) taken in the San Agustin playa of western New Mexico, U.S.A. The palynological analysis upon which the publication was based overlapped with the marine isotopic studies of Cesare Emiliani (1955). Clisby compared the minor changes recorded in her analyses with the large isotopic excursion in Emiliani's curves, in her 1962 presentation at the First IPC (Clisby, 1962). Clisby's work was followed by Paul Martin's analysis of Safford Basin, Arizona (Martin & Gray, 1962), Lake Cochise, Arizona (Martin, 1963) and the Great Salt Lake, Utah (Martin & Mehringer, 1965; Davis, 2002). These early studies, taken from dry lake beds, were plagued by sedimentation gaps and poor dating, but they demonstrated the potential for very long, detailed records in western North American tectonic basins.

It was not until Thomas Van der Hammen's (1974) and Genevieve Woillard's (Woillard and Mook, 1982) detailed analyses demonstrated a correlation between terrestrial and marine records that North American palynologists once again focused on long records. David Adam initiated coring projects in standing water rather than on dry lake beds: Walker Lake, Arizona (Berry et al., 1983) Clear Lake, California (Adam and West,1983) and Tulare Lake California (Adam et al., 1989). These investigations demonstrated the potential for millions of years of uninterrupted palynological record. More recent investigations have demonstrated ever more detailed and ancient records of vegetation and climatic change (Bader, 2000; Dean et al., 2002; Woolenden, 2003).

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WOOLFENDEN, W.B. 2003. A 180,000 year pollen record from Owens Lake, CA: Terrestrial vegetation change on orbital scales. **Quaternary Research** 59: 430-444.

High-resolution terrestrial vegetation record during marine isotope stages 1-6 from Owens Lake, California

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An 180,300-year pollen sequence (core OL-92) from Owens Lake, California (1067 m) indicates that desert vegetation had tracked part of the last two glacial and interglacial cycles, which were driven by orbital changes. The now dry Owens Lake is in a closed lake basin at the southern end of Owens Valley flanked by the Sierra Nevada and White-Inyo Mountains. It lies on an ecotone between the cold sagebrush desert of the Great Basin and mixed shrub hot desert of the Mojave Desert and so its sediments contain a historic vegetation archive sensitive to climatic change. The pollen sequence indicates shifts in the plant associations representing warm and cold desert shrub, pinyon-juniper woodland, and pine-fir forest during MIS 1-6. High percentages of *Juniperus* (51-71% maximum) and *Artemisia* pollen along with low percentages of warm desertscrub pollen (*Ambrosia*, Chenopodiaceae-*Amaranthus*, *Cercocarpus/Purshia*) during the intervals of about 180-130.2 ka and 80.1-17.7 ka alternate with low percentages of *Juniperus* and *Artemisia* pollen, and relatively high percentages of desertscrub pollen during the intervals of about 130-126.5 ka and 17.7-10.2 ka. *Pinus* and *Abies* pollen varies inversely with *Juniperus* over the long term. The interval of about 126.5-80.1 ka is characterized by the highest abundances of *Pinus* and *Abies* for the period of record, while abundances of *Juniperus* and Artemisia and warm desert taxa alternate between two shorter intervals.

As the pollen sequence is interpreted, during glacial and stadial climates, pinyon-juniper and big sagebrush woodland dominated the southern Owens Valley, apparently having expanded to the south and downslope to replace warm desert shrubs. At the same time upper montane and subalpine forests in the arid Inyo Mountains expanded, and much of the forest in the Sierra Nevada was apparently displaced by the ice cap and periglacial conditions. Conversely, during interglacial and interstadial climates warm desert plants expanded their range in the lowlands, juniper, pinyon and sagebrush retreated upslope, and montane and subalpine forests expanded in the Sierra Nevada. Variations in Chenopodiaceae-*Amaranthus* pollen between glacial and stadial periods may partly reflect the changing extent of valley habitat due to lake level fluctuations.

The time interval from 132.1 to 122.4 ka spans the transition from the pleniglacial (MIS 6) into the last interglacial (MIS 5). According to the pollen sequence, as surface temperature increased juniper decreased over a thousand-year period until 130 ka when taxa representing warm desert vegetation surged within 200 years, as if a threshold was reached. These taxa differentially decreased about 4000 years later as surface temperature declined. The early interglacial (MIS 5e) appears to have been slightly warmer and wetter than the Holocene because of the greater abundance of *Ambrosia* and *Quercus* pollen. This is possibly due to low-pressure anomalies over the eastern Pacific and more frequent summer and fall rainfall from humid air masses brought in by southerly flow.

A correspondence analysis indicates that besides the larger amplitude changes there were lower frequency variations in the dominant vegetation types of upper Mojave Desert grassland, Great Basin desert grassland, Great Basin steppe, and Rocky Mountains xeric forest (pinyon-juniper woodland). No modern analogue for full glacial vegetation has yet been found.

The reconstructed vegetation history demonstrates a regional climatic response, and the congruence of the pollen sequence with marine and ice cap oxygen isotope stratigraphies suggests a link between regional vegetation and global climate change at orbital scales.

Since the last interglacial is similar to the Holocene the pollen data set can be used for a comparative study of past and modern vegetation and climate dynamics of the deserts of south-eastern California. Such a study is important toward understanding climate/vegetation interactions for future projections of the consequences of human-induced global change.

A 60,000-year record of climate change from Lake Tulane, Florida, USA

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In an earlier paper (GRIMM *et al.* 1993) we identified peaks in pine pollen from Lake Tulane, Florida that were coeval with the Heinrich events. In that paper we suggested that pine peaks corresponded with five of the Heinrich events (H1–H5) and that an extra pine peak perhaps correlated with minor peaks in the lithic grains from DSDP 609 between H3 and H4. We also suggested that the pollen data indicated wetter and cooler climate in Florida during the Heinrich events.

Detailed analyses of a new core from Lake Tulane with 55 AMS radiocarbon dates indicate that the six Lake Tulane pine phases were, in fact, coeval with the six Heinrich events. The new core spans the past 60,000 years. Conventional radiocarbon dating of our original core did not reveal sudden jumps in age that occur at bases Tulane pine phases 3 and 4, which resulted in errors in our original age model. Although these jumps may indicate hiatuses in sedimentation, their coevality with the Laschamp and Mono Lake geomagnetic excursions suggests that they were owing to major variations in atmospheric ^{14}C concentration.

During the Pleistocene, oak-scrub and prairie phases at Lake Tulane were coeval with long, intense Dansgaard-Oeschger interstadials (warm periods) that initiated Bond cycles. Pine phases were coeval with the North Atlantic long stadials (cold periods) that ended Bond cycles and were terminated by Heinrich events. Analysis of aquatic and wetland macrofossils indicate that lake levels were higher during pine phases, confirming our earlier interpretation that climate was wetter. However, numerical analyses of the pollen data suggest that climatic conditions during the Heinrich events were similar to the late Holocene, which was wet and warm. Climate was cooler during the scrub oak-prairie phases. Therefore, climate at Lake Tulane showed a strong antiphase relationship with the North Atlantic region. Perhaps diminution of thermohaline circulation before and during Heinrich events reduced northward heat transport and retained warmth in the subtropical Atlantic and Gulf of Mexico.

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Dancing to different beats: vegetation community responses to orbital-scale climate forcing in the Australian Quaternary

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Detailed palynological records, predominantly from marine and volcanic crater sediments, cover a substantial part of the Quaternary of northern and southeastern Australia and extend from humid to arid environments. Comparisons are made with the marine oxygen isotope stratigraphy, indirectly with terrestrial records and directly with marine records.

Predictably, the 100,000 year eccentricity cycle is very evident, and frequently dominant, in Middle to Late Pleistocene sequences, reflecting ice volume forcing operating largely through sea level variation in the north of Australia and a combination of sea level and global temperature variation in the southeast of the continent. Glacial periods were substantially drier than interglacials.

However, in the northeast of the continent, a 30,000 year frequency predominates in tropical conifer and charcoal components over the last 300,000 years, that is attributed to a strong Pacific Ocean ENSO signal. Conversely, over this same period, savanna vegetation in northeastern Australia exhibits clear southern hemisphere precessional forcing, attributed to monsoon influences from the Indian Ocean, but then alters to global ice volume forcing back to at least 500,000 years BP. It is possible that this 'mid-Brunhes' event is the result of a combination of variation in the amplitude of precessional cycles related to the 400,000 year eccentricity frequency and alteration of atmospheric and oceanic circulation patterns with the development or expansion of the West Pacific Warm Pool. Increased climatic variability within the last 300,000 years has led to major changes in fire regimes and resulted in a more open vegetation. This trend has been exacerbated by Aboriginal burning within at least the last 50,000 years.

In Southeastern Australia, there is evidence for southern hemisphere precessional forcing of both diverse rainforest, now virtually extinct in the region, and sclerophyll vegetation from the beginning of the Quaternary until about 1.1 million years ago. There is little relationship shown to the marine isotope record. Throughout this period, the major climate variation was in precipitation and there is little evidence of major changes in temperature. The presence of annual laminations, a rare feature in Australian Quaternary records generally, suggests that the climate was very seasonal. It is hypothesized that, with little variation in global ice volume and reduced Pacific ENSO activity, the Indian Ocean monsoon may have exercised dominant control over the climate of this mid-latitude region. After a transition period, lasting until about 0.9 Ma, global ice volume forcing became the dominant influence on the vegetation in the Middle and Late Pleistocene with marked variation between cool, dry glacial and warm wet interglacial periods. Interglacials witness some expansion of depauperate and areally restricted rainforest patches.

An environmental history of the humid tropics of Northeastern Australia for the last 500,000 years (oxygen isotope stages 1 to 13) based on the ODP 820 marine core

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A continuous, though generalized record of vegetation, burning and climate changes for the humid tropics of northeastern Australia over the last 1.5 million years has been produced from the ODP 820 marine core (Kershaw et al. 1993). A more detailed pollen and charcoal analysis has been undertaken for the last 500,000 years (oxygen isotope stages 13 to 1) and compared with an equally detailed oxygen isotope record from the core (Peerdeman et al. 1993). The palynological records provides evidence of cyclical environmental change linked to Milankovitch periodicities, as well as three profound alterations in vegetation and burning linked to non-cyclical alterations for the last 250,000 years (oxygen isotope stages 7 to 1) at 170,000 years BP, 135,000 – 130,000 years BP and 45,000 years BP (Moss, 1999, Moss and Kershaw, 2000). This refined analysis of the ODP 820 record has been extended from 250,000 to 500,000 years BP (oxygen isotope stages 8 to 13) in order to provide a firmer basis for explanation of the late Quaternary events in relation to regional tectonics and possibly associated changes in atmospheric and oceanic circulation patterns in the west Pacific that occurred during the mid Quaternary. In addition, the role of Milankovitch orbital forcing on environmental change in the humid tropics of northeastern Australia for the mid Quaternary period will be examined.

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A continuous Southern Ocean terrestrial pollen record providing opportunity for inter-hemispheric comparison of mid-late Quaternary climatic change

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The assumption that the major Quaternary climate transitions occurred synchronously between northern (NH) and southern hemispheres (SH) is an important corollary to the Milankovitch orbital forcing hypothesis. Testing the assumption is problematic, however, because of a paucity of SH records where dating is not reliant upon 'tuning' to presumed NH or global signals. A new independently dated pollen record of climate change from Okarito, southwestern New Zealand, spanning much of the last two glacial-interglacial cycles (Fig. 1), provides a SH benchmark for comparison both with the marine isotopic record and with equivalent long continuous pollen records from the NH. In this paper, we focus on comparison with classic pollen records from western Europe. The correspondence between these records provides strong evidence for a closely coupled ocean-atmosphere-terrestrial system in the mid-latitudes of the SH with vegetation developments that occurred broadly in synchrony with those in the NH. Nevertheless there are some significant differences between the Okarito record and NH counterparts, including an earlier onset and longer duration to cooling during the Last Glacial Maximum and the lack of a pronounced thermal maximum during the Last Interglacial. These unexpected findings require explanations and have important implications for understanding how climate change is propagated around the globe. Here we consider the role of local insolation in modulating the northern insolation 'driver'.

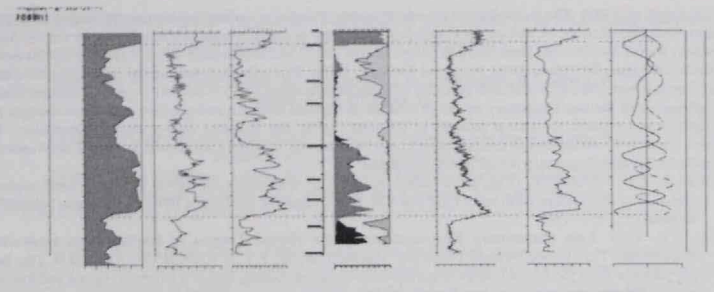

Fig. 1. Mid-Late Quaternary climate proxy records, from left to right: DSDP Site 594 pollen, $\delta^{18}O$ (planktic) and calcium carbonate records (Nelson et al., 1993; Heusser and van der Geer, 1994); Okarito summary pollen diagram showing (left to right) curves for forest trees, shrubs, and dryland herbs; Vostok temperature (Petit et al., 1999); Marine core MD 900963 $\delta^{18}0$ record (Bassinot et al., 1994); Summer insolation values for 40°S and 65°N (M-F Loutre pers comm.). Marine isotope stages in column on far right. Note compression of Holocene section of Okarito Pakihi record to aid comparison.

BASSINOT, F.C. et al. 1994. The astronomical theory of climate and the age of the Brunhes-Matuyama magnetic reversal. **Earth and Planetary Science Letters** 126: 91-108.

HEUSSER, L.E. & VAN DER GEER, G. 1994. Direct correlation of terrestrial and marine palaeoclimatic records from four glacial-interglacial cycles – DSDP site 594 southwest Pacific. **Quat. Sci. Rev.** 13: 273-282

NELSON, C.S. et al. 1985. Near-synchroneity of New Zealand alpine glaciations and northern hemisphere continental glaciations during the past 750 ka. **Nature** 318: 361-363

PETIT J.R. et al. 1999. Climate and Atmospheric History of the Past 420,000 years from the Vostok Ice Core, Antarctica. **Nature** 399: 429-436.

Vegetation history of the last 300,000 years for Kamiyoshi, Kyoto, Japan, based on pollen from a long peat core dated by tephra layers

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We have taken a long core over 350,000 yr BP from Kamiyoshi Basin near Kyoto City in western Japan. This core will provide a continuous vegetation history of the glacial-interglacial circles from the Marine Isotope Stage (MIS) 3 to MIS 9. The chronology was based on widespread tephra (AT: 25,000 , Aso4: 84,000, K-Tz: 91,000, ASO-1: 260,000 and Kkt: 330,000 yrsBP, age of the tephra after Machida and Arai (2003)) and several AMS ^{14}C dates. In this paper, we refer to the vegetation history since the MIS 5e. During the MIS 5e, forests were characterized by dominance of *Cryptomeria japonica* and evergreen oaks with fir, hemlock, and beech. Also, several percentages for pollen of *Lagerstroemia* were detected during the MIS 5e. Modern distribution of this genus is the subtropical zone from China to the southeastern islands of Japan. So, during the MIS 5e, both subtropical and cool-temperate genera were coexisted around the Kamiyoshi basin. In the boundary between the MIS 5e to 5d, evergreen oaks and temperate conifer forests were abruptly changed to temperate forests composed of *Sciadopitys verticillata* (umbrella pine) and *Cryptomeria japonica* associated mainly with Cupressaceae, spruce trees and deciduous oaks. Temperate conifer forests were composed primarily of *Cryptomeria japonica* with *Sciadopitys verticillata* and Cupressaceae trees the period from the MIS 5c to 5a. Pinaceous conifer vegetation dominated by *Tsuga, Picea, and Pinus* subgenus *Haploxylon* was dominant during the MIS 4. Around 60 kyr BP, this was followed by cool-temperate deciduous broad-leaved forests composed

mainly of *Fagus crenata, Quercus* subgenus *Lepidobalanus* and *Ostrya/Carpinus*. Temperate conifer forests dominated by Cupressaceae trees with *Tsuga, Pinus, Sciadopitys verticillata, Cryptomeria japonica* and *Lepidobalanus* (deciduous oaks) occurred in the interstade (MIS 3). Especially, between 45 to 30 kyr BP, Cupressaceae trees were most dominant in forests. The correlation between this record and one from Kurota Lowland (Takahara and Kitagawa, 2000) reveals differences in vegetation between the inland area and the coastal area of the Japan Sea during the MIS 3. In the inland Kamiyoshi Basin, Cupressaceae trees were dominant, associated with *Sciadopitys verticillata* and deciduous oaks. Meanwhile in Kurota Lowland, adjacent to the Japan Sea, *Cryptomeria japonica* was dominant, associated with cool-temperate deciduous broad-leaved trees such as *Fagus crenata* and deciduous oaks. The difference in vegetation probably indicates a slightly drier climate in the inland area and a wet and heavy snow climate in the coastal Japan Sea area during the MIS 3.

MACHIDA, H. and ARAI, F. (2003) Atras of tephra in and around Japan (revised edition), University of Tokyo Press, Tokyo.

TAKAHARA, H. and KITAGAWA, H. (2000) Vegetation and climate history since the last interglacial in Kurota Lowland, western Japan. Palaeogeography, Palaeoclimatology, Palaeoecology, 155□123-134.

A high resolution multi-proxy lacustrine record (pollen, diatoms, $\delta^{18}O_{si}$) of climate, vegetation and lake level changes in the Massif Central (France) from the rissian late glacial to the end of the Eemian

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The comparison of a new high resolution pollen diagram of Ribains with biological and geochemical data delivered by the same core, allow us to obtain detailled palaeoecological and palaeoclimatical informations for the last *ca* 140 000 years.

At the end of the penultimate glaciation, the landscape was characterized by a dominating open vegetation with steppics and some sparse mesophilous trees that could develop at lower altitude. Climate reconstruction indicate low annual precipitations and a high annual temperature amplitude. Lacustrine waters of the palaeolac of Ribains were very cold as it is proved by the domination of *Cyclotella rossii* among diatom assemblages.

Polle data and $\delta^{18}O_{si}$ values indicate that the beginning of the Eemian correspond to a warm period caracterized by high precipitation and a low annual temperature.

During the *Carpinus* phase, the climate become more continental (low annual precipitation, low annual temperature mean, high annual temperature amplitude).

When *Picea* populations expand, a serious decline in temperature occurs especially during summer, and the climate grow wetter. This trend is demonstrated by the drop of the $\delta^{18}O_{si}$ curve. At the end of the interglacial, as the vegetation is dominated by a boreal coniferous forest, a simultaneous and transitory rise of organic matter and *Picea* percentages is observed. This event, not recorded by the $\delta^{18}O_{si}$ of the Ribains diatoms but present in other European pollen and isotope profiles, could be related to a short warming of the climate.

Correlation of the climate changes over the last 200 ka recorded in long loess-palaeosol pollen profiles and ESR-dated marine deposits of Northern Eurasia

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The time span of the past 200 ka has been marked by many large-scale global and regional climate changes, between warmer and cooler conditions. At the same time, long and continuous terrestrial proxy climate records through this time interval are rare. A few most complete loess-palaeosol sections are situated in the glacial and extraglacial zones of the East European Plain. At present, these are among the longest and palynologically best studied sections (BOLIKHOVSKAYA 1995). Peculiarities of phytocoenotic and climatic successions and composition of characteristic taxa over the last 200 ka are considered in this study on the example of two most typical stratoregions of the central part of the Russian Plain – the Northern Central Russian glacial loess region and the Middle Desna glacial loess region.

The palynostratigraphical record derived from long continuous loess-palaeosol sequences was calibrated for age by correlation to the mollusc-based ESR-chronostratigraphical record in which warm-climate-related events were dated by ESR on more than 170 subfossil mollusc shell samples taken directly from the transgressive marine sediments. We have attempted to link marine mollusc-based age analysis from the two last glacial intervals and an interglacial between them with the palaeoclimatic data derived from the pollen-based vegetation signals of terrestrial environment from the East European loess province. The linkage of these two independent climatic records has provided better insight into palaeoenvironmental changes during the last two glacial periods where radiometrically dateable materials typically are scarce both in terrestrial and marine sediments.

Using pollen and mollusc-based ESR data, we have identified palaeoenvironmental events that we believe to correlate with a number of large-scale late Middle and Late Pleistocene climatic features in Northern Eurasia, including the penultimate glacial period (Dnieper/Saale, OIS 6) with three warmings within it, last interglacial (Mikulinian/Eemian, OIS 5), and subsequent glacial/periglacial period (Valdaian/Weichselian, OIS 4-OIS 3), interrupted by at least six relatively warm episodes of interstadial rank.

The pollen response in the sections examined in this paper documents a strong climatic signals bottom-up, covering an interval from OIS 6 to OIS 2. The Dnieper glacial rhythm is divided by an intermediate interstadial into two (Dnieper and Moscow) stages with the Early Dnieper and Late Moscow interstadials within them. During interstadials pine, pine-birch and birch light periglacial forests dominated in the glacial-periglacial zone of the Russian Plain. In the loess areas in the south of the Russian Plain the periglacial woods, forest-steppes, steppes and extraglacial light forests were spread during these warm intervals. Cold (glacial) phases are characterised by the spread of tundra-steppes, tundra-forest-steppes, periglacial forest-steppes, periglacial steppes and periglacial semi-deserts. The time of the Valdai glacial pessimum is characterised by development of periglacial tundras, periglacial forest-tundras, tundra-steppes, tundra-forest-steppes and periglacial steppes. Warm (interglacial) phases are characterised by successions of interglacial forests, forest-steppes and steppes.

The data obtained demonstrate also that the last interglacial event in Northern Eurasia may have been long lasting, correlating most likely with the whole of isotope stage 5 and the final phase of stage 6 rather than substage 5e only. During most of the period the vegetation cover has evidently been of interglacial character in Eastern Europe. At the same time, pollen and ESR records suggest that this interglacial was variable rather than stable in nature. During this interglacial period the warm climate was repeatedly interrupted by cold phases.

Coolings during the last interglacial may have been quite deep although of relatively short duration and appear to be less dramatic in Northern Eurasia than suggested by the oxygen isotope variability in the deep-sea isotopic records. Our ESR studies show that during these intra-interglacial cold periods of isotope stage 5 coastal areas of Eurasian North were partly occupied by transgressive basins. Time-dependent frequency distribution of all the ESR-dates obtained for the last interglacial also displays several intervals that can likely be correlated with the coolings and phases of sea regression.

BOLIKHOVSKAYA, N.S. 1995. The Evolution of Loess-Paleosol Formation of Northern Eurasia. Moscow University Press, Moscow. 270 pp.

A 400.000-yrs pollen record from Azzano Decimo (northern Italy)

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A few long pollen records covering the Late Pleistocene – Late Middle Pleistocene are available for northern Italy (MÜLLENDERS ET AL. 1996; AMOROSI ET AL. 1999), despite its palaeoecological importance. Indeed, the vegetation record of the southern side of the Alps allows for detecting survival areas, where plants could shelter during dry and cold periods of the Quaternary.

In the framework of the CARG Project (update of the official geological map of Italy), a continuously cored borehole was carried out in 2003 by the Univ. of Udine in the Friulian alluvial plain (NE Po Plain). A 262 m long core was realized at Azzano Decimo: 100% of sediments was retrieved. The stratigraphic investigation on this core involves the Univ. of Udine, Padova, Trieste, Roma and the CNR-IDPA, the last Institute being charged for pollen analysis.

The stratigraphic sequence shows two major transgressive-regressive cycles. The sedimentary environments include: silty clay marine settings, transitional-coastal and littoral facies with sandy sedimentation, and laminated silts of fluvial origin with peat levels testifying to local marshes.

Seven conventional ^{14}C datings were determined from peat layers in the upper 30 m of the core. These ages span from 27,160 uncal. yrs BP to > 46,000 yrs BP. Other AMS datings are currently in progress.

150 pollen samples were analysed. More than 100 pollen types were identified. Sporadic reworked pollen grains of Early Pleistocene age (*Tsuga, Carya, Pterocarya, Liquidambar*) can be distinguished on the basis of their different degree of preservation. Several types of microfossils belonging to Foraminifera, dinocysts, fresh-water algae (*Pediastrum, Spirogyra, Mougeotia*) were counted.

The stratigraphic distribution of pollen assemblages and the sea level record suggest that the main palynologic changes are climatically-driven and related to MIS 2 to 11. A previous record from the Po plain (AMOROSI ET AL. 1999) also confirms this picture.

At the base of the pollen diagram a phase of mixed conifer-broad leaved trees forests with *Pinus, Picea, Abies, Fagus, Alnus, Quercus* deciduous, *Ulmus* and *Tilia* is related to MIS 11. It's followed by a *Pinus, Artemisia* and Gramineae-dominated pollen assemblage suggesting a cold and dry phase related to MIS 10.

A new phase of expansion of mixed forests is related to MIS 9: cool-temperate forests with *Picea, Fagus* and *Carpinus* are followed by mixed conifer-broad leaved forests with *Abies, Quercus* dec., *Corylus Ulmus* and *Tilia*. Then a short interval with *Pinus* and *Artemisia* is related to MIS 8. The following 65 meters, related to MIS 7, include a sequence of three phases of expansion of broad-leaved trees and two cold phases marked by the abundance of *Pinus, Picea, Abies* and *Betula*. An interval with complete absence of broad-leaved trees and dominance of *Pinus* and xerophytes , related to MIS 6, is followed by a cler pollen succession typical of MIS 5. A detailed pollen stratigraphy during MIS 5 in N-Italy is obtained for the first time, enabling to show substantial differences with the northern side of the Alps. Continental deposits spanning the upper 32 m of the core yield mainly higher pollen % of conifers and xerophytes and can be related to the last glacial period.

The Azzano Decimo core offers a detailed palynostratigraphic record for the Late Pleistocene – Late Middle Pleistocene which can be used as a reference in northeastern Italy.

AMOROSI, A., COLALONGO, M.L., FUSCO, F., PASINI, G. & FLORINI, F. 1999. Glacio-eustatic control of continental-shallow marine cyclicity from late Quaternary deposits of the Southeastern Po Plain, Northern Italy. **Quat. Res.** 52: 1-13.

MÜLLENDERS, W., FAVERO, V., COREMANS, M. & DIRICKX, M. 1996. Analyses polliniques de sondages à Venise. In: Gullentops, F. (Ed.), Pleistocene Palynostratigraphy. **Aardk. Meded**. 7: 87-117.

Different responses of African climate to the intensification of the Northern Hemisphere glaciation around 2.6 Ma

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The present-day condition of bipolar glaciation characterised by rapid and large climate fluctuations, began at the end of the Pliocene with the intensification of the Northern Hemisphere's continental glaciations. The global cooling steps of the Pliocene have been documented in numerous studies of ODP sites from the northern Hemisphere. This study presents new pollen data from ODP Site 1082 (21°S 12°E) providing a Pliocene record of vegetation change in Southern Africa. I compare the pollen records of ODP Sites 658 (18°W 21°N) and 1082 to investigate the responses of African climate north and south of the equator, which turn out to be remarkably different in timing. Between 3.25 and 2.6 Ma North African climate became progressively drier and arid conditions culminated at Stage 104 (2.6 Ma). From then on the pollen diagram of ODP Site 658 displays time-transgressive maxima interpreted as repetitive southward shifts of the Saharan-Sahelian boundary. In southern Africa, the record of ODP Site 1082 suggests northward shifts of the savanna during the cold stages. However, the most prominent change toward drier conditions occurred at 2.1 Ma contemporaneously with a drop in sea surface temperatures marking the start of the modern Benguela upwelling system.

Vegetation response to lower Pleistocene climatic cyclicity in the Lamone River Valley (northern Apennines, Italy).

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The results of a palynological study carried out on marine deposits of the Lamone River Valley are here reported. The Lamone succession consists of marine grey-blue clays of the Argille Azzurre Formation, outcropping on the foothills of the northern Apennines. On the basis of foraminiferal content (VAIANI & VENEZIA 1999), the studied deposits are referred to lower Pleistocene.

Pollen data document a cyclic vegetation dynamics in which four different pollen assemblages in turn spread and retreat, indicating parallel vegetation changes. A vegetation cycle starts with the expansion of mixed deciduous forest, dominated by *Quercus*, followed by an expansion of Juglandaceae and *Tsuga*, indicating at first an increase of temperature, and then of humidity. Successively, a mountain coniferous forest dominated by *Picea* spreads, testifying a drop in temperature towards cool/cold climate conditions. The *Picea*-forest phase is followed by the diffusion of shrubby-herbaceous vegetation with *Artemisia* and *Ephedra*, indicating a drop in humidity. The lowest pollen concentration values are recorded during this latter vegetation phase, suggesting a forest retreat.

This cyclic vegetation dynamics reflects the cyclic climatic oscillations, and fluctuations from forest to open-vegetation reveal interglacial/glacial cycles. In the Lamone succession, two complete cycles are documented, in correnspondence of the appearance of the benthic foraminifer *Hyalinea baltica* (VAIANI & VENEZIA 1999), marker for the Santernian\Emilian boundary (~1,5 Ma) (PASINI & COLALONGO 1994).

Comparison with other lower Pleistocene long-pollen series from Italian sites shows wider spread of *Picea* and minor expansion of open vegetation in northern Italy with respect to southern Italy, suggesting the hypothesis of more humid climate condition.

Taxodiacee (mostly *Taxodium*-type) are continuously represented from the base to the top of the Lamone succession, exhibiting values of ~4% on average and maximum exceeding >11%. The presence of Taxodiaceae in the lower Pleistocene is also documented in other Italian sites, and their disappearance in Italian records can not be considered as a chronostratigraphical event for the Plio\Pleistocene boundary.

PASINI, G. & COLALONGO, M.L. 1994. Proposal for the erection of the Santernian\Emilian boundary-stratotype. **Boll. Soc. Paleont. It.** 33: 101-120.

VAIANI, S. & VENEZIA, P. 1999. La sezione pleistocenica del Lamone (Appennino Romagnolo): associazioni a foraminiferi ed evoluzione paleoambientale. **Boll. Soc. Paleont. It.** 38: 39-57.

Cyclic changes in the late Neogene vegetation of the Ptolemais Basin (northern Greece)

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The late Neogene (late Miocene, early Pliocene) sedimentary succession of the intramontane Ptolemais Basin in northern Greece displays a distinctive alternation of lignites and lacustrine marls. Lithological cyclicity is controlled by orbital precession and can be accurately correlated with the astrochronological timescale computed for the late Neogene (van Vugt et al, 1998 and Steenbrink et al, 1999). The palynological record from seven consecutive cycles, covering the time interval between 5.44 and 5.23 Ma, reveals significant responses of mountainside vegetation to orbital forcing, mainly precession. Frequency analysis from a pollen record from ten consecutive cycles more upward in the sequence, covering the period from 4.36 to 4.16 Ma, shows apart from the strong impact of precession, eccentricity as well as weak obliquity signals.

The observed cyclic trends in the relative abundance of vegetational elements are considered to express periodic variations in soil moisture availability, resulting from changes in orographic wintertime precipitation. At present, variations in rainfall during the winter in the East Mediterranean borderlands are related to 1) meridional shifts of the trajectories of precipitation-laden cyclones that are associated with the North Atlantic Oscillation and 2) the formation of cyclones originating from the Mediterranean Sea. We propose that both the North Atlantic teleconnection and the forming of Mediterranean cyclones are responsible for the reconstructed long-term precipitation variations in southern Europe.

VAN VUGT, N. ET AL., 1998. Magnetostratigraphy-based astronomical tuning of the early Pliocene lacustrine sediments of Ptolemais (NW Greece) and bed-to-bed correlation with the marine record. **Earth and Planetary Science Letters** 164: 353-551.

STEENBRINK, J. ET AL. 1999. Sedimentary cycles and volcanic ash beds in the lower Pliocene lacustrine succession of Ptolemais (NW Greece): Discrepancy between $^{40}Ar/^{39}Ar$ and astronomical ages. **Palaeogeography, Palaeoclimatology, Palaeoecology** 152: 283-303.

The Pianengo core (Po plain, northern Italy): a record of vegetation and climate changes during the Early Pleistocene and preliminary comparison with MIS chronology

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Within the project for the updating of the geological map of Italy, long cores were recently drilled in the Po plain, to describe the Quaternary stratigraphy of the Po basin. Multidisciplinary investigations are currently going on, namely sedimentology, petrography, bio- and magnetostratigraphy, pollen analysis. Magnetostratigraphy is used to build up a chronological frame and to set unconformities recognized by seismic profiles.

Several investigations were carried out on a 200m-long core from Pianengo (Lombardian plain). A main change in vegetation structure, depositional environments and river palaeogeography occurs across a regional sequence boundary, represented by a seismic surface (named "R surface"). The age of the sequence boundary was magnetostratigraphically constrained between the Brunhes/Matuyama boundary and the Jaramillo top, to about 0,87 Ma. The base of the Jaramillo subchron was also identified in the same core. This major environmental change is related to MIS 22, the first prominent Pleistocene event of glacio-eustatic lowstand. Indeed, MIS 22 records the end of the 'Mid-Pleistocene revolution' (BERGER ET AL. 1993), the transition from climate cycles forced by a 100.000 years periodicity to cycles of 40.000 years. Geological and biostratigraphical

data from Pianengo are interpreted as triggered by a major climate change possibly associated with a major expansion of the nearby Alpine valley glaciers (MUTTONI ET AL. 2003).

Six vegetation cycles can be observed in the pollen diagram from the base of the core up to the R surface. The beginning of a cycle is characterized by the expansion of mixed oak wood forests, dominated by *Quercus* deciduous, *Ulmus*, *Tilia*, *Carpinus betulus*, *Fraxinus*. This phase is followed by the development of Juglandaceae forests, with *Carya*, *Pterocarya*, and *Juglans*. Subsequently, conifer forests with *Pinus sylvestris/mugo*, *Pinus* Haploxylon type, *Picea*, and *Abies* take the place of former Juglandaceae stands. The expansion of xerophytes (*Artemisia*, Chenopodiaceae, *Hippophäe*, Ephedraceae) marks the end of a cycle. Climate changes induce changes in the structure of vegetation. Every cycle represents the transition from warm-dry temperate conditions to warm-very wet ones, from cold temperate to very cold-dry conditions. Only two of the cycles observed in the Pianengo core are complete, e.g. the four steps of the cycle are all represented. The other cycles partially miss in coarse sediments bearing no pollen.

A preliminary correlation can be proposed between the pollen diagram and MIS chronology. Vegetation and climatic phases observed in the pollen diagram of Pianengo may relate to MIS 22 to 26 and MIS 31. A wet-temperate phase occurring between 152-146 m depth may be related to important sea-level highstands of MIS 31. This interpretation is supported by sedimentological evidence. Expansion of conifer forests at 105 m and 93 m depth can be related to MIS 26 and 24 respectively. The development of Juglandaceae forests under warm-very moist temperate conditions, occurring at 103-99 m depth and at 89-84 m depth, may relate to MIS 25 and MIS 23. The strongest forest withdrawal described in the pollen diagram occurs just below the R surface, which is magnetostratigraphically dated to MIS 22.

The Pianengo record suggests that the first Quaternary major glacial advance on the Italian Alps occurred during the late Early Pleistocene. This picture agrees with investigations carried out in the last years in nearby prealpine sites of N-Italy (Leffe: RAVAZZI & MOSCARIELLO 1998), where, apart from a possible Pliocene glaciation, only climate changes of moderate amplitude are documented during the first half of the Quaternary.

BERGER, W.H., BICKERT, T., SCHMIDT, H. & WEFER, G. 1993. Quaternary oxygen isotope record of pelagic foraminifers: Site 806, Ontong Java Plateau. In (Berger, Kroenke, Mayer et al., eds): Proceedings of the Ocean Drilling Program, Scientific Results. College Station, Texas, Ocean Drilling Program, vol. 130: 381-395.

MUTTONI, G., CARCANO, C., GARZANTI, E., GHIELMI, M., PICCIN, A., PINI, R., ROGLEDI, S. & SCIUNNACH, D. 2003. Onset of major Pleistocene glaciations in the Alps. Geology 31(11): 989-992.

RAVAZZI, C. & MOSCARIELLO, A. 1998. Sedimentation, palaeoenvironmental evolution and time duration of earliest Pleistocene climatic cycles in the 24 - 56 m FM-core interval (Leffe Basin, northern Italy). Mededelingen Nederlands Instituut voor Toegepaste Geowetenschappen 60: 467-490.

Pollen analysis of the Pleistocene lacustrine succession of Pianico-Sèllere (northern Italy)

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The Pianico-Sellère Basin near Bergamo (calcareous Pre-Alps, northern Italy) represents a unique environmental record, covering an entire interglacial predating the Holocene with an annual resolution. This site is known since the middle of 19th century, mainly for the exceptionally well preserved fossil content (flora and fauna). The lacustrine deposits were considered "the best example of the Riss-Würm interglacial south of the Alps" (LONA & VENZO 1957). In 1998, an international working group (Pianico-Sèllere Working Group) was created. For the first time the site was investigated with a multidisciplinary approach, including pollen analyses (ROSSI 2003). Our research led us to define the biostratigraphical and climatostratigraphical units (ROSSI 2003). The sedimentary sequence outcrops along the Borlezza River and includes lacustrine deposits, defined "Pianico Formation" (MOSCARIELLO *et al.* 2000). The Pianico Formation consists of 4 lithostratigraphical units, which

indicate a transition from a peri/proglacial to a temperate lacustrine environment. The BVC unit represents a 9,6 m thick interval of annually laminated deposits (endogenic calcite varves, BRAUER 1999). At the top of the varved unit a tephra layer is present, dated by K-Ar at 779 ± 13 ka (PINTI *et al.* 2001).

A high-resolution pollen analysis of 20 m of the lacustrine succession (ROSSI 2003) shows the regional vegetation history. In the lower part of the sequence (BVC unit) the vegetation is dominated by dense meso-thermophilous woodlands (mixed-oak and hornbeam woods), with *Abies* forests at higher altitudes. High percentages of *Buxus* indicate the presence of wide-distributed *Buxus* formations. This long phase is interpreted as an interglacial period (Pianico-Sèllere interglacial), whose length is estimated of 15.700 ± 650 on the base of varve counting. The interglacial is interrupted by an abrupt and short cold interval. On the top, the pollen diagram shows alternating phases dominated in turn by *Pinus*, *Betula*, *Picea* formations with steppe grasslands and by broad-leaved forests. Varve counting provided the time span represented by each biozone and allowed to define the duration of the vegetation changes. The transitions between different vegetation assemblages occurred over 200-300 years.

The interglacial represented by the varved sequence has been tentatively correlated with the marine oxygen isotopic stage MIS 19 and with the Cromerian complex of the continental stratigraphy. Our data represent an important contribution to the knowledge of this poorly known geological period and highlight the possibility to detect minor climatic fluctuations in the Pianico-Sellère succession.

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Timing of vegetation changes during the penultimate warm stage (mis 7) in Southern Europe

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A new deep ocean sediment core from the Portuguese margin (MD01-2443) has enabled us to generate the first pollen record of vegetation development in southern Portugal during the penultimate warm stage, Marine Isotope Stage (MIS) 7. *In situ* correlation with the marine proxy records of sea surface temperature and ice volume, generated within the same core, permit the direct assessment of phase relationships between climate changes and the vegetation response. In this way we bypass the chronological uncertainties inherent in correlations that must rely on absolute age models, since the temporal relationship between the records is unproblematic and limited only by the resolution of the sequence. We use the land-ocean relationship established here to place another, this time terrestrial, record of the penultimate warm stage into the marine stratigraphic context, the marine pollen record acting as a stepping stone. A new core, I-284, from the Ioannina basin in northwest Greece has provided the opportunity to develop a complete, high resolution pollen record of MIS 7. Continuous and rapid sediment accumulation at this site has led to the accumulation of a detailed archive of regional vegetation development during the glacial-interglacial cycles of at least the last half-million years; work on the upper 100 m of this core has already produced detailed records of the last 135 kyr (Frogley *et al.* 1999; Tzedakis *et al.* 2003; Lawson *et al. in press*). The work presented here forms part of a project which aims to extend this record to encompass MIS 6 and 7 and, crucially, to correlate this with the high resolution marine pollen sequence from the

Portuguese margin. Pollen analysis of the MIS 7 sequence of I-284 will enable us to characterise the pattern and nature of the vegetation response to the specific combinations of global climatic parameters (atmospheric carbon dioxide, insolation, ice volume) in each of the MIS 7 substages, and clarify the relative vegetational and climatic status of each one.

FROGLEY, M.R., TZEDAKIS, P.C., HEATON, T.H.E. (1999) Climate variability in northwest Greece during the Last Interglacial. *Science*, 285: 1886-1889.
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Rates, causes and mechanisms governing long-term patterns in plant species richness: evidence from the 320,000 year pollen record of Pula Maar, Hungary

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For too long there has been a major gulf between models used to identify and understand the processes and mechanisms governing spatial patterns of plant species richness and those governing temporal patterns. In many spatial models, the temporal scale is at worst ignored, at best the assumption is made that the data is too coarse in scale to provide any meaningful ecological results. In temporal models, there are far too many examples where modelling of the long-term fossil records have focused entirely upon their use in climatic reconstruction with little or no attention paid the overall patterns in species richness observable through time.

In this paper, new modelling of the long-term palaeecological data from Pula maar, a 3 million-year-old crater lake in northeastern Hungary (WILLIS *et al* 1999a; 1999b), will be presented. The sediments in this crater are exceptional in that yearly accumulation is recognisable in the structure and provide a 320,000 year fossil record deposited between 3-2.67 Ma with an 'in-built' timescale of annual resolution. This dataset therefore represents multiple temporal changes in taxonomic richness through time.

Using models developed to primarily understand the spatial relationship of species richness to energy and water, we have compared variations in taxonomic richness in the 320,000 year fossil sequence to calculated orbital insolation (as a proxy for energy), and paleo-proxies for water. Results from this study indicate that such an approach can provide important information on the relative roles of water and energy in accounting for species richness through time. Interestingly, however, results also indicate that it is not only the amount of energy/precipitation that affects richness but also the amplitude of the variation.

These results have important implications for understanding both the relationship of present day species richness to climatic variables and also for predicting future trends with increasing variability of climate.

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WILLIS, K.J., KLECZKOWSKI, A, BRIGGS, K.M. & GILLIGAN, C.A. 1999b. The role of sub-Milankovitch climatic forcing in the initiation of the Northern Hemisphere Glaciation. **Science**, 285: 568-571.

Session h6

TAPHONOMY AND ARCHAEOLOGICAL PALYNOLOGY

Secrets of the Bilge: Piecing together the Microbotanical Remains of a 3,300-year-old Shipwreck

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The Uluburun shipwreck was found off the Mediterranean coast of Turkey, near the modern town of Kas. Excavations conducted from 1984 to 1994 uncovered a wealth of artifacts that provide extensive insight into the sea-borne trade of the Late Bronze Age. Among the various artifacts comprising the cargo were 354 rectangular-shaped, 'oxhide' ingots of pure copper, which were all recovered. Over the course of the ten-year excavation campaign, more than 100 microbotanical sediment samples were collected from the wreck site by the excavators for later palynological analysis, using the techniques outlined by Weinstein (1996) and Gorham and Bryant (2001). Of these, thirty were associated with copper oxhide ingots. These thirty sediment samples represent material found mainly sandwiched between the ingots, including dunnage, or plant material used for packaging and cushioning the ingots and other artifacts. The oxhide ingots also served as ballast for the ship, so the sediment samples are thought to have been in direct contact with water and detritus found in the ship's bilge. Due to the anoxic environment created by the presence of copper in such large quantities, unusual organic remains such as murex opercula were found among the ingots (Pulak, 2001:32). Preliminary analysis has confirmed that the sediment samples from the oxhide ingots also contain well-preserved botanical materials, including pollen. Once all the ingot samples have been analyzed, pollen types and concentrations will be plotted across the wreck site to determine if any correlations with other artifacts may be generated. Since the ingot samples come from a contamination-compromised environment which is also anoxic, a complete analysis of this group of samples should provide a substantial background portrait of pollen taxa to which the spectrum of taxa from more securely-contained samples could be compared. Such a comparison also will allow issues of contamination or low preservation in certain cargo containers to be more accurately addressed.

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Archaeological plant resins in the Mediterranean: Pollen extraction and analysis

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Shipwreck sites are known to be a wealth of information, nevertheless, more avenues are available for closer examination. Found on some shipwrecks are amphora filled with various types of resins used for trade, used as a sealant lining the inside the amphora, or resins used as an additive to flavour some foods, such as wine. Resins are plant based and due to their composition are highly preservable. Pollen trapped in resins can identify the type and origin of the resin sample. However, recovering fossil pollen from resins have presented a myriad of problems. Resins are distinguished from tar and pitch by the purity of the sample and the plant source from which