Polar Dinosaurs from South Australia

More than 150 taxa of plants, invertebrates and vertebrates are known from Early Cretaceous sediments of southeastern Australia. These include at least four species of hypsilophodontid dinosaurs found in Victoria and two species of theropods (Fig. 1). Dominant among the vertebrates were turtles and dinosaurs, but plesiosaurs, pterosaurs, lizards, birds, and a single labyrinthodont amphibian were present. A variety of fish are known, including lungfish. The flora were dominated by both deciduous and evergreen plants, such as ginkgoes, podocarps and araucarian conifers - all forest forming trees - while the understorey contained *Taeniopteris daintreei*, pentoxylaleans, ferns, sphenopsids, lycopsids, and both ground and epiphytic bryophytes. Over 80 species of invertebrates have been found, primarily hemipterans, coleopterans, and dipterans, but a variety of crustaceans, spiders, earthworms, freshwater bryozoans, and unionid bivalves have also been preserved.

The significance of this varied biota lies in the fact that southeastern Australia during the Early Cretaceous was located between 75° and 85°S latitude, well within the Antarctic Circle. For three months each year the biota had to cope with 24 hours a day of darkness. Studies on O18/O16 ratios in carbonate concretions by Dr. Robert Gregory (Monash University) and his colleagues indicate that mean annual temperatures of this area were between -4°C and 8°C, in contrast to the subtropical climate that had been proposed for this area by some previous workers. Tree rings in the forest trees also indicate distinct seasonality.

The host rocks for these Antarctic Circle biota are in volcanogenic fluvial and lacustrine sediments (the Otway and Strzelecki groups) deposited in a rift valley separating Antarctica and Australia. Dating based on palynological and fission track analyses place the containing sediments in the Valanginian to Albian ranges of the Early Cretaceous. The assemblage is unusual in having such a high proportion of small hypsilophodontid dinosaurs, not so varied as that known elsewhere.

Figure 1: Footprint of a human-sized dinosaur demonstrating *in situ* nature of at least part of the terrestrial fauna.

This fauna is, likewise, unusual in including archaic elements that had become extinct elsewhere in the world by Early Cretaceous times, namely labyrinthodont amphibians and the theropod dinosaur, *Allosaurus*. The hypsilophodontids have relatively large brains and large eyes for dinosaurs (Fig. 2), perhaps as a pre-adaptation for nocturnal existence during the long winter nights. The small size (like bantam hens) of some of the hypsilophodontids certainly suggests that migration to escape the long winter nights may not have been a viable option.

Figure 2: Hypsilophodontid dinosaurs in the cool to temperate Early Cretaceous rainforest of southeastern Australia. From a reconstruction by P. Schouten in Hand, S. and Archer, M., 1988. *The Antipodean Ark*, Angus & Robertson, Sydney.

The presence of dinosaurs in polar latitudes of southeastern Australia in the Early Cretaceous and in northern Alaska (see Brouwers et al., in *Science*, v. 237, p. 1608-10, 1987) in the Late Cretaceous demonstrates that their occurrence at such high latitude was not a single, random event. It is still to be established that they remained *in situ* during the winter. If this was the case, then it has implications with regard to the physiology of certain dinosaurs. It also may place constraints on any theory that invokes darkness and cold to extinguish the dinosaurs at the K-T boundary transition.

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IGCP Tackles Global Geochemical Mapping

In many countries there is increasing awareness among policy makers that geochemical surveys can have environmental significance. Concern about the rate of "Global Change" is beginning to attract media attention and to create popular pressure for government action, which in turn generates a need for factual information. Most geochemical surveys to date have been conducted for exploration purposes, and the question arises as to what steps could be taken to maximize the environmental usefulness of geochemical data? Could additional analyses of retained sample material be undertaken, and how might the design of future surveys and analytical procedures be modified?

Given the desirability of rapidly obtaining a global geochemical overview, there is a need to establish optimum methods of wide-spaced sampling. The question of single or composite samples is important. Stream or river sediments are generally considered to be the most universally available sampling media (Fig. 1). On the basis of Norwegian experience, a strong case has been made for "overbank" sampling, but questions have been raised as to whether the technique is of widespread applicability? Could the major river systems of the world be sampled by means of a few thousand samples in order to achieve worldwide coverage quickly? What would be the analytical requirements in order to detect significant regional differences? Could the material collected serve for control reference purposes?

There is a need to subdivide the world into physiographic-climatic zones within each of which geochemical methods could be optimized. It would be necessary to have overlap between the zones so that data can be normalized. Where are the most suitable areas for these overlap studies, and who would perform them? Should samples be totally or partially digested? For geological purposes the former is preferable; for mineral exploration applications some partial extractions are advantageous, and this is especially true for environmental interpretation. Conversely it is easier to obtain standardized data where total extractions are used.

Some countries involved in technical assistance hold large amounts of geochemical data pertaining to developing countries. These data are potentially suitable for incorporation in world maps and should, accordingly, be used, otherwise there will be no information about some areas of the world. It will be necessary to obtain formal permission from the countries concerned before these data can be used for this purpose. Who should take this initiative?

Against this background IGCP launched earlier this year Project 259, "International Geochemical Mapping." The aim is to facilitate the production of surficial geochemical maps of the world, to complement existing geological and geophysical maps. Four technical and other committees are being established, under the guidance of a Steering Committee chaired by the Project Leader (A.G. Darnley, Canada).

The technical committees include the Field Methods Committee, which will deal with selection of sample media, and methods of sample collection. The Analytical Methods Committee will include all matters concerning sample preparation and digestion, selection of analytical techniques, and provision of international reference materials.

The Data Processing and Management Committee will make recommendations on the organization and contents of the world index of geochemical surveys. It will also deal with the methods for levelling or normalizing diverse data sets, the development of standard formats for trans-border data and map publication, and the evaluation of data interpretation methods.

The fourth technical committee will deal with Radiometric Methods. It will consider all aspects of the collection, standardization, compilation and interpretation of geochemical data obtained by airborne gamma-ray spectrometry. A working group (under A.Y. Smith) has already commenced work on methods for combining existing airborne radiometric data, under the auspices of the International Atomic Energy Agency.

Figure 1: Panning for heavy minerals during a regional geochemical survey. Port Royal Mountains, Jamaica. Photo by R.G. Garrett.

Regional Committees have now been set up for North America (Leader - J. McNeal, U.S.A.), China (Xie Xuejing), Eastern Europe (F. Mrna, C.S.S.R.), Western Europe (B. Bolviken, Norway), and U.S.S.R. (P.V. Koval). Committees will also be set up for other regions as well as for countries that will take an active part in IGCP 259. The UN and related international agencies are being informed about Project 259 and their assistance requested to publicize the relevance of the project to agriculture and health, as well as to resource development.

All interested earth scientists are asked to inform their colleagues about this project to encourage the widest possible support and involvement. It is expected that there will be a small fund available to assist participants from developing countries to attend project meetings. More information may be obtained from the writer.

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Deserts Past and Future

It is really quite easy to make a desert, provided you have lots of sand. But, behind every desert in the geological past there always seems to have been another one. Apart from some special cases such as those at high latitudes or high altitudes, in rain-shadows or on ice, there are really only two main kinds of deserts: coastal, and continental-interior types associated with the tropical semi-permanent high-pressure systems. The latter get their sand mainly from ephemeral streams, often active only during humid climate cycles, and generally by reworking previous sand accumulations. In contrast, coastal desert sands are derived from littoral beaches and continental shelves that are exposed to wind action during a drop in sea level. We are thus learning more and more about climate by studying deserts, modern and ancient.

Many discussions on these matters were held earlier this year at a meeting organized by IGCP Project 252 ("Past and Future Evolution of Deserts"), which is led by Nicole Petit-Maire, Marseille, an indefatigable explorer of deserts herself. In addition to a symposium there were excursions on Fuerteventura, a semi-arid island, and Lanzarote, led by F. Hernandez, J. Meco and J. Onrubia from La Laguna University, Gran Canaria (Fig. 1), and along the Saharan coast near Tarfaya, led by Aziz Ballouche and members of the Geological Survey of Morocco. What follows is our personal view of some of the major topics considered.

Fossil Soils

Desert sands, in general, are impossible to date by themselves, but where they interfinger with coastal, lacustrine and paleosol deposits, their paleoclimatic signal becomes rather clear. In the eastern Canaries multiple cycles of younger Tertiary and Quaternary volcanogenic rocks are overlain by Late Pleistocene calcareous eolianites, interbedded with calcified fossil soils everywhere associated with abundant *Helix* and astonishing concentrations of fossilized wasp nests. The youngest paleosol (about 9000 yBP) contains the curiously truncated pulmonate gastropod *Rumina decollata*. By comparison with living examples, this tells us of an environment formerly marked by seasonal, winter rainfall on Fuerteventura of about 400 mm, though it is today only around 50 mm, or during dry spells even less.

A feature of the base of each eolianite is the very sharp, smooth truncation of the previous paleosol, which suggests sustained wind velocities over 20 m/s from the east at the termination of each dune (plus soil) accumulation phase. Several of the contacts on Fuerteventura are also marked by a thin layer of lapilli (2-5 mm diam.) that indicates volcanic eruptions coinciding with times of extreme climate stress (cold, dry phases), yet another suggestive connection between planetary motion, solar activity, terrestrial spin rate, volcanism and climate, though the physical systems still require intensive and protracted research.

The fossil soils are not locally derived, but consist of greyish brown Saharan dust (silty clay) and commonly measure 20 to 80 cm in thickness. Being unstratified they indicate very rapid accumulation, probably within a few decades, but requiring sustained high winds off the Saharan desert.

Climbing dunes are still active on the northeast coast of Fuerteventura, with strips of sand emerging from below sea level. The sands themselves are more than 50% quartz, which precludes a mid-ocean, volcanogenic origin, whereas the intervening ocean depths preclude ice-age eustatic

lowering as an explanation. It was concluded that they must be traceable through many cycles, back to pre-spreading Saharan connections, to the late Precambrian and Ordovician glacial outwash sands and Mesozoic equatorial sands of West Africa.

Figure 1: Recent boulder beachridge abutting a raised beach platform of the last interglacial, dated around 100,000 yBP. Fuerteventura, Canary Islands.

Moroccan Sahara

Less than 100 km east of Fuerteventura is the Atlantic coast of the Sahara. As the plane circles down over Laayoune, the observer is made acutely aware of the Saharan presence by the immense belts of dunes, first as scattered barchans, then uniting, anastomosing and building up into the star-shaped dunes of the famous sand seas. Where the barchans are partially blocked by scrub vegetation or rocky outcrops, they bank up on each other, building pyramidal complexes. During the day, the insolation and surface heating leads to a temperature at ground level that often exceeds 60°C. This leads to a hot wind that blows up-slope on all sides of the pyramid, maintaining knife edges and a quasi-permanent pin-point top. At night the process reverses and the air flow is down-dune on all sides. For these reasons most evolved dune complexes are in essence geographically fixed, though not all observers agree on this point.

The astonishing climatic contrast between northern Morocco (the Atlas Mountains) and the Moroccan Sahara makes the region particularly rewarding for paleoclimate studies. Wide tree rings of the famous cedars recently analyzed by Claudine Till (Belgium) seem to reflect a periodic southward shift of the Westerlies, bringing rain and snow to the mountains. Narrow rings, in contrast, reflect droughts, which local history shows were commonly culminated by catastrophic famines (Guy Martinet, Morocco). Only a few of these

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anomalous rings point to major volcanic eruptions, but a large number coincide with anomalous rings in North America. Clearly, this is a subject inviting close investigation.

From palynological work by Aziz Balouche, a clear and frequent alternation in wet-dry conditions during the Holocene in Morocco is evident. What is most striking is that they are frequently out of phase from the north (winter rain) areas to the Sahel (summer rain) in the south.

Calcareous Crusts

Another remarkable feature of both the Atlantic Sahara and the semi-arid Canaries is the occurrence of calcareous crusts of different ages, thickness and facies. Their history seems to indicate a chain of events related to a succession of changing environments. First, the calcium carbonate dust and sand is brought by wind from the coast where it originates from the shell fraction of beach sand. It accumulates as a blanket, unrelated to its substrate. Later it is leached downward by rain water and displaced to accumulate as a paleosol, often silicified. Similar carbonate paleosols are recognized in mid-latitude (usually maritime) belts around the world (soil travertine, caliche, calcrete, croutes calcaires etc. and they clearly carry a paleoclimatic message. Modelling interactions between sea level, wind, rain and soil would help to illuminate a key mid-latitude climate history.

The coastal sand dunes today have a visible fraction made of small pieces of broken marine shells, foraminifera and calcareous algae. During humid seasons or extended phases (with vegetation and soil formation) the calcium carbonate of the marine shells is progressively dissolved and migrates more or less in relation to water circulation. A notable part stays in the soil profile and accumulates as a banded travertine crust comparable to cave deposits (it may include the continental snail *Helix* as well as small marine shells). Reprecipitated carbonates also commonly define former roots (rhizomorphs, rhizonecretions) and may merge downwards into vertical pipes leading to an extensive karst system.

The visual contrast between the inland dune accumulations (largely quartz grains free from carbonates) and the calcareous crusts on which they sit, dramatically reinforces our appreciation of the multiple and tremendous climate changes in these latitudes. The old idea that glacial-interglacial fluctuations of climate were features only of higher latitudes is long obsolete, but quantitative modelling of low-latitude belts is still urgently needed.

Satellite Imagery

At the symposium, numerous comparisons were made between the different types of satellite images. The French SPOT scenes show beautiful detail that should be seen side-by-side with the products of other techniques, notably that of the radar imagery (John McCauley and Carol Breed, U.S.A.). This is particularly rewarding for those interested in old pre-Saharan drainage networks, for these show up underneath a cover of sand (often only 1-2 m thick). A good deal of trenching and sampling shows that these old channels form an extensive network in the eastern Sahara, a palimpsest of formerly humid climates.

The buried drainage systems relate mostly to an early Nile, which developed its superposed position during various differential uplifts and particularly during the eustatic lowering of base level caused by the Late Miocene (Messinian) "salinity crisis," which lowered the rock bed by more than 200 m. Prior to that lowering there was a "cobble phase" of alluviation in the eastern Sahara when large rounded cobbles from the Red Sea hills were transported by east-west streams to sites far to the west of the present Nile (both in Egypt and Sudan).

Uplift of the Red Sea hills began during the high heat-flow stage of initial rifting in the mid-Tertiary, and not before. The origin of those giant cobble beds far out in the Libyan Desert was always a mystery to early explorers. In the long history of fluvial drainage in North Africa (as summarized at the meeting by P.F. Burolet, France) there have been repeated reversals of drainage direction, relating to plate tilting during collision and rifting events, but the main trends today relate to the episodic uplift of the Red Sea block, Tibesti, Hoggar, Atlas and the western Sahara belt.

The last water flow in most of these old stream systems was during the mid-Holocene climatic optimum, when summer monsoonal rains regularly reached 500-600 km farther north than today, and when extensive winter rains penetrated farther south than today. Enormous, well-populated freshwater lakes were then spread right across the Sahara (see review by Petit-Maire, *Episodes*, March 1986). Indeed Newman and Fairbridge have suggested (*Nature*, v. 320, p. 319-21, 1986) that some of these old buried channels could be identified and used in the future for subsurface recharge. Underground water storage is far more efficient and hygienic than surface storage, which suffers greatly from evaporative losses, salinification and other problems.

Ice-Age Winds

Climatologists have pointed out that when the continental ice-sheet front lay at about 50°N in Central Europe, the various climatic zones to the south would necessarily be squeezed together, and the wind velocity accordingly increased. With the evidence of Mediterranean pollen, paleosols, snails, winter precipitation and fresh-water lakes, we can now plot rather precisely the southern limit (in North Africa) of the Westerlies (about 20-25°N), and of the northeastern Trades (about 5-10°N). In the field, the upper boundaries between eolianite sets are cut off sharply, and similar abrupt terminations have been observed in the eastern Sahara.

Figure 2: Beachridge conglomerate from the last interglacial with *Strombus bubonius*, a distinctive warm-water gastropod that lives today in Senegal. Fuerteventura, which now lies in the track of a cold, northerly current.

Like sea waves, dunes become higher with increasing wind velocity until a maximum is reached (37 m/s for water, and less for dunes), and the crests tend to flatten. Where sustained winds of about 10 m/s are the rule today, in glacial times there must have been prevailing winds of about 20 m/s in order to truncate the tops of pre-existing dunes with knife-sharp, flat surfaces. The stripped areas leave regs, virtually endless plains made up of rocky fragments that are commonly not more than 5-10 cm across, and from which all the finer materials have been swept away.

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Oceanographers find considerable deposits of dust just off West Africa, but airborne dusts also turn up in the Antarctic ice cores in quantities on order of magnitude, or more, above the present accumulation rate, in quite remote deep-sea sediment cores, and, in the Canary Islands. For researchers interested in modelling stratospheric transport of fine particles, in this case, non-volcanic, the Saharan ice-age dust transport would offer a challenging project, and the Canaries a key area because of the intermittent nature of readily dated dust accumulation here.

The Canaries deposits can be explained by tropospheric winds (Easterlies), which would be appropriate only during brief interstadials during the last (Wisconsinan, Würmian, Devensian) glacial cycle. To find an actualistic model for this condition one has only to go back to AD 1903 when violent and protracted Easterlies blanketed the Canary Islands with dust.

It may not be without interest that the year 1903 was marked by a large positive spike in the ^{14}C -flux record from tree rings (i.e. a brief incident of very low solar activity).

At such times there are not only almost continual dust storms carried from the Sahara by easterly winds, but the local air temperature in the eastern Canaries (normally 20–25°C) often exceeds 40°C. The meteorologic setting seems to have been a succession of Icelandic lows reaching far to the SE encountering a quasi-stable blocking by a high pressure system over northwest Morocco. Light winter rains follow, supporting sufficient vegetation to nourish the hordes of snails and wasps. Radiocarbon-dated examples of those paleosols occur at around 9800 BP, 15,000 BP, 23,600 BP and greater than 30,000 BP.

Variations in the strength of the Canaries Current through climatic cycles have been mapped on the basis of deep-sea sediments. From the evidence of the "Senegal-type" littoral fauna (*Strombus bubonius*) on Fuerteventura and in the Mediterranean during the Tyrrhenian interglacials, the repeated return of a sort-of Northern Hemisphere El Niño can be visualized for the major warm cycles (Fig. 2).

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