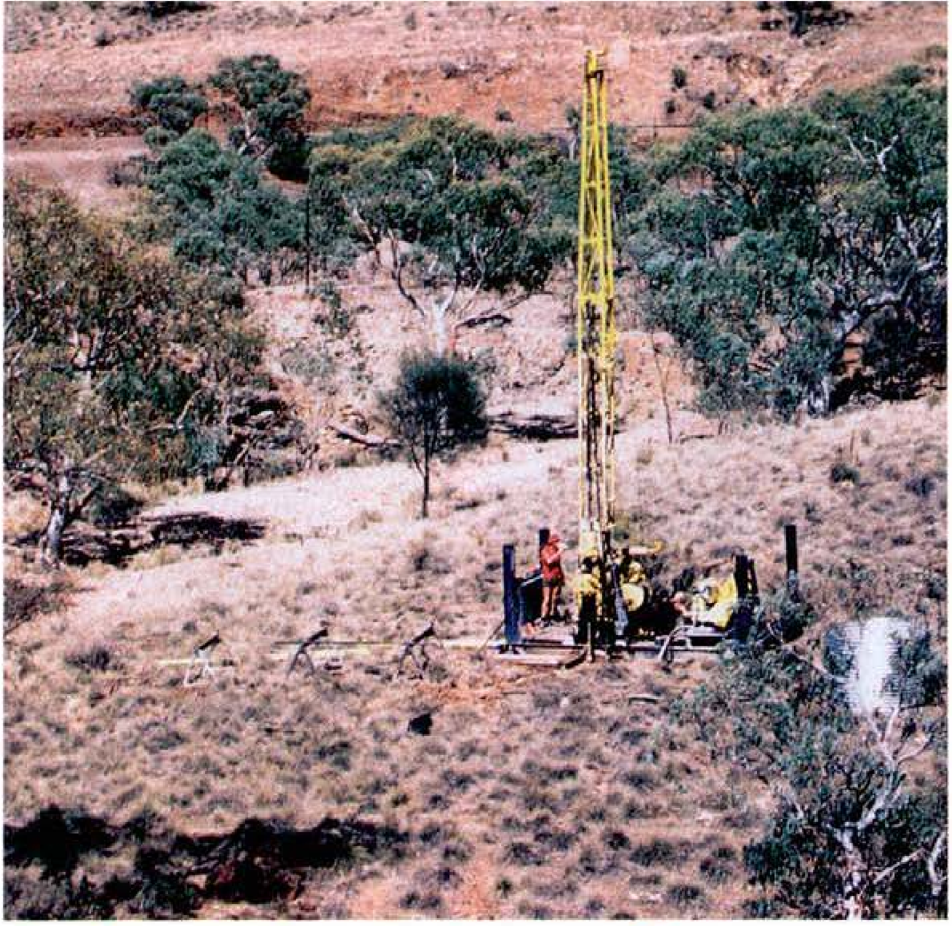


Drilling for varves at Pichi Richi Pass in the Flinders Ranges.

Solar signature from Australia's frozen past

Picture the hot dry Flinders Ranges in South Australia — and now try to imagine that landscape full of blue, icy-cold lakes and hard, frozen, treeless soil, perhaps like northern Canada.

Such athletic feats of the imagination are routine for geologists. According to them much of South Australia was totally frozen in the late Precambrian era, some 680 million years ago. Perhaps that's not so difficult to accept now that we all know about continental drift. If Australia had floated away to the North or South Pole we might expect a cold climate and glaciation. But, according to the latest evidence, Australia then was straddling the equator! Glaciers near the ancient equator suggest that the earth's climate differed radically from what we know today, which may have implications reaching far beyond this planet, and far outside the subject of geology.

Our story starts with fine-grained silt in the bottom of an ancient lake (deposited when lakes contained no animals or plants, as the highest forms of life then were bacteria and algae). The silt particles, mostly quartz fragments less than one-tenth of a millimetre across, with some clay, were washed into the lake each year following the spring thaw of the surrounding ice and permafrost.

Ice sheets existed near sea level close to the equator.

This yearly run-off into the bottom of the lake gave rise to a pattern of thin layers, or laminae. The coarsest material, being heavier, was deposited first and formed the bottom of each layer, with the finer material on top. Geologists call such annually recurring sedimentary layers in rocks varves. Varves are characteristic of a cold seasonal climate, and they often form in lakes near glaciers.

In 1979 Dr George Williams, a geologist with BHP's Exploration Department, became intrigued by regular laminae, or layerings, in rock outcrops at a place called Pichi Richi Pass in the Flinders Ranges. Although geologists had mapped the rocks of the Pichi Richi Pass area, the significance of these particular structures had not been appreciated. Dr Williams thought that the laminae might in fact be varves, but something else about the rocks fascinated him even more: the laminae displayed patterns caused by regular changes in their thickness.

Perhaps not many of us would have connected this with the sun, but Dr Williams had long been interested in astrogeology, and the solar cycle. This well-known phenomenon (see *Ecos* 26) concerns the occurrence of dark spots on the surface of the sun, which the ancient Chinese first detected thousands of years ago. More recently, in 1843, after 17 years of observations, Heinrich Schwabe in Germany announced a cycle, of about 10 or 11 years' duration, in the number of sunspots.

It's now known that sunspots are but one manifestation of variability in the sun. Ultraviolet and X-radiation, as well as the incidence of solar flares, also vary with the sunspot cycle. There has, of course, been considerable, and at times controversial, speculation about the effects of the solar activity cycle on climate (discussed in *Ecos* 26), but recognition of the solar cycle in rocks is something altogether more solid!

Other varved rocks had previously been the subject of dubious claims of sunspot rhythms, but they were 250 million years or more younger than those from Pichi Richi Pass, which originated in the Precambrian era.

Dr Williams reported his preliminary findings in *Nature*, but needed more data. However, as a full-time exploration geologist, he lacked opportunity for such research. This came in 1982, when CSIRO, under the terms of its Science and Industry Endowment Fund, sponsored the drilling of cores (using diamond drills) in Pichi Richi Pass. The three core samples obtained gave a far longer time sequence of varves than the 1760 years or so that Dr Williams had measured from the outcrop. He now had about 19 000 varves, which, if each varve truly represents an annual event, means a record of 19 000 years of sediment settling on the bottom of an ancient lake.

Variable varves

The crux of the whole matter lies in the variations in the thickness of these varves. A varve may range from 0·2 to 3 mm in thickness. A thicker one means that more silt entered the lake, which suggests a greater volume of melt-water, and therefore that the spring thaw was more intense in that year. Conversely, a thin varve indicates a relatively cool spring or early summer. So, by measuring varve thickness and analysing the variations, it's possible to come up with a great deal of information about changes in mean annual temperature in that far-off era.

The thickness of varves was measured with a precision of one-hundredth of a millimetre using equipment at the University of Arizona, U.S.A, designed for the precise measurements of tree rings, which incidentally also yield climatic data, albeit very recent in comparison with those from the rocks.

Dr Williams has carefully analysed the cycles contained in the varve data, and he compared the results with reliable records (unfortunately all too brief) of the solar activity cycle. The correspondence is excellent. Varve thickness and, therefore, summer temperature appear to have varied in sympathy with the solar cycle (see the box on page 17).

Both sets of data, when combed by a computer, reveal further cycles. The basic 12-year cycles themselves vary in intensity in a cyclical fashion. The 'highest' ones — that is, those containing the thickest varves — occur once every 26 cycles on average, which means about once every 310–20 varve years. Also, the precise duration of the basic cycles varies over about 13 cycles, and the thickest varves tend to coincide with relatively brief cycles. A zig-zag pattern results from the alternation of relatively thick and thin fundamental 12-year cycles.

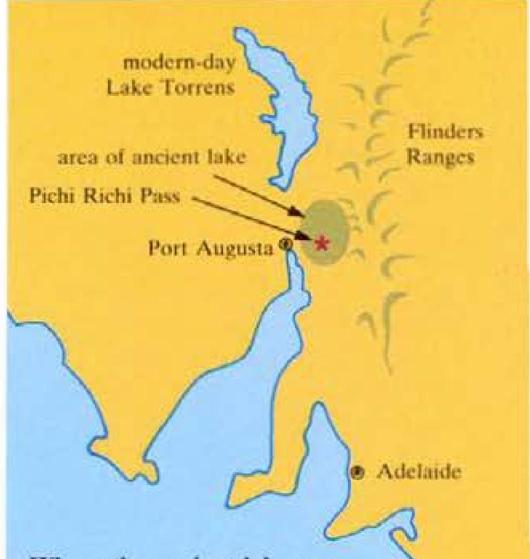
A drill core of red-brown siltstone from Pichi Richi Pass. Detailed study of the core material has revealed a remarkable variety of periodic signals that show similarities with sunspot periods.

These complex patterns are, remarkably, very similar to patterns seen in the solar activity cycle in modern times. The longer periods, of about 315 varve years, go beyond the time span of reliable solar records, but compare well with climatic periods — possibly of solar origin — that have been deduced from tree-ring studies.

But that's not all. The rocks from Pichi Richi Pass can also be analysed for the magnetism that has remained in them since their formation. This 'remanent' magnetisation, as the specialists call it, tells us the position of the earth's magnetic poles, and the strength of the magnetic field, during the period when the sediment hardened into rock (see *Ecos* 35).

Furthermore, these palaeomagnetic studies allow the scientists to infer the latitude of the rock when it was formed, because the magnetic particles in the rock are inclined towards the ancient magnetic pole. The angle of the miniature magnet — to what extent it is pointing up or down (which was set when the rock consolidated) — was determined by its position on the earth's surface relative to the pole.

Collaboration with Dr Brian Embleton of CSIRO's Division of Mineral Physics and Mineralogy, near Sydney, allowed analysis of the remanent magnetisation of the varved rocks. This showed that 680 million years ago Pichi Richi Pass was about 5° from the equator. (That's similar to the position of northern Papua New Guinea or Kuala Lumpur today.) The evidence is strong, and the conclusions seem inescapable: ice sheets and mean annual air temperatures below 0°C existed at or near sea level close to the equator during the late Precambrian. Other rock formations



Where the ancient lake was

from central and western Australia, with ages similar to those of the varves, yield results consistent with those from Pichi Richi Pass.

If regions near the equator were so cold, what about higher latitudes? Surprisingly, no clear evidence has yet been presented that shows glaciation (and therefore an inferred cold climate) at high latitudes at that time, although rocks of the correct age and palaeolatitude have been found. Dr Embleton suspects that glaciation was not world-wide; indeed it was probably confined mainly to the equatorial regions.

Of course, we could argue that something is amiss with, for example, the palaeomagnetic data. How do we know that the rocks have not been re-magnetised at a later period, long after they were laid down, and so our conclusions about latitude refer only to a more recent event? This has been the trouble about interpreting palaeomagnetic data for certain other late Precambrian glacial rocks.

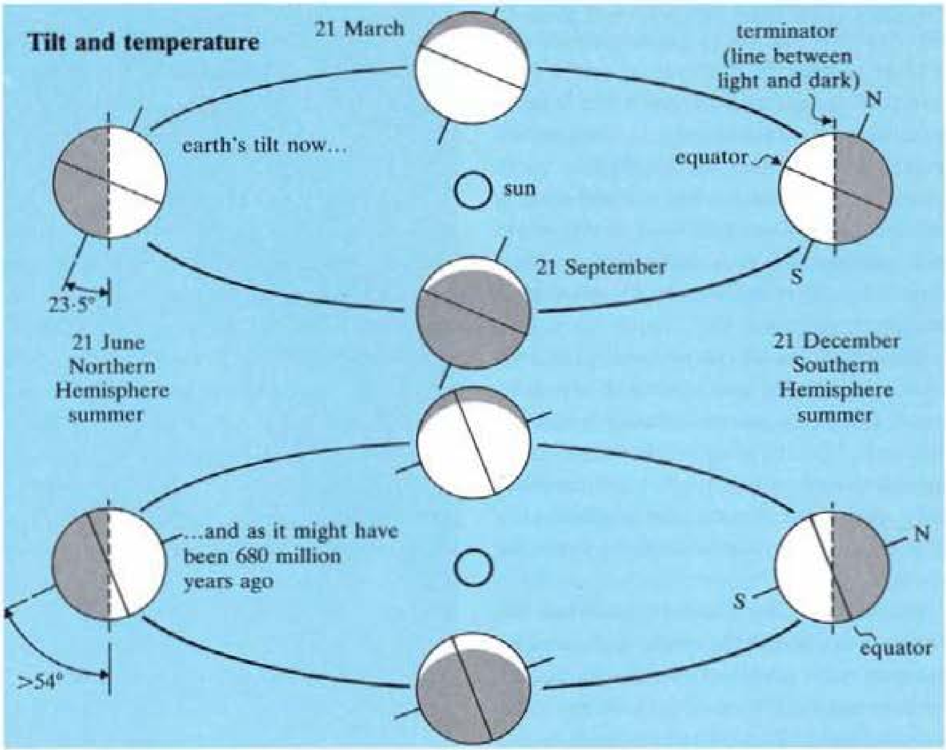
Dr Embleton and Dr Williams succeeded in demonstrating that the magnetisation in their rocks was definitely primary — that is, it occurred when the rocks solidified. This they did by heating the rocks to see what temperature destroyed the remanent magnetisation, and found that this had to exceed 600°C. Now, from a rock's structure it's possible to glean some information about certain physical extremes to which it has been exposed. If a rock shows no metamorphism (geologists' Greek for certain changes), you can conclude that it has not suffered any significant high pressures or temperatures. The Pichi Richi Pass rocks had not experienced anything in their life span that would cause them to lose their original magnetism.

Out into space

After considering all the evidence in the rocks, we have to ask an obvious question: what could cause such a difference in the

The varves in the rock from Pichi Richi Pass

The photograph depicts a thin section of rock viewed with transmitted light, in which the cycles, of about 10 to 14 laminae, show quite clearly. The laminae are up to 3 millimetres thick, the thickest occurring near the centres of the cycles. Typically the laminae are graded; that is, they consist of coarser-grained material near the base and progressively finer material towards the top. The coarser grains appear paler with transmitted light, as they consist mostly of translucent quartz and feldspar; the finer material appears darker because of its higher content of clays and other finely dispersed opaque material. The laminae are interpreted as annual increments (that is, varves) deposited in the lake by the settling out of grains from suspension following annual inflows of melt-waters.



climate of our planet? Nobody knows for certain, but there are various theories.

One easy suggestion is that perhaps the sun, for reasons best known to itself, went through a 'cool patch', decreasing its output of radiation for a few million years (a short time to geologists). In that case, however, the whole world would be cooler, and glaciation would be global. Now, as we've already observed, there's no evidence of glaciation occurring in polar latitudes in those days, even though polar land masses existed then, so we can safely rule out this idea, and conclude that our sun was reliable after all (and, we hope, still is).

Another possible explanation is quite simply that we have our facts wrong. Perhaps the rocks at Pichi Richi Pass weren't formed within 5° of the equator. This could only be the answer if the magnetic poles did not correspond (on average) with the geographic poles.

Put simply, geologists believe that material in the centre of our planet behaves something like a giant bar magnet, which, although it may wander slightly, is aligned with the earth's axis of rotation (when averaged over several thousand years), and that therefore geographic and magnetic poles coincide. If this model is wrong, then conclusions about the latitudes of our ancient rocks could be, too. The little magnetic particles in the rocks, remember, point to the poles of the earth's giant magnet. If these poles don't, on average, correspond with the geographic poles, then the calculated latitudes of the rocks are only magnetic latitudes and do not represent true geographic positions.

In fact, we have a great deal of evidence in support of what geophysicists call the axial geocentric dipole model — that is, our giant bar magnet aligned with the earth's axis. Firstly, it is strongly supported (for times more recent than the Precambrian era) by the fact that latitudes deduced from the study of ancient magnetism 'make sense', and generally correspond well with evidence from other areas of geology. Secondly, other planets (with the possible exception of Uranus) have their 'internal magnet' aligned near their axis of rotation.

Geophysicists would be unwilling to abandon this model totally, as it accords so well with known facts. However, it could still be said that perhaps the model is invalid just for the late Precambrian era, but there is absolutely no reason why it should be, other than the fact that it has led us to some rather astounding conclusions about the earth's climate.

Earth's current orbital inclination, like that of most of the other planets, is within about 25° of the vertical. But it may not always have been so — a much greater tilt could explain the conclusions about South Australia's ancient climate suggested by the varves. It would give cooler equatorial latitudes, warmer poles, and more extreme seasonal changes.

Finally, we are forced to consider another explanation, which takes us into the realm of celestial mechanics. It concerns the obliquity of the earth's ecliptic — that is, the angle that the axis of rotation makes with the perpendicular to the plane of the earth's orbit around the sun. This angle, currently about 23·5°, determines the maximum angle that the sun can achieve above the horizon anywhere on the planet, and hence our climatic zones.

Any increase in the angle would lead to important changes in global climate. The poles would receive more radiation annually than they do now, and ultimately, if the angle exceeded 54°, low latitudes would actually receive less energy from the sun per year than high ones, and therefore we might expect regions near the equator to be glaciated when areas near the poles were not. The difference between seasons would also be greater, and, unlike today's tropics, areas near the equator would undergo important seasonal temperature changes.

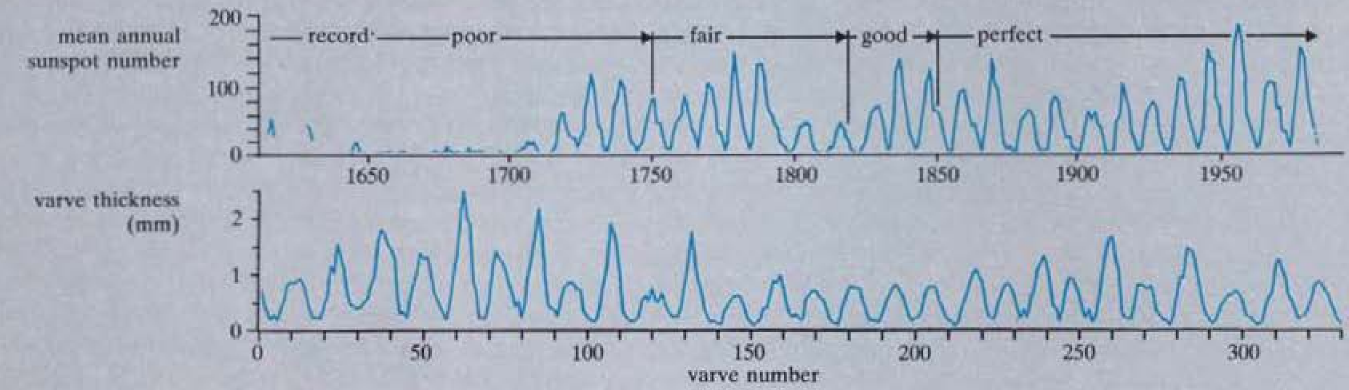
A comparison of cycles

The graphs show the similarity between the solar activity cycle in recent times and variations in the thickness of the ancient varves.

The first shows the mean annual sunspot number since 1610. Sunspot number broadly indicates total solar activity. According to astronomer John Eddy of the High Altitude Observatory in Boulder, U.S.A., the record may be regarded as 'perfect' back to about 1850. It may be regarded as 'good' from 1818 to 1850, only 'fair' from 1750 to 1817, and 'poor' prior to 1750. The change in structure of the curve in the mid nineteenth century may therefore be attributed to the unreliability of the data before that.

The second graph depicts varve thickness in drill-core material from Pichi Richi Pass. It shows 27 varve cycles that display alternating high and low amplitudes, as well as long-term variation in amplitude.

Essentially, this graph shows how mean annual (or summer) temperature varied with time in those far-off days.



When we consider what could cause such a change in the angle of the ecliptic, we enter an almost boundless realm of speculation. Certainly, the idea of a perturbation following a close approach by (or dramatic impact with) another body suggests itself, but we would need independent evidence.

The Australian rocks have yielded facts that force us to be broad-minded in our search for explanations. But, even if we think we can explain cold climates near the Precambrian equator, questions remain. The solar activity cycle continues today, and we have lakes near glaciers, or in areas of permafrost, where varves are formed — as they were in the cold lake that once existed in the Flinders Ranges. Do these recent varves record the solar cycle? It appears that they do, albeit very weakly. In other words, the relation between varve thickness and solar activity is not as strong today as it was in Precambrian times.

This leads us to a further, and debatable, question: does a 'solar signal' affect our weather or climate today? If it does, the effect is difficult to discern with any clarity.

So what accounts for the greater sensitivity to variations in the sun shown by the Precambrian climate? Dr Williams speculates that it may be connected with the different composition and structure of the earth's atmosphere then. The Precambrian atmosphere contained far less oxygen (much of the oxygen today has been released by plants, which acquire it from breaking down carbon dioxide). Ozone, a gas with molecules comprising three atoms of oxygen, can be made by the action of ultraviolet radiation on oxygen. Today's quite famous ozone layer is high up in the stratosphere. But Dr Williams believes that a smaller oxygen content would have allowed ultraviolet rays to penetrate further, to produce an ozone layer at lower levels.

We know that today's ozone layer changes in temperature and other properties in response to the solar activity cycle. Could such changes have occurred in the much lower ozone layer in the atmosphere of Precambrian times, and hence have influenced temperatures near the ground far more? With the increase in oxygen since the Precambrian, the atmospheric effects of the solar activity cycle might have been pushed upwards, to a level where they can only exert a subtle and often barely detectable influence on our weather and climate.

Solar signature

The data from Pichi Richi Pass lead to one firm conclusion: that the solar cycle was much the same 680 million years ago as it is today. It's a comforting thought, as it confirms the stability of our star. Furthermore, the precise details of the data may be useful for making more accurate predictions of variations in the maxima and minima of the solar activity cycle (of great importance in forecasting the occurrence and severity of 'solar storms'). As Dr Williams puts it, these varved rocks are potential solar observatories.

The search will now be on to find the sun's signature in even older rocks, to give us greater insight into the history and the workings of our star, and indirectly the entire solar system. Indeed, looking for varves on Mars (which once had running water and, presumably, lakes), to corroborate the results from earth and to find even older material, is likely to be an important task for unmanned probes or even for the first Martian astronauts. We await a possible extraterrestrial sequel to a story that had its origins among dry rocks in a remote corner of Australia.

Roger Beckmann

More about the topic

Sunspot periods in the late Precambrian glacial climate and solar–planetary relations. G.E. Williams. *Nature*, 1981, **291**, 624–8.

Precambrian varves and sunspot cycles. G.E. Williams. In 'Weather and Climate Responses to Solar Variations', ed. B.M. McCormac. (Colorado Associated University Press: Boulder, Colorado 1983.)

Solar signature in sedimentary cycles from the late Precambrian Elatina Formation, Australia. G.E. Williams and C.P. Sonnet. *Nature*, 1985, **318**, 523–7.

Solar affinity of sedimentary cycles in the late Precambrian Elatina Formation. G.E. Williams. *Australian Journal of Physics*, 1985, **38**, 1027–43.

The solar cycle in Precambrian time. G.E. Williams. *Scientific American*, 1986, **254** (in press).

Low palaeolatitude of deposition for late Precambrian periglacial varvites in South Australia: implications for palaeoclimatology. B.J.J. Embleton and G.E. Williams. *Earth and Planetary Science Letters*, 1986 (in press).