The Global Refrigerator - And Now A Switch?

By Bob Foster

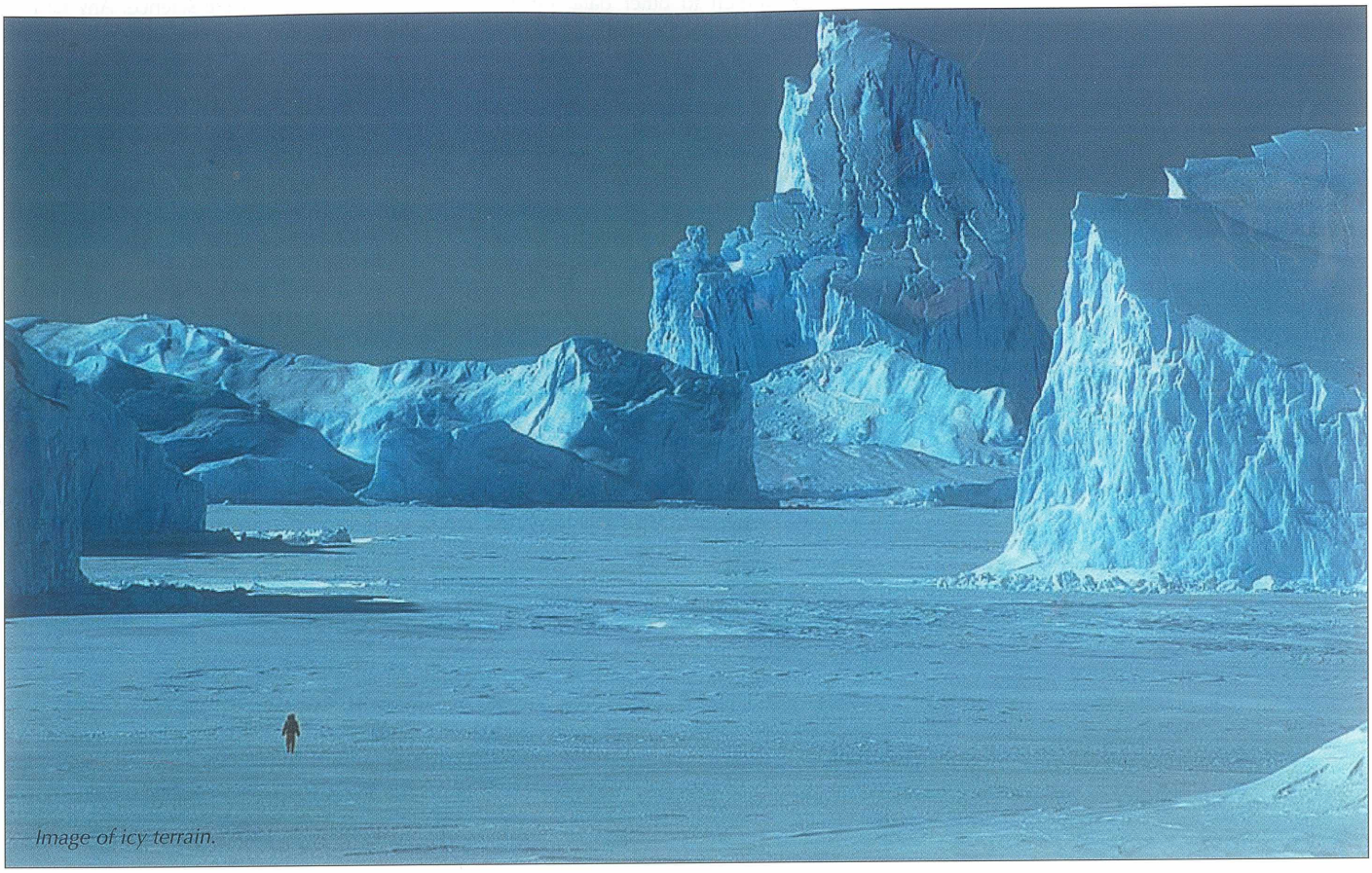

Image of icy terrain.

What happened to the warm, wet, Earthly Paradise of Cretaceous times? Why is our home planet so cold and dry now? Solar radiation is the key determinant of variation in the Earth's warmth at several time-scales, although the Sun appears to have played no crucial role here. Instead, tectonics took the lead. Over the past 50 million years (My), the northward march of the Indian subcontinent and resulting uplift of the Tibetan Plateau have been influential (Raymo and Ruddiman 1992). Continual rejuvenation of the high-relief terrain, consequent accelerated weathering, and subsequent increased deposition of carbonate sediments are likely to have been the major cause of reduced atmospheric CO_2 concentration - perhaps fourfold - over the period. A lesser greenhouse effect, means a cooler Globe.

Figure 1 is from Lear *et al* (2000), although a version of Figure 1B accompanied the paper by Raymo and Ruddiman. Because ice forms with a different ratio of the oxygen isotopes to that in the parent water-body from which it freezes, variations in the ^{18}O content of the world's oceans ($d^{18}O$, as enshrined in Atlantic sea-bed cores, see Figure 1B) is a good proxy for the volume of ice existing globally at that time. Notably, there are steps and still-stands in the growth of global ice volume - hardly characteristic of slowly changing atmospheric composition acting alone.

I correlated (Foster 1974) the sharp temperature drop in the still narrow seaway between Antarctica and Australia at about 41-36 My before the present (BP), with the opening of Drake Passage and the concomitant inception of the mighty Antarctic circumpolar current. My evidence was the dramatic change in the shallow water echinoid fauna at that time, from neo-tropical to neo-arctic in its aspect. As is the Tibetan uplift, this is a tectonic driver.

It appears that there was an abrupt increase of ice volume at about the same time as the opening of Drake Passage. Indeed, it is very likely that this tectonic event marks the beginning of the global accumulation of continental ice on any significant scale, and its early accumulation was on the continent of East Antarctica.

Lear *et al* have built up a deep-ocean temperature record across the Cainozoic, based on the magnesium/calcium ratio in benthic foraminiferal calcite (Figure 1A), showing a cooling of some 12 °C in steps which parallel those of global ice accumulation. However, and important to the theme of this paper, they conclude that the deep-ocean cooling was more gradual than was the ice accumulation in the vicinity of the Eocene/Oligocene boundary - and continued well beyond the time of rapid ice build-up, rather than running ahead of it. Ocean cooling did not create the East Antarctic Ice Sheet.

Preservation of the continental ice sheet on East Antarctica (whose rapid accumulation Lear *et al* place at about 34 MyBP) albeit with some subsequent variability in its volume, and the continued deep ocean cooling thereafter, are consistent with this ice sheet becoming the world's 'refrigerator'. There is little doubt that this ice sheet post dates the creation of Drake Passage, and that the ice-sheet-refrigerator owes its durability to the presence of the circumpolar current. But could breaching of the Andean-West Antarctic Cordillera, on its own, have been enough to switch it on, particularly in such emphatic fashion?

The Fohn-1 offshore exploration well in the Bonaparte Basin, drilled in the Zone of

Cooperation between Australia and (then) Indonesia, might have uncovered the switch when it encountered a buried impact crater formed in a late Eocene erosional surface (Gorter 1999). The well penetrated a 350 m breccia lens displaying high platinum-group-element abundances, including iridium, and PGE ratios indicative of an extra-terrestrial origin. Close spaced seismic profiling shows a possible rim anticline to the Fohn crater with a diameter of some 3 km, and a field of around 30 smaller depressions spread over an axial length of more than 100 km at the same horizon.

According to Gorter, the stratigraphic relationship and the limited palaeontological evidence place the bombardment at 38-34 MyBP; and he suggests that it could be contemporaneous with the Popigai (Siberia, 100 km diameter crater) and Chesapeake Bay (USA, 90 km) impacts. Indeed, new information from a presentation by Farley[1] makes it likely that the impacts in the Timor Sea region of Australia's continental shelf are indeed part of the same series of events as those in Russia (35.8+/-0.8 MyBP) and the United States (35.5+/-0.3 MyBP). These latter are by far the largest known impacts during the Cainozoic.

Using the helium isotope ^{3}He (otherwise extremely depleted on Earth) contained in seafloor sediments, Farley's group have built up a record of the delivery rate of cosmic dust (tiny fragments of asteroids or comets) over the past 100 My. Abundance of extra-terrestrial material increases by eight or nine orders of magnitude for a period of a million years or more at about 36-35 MyBP - and this is the only very pronounced peak in the Cainozoic.

Uplifted marine sediments in the Italian Apennines provide the type locality for the Late Eocene. Here, falling within the period of increased ^{3}He concentration, are twin peaks of Ir and shocked quartz abundance - evidence of comet or asteroid arrivals. Farley speculates that these events are cometary impacts, and are the result of galactic tidal perturbation of the Oort Cloud - presumably by a passing star; and that the lasting outcome on Earth was the extinctions which mark the Eocene/Oligocene boundary.

The lesser impacts, in the Timor Sea, are almost certainly part of the same million years or so of bombardment.

Even if the larger individual impacts were separated by a few hundred thousand years, episodes of 'nuclear winter' would be their likely result. Any of these coolings might have been severe enough to frost-over the Antarctic continent, and thus get the giant East Antarctic Ice Sheet started. The circumpolar cold current would have served to preserve the nascent covering of ice (and its crucial albedo change) between impacts.

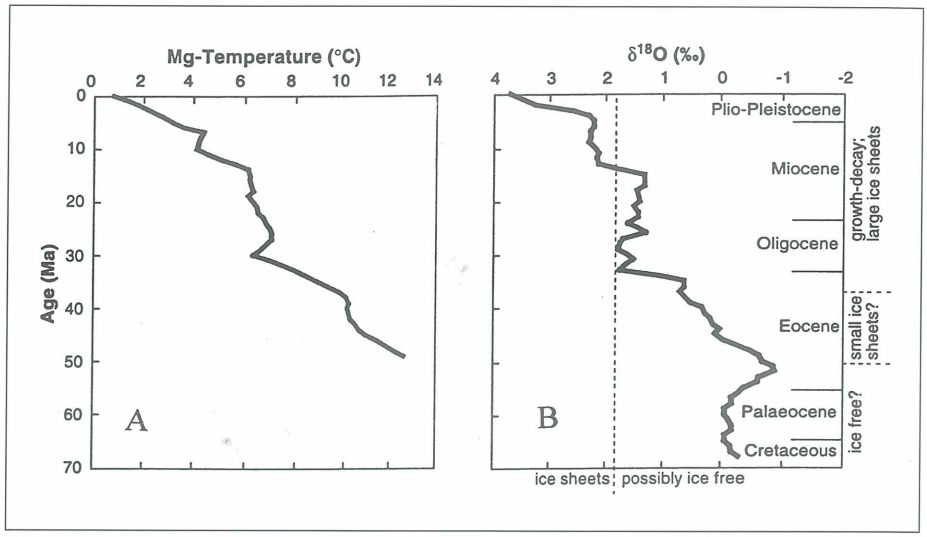

Fig. 1. (A) Magnesium-based temperature record obtained from composite Mg/Ca data for benthic foraminifera from deep-sea sites. (B) Cainozoic composite benthic foraminiferal record of oxygen-isotope differences from Atlantic cores. (Reprinted with permission from: Lear, C.H., H. Elderfield & P.A. Wilson 2000, "Cenozoic deep-sea temperatures and global ice volumes from Mg/Ca in benthic foraminiferal calcite", Science 287 269-72. Copyright 2000 American Association for the Advancement of Science).

Accumulation of a substantial ice sheet was the end result of the bombardment. Enter catastrophism.

However, there is another problem to be resolved; and it is well displayed in Figure 1B. The events prior to the beginning of the Oligocene, as summarised above, might well explain both the abrupt cooling at around 35 MyBP, and the absence of subsequent rebound to the previous (Upper Eocene) level of warmth. But what caused the further rapid growth of the East Antarctic Ice Sheet at around 14 MyBP? This surge of renewed accumulation appears to have brought the Ice Sheet to about its present volume (some 80% of today's global ice quantity, and equivalent to about 50 m on global sea level). Again, catastrophism might have been the key.

There is a well known example (Rampino and Self 1992) of another sort of catastrophic and climate influencing phenomenon in the volcanic winter and accelerated glaciation following the Toba (Sumatra) super eruption of about 74,000 years (ky) BP. It was this event which tipped an already cooling Earth into the depths of the last (Würm) Glacial, with massive ice sheets (reducing sea level by about 100 m) forming on northern North America and northern Eurasia. More of this later.

Cas (1999) explains how the 'aerosol' gas SO_2, emitted in volcanic eruptions, readily combines with H_2O to produce H_2SO_4 vapour droplets. These droplets, dispersed in the atmosphere, would significantly increase planetary albedo and hence the proportion of incoming solar warmth which is reflected to space. Global cooling would be the result.

He reminds us of the Mount Pinatubo eruption in 1991 (30 M tonnes H_2SO_4 released into the atmosphere), which caused a temporary global cooling of some 0.5°C; Toba (see above) with at least 1,000 Mt H_2SO_4 emitted, caused a cooling of some 3-5 °C; and much further into the past at some 14.7 MyBP, the Roza flood basalt (USA) with some 12,000 Mt of H_2SO_4 emitted at the time of its out-pouring, caused a cooling of 5-15°C over a period of a decade or so. Here, we have a plausible trigger for the growth of the East Antarctic Ice Sheet to its modern dimensions.

The *coup de grace* was the sealing about 3.5 MyBP (by the emergent Isthmus of Panama) of the seaway which had linked the equatorial Pacific and Atlantic, leading to the early accumulation of continental ice on Greenland. By some 2.5 MyBP, the current Ice Age was with us (see Figure 1B); and within the last million years it has taken on its modern (apparently solar-driven, and orbitally-controlled) Glacial/Interglacial cyclicity of about a hundred thousand years.

Ours is not a uniformitarian world, and extreme events have played a prominent part. The East Antarctic Ice Sheet is the Globe's refrigerator; and the on-switch was a shower of comets. But why am I pressing on you this memorial to happenings long ago?

The reason is that we humans are almost through our allotted 10,000 years or so of milder climate - and the Sun is again on the wane. Indeed, we live in a doubly mild period. We not only enjoy an Interglacial in an Ice Age cycle of long Glacials and short

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Interglacials. There is, in the Northern Hemisphere, a secondary 1,500+/-500 year cold/warm cycle overprinting the longer and stronger global cyclicity. The latest of these lesser cold periods was the Little Ice Age of *ca* AD1300-1900. Already, temperatures are running below the level in the middle of the Interglacial (the Holocene Optimum) some 6-4 kyBP, and the next 'Little Ice Age' might be the cold period which triggers the long decline into the next Glacial. Who knows?

Do we want the return of harsher conditions which might stay for the next 80 or 90,000 years? If the past is a guide, even a 'Little Ice Age' no more severe than the last has the potential to cause human misery on a vast scale. How can we ameliorate or prevent what now appears inevitable? Where should we be looking for the Ice Age's off-switch?

Finally, some ethics: is it wrong to interfere with the natural order? Some think not, it appears, because there is already the beginning of an organised look-out for objects in space whose orbits might intersect our own at the wrong time - with a view to self-preservation. Perhaps, we should now begin to assess the ethical and scientific pros and cons of taking the next step - seeking deliberately to warm our Globe.

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[1] New to me, anyway. On 16th March last, I attended a Geological Society of Australia lecture by Professor Kenneth A. Farley, a noble-gas geochemist from the Division of Geological & Planetary Sciences at Caltech, in which he gave details of the work of his research group.

New Words In The Making

We were recently sent a list of words that had been altered by changing, adding or subtracting one letter, followed by the meaning of the new word. The result was very funny, which got us thinking that perhaps we could do the same with words used in the oil and gas industry.

Some of you may well think that the originator of this material, and anyone who pursues it, has too much time on their hands. However, here are the words sent in followed by a few that apply to our industry (sent in by a past Federal President - who will remain nameless).

Reintarnation: Coming back to life as a hillbilly.
Foreploy: Any misrepresentation about yourself for the purpose of getting laid.
Giraffiti: Vandalism spray-painted very, very high.
Sarchasm: The gulf between the author of sarcastic wit and the person who doesn't get it.
Inoculatte: To take coffee intravenously when you are running late.
Hipatitis: Terminal coolness.
Osteopornosis: A degenerate disease.
Karmageddon: It's, like, when everybody is sending off all these really bad vibes, right? And then, like, the Earth explodes and it's, like, a serious bummer.
Glibido: All talk and no action.
Dopeler Effect: The tendency of stupid ideas to seem smarter when they come at you rapidly.
Intaxication: Euphoria at getting a tax refund, which lasts until you realize it was your money to start with.

The following is contributed by a past president.

Depth imagining: An arm-waving method of depth conversion.
Depth Conversation: Talking about methods of constructing velocity maps.
Joint venture: Getting together to grow the weed.
Bidget: Work program suitable only for the toilet.
Asproval: What you take to rid yourself of the headache of getting the correct signatures.
Permats: Very very very small permits.
Surat Bison: Large hairy bovines from near Roma, Qld.
Petroinsultants: Dinah and Maddie on a bad day.
Landmauk: Sean has returned!
Geoquestion: The service arm of Geoquest.

If anyone else has a few minutes of idle time during the next couple of weeks, send your 'new words' and their meanings to pesanews@oilfield.com.au

Irritations: Get Them Off Your Chest

I'm not sure about new words and their meanings but I am sure we have all been irritated by what we thought to be pretty obvious or even senseless sayings that offer little more than time wasting.

Maybe you would like to share some of these with us? Maybe you hear some of them every day at work - so you can never get away from them. Well, we would like to give you the chance to get them off your chests - perhaps the person who keeps saying them may even recognise their sayings and change their ways (oh yeh?).

Send us some that have made you grind your teeth, and just to help get the juices working we offer the following classics:

1. People who point at their wrist while asking for the time.
I know where my watch is pal, do you know where yours is? Do I point at my crotch when I ask where the toilet is?

2. People who are willing to get off their backsides to search the entire room for the TV remote because they refuse to walk to the TV and change the channel manually.

3. When people say "Oh you just want to have your cake and eat it too". *I ask you, what good is a cake if you can't eat it?*

4. When people say, "it's always the last place you look".
Of course it is. Why would you keep looking after you've found it? Do people do this? Who and where are they?

5. When people say while watching a film, "did you see that?" *No of course I didn't, I paid $13 to come to the cinema and just stare at the floor.*

6. People who ask, "Can I ask you a question?" *Didn't really give me a choice there, did you sunshine?*

7. When something is "new and improved"! *Which is it? If it's new, then there has never been anything before it. If it's an improvement, then there must have been something before it.*

8. When people say, "life is short." *Can you believe this? Life is the longest thing anyone ever does!! What can you do that's longer?*

9. When you are waiting for the bus and someone asks, "Has the bus come yet?" *If the bus had come would I be standing here?*

Drake Passage opening – and climatic impact

Robert J. Foster 1974, ""Eocene echinoids and the Drake Passage", *Nature* Vol. 249, p. 751.
Bob Foster 2000, "The global refrigerator – and now a switch?", *PESA News* Issue 46, pp. 56-8.

(Reprinted from Nature, Vol. 249, No. 5459, p. 751, June 21, 1974)

Eocene echinoids and the Drake Passage

AUSTRALIA and Antarctica separated about 50 million years (Myr) ago[1]. Echinoid populations indicate a warmer climate at the time of separation than later. A model of oceanic circulation in the Southern Hemisphere, consistent with this observation, leads to a more precise dating of the opening of the Drake Passage between South America and Antarctica.

The oldest echinoid fauna known from the opening seaway between Australia and Antarctica has been preserved at several localities between Albany and Adelaide. The fauna is most abundant and best known in the Late Eocene Tortachilla Limestone, which outcrops along the eastern flank of the St Vincent Basin, south of Adelaide. Eighteen species of echinoids have been described from this formation of small lateral extent and a further five have yet to be described. The marsupiate echinoids, which are intermittently common in the Tertiary of southern Australia, are notably absent. Echinoids are also abundant a little further up the section at a Late Eocene horizon, low in the Port Willunga Beds. Less than 10 species are known at this level, and almost all are of genera different from those in the earlier Tortachilla. They include the earliest of the Australian marsupiate echinoids, the temnopleurid *Paradoxechinus stellatis* Philip and Foster.

A similar situation exists on the opposite flank of the basin. There is a complete change in the echinoid fauna between the Muloowurtie Formation and the overlying Rogue Formation in which *P. stellatis* appears.

By analogy with recent Antarctic brood-protecting echinoids, it has been inferred that the marsupium, developed in the female of several species of Australian Tertiary Temnopleuridae, Clypeasteroida and Spatangoida, confers an advantage in colder water[2]. An unsatisfactory aspect of correlating the presence of marsupiate echinoids with cold water is that the earliest fauna of the discussed region contains no marsupiate echinoids—despite the fact that this fauna probably lived more than 20° further south than its present position. Marsupiate echinoids are, in fact, a conspicuous component of the fauna during the journey of Australia towards the tropics.

Frakes and Kemp[3] proposed a model of early Tertiary climates which may provide the answer. In the Eocene there was no circumpolar cold current in the Southern Ocean because of the presence of a continuous Andean–West Antarctic mountain chain. As Australia was far to the south of South-east Asia, ample room existed for the southern equatorial current of the Pacific to continue into the Indian Ocean, sweep south and return, at least in part, through the new seaway which separated Australia from Antarctica. Because of the long time spent travelling through about 200° of longitude in the tropics, the equatorial current, which left the coast of South America at about 19° C. began its southerly sweep into the Indian Ocean at about 37° C. It was probably still above 20° C as it passed along the southern coast of Australia. A warm water echinoid fauna can therefore be expected. By the mid-Oligocene, the northward drift of Australia had restricted the flow of warm equatorial Pacific water into the Indian Ocean. More important, the breaching of the Andean–West Antarctic mountain barrier allowed a circumpolar cold current to replace the warm current in the widening seaway between Australia and Antarctica. The water temperature probably fell to well below 10° C. A changed echinoid fauna, including brood-protecting species, is consistent with this model.

Dalziel and Elliot[4] estimate the opening of Drake Passage, and thus the beginning of the circumpolar current, to have occurred between the latest Cretaceous (65 Myr) and about 25 Myr ago.

The Tortachilla Limestone was deposited at the beginning of the Late Eocene, probably high in P15 in the planktonic foraminiferal zonation[5]. The Port Willunga Beds have been sampled and dated[6] especially to provide a time framework for the sequence of echinoids, and the horizon containing *P. stellatis* has been placed high in the Late Eocene, corresponding to P17.

Using ages attributed to the planktonic foraminiferal datum planes[5] as a guide, the event which caused the replacement of a warm water by a cold water echinoid fauna in the seaway between Australia and Antarctica can be dated at about 40 Myr—probably 41–36 Myr. This event was probably the inception of the mighty Antarctic circumpolar current, which began with the breaching of the Andean–West Antarctic Cordillera and the concomitant creation of the Drake Passage. Thus, there is indirect evidence which enables the separation of South America from Antarctica to be more precisely dated than before.

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