# The Little Ice Age and medieval warming in South Africa

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**The Little Ice Age in South Africa, from around AD 1300 to 1800, and medieval warming, from before 1000 to around 1300, are shown to be distinctive features of the regional climate of the last millennium. The proxy climate record has been constituted from oxygen and carbon isotope and colour density data obtained from a well-dated stalagmite derived from Cold Air Cave in the Makapansgat Valley. The climate of the interior of South Africa was around 1°C cooler in the Little Ice Age and may have been over 3°C higher than at present during the extremes of the medieval warm period. It was variable throughout the millennium, but considerably more so during the warming of the eleventh to thirteenth centuries. Extreme events in the record show distinct teleconnections with similar events in other parts of the world, in both the northern and southern hemispheres. The lowest temperature events recorded during the Little Ice Age in South Africa are coeval with the Maunder and Sporer Minima in solar irradiance. The medieval warming is shown to have coincided with the cosmogenic $^{10}$Be and $^{14}$C isotopic maxima recorded in tree rings elsewhere in the world during the Medieval Maximum in solar radiation.**

The climate of the last millennium has been reviewed extensively.[1–8] Two events are prominent features of the record, the Little Ice Age from about the fifteenth to nineteenth centuries, and the period of medieval warming from about the tenth to fourteenth centuries. Controversy attaches to both episodes;[4,9,40] some even doubt their occurrence at all.[10] Of the two, the Little Ice Age was more widespread and, though not a period of continuous cold, was one of the most globally-extensive cool periods since the Younger Dryas. The period of medieval warming was highly variable and not nearly as extensive; in many parts of the globe it has not been reported at all.

In South Africa, both medieval warming and the Little Ice Age are features of the climate of the last millennium. Initially, the evidence for their occurrence was episodic or based on low-resolution time series of proxy climatic data.[11] Recently, quasi-decadal resolution oxygen and carbon-stable isotope data derived from a speleothem recovered from Cold Air Cave in the Makapansgat Valley, approximately 30 km southwest of Pietersburg, has provided confirmation of the widespread regional significance of the events.[12] The derivation of actual temperatures from ~5-year-resolution colour banding in the stalagmite provides the basis for a detailed examination of the occurrence of the Little Ice Age and medieval warming in South Africa (K. Holmgren *et al.*, in prep.). Such an investigation is undertaken in this paper and the results compared with evidence for the events elsewhere in the world.

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## Data and methods

Alpha-spectrometry $^{230}$Th/$^{234}$U dating was used to establish the age of the stalagmite along its growth axis from the time of its formation 6600 years ago onwards. The stalagmite grew continuously until 1996 when it was first analysed. A low-resolution image (127 dpi) polished section of the central-line growth axis of the stalagmite was scanned using an HP ScanJet 11cx/T to determine an index of colour variations in the growth layers of the stalagmite.[13] Variations in the colour banding of the speleothem represent changes in the concentration of humic matter in the drip water feeding the stalagmite. Darker banding reflects increased concentrations of organic complexes, associated with enhanced grass cover on the surface above the cave during wetter and warmer spells; lighter banding occurs in dry periods with a sparse grass cover.[12,13]

Colour variations in banded growth-layer laminations of the stalagmite show a strong correlation (+0.78, significant at the 99% level) with changes in a 49-station, area-averaged, regional annual maximum temperature anomaly series for South Africa[14] over the years 1981–1995. A linear statistical transfer function has been derived for this period and applied to the variation in colour banding over the last 1000 years. The proxy temperature series so derived has a resolution of ~5 years and acceptable confidence limits for the last millennium (K. Holmgren *et al.*, in prep.).

## Results and discussion

Analysis of $\delta^{18}$O variations over the last 3000 years reveals that the greatest depletion occurred during the five centuries from 1300 to 1800.[12] Extension of the record back to 6600 B.P. confirms that the Little Ice Age depletion was the most pronounced prolonged event in the entire record.[16] The variation of oxygen and carbon isotopes and colour lamination in the Makapansgat stalagmite over the last 1000 years is striking (Fig. 1). The oxygen isotope proxy suggests that the cooling episode reached its greatest severity around 1700. Both the carbon isotope and colour index variation records confirm the occurrence of the event and also the medieval warming that occurred with considerable variability until about the beginning of the fourteenth century.

Two extreme events are manifest in the oxygen isotope record of the Little Ice Age, one centred at 1700, the other about a century or so earlier. First estimates of the cooling associated with the 1700 $\delta^{18}$O event in the record suggested a depression of about 2°C in mean annual temperature.[12] Colour variations in the Makapansgat stalagmite record show the Little Ice Age cooling to have been a more sustained event than the oxygen record suggests (Fig. 1). Statistically derived proxy temperatures from the modern correlation between annual daily maximum temperature and colour intensity suggest a depression of about 1°C relative to the present during the cooling around 1700. This accords with reports of widespread Little Ice Age cooling around the same time.[15] Closer examination of the 1700 event shows that it was manifest clearly in the oxygen isotope record derived from a coral in the ocean off southwestern Madagascar (Fig. 2) (G.A.

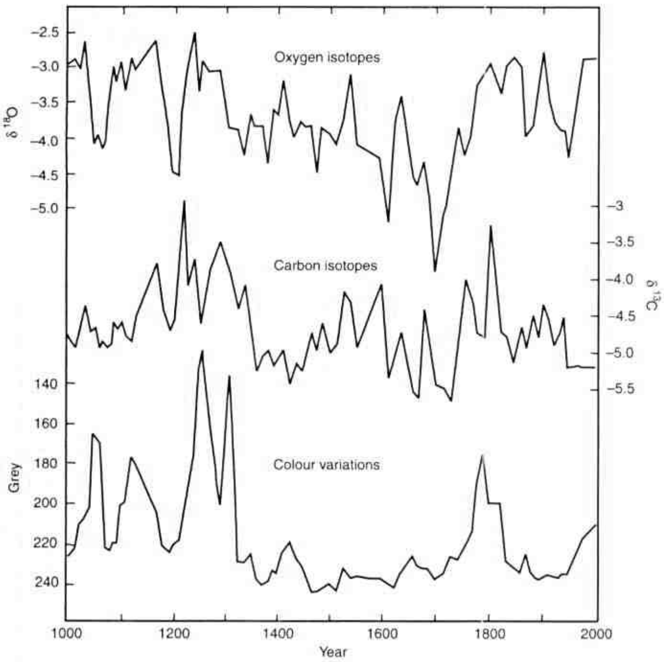


**Fig. 1**. Stalagmite-derived changes in $\delta^{18}O$, $\delta^{13}C$ and colour density (grey level) over the period AD 1000 to 1996 as determined from a speleothem taken from Cold Air Cave in the Makapansgat Valley southwest of Pietersburg.[12] Data have been filtered using a 5-term binomial filter.


**Fig. 2**. Proxy temperature anomalies from the 1961–1990 mean (determined from a linear transfer function developed from colour density variations) (K. Holmgren *et al.*, in prep.) and $\delta^{18}O$ variations in the Makapansgat stalagmite[12] and in a coral off southwestern Madagascar (G.A. Heiss *et al.*[32]).

Heiss *et al.*, in prep.). It is also coeval with cool events recorded in tree-ring records for the Karkloof[16] and Cedarberg[17] and in the Cango Cave speleothem oxygen isotope record.[18] Evidence of the Little Ice Age is also found in the foraminifera record in sediment cores taken off Namibia,[19] in river sediment analyses in Namibia,[20] in Kuiseb Valley pollen sequences in the Namib Desert,[21] in changing levels of lakes Malawi and Chilwa[22] and in perturbed borehole-temperature profiles from the northern half of South Africa.[23] Declining sea-surface temperatures at this time are likewise evident in isotope records from molluscs from coastal archaeological sites in the Western Cape Province[24,25] and from sea-level fluctuations along the southern coast at Knysna.[26] Palaeoflood hydrology of the lower Orange River valley points to increased flooding in the river catchment at about the same time.[27] The Little Ice Age was a widespread event in South Africa specifically and southern Africa generally. It imposed a more general signal on patterns of local variability. This is clearly illustrated in Fig. 2, where the Madagascar coral record is in phase with the maximum of the Little Ice Age at around 1700, but out of phase with the Makapansgat record in the late-nineteenth and twentieth centuries. It is well established that the summer rainfall region of South Africa and Madagascar experience out-of-phase variations in rainfall on inter-annual and decadal scales.[28] The coral record for Madagascar shows that climate in general did as well until the stronger Little Ice Age signal imposed its effect.

The termination of the Little Ice Age at Makapansgat was abrupt, particularly as evidenced in the oxygen isotope record. Such abrupt changes are a feature of the record. Sudden changes in climate occurred throughout the Little Ice Age, but more particularly in the earlier period, when oscillations in annual mean daily maximum temperature of 2–3°C in a few decades were observed during the warming of the tenth to early thirteenth centuries. Abrupt climate changes of this order in periods as short as 3–5 years have been observed in Greenland ice cores[29,30] and in tree-ring chronologies from Fennoscandia.[31]

The highly variable medieval warming that prevailed from before 1000 until just after 1300 was characterized by a number of warm episodes. The one peaking at around 1250 (Fig. 2) was one of the warmest events of the last six millennia. At that time, the positive temperature anomaly in annual daily maximum temperature about the 1961–1990 mean may have been as much as 3–4 °C. Medieval warming was not confined to the Makapansgat area. Though not as widely reported as the occurrence of the Little Ice Age, the tenth-to-thirteenth-century warming has been observed in southern Africa in the coastal mollusc isotope record,[25] in the sedimentary record of Namibian rivers[20] and in increased speleothem and tufa formation in the interior of southern Africa.[33] The medieval warming and subsequent Little Ice Age cooling have been advanced to explain changes in Iron Age population distributions in southern Africa.[34]

### Teleconnections beyond the region

Like the consequences of ENSO events around the world, the manifestation of Little Ice Age cooling was not globally uniform. Teleconnections definitely occurred.[4] Many of the extreme events in the Makapansgat stalagmite record are replicated in a variety of proxy records from other parts of the world in both the northern and southern hemispheres. The maximum cooling in evidence during the seventeenth century, and particularly at around 1700, at Makapansgat appears in the GISP2 Greenland oxygen isotope record,[30,35] in tree-ring reconstructions of summer temperatures at the Columbia Icefield, Canada,[36] and in composite temperature anomaly series for China[9] (Fig. 3). It is also evident in central England temperatures,[37] annual temperatures in Switzerland[38] and annual $\delta^{18}O$ values determined from Galapagos Island corals.[39] That the late-seventeenth century event was of widespread consequence in the northern hemisphere is evident in the recent multi-proxy reconstruction of hemisphere-wide temperature anomalies[40] (Fig. 3). Both the late-seventeenth century and earlier (and more pronounced) mid-fifteenth century cooling are present in the Makapansgat record.

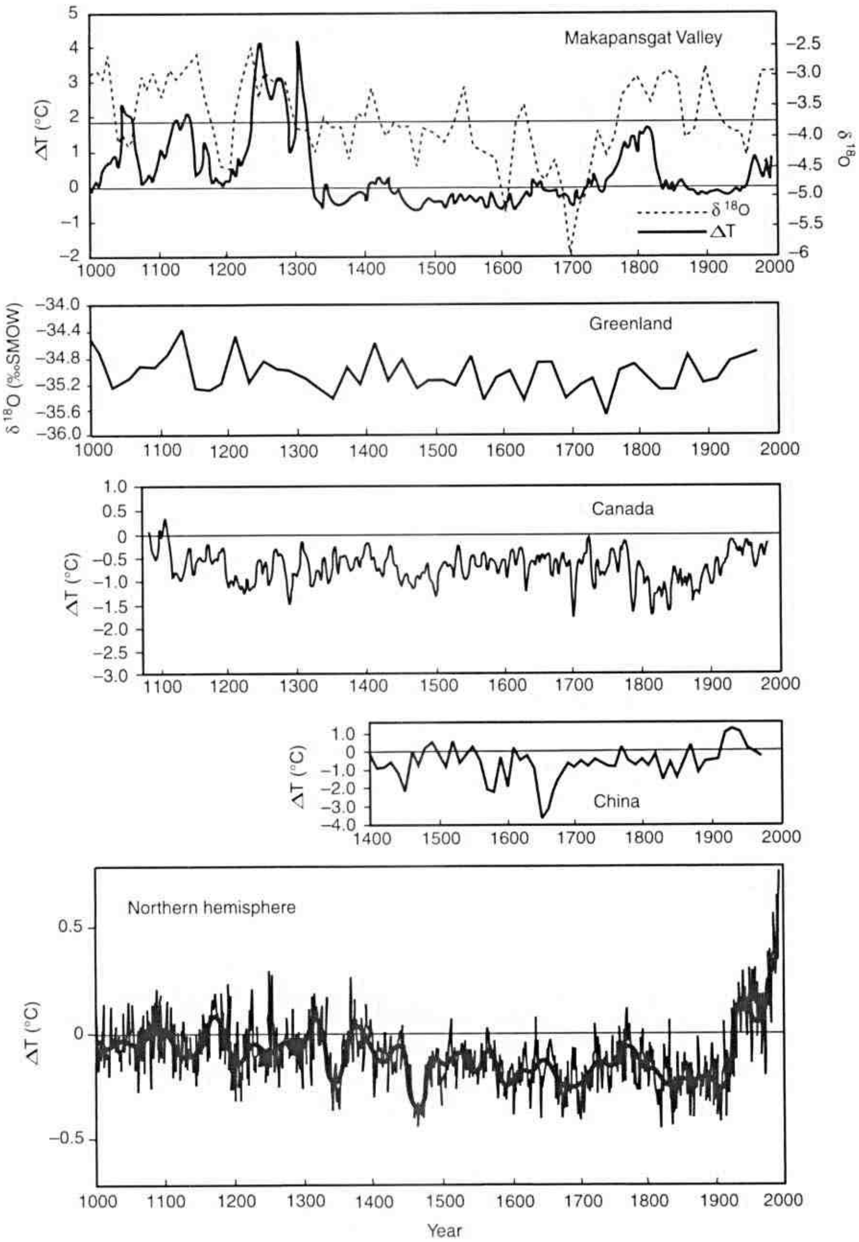


**Fig. 3**. Comparisons of the Makapansgat $\delta^{18}O$ record[12] and proxy anomaly temperature record with the $\delta^{18}O$ record from the GISP2 ice core, Greenland,[30,35] with tree-ring-derived anomalies from Canada[36] and China[9] and with a northern-hemisphere-averaged multiproxy anomaly series.[40]

Widespread southern hemisphere extreme-event teleconnections are difficult to establish owing to the paucity of good records. However, some high-resolution records do exist. The late-seventeenth century cooling experienced at Makapansgat is clearly present in cave speleothem and tree-ring chronologies developed for New Zealand[41,42] and northern Patagonia in Argentina,[43] but less so in the Tasmanian tree-ring record[44] (Fig. 4). It also compares with low $\delta^{18}O$ values in the Quelccaya summit ice core in the Peruvian Andes at around that time and with maximum late-seventeenth century snow accumulation, the highest between AD 1000 and the present.[45,46] The mid-fifteenth century cooling in South Africa has clear counterparts in the New Zealand and Tasmanian records, but not unequivocally so in the Andean proxies. Both the Argentinian and Tasmanian records show pronounced rapid and short-lived cooling at around the turn of the twentieth century. The Makapansgat record indicates cooling, but not pronounced, short or sharp at that time.

## Possible links to solar activity

Total spectral irradiance has been measured by satellite over the last two solar cycles and has been shown to vary slightly, but significantly, during periods of maximum and minimum solar activity.[47] Transfer functions linking wavelength-dependent effects of present-day solar irradiance of dark sunspots and bright faculae on the sun have been derived to provide 400 years of reconstructed solar variability based on amplitudes of sunspot features[48,49] or lengths of solar cycles.[50,51] The reconstructions compare well with long $^{10}Be$ and $^{14}C$ cosmogenic isotope records from tree rings and ice cores[52–56] (Fig. 5). Increased solar activity strengthens the magnetic coupling between the sun and earth, reduces the penetration of galactic cosmic rays into the earth's atmosphere and hence the production of the cosmogenic isotopes recorded in ice cores and tree rings.

The Maunder Minimum around 1700 was a period of minimal sunspot activity.[49,51,56] Since then, solar activity has varied significantly with periods of quiescence around the ends of the

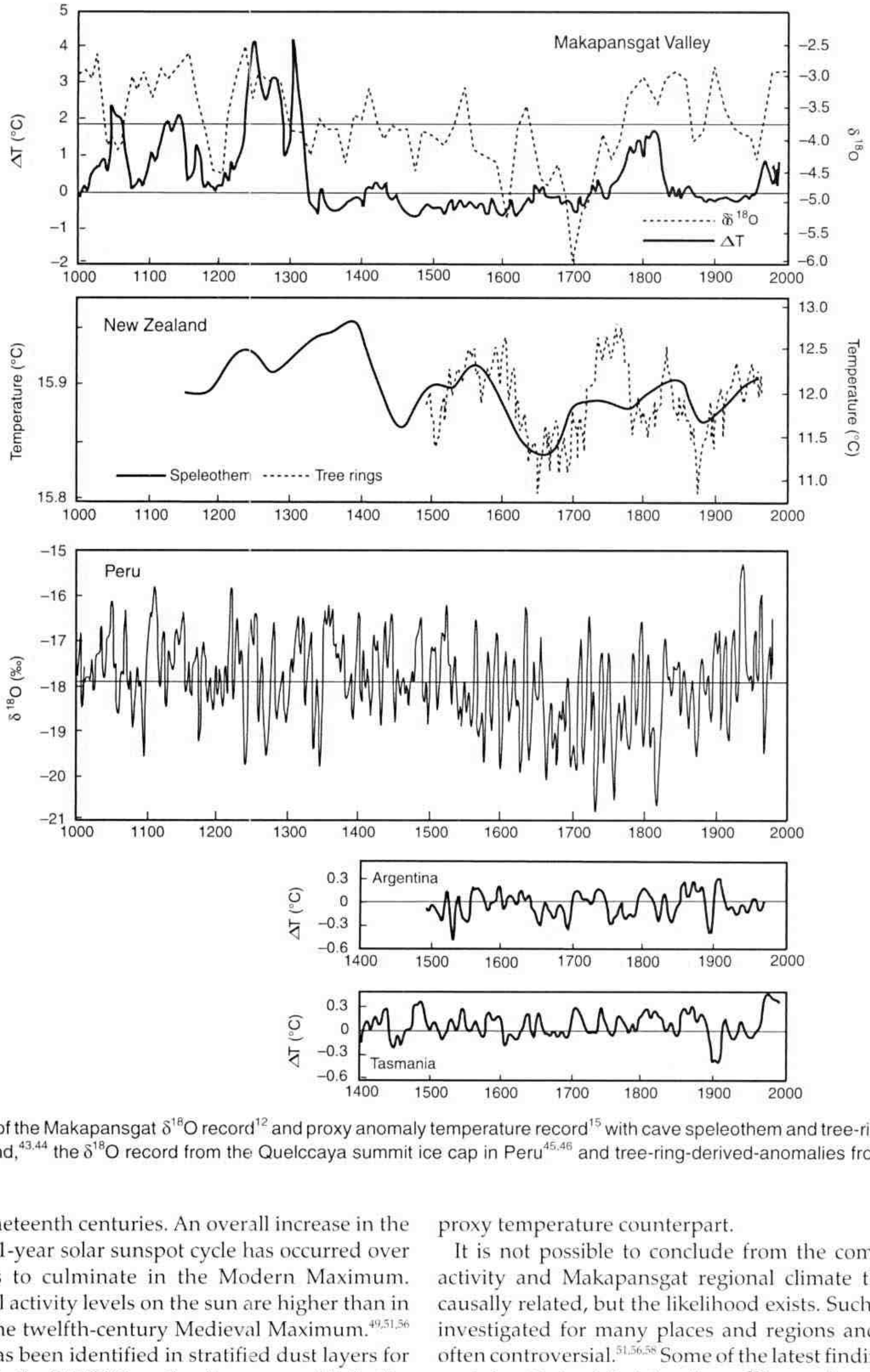


**Fig. 4**. Comparisons of the Makapansgat $\delta^{18}O$ record[12] and proxy anomaly temperature record[15] with cave speleothem and tree-ring derived temperatures in New Zealand,[43,44] the $\delta^{18}O$ record from the Quelccaya summit ice cap in Peru[45,46] and tree-ring-derived-anomalies from Argentina[43] and Tasmania.[44,66]

eighteenth and nineteenth centuries. An overall increase in the amplitude of the 11-year solar sunspot cycle has occurred over the last 400 years to culminate in the Modern Maximum. Present-day overall activity levels on the sun are higher than in any period since the twelfth-century Medieval Maximum.[49,51,56] An 11-year cycle has been identified in stratified dust layers for over 100 000 years in the GISP2 Greenland ice core and linked to possible solar forcing.[57]

The Makapansgat proxy temperature and oxygen isotope records are compared in Fig. 5 with the reconstructed solar irradiance and the observed cosmogenic isotope records. The 1700 minima in the temperature and oxygen isotope records for Makapansgat clearly correspond to the Maunder Minimum. The effect of the Sporer Minimum is likewise evident at around 1450 (also in the carbon isotope record given in Fig. 1). In general, the medieval warming experienced at Makapansgat corresponds to the Medieval Maximum in solar activity. The association is clearer in the case of the oxygen isotope record than the proxy temperature counterpart.

It is not possible to conclude from the comparison of solar activity and Makapansgat regional climate that the two are causally related, but the likelihood exists. Such links have been investigated for many places and regions and the results are often controversial.[51,56,58] Some of the latest findings relate cosmic ray intensity to global cloudiness.[59] In southern Africa, attempts have been made to link the observed 10–12 and ~18-year rainfall oscillations with the single and double sunspot cycles.[60–64] No major study of the possible association has been undertaken. Most recently, it has been shown that the effect of the Southern Oscillation and ENSO on South African rainfall is modulated by solar activity.[65]

## Conclusions

The Little Ice Age was a 500-year climatic event from around 1300 to 1800 that is clearly manifest in the Makapansgat stalagmite record. The cooling was a regional phenomenon of some

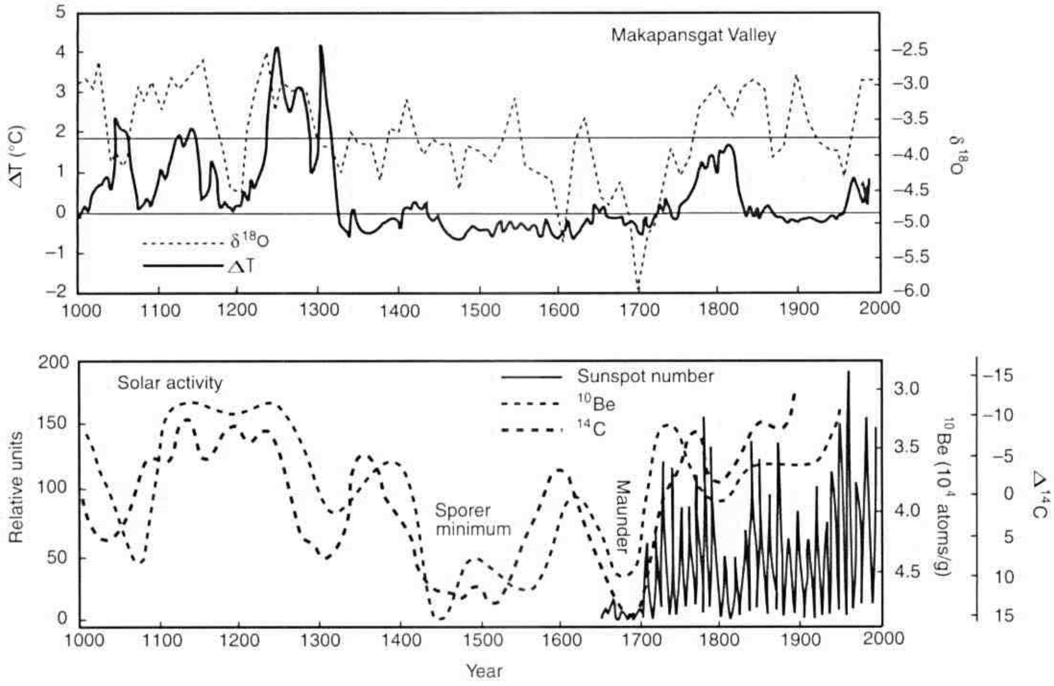


**Fig. 5**. Comparisons of the Makapansgat $\delta^{18}O$ record[12] and proxy anomaly temperature record with variations of sunspot number and the cosmogenic isotopes $^{10}Be$ and $^{14}C$ (ref. 49).

consequence throughout the subcontinent of southern Africa. Maximum cooling occurred around 1700, when annual mean daily maximum temperature was depressed by around 1°C. The late fifteenth century was also a period of maximum cooling.

The preceding period of medieval warming was characterized by highly variable conditions. Maximum warming at Makapansgat at around 1250 produced conditions up to 3–4°C hotter than those of the present. Teleconnections with medieval warming in the rest of southern Africa exist, but are not as widespread as their Little Ice Age equivalents.

Teleconnections between the Makapansgat record and other parts of both southern and northern hemispheres are clear. Extreme events recorded in southern Africa find counterparts in Argentina, Tasmania, Greenland, Canada, China and the northern hemisphere as a whole.

The question of a possible link between the climatic change that has occurred in the past millennium in southern Africa and changes in solar irradiance is one of great complexity and much controversy. Possible links between the Makapansgat speleothem record and solar activity have been demonstrated. Whether they are causal or coincidental remains to be established. What is clear is that the Makapansgat record is one of the best high-resolution terrestrial records of its kind for the southern hemisphere. It presents, in detail, a picture of change representative of major events occurring in southern Africa and elsewhere.

This paper is one several arising out of a cooperative research programme initiated by P.D. Tyson and K. Holmgren and carried out between four universities, two in South Africa and two in Scandinavia. Those principally involved in the collection, analysis and interpretation of the data were P.D. Tyson and T.C. Partridge of the University of the Witwatersrand, J. Lee-Thorp of the University of Cape Town, K. Holmgren of Stockholm University and S-E. Lauritzen from the University of Bergen. They were assisted by colleagues and students. To all who have contributed to the programme, thanks are extended. The authors also wish to acknowledge the support they have received from the universities of the Witwatersrand and Stockholm, from the FRD (now NRF) in South Africa, the Swedish Natural Research Council and the Nordic Council of Ministers. This paper represents a contribution to IGBP/WCRP/IHDP START regional global change research in southern Africa and to the PEP III activities of PAGES in the IGBP.

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## ✎ New Books

The following titles are either newly published or newly issued in paperback.

### Biological Sciences

**Insect Lives**. Edited by Erich Hoyt and Ted Schultz. Wiley. £27.95. A richly illustrated compendium in words and pictures drawing on observations made over the past two and a half millennia.

**Sex and Friendship in Baboons**. By Barbara B. Smuts. Harvard University Press. $19.95 (pbk).

**Mkomazi**. Edited by Malcolm Coe *et al.* Royal Geographical Society/IBG. £20. A model write-up on a Tanzanian savanna park, with particular emphasis on the park's ecology and recommendations for management.

**Mosaic Evolution of Subterranean Mammals: Regression, Progression and Global Convergence**. By Eviatar Nevo. Pp. 413. Oxford University Press. $175.

**Science as a Way of Knowing: The Foundations of Modern Biology**. By John A. Moore. Harvard University Press. $18.95 (pbk).

**The Handicap Principle: A Missing Piece of Darwin's Puzzle**. By Amotz and Avishag Zahavi. Oxford University Press. $16.95 (pbk).

**Neuronal Control of Locomotion: From Mollusc to Man**. By G.N. Orlovsky, T.G. Deliagina and S. Grillner. Pp. 322. Oxford University Press. £49.50.

**The Feeling of What Happens: Body and Emotion in the Making of Consciousness**. By Antonio Damasio. Pp. 386. Harcourt Brace. £20.

**Cassandra's Daughter: A History of Psychoanalysis**. By Joseph Schwartz. Pp. 339. Penguin. £20.

### Physical Sciences

**Noah's Flood: The New Scientific Discoveries about the Event that Changed History.** By William Ryan and Walter Pitman. Simon & Shuster. $14 (pbk). A gripping account of geological sleuthing in and around the Black Sea, that has much to inform historians of the rise of settled agriculture and the period preceding the Bronze Age in southeastern Europe.

**Quantum Generations: A History of Physics in the Twentieth Century**. By Helge Kragh. Pp. 494. Princeton University Press. $29.95. The author, who is professor of the history of science at Aarhus University in Denmark, has written was he calls 'a brief and selective account' of his subject's principal developments.

**Deep Space**. By Simon Goodwin and John Gribbin. Constable. £16.99. Another celebration of images from the Hubble Space Telescope.