the Lehner and Murray Springs mammoth-kill sites were apparently ambushes at streams. A realistic painting of mammoth hunting should show warmly clad professionals calmly spearing a mammoth already crippled by a trap or ambush.

Did hunting really exterminate mammoths or did they die out solely because of late-Pleistocene climatic changes and retreat of tundra? These alternatives have been much debated, not only for mammoths but also for other large extinct Pleistocene mammals[4]. The accurate radiocarbon dating of very small fossil samples by tandem accelerator mass spectrometry[7] may provide some of the answers. With this technique, Mead *et al.* have just shown that a species derived from cold climates, Harrington's mountain goat, and a species derived from warm climates, the Shasta ground sloth, both disappeared in Arizona at essentially the same time — 11,160 ± 125 and 11,018 ± 50 years BP, respectively[8]. This pairing does not fit a climatic extinction hypothesis but coincides suspiciously with the period of the Clovis hunters. It is also suspicious that the abundant mammoths and many other large New World mammals survived at least 22 Pleistocene glacial cycles, to disappear about the time that Clovis hunters arrived. Using tandem accelerator mass spectroscopy to date more precisely the last mammoths will provide a test of this suspicion. □

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Planetary meteorology

Is there lightning on Venus?

Janet G. Luhmann and Andrew F. Nagy

Is lightning unique to Earth, or does the phenomenon occur on other planets? The answer to this question will have implications for matters ranging from the nature of the atmospheric chemistry and the meteorology of the planets[1] to the existence of life. Because aerosols of volcanic origin enhance lightning production, geological processes must also be involved in this familiar phenomenon[2].

Venus is particularly fascinating, both because of its proximity and because of its permanent obscuring cloud layers. Because lightning on the Earth is associated with the generation of electrical charges in convective clouds, there seems a good chance that Venus is also a candidate for this type of meteorological activity. But the dynamic and thermal conditions in the venusian atmosphere are probably quite different from those on Earth; the clouds, for example, are composed of sulphuric acid instead of water vapour. If the necessary ingredient of strong convection is absent, and the electrical properties of the cloud constituents or other environmental conditions are not appropriate, venusian clouds should never be brightened by the types of discharges found on Earth. Yet there have been inferences that lightning does occur on Venus.

The Soviet space probes Venera 11 and 12 first detected impulsive very low frequency electric fields below the cloud tops which resemble the lightning-generated 'sferics' seen in terrestrial data[3]. A more recent reanalysis of Venera 9 spectrometer measurements[4] found supporting optical data, although a search with the star tracker on the US spacecraft Pioneer Venus Orbiter had failed to show any evidence for lightning[5]. However, the plasma-wave experiment on that spacecraft, showing a whistler-type electric field noise in the 100-Hz channel in the nightside ionosphere[6-8], reinforced the Venera results. (Whistlers are a well known electromagnetic signature of lightning discharges on Earth.)

Scarf and Russell[9] have extended the interpretation of the electric field observations of lightning by demonstrating that well-ordered magnetic fields with approximately vertical orientation 'duct' the whistlers from the lower nightside atmosphere to the spacecraft located at altitudes above 150 km. Moreover, these ducts, when traced along straight lines in the direction along the magnetic field towards the planet, all appear to intersect the ground near regions identified as volcanic highlands by radar experiments[10]. On this basis, Scarf and Russell concluded that the lightning sources on Venus are clustered near specific topographical features where aerosols, such as those associated with active volcanism, may be present.

Taylor and coworkers[11] have now suggested that Scarf and Russell's results are simply a coincidence arising from the combination of the sampling bias imposed by the spacecraft orbit, planetary rotation and the magnetic field geometry at Venus. Their main arguments stem from the observation that depletions or troughs in the observed ionospheric ion densities occur in conjunction with the vertical magnetic field present during the 100-Hz bursts, but that the vertical fields associated with the longer duration troughs do not map preferentially to the highlands. They point out that several other studies show that the vertical magnetic fields are related to the solar wind interaction with the planetary ionosphere causing the interplanetary field to become 'hung up' in the ionosphere[12,13], and that it is unlikely that these fields penetrate to the ground. Moreover, the ion-density depletions must also result from the interaction between the solar wind and the ionosphere[14]. Similar ion troughs occur in the Earth's ionosphere at mid- and high latitudes in response to magnetosphere – ionosphere coupling. As plasma instabilities can result from gradients in the plasma properties, it is not surprising that plasma waves occur in conjunction with the ionospheric density gradients on Venus. Lightning need not be invoked; therefore the argument for volcanism is moot.

Indeed, evidence continues to accumulate showing that the vertical magnetic fields in the nightside ionosphere of Venus are the result of the solar wind interaction. The ion-density depletions and density gradients are associated with the vertical fields[11] but this does not mean that the vertical fields and ionosphere troughs produced by the solar wind interaction cannot duct lightning-induced whistlers to the spacecraft when there is a favourable connection to the highlands.

Because the Pioneer Venus mission has continued to accumulate data, Scarf and coworkers can look for further support for their claims as new areas of venusian topography rotate into the nightside region of vertical magnetic fields. Meanwhile, theoretical investigations of the nature of the alleged plasma instabilities in the ion troughs may help finally to resolve the question. □

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