descent engine of the lunar module, venting of the lunar module and test firings of the attitude control system. For example, the first firing of the descent engine placed the lunar module in a 7.8 by 48.5 nautical mile orbit instead of the 8.5 by 57.2 nautical mile orbit intended.

Next time, the plan is for the astronauts to track lunar landmarks to determine the orbit just before the lunar module begins its descent to the surface, and the hope is to land within a kilometre of the target. In the Apollo 11 mission, the landing took place during the fourteenth lunar orbit, but the tracking by the astronauts of lunar landmarks which determined their orbit was carried out during the eleventh and twelfth orbits. Thus the tracking information was at least two orbits old by the time of the landing. The plan for Apollo 12 is to undock sooner, do the landmark tracking one orbit before touchdown (thus allowing for undocking impulses), and to start the descent engine soon after the orbit information has been brought up to date. The success of all this should be clear on November 19.

PALAEOMAGNETISM

Ancient Secular Variation

from our Geomagnetism Correspondent

A SIGN that palaeomagnetism has come of age is that the foremost workers in the field are no longer content solely to investigate first order effects. Although there are many gaps in the record of palaeomagnetic directions, techniques have now advanced to the point where the scatter of directions about the mean can be analysed to give significant information on the behaviour of second order fields. Mean directions are interpreted in terms of dipole field behaviour; but a complete description of the ancient field requires methods for deducing the magnitude and distribution of non-dipole components.

One of the more interesting questions centres around the geographical distribution of the ancient non-dipole field and, in particular, the asymmetry between hemispheres. At present, both the non-dipole field and the rate of secular variation are greater in the southern than in the northern hemisphere. If this asymmetry is permanent, there must be an asymmetry in the conditions governing the magnetohydrodynamic processes at the interface between the core and the mantle, where the non-dipole field is thought to originate. On the other hand, if the phenomenon is relatively transient, lasting, say, about 10,000 years, little fundamental rethinking of the conditions at the boundary of core and mantle will be required.

New data from Cox (*Earth and Planet. Sci. Lett.*, **6**, 257; 1969) suggest that during the Brunhes normal epoch, the average non-dipole field was similar in each hemisphere—that is, any asymmetry is transient. Cox shows, from a palaeomagnetic investigation of twenty-two volcanic formations (eight samples each) in New Zealand (North Island, latitude 38° S), that the angular standard deviation of the virtual geomagnetic poles about the geographic pole is 19.7°. When the contributions of within-site dispersion (principally experimental error) and local magnetic anomalies are removed, the standard deviation is reduced to 19.6° with 95 per cent confidence limits between 16.2° and

24.7°. The corresponding standard deviation for Brunhes epoch rocks from a similar latitude (37° N) in North America is about 17° with confidence limits between 14° and 20°. Thus although the New Zealand standard deviation is slightly larger, the difference is not statistically significant. The new results fail to prove the existence of the present non-dipole field asymmetry in the past, and imply just the opposite.

Cox also shows that the variation of polar angular dispersion with site latitude for the five sites already investigated (Galapagos Islands, latitude 0°; Hawaii, 19°; North America, 37°; New Zealand, 38°; Alaska, 60°) obeys none of the three models so far proposed to describe the variation of secular variation with latitude. According to the so-called model *A*, in which secular variation is produced by adding vectors of constant amplitude and varying orientation to the field of a constant axial dipole, polar angular dispersion should vary monotonically between about 15° at the equator and about 19° at the poles. Model *B*, which neglects the non-dipole field and ascribes all secular variation to dipole wobble, predicts a polar angular dispersion of about 13° for all latitudes. Model *C*, in which the latitude dependence of secular variation is estimated from the present non-dipole field, predicts a polar angular dispersion from about 14° at the equator to about 20° at the poles. Experimentally, the dispersion is found to vary from about 12° at latitude 0° to about 24° at latitude 60°; that is, the variation is much steeper than that predicted from any extant model. The field is wide open to the model builders.

BIOLOGICAL MATERIALS

Sea Urchin Spines

from our Materials Science Correspondent

Two years ago, Currey and Nichols reported that the spines of sea urchins were single crystals of a thermodynamically metastable calcite containing a substantial percentage of magnesium (*Nature*, **214**, 81; 1967). This discovery was bound sooner or later to excite the interest of materials scientists, and now an intriguing study has been published, devoted to the morphology and mechanical strength of these spines (Weber, Greer, Voight, White and Roy, *J. Ultrastructure Research*, **26**, 355; 1969).

The spines of various species were examined by scanning electron microscopy and all turned out to be highly porous, as were other parts of the skeleton. The porosity is intercommunicating or "fenestrate", so that the spine consists of two interpenetrating continuously connected phases (like, for example, a glass that has decomposed into two immiscible glasses); one "phase" consists of pores. The strength in compression of such spines has been compared with that of a range of polycrystalline limestones, molluscs and corals of different densities. All the measured strengths clustered near a smooth curve when plotted against density, except for the monocrystalline spines which combined high strength with low density: limestones of density as low as that of typical spines had strengths three to twenty times lower—indeed, some of them were barely cohesive. There are obvious evolutionary advantages in the high ratio of strength to density of the spines in terms of the modest mass of muscle which their deployment entails.