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Concluding Remarks

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Concluding remarks

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A predominant aim of planetary exploration is to discover as much as possible about the origin of the Solar System. Therefore it is appropriate that the closing paper by Dr H. Reeves should be explicitly about this. Of course, almost every paper has implicitly provided constraints upon models for the formation; many are already familiar, but the recent work reported here renders them more severe or precise than before. The discussion prompts, in particular, the following considerations.

In regard to terrestrial planets and the Moon and other large satellites, much is being learnt from recent comparative studies of surface features, of possible effects of volcanism, and of the physics of impact cratering. After taking account of differences due to the presence or absence of various sorts of atmosphere and of the consequences of the different values of surface gravity, the 'geologies' of the various bodies are still surprisingly different. Some of the differences that have been described are undoubtedly owing to the presence or absence of water in various states. This feature must surely be an important clue to the way in which the bodies were assembled. For instance, one cause of the difference between Earth and Venus is probably the circumstance that, if as generally supposed the solar luminosity had about 70 % of its present value in the early stages of the Solar System, a water-ice coating on a dust grain (assumed to behave as a small blackbody) at the Earth's distance would remain frozen, but at the distance of Venus it would be melted. This must make a considerable difference to the way in which water was originally incorporated into the structures of these two planets.

Another marked difference between the bodies in this category is in manifestations of tectonism. The Discussion has shown the Earth to be the body still seen as exhibiting the clearest evidence of plate motions, but it is now evident that there are important tectonic effects on Venus. The other bodies seem to have experienced much weaker tectonic effects. All such effects relate surface phenomena to internal convective motions in the bodies concerned, or at any rate in certain regions in them. The Discussion shows that there is apparently emerging a picture of the internal structure and motions in all these bodies that is consistent with what is coming to be known about the equations of state of the materials and their solid-state physics. These motions, or related motions in the cores, seem to be in accordance with most of what is understood about past and present dynamos in these bodies. However, the inferred absence of an appreciable magnetic field of Venus remains a mystery. Some of the suggested patterns of internal circulation now or in the past might apparently account for the prevalent departure from spherical symmetry in nearly all these bodies. At first sight it might thus seem that these various properties have to do mainly with the evolution of the bodies rather than their origin.

The Discussion has brought out many interesting features of the chemical composition of these bodies; such features certainly ought to reveal something about origins. Most speakers tend to relate the composition to a process of formation by accretion. However, I wish to call attention to a consequence of the figures quoted by Professor H. Wänke for the nickel–iron content of the terrestrial planets. If Mercury and Venus are combined into one single body, and Earth, Moon and Mars into another single body, according to Wänke's figures both resulting bodies would have 31 % nickel–iron. Were the components so combined that their actual volumes are to be simply added together, the resulting bodies would have densities 5.25 and 5.26 g cm^{-3}. Thus we should have two bodies of effectively identical composition. I have pointed this out before (McCrea 1978), but Wänke's values for the nickel–iron content make the result even closer than before. (It might be better to try to use volumes calculated from Wänke's 'uncompressed densities', rather than actual volumes, but this would introduce an additional theoretical feature.) The result seems to give strong support for the hypothesis first put forward, so far as I know, by R. A. Lyttleton (1960) that the actual bodies are indeed the results of fission of two very similar parent bodies ('protoplanets'). The fission process would follow a slow change of shape and structure of the parent body. So the resulting portions after fission would not be left with spherically symmetrical structure. Therefore the empirical results on departures from spherical symmetry may, after all, be of crucial relevance to the origin of the bodies as they now exist.

An exceedingly interesting feature of the paper by Dr Reeves has special relevance to the formation of the Earth. As I understood him, he adduced the terrestrial abundance of deuterium as evidence that interstellar *molecules* must have entered directly as such into the forming Earth. If this occurred for molecules containing deuterium, it must have occurred for effectively all the other molecules, including the quite complicated organic molecules known to be present in the same interstellar material and the still more complicated ones that the chemistry almost certainly requires to occur in the same conditions. If such molecules were thus present from the outset, it is no longer necessary to postulate a primordial reducing atmosphere on the Earth as a necessary environment for forming the first such molecules.

Incidentally, since a protoplanet is originally simply a diffuse body of the material of the interstellar cloud from which the Sun and the Solar System originated, it would inevitably include whatever molecules are present. On an accretion model it is less certain that molecules would be incorporated without damage into a planet in process of formation.

In regard to the major planets, Dr W. B. Hubbard has proposed models in which a rocky core surrounded by an ice layer is about the same in all four bodies, and they differ essentially only in the size of the envelope of light gases. He envisages, one gathers, that four very similar bodies grew by accretion of similar amounts of heavy material, and that they then proceeded to accrete vastly different amounts of light gases, with in all cases the same hydrogen–helium ratio as in the Sun. I do venture to suggest, as a simpler hypothesis, that all four planets could have started as mutually similar bodies of the same raw material as the Sun; similar central parts would form by sedimentation of dust and heavy elements (McCrea & Williams 1965); subsequently varying amounts of light gases would have been lost. As Professor T. Gold remarked, the smaller amounts of these gases in the outer planets is a well known puzzle. He proposed a drastic solution in the form of a nearby supernova explosion. If indeed anything so violent is needed, it might well serve just as well for a protoplanet model as for the accretion model.

Much has been said in the Discussion about satellites of all sorts, ranging from small bodies that may control gravitationally the dynamical behaviour of some of the rings round the planets, notably Uranus, to the seven 'main' satellites Moon, Galilean satellites, Titan and Triton. The Discussion has shown these seven bodies to have fascinating individualities, produced apparently mainly by environmental conditions, but at the same time it seems to confirm that by intrinsic

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properties they form one clear category of body distinct from anything else in the Solar System, unless Pluto and Charon have affinities with them. In the context of origins, the whole trend seems to be to show that the formation of a satellite system must be an exercise greatly different from the formation of a planetary system.

As regards formation of the planets, this may be a good opportunity to call attention to a simple feature that is not usually remarked upon explicitly but that is inevitably implicit in all such discussions. It is that the main planets occur in three pairs: Venus–Earth, Jupiter–Saturn, Uranus–Neptune. It seems appropriate to describe them as twins, while emphasizing that they are not 'identical' twins. On the protoplanet model that I wish to commend for consideration, the property would be more obvious since the planetary system would have started with simply six quite similar protoplanets, the subsequent evolution would have been closely similar in pairs, and all other planets and satellites would be secondary products (McCrea 1978). Thus Nature appears to find it more convenient to produce planets in pairs; no reason has ever been suggested, but it may be one of the most important clues to the process of formation of the whole System.

The papers by Professor R. N. Clayton, and Professor L. Biermann and the oral contribution by Dr C. Allègre show that the properties involving isotope abundances provide the most stringent quantitative constraints upon cosmogonic theories. The ultimate challenge is to discover a model that will correctly reproduce all the observed values.

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