remarked that the standard of his drawings (for example, of ammonites) is not always equalled at the present day. Some of his work was quoted by eighteenth century geological writers, and doubtless helped to prepare the ground for the great advances at the close of that century. But we do not even know whether William Smith had read the "Discourses of Earthquakes", and there is no sign that Hooke's evolutionary views were appreciated.

Cosmic Rays and the Origin of Species*

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WHEN we turn to consider wild plants in Nature, two lines of inquiry present themselves: (1) the comparison of the number of plant species in warm mountain and lowland regions, and (2) the question of endemic species.

It would be interesting to compare the floras of regions where, owing to altitude and latitude, the cosmic ray fall is great, but the conditions are favourable for plant growth, with regions having similar climatic conditions at low altitudes; but the data now available scarcely allow this to be done. There can be, however, no doubt that the floras of mountain regions in the tropics and warm temperate zones are much richer in species than the lowland areas. Thus according to Standley[20], the known flora of the tiny republic of Costa Rica contains more than 6,000 species of vascular plants, approximately the same number as in the whole of the south-eastern United States, although its area is less than half of the area of Florida and it contains mountain ranges not yet explored by botanists. Its mountains rise to more than 11,000 ft., and more than half its area lies above 3,000 ft. Its flora is especially rich in orchids, nearly 1,000 species having been recorded; they appear to reach their best development at about 6,000 ft. When Hemsley described the flora of Mexico and Central America, he stated that the species of angiosperms in this region outnumbered those in the whole of North America by some 2,200. No doubt the habitats in these tropical mountain regions are very varied, but it may be questioned as to whether the immense richness of species can be explained in this way. Costa Rica is an interesting case because it is a fairly recent mountain area, and was most probably submerged in late Eocene and Oligocene times[21], while the very high percentage of endemics suggests that its flora cannot be regarded as merely due to the spread of species from the north and south.

It would be interesting to know more about the relative numbers of forms at different altitudes in widespread genera. The genus *Primula* might be quoted in support of my ideas, for while the Vernales section is very widespread in Europe and northern Asia, mainly at low altitudes, it contains only about nineteen species; but many of the other sections which live on high mountains are very much richer in species and endemic forms; for example, the Petiolares with sixty-six species, the Nivales with sixty-one[22]. In all, there seems to be about 330 species of mountain primulas. Almost all the other alpine genera of the Primulaceæ are much richer in species than the genera of the plains.

The discussion of endemic species and genera raises many difficulties which cannot be solved at present. There can be no doubt that many endemics are survivors of races which were once widespread, for example, *Matonia*, *Cupressus macrocarpa*[23] and *Neviusia*. On the other hand, it seems fairly certain that plants like the tetraploid subspecies and varieties of *Biscutella lævigata*[24], and several of the European alpine species of *Soldanella* and *Primula* are of comparatively recent origin. Probably as time goes on and endemic species receive more exact attention, we shall be in a position to distinguish new forms from relics. Cockayne in his survey of the flora of New Zealand divides up the numerous endemic plants of the region into groups according to their affinities, and concludes that the endemics closely related to other New Zealand species, and which may be considered of comparatively recent origin, make up 43 per cent of the whole flora and 58 per cent of the total number of its endemics[25]. The alpine flora of New Zealand numbers 945 species as against 998 species in the lowlands; 597 species belong to the high mountains, and of these no less than 94 per cent are endemic[25]. Many of the lowland plants are also endemic, but Cockayne considers that this group consists largely of descendants of an ancient palæotropic stock, often not perfectly attuned to the present-day climate.

* *Continued from p. 53.*

In a recent address, Jepson[26] directed attention to the endemics of California. In this province some 2,000 species (forty per cent of the spermatophytes and pteridophytes) are endemic, representing both indigenous and relict forms, and, as he remarks, this fact calls for explanation. He states that the more important areas of marked endemism are the San Bernardino Mountains, the Sierra Nevada Mountains, the Lassen-Shasta region, the 'Klamath Mountains' in the geological sense, the North Coast Ranges, the Inner Coast Ranges and the Santa Barbara Islands. He considers it certain that the most abundant production of new forms is associated with successive uplift and subsidence of fault blocks, and notes that the operative physical and edaphic factors have affected species very unequally or in some cases not at all. Some Gramineæ and Compositæ have been raised from levels of about 1,000 ft. to 6,000 ft. or higher without apparent morphological change. Such facts seem to me to be more explicable on the view that variations are produced by radiation than on any hypothesis of climatic effect.

According to my suggestions we should expect to find endemics mainly in regions where the climate is sufficiently temperate to allow plant growth now or in Tertiary times at really high altitudes, and it is therefore interesting to note that according to Willis[27] endemics chiefly occur from about 48° N. to 50° S.; he also states that they are found within these limits on all important mountain chains above 4,500 ft. Very many of the islands noted for their endemics possess high mountain peaks, and some large areas like the Cape region of South Africa, which are so rich in distinct forms, are of high average altitude. It is a commonplace that endemic forms are characteristic of isolated areas, but though isolation may explain the persistence of forms it does not explain their origin.

Finally, one may notice that our present knowledge of the history of plant evolution seems to show that the appearance of new genera and species did not take place gradually and regularly, but in a series of steps, the world's flora becoming richer and richer in forms. Many of the important changes in the fossil floras are definitely associated with periods of mountain building or uplift. For example, a great period of uplift took place in western North America during the Upper Cretaceous, when the Laramide folding is thought to have raised mountain blocks to a height of 20,000 ft. Since this was a warm period when a rich vegetation flourished in the arctic part of North America, the Laramide orogeny must have raised many plant species to a very high altitude and at this altitude some may have survived and mutated. Not long afterwards, we find that the number of genera and species found in the fossil floras of the United States (Wilcox group) has greatly increased, eighty-three genera and a large number of species appearing which are unknown from Cretaceous floras[28]. So far as we know, there was no distinct climatic difference and no marked difference in the habitat factors between the Upper Cretaceous and Lower Eocene floras of south-eastern North America. Undoubtedly new geographical conditions and new routes of migration were opened up, but this does not explain how so many new forms originated.

We thus have several different reasons for the hypothesis that the origin of new species may be connected with plant growth at high altitudes, where the intensity of cosmic rays and showers is high, while at the same time we know that some of the aquatic and marsh plants growing at sea-level have varied very little in many millions of years. It is quite possible that the production of new forms on mountains has no connexion with cosmic radiation but may be due to other factors such as temperature fluctuations, but there is as yet no definite evidence that mutations are produced in this way, and also there must be many lowland areas where comparable temperature fluctuations occur. In many of the problems of evolution we can do nothing more than collect evidence and weigh possibilities, but in the present connexion it should be possible to test the ideas now put forward by direct experiment. Let us hope that at some future time it may be possible to carry out culture experiments under suitable conditions at a very high altitude, and to demonstrate whether or not cosmic radiation is significant in the origin of species. In the meantime, my tentative hypothesis may possibly add fresh interest to the work of those who are studying the high mountain floras of the tropics.

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