Feldspar in Chondrites

Abstract. *Whereas most chondrites contain sodic plagioclase (or occasionally maskelynite, its glassy equivalent), a few are free of feldspar. Absence of plagioclase is correlated with the presence of calcium-poor clinopyroxene (pigeonite* sensu lato*) instead of orthopyroxene. Olivine in feldspar-free chondrites is frequently variable in composition; in feldspar-bearing chondrites this mineral has essentially uniform composition. It appears that the silicate material of most chondrites was initially an association of olivine and pigeonite (or perhaps olivine and glass), and recrystallization has produced the usual olivine-orthopyroxene-sodic plagioclase association.*

As Edwards (*1*) has shown, chondrites contain a remarkably uniform amount of sodium, about 0.7 percent. In most chondrites the sodium is present as plagioclase of albite or oligoclase composition; the plagioclase is the disordered (high-temperature) form of this mineral (*2*).

In studying the mineralogy of chondrites, I have found that it is frequently very difficult or impossible to detect feldspar in thin sections under the microscope, although the mineral may be identified in powder patterns and diffractograms obtained by x-ray diffraction, especially when it is concentrated from an acid-insoluble fraction by density separation, by means of heavy liquids. This feldspar is very fine-grained, and it is difficult to determine its refractive indices precisely by the immersion method. Meteorites having this very fine-grained feldspar also contain much clinopyroxene giving an x-ray pattern similar to that of pigeonite, together with orthopyroxene. In some chondrites I have found no feldspar, even in carefully prepared concentrates; and in these meteorites the pyroxene seems to be entirely clinopyroxene. Since the olivine structure is incapable of incorporating more than trace amounts of sodium and aluminum, the obvious deduction is that these elements are combined in the clinopyroxene, in the form of the $NaAlSi_2O_6$ component.

The chondrites with little or no feldspar are always highly chondritic; Bjurböle and Chainpur are typical examples (*3*). The feldspar-bearing chondrites always show signs of recrystallization, the boundaries of the individual chondrules merging more or less with the groundmass. The mineralogical changes are thus linked with structural changes.

It seems reasonable to postulate that the highly chondritic, feldspar-free chondrites represent a more primitive stage than the somewhat recrystallized feldspar-bearing chondrites. It is interesting that, in those meteorites with very fine-grained feldspar and appreciable amounts of clinopyroxene as well as orthopyroxene, the feldspar is almost pure albite, whereas the more recrystallized chondrites have more calcic plagioclase, usually with between 10 and 20 percent of the anorthite component. This is analogous to the increase in calcium content of plagioclase with increasing metamorphic grade in terrestrial rocks.

These facts appear to fit best in theories of chondrite formation expounded by Wood (*4*) and Anders (*5*), in which chondrules formed very rapidly as molten droplets in a primordial dust cloud, and then aggregated together with some of the dust into larger bodies (asteroids?). If, as seems likely, the aggregated bodies had an internal heat source, such as short-lived radionuclides, thermal metamorphism would take place, resulting in the recrystallization and the phase changes we observe in the individual meteorites.

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References and Notes

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3. W. Ramsay and L. H. Borgström [*Bull. Comm. Geol. Finlande* **12**, 1 (1902)] recorded a plagioclase chondrule in Bjurböle, but their detailed description suggests that they were actually observing polysynthetically twinned clinopyroxene.
4. J. A. Wood, *Geochim. Cosmochim. Acta* **26**, 739 (1962).
5. E. Anders, *Space Sci. Rev.* **3**, 583 (1964).
6. Work aided by NSF grant GP 1218.

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Paleontologic Technique for Defining Ancient Ocean Currents

Abstract. *Subtraction from the new data, of a quadratic surface fitted to the taxonomic diversity data of recent planktonic foraminifera yields a residual surface closely related to ocean current systems. This technique could be applied to fossil materials to develop knowledge of ocean circulation patterns during glacial and interglacial climatic episodes.*

Gradients in taxonomic diversity (the number of "kinds" of organisms present) are generally covariant with the planetary temperature gradient (*1*). This relationship, if found in fossil populations, could be used to locate past rotational pole positions and thus test the hypothesis of polar wandering (*2*). Observed taxonomic diversity gradients include both a primary response to the planetary temperature gradient and secondary responses to local conditions (Fig. 1).

It is desirable to separate these responses by mathematical calculation of a quadratic surface that best fits the observed distribution (*3*). The resulting surface isolates the response to the planetary temperature gradient and may be referred to as the "regional surface" (Fig. 2). Failure of the regional surface to fit all of the observed data results in a "residual surface" which includes all secondary sources of variation (Fig. 3). Attention was originally focused on the utility of the regional surface for defining the thermal equator. It now appears that the residual surface can be of comparable significance. Specifically, it is considered that taxonomic diversity residuals for planktonic foraminifera can be used as a reasonably accurate means of revealing past configurations of the surface circulation patterns of the oceans.

Since it can be assumed that the "regional surface" isolates the response of a taxonomic diversity gradient to the planetary temperature gradient, the "residual surface" must comprise the composite effects of all remaining factors affecting diversity. In a few groups of organisms, the factors contributing to the residual surface can be recognized as arising primarily from a single source. When such a situation occurs, the residual surface becomes an effective measure of this factor. Such a condition seems to be largely fulfilled by the planktonic foraminifera. These animals are involuntarily distributed by the motion of the water masses they inhabit. Allochthonous water masses thus carry with them an exotic population when they move from their place of origin. Because this is the case, and