

diagram corresponds to an error of $\pm 20\%$, which is probably representative of most of the measurements. But, as noted earlier, shielding corrections greater than 20% are probably required for about one-third of these meteorites, and this factor may have caused some further broadening of the peaks. Moreover, just as in the case of the iron meteorites, multiple breakups will tend to blur the distribution even further, by producing a continuum on the shortward side of each peak.

The remaining two plots, for achondrites and the rarer types of chondrites, show little regularity. This is not surprising in view of the smallness and heterogeneity of the sample. Nevertheless, the aubrites, diogenites, and pigeonite chondrites show a remarkable tendency to cluster at 45, 20, and 35 m.y., respectively. All three are rare and highly distinctive classes of meteorites. The fact that they cluster in sparsely populated regions of the age spectrum further strengthens the inferences drawn from the irons and ordinary chondrites: that the majority of meteorites are produced in a few large collisions, rather than in many small ones. Just as in the case of the irons, these collisions must have involved the order of 10^2 cubic kilometers of material, and possibly a good deal more (EBERHARDT and GEISS, 1963).

We noted in the discussion of U-He ages (Figure 20) that many hypersthene chondrites apparently suffered severe shock and outgassing some 0.4 AE ago (and possibly 0.6–0.8 AE ago as well). It is instructive to look for correlations between the U-He and exposure ages (Figure 24). Two trends are at once apparent. Heavily shocked hypersthene chondrites with short U-He ages predominate in the 2–5 m.y. cluster, and become progressively less abundant in the older clusters. What is even more significant, is that *every* exposure age group among the hypersthene chondrites, even the 16–31 m.y. cluster, contains a much higher proportion of short U-He ages than any comparable group of bronzite chondrites. In particular, the 0.4 AE U-He age (which presumably gives the actual date of the outgassing) is found among *all* clusters: 0.025, 3–5, 7–13, and 16–31 m.y.

This should lay to rest any unallayed suspicions that the outgassing of the hypersthene chondrites happened during the final impacts which produced the meteorites. Why should the hypersthene chondrites always be struck harder than the bronzite chondrites, and why should the outgassing always give apparent ages converging on 0.4 AE? But precisely the same argument suggests very strongly that the several clusters of hypersthene chondrites all come from a single body, rather than from a number of unrelated ones. This is an astonishing conclusion for people who believe that the chondrites are produced by random collisions among the 55000 or so asteroids. We shall return to this matter in Section 4.

3.4. PRIMORDIAL GASES AND ISOTOPIC ANOMALIES

Along with their radiogenic and cosmogenic noble gases, some meteorites contain large amounts of yet a third, "primordial" component, resembling atmospheric noble gases in isotopic composition. The original discovery was made in the aubrite Pesyanoe (GERLING and LEVSKIJ, 1956). Later it became apparent that primordial gases are rather common in meteorites, and occur in at least one member of every major class.

There has been a great deal of speculation about the origin and significance of these gases. Recent reviews on the subject have been given by ZÄHRINGER (1962a), SIGNER and SUESS (1963), and ANDERS (1963ac). Let us begin our discussion by reviewing the principal facts on primordial gases.

1. The undifferentiated meteorites, i.e. the chondrites, *always* contain primordial noble gases. These meteorites also contain other volatiles (carbon, organic compounds, etc.), and do not, as a rule, show evidence of shock (Table 8). The amount of gas is

TABLE 8
METEORITES CONTAINING PRIMORDIAL NOBLE GASES

Class	Meteorite	Type of Gas		Carbon	Shock	Ref.
		Fract.	Unfract.			
Irons	Washington Co.		×		×	a, b
Aubrites	Pesyanoe		×		×	c, d, e
Howardites	Kapoeta		×		×	e, f, g
Mesosiderites	Weatherford	×		?	×	h
Bronzite Chondrites*	Pantar	×	×	×	×	i, j
Hypersthene Chondrites	Mezö-Madaras	×		?	×	k
Ureilites	All?	×		×	×	d
Carbonaceous Chondrites	All	×		×		d, l
Pigeonite Chondrites	All	×		×		d, l
Enstatite Chondrites	All	×		×		f, g, l

* All bronzite and hypersthene chondrites contain *small* amounts of primordial gases, even if they show no signs of shock (ZÄHRINGER, 1962a). But *large* amounts of primordial gases are found only in brecciated chondrites with a definite shock history.

- a. SCHAEFFER and FISHER (1959)
- b. SIGNER and NIER (1962)
- c. GERLING and LEVSKIJ (1956)
- d. STAUFFER (1961a)
- e. ZÄHRINGER (1962b)
- f. ZÄHRINGER and GENTNER (1960)

- g. SIGNER and SUESS (1962)
- h. STAUFFER (1962)
- i. KÖNIG *et al.* (1961)
- j. MERRIHUE *et al.* (1962)
- k. GEISS (1964)
- l. ZÄHRINGER (1962a)

rather well correlated with the content of carbon and other volatiles (Figure 16b), which suggests that the gases, too, were brought in with fraction A (Section 2,371).

2. Among the differentiated classes (e.g. irons and achondrites), primordial gases are found only sporadically, in some 1–20% of the meteorites examined. Carbon and other volatiles are rare or absent; instead, the gases are invariably correlated with shock effects.*

* The ureilites are a borderline case. All three members of this class contain about 1–2% of carbon, all three show severe shock effects, and at least two contain primordial gases. One might therefore group them with the carbonaceous chondrites, and consider the carbon and noble gases to be of primary origin. But their matrix is differentiated and although the oxygen isotopic composition of their silicates suggests that they are closely related to the carbonaceous chondrites (VINOGRADOV *et al.*, 1960), their texture indicates that the carbon is of late origin (Section 2.42). As suggested earlier they may represent a differentiated region of the parent body of the carbonaceous chondrites, into which carbonaceous material and primordial gases were introduced during a pre-terrestrial collision.

The Weatherford mesosiderite is another interesting case. While most other mesosiderites possess a highly differentiated silicate phase and are free of primordial gases, Weatherford's silicate phase is chondritic (RAMDOHR, personal communication).