tion took place within a narrow temperature range of only 200° to 400°C. This would be compatible with the transient nature of the pressure.

The crystal habit of stishovite, therefore, might constitute a useful geological thermometer which could indicate the limiting temperature at peak pressure at impact craters in highly siliceous rocks. The applicability of this thermometer is evidently limited at present to silica-rich environments. As already discussed, however, stishovite has a nonacicular habit in magnesia-rich environments between 500° and 650°C in the range 115 to 125 kb. It would be of interest to synthesize stishovite through the clinoenstatite reaction (*9*) at temperatures above 900°C, but the pressures required would probably be in excess of 125 kb. This pressure-temperature combination has not yet been achieved, and such pressures at sustained high temperatures are at or near the ultimate limits of existing devices.

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Rhenium and Osmium Abundances in Stony Meteorites

Abstract. *Neutron activation measurements of rhenium and osmium abundances in the Orgueil, Mokoia, Karoonda, Mocs, and Hvittis chondrites indicate no fractionation of these elements between the various chondrite types. The average abundances in chondritic material are RE = 60.3 × 10^{-9}g/g and Os = 710 × 10^{-9}g/g (Os/Re = 11.5). The rhenium abundance in the Bishopville enstatite achondrite is about 1/300 as much, and the osmium abundances about 1/100 as much, as the abundances in parental enstatite chondrites, indicating that most of the rhenium and osmium in the enstatite chondrites is in the metallic phase.*

Very few data are available on rhenium and osmium abundances in chondritic meteorites, and it is not known whether these elements have been fractionated among the type I carbonaceous chondrites, the enstatite chondrites, the olivine-pigeonite chondrites, and the "ordinary" chondrites (that is, the hypersthene and bronzite chondrites) during the evolution of the various chondrite types. For example, Pb, Bi, and Tl (*1*); I, and Te (*2*); Cd (*3*); and Ge (*4*) occur in approximately cosmic abundances in the type I carbonaceous chondrites and the enstatite chondrites but are depleted in other chondrites. Other elements, for example, Zn, and Cl (*4*); U, and Th (*5*), are found in approximately cosmic abundance in type I carbonaceous chondrites but are depleted in at least some enstatite chondrites and all other chondrites.

The only data available on Re and Os abundances determined on the same samples of chondrites were reported by Herr *et al.* (*6*). They found, per gram, 31 × 10^{-9} g of Re, and 350 × 10^{-9} g of Os in the silicate portion of the Mocs hypersthene chondrite, and 291 × 10^{-9} g of Re and 3670 × 10^{-9} g of Os in the metallic portion. The metallic portion of the Ramsdorf chondrite was found to contain 188 × 10^{-9} g of Re and 2570 × 10^{-9} g of Os. Bate and Huizenga (*7*) reported recently that Os abundances in nine ordinary chondrites and one type II carbonaceous chondrite showed a range of 640 to 1220 × 10^{-9} g of Os per gram (average 910 × 10^{-9} g/g). No data are available for either Re or Os abundances in type I carbonaceous chondrites, olivine-pigeonite chondrites, or enstatite chondrites.

Clayton (*8*) has shown that the decay scheme $Re^{187} \rightarrow Os^{187}$ can be used to calculate the time at which galactic nucleosynthesis began relative to the time the solar system formed. This calculation can be made by assuming a model for nucleosynthesis and provided (i) the neutron-capture cross-sections of Os^{186} and Os^{187}, (ii) the $Re^{187} \rightarrow Os^{187}$ half-life, and (iii) the Os/Re ratio in chondrites are all known precisely. It is the purpose of this work to provide new data for Re and Os abundances and Os/Re ratios in chondrites.

The chondrites studied were Orgueil (type I carbonaceous chondrite), Mokoia (carbonaceous olivine-pigeonite chondrite), Karoonda (olivine-pigeonite chondrite), Mocs (hypersthene chondrite), and Hvittis (enstatite chondrite). Since enstatite achondrites seem to rep-

Table 1. Neutron activation analysis of rhenium and osmium in stony meteorites. (The errors reported are the standard deviations based on the counting data.)

Rhenium (10^{-9} g/g)	Osmium (10^{-9} g/g)		Os/Re*
	From Os^{191}	From Os^{185}	
Orgueil (*type I carbonaceous chondrite*)			
37.0 ± 0.4	435 ± 5		11.8
35.8 ± 0.4	466 ± 5		13.0
Mean = 36.4	Mean = 451		
Recalculated Mean† = 57.8	Recalculated Mean† = 716		
Mokoia (*carbonaceous olivine-pigeonite chondrite*)			
58.8 ± 0.6	721 ± 8	736 ± 9	12.3
58.0 ± 0.6	660 ± 7	715 ± 10	11.4
Mean = 58.4	Mean = 691	Mean = 726	
Karoonda (*olivine-pigeonite chondrite*)			
59.3 ± 0.6	808 ± 8	803 ± 9	13.6
58.1 ± 0.6	881 ± 9	878 ± 9	15.2
Mean = 58.7	Mean = 845	Mean = 841	
Mocs (*hypersthene chondrite*)			
79.4 ± 0.8	788 ± 8	744 ± 4	9.9
37.6 ± 0.4	348 ± 4	325 ± 3	9.3
Mean = 58.5	Mean = 568	Mean = 550	
Hvittis (*enstatite chondrite*)			
69.3 ± 0.8	797 ± 8	809 ± 12	11.5
67.2 ± 0.7	668 ± 7		9.9
Mean = 68.3	Mean = 733		
Average chondrite†			
60.3	710		11.8
Bishopville (*enstatite achondrite*)			
0.223 ± 0.008	4.77 ± 1.1		21.4
0.281 ± 0.010	5.10 ± 0.7		18.1
Mean = 0.252	Mean = 4.94		

* Os/Re ratios calculated by using Os abundances measured from Os^{191}. † Orgueil mean abundances recalculated with the assumption of total removal of water and carbon.

Table 2. Comparative measurements of rhenium and osmium abundance in the Mocs chondrite by various neutron activation techniques.

Rhenium (10^{-9} g/g)	Osmium (10^{-9} g/g)	Os/Re	Reference
46.2	544.2	11.8	Herr *et al.* *(6)**
	820		Bate and Huizenga *(7)*
	960		Bate and Huizenga *(7)*
79.4	788	9.9	This work
37.6	348	9.3	This work

* Recalculated from separate metal and silicate portion analyses on the assumption that there is 5.85 percent metal portion by weight in the meteorite *(12)*.

resent completely melted enstatite chondrite material from which the metal and sulphide phases have been removed and, as such, are more closely related to the chondrites than the other achondrites *(5)*, the Bishopville enstatite achondrite was also analyzed. All these meteorite samples were described previously *(5)*.

Both Re and Os were determined by means of a neutron activation technique which has been described in detail elsewhere *(9)*, but which in essence depends upon the nuclear reactions Re^{185} (n, γ) Re^{186} ($t_{\frac{1}{2}}$ = 88.9 hours) and Os^{190} (n, γ) Os^{191} ($t_{\frac{1}{2}}$ = 16 days) with both the Re^{186} and Os^{191} being determined by counting the β particles). The Os abundances determined in this way were also checked by another reaction, Os^{184} (n, γ) Os^{185} ($t_{\frac{1}{2}}$ = 94 days), and the Os^{185} determined by γ-spectrometry with the 646-kev photopeak. The results (Table 1) indicate good agreement between Os abundances determined by both methods so that it may also be concluded that the Os^{184}/Os^{190} ratios in the chondrites are essentially constant. For most samples the reproducibility of the analytical method and the adequacy of the sampling procedures are illustrated in the very good agreement between analyses of duplicate samples of each meteorite. In the case of the Mocs chondrite, one sample contains about twice as much Re and Os as does the other (Table 2). This variability is almost certainly due to inhomogeneity of the metal phase in the crushed meteorite from which the two samples were taken, since Herr *et al.* *(6)* have shown that the metal phase of Mocs contains an order of magnitude more Re and Os than does the silicate phase. The metal phase in Mocs is sparsely distributed and generally occurs as relatively large grains which cannot be ground as finely as the silicate fraction, so that sampling becomes difficult. It is significant that the Os/Re ratios in both our samples were identical and that the ratios Herr *et al.* *(6)* found in the silicate and metal portions were also very close. Since the Mocs chondrite has also been analyzed for Re or Os, or both by previous workers *(6, 7)*, it is possible to draw some comparisons between the various neutron activation methods used (Table 2). The Re and Os results recalculated from data reported by Herr *et al.* *(6)* are within the range found in the present work although the Os/Re ratio is slightly higher. The Os results reported by Bate and Huizenga *(7)* are outside the range found in the present work but in view of the problem of getting a representative sample of the Mocs chondrite, their results may simply reflect slightly more metal phase than normal, and it is significant that they report an unusually high metal phase content of 19 percent in their sample of Mocs.

Table 3. Comparison of cosmic and chondritic atomic abundances of rhenium and osmium (on the basis of 10^6 Si atoms).

Element and ratio	Cosmic abundances		Average chondritic abundances
	Suess and Urey *(10)*	Cameron *(11)*	
Re	0.155*	0.054	0.0512
Os	1.00	0.64	0.590
Os/Re	6.5	11.9	11.5

* The value in the table of abundances is 0.135 but the text shows it should be 0.155 *(10)*.

The most important result is that both Re and Os have virtually identical abundances in all classes of chondrites if the abundances in the type I carbonaceous chondrites are recalculated with the assumption of total removal of water and carbon. It may be concluded that Re and Os have not been fractionated during the evolution of the various chondrite types. The cosmic atomic abundances of Re and Os (relative to 10^6 Si atoms) estimated by Suess and Urey *(10)* and Cameron *(11)* are compared with the average chondrite abundances in Table 3 and seem to agree very closely with Cameron's estimates. The work reported here also suggests that the Os/Re atomic ratio required for Clayton's calculations on the time for the beginning of nucleogenesis *(8)* is 11.5, which is very close to his assumed value of 11.3.

The Bishopville enstatite achondrite contains about 300 times less Re and about 100 times less Os than the Hvittis enstatite chondrite. If the Hvittis abundances are characteristic of enstatite chondrites and if the Bishopville enstatite achondrite has been derived by simple melting of Hvittis-like material with removal of metal and troilite phases from the melt, then most of the Re and Os is also removed at this stage with more of the original Re being removed relative to the original Os abundance, so that the Os/Re ratio in the remaining silicate is about 19.6. If, on the other hand, the Re and Os abundances in Bishopville are typical of the abundances in the silicate portion of the Hvittis enstatite chondrite, then the Re and Os abundances in the metal-plus-troilite (FeS) portion may be calculated given that Hvittis contains 21.44 percent by weight of metal phase and 7.40 percent by weight of troilite *(12)*. From this calculation, the Re content of the metal-plus-troilite fraction should be 236 × 10^{-9} g/g and the Os content 2530 × 10^{-9} g/g (Os/Re = 10.7). Previous workers *(6, 7)* have shown that troilites from iron meteorites contain very much less Re and Os than does the metal phase so it may be assumed that most of the Re and Os occurs in the metal phase of the enstatite chondrites.

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