GAS PERMEABILITY OF SOME ANTARCTIC CHONDRITES

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Abstract: Gas permeability of 11 Antarctic chondrites was measured at various gas flow pressures (0.5–2.5 bars) under confining pressures up to 120 bars. The gas permeability ranges from less than 1 microDarcy to more than 1 milliDarcy.

1. Introduction

The gas permeability of chondrites is an important physical parameter which might have controlled the redistribution of volatile elements in meteorite parent bodies during a period of thermal metamorphism.

We measured gas permeability of 11 Antarctic chondrites. Together with the previous results on 15 chondrites (SUGIURA *et al.*, 1984; MATSUI *et al.*, 1986), the permeability data on H and L chondrites show fairly well defined trends.

2. Samples and Experiments

The Antarctic meteorites used for the present experiments were previously used for measurements of other physical properties. Detailed descriptions are given in YOMOGIDA and MATSUI (1983). Visible cracks could be seen on Yamato-74191, Y-74156 and Allan Hills-78251. Veins were observed on Y-74647. Rectangular-shaped pieces of chondrites were set in epoxy to make disk-shaped samples. The gas flow through the sample was measured with a water manometer. The average gas pressure ranged from 0.5 to 3 bars. A confining pressure up to 120 bars was applied to the sample. Further details of the apparatus are described in SUGIURA *et al.* (1984).

3. Results and Discussion

The results are summarized in Table 1. Figure 1 has representative data showing the relation between permeability and reciprocal mean pressure. The non-linear relationship observed for Y-74647 suggests that the flow is turbulent at high driving pressures (low reciprocal mean pressure), and viscous at low driving pressures. The implication is that the aperture of the flow channel is quite large. The linear relationship observed for both Y-74191 and Y-75097, indicates on the other hand that the flow is in the transition range between viscous flow and molecular flow. It is noted that the permeability of Y-74191, which has a visible crack, shows a large confining

Table 1. Gas permeability of 11 Antarctic chondrites.

Sample type	Permeability* milliDarcy	Porosity %	$p(106)/p(8)$	s/p** ATM
Y-74647 H4-5	6.02	9.1	.771	—
Y-74191 L3	2.31	10.3	.654	.214
Y-74156 H4	1.72	9.2	.730	.386
ALH-78251 L6	1.66	13.2	.702	.373
ALH-78103 L6	1.60	13.4	.679	.300
ALH-769 L6	1.08	19.4	.796	—
ALH-77294 H5	0.94	12.9	.697	—
Y-75097 L4	0.93	10.3	.855	.399
ALH-77231 L6	0.64	14.3	.766	.417
MET-78003 L6	0.298	7.8	.799	.339
ALH-77288 H6***	4.33E-4	2.0	—	—

* At confining pressure of 8 bars.

** Normalized slope, not determined for samples whose gas flow is turbulent.

*** ALH-77288's permeability was too small to measure the confining pressure dependence and normalized slope accurately.

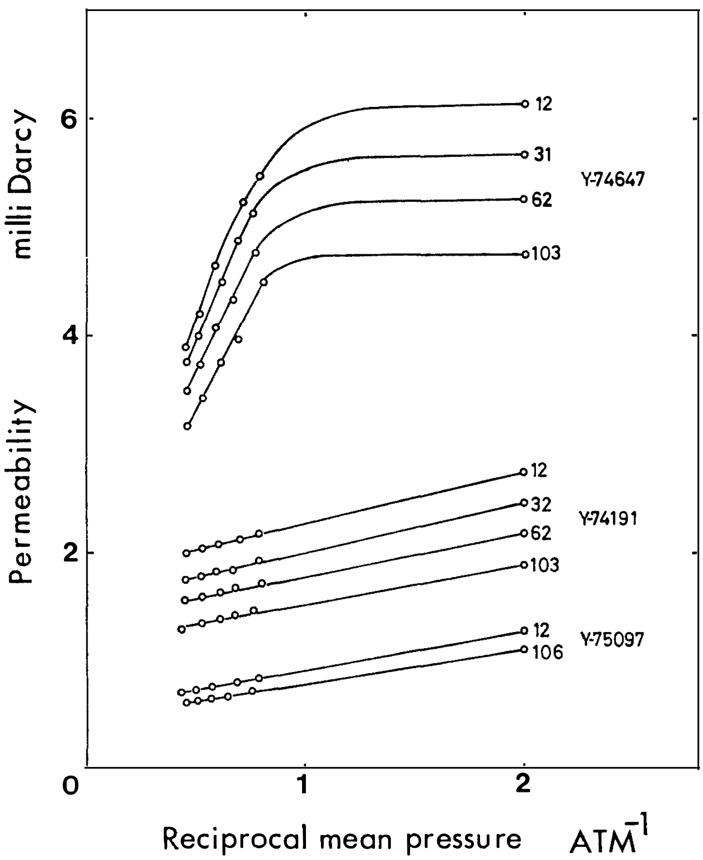

Fig. 1. Permeability of 3 chondrites is plotted against reciprocal mean pressure. Confining pressure is given next to each curve.

pressure dependence and a relatively small slope (reciprocal mean pressure dependence). In contrast the permeability of Y-75097 has a small confining pressure dependence and a relatively large slope (which becomes clear if the curves are normalized to the permeability). Such a relationship between confining pressure dependence and normalized slope was first noticed among shocked chondrites (MATSUI *et al.*, 1986). As shown in Fig. 2, the relation holds for most of the chondrites we have measured. The confining pressure dependence is considered to be an indication of

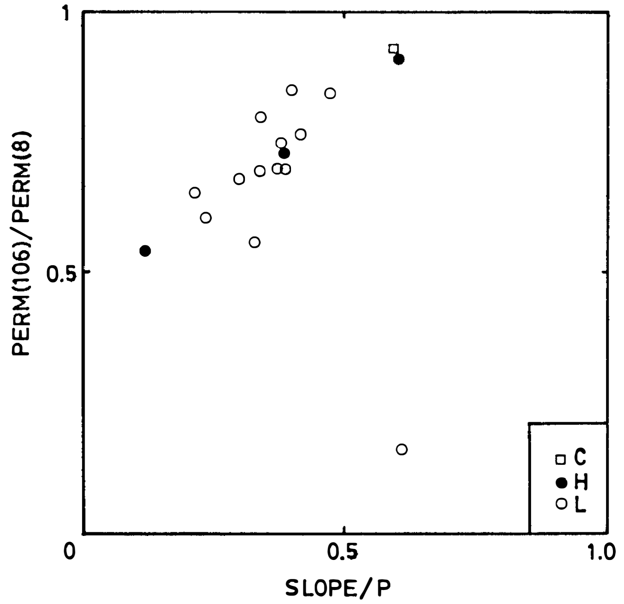

Fig. 2. Relationship between confining pressure dependence and normalized slope of Fig. 1. The ordinate is the ratio of permeabilities at confining pressure of 106 bars and of 8 bars. The abscissa is the slope of the permeability vs. reciprocal mean pressure at confining pressure of 8 bars, normalized to permeability at 1 ATM.

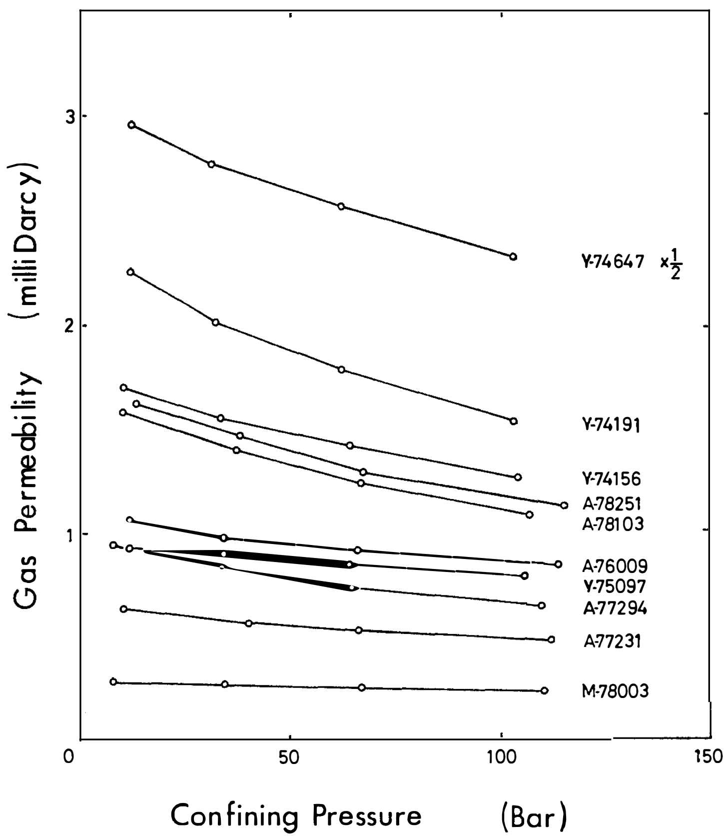

Fig. 3. Confining pressure dependence of gas permeability at gas pressure of 1 ATM.

the permeability through cracks. The driving pressure dependence is an indication of the size of the channel through which the gas permeates, *i.e.* the larger the slope, the smaller the size. Therefore, the positive correlation of Fig. 2 suggests that the size of cracks is larger than that of non-crack (spherical) pores. It should be noted that some pores and some cracks, particularly microcracks may be closed to the gas flow experiments described here. We use the term pore to refer to accessible openings that are roughly equidimensional and the term cracks to refer to plate-like openings that are accessible.

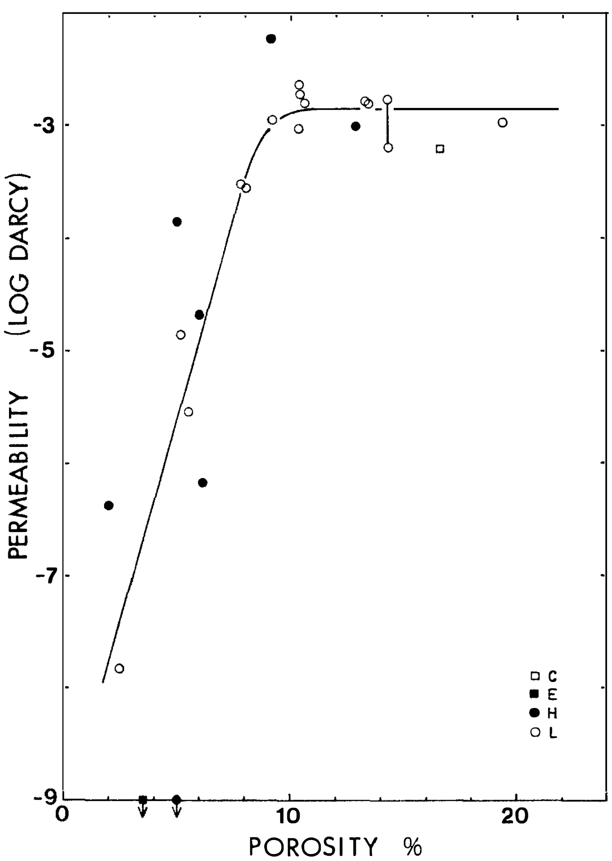

Fig. 4. Gas permeability vs. porosity plot.

Figure 3 shows the confining pressure dependence of the gas permeability. It indicates that a pressure of more than 100 bars (this corresponds to the central pressure of a parent body with a radius of 80 km) is required to close all cracks.

In Fig. 4 permeability is plotted against porosity (porosity data from YOMOGIDA and MATSUI, 1983). The permeability of L chondrites increased systematically with increasing porosity at lower porosities. At porosities above 8%, the permeability is almost independent of the porosity. H chondrites seems to follow the same trend, although with greater scatter. The larger deviation for H chondrites might be explained as follows. One of the major differences between H and L chondrites is the amount of metallic iron grains which can easily deform. This could cause selective plugging at channels through which the gas moves. As far as L chondrites are concerned, the least porous (and less permeable) 5 chondrites are heavily shocked (types d and e of DODD and JAROSEWICH, 1979), and the shock events are fairly recent ones. Therefore, the typical gas permeability of L chondrites which have not been heavily shocked appears to be 10^{-3} Darcy.

There is a positive correlation between the permeability and its dependence on confining pressure. Figure 5 shows that for most unshocked chondrites, the correlation is linear. If we make the following assumptions, we can estimate the non-crack permeability of those chondrites. We assume that (1) the permeability is divided into two parts; confining pressure-dependent crack permeability (P_c) and confining pressure-independent non-crack permeability (P_{nc}), (2) these two permeabilities are additive (*i.e.* parallel channels), and (3) the non-crack permeability does not vary between chondrites.

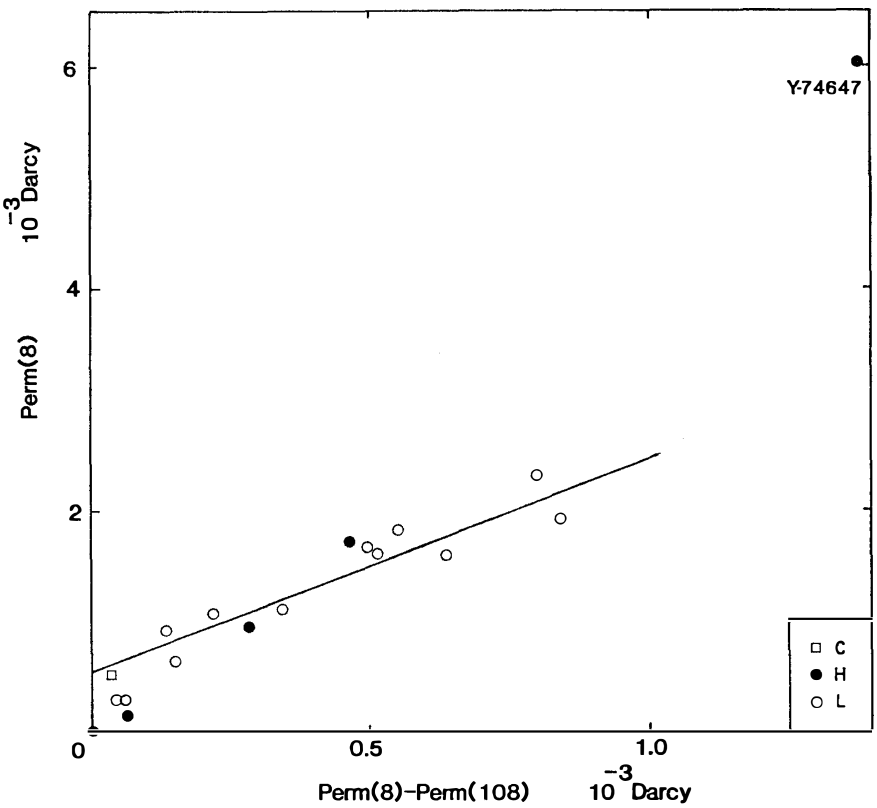

Fig. 5. Relationship between permeability at gas pressure of 1 ATM and its changes under confining pressure.

Then
$$P(8\ \text{bar}) = P_{nc} + P_c\ ,$$
$$P(106\ \text{bar}) = P_{nc} + (1-c)P_c\ ,$$

where c is the fraction of cracks which are closed at 106 bars. The correlation line in Fig. 5 gives $P_{nc}=0.55$ milliDarcy and $c=0.53$. Admittedly, the assumptions are not rigorously justified, and consequently the non-crack permeability is a very crude estimate.

Y-74647 does not follow the trend, probably because its cracks (veins) are partially filled and do not close efficiently under pressure. Those chondrites which have much smaller permeabilities and do not follow the trend of Fig. 5, may have been shock deformed and have much smaller non-crack permeability. Detailed petrographic studies are needed to study the character of the crack formation, the nature of thermal metamorphism and the deformation of metallic iron in pores and cracks. It seems likely that if such cracks were formed before thermal metamorphism they would heal during the metamorphism. Therefore, crack formation is likely to be subsequent to metamorphism. 0.55×10^{-8} Darcy may be a representative gas permeability for chondrite parent bodies before and during thermal metamorphism. Cracks are likely to have been produced by impacts. It is possible that light impacts opened up cracks without changing the porosity appreciably, while strong impacts closed cracks and reduced porosity. Experimental confirmation of the shock effects on the permeabilities of chondrites is needed. This is of considerable importance because these properties may be related to the accretion processes of planetesimals.

4. Summary

(1) Gas permeability *vs.* porosity relationships are well established for L chondrites.

(2) Heavy shocks reduce both permeability and porosity, while light shocks increase permeability slightly without changing the porosity very much.

(3) Typical gas permeability of L-chondrite parent bodies is estimated to be 0.5 milliDarcy before and during thermal metamorphism.

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References

Dodd, R. T. and Jarosewich, E. (1979): Incipient melting in and shock classification of L-group chondrites. Earth Planet. Sci. Lett., **44**, 335–340.

Matsui, T., Sugiura, N. and Brar, N. S. (1986): Gas permeability of shocked chondrites. Meteoritics, **21**, 109–116.

Sugiura, N., Brar, N. S., Matsui, T. and Strangway, D. W. (1984): Degassing of meteorite parent bodies. Proc. Lunar Planet. Sci. Conf., 14th, Pt. 2, B641–B644 (J. Geophys. Res., **89** Suppl.).

Yomogida, K. and Matsui, T. (1983): Physical properties of ordinary chondrites. J. Geophys. Res., **88**, 9513–9533.

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