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N66-12980

N66-12980	
(ACCESSION NUMBER)	(THRU)
16	1
(PAGES)	(CODE)
CR-68308	03
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

FACILITY FORM 602

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 1.00

Microfiche (MF) .50

ff 653 July 65

Third Quarterly Progress Report
IITRI Project No. M272, Phase III

STUDIES OF LUNAR AND MARTIAN SOIL MECHANICS

by

E. Vey and J. D. Nelson

September 30, 1965

IIT RESEARCH INSTITUTE
Technology Center
Chicago, Illinois 60616

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E. Vey and J. D. Nelson

for

National Aeronautics and Space Administration
Structures and Operations Problem Group
Space Vehicles Division
Washington, D. C.

September 30, 1965

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STUDIES OF LUNAR AND MARTIAN SOIL MECHANICS

I. INTRODUCTION

This is the third quarterly report on Phase III of Project NASr-65(02), "Studies of Lunar and Martian Soil Mechanics". Phase III was initiated on December 15, 1964 and this report covers the period from June 15, 1965 to September 15, 1965.

The work to date has closely followed the outline of work set forth in IITRI Proposal No. 65-183M, entitled "Studies of Lunar and Martian Soil Mechanics". Efforts during the three month period covered in this report have been devoted to the determination of shear strength parameters under vacuum, the resistance of soil to dynamic penetration, and the determination of the composition of desorbed gases.

II. DETERMINATION OF SHEAR STRENGTH PARAMETERS

In the final report on Phase II,[1/*] it was pointed out that because of scatter in the data it would be necessary to obtain additional data points before the apparent trends could be firmly established. In this reporting period additional direct shear tests were performed on quartz powder.

In agreement with previous results a marked increase in stiffness of the soil was observed under ultra-high vacuum. At low values of normal stress, the shear stress reached a peak at very small displacements (approximately 0.005 in.) after which the shear stress decreased and then increased to a maximum at approximately 0.150 to 0.200 in. Figure 1 shows the maximum

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1/ Vey, E. and J. D. Nelson, "Studies of Lunar Soil Mechanics", Final Report, IIT Research Institute Proposal No. M272-II, Contract NASr-65(02), February 1965.

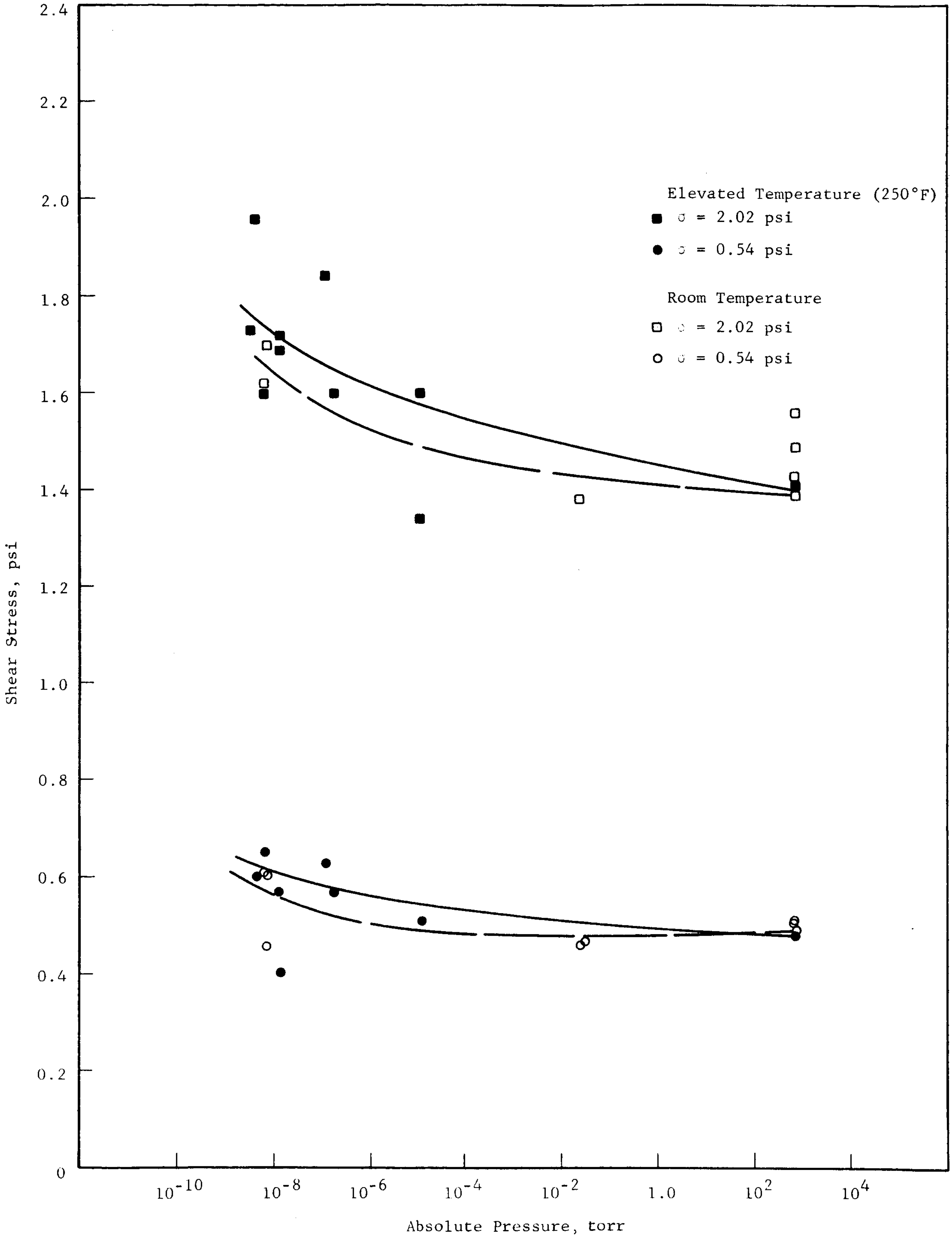

Fig. 1 EFFECT OF VACUUM ON MAXIMUM SHEAR STRESS IN QUARTZ POWDER

shear stress as a function of the vacuum level at which the experiment was performed. In those cases where two peak shear stresses were observed the second maximum point is the one shown in this figure.

The shear stress was plotted as a function of normal stress in Fig. 2 to obtain the rupture diagram for the soil. Although there is a considerable amount of scatter in the data it can be seen that if lines are drawn bounding the points for atmospheric conditions and ultra-high vacuum an increase in shear strength under vacuum is indicated quite clearly. From Fig. 1 it appears that the shear strength decreased somewhat at rough vacuum levels (approximately 10^{-2} torr). While the data indicating this are scarce it would be reasonable to expect because of the removal of hygroscopic moisture and, hence, surface tension in the soil. Consequently, the increase in shear strength due to the removal of adsorbed gas from the particle surfaces should be at least equal to or greater than the difference indicated in Fig. 2.

While the scatter makes it difficult to separate the increase in shear strength into cohesive and frictional components the slopes of the boundary lines do not change appreciably and, hence, an increase in the apparent cohesion is indicated.

If the strength increase is caused by the development of interparticle forces and/or an increase in friction as the result of the removal of adsorbed gas then the shear strength would be a function of the amount of gas removed rather than the vacuum level at which the test was performed. The amount of gas removed depends not only on the ultimate attainable vacuum level but also the length of time under vacuum, the amount of bakeout of the system and soil and the degree and type of contamination of the entire system prior to pumpdown. Consequently, the scatter of the data in Fig. 1 and 2 may be attributed, at least in part, to variations in the pumpdown history of different experiments.

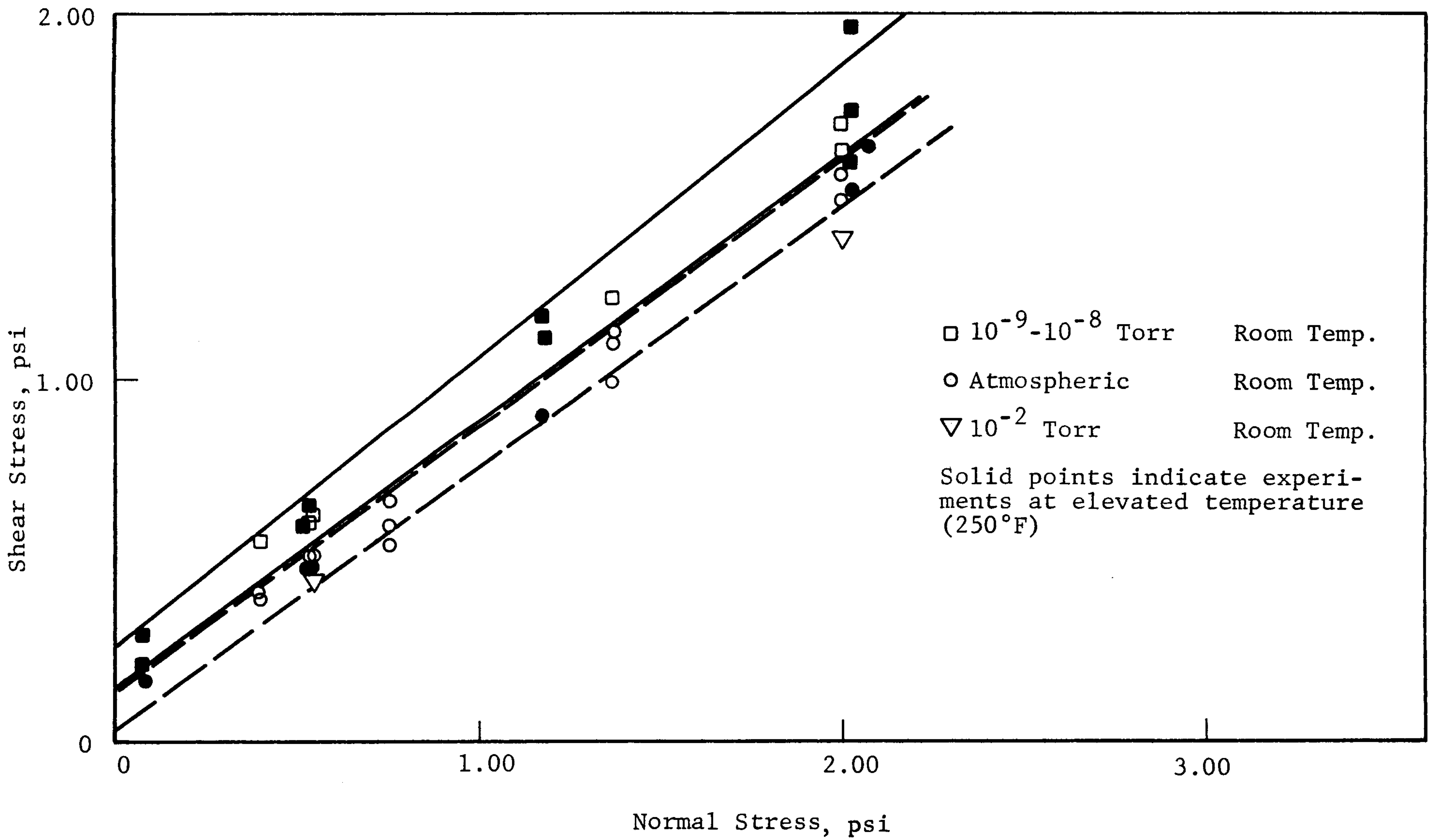

Fig. 2 MOHR'S RUPTURE DIAGRAM FOR QUARTZ POWDER

Thus, while a quantitative measure of the change in shear strength is not possible an increase under ultra-high vacuum is definitely indicated. It is believed that this increase is derived from increases in both apparent cohesion and internal friction.

III. PENETRATION RESISTANCE UNDER DYNAMIC LOADING

Dynamic penetration experiments were also performed to supplement the data obtained in Phase II of this program. The results of these experiments are shown in Fig. 3 and 4 along with those obtained previously in the form of the penetration caused by 0.3 in.-lb work as a function of the porosity.

In Fig. 3 which shows the results in quartz powder it can be seen that the curves have the same shape as was indicated before. An increase in penetration resistance under rough vacuum is indicated and this was due to the removal of pore air effects. A further increase in resistance is indicated at high and ultra-high vacuum levels.

From Fig. 4 it can be seen that the results for olivine powder also agree closely with the previous results. In these data an increase in penetration resistance under rough vacuum levels and a further increase under ultra-high vacuum is evident as was the case for quartz. However, the results for high vacuum (approximately 10^{-6} torr) are closer to those for rough vacuum whereas in the quartz they were closer to those for ultra-high vacuum. Thus, although the removal of adsorbed gas from the particle surfaces produces an increase in the shear strength (and, hence, the penetration resistance) in both soils, the vacuum level at which this effect becomes appreciable is considerably higher for the olivine than the quartz. Possible reasons for this are 1) the gas adsorbed on the olivine has a higher adsorption energy than that adsorbed on the quartz, 2) a greater amount of gas is adsorbed on the olivine than the

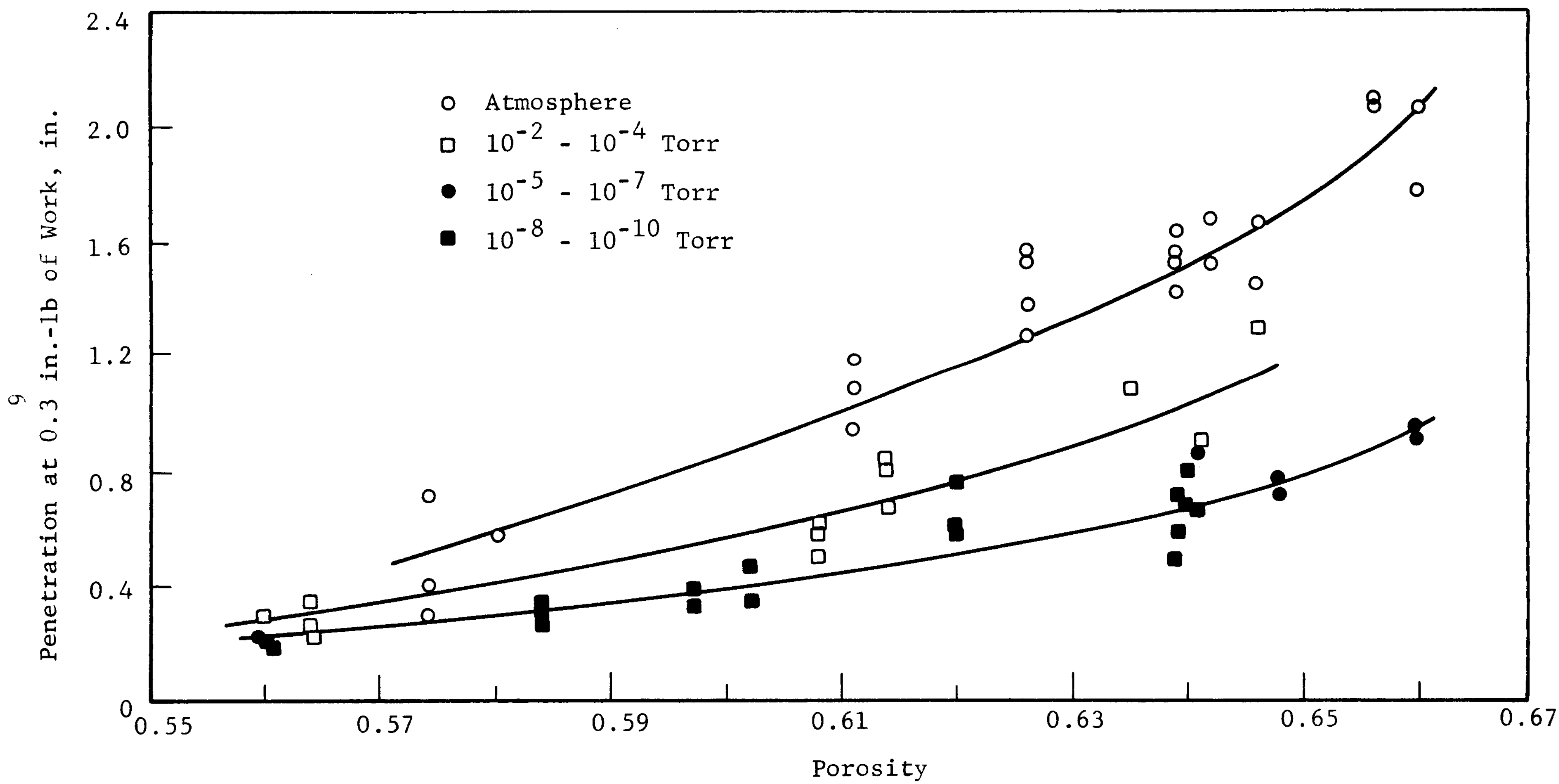

Fig. 3 EFFECT OF POROSITY ON PENETRATION AT 0.3 IN.-LB WORK IN QUARTZ POWDER

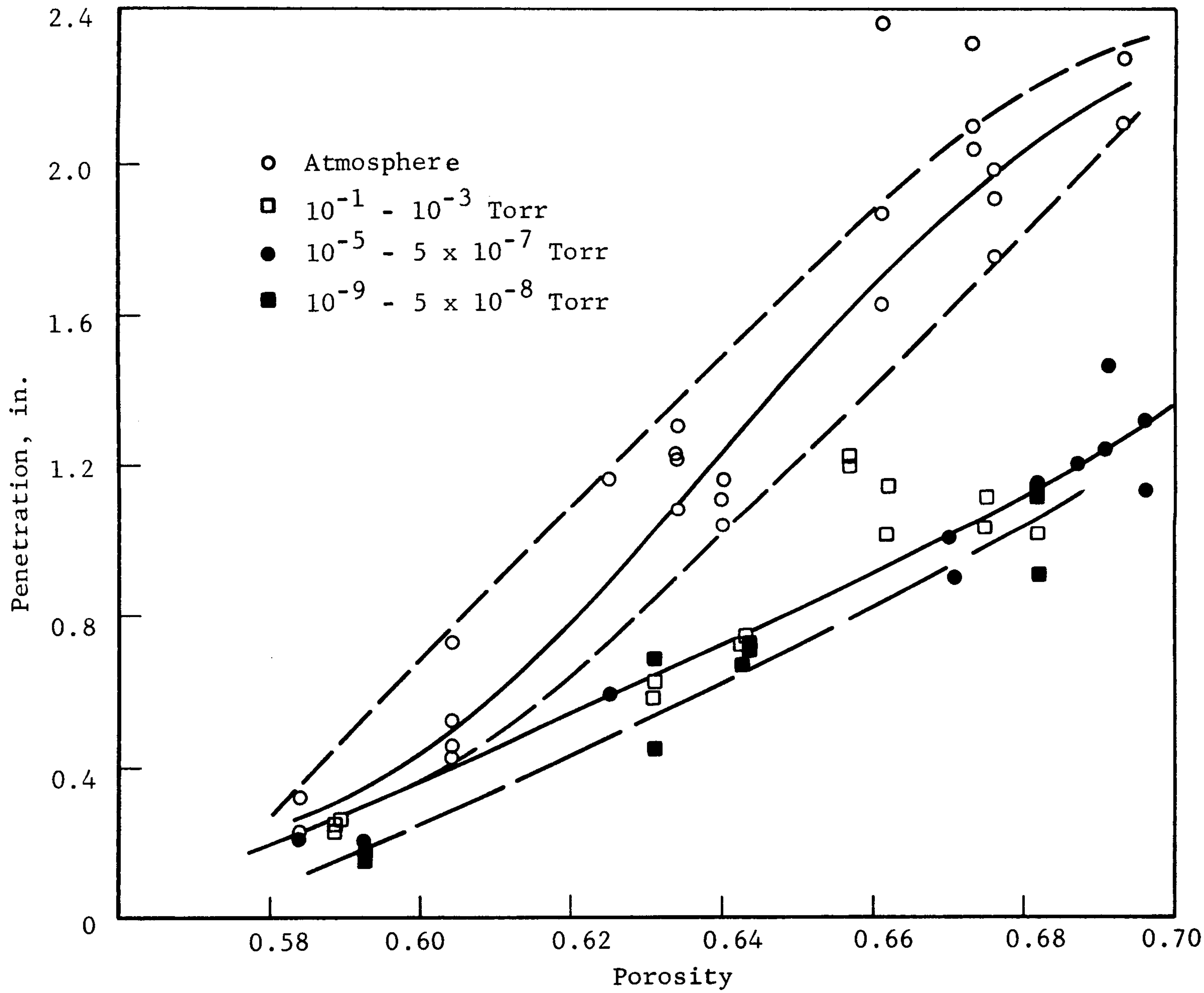

Fig. 4 EFFECT OF POROSITY ON PENETRATION AT 0.3 IN.-LB WORK IN OLIVINE POWDER

quartz at the start of pumpdown and/or 3) the surface energy and/or contact area at asperities because of different grain shape and size is less for the olivine than the quartz.

It may be noted that these results are consistent with those of the direct shear tests and porosity attained by soil deposited in vacuum.

IV. COMPOSITION OF ADSORBED GAS LAYERS

Experiments are presently being performed to determine the components of the gas layers adsorbed on the soil particles. The equipment being used in these experiments was described in the previous quarterly report.[2] It consists of a small container fabricated from thin tantalum sheet into which the soil is placed and through which low voltage alternating current is passed to heat the soil. The maximum temperature that can be obtained in this way is approximately 900°C. The container is completely closed except for a small hole facing the inlet port of an ultra-high vacuum, mass spectrometer type, residual gas analyzer. Thus, the desorbed gas issues from the hole in a molecular beam which is then analyzed with the mass spectrometer.

Preliminary experiments have been performed on quartz crystals, quartz powder and olivine crystals. The pure quartz and olivine crystals were prepared by first coating a large quartz crystal or piece of olivine with machinists bluing. It was then wrapped in aluminum foil and crushed between two steel plates. In this way smaller pieces having all fresh surfaces could be obtained. The powder was the same as that used in all previous experiments.

The relative peak heights of the major peaks that were observed are shown in Fig. 5, 6 and 7. While these results are

[2] Vey, E. and J. D. Nelson, "Studies of Lunar and Martian Soil Mechanics", Second Quarterly Progress Report, IIT Research Institute Project M272-III, June 30, 1965.

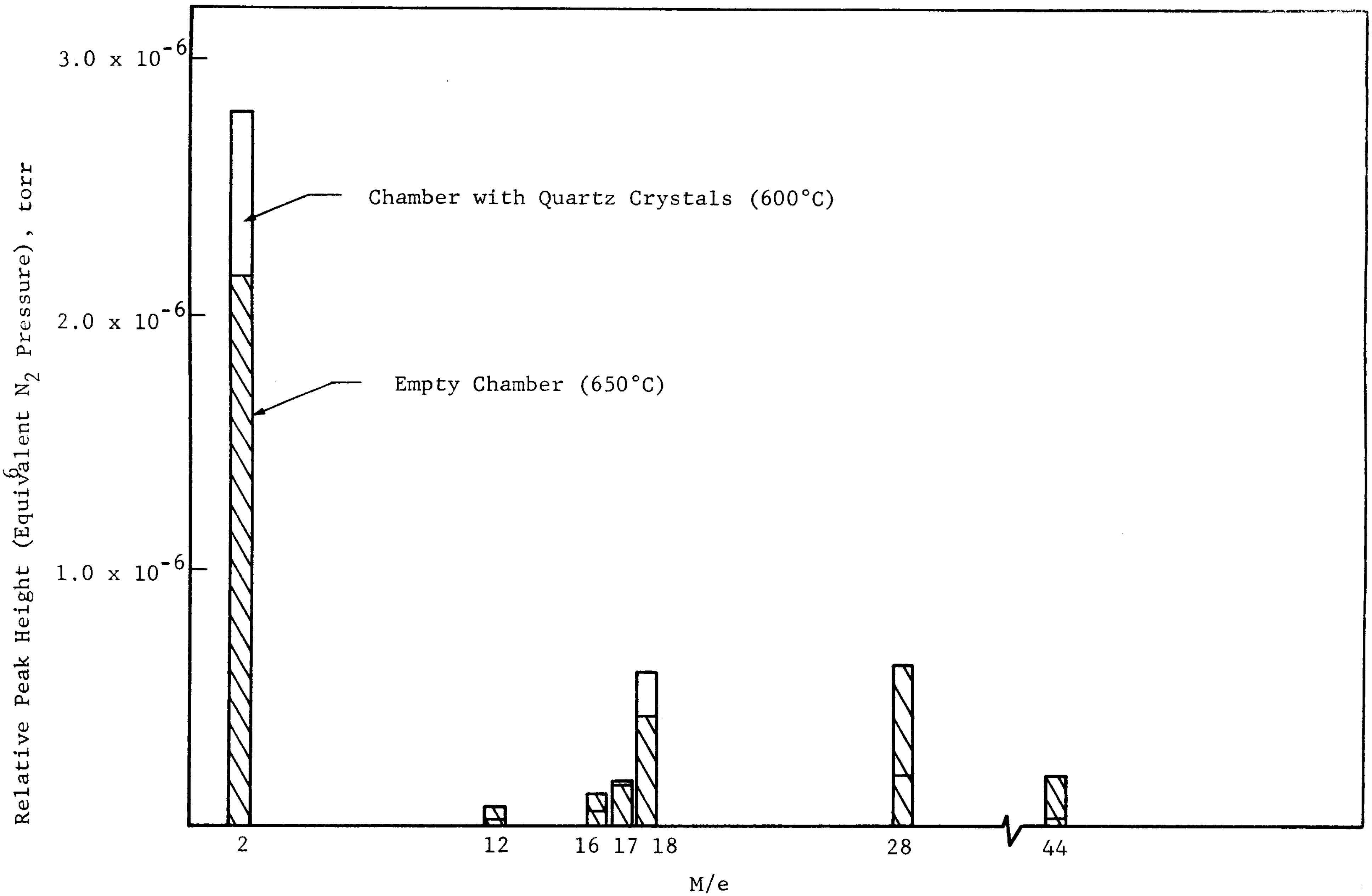

Fig. 5 SPECTRUM OF RESIDUAL GASES FOR CHAMBER WITH QUARTZ CRYSTALS

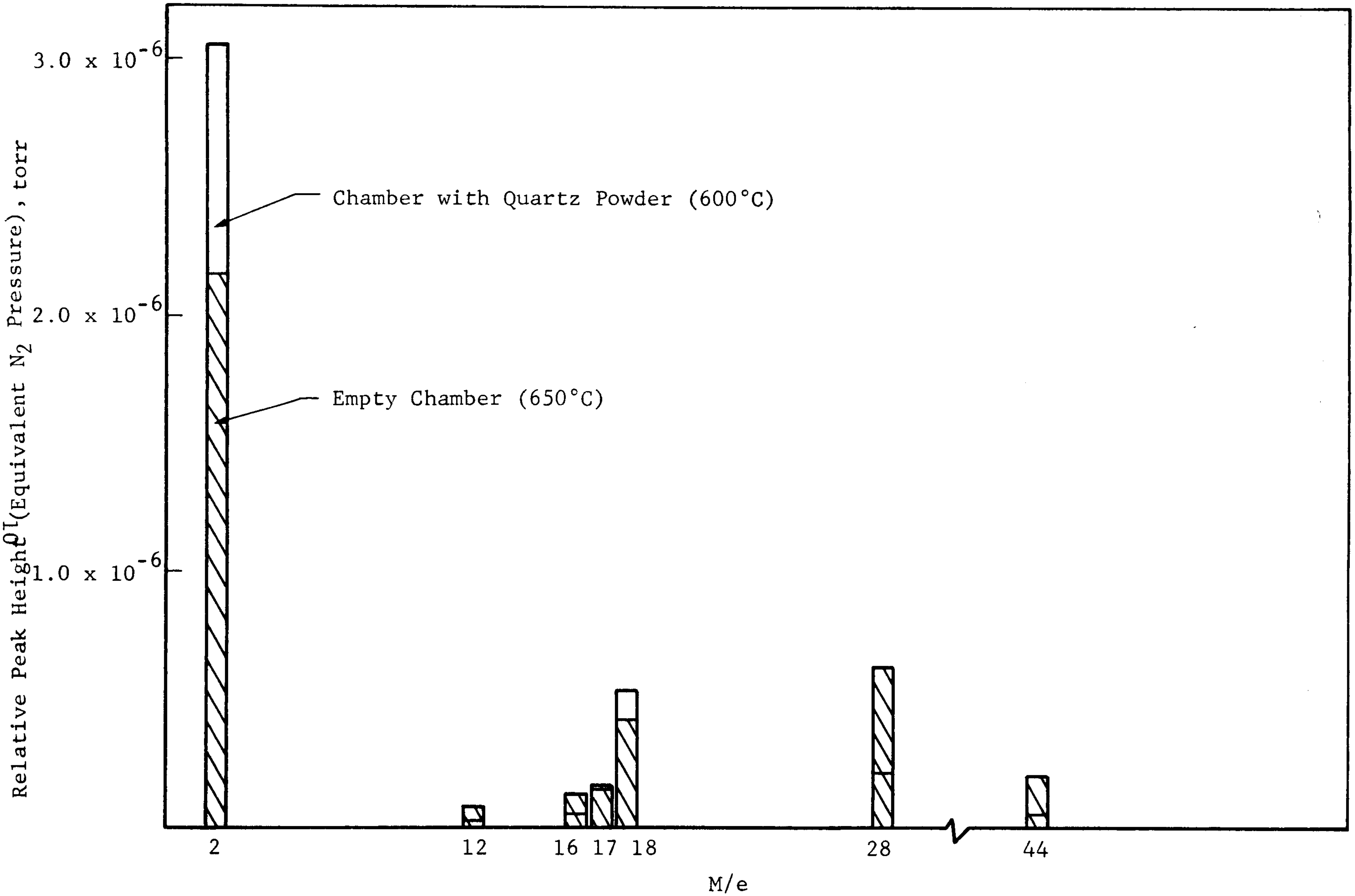

Fig. 6 SPECTRUM OF RESIDUAL GASES FOR CHAMBER WITH QUARTZ POWDER

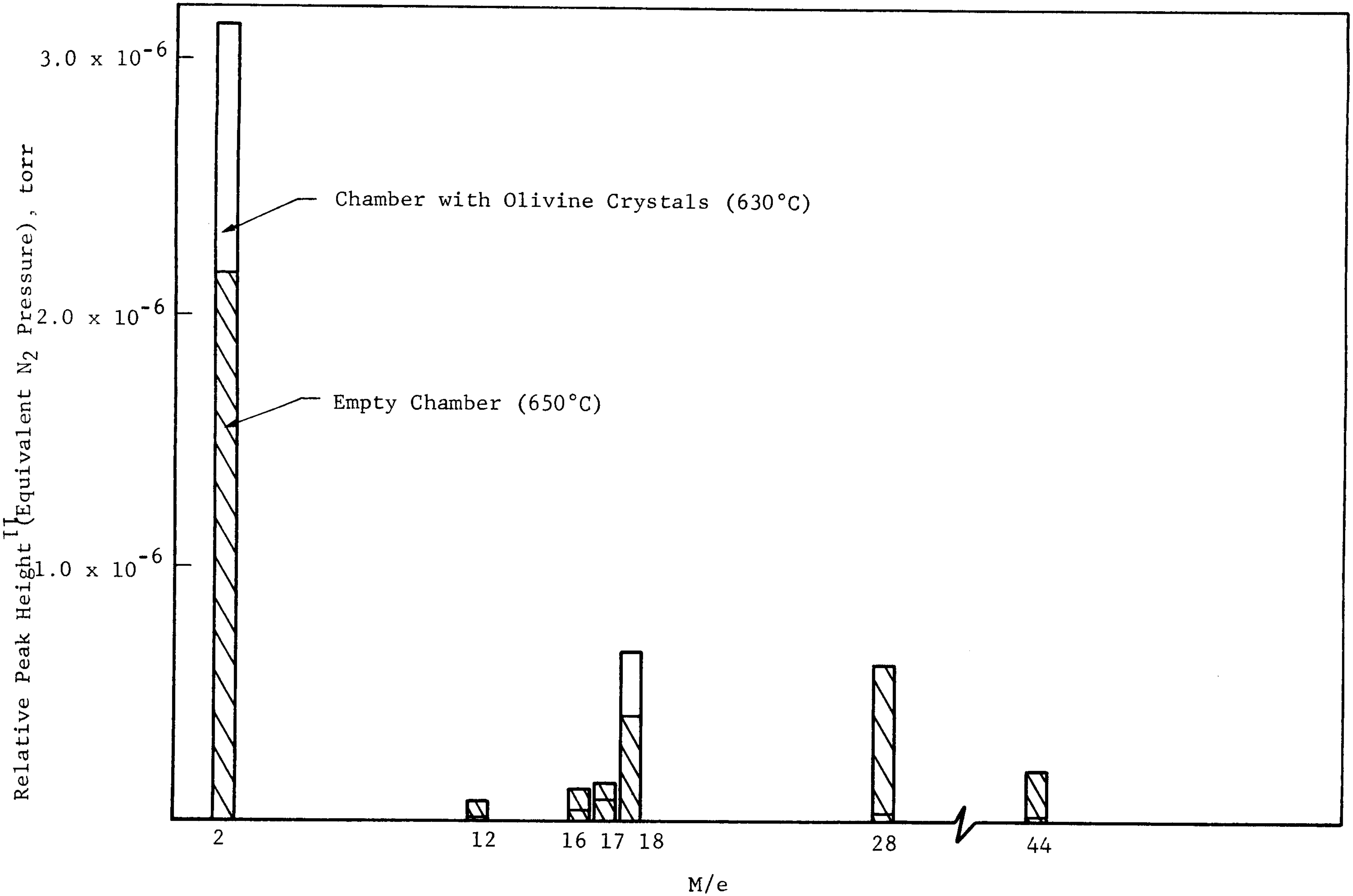

Fig. 7 SPECTRUM OF RESIDUAL GASES FOR CHAMBER WITH OLIVINE CRYSTALS

only preliminary it appears that the major peaks of the desorbed gas for all three materials are at M/e values of 2 and 18. The existence of the relatively high 18 peak suggests that both the 2 and 18 peaks are due to desorbed H_2O from the crystals. It also appears that a greater amount of gas is desorbed from the olivine than the quartz but the data is not conclusive.

V. PLANNED RESEARCH FOR THE NEXT QUARTER

The work to be carried out in the remaining quarters will closely follow that outlined in IITRI Proposal No. 65-183M, "Studies of Lunar and Martian Soil Mechanics". The schedule for the next quarter is as follows:

1. Direct shear tests on enstatite and obsidian powders in vacuum at temperatures from +270°F to the lowest obtainable.
2. Dynamic penetration tests on enstatite and obsidian powders at varying vacuum levels and porosities.
3. Determination of the composition of adsorbed gas.
4. Generation of clean particle surfaces.
5. Martian soil experiments.

VI. CONTRIBUTING PERSONNEL

The following personnel contributed to the work described in the present program.

E. Vey was project engineer.

J. D. Nelson was responsible for the experimental work and analysis of the data.

R. A. Wetzel assisted in the performance of the experiments and data analysis.

W. E. Jamison was in charge of the vacuum facilities and designed the equipment for the determination of the composition of adsorbed gases.