obtained for impact experiments on earth.

Conclusions. We summarize below in four major conclusions:

1) Body wave velocities measured from the LM and S-IVB impacts are in reasonably close agreement with the velocities predicted from laboratory measurements on lunar rock samples. This result implies that the rock material collected at the surface of the mare near the Apollo 12 landing site is similar to the material that forms the mare to depths of at least 20 km.

Present data for the mare region near the Apollo 12 landing site suggest that the outer shell of the moon consists of low-velocity material near the surface, with velocity increasing rapidly with depth in the upper 20 km. It is unlikely that a major discontinuity similar to the Mohorovicic discontinuity, which defines the lower limit of the crust of the earth, exists in the outer 20 km of the moon.

The fact that NASA was able to achieve such high targeting accuracy for the S-IVB and that the resulting seismic signals were so large suggests that planned future impacts can be extended to ranges up to at least 500 km and that the data returned will provide information on lunar structure to depths of several hundred kilometers.

2) The lunar seismic reverberation can be explained equally well as resulting from dispersion of surface waves or from scattering or, perhaps more likely, from a combination of these mechanisms. Scattering of surface waves implies the presence of heterogeneity in the outer shell of the moon on a scale from several hundred meters, or less, to several kilometers. Surface irregularities may contribute significantly to the scattering. The dispersion hypothesis requires the presence of a low-velocity outer zone. The presence of this zone to depths of several meters has been confirmed by measurements of seismic waves from sources associated with the LM and from Surveyor measurements. Very low absorption of seismic wave energy in the lunar material is inferred, independent of the assumed mode of propagation. This may be a consequence of the absence of fluids in the near-surface materials or low temperature or a combination of these factors.

3) Estimates of the fraction of impact kinetic energy that is converted to seismic wave energy are reasonably close to results obtained from impact experiments on earth.

4) Seismic signals of natural origin are produced by moonquakes and by meteoroid impacts. The low level of detectable lunar seismic activity relative to the earth suggests that the outer shell of the moon is tectonically stable as compared with the lithosphere of the earth. Tidal stresses appear to be an important factor in the occurrence of moonquakes. Meteoroid flux in the kilogram mass range, as it has been inferred from seismic data, is in approximate agreement with the Hawkins flux estimate (*2*).

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Mechanism for the Water-to-Air Transfer and Concentration of Bacteria

Abstract. *Air bubbles breaking at the air-water interface can remove bacteria that concentrate in the surface microlayer and eject the bacteria into the atmosphere. The bacterial concentrations (numbers per milliliter) in the drops ejected from the bubbles may, depending on drop size, be from 10 to 1000 times that of the water in which the bubbles burst.*

Woodcock (*1*) found that small droplets in the air were most likely the causative factor in human respiratory irritation associated with high concentrations of plankton in the sea. He showed that droplets carrying the irritant were easily generated by bubbling through the water rich in plankton. He later showed (*2*) that organic surface films could be removed from the water by the drops and suggested that bacteria in the surface layers of either sea water or fresh water might be removed in a similar way. Higgins (*3*), following up on this suggestion, collected the aerosol produced by bubbling through water that contained several species of bacteria. The ratios of the recoveries of some of the bacteria in the aerosol were higher than expected. He deduced from this that *Serratia marcescens* in particular must be concentrated at the surface of the liquid. The biological implications of these surface phenomena have been reviewed (*4*).

Material in the upper few microns of the surface is easily removed by drops from bursting bubbles. It has been investigated in the laboratory (*5*, *6*) and it has been shown that the nat-

ural marine aerosol carries surface-active organic material (*7*). Presumably this material originally had been present on the surface of the sea. Were bacteria also transported into the air?

We report here that bacteria can be carried into the air by drops from bursting bubbles and that the concentration of bacteria (numbers per milliliter) in the drops can far exceed that in the water in which the bubbles broke.

Bubbles were generated, one at a time and upon demand, in a 400 ml glass beaker (about 7 cm in diameter and 10.5 cm deep) containing tap water inoculated with bacteria, by forcing filtered air through a U-shaped glass capillary tube that had been heated and drawn out to a fine hairlike tip and placed about 1 cm beneath the surface of the water. The diameter of the tip determines the bubble size; the bubble production rate is determined by the air pressure. For a given air pressure, the bubbles are uniform in size (*8*). When a bubble breaks at the surface, it rapidly collapses, and a vertical jet of water rises at high speed from the bottom of the cavity (*9*). The jet becomes unstable and breaks up into four or five drops (of approximately one-tenth the diameter of the bubble) that continue on upward to a height that is reproducible from one bubble to the next. The first drop produced by the jet will rise to heights of up to 19 cm, depending on bubble size, while the second drop may rise only about half this height.

Here we deal only with data obtained by collecting the top jet drop. This was done by placing an inverted petri plate of standard Difco nutrient agar at such a height above the water surface that only the top drop would impact on the agar. To determine the number of bacteria carried by the drop, a small amount of sterile water was placed on the area of impact; the water (and bacteria) were then spread over the agar surface with a glass rod, and the colonies that developed were counted. Depending on drop size and anticipated bacterial count, from 1 to 200 drops were collected on each plate. The drop size was determined by using the same capillary tip and collecting 20 or more drops on gelatin-coated slides (*10*). This was usually done several times during the course of each experiment. These drops seldom showed any significant variation in size. The bacterial concentration (numbers per milliliter) per drop was determined by dividing the number

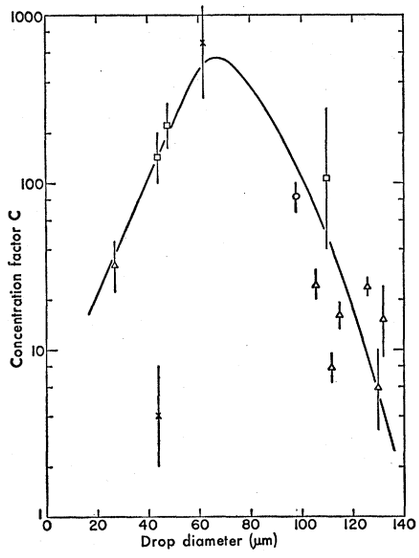

Fig. 1. Concentration factor C as a function of drop diameter. The bacterial concentrations in bulk suspension are: circles, $> 10^3$/ml; crosses, $>10^4$/ml; triangles, $> 10^5$/ml; and squares, $> 10^6$/ml.

of bacteria per drop by drop volume. The bacterial concentration of the water in the beaker was determined by the colony count method. Pipette samples for colony counting were generally obtained at two different water depths (0.2 to 0.4 cm and 3 to 6 cm), both before and at the end of each experiment. There was no significant difference in bacterial concentration with regard to depth or time the count was made. Dividing the bacterial concentration of the drop by that of the beaker water gave the concentration factor C.

The species of bacteria used in all experiments was *Serratia marcescens*. This bacterium is rod-shaped (about 0.5 μm in diameter and 1 μm long), motile with peritrichous flagella, and aerobic. It forms well-defined red pigmented colonies, a feature enabling us to clearly identify the *S. marcescens* colonies among the relatively few produced by other microorganisms in the water or by contamination from the air.

For each experiment we added a few tenths of a milliliter of a concentrated bacterial suspension to fresh tap water in the beaker and used a magnetic stirrer for about 15 minutes. A capillary bubbling tip was then placed in the water, and it was noted to what height the top and second jet drops were ejected. These drops can be seen by eye, but only against a black background and in the forward scattered light from a good source. Samples were taken from the beaker to ascertain the bacterial concentration, after which the collection of jet drops on nutrient plates was begun. About 30 minutes elapsed from the time the stirring was finished to the time the first jet drops were collected.

In 13 experiments the concentrations of bacteria in the bulk water varied over a range of 10^3 to 10^6/ml. The results (Fig. 1) indicate that *S. marcescens* can be concentrated in the top jet drop up to a factor of 1000 over that of the bulk water. It seems that the bacteria are concentrated in the surface microlayer and ejected into the air when bubbles burst. The concentration factor C shows a maximum of nearly 1000 for drops of 60 to 80 μm in diameter, decreasing to about 20 for drops of 20 and 120 μm. We feel that the experiment with the 22 μm drop giving a C of less than 10 is an anomalous one and have not used it in drawing the curve.

We had expected to find C greater than unity but were surprised to find a maximum in the concentration factor. The decrease in C for drops less than about 70 μm diameter is puzzling. Based on surface-to-volume ratio arguments and on our belief that the bacteria were concentrated in the microlayers, we felt that a higher percentage of microlayer material would be found on the smallest jet drops. Thus, C should increase with decreasing drop (and bubble) size. More data are needed to firmly establish the maximum, not only for *S. marcescens* but possibly for other bacteria as well.

Since C is greater than unity for all drop sizes investigated (20 to 140 μm), we suggest that the bubble-jet-drop mechanism may contribute significantly to a biological pollution of the atmosphere. This may be especially true in areas where rivers and lakes are polluted. We assume that a significant number of other organisms behave the same as *S. marcescens*. Perhaps virus could also be concentrated in airborne droplets in the same manner. Morrow (*11*) has shown that the virus of foot-and-mouth disease can be concentrated at the surface by bubbling. Couldn't the jet drops from the same bubbles carry the surface virus in concentrated form into the air? If so, this mechanism could be an important factor in the spread of foot-and-mouth disease by wind (*12*). It should be noted there are many ways in which bubbles are produced in natural bodies of water. Breaking waves are probably the most prolific source of bubbles, but rain and

snow impacting on the surface are also effective bubble producers (*13*).

The bubble-jet-drop mechanism of water-to-air transport of bacteria and virus deserves more study. Many species of bacteria as well as other organisms should be used, both aerobic and anaerobic, sporal and nonsporal. The depth of water through which the bubbles rise should be varied because bacteria can become attached to bubbles and be carried to the surface. Our initial work in this direction with *S. marcescens* indicates that the concentration factor C for the top jet drop increases by about five times as the depth of bubble origin increases from 1 to 30 cm.

A high concentration of many species of organisms would be expected at air-water interfaces, for it is here that they can find the organic material they need for survival (*14*). Not only might viable material be concentrated in natural surface films, but one would also expect to find high concentrations of DDT and radioactivity. One of the main sources of these films is plankton and fish, both of which are known to concentrate DDT and radioactivity (*15*). If this material is present near the surface, then it, too, like *S. marcescens*, may become concentrated in airborne drops.

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Thermochemical Remanent Magnetization and Thermal Remanent Magnetization: Comparison in a Basalt

Abstract. *Recent studies have shown that the remanent magnetization carried by an extrusive igneous rock may not be entirely thermal remanent magnetization (TRM). Some may be thermochemical remanent magnetization (TCRM) acquired by the rock at temperatures at least as low as 300°C during oxidation of the contained titanomagnetite grains. Results from a study of a set of basaltic samples from one locality indicate that the intensity of TCRM acquired by a sample in a known magnetic field is equal to that of TRM subsequently produced in the same sample in the same field. On the assumption that the samples we studied are not magnetically unique, we tentatively conclude that paleointensity studies are valid in spite of the presence of TCRM, as long as the rock acquired the magnetization during the initial cooling.*

Verhoogen has pointed out (*1*) that the stable phases of the natural iron-titanium oxides in air at low temperatures are hematite and rutile. The fact that we commonly observe other phases, such as ilmenite and members of the ulvöspinel-magnetite solid-solution series, in basalts suggests that either the basalts cooled quickly or there was insufficient oxygen (such as air or oxygenated water) present to cause the reactions to go to completion.

Certain quickly quenched basalts often have virtually unaltered titanomagnetites, with Curie temperatures of 200°C or less (*2, 3*). When these basalts (or powdered preparations made from them) are heated in air at a temperature higher than the initial Curie temperature, certain changes occur, notably an increase in Curie temperature and saturation magnetization J_s (*3, 4, 4a*). The changes in magnetic character occur simultaneously with the alteration of the original titanomagnetite to ilmenite and a ferrimagnetic mineral (generally titanomagnetite) of lower titanium content than the original material. Further heating in air will cause the iron-titanium oxides to oxidize to hematite and rutile; and at temperatures at or above 600°C pseudobrookite can be formed (*4a, 5*).

During the heating, in the presence of oxygen, of a basalt that contains homogeneous titanomagnetite, a stable remanence may be induced at temperatures far lower than the final Curie temperature (or range of Curie temperatures) of the magnetic material. Remanence acquired in virtue of this process has been referred to as thermochemical remanent magnetization (TCRM) (*6*).

In 1967 Carmichael and Nicholls pointed out (*7*) that the titanomagnetite in most naturally occurring basalts has undergone some oxidational modification and that the natural remanent magnetization (NRM) was probably not entirely thermal remanent magnetization (TRM). A more recent study of basalts in some Hawaiian lava lakes (*8*) reconfirmed the latter conclusion and indicated that the NRM of the lava-lake basalts was probably a TCRM.

We report here some preliminary results concerning the nature of TCRM. Our conclusions bear significantly on the validity of some paleomagnetic studies which have been carried out under the assumption that the magnetization of naturally occurring samples is a simple TRM.

A set of cores (2.5 cm in diameter) was drilled from a highly vesicular basalt collected in northern New Mexico. Analysis with a Curie balance indicated that the magnetic opaque minerals possessed an initial Curie temperature of 340°C. To facilitate uniform oxidation throughout the specimens and to increase the rapidity of heating and cooling, the cores were sliced into disks 0.4 to 2.0 cm thick.

In order to obtain the rate at which the samples altered, two equal-sized disks, each 0.4 cm thick, were heated, one at 300°C and the other at 400°C, in air for various periods up to 2 days. The heating was interrupted at different stages, and the acquired TCRM was measured. Care was taken to replace the samples in exactly the same position in the furnace after each measurement. Heating was done in the vertical component of the earth's field; Helmholtz coils were used to cancel the horizontal components. The samples were then cooled in field-free space to room temperature and removed from the furnace; their magnetization was measured on a Marathon spinner magnetometer with a sensitivity of 10^{-7} electromagnetic unit/cm^3 (*9*). During heating at 400°C, there was a rapid increase in magnetization, which leveled off in 20 to 30 hours. The rate of increase at 300°C was much slower than it was