ORGANIC MOLECULES RELEASED FROM OLIVINE BY IMPACT FRACTURE

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To evaluate the possible inventory of organic matter on the prebiotic Earth efforts have been concentrated on reactions in the atmosphere. Examples are the classic Miller-Urey experiments, using electric discharges, and photochemistry. Minerals have been considered only with respect to their surfaces which provide potential sites for catalytic activity, or as templates for the synthesis of complex organic molecules out of simple precursors.

We carried out slow impact fracture experiments at ≈ 10 cm·sec^{-1} in ultrahigh vacuum (UHV) with mantle-derived olivine single crystals, $(Mg,Fe)_2SiO_4$ from San Carlos, AZ, USA. According to previous studies these crystals contain the biogenic elements H and C as trace impurities at a level of ≈ 50 and ≈ 200 ppm, respectively, plus an unknown concentration of N, introduced during crystal growth in the presence of H_2O, CO_2 and N_2. With µsec to msec resolution we observed atoms, simple and complex molecules evolving from the fracture surfaces from the time of fracture until ≈1.5 sec after. We also cleaved the olivine crystals in air and measured the evaporation of gases in UHV after fracture at room temperature and during heating up to 450°C, using non-resonant laser ionization and a time of flight (TOF) mass spectrometer.

The impact fracture experiments show a wide variety of atoms and molecules emitted from the fresh fracture surfaces. Their specific nature and release kinetics suggest that they were not present in gas or fluid inclusions prior to fracture. Typical emission intensities are $\approx 2 \cdot 10^{16}$ molecules · cm^{-2}. We observe the "common" gases H_2/H_2O, CH_4, CO/CO_2, probably also N_2, together with complex H-C, H-C-N and H-C-O compounds and a strange, often long-lasting (≤ 1 sec) emission of Mg and Fe metal vapor. Prominent peaks of organic fragments are observed at 27, 29, 39, 41, 51, 63, 65, 77, 91, 105 amu. It is suggested that the gases which evolve upon impact fracture contain members of a homologous series of carbon chain molecules with H and N at each end and/or ketenes of increasing carbon chain length. Higher molecular weight fragments appear to derive from aromatic and polycyclic aromatic compounds. When the olivine crystals are cleaved in air and analyzed immediately afterwards in UHV, many of the same gases are observed. At room temperature in vacuum their partial pressure slowly decreases, suggesting evaporation from the crystal surface. Upon heating more of the same molecules are released in a characteristic pattern.

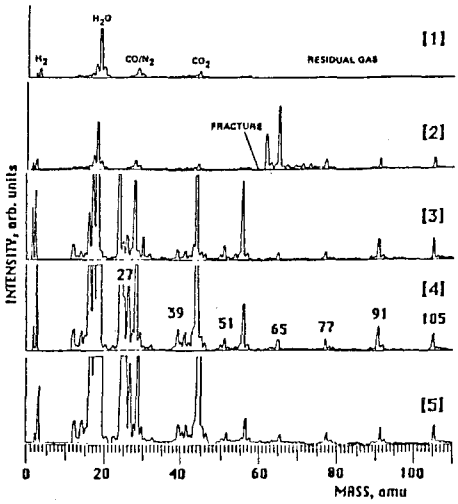

Fig. 1 depicts five fast (80 msec) quadrupole mass spectrometer scans for the mass range 1-110 amu. Scan (1) shows the residual gas spectrum immediately before fracture, $>5 \cdot 10^{-8}$ mbar total pressure. Scan (2) includes the fracture event which occurred within <1 μsec near ≈ 62 amu and which is immediately followed by an emission of complex organic molecules from the fracture surface. In many experiments the singular peaks at 65, 77, 91 and 105 amu went off-scale. Scans (3-5) demonstrate that the release kinetics for different gases and vapors is rather complicated. Organics account for ≈ 5% of the total carbon released from the crystal surface within ≈ 1.5 sec, corresponding to $\approx 10^{15}$ $C_{org} \cdot cm^{-2}$.

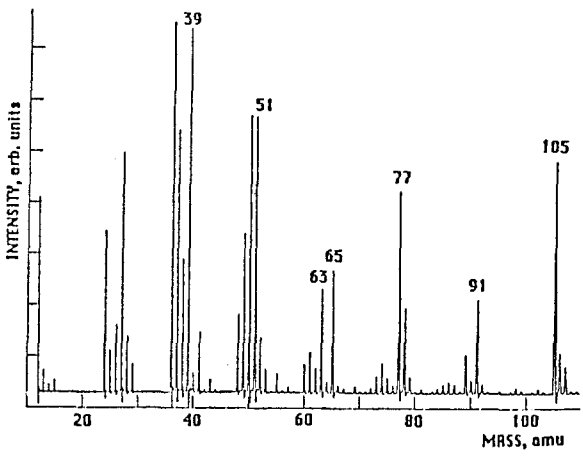

Fig. 2 shows a TOF mass spectrum of the gases released from an olivine crystal which was cleaved in air and introduced into the UHV within <5 min. The mass spectrum shows many organic fragments, in particular at 39, 51, 65, 77, 91, 105 amu, which are identical to the ones registered upon impact fracture. Other mass peaks are conspicuously absent such as those suggesting metal vapors. By order of magnitude the total number of organic molecules released in these experiments is $\approx 10^{14}$ cm^{-2}.

We can use these gas release data to estimate, by order of magnitude, the amount of organic compounds released when meteorites strike an Earth-sized planet composed of olivine-rich rocks. Let us assume (i) that supersonic impacts produce the same amount of gases per unit surface area as our slow impacts, (ii) that the ejecta have an average specific surface area of ≈ 1 $m^2 \cdot g^{-1}$, and (iii) that repetitive bombardments of the planet during its early history form a regolith layer of ≈10 km accumulative thickness. Then, even with no contribution from the impacting meteorites, $\approx 10^{21}$ g of organic carbon may be released. This value must be compared with the reported total inventory of C_{org} on the present Earth, $6.4 \cdot 10^{21}$ g. We therefore conclude that, if the processes described here have occurred on the early Earth, a large reservoir of organic compounds may have been produced from the biogenic elements dissolved in solid rocks.