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FINAL REPORT, NAGW-454

Impact Cratering: The Process and its Effects on
Planetary Evolution

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INTRODUCTION

This grant, NAGW-454, was initiated in February 1983 and was originally concerned with two research areas entitled: (i) Impact Cratering: The process and its effects on planetary evolution, and (ii) Surface reactions on Venus: An experimental study. Following the September 1983 decision by the Principal Investigator to resign from the Brown faculty, the Principal Investigator and NASA Technical Officer, J. Boyce, agreed to concentrate research efforts in the area of Impact Cratering. Following a brief discussion of the results of the Venus studies, this report reflects this decision by concentrating on the research performed in the area of Impact Cratering.

SURFACE REACTIONS ON VENUS

The basic goal of this study was to explore the potential for silicate-CO₂ reactions as a geochemical weathering agent on Venus. A number of authors (Florensky et al., 1977; Nozette and Lewis, 1982) have suggested that a variety of silicate-carbonate reactions may occur under the P,T, fCO₂ conditions encountered in topographically elevated areas of the venusian surface. If such reactions take place, they involve large increases in molar volume during carbonation and provide a powerful geochemical force for rock disintegration. These earlier suggestions and the abundant evidence that degradation processes on the decimeter to centimeter scale are occurring on Venus (Garvin et al., 1984) prompted the study.

The initial approach was experimental. As the interest was not only in the chemical but also in the physical consequences of such reactions, natural rocks were used as starting material. A tholeiitic basalt close to the composition determined by the XRF experiment at the Venera 14 sites (Table 1) was selected as starting material. The sample consisted of ~ 21% plagioclase and ~ 3% olivine phenocrysts in a cryptocrystalline to partially

devitrified glassy matrix. The sample was crushed to a range of particle sizes (~ 1 μm - 2 mm), dried, contained in crimped silver tubes and placed in externally heated pressure vessels with pure CO_2 as the pressure medium. The experimental conditions ranged from 396-480°C, 56-113 bars, with run times of between 14 and 75 days.

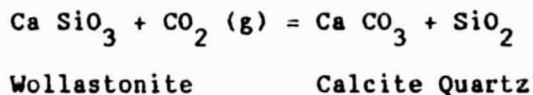
Table 1: Composition of starting material (9D2) compared with Venera 14 XRF data

	<u>9D2</u>	<u>Venera 14</u>
SiO_2	50.49	48.7
TiO_2	1.29	1.50
Al_2O_3	16.94	17.9
Fe_2O_3	1.24	-
FeO	7.75	8.8*
MnO	0.16	0.16
MgO	7.45	8.1
CaO	11.88	7.1
Na_2O	2.72	n.a.
K_2O	0.07	0.2
P_2O_5	0.13	n.a.

*Total Fe as FeO

Starting material and run products were examined optically and by XRD and SEM. No obvious mineralogic changes were observed in the starting material even after runs of 75 days. The problems were the inherent difficulties associated with reaction detection and kinetics. The nature of the starting material with its range of grain sizes and compositional inhomogeneities, even at very fine scales, due to partially devitrified glass made the chemical detection of reaction difficult using the SEM. Kinetic data on silicate-carbonate reactions indicate relative rapid reaction (35%) in 20 hours at 800°C. Lower temperatures, however, appear to result in reaction rates that are slower than the maximum 1800 hours in the initial experiments undertaken in this study.

In order to get some indication of minimum reaction times under approximately venusian P,T conditions, a charge of wollastonite was placed within the calcite-plus quartz stability field. The reaction, which has been quoted as a possible surface reaction on Venus, is:



After 33.5 days at 460°C and 223 bars CO₂, a ~ 500 μm grain of calcite was observed by EDA on the SEM. Although there were changes in the relative intensities of Si and Ca peaks in particular areas on the wollastonite, quartz was not observed as a discrete phase and, accordingly, it was difficult to determine unequivocally that reaction had taken place. Following these initial experimental results, it was planned to supplement the basaltic starting material with charges containing mixtures of minerals which were believed to undergo reaction at venusian P,T conditions on the basis of thermodynamic considerations. Although such starting materials were obtained and prepared, no actual experiments were undertaken. This was a consequence of the belief that required times would still be on the order of 1000 hrs coupled with the decision to concentrate on the area of Impact Cratering studies in the time remaining in the grant period.

The results of a more theoretical aspect of the study were published in Lunar and Planetary Science XV (Garvin et al., 1984). Briefly, the equilibrium P,T, f_{CO_2} of several reactions were calculated from thermodynamic data and converted to the specific elevations corresponding to these equilibrium conditions on Venus. These intervals were then compared with data on global radar reflectivity from Pioneer Venus (PV) to establish surface units where particular minerals were stable and there were appropriate rock densities and dielectric values. Although some correlation was observed, unit definition based on modelled reactions was not totally consistent with modelled surface characteristics on the basis of PV radar data. Undoubtedly, more complex equilibria and coupled reactions need to be considered. These equilibria, e.g. the formation of pyrite to explain high dielectric areas (Pettengill et al., 1982), are highly sensitive to the accurate determination of the fugacities of other volatile species, e.g. f_{O_2} , f_{H_2O} . These data, however, are currently not available.

IMPACT CRATERING

The principal goals of this study are to elucidate details of impact processes and to assess the effects of impact on planetary evolution and the geologic environment. A number of sub-topics were considered in the course of the study.

(a) Crater formation and impact processes

An analysis of the excavation and modification stages of simple crater development has been accepted for publication in Journal of Geophysical Research (Grieve and Garvin, 1985). The analysis combines the Maxwell Z-model for cavity excavation with a model of transient cavity wall collapse and is constrained and tested by observational data from Brent and Meteor Crater. The abstract of the publication is given below.