

**BASALT-ATMOSPHERE INTERACTION ON VENUS: PRELIMINARY RESULTS ON WEATHERING OF MINERALS AND BULK ROCK.** A. H. Treiman and S. P. Schwenzer, Lunar & Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058. <treiman@lpi.usra.edu, schwenzer@lpi.usra.edu>.

**Introduction:** Chemical interactions between Venus' atmosphere and surface rocks may be crucial to understanding the atmosphere's composition [1-3], and to interpreting surface geology and physical properties [2,4,5]. Most studies have emphasized the atmosphere – its composition and 'chemical sediments,' and few have focused on what happens to basalts and their minerals in reaction with the atmosphere. Our preliminary re-investigation of the mineralogy of altered basaltic minerals and rocks shows that: the anorthite component of plagioclase reacts to anhydrite + andalusite + quartz; diopside pyroxene reacts to anhydrite + orthopyroxene + quartz; and bulk basalt reacts to anhydrite + cordierite + orthopyroxene + quartz ( $\pm$  iron oxide, depending on  $f(\text{O}_2)$ ).

**Venus:** Venus' surface is at  $\sim 740\text{K}$  and  $\sim 96$  bars pressure [5] – a metamorphic environment of 'amphibolite grade,' 'hornfels facies [6];' the paucity of  $\text{H}_2\text{O}$  in Venus' atmosphere ( $30\pm 15$  ppm) prevents formation of amphibole. Venus' atmosphere, at its surface, is mostly  $\text{CO}_2$  (96.5 %), with significant proportions of S gases ( $\text{SO}_2$ ,  $150\pm 30$  ppm,  $\text{COS}$   $4.4\pm 1$  ppm,  $\text{H}_2\text{S}$   $3\pm 2$  ppm and S, 20 ppb [5,7]). The oxidation state at the Venus surface is not entirely clear, but it probably is relatively oxidizing, above the magnetite-hematite oxygen buffer,  $\log f(\text{O}_2) \sim -21.3$  [8].

Venus' surface materials are known only through the Soviet Venera and VEGA landers, which all landed on lava flows and volcanic constructs [9]. All analyzed materials were of basaltic composition. Here, we work from the V14 basalt, which (within its large imprecision) is similar to Earthly MORB (Table 1), and investigate how a MORB model of the V14 basalt would react at the Venus surface.

Table 1. Basalt Compositions, with uncertainties.

	MORB [10]	$1\sigma$	V14	$1\sigma$
$\text{SiO}_2$	49.8	0.37	48.7	3.6
$\text{TiO}_2$	1.45	0.11	1.25	0.4
$\text{Al}_2\text{O}_3$	15.1	0.42	17.9	5.2
$\text{FeO}$	10.3	0.27	8.8	1.8
$\text{MnO}$	0.2	0.03	0.16	0.08
$\text{MgO}$	7.79	0.12	8.1	3.3
$\text{CaO}$	12.4	0.18	10.3	1.2
$\text{Na}_2\text{O}$	2.47	0.12	n.d.	-
$\text{K}_2\text{O}$	<u>0.09</u>	0.03	<u>0.2</u>	0.07
Sum	99.60		95.4*	

\*Does not include  $0.35\pm 0.3\%$   $\text{SO}_3$ .

**Mineral Reactions:** Reactions between individual minerals and Venus atmosphere were investigated via the SUPCRT code (and self-consistent database)[11], which accesses a large database of minerals, but is designed for aqueous solution chemistry. So far, computations have been done up to 623K with manual extrapolation to higher T with data from [12]. Neither database has values for relevant sulfates besides anhydrite, nor for carbonate or sulfate liquids [13].

The anorthite component of plagioclase can react with the Venus atmosphere:  $\text{CaAl}_2\text{Si}_2\text{O}_8 + \text{SO}_3 \Rightarrow \text{CaSO}_4 + \text{Al}_2\text{SiO}_5 + \text{SiO}_2$  (anhydrite + andalusite + quartz; corundum + quartz is always unstable [14]). This reaction should proceed [2,6], although its equilibrium  $\text{SO}_3$  is close to that of the Venus atmosphere [7,15]; our calculations imply that plagioclase with anorthite activity of  $\sim 0.3$  should be in equilibrium with anhydrite, andalusite, quartz, and the atmosphere. The albite component of the plagioclase remains in feldspar (jadeite is unstable at Venus surface P [6]).

Among mafic minerals, diopside is calculated to react via  $\text{CaMgSi}_2\text{O}_6 + \text{SO}_3 \Rightarrow \text{CaSO}_4 + \text{MgSiO}_3 + \text{SiO}_2$ . This reaction should proceed to near completion in the Venus atmosphere [7,15,16], leaving pyroxene with diopside activity  $\sim 0.05$ . Enstatite and forsterite remain stable, while ferrosilite and fayalite may oxidize/sulfidize to iron oxides/sulfides and quartz.

**Bulk Rock Reaction:** Our second approach is to model the reaction of a bulk basalt (Table 1) with the Venus atmosphere. This model would correspond to alteration of basalt glass, or of a crystalline basalt with easy element diffusion between crystals. We determine the equilibrium mineralogy of that basalt at Venus surface p-T-X, using analog systems, chemography, and thermochemical calculations [17]. Analog and synthetic systems and their chemography are summarized in [6], but few such systems take into account the high  $f(\text{SO}_2)$  of the Venus surface. Thermochemical calculations are done (so far as possible) with Thermocalc<sup>®</sup> and its self-consistent database [18,19], which does not include S-bearing species. To apply that code and database, we assume that all CaO in the model basalt reacts with atmospheric  $\text{SO}_2/\text{SO}_3$  to form anhydrite,  $\text{CaSO}_4$ . This assumption is justified by the mineral reaction results above, and results cited in [2,7,16,17]. We further assume that: {1} carbonates are not stable [16]; {2} no other sulfate phases form; {3} volatile-bearing silicates (scapolites, micas, amphiboles) do not

form; and {4} Na and K reside in alkali feldspar (not in sulfates, carbonate melt, or feldspathoids). The last assumption is reasonable here (Table 1), but will not be appropriate for K-rich basalts (Venera 8,13). We consider two simple cases: reduced, in which Fe is treated as a divalent cation and lumped with Mg and Mn; and oxidized or sulfided, in which Fe is assumed to all be reacted to form an oxide (hematite or magnetite; [8,20] or a sulfide (pyrite; [21,22])).

Table 2. Masses of Alteration Products from 100 grams of MOR Basalt (Table 1), & Volume Change on Alteration.

Grams	Case 1 – Divalent Fe	Case 2 – All Fe as hematite
Anhydrite	28.3	28.3
Albite	21.4	21.4
Cordierite	30.8*	30.1
Enstatite	26.4*	8.9
Quartz	5.1	13.67
Hematite	0	11.5
Total Mass	112.0	113.9
Δ Volume %	+12	+14.6

Assumes all anorthite component reacts to form anhydrite.

\*With Fe/Mg ratio of bulk rock.

Volumes calculated for 25°C, 1 bar.

In the first case (Fe as a divalent cation), removal of Ca as anhydrite and Na & K as 'albite' yields a residue with molar ratios Si:Al:'M' of 2.1:1:1.6 ('M' = molar Mg+Fe+Mn). This material is inferred to equilibrate to anhydrous cordierite + enstatite + quartz [23], Table 2 (pyrope & sapphirine are unstable at Venus surface P [24,25]; spinel + quartz is unstable at Venus surface T [26]). In the latter case, in which Fe is allowed to be oxidized to hematite by the atmosphere, the alteration assemblage remains the same but the proportions of enstatite and quartz change (Table 2).

**Implications:** Within the available datasets and current understanding of Venus' atmosphere and rocks, it appears that the principal reaction at the Venus surface will be production of anhydrite from essentially all the Ca in basaltic minerals and rocks. Iron in the rocks and minerals will likely react to either oxides or sulfides, depending on the oxidation state of the atmosphere. The fate of alkalis is not clear – our calculations yield only alkali feldspar (albite), but alkalis could be partitioned into ionic (carbonate-sulfate) melts [13]. Some Venus basalts are so rich in potassium that phases besides feldspar may be present (e.g., leucite, nepheline-group, or sodalite-group).

In Venus surface weathering, sequestration of Ca in anhydrite and Fe in iron oxide (sulfide) leaves the residue rich in Al and Si, which then equilibrates to anhydrous cordierite + enstatite + quartz (Table 2). Weathering causes a significant increase in mass and volume

(Table 2), most of which derives from formation of anhydrite. However, a portion of the increase comes from formation of quartz and cordierite, which both have open crystalline structures. The volume increase could be responsible for the platy structure visible in lander images of the Venus surface.

**Prospects:** This work is preliminary, with several areas of improvement forthcoming. First, the thermochemical databases lack several phases and components needed for full treatment: S-bearing gas and mineral species into the Thermocalc<sup>®</sup> database; Fe- and Mg-sulfates need to be added, as do those on S-bearing silicates (e.g., sulfate scapolite, S-sodalite); and explicit consideration of ionic melts. Solid solutions need to be considered explicitly. We look forward to Venus Express' new constraints on the composition of Venus' atmosphere.

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