CRUSTAL STRENGTH OF THE TERRESTRIAL PLANETS, H. Spetzler, CIRES and Dept. of Geological Sciences, University of Colorado/NOAA, Boulder, CO 80309, H. Mizutani, Dept. of Earth Sciences, Univ. of Nagoya, Chikusa-ku, Nagoya I.C. Getting, CIRES, University of Colorado/NOAA, Boulder, CO 80309

The differences in the topographies and gravity fields of the terrestrial planets imply large differences in tectonic activities and suggest considerable differences in the strengths of their crusts. The strength of the planetary crusts depend upon the composition of the rocks, their fracture systems caused by tectonic stresses and meteor impacts, the surface temperature and thermal gradient, the pressure gradient and the water content of the rocks.

We have developed a deformation and failure model that is based upon stress corrosion theory and the interaction of growing subcritical cracks. In this model any external stress, S, that is applied to the rock is supported by intact material. The cross-section of a rock consists of an effective cross-section of the intact material A_a and an effective crossection of the cracks A_c. In response to an applied stress the crack crossection grows and the expense of the intact crossection. At constant applied external stress, the average local stress σ which is responsible for crack growth, increases as the intact crossection area decreases. The final brittle failure occurs when the average local stress exceeds some critical stress σ_c which is a material property. Assuming penny-shaped cracks with an average crack length a we may write the following expression for the intact material crossection $A_a = A_o - B^*(a^2 - a_o^2)$, (1), where A_o denotes the initial intact material crossection, a is the average crack length, and a_o is the initial average crack length. B^* is a geometrical factor which depends on the number, orientation and initial distribution of the cracks. For convenience we normalize the intact material crossection such that $A_n = A_a/A_o = 1 - B[(a/a_o)^2 - 1]$, (2), where $B = a_o^2 B^*/A_o$, which will be referred to as the crack morphology parameter. The stress responsible for crack growth is $\sigma = kS/A_n$, (3), where k is a stress concentration factor which establishes the proportionality between the applied stress and the crack growth stress. Initially $A_n = 1$. The rock must have failed however before A_n becomes zero, i.e. before σ becomes infinite. This failure condition puts a limit on the crack morphology parameter B. It must meet the condition $B < (a_f/a_o)^2$, (4), where a_f is the average crack length at failure.

Cracks are assumed to grow stably in response to the stress until σ reaches a critical value σ_c where brittle failure occurs. Following our earlier approach [1], we use stress corrosion theory [2] to describe the rate of crack growth, $\dot{a}$: $\dot{a} = D_W P^n [\exp\{-(E_W - V_W\sigma)/RT\} - \underline{\exp\{-E_W/RT\}}] + D_D[\exp\{-E_D - V_D\sigma)/RT\} - \underline{\exp\{-E_{D/RT}\}}]$, (5),

where P is the partial pressure of H_2O; n is the order of the chemical reaction; D_W, D_D are constants appropriate for wet and dry processes; E_W, E_D are activation energies for the wet and dry processes; V_W, V_D are activation volumes for the wet and dry processes; R is the gas constant and T is absolute temperature.

The underlined terms are back reaction terms and correspond to crack healing. In most treatments of stress corrosion cracking these terms can be ignored because the forward reaction, ie. crack growth, clearly dominates. In geological situations however, where the time may be very long and the stress very small, the backreaction cannot be ignored. When σ becomes zero, the net crack growth stops.

The term starting with D_W describes stable crack growth in the presence of moisture. The term starting with D_D describes stable crack growth without the influence of moisture. In those crusts of the terrestrial planets which contain more than trace amounts of water (Venus, Earth and Mars), the moisture assisted crack growth dominates until shortly before failure. In the dry crusts of Mercury and Moon stable crack growth is very slow and does not become important until the stress σ increases near the critical value σ_c.

To obtain quantitative results equation (5) must be integrated and be solved simultaneously with equations (2) and (3). Numerical values for the parameters in equation (5) come from single crack propagation experiments. The crack morphology parameter B, the initial crack length a_o and the stress concentration parameter k and its pressure dependence come from whole rock experiments. Complications encountered in single crack propagation experiments and the current state

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of the art are described by Swanson and Spetzler [3].

We can now examine the behavior of our artificial igneous rock under the crustal conditions of the terrestrial planets. Thermal data from references [4] and [5] were used. For Earth and Mars we have used the equilibrium water vapor pressure appropriate for the surface temperature. For Venus we used the water pressure in the atmosphere i.e.a minimum value since the rocks can not be drier than the atmosphere into which they outgassed. For Mercury and Moon we choose an arbitrary value for the water vapor pressure of 10^{-3} mm of Hg. The brittle failure strength for two strain rates ($10^{-5}s^{-1}$ and $10^{-12}s^{-1}$) are shown as a function of pressure for the terrestrial planets in Figure 2. The increase of temperature with pressure within the planets has been included. For the lower strain rate brittle failure strength as a function of depth is shown in Figure 2.

While the model must still be considered to be preliminary and the input data are from various experiments and material the general failures shown in Figures 1 and 2 should represent the major differences in the brittle failure strength of the terrestrial plants. For all dry planets (Mercury and Moon) and for Mars the strength seems sufficiently high to statically support large elevation differences. For Earth major elevation differences must at least partially be supported by convection. The crust of Venus, inspite of the very low (assumed) moisture content, is too weak to statically support the large stresses that are necessary to maintain large elevation differences. We suspect therefore that convection must be responsible for dynamically supporting the mountains on Venus. Furthermore the Venusian crust seems too weak to allow plate tectonics on the scale of Earth's to develop.

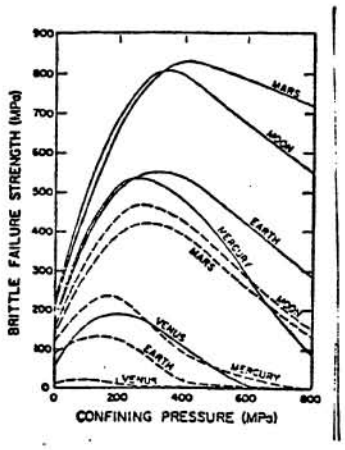

Figure 1.

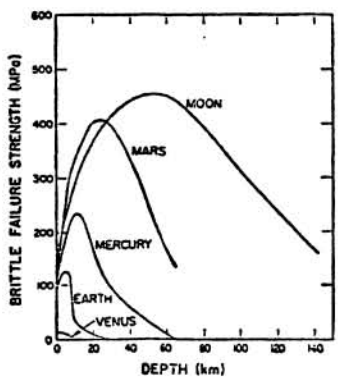

Figure 2.

Fig. 1. Calculated crustal strengths versus confining pressure for strain rates of $10^{-5}\,s^{-1}$ (solid curves) and $10^{-12}\,s^{-1}$ (dashed curves).

Fig. 2. Calculated crustal strengths versus depth for $10^{-12}\,s^{-1}$.

(1) Spetzler, H., Sondergld, C. and Getting, I.C. (1981) in Anelasticity in the Earth, Stacey F.D. et al. (ed) p. 108-112, AGU and GSA. (2) Hillig, W.B. and Charles, R.J. (1965) in High Strength Materials, Zackey V.F. (ed.), p. 682-701, J. Wiley and Sons, Inc., New York. (3) Swanson, P.L. and Spetzler, H. - this conference. (4) Wood, J.A. (1979), The Solar System, Prentice Hall. (5) Solomon, S.C. and Chaikey, J. (1976), *Proc. Lunar Sci. Conf. 9th.*, p. 3229.

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