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# Shock Wave Data for Rocks

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## 1. INTRODUCTION

Shock wave equation of state data for rocks is the primary physical starting point for calculation of the effect of meteorite impact and explosions on the surfaces or in the crusts of the earth, moon, and other terrestrial planets [2,3,12,25,32,37,38,39,40,43], and primitive bodies such as comets and asteroids [9,54].

## 2. EQUATIONS OF STATE

Rocks are, by definition, composed of one or more minerals, and hence largely their equation of state behavior (Table 1) reflects the behavior of their constitutive minerals. The Hugoniot of rocks demonstrate the same regimes as sketched in Figures 1 and 2.

Dynamic yielding behavior for porous rock, like ceramics which have been more extensively studied, reflect both the Hugoniot elastic limit of the porous mineral aggregate, as well as the porous rock. [15,46].

Mixture theories are quite successful in synthesizing the Hugoniot of rocks from knowledge of the equations of state of constituent minerals.

For silicate rocks, Teagin et al. [47] have demonstrated good agreement between the observed

Hugoniot and the calculated Hugoniot based upon an oxide mixture model. According to this model,

$$C_0 = a_{00} + a_0 \rho_0 + \sum_i a_i Z_i \quad (1a)$$

$$S = b_{00} + b_0 \rho_0 + \sum_i b_i Z_i \quad (1b)$$

where  $\rho_0$  is the initial density,  $Z_i$  is the mass fraction of component oxide  $i$ , and  $a_{00}$ ,  $a_0$ , the  $a_i$ 's,  $b_{00}$ ,  $b_0$ , and the  $b_i$ 's, are constants. This approach works well in the high pressure regime (4, of Fig. 2). More successful over the pressure range of the entire Hugoniot is the mineral mixture model [8].

$$V(P) = \sum_i V_i(P) M_i \quad (2)$$

where  $V_i$  is the volume of constituent mineral,  $i$ , at pressure  $P$  and  $M_i$  is the mass fraction of mineral,  $i$ . Using the Rankine-Hugoniot equations,  $U_s$  and  $U_p$  are computed from the resulting P-V relation. Additional examples of construction of a theoretical Hugoniot from constituent minerals are given in [6] and [4].

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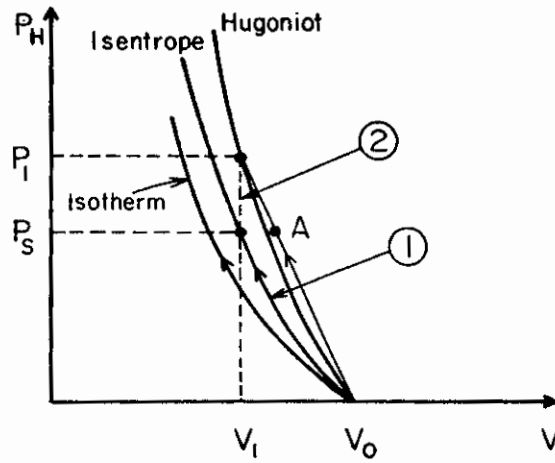


FIG. 1. Pressure-volume compression curves. For isentropes and isotherms, the thermodynamic path coincides with the locus of states, whereas for shock, the thermodynamic path is a straight line to point  $P_1, V_1$ , on the Hugoniot curve, which is the locus of shock states.

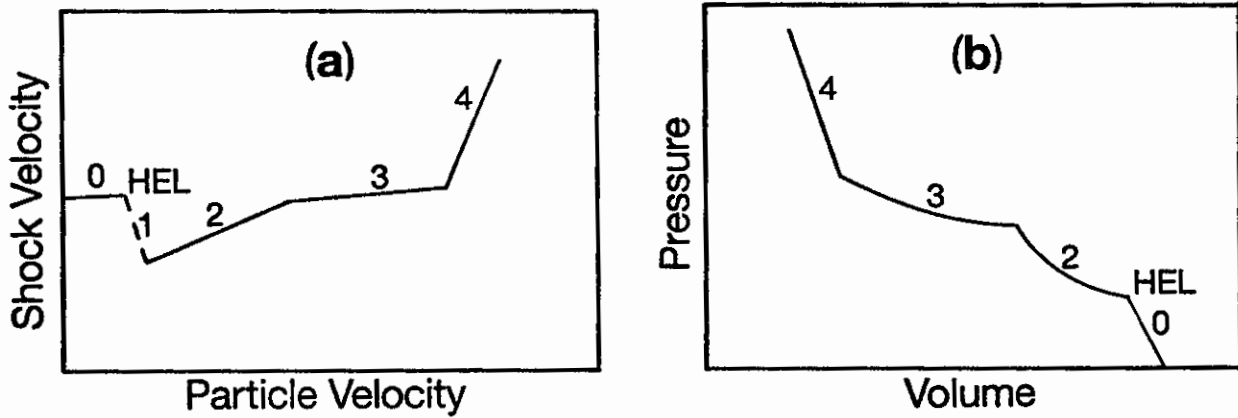


FIG. 2. Sketch of shock velocity-particle relation (a) and corresponding pressure-volume Hugoniot curves (b) for a mineral which undergoes dynamic yielding and a phase change.

- 0: compression up to the Hugoniot Elastic Limit (HEL)
- 1: transition via dynamic yielding to a quasi-hydrostatic state
- 2: low pressure state
- 3: mixed region
- 4: high pressure state

TABLE 1. Equations of State of Rocks

| Rock Name           | Locality,<br>Comments                                       | Sample<br>Density<br>(Mg/m <sup>3</sup> ) | C <sub>0</sub><br>(km/sec) | error                       |      | S    | error<br>ΔS | lower          |                | upper |         | Phase*        | No. of<br>Data | References |
|---------------------|---|---|----------------------------|-----------------------------|------|------|-------------|----------------|----------------|-------|---------|---------------|----------------|------------|
|                     |   |   |                            | ΔC <sub>0</sub><br>(km/sec) | ΔS   |      |             | Up<br>(km/sec) | Up<br>(km/sec) |       |         |               |                |            |
| Albite              | Sylmar, PA  | 2.610                                     | 5.42                       | 0.09                        | 0.09 | 0.09 | 0.10        | 0              | 1.287          | 2     | 3       | [11,33,35,53] |                |            |
|                     |   |   | 4.83                       | 0.05                        | 0.51 | 0.03 | 1.287       | 3              | 4              |       |         |               |                |            |
|                     |   |   | 2.73                       | 0.17                        | 1.49 | 0.05 | 2.017       | 4              | 8              |       |         |               |                |            |
| Andesite            | Amchitka Is.,<br>Alaska                                     | 2.59                                      | 3.60                       | 0.08                        | 0.98 | 0.05 | 0.45        | 2.49           | 2              | 9     | [10]    |               |                |            |
|                     |   |   | 1.7                        | 1.0                         | 1.8  | 0.3  | 2.49        | 4              | 4              |       |         |               |                |            |
| Anorthosite         | Lunar 60025   | 2.229                                     | 2.02                       | 0.10                        | 1.57 | 0.03 | 2.036       | 5.196          | 2              | 11    | [28,29] |               |                |            |
| Anorthosite         | a   | 2.774                                     | 5.73                       | 0.07                        | 0.07 | 0.08 | 0           | 1.99           | 1              | 15    |         |               |                |            |
|                     |   |   | 3.2                        | 0.5                         | 1.46 | 0.13 | 1.99        | 2              | 19             |       |         |               |                |            |
|                     |   |   | 4.45                       | 0.15                        | 1.23 | 0.01 | 4.99        | 4              | 7              |       |         |               |                |            |
| Basalt              | low density <sup>b</sup>                                    | 2.793                                     | 5.80                       | 0.15                        | -1.2 | 0.3  | 0.291       | 0.79           | 1              | 4     |         |               |                |            |
|                     |   |   | 4.2                        | 0.2                         | 0.71 | 0.12 | 0.79        | 2              | 6              |       |         |               |                |            |
|                     |   |   | 2.4                        | 0.2                         | 1.60 | 0.06 | 2.1         | 4              | 14             |       |         |               |                |            |
| Basalt              | high density <sup>c</sup>                                   | 3.200                                     | 4.96                       | 0.14                        | 0.88 | 0.10 | 0.385       | 1.963          | 2              | 8     |         |               |                |            |
|                     |   |   | 4.09                       | 0.15                        | 1.35 | 0.04 | 1.913       | 4              | 12             |       |         |               |                |            |
|                     |   |   |                            |                             |      |      |             |                |                |       |         |               |                |            |
| Molten basalt       | synthetic<br>An <sub>36</sub> Di <sub>64</sub> <sup>d</sup> | 2.615                                     | 3.67                       | -                           | 0.19 | -    | 0.44        | 0.65           | 1              | 2     |         |               |                |            |
|                     |   |   | 2.93                       | 0.15                        | 1.46 | 0.13 | 0.65        | 2              | 4              |       |         |               |                |            |
|                     |   |   | 0.8                        | 0.4                         | 2.6  | 0.2  | 1.72        | 4              | 3              |       |         |               |                |            |
| Molten basalt       | Komatiite <sup>e</sup>                                      | 2.745                                     | 3.13                       | 0.02                        | 1.47 | 0.02 | 0.47        | 2.1            | 2              | 12    | [36]    |               |                |            |
|                     |   |   |                            |                             |      |      |             |                |                |       |         |               |                |            |
| Volcanic<br>Breccia | Amchitka Is.,<br>Alaska                                     | 1.82                                      | -0.5                       | -                           | 3.2  | -    | 1.1         | 1.22           | 1              | 2     |         |               |                |            |
|                     |   |   | 3.3                        | -                           | 0.0  | -    | 1.22        | 3              | 2              |       |         |               |                |            |
|                     |   |   | -1.1                       | -                           | 3.1  | -    | 1.44        | 2              | 2              |       |         |               |                |            |
| Bronzite            | Bushveld,<br>Transvaal                                      | 3.296                                     | 1.9                        | 0.2                         | 1.2  | 0.9  | 1.65        | 3.25           | 4              | 3     | [10]    |               |                |            |
|                     |   |   | 6.28                       | 0.08                        | 0.56 | 0.05 | 0.485       | 2              | 7              |       |         |               |                |            |
|                     |   |   | 4.3                        | 0.2                         | 1.45 | 0.08 | 2.147       | 3              | 4              |       |         |               |                |            |
| Bronzite            | Stillwater,<br>Montana                                      | 3.277                                     | 5.99                       | -                           | 1.56 | -    | 0           | 0.483          | 1              | 2     |         |               |                |            |
|                     |   |   | 6.47                       | 0.06                        | 0.60 | 0.04 | 0.483       | 2              | 25             |       |         |               |                |            |
|                     |   |   | 5.16                       | 0.07                        | 1.17 | 0.03 | 2.043       | 3              | 21             |       |         |               |                |            |

TABLE 1. Equations of State of Rocks (continued)

| Rock Name       | Locality,<br>Comments                  | Sample<br>Density<br>(Mg/m <sup>3</sup> ) | C <sub>0</sub><br>(km/sec) | error<br>$\Delta C_0$<br>(km/sec) | S     | error<br>$\Delta S$ | up                      |                         | Phase* | No. of<br>Data | References                    |
|-----------------|--|---|----------------------------|-----------------------------------|-------|---------------------|-------------------------|-------------------------|--------|----------------|-------------------------------|
|                 |  |   |                            |                                   |       |                     | lower<br>Up<br>(km/sec) | upper<br>Up<br>(km/sec) |        |                |                               |
| Bronzite        | Pyroxenite<br>(unspecified)            | 3.29                                      | 6.26                       | 0.19                              | 0.96  | 0.14                | 0.6                     | 1.74                    | 1      | 3              |                               |
|                 |  |   | 8.35                       | -                                 | -0.21 | -                   | 1.74                    | 2.26                    | 2      | 2              |                               |
|                 |  |   | 5.1                        | 0.2                               | 1.30  | 0.07                | 2.26                    | 5.8                     | 3      | 4              | [48]                          |
| Chalk           | Dover, England                         | 1.365                                     | 1.0                        | 0.7                               | 1.5   | 0.7                 | 1.414                   | 1.959                   | 2      | 4              | [50]                          |
| Chalk           | (unspecified)                          | 1.705                                     | 1.15                       | 0.12                              | 1.60  | 0.04                | 1.65                    | 4.34                    | 2      | 5              | [31]                          |
| Chalk           | (unspecified)                          | 2.02                                      | 1.74                       | 0.06                              | 1.61  | 0.02                | 1.51                    | 4.18                    | 2      | 5              | [31]                          |
| Chalk           | moist                                  | 2.2                                       | 2.68                       | 0.06                              | 1.49  | 0.02                | 0.89                    | 3.61                    | 2      | 5              | [31]                          |
| Clay            | f                                      | 1.457                                     | 1.86                       | 0.17                              | 0.97  | 0.07                | 1.04                    | 3.54                    | 2      | 9              | [23]                          |
| Clay            | not given;<br>4% water                 | 2.15                                      | 2.52                       | -                                 | 0.71  | -                   | 0.005                   | 0.96                    | 1      | 2              |                               |
|                 |  |   | 1.86                       | 0.09                              | 1.36  | 0.04                | 0.96                    | 3.32                    | 2      | 3              | [7]                           |
| Clay            | not given;<br>4-20% water <sup>g</sup> | 2.11                                      | 1.8                        | 0.2                               | 3.1   | 0.7                 | 0.127                   | 0.42                    | 1      | 4              |                               |
|                 |  |   | 2.69                       | 0.11                              | 1.30  | 0.05                | 0.42                    | 3.28                    | 2      | 12             |                               |
|                 |  |   | 1.9                        | 0.2                               | 1.55  | 0.06                | 3.26                    | 4.37                    | 4      | 3              | [7,24]                        |
| Diabase         | h                                      | 3.00                                      | 4.89                       | 0.11                              | 1.20  | 0.15                | 0                       | 0.915                   | 2      | 6              |                               |
|                 |  |   | 5.68                       | 0.06                              | 0.25  | 0.05                | 0.843                   | 1.758                   | 3      | 14             |                               |
|                 |  |   | 3.61                       | 0.07                              | 1.41  | 0.02                | 1.713                   | 3.727                   | 4      | 21             | [11,33,35,53]                 |
| Olivine Diabase | not given                              | 3.13                                      | 6.8                        | -                                 | 0.1   | -                   | 0.61                    | 1.45                    | 3      | 2              |                               |
|                 |  |   | 4.9                        | 0.3                               | 1.22  | 0.07                | 1.45                    | 5.92                    | 4      | 4              | [35,48]                       |
| Dolomite        | i                                      | 2.828                                     | 6.2                        | 0.5                               | 0.4   | 0.5                 | 0.495                   | 1.15                    | 1      | 5              |                               |
| Dunite          | low density <sup>j</sup>               | 3.262                                     | 5.30                       | 0.10                              | 1.16  | 0.03                | 1.12                    | 5.32                    | 2      | 19             | [31,45,52]                    |
|                 |  |   | 6.38                       | 0.09                              | 0.81  | 0.06                | 0                       | 2.4                     | 2      | 55             |                               |
| Dunite          | high density <sup>k</sup>              | 3.791                                     | 4.82                       | 0.16                              | 1.33  | 0.05                | 2.399                   | 5.95                    | 4      | 29             | [11,21,27,33,<br>34,35,48,53] |
|                 |  |   | 5.5                        | 0.2                               | 1.8   | 0.4                 | 0                       | 0.701                   | 2      | 3              |                               |
| Dunite          | high density <sup>k</sup>              | 3.791                                     | 6.35                       | 0.11                              | 0.49  | 0.07                | 0.701                   | 2.429                   | 3      | 18             |                               |
|                 |  |   | 4.0                        | 0.2                               | 1.47  | 0.08                | 2.429                   | 3.407                   | 4      | 13             | [11,33,34,35,<br>53]          |

TABLE 1. Equations of State of Rocks (continued)

| Rock Name              | Locality,<br>Comments       | Sample<br>Density<br>(Mg/m <sup>3</sup> ) | C <sub>0</sub><br>(km/sec) | error<br>ΔC <sub>0</sub><br>(km/sec) | S                            | error<br>ΔS                | lower<br>Up<br>(km/sec)          | upper<br>Up<br>(km/sec)          | Phase*           | No. of<br>Data     | References                 |
|------------------------|-----------------------------|---|----------------------------|--------------------------------------|------------------------------|----------------------------|----------------------------------|----------------------------------|------------------|--------------------|----------------------------|
| Eclogite               | i                           | 3.480                                     | 5.55<br>6.34               | 0.14<br>0.06                         | 2.0<br>0.92                  | 0.3<br>0.03                | 0<br>0.714                       | 0.73<br>3.305                    | 1<br>4           | 7<br>45            | [33,34,35,53]              |
| Feldspar<br>Peridotite | not given                   | 3.22                                      | 5.78<br>4.59               | -<br>0.06                            | 0.93<br>1.373                | -<br>0.014                 | 1.4<br>2.73                      | 2.73<br>5.84                     | 2<br>4           | 2<br>3             | [48]                       |
| Gabbro                 | m                           | 2.941                                     | 6.4<br>8.1<br>5.8<br>3.3   | 0.7<br>0.2<br>0.2<br>0.3             | 0.2<br>-2.6<br>-0.64<br>1.41 | 1.4<br>0.3<br>0.19<br>0.10 | 0.286<br>0.515<br>0.864<br>1.629 | 0.608<br>0.878<br>1.677<br>3.059 | 1<br>2<br>3<br>4 | 5<br>9<br>13<br>17 | [27,33,35]                 |
| Enstatite<br>Gabbro    | not given                   | 3.15                                      | 4.98                       | 0.14                                 | 1.28                         | 0.04                       | 1.44                             | 5.88                             | 2                | 4                  | [48]                       |
| Gneiss                 | n                           | 2.79                                      | 5.30<br>2.68               | -<br>0.19                            | 0.20<br>1.54                 | -<br>0.04                  | 0.704<br>1.788                   | 1.788<br>6.047                   | 1<br>2           | 2<br>10            | [45]                       |
| Granite                | o                           | 2.657                                     | 5.6<br>4.88<br>2.06        | 0.2<br>0.13<br>0.17                  | -0.2<br>0.41<br>1.66         | 0.3<br>0.09<br>0.05        | 0<br>0.945<br>2.034              | 1.00<br>2.044<br>6.01            | 1<br>2<br>4      | 21<br>27<br>58     | [10,23,33,34,<br>35,52,53] |
| Granodiorite           | p                           | 2.664                                     | 5.879<br>2.2               | 0.015<br>0.4                         | 0.383<br>1.64                | 0.017<br>0.08              | 0.2<br>3.191                     | 3.191<br>5.999                   | 1<br>2           | 14<br>10           | [45,52]                    |
| Jadeite                | Burma                       | 3.335                                     | 6.41<br>6.57<br>7.44       | 0.06<br>0.10<br>0.12                 | 1.30<br>1.09<br>0.64         | 0.08<br>0.07<br>0.04       | 0<br>0.986<br>1.94               | 1.005<br>1.94<br>3.434           | 1<br>2<br>3      | 3<br>8<br>8        | [33,34,35,53]              |
| Limestone              | Salisbury<br>Plane, England | 1.742                                     | 0.00<br>2.24               | 0.18<br>0.15                         | 2.61<br>1.18                 | 0.15<br>0.06               | 0.56<br>1.51                     | 1.67<br>3.8                      | 2<br>4           | 10<br>11           | [52]                       |
| Limestone              | q                           | 2.286                                     | 1.8<br>2.6                 | 0.2<br>0.2                           | 2.11<br>1.43                 | 0.18<br>0.07               | 0.789<br>1.62                    | 1.62<br>5.05                     | 2<br>4           | 7<br>7             | [5,30]                     |

TABLE 1. Equations of State of Rocks (continued)

| Rock Name | Locality,<br>Comments  | Sample<br>Density<br>(Mg/m <sup>3</sup> ) | C <sub>0</sub><br>(km/sec) | error<br>$\Delta C_0$<br>(km/sec) | S     | error<br>$\Delta S$ | lower<br>U <sub>p</sub><br>(km/sec) | upper<br>U <sub>p</sub><br>(km/sec) | Phase* | No. of<br>Data | References              |
|-----------|------------------------|---|----------------------------|-----------------------------------|-------|---------------------|-------------------------------------|-------------------------------------|--------|----------------|-------------------------|
| Limestone | r                      | 2.597                                     | 6.7                        | 0.8                               | -16   | 7                   | 0.036                               | 0.163                               | 1      | 4              |                         |
|           |                        |   | 3.70                       | 0.13                              | -1.0  | 0.5                 | 0.163                               | 0.387                               | 3      | 3              |                         |
|           |                        |   | 2.67                       | 0.17                              | 2.26  | 0.16                | 0.387                               | 1.487                               | 2      | 18             |                         |
|           |                        |   | 3.4                        | 0.2                               | 1.54  | 0.07                | 1.487                               | 5.791                               | 4      | 21             | [5, 10, 23, 45, 50, 52] |
| Marble    | s                      | 2.697                                     | 5.2                        | 0.4                               | -2.8  | 1.6                 | 0.086                               | 0.43                                | 1      | 8              |                         |
|           |                        |   | 3.71                       | 0.10                              | 1.48  | 0.08                | 0.43                                | 2.56                                | 2      | 16             | [5, 22, 26, 52]         |
| Marble    | t                      | 2.841                                     | 5.4                        | 0.3                               | 1.14  | 0.18                | 0.913                               | 3.08                                | 2      | 10             | [23]                    |
| Olivinite | not given              | 3.376                                     | 6.38                       | 0.09                              | 1.01  | 0.09                | 0.59                                | 1.33                                | 1      | 4              |                         |
|           |                        |   | 7.1                        | 0.6                               | 0.4   | 0.3                 | 1.27                                | 2.2                                 | 3      | 6              |                         |
|           |                        |   | 5.21                       | 0.11                              | 1.27  | 0.02                | 2.04                                | 9.07                                | 4      | 11             | [48]                    |
| Pumice    | u                      | 0.55                                      | 0.31                       | -                                 | 1.06  | -                   | 2.32                                | 2.96                                | 2      | 2              |                         |
|           |                        |   | -0.54                      | 0.05                              | 1.347 | 0.011               | 2.96                                | 6.19                                | 4      | 3              | [30]                    |
| Quartzite | not given              | 2.65                                      | 4.72                       | 0.09                              | 1.24  | 0.17                | 0.25                                | 0.79                                | 1      | 4              |                         |
|           |                        |   | 5.621                      | 0.006                             | 0.062 | 0.004               | 0.79                                | 2.05                                | 2      | 4              |                         |
|           |                        |   | 2.3                        | 0.3                               | 1.59  | 0.07                | 2.05                                | 6.18                                | 3      | 4              |                         |
|           |                        |   | 4.32                       | 0.06                              | 1.258 | 0.006               | 6.18                                | 12.37                               | 4      | 5              | [49]                    |
| Quartzite | v                      | 2.648                                     | 6.13                       | 0.02                              | 0.05  | 0.02                | 0.135                               | 2.7                                 | 2      | 45             | [5, 52]                 |
| Quartzite | w                      | 2.646                                     | 5.43                       | 0.10                              | 1.0   | 0.3                 | 0.174                               | 0.54                                | 1      | 9              | [5, 52]                 |
| Sand      | x                      | 1.61                                      | 1.70                       | 0.08                              | 0.46  | 0.08                | 0.5                                 | 0.86                                | 1      | 12             |                         |
|           |                        |   | 1.0                        | 0.4                               | 1.7   | 0.3                 | 0.82                                | 1.72                                | 2      | 14             |                         |
|           |                        |   | 2.1                        | 0.2                               | 1.10  | 0.09                | 1.71                                | 3.88                                | 4      | 16             | [19, 23, 52]            |
| Wet Sand  | 4% water <sup>y</sup>  | 1.72                                      | 1.61                       | 0.14                              | 1.26  | 0.06                | 1.14                                | 3.49                                | 2      | 5              |                         |
|           |                        |   | -0.15                      | -                                 | 1.76  | -                   | 3.49                                | 3.74                                | 4      | 2              | [52]                    |
| Wet Sand  | 10% water <sup>y</sup> | 1.84                                      | 1.79                       | -                                 | 1.45  | -                   | 1.11                                | 1.98                                | 2      | 2              |                         |
|           |                        |   | 3.05                       | -                                 | 0.82  | -                   | 1.98                                | 2.79                                | 3      | 2              |                         |
|           |                        |   | 0.8                        | 0.3                               | 1.62  | 0.10                | 2.79                                | 3.44                                | 4      | 3              | [52]                    |

TABLE 1. Equations of State of Rocks (continued)

| Rock Name   | Locality, Comments           | Sample Density (Mg/m <sup>3</sup> ) | C <sub>0</sub> (km/sec) | error ΔC <sub>0</sub> (km/sec) | S     | error ΔS | Up (km/sec) |       | Phase* | No. of Data | References      |
|-------------|------------------------------|-------------------------------------|-------------------------|--------------------------------|-------|----------|-------------|-------|--------|-------------|-----------------|
|             |                              |                                     |                         |                                |       |          | lower       | upper |        |             |                 |
| Wet Sand    | 19% water <sup>y</sup>       | 1.96                                | 2.75                    | 0.14                           | 1.11  | 0.07     | 1.01        | 2.71  | 2      | 6           | [52]            |
|             |                              |                                     | 1.2                     | 0.4                            | 1.68  | 0.12     | 2.67        | 3.52  | 4      | 6           |                 |
| Wet Sand    | z                            | 1.985                               | 3.39                    | 0.08                           | 1.14  | 0.05     | 0.98        | 1.94  | 2      | 4           | [23]            |
| Sandstone   | aa                           | 1.993                               | 3.11                    | 0.16                           | -1.7  | 0.5      | 0.058       | 0.508 | 1      | 20          |                 |
|             |                              |                                     | 1.58                    | 0.09                           | 1.49  | 0.07     | 0.472       | 2.041 | 2      | 23          |                 |
|             |                              |                                     | 2.9                     | 0.6                            | 0.8   | 0.3      | 1.70        | 2.18  | 3      | 7           |                 |
|             |                              |                                     | 0.57                    | 0.14                           | 1.63  | 0.03     | 2.57        | 6.43  | 4      | 11          |                 |
| Serpentine  | bb                           | 2.621                               | 5.30                    | 0.15                           | 0.90  | 0.11     | 0.431       | 2.025 | 2      | 10          |                 |
|             |                              |                                     | 6.5                     | 0.4                            | 0.20  | 0.18     | 1.719       | 2.561 | 3      | 10          |                 |
|             |                              |                                     | 3.8                     | 0.5                            | 1.34  | 0.12     | 2.658       | 5.427 | 4      | 16          |                 |
| Shale       | cc                           | 2.545                               | 1.6                     | 0.3                            | 5.3   | 0.5      | 0.104       | 0.72  | 1      | 29          |                 |
|             |                              |                                     | 3.85                    | 0.17                           | 1.38  | 0.16     | 0.656       | 1.39  | 3      | 33          |                 |
|             |                              |                                     | 4.56                    | 0.11                           | 0.79  | 0.05     | 1.388       | 2.832 | 2      | 63          |                 |
| Oil Shale   | dd                           | 2.239                               | 2.3                     | 0.3                            | 1.61  | 0.09     | 2.821       | 3.877 | 4      | 38          | [7,18,24,33,41] |
|             |                              |                                     | 3.66                    | 0.07                           | 1.18  | 0.03     | 0.663       | 2.812 | 2      | 51          |                 |
|             |                              |                                     | 7.1                     | 0.5                            | -0.04 | 0.16     | 2.802       | 3.108 | 3      | 6           |                 |
| Soil (peat) | not given                    | 0.32                                | 0.00                    | -                              | 1.66  | -        | 0.5         | 1.5   | 2      | -           | [20]            |
|             |                              |                                     | 3.3                     | 0.4                            | 1.28  | 0.12     | 3.091       | 4.343 | 4      | 30          |                 |
| Tuff        | low density <sup>ee</sup>    | 1.298                               | 1.18                    | 0.10                           | 1.25  | 0.04     | 0.95        | 3.653 | 2      | 38          |                 |
|             |                              |                                     | 5.4                     | 0.6                            | 0.04  | 0.18     | 3.344       | 4.061 | 3      | 6           |                 |
|             |                              |                                     | 0.9                     | 1.3                            | 1.3   | 0.3      | 4.057       | 5.52  | 4      | 15          |                 |
| Tuff        | medium density <sup>ff</sup> | 1.610                               | 1.29                    | 0.12                           | 1.43  | 0.04     | 1.026       | 5.19  | 2      | 27          | [10,23,33]      |
|             |                              |                                     | 2.45                    | 0.19                           | 1.13  | 0.10     | 0.78        | 2.82  | 2      | 74          |                 |
| Tuff        | high density <sup>gg</sup>   | 1.851                               | 1.7                     | 0.3                            | 1.48  | 0.06     | 2.79        | 6.50  | 4      | 57          | [10,23,33,45]   |

\*Phases: 1) Elastic shock; 2) Low pressure phase; 3) Mixed region; 4) High pressure phase.

TABLE 1. Equations of State of Rocks (continued)

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| <sup>a</sup> Tahawus, NY; San Gabriel Anorthosite, CA; Apollo 15,418; "gabbroic anorthosite", locality unspecified; Agua Dulce Canyon, CA |
| <sup>b</sup> Vacaville basalt, Mt. Vaca Quad. CA; locality unspecified; Nevada Test Site, NV  |
| <sup>c</sup> Terrestrial dolerite - locality not given; lunar basalt 70215  |
| <sup>d</sup> Starting temperature 1673 K  |
| <sup>e</sup> Synthetic: matching komatiite from Munro Township, Ontario; starting temperature 1773 K                                      |
| <sup>f</sup> Lakebed Area 5, Nevada Test Site, NV   |
| <sup>g</sup> not given; 4-20%-water; also site U2, Nevada Test Site, Nye Co. NV   |
| <sup>h</sup> Centreville, VA; Frederick, MD   |
| <sup>i</sup> Hole U10B, Nevada Test Site, NV; Banded Mtn., Nevada Test Site, NV; Ferris Wheel Dolomite, Nevada Test Site, NV; not given   |
| <sup>j</sup> Jackson County, NC; Twin Sisters Peaks, WA; not given  |
| <sup>k</sup> Moolhoek Mine, Transvaal   |
| <sup>l</sup> Healdsburg, CA; Summerville, Norway  |
| <sup>m</sup> Bytownite gabbro, Duluth, MN; San Marcos, Escondido, CA  |
| <sup>n</sup> Rock Cove, Nevada Test Site, Nevada  |
| <sup>o</sup> near Lithonia, GA; near Shoal Nuclear Detonation, Fallon NV; near area 15, Nevada Test Site, Nevada                          |
| <sup>p</sup> Hardhat; Climax Stock Granodiorite, Nevada Test Site, NV   |
| <sup>q</sup> Kaibab Limestone, AZ; Spargen Limestone, Bedford, IL   |
| <sup>r</sup> Solenhofen, Bavaria; Banded Mountain limestone, Nevada Test Site, NV   |
| <sup>s</sup> Yule Marble, Gunnison City, CO; Vermont Marble, West Rutland, VT; not given  |
| <sup>t</sup> Area 15, Nevada Test Site, NV  |
| <sup>u</sup> U. S. Pumice Mine, Mono Craters, Lee Vining, CA  |
| <sup>v</sup> Novaculite, Arkansas   |
| <sup>w</sup> Eureka quartzite, Confusion Mountain, nr. Ely, NV  |
| <sup>x</sup> synthetic SiO <sub>2</sub> ; Ottawa banding sand, Ottawa IL, at -10°C; oven furnace sand (silica sand); not given            |
| <sup>y</sup> Ottawa banding sand, Ottawa IL at -10°C  |
| <sup>z</sup> Oven furnace sand (silica sand), locality not given  |
| <sup>aa</sup> Coconino sandstone, Flagstaff, AZ; Massillon sandstone, Glenmont, OH; St. Peters sandstone, Klondike, MO                    |
| <sup>bb</sup> Ver-myen, Italy; antigorite, Thurman NY; chrysothile, Quebec  |
| <sup>cc</sup> Gas shale, Devonian, Lincoln Co., WY; clay shale, locality not given; shales, Site U2, Nevada Test Site, Nye Co., NV        |
| <sup>dd</sup> Green River, Rifle CO; Laramie oil shale; Mahogany ledge oil shale  |
| <sup>ee</sup> Areas 3, 12, 16, buff Raimier Mesa Tuff, white Raimier Mesa Tuff, and unspecified, Nevada Test Site, NV                     |
| <sup>ff</sup> Areas 3, 12, 16, pink Raimier Mesa Tuff, and unspecified, Nevada Test Site, NV  |
| <sup>gg</sup> Raimier Mesa Tuff, Areas 3, 12, 16, Pahute Mesa Tuff, and unspecified, Nevada Test Site, NV                                 |

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