**Table S1.** Information-based mean chemical and structural complexities of minerals for different paragenetic modes and stages of mineral evolution\*

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| P | *n* | chem*IG*  [bits/atom] | | chem*IG,total*  [bits/f.u.] | | *n* | str*IG*  [bits/atom] | | str*IG,total*  [bits/cell] | | Paragenetic modes |
|  |  |  |  |  |  |  |  |
| Stage 0: Pre-terrestrial “Ur-minerals” | | | | | |  |  |  |  |  |  |
| St 0 | 21 | 0.775 | 0.115 | 5.21 | 1.715 | 21 | 1.247 | 0.220 | 37.32 | 15.32 |  |
| P01 | 21 | 0.775 | 0.115 | 5.21 | 1.715 | 21 | 1.247 | 0.220 | 37.32 | 15.32 | P01. Stellar atmosphere condensates |
| P02 |  |  |  |  |  |  |  |  |  |  | P02. Interstellar condensate |
| Stage 1: Primary nebular phases | | | | |  |  |  |  |  |  |  |
| St 1 | 81 | 1.170 | 0.050 | 14.83 | 2.140 | 76 | 2.084 | 0.151 | 83.42 | 14.50 |  |
| P03 | 43 | 1.168 | 0.077 | 13.631 | 2.098 | 40 | 2.138 | 0.332 | 103.55 | 22.316 | P03. Solar nebular condensates |
| P04 | 81 | 1.170 | 0.049 | 14.830 | 2.137 | 76 | 2.084 | 0.245 | 89.425 | 14.510 | P04. Primary chondrule phases |
| Stage 2: Planetesimal differentiation & alteration | | | | | |  |  |  |  |  |  |
| St 2 | 248 | 1.312 | 0.027 | 28.37 | 3.220 | 213 | 2.301 | 0.092 | 129.72 | 17.99 |  |
| P05 | 93 | 1.234 | 0.044 | 23.146 | 5.215 | 84 | 2.197 | 0.569 | 110.170 | 21.867 | P05. Primary asteroid phases |
| P06 | 192 | 1.304 | 0.031 | 26.794 | 2.585 | 167 | 2.308 | 0.200 | 139.99 | 22.120 | P06. Secondary asteroid phases |
| Stage 3 | | | |  |  |  |  |  |  |  |  |
| St 3 | 381 | 1.530 | 0.022 | 61.87 | 4.145 | 385 | 3.062 | 0.074 | 268.80 | 28.20 |  |
| Stage 3a: Earth’s earliest Hadean crust | | | | |  |  |  |  |  |  |  |
| St 3a | 387 | 1.533 | 0.027 | 72.343 | 6.046 | 350 | 3.098 | 0.080 | 320.234 | 44.82 |  |
| P07 | 119 | 1.357 | 0.044 | 28.820 | 4.347 | 105 | 2.312 | 0.424 | 113.86 | 20.912 | P07. Ultramafic igneous rocks |
| P08 | 87 | 1.631 | 0.048 | 51.374 | 5.632 | 81 | 2.948 | 0.626 | 172.391 | 23.220 | P08. Mafic igneous rocks |
| P09 | 121 | 1.640 | 0.030 | 73.799 | 8.503 | 112 | 3.446 | 0.803 | 331.266 | 54.915 | P09. Lava/xenolith minerals (hornfels. sanidinite facies) |
| P10 | 100 | 1.714 | 0.026 | 161.886 | 17.475 | 94 | 3.955 | 1.802 | 705.295 | 153.480 | P10. Basalt-hosted zeolite minerals |
| P11 | 38 | 1.163 | 0.082 | 14.374 | 2.981 | 34 | 2.158 | 0.511 | 76.657 | 18.330 | P11. Volcanic fumarole minerals; reduced phases |
| Stage 3b: Earth’s earliest hydrosphere | | | | |  |  |  |  |  |  |  |
| St 3b | 338 | 1.500 | 0.022 | 61.153 | 4.457 | 285 | 3.047 | 0.264 | 262.067 | 27.965 |  |
| P12 | 105 | 1.280 | 0.038 | 26.550 | 5.243 | 95 | 2.199 | 0.538 | 116.185 | 30.282 | P12. Hadean hydrothermal subsurface sulfide deposits |
| P13 | 64 | 1.555 | 0.058 | 72.890 | 11.99 | 51 | 3.175 | 0.245 | 362.795 | 88.83 | P13. Hadean serpentinisation |
| P14 | 61 | 1.472 | 0.048 | 71.337 | 12.294 | 59 | 3.383 | 1.600 | 301.294 | 50.414 | P14. Hot springs. geysers. and other subaerial geothermal minerals |
| P15 | 32 | 1.195 | 0.070 | 18.720 | 3.727 | 32 | 2.225 | 0.285 | 173.827 | 88.72 | P15. Black/white smoker minerals and other seafloor hydrothermal minerals |
| P16 | 76 | 1.784 | 0.016 | 120.809 | 11.380 | 76 | 4.063 | 1.305 | 353.501 | 31.861 | P16. Low-T aqueous alteration of Hadean subaerial lithologies |
| P17 | 48 | 1.635 | 0.043 | 74.057 | 10.494 | 45 | 3.510 | 1.564 | 392.953 | 104.234 | P17. Marine authigenic Hadean minerals |
| P18 | 4 | 1.394 | 0.174 | 31.000 | 15.82 | 4 | 2.834 | 7.91 | 116.751 | 34.76 | P18. Minerals formed by freezing |
| Stage 4 | | |  |  |  |  |  |  |  |  |  |
| St 4 | 3179 | 1.614 | 0.007 | 61.03 | 1.532 | 2707 | 3.362 | 0.027 | 275.44 | 8.615 |  |
| Stage 4a: Earth’s earliest continental crust | | | | |  |  |  |  |  |  |  |
| St 4a |  |  |  |  |  |  |  |  |  |  |  |
|  | Igneous rocks | | |  |  |  |  |  |  |  |  |
| P19 | 149 | 1.633 | 0.031 | 49.470 | 3.913 | 140 | 3.112 | 0.331 | 158.976 | 11.634 | P19. Granitic rocks |
| P20 | 40 | 1.642 | 0.057 | 40.911 | 4.944 | 38 | 2.921 | 0.802 | 114.663 | 14.127 | P20. Acid volcanic rocks |
|  | Near-surface Processes | | |  |  |  |  |  |  |  |  |
| P21 | 76 | 1.630 | 0.027 | 54.810 | 9.421 | 73 | 3.745 | 1.103 | 362.132 | 55.562 | P21. Chemically precipitated carbonate. phosphate. iron formations |
| P22 | 237 | 1.772 | 0.015 | 82.327 | 5.844 | 190 | 3.884 | 0.423 | 314.606 | 19.353 | P22. Hydration and low-T subsurface aqueous alteration |
| P23 | 384 | 1.663 | 0.016 | 57.918 | 3.906 | 348 | 3.366 | 0.209 | 243.253 | 17.70 | P23. Subaerial aqueous alteration by non-redox-sensitive fluids |
| P24 | 74 | 1.561 | 0.039 | 80.500 | 12.329 | 72 | 3.232 | 1.453 | 288.772 | 66.32 | P24. Authigenic minerals in terrestrial sediments |
| P25 | 204 | 1.654 | 0.018 | 70.475 | 5.531 | 188 | 3.842 | 0.403 | 391.754 | 33.80 | P25. Evaporites (prebiotic) |
| P26 | 239 | 1.263 | 0.032 | 29.352 | 2.877 | 216 | 2.193 | 0.195 | 110.018 | 12.30 | P26. Hadean detrital minerals |
| P27 | 9 | 1.513 | 0.044 | 105.708 | 27.924 | 8 | 5.570 | 9.873 | 1797.61 | 573.92 | P27. Radioactive decay; auto-oxidation |
| P28 | 10 | 1.412 | 0.11 | 18.220 | 6.887 | 10 | 2.656 | 2.177 | 92.037 | 29.92 | P28. Photo-alteration. pre-biotic |
| P29 | 8 | 0.781 | 0.254 | 4.660 | 2.224 | 8 | 1.253 | 0.786 | 27.705 | 17.28 | P29. Lightning-generated minerals |
| P30 | 15 | 0.897 | 0.155 | 9.207 | 4.311 | 8 | 1.109 | 1.524 | 29.912 | 21.12 | P30. Terrestrial impact minerals |
|  | High-T alteration and/or metamorphism | | | | |  |  |  |  |  |  |
| P31 | 342 | 1.702 | 0.016 | 65.834 | 5.120 | 303 | 3.553 | 0.294 | 298.091 | 28.76 | P31. Thermally altered carbonate. phosphate. and iron formations |
| P32 | 407 | 1.711 | 0.012 | 62.635 | 3.403 | 357 | 3.673 | 0.180 | 331.198 | 23.66 | P32. Ba/Mn/Pb/Zn deposits. including metamorphic deposits |
| P33 | 763 | 1.359 | 0.014 | 31.990 | 2.067 | 602 | 2.580 | 0.084 | 172.654 | 15.73 | P33. Minerals deposited by hydrothermal metal-rich fluids |
| Stage 4b: Highly evolved igneous rocks | | | | |  |  |  |  |  |  |  |
| St 4b | 1413 | 1.637 | 0.011 | 64.935 | 2.528 | 1226 | 3.306 | 0.040 | 257.116 | 11.30 |  |
| P34 | 524 | 1.640 | 0.013 | 51.623 | 2.653 | 455 | 3.314 | 0.124 | 237.625 | 13.80 | P34. Complex granite pegmatites |
| P35 | 701 | 1.808 | 0.046 | 88.560 | 4.404 | 623 | 3.780 | 0.176 | 324.320 | 18.91 | P35. Ultra-alkali and agpaitic igneous rocks |
| P36 | 261 | 1.393 | 0.033 | 31.980 | 2.836 | 261 | 2.422 | 0.175 | 127.524 | 11.88 | P36. Carbonatites. kimberlites. and related igneous rocks |
| P 37 | 130 | 1.078 | 0.039 | 11.024 | 1.436 | 104 | 1.635 | 0.140 | 53.416 | 13.30 | P37. Layered igneous intrusions and related PGE minerals |
| Stage 5: Initiation of plate tectonics | | | | |  |  |  |  |  |  |  |
| St 5 | 3179 | 1.614 | 0.007 | 61.03 | 1.532 | 2707 | 3.362 | 0.027 | 275.44 | 8.615 |  |
| P38 | 104 | 1.060 | 0.061 | 31.816 | 8.164 | 99 | 1.833 | 0.820 | 133.258 | 31.79 | P38. Ophiolites |
| P39 | 68 | 1.628 | 0.161 | 42.051 | 4.596 | 63 | 3.334 | 0.579 | 225.187 | 44.77 | P39. High-P metamorphism (blueschist. eclogite. ultrahigh P facies) |
| P40 | 308 | 1.650 | 0.018 | 55.941 | 5.058 | 284 | 3.224 | 0.300 | 194.431 | 13.87 | P40. Regional metamorphism (greenschist. amphibolite. granulite facies) |
| P41 | 16 | 1.465 | 0.070 | 35.425 | 9.00 | 15 | 2.822 | 2.324 | 138.072 | 35.85 | P41. Mantle metasomatism |
| P42 | 14 | 1.460 | 0.084 | 78.483 | 30.874 | 11 | 2.627 | 9.309 | 108.820 | 41.85 | P42. Sea-floor Mn nodules |
| P43 | 9 | 1.580 | 0.098 | 48.382 | 18.789 | 9 | 3.500 | 6.263 | 157.095 | 43.30 | P43. Shear-induced minerals (including mylonite/slickensides) |
|  |  |  |  |  |  |  |  |  |  |  |  |
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| Stage 6: Anoxic biosphere | | | |  |  |  |  |  |  |  |  |
| St 6 |  |  |  |  |  |  |  |  |  |  |  |
| P44 | 11 | 1.098 | 0.133 | 9.843 | 2.808 | 11 | 1.549 | 0.846 | 29.894 | 11.90 | P44. Anoxic microbially-mediated minerals |
| Stage 7: Great Oxidation Event | | | | |  |  |  |  |  |  |  |
| St 7 | 5028 | 1.632 | 0.005 | 63.66 | 1.23 | 4191 | 3.508 | 0.021 | 326.91 | 10.40 |  |
| P45 | 447 | 1.590 | 0.017 | 47.190 | 2.605 | 410 | 3.313 | 0.128 | 281.545 | 21.90 | P45. Oxidized fumarolic minerals |
| P45a | 242 | 1.627 | 0.022 | 57.335 | 4.013 | 221 | 3.670 | 0.270 | 382.211 | 36.90 | P45a.  [Sulfates. arsenates. selenates. antimonates] |
| P45b | 267 | 1.593 | 0.023 | 39.125 | 2.996 | 249 | 3.095 | 0.190 | 196.098 | 14.85 | P45b.  [Other oxidized fumarolic minerals] |
| P46 | 49 | 1.723 | 0.037 | 56.905 | 6.975 | 44 | 3.432 | 1.051 | 241.750 | 38.66 | P46. Near-surface hydrothermal alteration of minerals |
| P47 | 1919 | 1.662 | 0.006 | 70.426 | 2.048 | 1537 | 3.785 | 0.052 | 403.991 | 22.60 | Low-T subaerial oxidative hydration. weathering |
| P47a | 1561 | 1.714 | 0.005 | 78.548 | 2.372 | 1230 | 4.045 | 0.068 | 460.557 | 27.60 | P47a. [Near-surface hydration of prior minerals] |
| P47b | 408 | 1.672 | 0.010 | 80.014 | 3.583 | 325 | 4.244 | 0.199 | 494.625 | 30.75 | P47b.  [Sulfates and sulfites] |
| P47c | 544 | 1.730 | 0.007 | 76.990 | 3.235 | 430 | 4.108 | 0.156 | 490.990 | 59.75 | P47c.  [Carbonates. phosphates. borates. nitrates] |
| P47d | 485 | 1.695 | 0.011 | 72.054 | 4.844 | 397 | 3.825 | 0.243 | 400.463 | 44.74 | P47d.  [Arsenates. antimonates. selenates. bismuthinates] |
| P47e | 262 | 1.620 | 0.015 | 71.176 | 6.256 | 196 | 3.744 | 0.446 | 424.560 | 81.09 | P47e.  [Vanadates. chromates. manganates] |
| P47f | 246 | 1.620 | 0.010 | 84.725 | 5.013 | 173 | 4.720 | 0.381 | 836.070 | 146.40 | P47f.  [Uranyl (U6+) minerals] |
| P47g | 251 | 1.806 | 0.020 | 66.690 | 4.933 | 224 | 3.350 | 0.329 | 295.115 | 27.95 | P47g.  [Halogen-bearing surface weathering minerals] |
| P47h | 292 | 1.410 | 0.021 | 33.470 | 3.636 | 248 | 2.728 | 0.230 | 154.815 | 17.60 | P47h.  [Near-surface oxidised. dehydrated minerals] |
| P47i | 28 | 1.485 | 0.064 | 32.054 | 6.477 | 25 | 2.611 | 1.295 | 90.790 | 21.04 | P47i.  [Terrestrial weathering of meteorites] |
| Stage 8: “Intermediate Ocean” (no new paragenetic modes) | | | | | | |  |  |  |  |  |
| Stage 9: “Snowball Earth” (no new paragenetic modes) | | | | | | |  |  |  |  |  |
| Stage 10 | | |  |  |  |  |  |  |  |  |  |
| St 10 | 5400 | 1.623 | 0.005 | 63.04 | 1.20 | 4492 | 3.485 | 0.021 | 320.14 | 9.760 |  |
| Stage 10a: Neoproterozoic oxygenation/terrestrial biosphere | | | | | | | | |  |  |  |
| St 10a | 581 | 1.492 | 0.016 | 49.713 | 2.950 | 529 | 3.144 | 0.067 | 371.565 | 16.92 |  |
| P48 | 70 | 1.631 | 0.030 | 79.741 | 14.050 | 63 | 3.438 | 1.770 | 247.206 | 40.11 | P48 Soil leaching zone minerals |
| P49 | 77 | 1.338 | 0.050 | 29.703 | 5.076 | 76 | 2.842 | 0.582 | 208.143 | 40.74 | P49. Oxic cellular biomineralisation |
| P50 | 265 | 1.372 | 0.027 | 36.440 | 2.984 | 248 | 2.897 | 0.189 | 243.196 | 24.99 | P50. Coal and/or oil shale minerals |
| P51 | 122 | 1.478 | 0.032 | 37.504 | 3.649 | 110 | 2.756 | 0.347 | 162.904 | 22.48 | P51. Pyrometamorphic minerals |
| P52 | 69 | 1.700 | 0.029 | 49.190 | 5.898 | 62 | 3.752 | 0.749 | 318.627 | 44.66 | P52. Guano- and urine-derived minerals |
| P53 | 110 | 1.515 | 0.036 | 56.710 | 7.410 | 96 | 3.483 | 0.756 | 307.010 | 37.92 | P53. Other minerals with taphonomic origins |
| Stage 10b: Anthropogenic minerals | | | | | | |  |  |  |  |  |
| St 10b | 586 | 1.510 | 0.015 | 52.648 | 2.925 | 528 | 3.430 | 0.067 | 347.187 | 24.50 |  |
| P54 | 227 | 1.348 | 0.029 | 34.354 | 3.062 | 213 | 2.731 | 0.209 | 207.893 | 24.63 | P54. Coal and other mine fire minerals |
| P55 | 255 | 1.592 | 0.014 | 73.365 | 5.306 | 226 | 4.278 | 0.352 | 563.804 | 48.60 | P55. Anthropogenic mine minerals |
| P56 | 139 | 1.611 | 0.032 | 43.338 | 5.123 | 127 | 3.255 | 0.454 | 243.557 | 28.95 | P56. Slag and smelter minerals |
| P57 | 48 | 1.584 | 0.042 | 35.754 | 5.420 | 44 | 3.250 | 0.817 | 246.243 | 50.77 | P57. Other minerals formed by human processes |

\* *n* = number of minerals taken into account; = arithmetic mean; = standard error of mean.