One hundred mineralogical questions impacting the future of Earth, planetary, and environmental sciences

Atmosphere

1. What role does mineral content and the mineralogical interrelationships of airborne dust play in the global climate, and can temporal and spatial variations thereof be applied as indicators of current and future climate?
2. Which are the most abundant airborne minerals, how do they react with other atmospheric constituents, and what are their health and other environmental effects?
3. Which abundant airborne minerals, if any, have important radiative properties and, thus, effects on climate change?
4. What atmospheric gas phase reactions are catalyzed on mineral dust surfaces in the atmosphere?
5. Which airborne minerals are the most effective ice nuclei, influencing the formation of ice clouds, and what is the atomic level mechanism of nucleation?
6. What are the impacts of volcanic ash on the performance of jet engines, and what exactly is the tolerance of those engines to volcanic ash?

Biomineralization

7. What are the universal characteristics of the biomolecules that induce/inhibit the growth of biominerals, and by what mechanisms is this regulated and very finely and selectively controlled? How do we manipulate such characteristics, so that biominerals with special morphology and size result?
8. How does the biological control of non-equilibrium crystal morphologies work in biominerals?

9. What are the molecular-scale mechanisms involved in electron transfer (redox) processes at the mineral–microbe interface?
10. What specific properties of the biological form of apatite make it so biologically successful in a nanocomposite with protein (collagen), as in bone?
11. What is the mechanism for nucleation and growth of oriented nanocrystals of hydroxyapatite within collagen in the biomineralization of bone?
12. Do biological processes play a role in the genesis of ore mineralization at depths which might be described as belonging to 'the deep biosphere'?
13. Why do some organisms precipitate a skeleton of calcite whilst others an aragonite skeleton, and why do some biological groups (*e.g.* corals and molluscs) precipitate both calcite and aragonite?
14. What are the criteria by which crystalline graphite derived from biological carbon sources can be robustly distinguished from crystalline graphite derived from abiological carbon sources?

Climate

15. What is the stability of naturally occurring methane hydrates, and how will they be affected by global warming?
16. What are the mineralogical influences on the operation of paleoclimate proxies?
17. How can we use fine-scale mineralogical and chemical variations within speleothems (cave deposits) to understand how seasonality changes as mean climate changes?

Early Earth

18. Are shocked minerals preserved in rocks or sediments from the Late Heavy Bombardment?
19. Are there mineralogical clues that a giant impact really did produce the Earth-moon system?

20. What role did minerals play in the emergence of life on Earth?

Environmental

21. How does organic matter affect contaminant uptake and dissolution from mineral surfaces?
22. How do minerals at the Earth's surface interact with light to drive chemical reactions that affect our living environment?
23. What are the mineralogical controls (grainsize, shape, crystallinity, surface structure and composition) determining the effective use of nanoparticle minerals (such as iron oxyhydroxides) in the selective removal of toxic elements such as arsenic from contaminated waters and how do they operate?
24. What are the thermodynamic properties of the poorly crystalline, impure, large-surface area, arsenic-bearing Fe- and Mn-(hydr)oxide phases found in the shallow aquifers widely used for drinking and irrigation in parts of Asia?

Extraterrestrial Materials

25. Is there mineralogical evidence that would definitively prove the existence of extinct or extant extraterrestrial microbial life?
26. How did pristine molecules become minerals during the first stages of solar nebulae?
27. How did chondrules and refractory inclusions in chondritic meteorites form?
28. Is it possible to date presolar grains, and if so, what will their age-range tell us about their origin?
29. In which mineralogical form was water delivered into the inner solar system, and particularly to Earth, during the formation of the terrestrial planets?
30. What role, if any, have minerals played in the diversity of organic matter in carbonaceous asteroids?
31. What was the mineralogical role in the availability of water on Mars?

32. Does the lunar mantle contain H present as defects in minerals? If it does, how did it get there, and what does it say about our models for how the Moon formed and how the Earth obtained its water?
33. What is the mineralogy and chemistry of volatiles cold trapped at the poles of the Moon and Mercury?
34. Are there geochemical signals of large-scale extraterrestrial events, such as supernova explosions or gamma ray bursts, that are preserved in the geological record?

Geochemistry

35. What does the temporal distribution of minerals through >4 billion years of Earth history reveal about the changing geochemistry of Earth's oceans and atmosphere, about global tectonics and the supercontinent cycle, about the co-evolution of the geosphere and biosphere, and even about the origins and evolution of life on Earth?
36. What are the atomic-scale mechanisms that dominate the mobility of trace elements in the geosphere?
37. How do atoms in aqueous solutions come together to make minerals?
38. Can we be sure that zircons of Archaean/Hadean age are actually recording a true age of formation, and thus providing us with information about Early Earth history?
39. Are geochemical reactions within the Critical Zone driven primarily by minerals, microbes, natural organic matter, or some combination of all three, and how might these factors be determined reliably?

Geophysics

40. Which minerals and under what conditions (T, P, strain-rate, pore-pressure, cumulative strain, *etc.*) produce stably-sliding fault surfaces rather than cycles of strain accumulation and release?

41. What role do fluids and hydrous minerals have in controlling the frictional properties of subduction zone faults where great earthquakes occur or do not occur?
42. How do minerals behave under extreme shock loading: faults and impacts?
43. Is the presence of water in the mantle, and its effect in softening and/or melting the asthenosphere, the only reason that we have plate tectonics on Earth and not on other rocky planets in the solar system, or do other mineralogical, compositional and rheological factors play a role?

Global Element Cycles

44. How does the deep carbon cycle operate?
45. What are the mechanisms through which minerals stabilize organic carbon in soils (the largest reservoir of organic carbon in terrestrial environments) and sediments?
46. How has the global cycling of phosphorous, an element essential for all forms of life, been affected by the impact on terrestrial and continental shelf processes of glacial-interglacial cycles?

Kinetics

47. How can we find new ways to relate laboratory measurements of processes taking place on timescales from minutes to years to the geological timescale, often from thousands to millions of years?
48. What are the timescales of silicate and carbonate mineral weathering on a global scale, and what factors govern these timescales ?
49. How quickly do mineral assemblages re-equilibrate to changing P-T conditions as a subducted lithospheric slab descends into the Transition Zone and Lower Mantle?
50. What are the rates and mechanisms of replacement reactions in minerals at temperatures below 300°C, and the role of defect microtextures in these reactions?

Magnetism

51. Do nanoscale magnetic inclusions contained within individual silicate grains provide a faithful record of Earth's ancient magnetic field, and can we use them to obtain primary paleomgnetic information from Archean/Hadean rocks?
52. How can we identify, isolate and analyse primary paleomagnetic signals from extraterrestrial materials, and what can these signals tell us about the existence of active dynamos in the early solar system (how long did they last, how intense was the field they generated and were they dipolar in nature)?
53. What are the atomic and nanoscale mineralogical processes that link the magnetic properties of rocks, sediments and soils to external enviromental and climatic variables?
54. Are magnetic minerals involved in the magnetic sensing mechanisms of complex organisms (such as vertebrates), and if yes, how do they work?

Metamorphism

55. Does the appearance of UHP metamorphism in the Neoproterozoic Erathem signify a change in global geodynamics?
56. What are the mechanisms of porosity generation during interface coupled dissolution-reprecipitation reactions?
57. Are the pressure estimates obtained from UHP mineral assemblages in metamorphic rocks directly 'convertible' to lithospheric depths?
58. What are the rates of retrograde metamorphism?

Mineral Physics

59. What is the chemical composition, crystal structure and microstructure of the inner core, and will this knowledge help to explain the seismic anisotropy that seems to be present?

60. What are the different effects of temperature, chemical composition and microstructure on the elastic and anelastic properties of minerals in the deep Earth, and how can variations in these three variables be discriminated seismologically?
61. How do melts and fluids influence the physical properties of the deep crust and upper mantle?
62. How do the properties of liquid silicate and iron-alloy change under high pressure?
63. What are the thermal conductivity values for the deep mantle and outer core materials?
64. What is the viscosity of the deep mantle and core, and what are the mechanisms that control viscosity under different regimes of temperature, pressure and applied stress?
65. What is the distribution of mineral grain size with depth in the mantle and inner core?
66. Can the presence of $MgSiO_3$ post-perovskite explain the anomalous seismic properties of the D" layer above the core–mantle boundary?
67. How does Fe (and Ca, Al, Na, K *etc.*) interact with the perovskite to post-perovskite phase transition in $MgSiO_3$ predicted to occur at the base of the mantle?
68. What is the nature of the ultra-low velocity zones observed at the base of the mantle?
69. What are the geochemical and geophysical consequences of core–mantle interaction?
70. How much 'water' is stored in Earth's deep interior, and what effect does its presence have on planet-wide geological processes ?
71. Which mineral phases control the budget and behaviour of volatile elements (H, C, S, halogens, *etc.*) in the mantle, and what is the nature of the defects that allow volatiles to be incorporated into their host structures?
72. What do computational studies of minerals at the atomic scale tell us about geological processes occurring on the planetary scale, and what is the best way to bridge the gap in length scales and time scales between computer simulations and geological processes?
73. Can atomic-scale *ab initio* calculations be used to predict slip systems activities and deformation mechanisms of geological materials?

74. How do phase transformations begin at interfaces, including mineral–water interfaces, and nanoparticle surfaces?
75. Does atomic structure (Å scale) or microstructure (nm–μm scale) play the dominant role in controlling the macroscopic properties of rocks and minerals under geologically relevant conditions?

Nanogeoscience

76. How and why do the chemical and mechanical properties of minerals vary as a function of crystal size and shape, something that is expected to occur as grain size is reduced into the nano-scale?
77. How do nanominerals (including clay minerals) and mineral nanoparticles influence macroscopic (bio)geochemical processes at local, regional, and global scales?
78. How do nanominerals and mineral nanoparticles, as well as manufactured nanoparticles inadvertently entering the environment, influence/affect life on Earth?
79. What is the inventory of mineral nanoparticles in the world's oceans, and what biogeochemical role do they play, including the role they play in supplying limiting nutrients to the microorganisms of the oceans?
80. What is the spatial and temporal distribution of all forms of iron oxyhydroxides in the euphotic zone of the oceans, and which of these forms are bioavailable?
81. What are the best ways to describe naturally-occurring, poorly crystalline materials in soils and sediments, and predict their reactivities with important inorganic and organic compounds, as well as microbes?

Nuclear Waste

82. What are the dissolution reactions that lead to the breakdown of nuclear waste materials in deep geological disposal facilities, and what might be the long-term impact of nuclear waste dissolution?
83. What is the long-term fate of man-made actinides, mainly plutonium, in the environment?

Petrology

84. In magmatic systems, what is the role of a solidification front in modulating convection, in truncating the liquid line of descent, and in controlling crystal nucleation and growth, and can liquid lines of descent be used to infer magma dynamics?
85. How prevalent is liquid immiscibility in mafic magmas and what implications does it have for crustal evolution?
86. Is all layering in igneous rocks simply the result of the self-organization, or sorting and re-crystallization of granular flows associated with periodic crystal-rich injections?

Resources

87. What are the main geological processes by which minerals containing the rare earth elements and other metals required for advanced technological applications are formed and concentrated?
88. When will it become economically viable to exploit the mineral resources of other planets and asteroids?
89. Given the historical importance of minerals such as the zeolites as materials with important industrial applications, what strategies could be adopted further to exploit the mineral world for the benefit of industry?
90. Did carbonados originate in the Earth's mantle, at its surface, or through an extrasolar event, and when and how did it happen?

91. How do the secondary gold grains found in certain soil and placer environments 'grow' to be larger than the primary source material from which they are derived?
92. Can we control the mineral–fluid reactions governing many of the processes of crucial importance to the sustainability of human society, processes concerned with resource exploitation, recycling and waste disposal?
93. How might our exploitation of mineral resources influence the biosphere and natural selection in the long term?

Sequestration

94. How can we accelerate mineral carbonation to sequester CO_2?
95. What is the long-term fate of CO_2 that is injected into the subsurface during carbon sequestration?
96. How important is reaction-driven fracturing for the rate and extent of volatilization processes?

Volcanology

97. To what extent are the health impacts of volcanic ash fall controlled by the mineralogy of the eruptive materials?
98. What are the conditions under which polymorphs of silica (especially cristobalite) form in volcanic conduits, and what is their fate once released to the environment?
99. How do minerals record volatile components in magmatic systems?
100. What is the role of the mineral source composition in generating supereruptions and large igneous provinces?