American Mineralogist, Volume 73, pages 936–938, 1988

Planet Alsioff: A problem set for students of phase equilibria or metamorphic petrology

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This contribution might more appropriately appear in a publication such as Journal of Geological Education. *Nevertheless, it has been brought to my attention that this part of the geological literature is not routinely followed by most readers of* American Mineralogist. *For this reason and others, I felt that many of our readers would find this deviation from our normal articles useful or entertaining.*

J. L. Munoz, Editor

Introduction

You are given incomplete data about a hypothetical planet Alsioff where SiF_4 is the major volatile and Al, Si, O, and F are the only elements present. You then are challenged to answer a series of questions that involve qualitatively working out the metamorphic and metasomatic phase equilibria on such a planet. Thermodynamic data are not required; all that is needed to answer the questions are a paper and pencil. (In fact, thermodynamic calculations yield answers that are inconsistent with the problems; see section entitled "Disclaimer" following the problems). An internally consistent set of answers will be presented in the next issue (Burt, 1988).

Data

The C.I.A. has recently intercepted a report allegedly originating with the Sobriskian Academy of Sciences. The report, which is somewhat garbled, states that survivors of the first Sobrisky Interstellar Space Expedition (SISE) recently returned to Earth from the planet Alsioff, bearing the body of their captain, Ivigtut Greisenovich Alsioff (for whom the planet was named).

The planet, for which even the general location is not given, is reported to have a remarkable geochemistry, in that its surface consists solely of the elements Al, Si, O, and F. The surface is very hot, and the atmosphere consists predominantly of gaseous SiF_4 in equilibrium with minor O_2. Precipitation, classified as "snow" by the Sobriskians, occurs in the form of doubly terminated and complexly twinned quartz crystals of incredible beauty and variety. Violent surface "quartz storms" are the major erosional elements on the planet. In fact, some members of the first expedition perished during such a storm, when the sharp points of quartz crystals penetrated their space suits. The victims (including the captain) were immediately petrified and, except for the captain, were left on the planet as their own agate gravestones. (The captain's shrunken and agatized remains have been placed in an upright position near the front entrance of SISE headquarters in the Sobriskian capital city of Ivresia. Tours are contemplated.)

The crystalline basement rocks, metamorphic and igneous, are largely bimineralic assemblages involving quartz, kyanite, andalusite, sillimanite, topaz, corundum, and a new mineral, crystalline AlF_3, named "alfite"[1] by the Sobriskian scientists. (Properties: Transparent, greasy luster, hardness 3, sp. gr. 3.20, rhombohedral, space group $R32$, no cleavage.)

The planet is tectonically active and as rocks from the interior become exposed at the surface, sediments form by physical and chemical weathering; these then are buried and undergo progressive metamorphism. Progressive metamorphism on Alsioff mainly involves devolatilization of fluid SiF_4.

Sediments consist largely of windblown deposits of quartz and "alfite." Nearly monomineralic sedimentary rocks are common and consist of coarse-grained quartzites and fine-grained phyllitic "alfitites," but sedimentary rocks of intermediate bulk composition also occur.

Ingneous rocks, consisting mainly of "alfite" with accessory corundum, occur as both intrusive and extrusive bodies.

Fluid inclusions in metamorphic quartz crystals consist mainly of gaseous SiF_4, commonly with daughter crystals of "alfite." Topaz does not contain fluid inclusions but instead contains solid inclusions consisting of intergrown quartz and "alfite."

Problems

1. What chemical reaction should affect water exposed to the atmosphere of Alsioff? (The same thing should happen to water in the human body and did destroy and preserve the agatized members of the first expedition.) What would happen to a specimen of wollastonite, $CaSiO_3$? Write the relevant reactions.

2. What can you say about controls on the O_2 and F_2 contents of the Alsioffian atmosphere? What about their

[1] See Section entitled "Disclaimer."

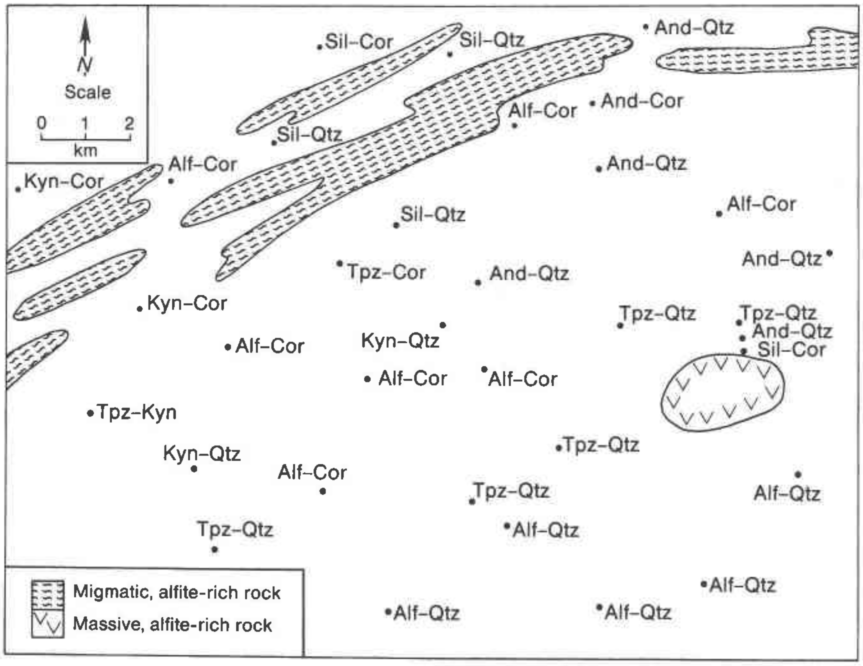

Fig. 1. Sketch map of sample locations near landing site (to accompany Problem 9). Mineral abbreviations are given in Problem 3.

relative abundances? (Hint: write the buffer reaction involved and the form of its equilibrium constant.)

3. Consider the phases in Table 1 and plot their compositions on a suitable planar polyhedron (triangle or "reciprocal ternary" rectangle).

4. On the polyhedron above, draw tie lines that indicate the probable phase compatibilities at low temperatures and relatively high pressures of SiF_4. Assume that corundum never occurs with quartz nor aluminosilicate with "alfite."

5. Deduce the probable sequence of devolatilization reactions involving SiF_4 with progressive thermal metamorphism. Write the four reactions in order of increasing temperature. (Note: during progressive thermal metamorphism on Alsioff, corundum appears at lower grades than an aluminosilicate phase.)

6. Where sillimanite is the first aluminosilicate phase to appear during progressive metamorphism, quartz is always absent. In quartz-bearing rocks, the first aluminosilicate phase to appear is either kyanite or andalusite,

TABLE 1. Phases on planet Alsioff

Phase	Composition	Symbol
Corundum	Al_2O_3	Cor
Quartz	SiO_2	Qtz
Aluminosilicate	Al_2SiO_5	Als
andalusite		And
sillimanite		Sil
kyanite		Kyn
Topaz	$Al_2SiO_4F_2$	Tpz
"Alfite"	AlF_3	Alf
Fluid (vapor)	SiF_4	Vap

never sillimanite. Using this information, draw a schematic *P-T* diagram of metamorphic facies on Alsioff, showing the devolatilization reactions in addition to the stability fields of the Al_2SiO_5 polymorphs. Assume that the devolatilization reactions form curves that are concave upward, with gradually increasing slopes (similar to devolatilization reactions on Earth).

7. At high temperatures, AlF_3 becomes somewhat volatile, and an appreciable amount of it dissolves in the SiF_4 metamorphic fluid (indicated by the AlF_3 daughter crystals found in these inclusions, as mentioned under "Data"). At an arbitrary pressure, and neglecting the possible solubility of other condensed phases in the SiF_4-AlF_3 metamorphic fluid, draw a schematic T-X_{AlF_3} diagram that shows the condensed phases in equilibrium with the fluid. Explain, if you can, the solid inclusions of "alfite" and quartz in topaz, also mentioned under "Data."

8. Describe in detail the outcrop-scale changes (with respect to both mineralogy and physical appearance) that one might expect to see developed during progressive thermal metamorphism of thick beds consisting of pure "alfite" (possibly the result of a volcanic pyroclastic eruption or lava flow), alternating with thick beds of pure quartz (possibly the result of a heavy fall of quartz "snow").

9. Limited sampling of crystalline basement rocks was carried out at the Sobriskian landing site during a lull between "quartz storms." The locations of these samples, together with the observed mineral assemblages, are plotted on the accompanying map (Fig. 1), along with several easily recognizable geologic contacts. Use the mineral-

asemblage data and the results of question 6 above to draw appropriate metamorphic isograds on the map.

10. Which two-phase assemblage indicates the highest metamorphic pressures that can be specified on Alsioff? Circle the area of the map where it occurs.

Disclaimer

This problem set is based solely on deriving topologic and reaction relations (note that I have deliberately avoided specifying temperatures and pressures for the planet); it is not claimed that the problems or derived results are thermodynamically reasonable or even possible, particularly as regards topaz, which is much more stable than indicated. The rationale for this approach will be explained in the second half of this paper (Burt, 1988). Also, the properties ascribed to "alfite" for the purposes of this exercise do not correspond to those of any known mineral, and use of the term "alfite" for AlF_3 (not yet known as a mineral) does not imply approval by the International Mineralogical Association nor the editors of this journal.

Acknowledgments

These problems were created in essentially their present form in 1974 while I was J. Willard Gibbs Instructor at Yale University, and the late Phil Orville who was a professor there is thanked for his encouragement and contribution to Problem 9. I also thank subsequent classes at Arizona State University for trying them and seeming to enjoy them, Jim Munoz and Doug Rumble for helpful editorial comments, and Deborah Barron for drafting the figure. The problem set and answers were brought to their present form while I was Visiting Scientist at the Lunar and Planetary Institute, Houston, Texas, where I was studying the possibility of fluorinating Moon rocks to release oxygen and metals. The L.P.I. is operated by the Universities Space Research Association under Contract No. NASW-4066 with the National Aeronautics and Space Administration. This is Lunar and Planetary Institute Contribution no. 655.

Reference cited

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Manuscript received October 7, 1987
Manuscript accepted March 21, 1987