60 to 68 cm; in core 114, at 55 to 80 cm. These portions are being saved for possible dating by the K-Ar method (*8*). Errors due to counting statistics in the Io : Th ratio are 8 percent. The half-life of ionium used to calculate the rate of sedimentation is 75,200 years (*9*).

In Fig. 5 cores 98C and 114 are divided into glacial and interglacial stages on the basis of faunal analyses; the three other cores are the Atlantic cores, similarly divided on the basis of faunal analyses and dated beyond the range of C^{14}. These cores have been dated by the protoactinium method and the protoactinium-ionium method, as indicated in Fig. 5. Other Atlantic cores, dated past the range of C^{14} and divided into glacial and interglacial stages on the basis of $O^{18} : O^{16}$ analysis, are not included here because the correlation between $O^{18} : O^{16}$ changes and faunal changes is questionable (*2, 10*).

The ages of the boundaries between faunal intervals 1 and 2 in cores 98C and 114 are 7000 and 8000 years, respectively; these ages have been well-established in Atlantic cores by C^{14} dating (*2*) as 11,000 years. The age of the boundary between intervals 2 and 3 ranges from 51,000 to 85,000 years; between intervals 3 and 4, from 110,000 to 140,000 years; and between intervals 4 and 5, from 120,000 to 180,000 years. These ranges in age are not unreasonable if allowances are made for the accuracy and precision of the dating method, the use of different dating methods, and a 5-cm uncertainty in the positions of the boundaries. Arrhenius (*11*) reports a Pa : Io age of 80,000 years for the boundary between intervals 2 and 3 for Pacific equatorial core SW60 (Fig. 1), which falls in the range reported here. Ages of the boundaries between faunal intervals are taken at the midpoints of the changes.

Thus there is good agreement between the ages of the postglacial stage 1 and stages 2, 3, and 4 in all cores. Comparison with Emiliani's (*10*, p. 140, fig. 7) generalized climatic zonation of Atlantic deep-sea cores shows that his interval 3 is not detectable by the faunal analysis used by us. It is not desirable to speculate upon a generalized Pleistocene chronology before more cores that have been analyzed faunally are dated.

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References and Notes

1. F. B. Phleger, F. L. Parker, J. F. Peirson, in *Swed. Deep-Sea Exped. Rept.* (1953), vol. 7, fasc. 1.
2. D. B. Ericson, M. Ewing, G. Wollin, B. C. Heezen, *Bull. Geol. Soc. Amer.* **72**, 193 (1961).
3. G. Arrhenius, in *Swed. Deep-Sea Exped. (1947–48) Rept.* (1952), vol. 5, fasc. 1.
4. F. L. Parker, *Micropaleontology* **8**, 219 (1962).
5. J. Imbrie, *ONR Geograph. Branch Tech. Rept. 6* (1963).
6. E. D. Goldberg and M. Koide, *Geochim. Cosmochim. Acta* **26**, 417 (1962).
7. E. D. Goldberg and J. J. Griffin, *J. Geophys. Res.* **69**, 4293 (1964).
8. J. R. Dymond, *Science* **152**, 1239 (1966).
9. R. W. Attree, M. J. Cabell, R. L. Cushing, J. J. Pieroni, *Can. J. Phys.* **40**, 194 (1962).
10. C. Emiliani, *Bull. Geol. Soc. Amer.* **75**, 129 (1964).
11. G. Arrhenius, *The Sea* (Interscience, New York, 1963), pp. 710–15.
12. D. B. Ericson, M. Ewing, G. Wollin, *Science* **146**, 723 (1964).
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Absence of Neutral Alkali Atoms in Rhodizite

Abstract. *The formula $CsB_{12}Be_4Al_4O_{28}$ has been proposed by others for the mineral rhodizite. Electron-spin-resonance and magnetic susceptibility measurements prove the absence of neutral cesium atoms. An ionic formula $CsB_{11}Be_4Al_4O_{26}(OH)_2$ is proposed.*

Buerger and Taxer (*1*) have proposed the formula $CsB_{12}Be_4Al_4O_{28}$ for the mineral rhodizite; cesium or the substituting alkali atoms would have to be present in the neutral state. Their proposal is based on a structure determination, whose unweighted residual *R* (discrepancy index) was 0.125 at the time that they published their results. A neutral alkali atom is placed at the origin of the cell, at a distance of 3.24 Å from 12 oxygen atoms that form a cage around it, as has been predicted by Frondel and Ito (*2*). The recorded Cs—O distances for 12-coordinated cesium ions range from 3.28 to 3.42 Å (*3*), so that the distance reported by Buerger and Taxer is small for an atomic contact even if the substitution of smaller alkalis for cesium is taken into account. But, more important, the nature of the structure, which is a close packing of oxygen ions with boron, beryllium, and aluminum ions in tetrahedral and octahedral interstices, rules out a covalent or metallic bond treatment. In a clathrate structure such as Na_8Si_{46} (*4*) to which Buerger and Taxer refer, neutral sodium atoms are acceptable because silicon forms a covalently bonded framework. In rhodizite, on the other hand, we can see no reason why the formal valences should not be expected to add up to zero. All formulas of oxide minerals would have to be reexamined if neutral alkali atoms were found in rhodizite.

Two independent physical measurements can be made to test the hypothesis that neutral cesium atoms exist in rhodizite. In that neutral cesium has an unpaired electron, its presence should lead to absorption peaks on an electron-spin-resonance (ESR) spectrum. For the same reason rhodizite should be paramagnetic. When the ionic susceptibilities of Angus are used (*5*), the calculated magnetic susceptibility for the formula used by Buerger and Taxer, $(Cs_{0.47}K_{0.33}Rb_{0.17}Na_{0.03})B_{12}Be_4Al_4O_{28}$, is $+1.10 \times 10^{-6}$ emu/g.

Professor C. Frondel has given us some of the material from Manjaka, Madagascar, on which Buerger and Taxer determined the structure. Sioda obtained an ESR spectrum both at room temperature and at the tempera-

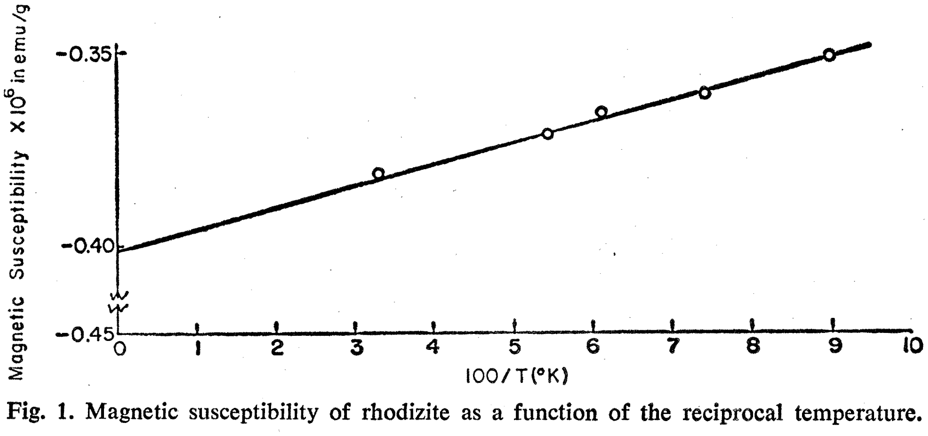

Fig. 1. Magnetic susceptibility of rhodizite as a function of the reciprocal temperature.

ture of liquid nitrogen with an x-band Varian spectrometer, a magnetic field of from 0 to 4000 oersteds, and a powder sample of 0.2 g. The work of Jen *et al.* (*6*) on ESR of alkali atoms in inert-gas matrices indicates that, owing to hyperfine interaction of the 6*s* electron of cesium with the magnetic field of the nucleus, cesium should give lines near 800, 2450, 4200, and 5700 oersteds. A few very weak lines were observed, but none were observed at these fields. It is thus unlikely that the observed lines are due to the unpaired electron in neutral cesium.

Measurements of magnetic susceptibility as a function of temperature have been made (by Thorpe) and show that rhodizite is diamagnetic rather than paramagnetic (Fig. 1). The experimental magnetic susceptibility at infinite temperature is -0.40×10^{-6} emu/g, a value in good agreement with the calculated value (*5*) of -0.44×10^{-6} emu/g for the following formula, and in better agreement with Ito's analysis (*2*), in which the alkali atoms are present as ions:

$$(Cs_{0.44}K_{0.31}Rb_{0.16}Na_{0.03}\square_{0.06})B_{11}Be_4Al_4O_{26}(OH)_2$$

The slope of the line of susceptibility plotted against $1/T$ does indicate the presence of a small amount of paramagnetic impurity. This slope corresponds to a magnetic moment of 0.19 Bohr magneton, whereas the magnetic moment of the unpaired electron in a neutral cesium atom would be 1.7 Bohr magnetons. The number of spins being proportional to the square of the moment, there are only $(0.19)^2/(1.7)^2$ or about 1.5×10^{-2} as many unmatched spins in rhodizite as there would be if neutral cesium atoms were present in the formula.

Ito (*7*) has confirmed that water is retained to a high temperature. The quantitative determination of OH^- is complicated by the concomitant partial loss of B_2O_3 on heating. Ito's recent analytical work, not yet completed, indicates that at least one, but less than three, hydroxyl groups are present instead of four as reported (*2*). The different values given in the literature for the atomic ratio of total oxygen to boron in rhodizite emphasize the analytical problem, namely, 2.70 (*8*); 2.64 or 2.50 (*2*); 2.33 (*1*). A formula such as $CsB_{11}Be_4Al_4O_{26}(OH)_2$ gives a ratio of 2.54. The calculated density for this formula and for $a = 7.319$ Å is 3.38 g/cm^3, as compared with 3.42 g/cm^3 which is the calculated density for the formula proposed by Buerger and Taxer. An experimental density of 3.45 g/cm^3 was obtained (by Donnay) on the Berman balance, in agreement with the value of 3.44 g/cm^3 reported by Frondel and Ito (*2*). To preserve the space group $P\bar{4}3m$ and Buerger and Taxer's structure, the proposed formula requires that 11 borons be statistically distributed over the 12 sites of position 12*h*, and that two hydroxyl groups be substituted randomly for oxygen atoms in one or more of the three oxygen positions. Extreme refinement is needed to detect disorder of such light atoms.

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References and Notes

1. M. J. Buerger, and K. H. Taxer, *Science* **152**, 500 (1966).
2. C. Frondel and J. Ito, *Mineral. Petrogr. Mitt.* **10**, 409 (1965).
3. *International Tables for X-Ray Crystallography* (Kynoch Press, Birmingham, 1962), vol. 3, p. 259.
4. J. S. Kasper, P. Hagenmuller, M. Pouchard, C. Cros, *Science* **150**, 1713 (1965).
5. W. R. Angus, *Proc. Roy. Soc. London Ser. A* **136**, 569 (1932).
6. C. K. Jen, V. A. Bowers, E. L. Cochran, S. N. Foner, *Phys. Rev.* **126**, 1749 (1962).
7. J. Ito, personal communication.
8. H. Strunz, *Mineralogische Tabellen* (Akademische Verlagsgesellshaft, Leipzig, ed. 3, 1957), p. 185.
9. We thank Prof. H. J. Silverstone for suggesting the electron-spin-resonance experiment and Prof. W. S. Koski for the use of his ESR equipment. We also thank Prof. Frondel for supplying the sample of rhodizite.

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Beach Cusps: Response to Plateau's Rule?

Beach cusps (Fig. 1), familiar to many frequenters of shorelines, occur along beaches that lie parallel with the approaching wave train. Characteristically, they appear (in plan view) as a remarkably evenly spaced, linear array of symmetric sinusoidal or deltoidal "horns," or low mounds, of seaward-projecting sediment, separated by equally symmetric crescent-shaped depressions, concave toward the sea. The beach sediment is commonly coarser on the cusps than in the intervening depressions between them. Cusps develop during recession of the water level, characteristically following storms, but also with falling tides.

The many descriptions and illustrations of beach cusps (*1*) generally agree as to their characteristic regularity, preference for relatively protected beaches little affected by longshore drift, sorting characteristics, and usual time of origin relative to storm and tidal conditions; and as to the fact that the spacing of cusps seems to be in some way related to the height of the waves. These descriptions also include discussion of details of the movement of water and sediment along and across the cusps and down the intercusp depressions, of the variation in size and spacing of cusps with change in wave height, and of their eventual disappearance.

What does not appear in any discussion known to me is a satisfactory explanation of the usual approximate regularity of spacing and the symmetry of these features. While investigating quite another problem, however, I stumbled on a possible explanation that may deserve further consideration.

This explanation derives from publications between 1843 and 1869 by the Belgian physicist and philosopher Joseph Plateau, who showed that, under esentially gravity-free conditions, a liquid cylinder becomes unstable when its length exceeds $2\pi r$, and that it then separates into subequal divisions whose lengths are proportional to the diameter of the cylinder (*2*). The ratio of the average length of individual segments to the diameter of the cylinder, however, also varies. For a cylinder of oil 4 mm in diameter in a mixture of alcohol and water of the same density, Plateau (*3*) found the ratio (segment) length : diameter to vary from 15.5 to 16.7.

A breaking wave, of course, approximates a cylindrical form and, at the instant of collapse, it may shoot forward a regularly spaced array of jets (*4*) that correspond to the segmentation of the cylindrical rim specified by Plateau's rule. Waves do not ordinarily break directly against the beach, but somewhat offshore as frictional drag against the bottom produces oversteepening and collapse. Where the profile of equilibrium has been steepened as a result of rearrangement of materials by storm waves or rising tide, however, the following waves may break directly against the beach, segmenting in regular fashion. If they are running straight