some of the photographs given as evidence for the existence of lake monsters.

In summary, many of the conditions under which lake monsters have been sighted are ideal for the existence of strong atmospheric refraction. A critical analysis of sighting reports and photographs could likely explain many of them as distorted images of familiar objects.

It is to be hoped that all future reports of monster sightings will include sufficient meteorological data, such as general weather conditions, air temperature, temperature gradient if possible, and water temperature. Then a reasonable assessment can be made of whether the observation can, wholly or in part, be attributed to anomalous atmospheric refraction.

It is not the aim of this report to discredit the existence of yet unidentified animals or species, for there is impressive evidence to the contrary from sonar data and underwater photography. Rather, the objective is to sharpen optical observation techniques and to provide one more stage of evaluation before accepting such observations as unequivocal evidence.

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References and Notes

1. R. T. Gould, *The Case for the Sea Serpent* (Philip Allan, London, 1930).
2. R. P. Mackal, *The Monsters of Loch Ness* (Swallow, Chicago, 1976).
3. An extensive literature exists. On atmospheric refraction, see texts such as J. M. Pernter and F. M. Exner, *Meteorologische Optik* (Braumüller, Vienna, 1922); M. Minnaert, *Light and Colour in the Open Air* (Bell, London, 1940); W. J. Humphreys, *Physics of the Air* (Dover, New York, 1964); H. R. Reed and C. M. Russell, *Ultra High Frequency Propagation* (Boston Technical Publishers, Cambridge, 1966). On image distortion see, for example, A. B. Fraser, *Appl. Opt.* **14**, A92 (1975); W. H. Lehn and H. L. Sawatzky, *Polarforschung* **45**, 120 (1975); W. H. Lehn and M. B. El-Arini, *Appl. Opt.* **17**, 3146 (1978); W. H. Lehn, *J. Opt. Soc. Am.*, in press.
4. The curvature of a nearly horizontal ray is approximately proportional to the temperature gradient. As an example, if the surface temperature is 0°C, an inversion with the relatively mild gradient of 0.11°C/m is sufficient to produce rays with the same curvature as the earth's.
5. See, for example, I. P. Koch, *Medd. Groenl.* **46**, 191 (1917); J. P. Koch and A. Wegener, *ibid.* **75**, 610 (1930). I have similarly made frequent observations of such zones of vertical distension.
6. P. Costello, *In Search of Lake Monsters* (Garnstone, London, 1974), p. 290.
7. I have observed and photographed numerous mirages on Lakes Manitoba and Winnipeg. One of the observations was made by chance while swimming in Lake Manitoba on a hot day (7 August 1976); a thin horizontal black strip appeared on the surface of the lake for a few minutes, at an apparent distance of 1 or 2 km. Experience dictated that the observation be attributed to atmospheric refraction, but very little help from the imagination would have been required to interpret the shape as a long black serpent. For a brief history of the Manipogo case, see Costello (*6*, pp. 229-232).
8. To estimate distances of this magnitude by eye is difficult enough in a normal atmosphere; to do it in the presence of refractive anomalies is virtually impossible [for example, see W. H. Hobbs, *Ann. Assoc. Am. Geogr.* **27**, 229 (1937)].
9. I have filmed such wavelike motion on Lake Winnipeg.
10. T. Dinsdale, *Loch Ness Monster* (Routledge & Kegan Paul, London, 1976), pp. 101-103.
11. For a camera height of 1.4 m, normal atmospheric conditions give a horizon elevation of about 2′ *below* the level.
12. Between 3:20 and 6:23 p.m., 22 exposures were made of this subject, each at a shutter speed of 1/250 second.
13. The photographs have been highly magnified, but not beyond the resolving ability of the unaided eye. Mackal (*2*, p. 205) gives the latter as 1/2′ of arc, and in a number of his cases the object observed subtended angles of this magnitude.
14. This work was supported in part by the University of Manitoba Northern Studies Committee, funded through the Federal Department of Indian and Northern Affairs, Ottawa, Canada.

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Reliability of Minor Planet Satellite Observations

Abstract. *In an examination of the reliability of occultation observations of minor planet companions, redundant photoelectric observations have been made of possible occultation events. These observations indicate that spurious events may be easily misidentified as true occultations, and that caution must be exercised in interpreting such occurrences. Further analysis of observations of the 1973 Pallas occultation suggests that earlier results may be unreliable.*

Although there are now several reports of minor planet occultation observations that support arguments for minor planet multiplicity (*1*), the evidence is as yet not conclusive. Only a single secondary body has been reported by more than one observer, the 532 Herculina event of 7 June 1978. Even that pair of observations is not ideal, since the visual observer recorded five unconfirmed and apparently spurious events and the photoelectric record of the remaining event was obtained when the asteroid was a mere 2° above the horizon (*2*).

There are, in fact, a number of circumstances which can produce spurious occultation observations. Drifting clouds, airplanes, and atmospheric turbulence may cause a sudden drop in brightness, while instrumental effects may also produce apparent events. Visual observations are necessarily subjective, producing no documentation which may be carefully examined and considered. Reports based on photoelectric observations are inherently more reliable since a quantitative record is obtained of the brightness of the star and minor planet. The reliability of a single observation is increased when the duration of the occultation event is significantly longer than the instrumental time constant and when the minor planet brightness is such that the signal during occultation is significantly different from either sky or asteroid-plus-star levels.

In an effort to study these spurious events, we designed a program for observation of the 28 February 1979 occultation of 13 Egeria in a manner which would provide redundant photoelectric data. The predicted occultation path passed near the U.S.-Canadian border, but observations made from nearly 1500 km away in Tucson, Arizona, still probed well within the gravitational sphere of influence of the asteroid. Three separate telescopes were utilized, each with its photoelectric photometer. The telescopes were all located along the same ground track of the occultation; one telescope (the Steward Observatory 21-inch reflector) was located on the University of Arizona campus, and two portable telescopes were located approximately 6 km west along the same occultation chord (*3*). Data were recorded for 10 minutes on either side of the predicted time of occultation. While the portable telescopes recorded several "occultations" each, most such events were noted as times when the star had wandered out of the measuring diaphragm and none were coincident. The data record from the fixed telescope showed two events which were not identified as guiding corrections but which were recorded as periods of constant brightness in the data from the remote locations. Thus, even these events are definitely of local origin (*4*).

The conclusion which we draw from this experiment is that singly observed occultation events are not uncommonly caused by instrumental or atmospheric effects. Only multiple photoelectric observations of events should be considered as firm evidence for minor planet satellites.

An example in which redundancy eliminated an otherwise plausible occultation event occurred during 11 December 1978 occultation by 18 Melpomene. Visual observations by P. McBride at Green Forest, Arkansas, suggested several brief "blinks," while B. Zellner, observing the event from within a few kilometers of the same occultation path, photoelectrically recorded no change in brightness (*5*).

We would like to discuss one reported occultation event in some detail. This event, the 6 February 1973 occultation of SAO 120836 by 2 Pallas, was observed

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from at least four locations and astrometric plates were obtained on the same night (*6*). Three groups reported an occultation [Calgary, Alberta, 6 seconds; Boulder, 38.3 seconds; and the High Altitude Observatory (HAO), uncertain, but consistent with Boulder], while a fourth group in Denver observed the appulse but recorded no occultation. The Boulder and HAO events correspond to occultation by an 800-km object, while the diameter of Pallas is accurately known to be no more than 560 km (*7*). The negative result at Denver was obtained at a distance of 47 km perpendicular to the Boulder path and is not reconcilable with either the Boulder or the HAO observation. The Calgary event is certainly not an observation of an occultation by the Boulder object, since the two stations are separated by 1400 km. The Boulder recording suggests a secondary component for the star, providing a possible explanation for the lengthy occultation. However, this interpretation actually increases the difficulties in reconciling the various observations, since the Boulder event suggests a brightness ratio of 2 to 1, while the Calgary observation requires a ratio of more than 5 to 1. An additional suggestion that the Boulder and HAO observations were spurious comes from the astrometric reduction of photographs taken from Las Cruces, New Mexico, which indicates that the main occultation event passed well to the north of the U.S.-Canadian border (*8*) (and presumably north of Calgary). The most satisfactory resolution of these contradictory results is the conclusion that the Boulder and HAO observations are not occultation events and that Calgary may have observed a short occultation. The observations are definitely not explained more satisfactorily by postulating a secondary body.

The case for minor planet multiplicity is being argued on the basis of the 532 Herculina event discussed above, a lightcurve behavior for several minor planets which is reminiscent of that of binary stars (*9*), and a number of single, unconfirmed reports of secondary occultations. So far, a majority of the unconfirmed observations appear to be spurious, and it is certainly premature to state that minor planet satellites are "both numerous and commonplace" (*1*).

It is not our contention that minor planet satellites do not exist but rather that the problem needs to be dealt with carefully and objectively. Certainly, many more reliable observations are needed before the frequency of such multiplicity can be discussed. Because of the experimental problems associated with occultation observations, we urge the use of redundant photoelectric observations of the type reported here (*10*). It is perhaps from lightcurves or direct imaging that the most reliable data will be obtained.

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References and Notes

1. R. P. Binzel and T. C. Van Flandern, *Science* **203**, 903 (1979).
2. E. Bowell *et al.*, *Bull. Am. Astron. Soc.* **10**, 594 (1978).
3. The 21-inch telescope was operated by W. B. Hubbard and W. Wisniewski, and portable 14-inch and 8-inch Celestrons were operated by H. J. Reitsema, D. M. Hunten, F. Vilas, and C. Stoll. These portable telescopes were located on the roof of a building at Pima Community College; the cooperation of the college personnel, especially B. Barber, was essential to the successful observations at that site.
4. The time delay between corresponding observations at the two locations is less than 0.1 second, eliminating orbital motion as an explanation.
5. D. W. Dunham, *Occultation Newsl.* **2**, 16 (1979).
6. The observations involved may be summarized as follows. The Boulder data were obtained by C. F. Lillie and E. Chipman [*IAU Circ. 2488* (1973)] with a portable 25-cm telescope having an approximately 80-arc second diaphragm (C. F Lillie, personal communication); they reported a 38.3-second event which had an abrupt beginning and end and showed a discrete change in brightness midway through. The HAO observation was obtained by G. Emerson [*IAU Circ. 2506* (1973)] through microphotometry of a photograph made with a 15-cm *f*/4 lens and indicated a beginning time consistent with the Boulder observation and an approximately comparable duration. The Calgary event [T. A. Clark, E. F. Milone, D. J. I. Fry, *IAU Circ. 2506* (1973); T. A. Clark and E. F. Milone, *J. R. Astron. Soc. Can.* **67**, 198 (1973)] was observed with a 40-cm telescope as a 6-second discrete feature (of 85 percent of the expected drop) superimposed on a modulation produced by telescope tracking error whose amplitude was greater than the expected occultation depth. K. A. Janes and H. J. Reitsema [*IAU Circ. 2094* (1973)] observed from Denver with a 51-cm refractor and recorded no event. It is our opinion that the low-noise data of the Denver event have highest weight and may not be ignored in a resolution of the observations of this event. Photographic plates of the appulse were obtained at New Mexico State University, Las Cruces, by C. Knuckles with the *f*/40 61-cm telescope.
7. L. H. Wasserman *et al.*, *Astron. J.* **84**, 259 (1979).
8. B. A. Smith, personal communication.
9. E. F. Tedesco, *Science* **203**, 905 (1979).
10. Similar caution is urged by D. Dunham [*Occultation Newsl.* **2**, 14 (1979); *Sky Telesc.* **57**, 272 (1979)].
11. The Lunar and Planetary Laboratory of the University of Arizona continues to develop its asteroid occultation program with the support of NASA. We will be pleased to coordinate future observations with other investigators.

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Stable Isotopes in a Mollusk Shell: Detection of Upwelling Events

Abstract. *The California mussel* Mytilus californianus *records with high fidelity annual temperature variations of nearshore waters in the oxygen isotope composition of its shell. The onset and termination of upwelling events (and metabolic activity) are recorded in the associated carbon isotope signal, and the magnitude and timing of upwelling can be estimated. The method has implications for studying the history of upwelling and the life history of living and fossil mollusks and for analyzing shell midden deposits.*

Coastal upwelling is of fundamental importance in the study of the physics, chemistry, and fertility of the ocean. Its intensity changes seasonally but there are also long-term changes on scales from decades to millennia as well as through geologic time (*1*). Mollusk shells are useful indicators of their environment of growth, through both morphology and chemical composition (*2, 3*). In particular, they record the range and successions of seasonal temperatures (*4*) and therefore provide time markers for the study of both physical and biological processes.

We show here how the $^{13}C/^{12}C$ ratio in mollusk shells can be used to detect the onset and course of seasonal upwelling during the time of shell growth. The implication is that dated shells can provide a glimpse of seasonal variations in upwelling over a number of years, within a given period in the past.

The signals recorded in epifaunal mollusk shells exposed to the open ocean are temperature (as oxygen isotope variation) and upwelling (as carbon isotope variation). Our sample is a modern shell of the California mussel *Mytilus californianus* from the shores of La Jolla, California. The seasonal variations of the temperature of growth of the mussel are known (Fig. 1A). Temperatures corresponding to the oxygen isotopic variations can be calculated from a paleotemperature equation (*5*) for comparison with the actual temperature measurements (Fig. 1B).

The seasonal course of upwelling in the region is reflected in the Bakun upwelling indices (*6*) (Fig. 1C). These indices are based on the sea-surface stress fields estimated from atmospheric pressure fields. Wind stress transports surface water offshore and causes this water to be replaced by the upwelling of deeper water. The stress field determines an Ekman transport field, the offshore-directed component of which is considered an indication of the amount of upwelling re-

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