to develop a model for the depositional environment of Precambrian iron formation stromatolites (*12*).

Photosynthetic flexibacteria have the essential characteristics required for stromatolite building: They are filamentous and capable of gliding motility, and so can trap sediment, and they will grow or move up through covering sediment toward the light. It is possible that some Precambrian stromatolites were built by bacteria, rather than cyanophytes or eucaryotic algae. Since bacterial photosynthesis does not release oxygen (*13*), correlations between the appearance of Precambrian stromatolites and the origin of an oxygenated atmosphere (*14*) may not be valid. This is particularly relevant in interpreting the Archean Bulawayan stromatolites of Rhodesia, the oldest known. The evidence previously used to indicate a cyanophytic origin for these stromatolites (*14*) is equally consistent with a bacterial origin now that photosynthetic flexibacteria are known. Here we are suggesting that organisms lacking the oxygen-releasing photosystem II could have built the Archean stromatolites, not that they were necessarily built by photosynthetic flexibacteria identical to those in Yellowstone.

The most abundant components of the famous Gunflint microbiota closely resemble the hot spring microbiota. The similarity in size and morphology of *Gunflintia minuta* Barghoorn and the photosynthetic flexibacteria and *Phormidium*-like cyanophytes is striking. The occurrence of *G. minuta* in stromatolites is used to support identification as a cyanophyte, although most authors note its resemblance to filamentous bacteria (*11, 15*). However, Licari and Cloud (*16*) report putative specialized cells (heterocysts and akinetes) from this fossil, and no similar cells are known from filamentous bacteria although they occur in cyanophytes.

The columnar stromatolites with conical laminae closely resemble the Precambrian form *Conophyton*. This was thought to have become extinct near the end of the Precambrian (*17*) and has been used to define the Proterozoic-Paleozoic boundary (*18*), although that definition was later found to be untenable (*19*). The Yellowstone form could be convergent with those in the Precambrian, but its close resemblance to some of them makes this unlikely. Particularly notable similarities are the banded microstructure, the irregular apical thickenings of the laminae, and the scalloped transverse sections of many columns. In these features and in size it resembles *Conophyton* cf. *garganicum* from the Sibley Group of Canada (*20*). Its columns are a little narrower than in that form, and much narrower than in most Precambrian forms. It has thinner laminae than any Precambrian *Conophyton* and cannot be equated with any described forms. Few, if any, Precambrian conophytons grew in hot springs. We predict that a careful study of fossil hot spring deposits will lead to the discovery of Phanerozoic conophytons.

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21. Supported in part by a research grant from the National Science Foundation (to T.D.B.) and by the Wisconsin Alumni Research Foundation. J.B. received a travel grant from the Australian-American Educational Foundation (Fulbright). We are grateful for the advice of R. W. Castenholz (University of Oregon). We thank the following persons for critically reading the manuscript: A. L. McAlester, G. Pannella, D. C. Rhoads, B. J. Skinner, and J. C. G. Walker (all of Yale University), H. J. Hofmann (Université de Montréal), P. E. Cloud (University of California, Santa Barbara), J. W. Schopf, Jr. (University of California, Los Angeles), and S. M. Awramik (Harvard University). The National Park Service kindly allowed research and collecting in Yellowstone National Park.

10 April 1972; revised 22 May 1972

Polar Motion from Laser Tracking of Artificial Satellites

Abstract. *Measurements of the range to the Beacon Explorer C spacecraft from a single laser tracking system at Goddard Space Flight Center have been used to determine the change in latitude of the station arising from polar motion. A precision of 0.03 arc second was obtained for the latitude during a 5-month period in 1970.*

A preliminary analysis of range data collected by a laser tracking station at Goddard Space Flight Center, Greenbelt, Maryland, during a 20-week period in 1970 indicates that the orbital inclination of the Beacon Explorer C spacecraft can be determined to a precision of better than 0.03 arc second from data collected over 6 hours. This result suggests that a single laser tracking system can measure changes in the position of the pole of rotation of the earth in the meridian of the tracking station to a precision of at least 1 m with a time resolution of ¼ day. The value of ultimately having high-precision, high-resolution information about polar motion is in its usefulness for understanding the dynamics of the earth and, in particular, the correlation between earthquakes and polar motion (*1*).

The laser at Goddard is a 1-joule ruby system with a pulse rate of 1 per second; it is capable of measuring the distance (ranging) to satellites equipped with laser reflectors (*2*). These measurements can be made during both day and night (weather permitting). Tests of the laser ranging systems and comparisons of independent stations have shown that the measurement reproducibility and the root-mean-square scatter in the range measurements is of the order of ± 30 cm (*3*). The satellite used in the experiment, Beacon Explorer C (BE-C), has an orbit with an inclination of 41.1°, an apogee of about 1300 km, and a perigee of about

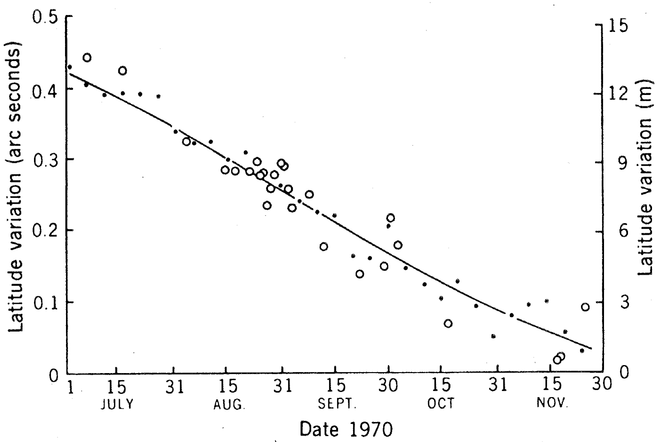

Fig. 1. The latitude of the laser tracking station at Goddard Space Flight Center, Greenbelt, Maryland (39°01′N), changed by 0.4 arc second during the experiment. The root-mean-square of the laser residuals to the smoothed curve obtained by the Bureau International de l'Heure (BIH) is 0.03 arc second. (Solid line) BIH smoothed curve, (filled circles) BIH raw values (5-day averages), (open circles) laser raw values (6-hour averages).

950 km. The latitude of the tracking station is 39°01′N, and since this is similar to the orbital inclination of the BE-C satellite, the station was able to track the satellite on four consecutive passes each day, covering a time span of about 6 hours. During the other 18 hours, the spacecraft was generally below the horizon from the station.

A typical pass of the satellite over the station lasts about 10 minutes, during which about 300 measurements of the range are obtained. During the tracking period we have been investigating, from 6 July to 30 November 1970, four consecutive passes of the BE-C satellite were obtained on 26 occasions, yielding a total of nearly 20,000 range observations. Through each of these 26 four-pass configurations we fitted an orbit in which the earth's gravitational field (*4*), complete through degree and order 12, was modeled, plus atmospheric drag (*5*), solar radiation pressure, lunar and solar gravitational perturbations, and the solid-earth tides. Because the motion of the satellite was predominantly from west to east with respect to the tracking station, the orbital parameter determined most precisely was the inclination. Furthermore, since changes in the latitude of the tracking station are reflected directly in the orbital inclination, a detailed analysis of the changes in the inclination of BE-C over a period of time could lead to the detection of polar motion in the meridian of the tracking station (*6*).

The values of the orbital inclination obtained from the four-pass orbital arcs showed large systematic variations caused primarily by the gravitational effects of the sun, the moon, and the solid-earth tides. After these were subtracted and a resonance with the thirteenth-order terms of the earth's gravitational field was removed, the resulting values of the orbital inclination showed an increase during the 4-month period of approximately 0.37 arc second. These values are shown in Fig. 1 as changes in the latitude of the Goddard laser. Also shown are the raw and smoothed changes in the latitude given by the Bureau International de l'Heure (BIH) (*7*). The root-mean-square of the differences between the laser values and the smoothed BIH curve is 97 cm, slightly less than 0.03 arc second, and the fit about a straight line through the laser data is 95 cm. The raw BIH positions are derived from observations made at up to 40 astronomical observatories using zenith telescopes.

In the analysis, the value of 0.25 was used for Love's tidal number k_2. This value was obtained by Anderle (*8*) from Doppler tracking of several satellites and by Douglas *et al.* (*9*) from optical tracking of the GEOS geodetic satellites. The value is somewhat smaller than the 0.3 obtained from surface measurements (*10*), but the lower figure appears to give a slightly better fit to our laser data. It is important to know the magnitude of k_2 because the tidal perturbation of the orbital inclination of BE-C leads to a full variation of about 2 arc seconds over a period of about 3 months. In the analysis, so far, no attempt has been made to determine the best value of k_2 that fits the data. Our results are also sensitive to the phase of the solid-earth tides. The initial calculations were all conducted with zero phase, so that the peaks of the tidal bulges are directly beneath the sun and the moon. When a phase lag of 2.5° was introduced into the tidal potential, a significant improvement, from about 0.05 to 0.03 arc second (1.54 to 0.97 m) was obtained in the fit of the laser values to the smoothed BIH curve. No other values of tidal lag have been tested, but an inspection of the latitude residuals suggests that the patterns that originally prompted the testing for phase dependence have not yet been entirely removed. It is possible that the apparent phase lag is the result of not having used the correct value of k_2, and a new determination of k_2, and possibly of the phase lag, should be made.

We have found that the basic quality of the laser data is good. There has been no indication in the data analysis that any of the 26 four-pass orbital arcs is suspect. The largest latitude residual is only 1.7 times the root-mean-square, or about 160 cm. From data spans of 6 hours, the latitude of the station has been determined to a precision of better than 1 m for a period of nearly 5 months. This is probably the shortest averaging time over which the position of the pole has been determined with such precision.

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3 July 1972