MOON HISTORY

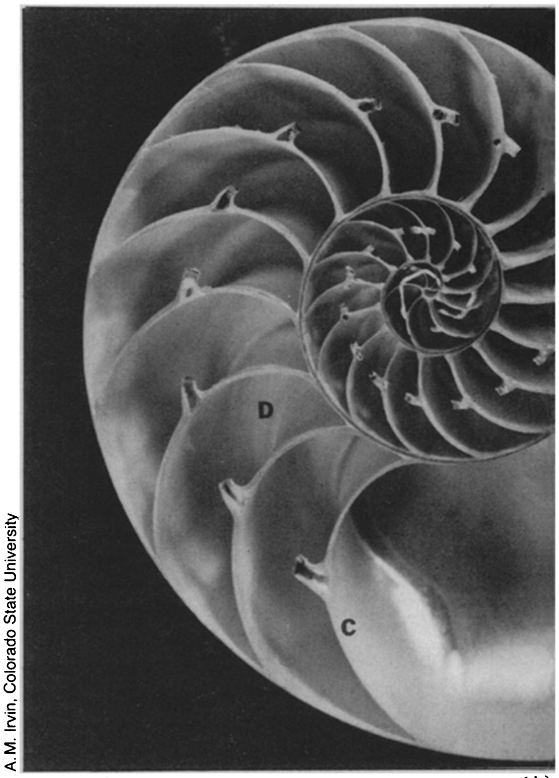
The birth of a theory, like the birth of a nation, is often fraught with controversy. A case in point follows.

BY SUSAN WEST

Soon as the evening shades prevail,
The moon takes up the wondrous tale,
And nightly to the listening earth
Repeats the story of her birth.
The Spectator
Joseph Addison

Would that scientists had ears tuned to the moon's nightly account. The ruler of tides, a symbol of fertility, the cycle of life and death captured in its phases, the earth's stark satellite remains silent. Scientists have spun something of its wondrous tale from ancient eclipse data. Such records, dating back 3,000 years, suggest that the grinding of tidal forces has slowed the earth's rotation at a rate of two seconds every 100,000 years and weakened its tug on the moon. Taking advantage of the situation, the moon is thought to be slipping away at a current rate of about 5.8 centimeters per year. Based on these findings and for lack of other data, scientists have assumed that the moon's orbit has expanded at a constant, predictable rate. Now, one theory suggests that such is not the case — that the rate has varied unpredictably and radically. According to this theory, the current calculated rate may be an anomaly of the last few thousand years, but prior to that, for the previous 70 million years, the moon has fled the earth's grip at an average rate of 94.5 centimeters per year — 17 times the rate based on eclipse studies. Prior to 70 million years ago, say Peter G.K. Kahn and Stephen M. Pompea in the Oct. 19 NATURE, the rate of lunar orbital expansion varied considerably. The variation, they say, depended on the changing forces exerted on the moon as the earth's continents formed and separated and as the oceans rose and fell. Such conclusions alone are startling, but it is the means by which Kahn and Pompea reached them that has raised scientific eyebrows and, in some cases, ire.

The catch is that Kahn and Pompea base their theory on the chambered nautilus, a shelled cousin of the octopus. Characteristic of mollusks, the nautilus secretes its shell gradually. Distinct lines or ridges on the outside of the shell mark its growth. In addition, as the nautilus grows it moves forward in its enlarging spiral coil and produces partitions, or septa, to seal off the abandoned chambers behind it. Kahn, on leave from Princeton University at the Free University of Berlin, and Pompea, currently teaching in Colorado Springs, Colo., noticed that in present-day nautiloids the number of growth lines between two septa appears constant. They counted an average of 30 lines per chamber; a number, they noted, that correlates well with the length of the present lunar month — 29.53 days. Based on this observed correlation, Kahn and Pompea suggest that the growth lines visible on the animal's shell may be produced at a rate of one per day and that the septa may be laid down one per lunar month. In other words, they believe the animal may be a biological clock.



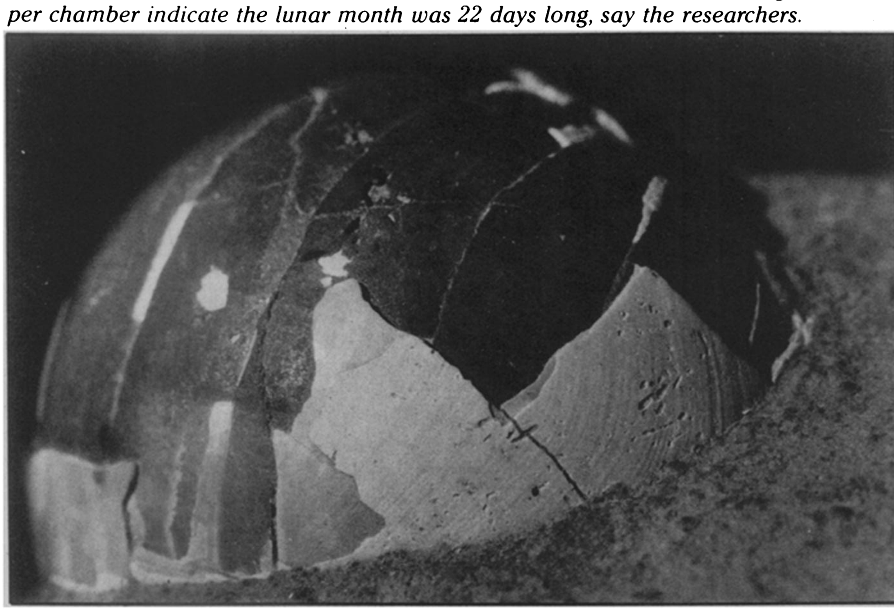
A. M. Irvin, Colorado State University

Cross section of a nautilus shell showing (A) secreted; (B) chamber where animal lives;

If this is so, the investigators note, then the lengths of ancient lunar months can be read from fossil nautiloids. More important, the distance to the moon can be calculated from the length of the lunar month. The nautilus, they suggest, might have tracked the history of the moon's retreat from the earth. The researchers examined fossil nautiloids dating back 420 million years from a range of species and locations. For any given geologic time, they found all species from all locations showed a similar number of growth lines. They also found a gradual, though not steady, decrease in the number of lines per chamber with age, a finding consistent with a closer and more rapidly revolving moon. If Pompea and Kahn are correct and the nautilus does show a lunar growth rhythm, their conclusions may stir up a decade-old controversy and cause astronomers and paleontologists alike to recheck their data.

Could it be? Such a lovely theory: An exquisite sea creature mindlessly trapping in its pearly spiral the secrets of earth's cold companion. It seems a satisfying mix

A 69.5-million-year-old South Dakota cousin of the modern nautilus. The 22 growth lines per chamber indicate the lunar month was 22 days long, say the researchers.


Irvin/CSU

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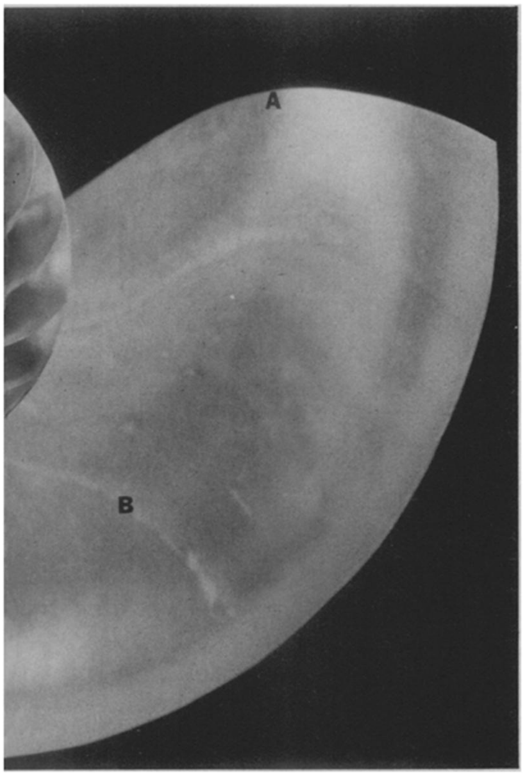
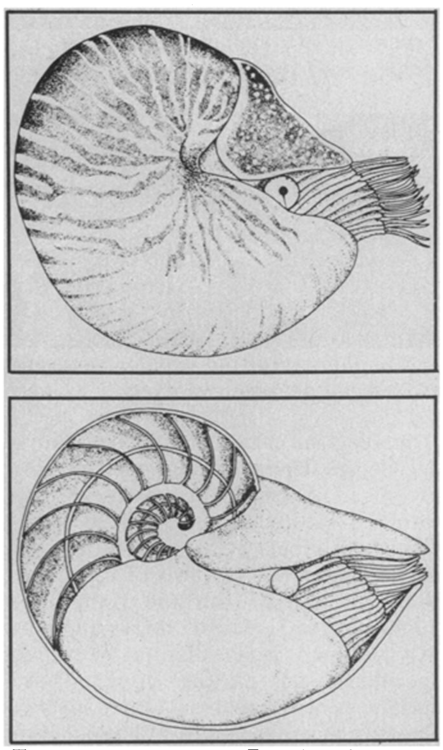
IN A SEASHELL



shell opening where growth lines are (C) septum; (D) chamber.

of imagination and empiricism; a mating of science and mythology. But that's just the problem, according to the theory's detractors. Says one skeptic: "It's a can of worms." But what is science without daring?

The idea is not new. In 1963, John Wells published "Coral Growth and Geochronometry." He proposed that animals such as corals deposit daily rings of exoskeleton and that the rings cluster into yearly growth bands. Simply by counting the growth bands, then, the age of any specimen, fossil or living, could be found. When Wells counted fossil corals from the Devonian period (about 350 to 400 million years ago), he found about 400 days per year. He pointed out that this figure agreed with the number of days in a Devonian year obtained by back-projecting the accepted current rate of deceleration of the earth's rotation. When geophysicists realized the implications for studying the history of the earth-moon system, they took the fossils and ran. Caught in the fever, researchers tried for several years to establish lunar or solar growth rhythms in bivalve mollusks such as clams, in stromatolites (fossil remains of blue-green algae and bacteria) and in other shallow-water species. Soon, the uncritical use of data, the use of incomplete sequences, the subjective counting methods and the lack of statistical testing brought criticism. Moreover,



The nautilus at home. Exterior view, above; cutaway, below.

the central hypothesis — that growth lines are faithful records of some environmental periodicity — remained untested. Burned by such reviews, most paleontologists interested in growth rhythms have concentrated since the early 1970s on discovering the causes of growth lines and on establishing standard methods for analyzing their samples and results.

It is for raising a tainted specter that Kahn and Pompea may feel their colleagues' wrath. Says Ida Thompson of Princeton University, "Papers like this perpetuate the idea of growth line research as a cultish business." Thompson's own research (SN: 11/26/77, p. 360) has established that growth bands on clams are annual and that the widths of the bands are controlled by ocean conditions such as temperature and dissolved oxygen. Her criticism of the work, which has been submitted as a letter to NATURE, stems from personal knowledge: Kahn did some of his research while a graduate student at Princeton and part of it was done under her supervision.

Foremost, Thompson says, no evidence exists that the nautilus deposits one growth line per day or that it produces one septum every 30 days. In fact, very little research at all has been done on the nautilus. A bottom-dwelling creature, once ubiquitous but now represented by only six species found in the southwestern Pacific Ocean, the nautilus has successfully eluded the laboratory and the researcher's probe. However, Thompson points out, the most current available research by Arthur Martin of the University of Washington in Seattle indicates that the animal may make one line every two days, and that even this activity may be irregular.

Even so, Pompea says, some aspects of Martin's work support their theory. For instance, while the nautiluses were in captivity, Martin and his co-workers noticed a sudden periodic increase in weight, which they associated with the formation of a septum. While Pompea believes the apparent 30-day periodicity gives their theory credence, Martin says the data were too irregular to draw that conclusion. At any rate, as both Martin and Pompea point out, Martin's study is by no means conclusive: The aquarium conditions, including a water temperature of 24°C rather than the usual 12°C, may have caused abnormal shell growth.

However, other independent data indicate even longer and more irregular intervals between septum growth. According to Bruce Saunders of Bryn Mawr College, when a nautilus prepares to build a new septum, it moves forward and secretes the septum behind it while supported by a cushion of fluid. When the septum is finished, the nautilus pumps the fluid out of the abandoned chamber via a tube that runs through the spiral shell. The interval between septum building must therefore be related to the time required to drain the fluid, says Peter Ward, one of Martin's coworkers from the University of California at Davis. Ward says, based on his experiments, that draining the fluid takes 36 to 52 days, significantly more time than the days in a lunar month.

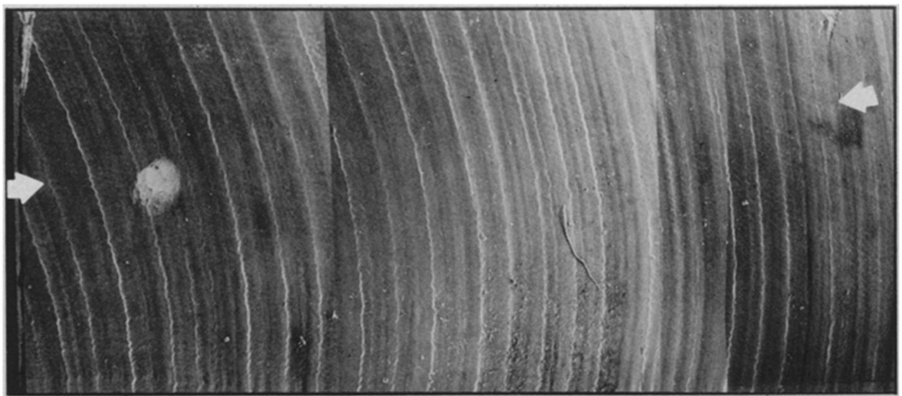
A related criticism voiced by Thompson and others is the implication of an association between the formation of the growth lines and the formation of septa. The growth lines are produced at the opening of the shell; the septa form nearly half a revolution behind the opening. "A span of months separates the deposition of a chamber wall and the growth lines counted for the chamber," admit Pompea and Kahn. "It's like examining something that happens in the locomotive of a train and relating it to something 18 cars back," says George Clark, a growth rhythm researcher at Kansas State University. Still, Pompea maintains, the septa are placed at convincingly regular intervals.

Even if critical experiments show growth lines and septa to be produced regularly, their formation may not be related to the lunar cycle at all, the paper's critics point out. The touchstone for establishing geophysical rhythms in any creature is finding the biological activity that might be tied to the solar or lunar cycle.

However, most animals that do show lunar rhythms, such as tide-related activity, are shallow-water species, points out John Arnold of Pacific Biomedical Research Center in Honolulu, Hawaii. Arnold has studied the nautilus in its habitat from the vantage of the National Science Foundation's floating marine physiology laboratory, the *Alpha Helix*. While moon-induced environmental changes may figure prominently in the survival of shallow-water organisms, the nautilus has adapted to the stable environment of the ocean bottom, he says. It would have little cause, for feeding or protection, to adapt itself to external cues. Nevertheless, some features of the nautilus suggest that it may link its behavior to the light of the moon. Most notable are its quite sensitive, though simple, "pinhole camera" eyes. Pompea speculates, and Martin agrees, that, for the sake of its eyes, it may rise to hunt by the soft light of the moon and scuttle to the dark depths by day.

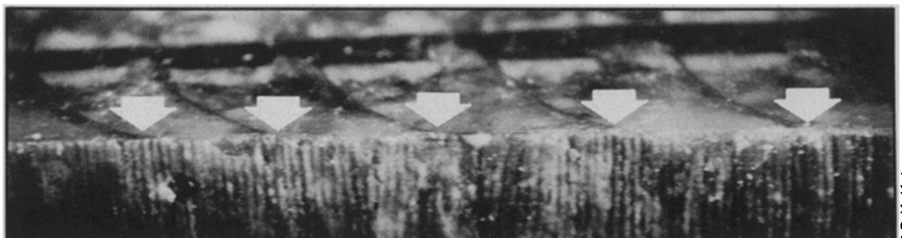
Even so, say Thompson, Martin and others, no research exists to suggest a mechanism for lunar cycle-triggered septa formation. Pompea has a suggestion—just speculation, mind you — that the nautilus may be more vulnerable while building its septum and it may prefer the darkened nights of the new moon to conceal its periodic home renovations.

Establishing a solar-triggered, or daily, activity seems more straightforward. A recent theory on molluscan shell growth proposed by Donald Rhoads and Richard Lutz of Yale University implies that growth lines may result from shell deposition and dissolution during aerobic and anaerobic respiration, respectively. Pompea and Kahn speculate that the nautilus may show similar behavior, respiring aerobically and depositing its shell by night as it feeds in shallow water and dissolving the shell during daily anaerobic respiration on the ocean bottom. However, in his recent work Martin rather inadvertently found strong evidence that the animals deposit their shells by day. As he cleaned the tank or jostled the nautiloids in the course of other work, he found them steadfastly clinging to a stable object with the mantle, the shell-secreting organ, extruded over the shell opening.



P.G.K. Kahn

Scanning electron micrograph of growth lines on the outer shell of a present-day nautilus, showing two-thirds of one chamber.



P.G.K. Kahn

A 326-million-year-old nautiloid showing 15 growth lines per chamber. The arrows mark septa between chambers.

Echoing the criticism of similar work a decade ago, Thompson also questions the investigators' choice of specimens. She warns of the pitfalls of choosing specimens to fit a theory. Others agree. According to Alfred Fischer, also of Princeton, who encouraged Kahn and Pompea to publish but says some of the assumptions may be open to question, some of the specimens "fall off the curve." Those specimens, which represent three species, show evidence of modes of life different from those of other fossilized and modern nautiloids, Pompea says. In addition, they show integral multiples of the expected number of growth lines, rather than single lines. Rather than risk comparing apples and oranges, Pompea argues, the specimens were eliminated from the data although they are discussed in the paper. As for other specimens, the only criterion, the researchers say, was the "best preserved fossils" — unbroken fossils in which the growth lines were not obscured by ribbing or ornamentation and which show at least seven chambers and the original mother of pearl. Pompea notes that, in terms of the number of specimens examined, theirs is the most extensive study of growth lines. "There wasn't really a choice — we took every specimen we found," he says. Few paleontologists do better, says Rhoads. "They have done as much as one could working with shell material. You can never prove anything in the fossil record, you can only gather enough to say 'Hey, look, this is more than likely.' And that's just what they've done."

Another traditional criticism confronts Kahn and Pompea: the accuracy and reliability of their growth line counts. Thompson and another researcher, who asked not to be named, said their own counts of some of the same specimens do not jibe with those in the paper. It's all in the method, says Pompea, who believes he and his co-worker have hit on the most reliable means of counting. Researchers commonly use light microscopes, graphite "rubbings," or, like Thompson, acetate peels—acetate painted on a specimen and peeled off as a replica of the specimen. Kahn and Pompea's better mousetrap is the scanning electron micrograph. Pompea says — and he and Kahn are preparing a paper to this effect — the excellent contrast of the micrographs will allow researchers to better define and distinguish growth lines.

Geophysicists, on the other hand, are not too concerned with intradisciplinary squabbling. Tom Van Flandern of the U.S. Naval Observatory says of the work, "It seems very reasonable — it presents the adverse as well as the favorable evidence." Though he sees some problems with the actual calculations, he says, "It confirms my own suspicion that the rate [of expansion of the moon's orbit] was not strictly uniform."

Few researchers who talked to SCIENCE NEWS are ready to throw out the theory. Because of a lack of astronomical data, Van Flandern says, such studies should not be discounted—"They may indeed be giving the true story."

Kahn and Pompea, a paleontologist and an astronomer, respectively, see cross-disciplinary studies as the best means of probing such problems. And if their theory creates a little controversy, so much the better; it may spur new research. As Fischer puts it, "I think it's great. It stirs up the pot." □