IS THE SUN AN AGE INDICATOR?

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Abstract

Questions on the age of the sun necessarily hinge on how it produces its enormous energy. Long-age evolutionists favor thermonuclear fusion, the only known process that could last for billions of years. Young-age creationists counter that the evidence for fusion is scanty at best, and many have readily adopted data which seems to show that the sun is shrinking. If so, it could be heating itself by gravitational collapse instead of fusion. However, such data is probably in error, and, in any case is so much larger *than the rate actually necessary to produce the sun's heat as to be irrelevant. The sun may be heated by gravitational collapse, by fusion, or a combination of both—there is simply not enough evidence to tell. The sun is therefore not an age indicator one way or the other.*

Introduction

In 1979, noted astronomer John Eddy of the Harvard-Smithsonian Center for Astrophysics and High Altitude Observatory in Boulder, Colorado, and Aram Boornazian, a mathematician in private practice, made a dramatic announcement: the sun is shrinking. By analyzing measurements of solar transits made at the Royal Greenwich Observatory since 1836 and the U.S. Naval Observatory since 1846 (for the original purpose of determining exactly when is high noon), they calculated that the sun is apparently shrinking at the rate of 5 ft/hr in diameter (0.1% per century, 2 arc-sec/century). When they considered more tenuous data from observations of solar eclipses for the past four centuries, they saw some evidence for a longer term solar contraction. They pointed out that such a contraction could produce a significant portion of the sun's luminosity (Eddy and Boornazian, 1979; Lubkin, 1979).

For those committed to a view of the sun as several billion years old, and for those who accepted Eddy and Boornazian's interpretation of the data, this was seen as only part of a long solar cycle or pulsation. Such a large rate of contraction could obviously not be maintained for long, they reasoned, and so a cyclic change was assumed. Actually observed solar cycles range from five minute oscillations to, perhaps, several centuries in the case of sunspots. Some are regular, but some are irregular coughs and sputters. Eddy laments, "I don't think that such irregularity is a mark of health. I think it's the mark of a shaky, rickety machine" (Bell, 1978).

Some young-age creationists, on the other hand, eagerly accepted the initial report, including Akridge, 1980; Hanson, 1981; Hinderliter, 1980a, 1980b; Steidl, 1980; Taylor, 1984; Chaffin, 1987; Barnes, 1987; Benton, 1987. They used it as evidence that the sun generates its heat not by thermonuclear fusion but by gravitational collapse, and hence cannot be more than 30 million years old (Appendix A-C). Some (e.g. Akridge) also used the uniformitarian's favorite cliche, "The present is the key to the past" to extrapolate the 5ft/hr rate backwards and obtain a time when the sun would have engulfed the earth. This was on the order of 20 million years ago, and would also set an upper limit to the age of life on the earth that is obviously much less than evolution requires. Had this been done merely to poke fun at the evolutionist's most sacred principle, all would have been fine. But using the data as serious evidence for a young sun, and hence a young solar system and earth, is not valid.

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Problem Analysis

There are three main problems with placing undue emphasis on solar diameter measurements. Each of these will be discussed in detail.

1. Eddy and Boornazian's results are suspect.

A number of other observers do not accept Eddy and Boornazian's conclusions. They do so on the basis of other historical data (e.g. transits of Mercury), and a reanalysis of the Greenwich data, which was gathered using several different instruments by different observers at different locations (Gilliland, 1981; Brown, 1982; Labonte and Howard, 1981; Sofia *et al.*, 1985; Parkinson, 1983; Parkinson *et al.*, 1980; Endal and Twigg, 1982; Krasinsky *et al.*, 1985; Dunham *et al.*, 1980; Shapiro, 1980; Sofia *et al.*, 1979; Ribes *et al.*, 1987; O'Dell and Van Helden, 1987). Some of these writers suggest a slight contraction of the sun, but most see no real change. Eddy and Boornazian themselves have been silent on the matter, neither retracting nor defending their results. Accordingly, the controversy they stirred up seems to be settling down. From 1984 through mid-1988, their original articles have been referred to only four times in non-creationist scientific literature, according to the Citation Index. These are articles by Dransinsky *et al.* (1985), Sofia *et al.* (1985), Ribes *et al.* (1987), and O'Dell and Van Helden (1987). Eddy has not referred to his articles since their publication (again, according to the Citation Index). Even if the initial report had been accepted by everyone, creationists would still not be justified in applying the gross extrapolation the uniformitarian principle entails to those results and then proclaiming "proof" of a young earth.

Because of Eddy's prestige within the astronomical community, attention has been given not only toward reanalyzing historical data but also to gathering current measurements of the solar diameter (Lites, 1983; Rosch and Yerle, 1983; Sofia *et al.*, 1985; Morrison *et al.*, 1988) Methods of measurement are being standardized, special instruments have been developed, and more accurate results should be available in coming years.

The sun diameter topic has been complicated by the efforts of some to caricature creationists. For example, Van Till (1988) has titled solar changes as a false "legend" which creationists alone continue to believe and perpetuate. Three comments are in order: First, the point is well taken, but it goes entirely too far. As the list of references shows, discussion of solar changes still remains active both in creationist and in secular science. The question of solar changes has not been settled as completely as Van Till implies. A science topic which is less than 10 years old certainly does not deserve the term "legend." Second, creationists have always shown a diversity of views concerning the solar diameter problem. *Third*, it is unfair to connect the creation view with the word "legend." This seems to reveal a hidden agenda of maligning the Biblical foundation of creationism.

2. The suggested rate of solar diameter change is irrelevant to theoretical gravitational contraction.

If the sun were slowly shrinking, each particle as it fell inward would release gravitational potential energy as heat. This heat would be radiated away to space, thereby lowering the temperature, reducing the supporting pressure, and allowing the cycle to begin again with more contraction. The theoretical rate of gravitational collapse necessary to produce the sun's current luminosity has been known for a long time. Its principles were worked out by Helmholtz (1854) and Kelvin (1861). All the sun's current heat could be produced by a contraction rate of only .02 ft per hour (Appendix B), some 250 times *less* than Eddy and Boornazian's rate. They were aware of this, and therefore suggested that only a thin outer shell is contracting, with the massive interior staying at constant diameter. Some creationists (Akridge, 1980; Hinderliter, 1980b; Steidl, 1979) have readily adopted this view. It enables them to keep the suggested contraction rate (which throws the evolutionist's long time scale into jeopardy) without over-heating the sun. But it is plainly an *ad hoc* hypothesis, since the only reason it is put forth is to reconcile Eddy and Boornazian's interpretation of the data with the theoretical contraction rate. It is certainly speculative to (1) extrapolate the questionable 5 ft/hr rate (2) in a straight line manner (it should vary inversely as the radius) (3) for vast lengths of time, as Akridge has done (even though he qualifies his reasoning).

The theoretical gravitational collapse rate of .02 ft/hr (at the present value of the diameter) is much too small to be seen, if indeed it is occurring. It will be *centuries* before a new generation of instruments, sophisticated though they are, gather enough information to pass judgment. The reason is that a rate of .02 ft/hr, or 3 miles/century, amounts to only .007 arc-sec/century, an extremely small change. The best ground-based instruments are limited for this purpose to about .25 arc-sec of resolution. Satellites may do somewhat better in the future, but there is probably enough inherent uncertainty in determining the "edge" of a hot, active ball of gas to preclude definitive contraction measurements of this magnitude for generations to come. Even if the 5 ft/hr rate were true, that is still only 2 arc-sec/century, a rate that would take many decades to verify, especially if there really is an 80-year cyclic variation in diameter, as Parkinson (1983) claims.

Creationists have *always* been justified in pointing out that gravitational collapse *could be* providing the sun's heat. Theoretically, it could have been doing so for up to 30 million years (Appendix C). The creationist can easily live within this constraint, but the evolutionist requires much more time. He must come up with another source of energy. The question both must now ask is, Is there any other possible source of energy? The answer appears to be, yes, it is probable that hydrogen fusion is energizing the sun.

3. Theory and observation indicate that thermonuclear fusion is probably working in the sun.

Calculations show that the interior of the sun experiences an extremely high temperature and pressure which should force nuclear fusion to occur (Appendix A). In addition, a "laboratory experiment" that shows fusion actually is possible is the hydrogen bomb. These two lines of reasoning can be used to say the sun could be burning hydrogen. But is there any evidence that it actually *is?* The answer is a fairly certain, yes.

It is generally conceded by creationists and evolutionists that a byproduct of fusion reaction, the neutrino, is detected on earth. However, the evidence is equivocal, since the neutrino signal is barely above the background noise, and is only a fraction (usually put at 1/3) of what it should be. These well known "missing neutrinos" are seen as a major problem of modern solar physics (DeYoung, 1987 p. 64; Zeilik and Smith, 1987 p. 276; Waldrop, 1985; Gingras, 1987). In addition, the faint signal is nondirectional. Sensitive experiments are now underway to determine if the signal is indeed directed from the sun. Results are expected within two or three years.

Of perhaps greater promise is the proposed test to detect low-energy neutrinos (Hudson, 1987; Perkins, 1988), which the present experiments cannot detect. By conventional theory, they should be produced by nearly all of the basic proton-proton chain reactions, whereas the high-energy ones actually detected are produced by only .02% of the reactions. There should therefore be more of the low-energy variety, and their detection from the sun's direction would be virtual proof that hydrogen fusion is powering the sun. Conversely, their lack of detection would be strong evidence that fusion is not powering the sun. Low-energy neutrinos will occasionally interact with gallium to produce germanium, so scientists have gathered much of the earth's meager supply of gallium and concentrated it in two detectors. One is in the Soviet Union and the other in Western Europe. Both are due to start in 1989. Another type of neutrino detector, using heavy water, is in the planning stage (Aardsma, 1987). The instrument will be able to measure the direction of incoming neutrinos, an important factor in the solar neutrino question.

The missing neutrinos have obviously sparked a great deal of international interest. Maddox (1988) comments, "However this tale turns out, it will remain a marvel that so much work, experimental as well as theoretical, has been stimulated by a single discrepant observation." As if the present data has not already caused enough trouble with standard solar theory,

there has recently emerged yet another intriguing speculation on the mysterious neutrinos. Maddox (1988) writes,

> Now there has arisen a further source of distraction in a field already sufficiently confused—the possibility that some of the conversion of chlorine to argon nuclei observed originally by Davis may be driven not by neutrinos from the core of the Sun, but by solar flares. The suggestion appears to have been made last year by Davis himself, based on an apparent correlation between records of the Homestake equipment and the presence of flares on the Sun . . . Evidently, if this speculation were correct, the discrepancy between the expected and measured fluxes of neutrinos from the Sun would be further magnified.

However, Maddox goes on to say that other detectors have found no such correlation between solar flares and neutrinos.

There may be a correlation between sunspot number, apparent semidiameter of the sun, solar irradiance, and neutrinos. If so, ". . . then it is almost inevitable that the nuclear reaction rates in the core are varying with the cycle" (Gough, 1988). What further modifications in fusion theory this may require has apparently not yet been explored. The neutrinos that are now detected, then, are evidence for both sides of the solar energy question. The evolutionist says they show at least some of the sun's heat is produced by fusion, while the creationist says that, if they even exist, they show only that some other source, i.e. gravitational contraction, accounts for most the sun's energy.

It is worthwhile to note in passing what the evolutionist considers his strongest evidence for fusion: ". . . *gravitational contraction* can sustain the Sun at its present luminosity for only 15 million years; some other energy source must be sought if we are to account for billions of years of sunshine" (Zeilik and Smith, p. 274. italics theirs).

> Now, life has existed on Earth for more than three billion years . . . and during that interval, at least, the Sun must have been shining more or less stably with a luminosity close to its present value (Shu).
>
> Geological evidence, however, indicates that the terrestrial crust has an age of several billion years, and it is surely to be expected that the Sun is at least as old as the Earth . . . We must conclude that, although gravitational contraction may play an important role during short phases of stellar evolution, another source must be responsible for most of the energy output of a star (Novotny, p. 248).

Other Solar Energy Considerations

As further evidence against fusion, and for contraction, Steidl (1980) mentions what is now famous in solar physics as the 160 minute oscillation. This was detected via Doppler shifts of the solar surface which were interpreted as radial pulsations. The long period implies conditions in the sun's interior which do not fit into modern solar theory. (Deep shock waves would efficiently transmit energy, setting up a lower temperature gradient.) The discoverers say bluntly, "The interpretation of this phenomena seems to cause much theoretical difficulty" (Severny *et al.*, 1976).

However, the 160 minute cycle is not universally acknowledged. Woodard and Hudson (1983) and van der Raay (1980) have not found it, and Hudson has recently said, "Following its initial apparition . . . the 160 minute oscillation has remained elusive both theoretically and also observationally" (Hudson, 1987). The following papers from the majority who do accept the 160 minute oscillation and attempt to explain it will aid those interested in pursuing this new science of "helioseismology" and its implications: Severny *et al.*, 1976; Hill *et al.*, 1986; Grec *et al.*, 1980; Isaak, 1982; Claverie *et al.*, 1981; Delache and Scherrer, 1983; Scherrer and Wilcox, 1983; Ando, 1986.

Steidl (1980) lists "one final consideration," which is important. He cites Cameron, an astrophysicist with Harvard University and the Smithsonian Institution, who calculated the maximum temperature obtainable by the standard evolutionary collapsing gas cloud theory of star formation as one million degrees Kelvin, or much too cool to initiate hydrogen fusion (Cameron, 1976). Steidl has a valid point. Whenever and wherever evolutionists start talking about origins they are quickly in deep trouble. But with their sacred philosophy, they usually just shrug their way out of it, as Cameron does here:

> The existence of this large uncertainty about the way in which nuclear reactions turn on in the sun is an indication that the pre-main sequence evolution of the sun is not presently understood.

This natural origin problem is a strong testimony to the supernatural creation of the sun. The question we are addressing, however, is not one of origins but one of operation. For that, we need only do some simple calculations to arrive at a solar core temperature of 12 million K, which (with the help of quantum mechanics) should be enough to sustain hydrogen fusion (Appendix A).

Conclusion

The evidence, whether from analysis of historical data, theory, or observation, is not conclusive as to how the sun heats itself. We can say only that the sun *may* be shrinking, not that it definitely is.

APPENDIX A

The following theoretical analysis of the sun's interior follows that given in introductory astrophysics texts; for example, *Astrophysics* (DeYoung), *Introductory Astronomy and Astrophysics* (Zeilik and Smith) and *Introduction to Stellar Atmospheres and Interiors* (Novotny).

Calculation of the sun's central pressure (P_c):

Assumptions:

a) The ideal gas law applies throughout the sun. This seems reasonable since the surface, which is certainly much cooler than the interior, is 6000 K, well above the boiling point of any element. In addition, hydrogen and helium make up 98% of the sun's mass.

b) The equation of hydrostatic equilibrium applies. This is the basic equation for any atmosphere, and it

seems reasonable to assume it describes the balance between the inward gravitational force and the outward gas pressure force. For a star the size of our sun, the outward radiation force may be neglected for an order of magnitude calculation.

Hydrostatic Equation $\frac{dP}{dR} = -\rho g$

P = pressure
R = radial distance
ρ = density
g = gravity acceleration

As an approximation, let $\frac{dP}{dR} = -\frac{P_c}{R}$

P_c = pressure at core of sun
R = radius of sun
$= 7 \times 10^8$ meters (m)

Surface gravity, $g = \frac{GM}{R^2}$

$= 273$ m/sec^2

M = solar mass
$= 2 \times 10^{30}$ kilograms (kg)

$G = 6.67 \times 10^{-11} \frac{\text{newtons} \cdot \text{meter}^2}{\text{kilogram}^2}$

Solar density, ρ = mass/volume
$= 1410$ kilograms/meter^3

Core pressure, $P_c = \rho g R$
$= 3 \times 10^{14}$ nt/m^2
$= 3 \times 10^9$ earth atmospheres

Once the pressure is known, it may be used to estimate the temperature (T):

Ideal gas law $P = nkT$

n = number density of particles
= particles/m^3
$= \rho/\mu$
μ = average particle weight
$\simeq$ .5 amu, since the sun is mostly ionized hydrogen
k = Boltzmann constant
T = absolute temperature

Therefore, $T = \frac{\mu P}{\rho k}$

$= 12 \times 10^6$K

APPENDIX B

Calculation of the theoretical (Helmholtz-Kelvin) gravitational contraction rate.

1. Potential Energy, PE

The total solar PE may be estimated by imagining each solar particle as falling from infinity to the solar surface:

$PE = \int_{\infty}^{R} \frac{GMm}{R^2} dR$

$= -\frac{GMm}{R}$

$= 3.8 \times 10^{41}$ joules

M = solar mass
m = particle mass

Solar power per unit mass

$\frac{\text{luminosity}}{\text{mass}} = 2 \times 10^{-4}$j/sec·kg

L = solar luminosity
$= 4 \times 10^{26}$ joules/sec

Solar contraction rate, v

$\text{Power} = \frac{d(PE)}{dt}$

$= \frac{GmM}{R^2} \frac{dR}{dt}$

$\frac{dR}{dt}$ = v, a constant contraction rate

$v = \frac{PR^2}{mGM}$

$= 7 \times 10^{-7}$m/sec.

= 0.01 ft/hour, radially

APPENDIX C

Maximum age of the sun considering gravitational contraction only.

$\text{Maximum age} = \frac{\text{Total available energy}}{\text{Present luminosity}}$

$= \frac{PE}{L}$

$= 10^{15}$ sec

$\simeq$ 30 million years

References

Aardsma, G., et al. 1987. A heavy water detector to resolve the solar neutrino problem. *Physics Letters B* 194(2):321-5.

Akridge, Russell, 1980. The sun is shrinking. *ICR Impact #82.*

Ando, Hiroyasu. 1986. Resonant excitation of the solar g-modes through coupling of 5-min oscillations. *Astrophysics and Space Science* 118:177-81 (p. 177).

Barnes, Thomas G. 1987. The dilemma of a theistic evolutionist: an answer to Howard Van Till. *Creation Research Society Quarterly* 23:167-71.

Bell, Trudy E. 1978. The shaky machine. *Astronomy* 6(2):14.

Benton, Dudley J. 1987. Creationist referencing practices and the young earth hypothesis. *Creation Research Society Quarterly* 24:152-3.

Brown, T. M., D. F. Elmore, L. Lacey and H. Hull. 1982. Solar diameter monitor: an instrument to measure long-term changes. *Applied Optics.* 21(19):3588.

Cameron, G. G. W. 1976. The primitive solar accretion disk and the formation of the planets. In The origin of the solar system. S. F. Dermott, (Ed.). John Wiley. New York. pp. 49-74 (p. 72).

Chaffin, Eugene F. 1987. A young earth?—a survey of dating methods. *Creation Research Society Quarterly* 24:109-17 (p. 115).

Claverie, A., G. R. Isaak, C. P. McLeod, and H. B. van der Raay. 1981. Rapid rotation of the solar interior. *Nature* 293:443-5.

Delache, Phillippe and Philip Scherrer. 1983. Detection of solar gravity mode oscillations. *Nature* 306:651-3.

DeYoung, Don B. 1987. Astrophysics, a workbook to accompany classes taught at Grace College and ICR. Unpublished.
Dunham, David W., Sabatino Sofia, Alan D. Fiala, David Herald, and Paul M. Muller. 1980. Observations of a probable change in the solar radius between 1715 and 1979. *Science* 210:1243-5.
Eddy, J. A., and A. A. Boornazian. 1979. Secular decrease in the solar diameter, 1863-1953. Bulletin of the American Astronomical Society 11(2):395.
Endal. A. S.. and L. W. Twigs. 1982. The effect of perturbation of convective energy transport on the luminosity and radius of the sun. *The Astrophysical Journal* 260:342-52 (pp. 343, 351).
Gilliland, Ronald L. 1981. Solar radius variations over the past 265 years. *The Astrophysical Journal* 248:1144-5.
Gingras, Yves. 1987. A debate in solar physics. *Science* 235:225-6.
Gough, Douglas. 1988. Deep roots of solar cycles. *Nature* 336:618-9.
Grec, Gerard, Eric Fossat, and Martin Pomerantz. 1980. Solar oscillations: full disk observations from the geographic South Pole. *Nature* 288:541-4.
Hanson, James. 1981. The sun's luminosity and age. *Creation Research Society Quarterly* 18:27-9.
Hill, Henry A., Jonathan Tash, and Clem Padin. 1986. Interpretation and implications of diameter and differential radius observations of the 160 minute period solar oscillation. *The Astrophysical Journal* 304:506-78 (p. 560).
Hinderliter, Hilton. 1980a. The shrinking sun: a creationist's prediction, its verification, and the resulting implications for theories of origins. *Creation Research Society Quarterly* 17:57-9.
_____. 1980b. The inconsistent sun: how has it been behaving, and what might it do next? *Creation Research Society Quarterly* 17:143-5.
Hudson, Hugh S. 1987. Solar variability and oscillations. *Reviews of Geophysics* 25(3):651-2 (p. 652).
Isaak, G. R. 1982. Is the sun an oblique magnetic rotator? *Nature* 296:130-1.
Krasinsky, G. A., E. Y. Saramonova, M. L. Sveshnikov, and E. S. Sveshnikov. 1985. Universal time, lunar tidal deceleration. and relativistic effects from observations of transits, eclipses; and occultations in the XVIII-XX centuries. *Astronomy and Astrophysics* 145:90-6.
LaBonte, Barry J., and Robert Howard. 1981. Measurement of solar radius changes. *Science* 214:907-9.
Lites, Bruce W. 1983. An estimation of the fluctuations in the extreme limb of the sun. *Solar Physics* 85:193-214.
Lubkin, Gloria B. 1979. Analyses of historical data suggest Sun is shrinking. *Physics Today* 32(9):17-9.
Maddox, John. 1988. More sideshows for solar neutrinos. *Nature* 336:615.
Morrison, L. V., F. R. Stephenson, and J. Parkinson. 1988. Diameter of the sun in AD 1715. *Nature* 331:421-3.
Novotny, Eva. 1973. Introduction to stellar atmospheres and interiors. Oxford University Press, New York.
O'Dell, C. R.. and A. Van Helden. 1987. How accurate were seventeenth-century measurements of solar diameter? *Nature* 330:629.
Parkinson, John H. 1983. New measurements of the solar diameter. *Nature* 304:518-20.
_____, Leslie V. Morrison, and F. Richard Stephenson. 1980. The constancy of the solar diameter over the past 250 years. *Nature* 288:548-51.
Perkins, Don. 1988. Neutrino deficiency declines? *Physics World* 1(11):15.
Perri, Fausto, and A. G. W. Cameron 1973. Hydrogen flash in stars. *Nature* 242:395-6.
Ribes, E., I. C. Ribes. and R. Barthalot. 1987. Evidence for a larger sun with a slower rotation during the seventeenth century. *Nature* 288:52-5.
Rosch, J. and R. Yerle. 1983. Solar diameters. *Solar Physics* 82:139-50.
Scherrer, Philip H. and John M. Wilcox. 1983. Structure of the solar oscillation with period near 160 minutes. *Solar Physics* 82:37-42.
Severny, A. B., V. A. Kotov, and T. T. Tsap. 1976. Observations of solar pulsations. *Nature* 259:87-9 (p. 87).
Shapiro, Irwin E. 1980. Is the sun shrinking? *Science* 208:51-3.
Shu, Frank H. 1982. The physical universe. (University Science Books, Mill Valley, CA.
Sofia, S., J. O'Keefe, R. R. Lesh, A. S. Endal. 1979. Solar constant: constraints on possible variations derived from solar diameter measurements. *Science* 204:1306-8.
Sofia, Sabatino, Pierre Demarque and and Andrew Endal. 1985. From solar dynamo to terrestrial climate. *American Scientist* 73:326-33.
Steidl, Paul M. 1980. Solar neutrinos and a young sun. *Creation Research Society Quarterly* 17:60-4.
_____. 1981. Recent developments about solar neutrinos. *Creation Research Society Quarterly* 17:233.
Taylor, Ian T. 1984. In the minds of men. TFE Publishing. pp. 322-5.
van der Raay, H. B. 1980. Solar oscillations. *Nature* 288:535-6.
Van Till, Il., D. A. Young, and C. Menninga. 1988. Science held hostage. Intervarsity Press, Downers Grove, I (See especially pp. 47-65). See also, The legend of the shrinking sun. *Journal of the American Scientific Affiliation* 38:164-74 (Van Till).
Waldrop, M. Mitchell. 1985. WIMP's cosmions, and solar neutrinos. *Science* 229:955-6.
Woodard, M. and H. Hudson. 1983. Solar oscillations observed in the total irradiance. *Solar Physics* 82:67-73.
Zeilik, Michael, and Elske V. P. Smith. 1987. Introductory astronomy and astrophysics. Saunders College Publishing. Philadelphia.

PANORAMA OF SCIENCE

Bitterroot

In 1805 when Lewis and Clark crossed the Continental Divide they found Indians gathering the exquisite flower from the plant *Lewisia rediviva* (shown on the cover). The copious roots of the plant, when cooked, comprised an important staple in their native diet. When Lewis saw them preparing the raw roots, he asked for a taste of one; and with a wry face, immediately named it Bitterroot, the name it still bears today. From this incident our maps acquired several geographical names such as Bitterroot River and Mountains. In honor of Lewis' interesting commentary, the botanists later included his name in the scientific genus *(Lewisia)* of this beautiful plant.

Rediviva literally means resurrection and the plant gives ample evidence of that renewal. Notice there are no leaves visible. Since it grows in an extremely rocky habitat, the soil is too thin and sterile to afford leaves and flowers at the same time. Consequently the leaves appear early in the spring, perform their ordained function of photosynthesis, and store the energy in the roots. The leaves then wither away and presently the buds appear to blossom and reproduce from the strength of that bitterroot reservoir.

Further testimony of its vitality is found in the vigor retained in those roots, as they may be replanted and will grow, even after being dried for several months. It is difficult to understand even the basics of photosynthesis, and here is a situation which compounds the problem. An organism can adapt to its environment but always there is that burning question of survival before adaptation. Also it is true for any group of plants that there are limits of adaption beyond which no individual of that species can survive. No less perplexing is the precision of timing if we assign this critical function to mere haphazard chance; for that photoperiodic timing of leaf and flower in this plant must be exact. Then there is the restoration in a dessicated root. Truly it is a "root out of a dry ground." (Isaiah 53:2)

Contributed by Willis E. Keithley