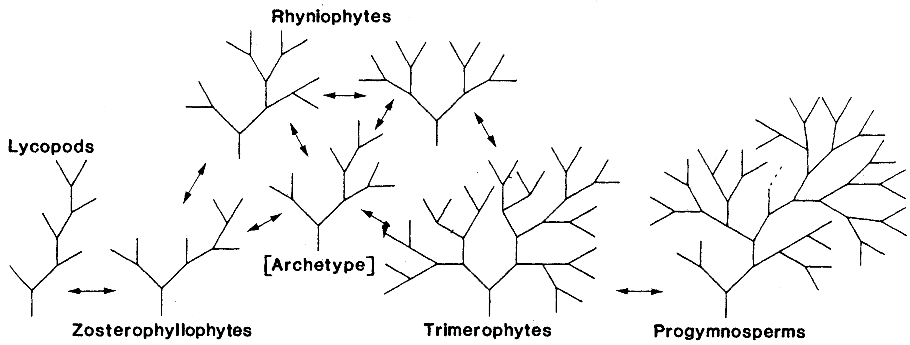
quest for the archetypal branching pattern is to start with the well-defined branching patterns of later groups and then work back through successive precursors, by the mathematically most parsimonious route for transitions between groups.

Niklas's simulations show that the changes in branching patterns between the lycopods and the zosterophyllophytes and between the progymnosperms and the trimerophytes are distinct. The putative transitions are therefore not in any doubt. Beyond that one finds a plexus of branching patterns composed of certain rhyniophyte groups and a mathematically inferred archetype, which is characterized by regular branching with a certain degree of asymmetry. Exactly which paths ran where at this very early period remain to be established. "We can say, however, that the archetype must have been a plexus of organisms defined on the basis of very plastic branching patterns."

In that Niklas's current model is a two-dimensional representation of growth patterns, it is of course limited in its sophistication. Moreover, it does not take into account the effect of the distribution of sporangia (the spore-forming organs) over the plant, which must influence in important ways the branching patterns that are possible. "The computer analyses do, however, provide a first-order approximation of the random and nonrandom components of branching systems," concludes Niklas.



Branching pattern transitions in plant evolution

Analysis of the most parsimonious transitions among the computer-simulated branching patterns shows the trimerophyte to progymnosperm change and the zosterophyllophyte to lycopod change to be distinct and therefore not in doubt. Theoretically the rhyniophytes, zosterophyllophytes, and trimerophytes can be derived from one of several possibilities.

Meanwhile, Niklas, O'Rourke, and Vincent Kerchner, also at Cornell, are beginning to develop three-dimensional models. "By contrast with the two-dimensional model, you have many more variables to compute: the rotation angle, how does the next branch rotate with respect to the last, and so on. In the model we can also alter the bifurcation angle and the length of successive branches. We are interested in looking at the influence of rotation angle on photosynthesis and on mechanical stability." The upshot is a massive simulation, which, for 10,000 structures with just ten branching increments, would run for 8.33 days on a small computer!

—ROGER LEWIN

Does California Bulge or Does It Jiggle?

Southern California may be bouncing up and down every few years; could this have been mistaken for the ominous bulge?

First, it was the Palmdale bulge, a 35-centimeter-high, 200-kilometer-long swelling of the ground that reportedly developed during the 1960's. Now, a group of geophysicists is suggesting that some of the same area of southern California may be bouncing up and down every few years, although these apparent oscillations in elevation have never lifted the ground to the extreme height claimed for the bulge. In fact, such rapid but modest oscillations, together with recently discovered measurement errors, may account for most of the reported towering bulge.

In this issue of *Science* (p. 1215), Robert Jachens, Wayne Thatcher, Carter Roberts, and Ross Stein of the U.S. Geological Survey (USGS) in Menlo Park, California, present a 5-year record of three different geophysical measurements, each of which bears on changes in elevation. All three seem to trace the same pattern of uplift and subsidence at Tejon Pass on the San Andreas fault about 100 kilometers northwest of Los Angeles. The ground there seems to have risen and fallen 5 to 15 centimeters twice during the past 5 years. The USGS group reports similar but less striking movement at two other San Andreas sites: Palmdale, which is at the center of the purported bulge, and Cajon Pass, 70 kilometers northeast of Los Angeles.

Researchers keeping an eye on southern California have seen plenty of variations in the crustal properties they have been monitoring (*Science*, 15 February 1980, p. 748), but all too often the anomalous readings have been at different places, at different times, or on instruments whose measurements could not be checked against related observations. Three measurements, gravity, strain, and elevation, were made at each of several sites by the USGS group, and the possible errors in each type of measurement are thought to be unrelated. All three measurements at a particular site tend to record the same episodes of uplift and subsidence. When the ground rises, strain (the distortion of the rock) increases and gravity decreases. That is just what theory would predict if the crust were being squeezed like a sponge. Squeezing the crust would distort the rock, push the ground up, and carry any gravimeter farther from the center of the earth's mass, which decreases the observed gravity.

The concerted behavior of the three measurements impresses many researchers, more so than a glance at the plotted values might seem to warrant. The apparent changes are only a few times larger than the calculated errors, and the statistical correlations among the three are only significant at the 90 to 95 percent confidence levels. Still, the changes appear surprisingly well behaved when compared to the assortment of microearthquakes, bubbling springs, and barking dogs that have often created excitement in California. In addition, the observed elevation changes, which have

Robert Jachens

Measuring relative elevation changes with a gravimeter

This gravimeter, which is temperature-controlled and weighs about half a kilogram, can measure differences in the force of gravity at different locations that are as small as one hundred millionth of Earth's gravity. That is sensitive enough to detect its being lifted 5 centimeters farther from the center of mass of Earth. It contains a weight suspended from a sensitive spring-lever system, the change in the stretching of the spring being a measure of the change in gravity.

the poorest correlations of the three, and the gravity changes have the same relation as that determined from measurements in the aftermaths of the 1964 Alaska and 1971 San Fernando earthquakes. "That seems to me to be a very strong argument that [the changes] are real," says James Savage of the USGS in Menlo Park. "The correlations look too strong to be a coincidence. It's very impressive."

Although not reported in this paper, the earth's magnetic field seems to be varying in step with the changes in elevation, strain, and gravity, according to Malcolm Johnston of the USGS in Menlo Park. The magnetic field, which is continuously recorded at the same sites at which the other properties were measured, could be responding to changes in the magnetic materials of the crust induced by changes in strain, Johnston says. He has so far been unable to identify any extraneous causes, such as variations in rainfall or temperature.

If the jiggling is real, what could be causing it? The squeezed-sponge analogy holds well for the relation between gravity and elevation but not for the elevation-strain relation. That has prompted the USGS group to suggest that the ground may be bouncing up and down because southern California is occasionally slipping sideways. It will not slip into the sea, as fantasized by some, but a number of investigators have speculated that a nearly flat-lying fault has detached the upper 10 kilometers of southern California from the rock below. Such a detachment fault underlies at least part of the Appalachian Mountains and piedmont region of the eastern United States. Uneven slipping on this fault might produce the observed rapid heaving without generating any earthquakes, the group says. Savage cautions, however, that although the required calculations can be made to be consistent, they remain somewhat strained and unsatisfying.

Whatever the cause, these apparent oscillations in elevation could have contributed to the current confusion over the true size of the uplift centered on Palmdale. The leveling surveys used to measure those elevation changes were separated by several years, and each took as long as a year or more to complete. Rapid oscillations between and even during surveys could have created inconsistencies that later were taken as evidence of large elevation changes by some. Others saw them as systematic leveling errors.

Any real, enduring increase in elevation, however modest, may have been inflated into an intimidating bulge by leveling errors that have only recently been fully appreciated (*Science*, 14 December 1981, p. 1331). Some researchers had expected that correction for errors due to atmospheric refraction would reduce the reported 30- to 45-centimeter height of the bulge, as William Strange of the National Geodetic Survey (NGS) in Rockville, Maryland, had claimed. Sandford R. Holdahl of the NGS has now made a more sophisticated calculation of the refraction errors. He also has evaluated 14 years of corrected leveling surveys by a mathematical method that fits all survey results to a single, steady uplift. Holdahl's final bulge is 7.5 ± 4.0 centimeters high at Palmdale, a far cry from 35 centimeters. Even that uplift might be due to other errors, he says.

Although other investigators have praised Holdahl's approach, they caution that his assumption that a bulge's motion would be steady and uniformly distributed must be suspect, if the oscillations reported by Jachens and his colleagues have any validity. In part because of these reservations, many observers still do not believe that all of the uplift attributed to the bulge has been explained away as erroneous. Stein, for one, thinks that the fit of the observations to Holdahl's mathematical model is poor enough that the model could contain significant but irregular uplifts. In a survey-by-survey analysis, Stein notes, corrections can reduce the uplift but not eliminate it. The refraction correction to the 1964 leveling survey between Saugus and Palmdale, a line crucial to the construction of a large bulge, would drop the apparent uplift from about 20 centimeters to about 13, he says. An additional correction of about 7 centimeters for a rare error related to the surveying rod used would lower that uplift to about 6 centimeters.

Surveys of areas including Tejon Pass, which shows the greatest changes of the past 5 years, fare better, Stein says. The leveling route up to Tejon Pass is too steep to accumulate significant refraction error, and surveying rod errors were negligible there. Thus, the refraction-corrected, 15-centimeter uplift across this route that persisted from 1965 to 1971 and then partially collapsed seems to be real, he says. No one has applied corrections to all of the individual leveling routes around the periphery of the bulge, but some researchers expect that, were this done, the shoulders of the reported bulge would be much reduced or would disappear, leaving the bulge not only lower but also narrower than originally reported.

If there is a middle ground in this debate, it is the view that the surveying errors are larger and the bulge smaller than had been thought. The reasonably good correlation of several kinds of observations, suggesting rapid elevation changes over the past 5 years, supports the reality of some kind of uplift in southern California. What it all may mean for the next large earthquake there no one is quite sure.—**Richard A. Kerr**

Additional Reading

S. R. Holdahl, *J. Geophys. Res.* **87**, 9374 (1982).