P.54

Science Fairs and Observational Science: a Case History from Earth Orbit

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Introduction

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Having judged dozens of science fairs over the years, I am repeatedly disturbed by the ground rules under which students must prepare their entries. They are almost invariably required to follow the "scientific method," involving formulating a hypothesis, a test of the hypothesis, and then a project in which this test is carried out.

As a research scientist for over 40 years, I consider this approach to science fairs fundamentally unsound. It is not only too restrictive, but actually avoids the most important (and difficult) part of scientific research: **recognizing a scientific problem in the first place.** A well-known example is one of the problems that, by his own account, stimulated Einstein's theory of special relativity: the obvious fact that when an electric current is induced in a conductor by a magnetic field , it makes no difference whether the field or the conductor is actually (so to speak) moving. There is in other words no such thing as absolute motion. Physics was transformed by Einstein's recognition of a problem. Most competent scientists can solve problems after they have been recognized and a hypothesis properly formulated, but the ability to find problems in the first place is much rarer.

Getting down to specifics, the "scientific method" under which almost all students must operate is actually the *experimental* method, involving controlled variables, one of which, ideally, is changed at a time. However, there is another type of science that can be called *observational* science. As it happens, almost all the space research I have carried out since 1959 has been this type, not experimental science.

The most obvious example of "observational science" is of course astronomy; we have no way to control the many variables involved in, for example, star formation. Back on Earth, oceanography, meteorology, and much of geology are largely observational, as are exploration and mapping in general. The observations in these fields consist essentially of the systematic collection of new knowledge about the world, or the universe. They can result in star catalogues, geologic maps, or collections of fossils. Such observational science is generally the foundation for subsequent scientific research, by promoting recognition of previously unknown problems or questions. After a problem has been recognized, efforts to solve it will involve construction of hypotheses, which are then tested by the experimental method *or* by further observations.

A Case History: the Elsinore Fault

To illustrate the interplay of observation, problem recognition, and hypothesis testing, I will give an extremely condensed example from my own research: a study of the Elsinore Fault in southern California based on 70 mm terrain photographs taken by astronauts on the Gemini 5 and Apollo 9 missions in 1965 and 1969 respectively.

The Elsinore Fault, roughly 200 km long, is a seismically active fracture parallel to the segment of the San Andreas fault east of San Diego (**Fig. 1**). It forms the east face of the southern California batholith, the southern equivalent of the Sierra Nevada batholith - enormous composite igneous intrusions of granitic rock. Topographically, the fault bounds the crest of the Peninsular Ranges, though this crest is by no means the highest point.

The Elsinore Fault is considered one of the San Andreas system, sharing the regional interplate shearing motion by slipping in a right-lateral sense (opposite side of the fault moving to the right, as seen from either side). The current interplate motion between Pacific and North American plates in this region, as measured by space geodesy, is roughly 4 to 5 cm/year, distributed across a broad zone of faulting. Authoritative estimates in the 1960s of the total displacement on the Elsinore Fault were around 30 kilometers of horizontal movement ("strike slip" in geologic terms). The term "Elsinore fault zone" has been used by some geologists to allow for the possibility that less prominent faults just to the east may share in this movement.

In 1965, astronauts Pete Conrad and Gordon Cooper on the Gemini 5 earth orbital mission took a striking 70mm color photograph of the Salton Sea (**Fig. 2**), probably to show the conspicuous gyre resulting from suspended sediment stirred up by wind from the north. As Principal Investigator for terrain photography, I was asked by the Educational Programs Office at

Goddard Space Flight Center to draw a sketch map of the photo, showing the San Andreas fault.

The fault's location is well-known, and was easy to plot. However, several other prominent faults parallel to it were also visible, notably the San Jacinto and Elsinore Faults, so I plotted them too. However, I noticed an anomaly: a prominent linear feature (lower left corner) extending northeast across the Elsinore Fault without any apparent lateral offset. Since I knew the Elsinore was considered to be a strike-slip fault, like the San Andreas, this at once set me to wondering how these relations could be reconciled with the prevailing interpretation of the Elsinore. To step back to the theme of this article, this was the crucial event: **recognition of a problem.**

The space program was moving at a frenetic pace in the mid-1960s,and I was unable to investigate the Elsinore Fault problem at the time. However, in 1969 the Apollo 9 crew, Jim McDivitt, Dave Scott, and Rusty Schweikart, carried out systematic multispectral 70 mm photography, intended to demonstrate the feasibility of imaging similar in principle to that of the planned Landsat system. The superb vertical photographs included one of San Diego and the adjacent Peninsular Ranges, including the Elsinore Fault (**Figs.** 3, 4). The cross-cutting feature I had noticed on the Gemini 5 picture was shown in true geometry and with high resolution. It was a deep valley , occupied by the San Diego River, that apparently continued as San Ysidro Creek northeast of the Elsinore Fault. However, the Apollo 9 photo showed several other northeast-trending features, at least one of which also crossed the Elsinore without lateral displacement. The age relationships, incidentally, are clear; the northeast-trending features are clearly old, judging from their topography, whereas the Elsinore fault is seismically active, and is known to be slipping now although the rates and directions are still poorly known.

In 1970 I was invited to teach two courses at the University of California in Santa Barbara during the 3 month winter quarter. I accepted, and thus had the opportunity on weekends to do field work in San Diego County. My first objective was simply to find out what the northeast-trending features were. I found that topographically they were chiefly valleys, following fractures of some sort - faults or joints. However, one of the Elsinore-crossing features was a straight valley in the mountains west of the Elsinore Fault, but a ridge east of it. Topographic maps showed the ridge to be the "Sawtooth Range," a somewhat pretentious name for a small spur of the mountain front. The Sawtooth Range was, unlike the other features, largely on public land and easily reached by good roads. I therefore decided to study its structure where it was cut by the Elsinore Fault.

To examine this critical area more closely, I obtained high altitude air photos from the U.S. Geological Survey (**Fig. 5**), and, some years later, Landsat pictures. In addition, with two California colleagues, Jack Estes and Bill Finch, I hired a Cessna with pilot to take us on a 2 hour photo-reconnaissance flight over the Peninsular Ranges. Among the 35 mm pictures I took was **Fig. 6**, an oblique view of the Sawtooth Range at its intersection with the Elsinore Fault.

The space program's pace was increasing, and I became involved in Landsat, Mariner 9, Apollos 15 and 16, and the Voyager mission. The Elsinore Fault anomaly was therefore put on the shelf for several years, except for an occasional day stolen from California trips for other purposes. However, I continued study of the problem, publishing a preliminary report in 1976 after Landsat pictures became available. In 1979 I spent several days mapping the bedrock structure of the Sawtooth Range and the areas to the east, where possibly related faults exist. My findings were that the structure - exposed as foliation in Cretaceous age metamorphic rocks and flow structure in igneous rocks - was continuous across the Elsinore Fault and other faults to the east, with no lateral offset at all.

The culminating observation was in a road cut (locally known as Campbell Grade) on the Sawtooth Range where an actual plane of the Elsinore Fault was exposed (**Fig. 7**). This smooth surface was strongly grooved (slickensides in the geologic term), with the grooves oriented straight down the fault plane. Slickensides obviously give the direction of the slip along the fault, or at least the most recent slip. Those in the road cut clearly indicated vertical movement, directly contrary to the prevailing interpretation of the Elsinore as a fault with major horizontal movement. It is worth repeating that this fault is seismically active, and if slipping horizontally at even half a centimeter per year (a 1996 estimate), the Sawtooth Range would have been offset at Campbell Grade by 100 meters in only 20,000 years.

My interpretation was confirmed independently by two California geologists, Vicky Todd and Wendy Hoggatt, doing geologic mapping for other purposes. Paul Merifield and Don Lamar, using Skylab and Landsat pictures, arrived at the same general conclusion for the Elsinore Fault. I therefore wrote a paper for the Journal of Geology in which I showed that the Elsinore Fault was not a strike-slip one, but characterized by vertical movement. After peer review, the paper was published in 1980.

To summarize this case history, *observational* science - here the photograph from Gemini 5 - permitted recognition of a scientific problem, namely the apparent evidence against the prevailing interpretation of the Elsinore Fault as having many kilometers of lateral offset. This interpretation was the *hypothesis to be tested*. It was tested by several years of intermittent field mapping, that is, by further observations. The final critical observation was the discovery of slickensides oriented up and down, not horizontally. To the extent that the Elsinore Fault is a single feature, and that the Campbell Grade exposure is representative, the hypothesis was disproven, or "falsified" in the term used by Karl Popper. (I had also mapped two parallel subsidiary faults to the east, finding no evidence for horizontal motion on them either; details are given in my Journal of Geology paper cited in the reference list.)

The experimental method played no role at all in this hypothesis testing; the project was purely observational. Experimental and observational science are of course not mutually exclusive. The overall approach in the Elsinore Fault study, once the problem had been recognized, was similar to that of the experimental method. Returning to the purpose of this article, the absolutely crucial part of this study was the first, namely discovery of the problem itself. The subsequent field mapping was by professional standards fairly straightforward, and could have been done by a third-year geology student with strong legs and cactus-proof boots. But it led to an interpretation directly contradicting the views of the most eminent California geologists of the day.

I should amplify the foregoing account slightly. James Watson's "The Double Helix" was written to give a realistic account of how science is actually done. This Elsinore Fault article gives an extremely simplified and rather drab account of a scientific investigation. A student reading it would probably get the impression that geology is a dull subject. In fact my California field work was intensely interesting, physically and intellectually challenging, and carried out in magnificent country. My memories are a montage of desert flowers in spring time; 100 degree temperatures in the Imperial Valley; outcrop graffiti from the 19th century, when Campbell Grade was a stagecoach route; finding a jettisoned canopy from a Navy A-4 jet fighter (presumably the pilot survived); scrambling down a cactus-covered slope in near-darkness; rationing my quart of water through a day of desert heat; coyotes sounding the alarm that there was an intruder on Vallecito Creek. So if any of my readers use this example in class, please don't make it as colorless as I have ; it was great fun.

Summary and Conclusions

The recommendation to which this example points is that science fair organizers should permit students to submit observational science projects, not only experimental ones. Such projects, especially carried out by younger students, may not get as far as formulation of an hypothesis, or even identification of a problem. But they would be the same kind of science carried out by Charles Darwin in his five year voyage on the Beagle : the collection of knowledge about the natural world or some aspect of it.

Science projects of this sort could be as simple as a map of weed species in a back yard, a labeled and location-keyed collection of local rocks, a meteor count, a photographic atlas of cloud types, a soil profile from a garden, a species count of birds at a back yard feeder. Students might do a UFO watch, in which they record *everything* they see in the sky - constellations, planets, airplanes, bats, satellites, aurorae, meteors - during a one hour period shortly after sunset. (They may see a spaceship, but it will be one of ours.) Projects could be more ambitious, such as an analysis, however elementary, of a recent image of the Earth from space similar to my Elsinore Fault project. Such pictures are now plentiful and easily obtained through the Internet. Three sources in particular should be described.

Several major earth-observing satellites are operated by NASA, including Landsat 7, EOS Terra, and EOS Aqua, in addition to others that produce largely non-visual data. These satellites generate and transmit to Earth enormous amounts of information every day, some of which should be usable by students for observational science projects. A good starting point for this is the NASA Earth Observatory "Image of the Day, " which can be downloaded from the Internet with suitable software, from **http://earthobservatory.nasa.gov**. One of the sites listed under the Earth Observatory is a digital tectonic activity map, illustrated in Fig. 8. This map and several co-registered ones, such as seismic activity, can be accessed at **http://denali.gsfc.nasa.gov/dtam** . They may be useful in picking areas for study and in interpreting images acquired.

Hand-held astronaut photography similar to that illustrated in this article was resumed when the Shuttle started flying in 1981, under the Space Shuttle Earth Observation Program administered by Johnson Space Center. Tens of thousands of color pictures have been taken over the decades; some of the best are shown in "Orbit: NASA Astronauts Photograph the Earth," published by the National Geographic Society in 1996. These pictures, and in fact all astronaut photographs taken since 1962, can be viewed on the Internet through **http://eol.jsc.nasa.gov/sseop.** The SSEOP has now been expanded to the International Space Station, and pictures from it can be viewed at the same Website.

Students in middle school have actually been taking pictures from space, vicariously, as part of the EarthKAM project administered by the University of California (San Diego). A digital camera, mounted initially in the Shuttle and now on a space station window, is turned on for specific areas requested by students. Information on the project, and the pictures themselves, can be viewed at **http://datasystem.earthkam.ucsd.edu/** . For general information about NASA educational programs, the Website at **http://education.nasa.gov** is recommended.

A note of caution for science teachers: do not expect too much of your students if they use these photographs for projects. I recommend relatively limited objectives, such as hand-drawn and documented maps of interesting land areas or features. The simplicity of the Elsinore Fault study described here may be deceptive; it was done by an experienced Ph.D., and took years of work covering some 2500 square miles. But there are many parts of the Earth, especially in desert areas such as North Africa and Australia, where unexpected anomalies may be found, and problems to be solved at least outlined.

Observational science projects take the world as it is, rather than trying to experimentally control selected aspects. They are exploration, even if limited to a back yard, and I suggest the term **exploration science**.

Figures

1. Geologic structure of the southwest United States, from Landsat 1 mosaic. S.J.F. is San Jacinto Fault.
2. Gemini 5 photograph (S-65-045748), from 240 km altitude, looking northeast across the Salton Sea. Note lineament extending from lower left corner toward upper right, crossing the Elsinore Fault. Photo taken in 1965.
3. Apollo 9 photograph (AS-9-26-3733), from 250 km altitude, showing Peninsular Ranges, southern California. Locations and features shown in Fig. Photograph taken in 1969.
4. Map of Fig. 3.
5. Aerial photograph of Sawtooth Range; original scale 1:60,000.
6. Hand-held 35mm oblique view of Sawtooth Range at Campbell Grade, looking northeast from 2000 feet above ground. Photo by author, 1970. Elsinore Fault exposed in hairpin turn on top of ridge, upper right, on San Diego County Road S 2.
7. Outcrop view of fault plane of Elsinore Fault at Campbell Grade, showing slickensides indicating dip slip for last movement. Pen (upper right) gives scale.
8. Global tectonic activity map of the Earth.

References

Apt, J., Helfert, M., and Wilkinson, J., Orbit: NASA Astronauts Photograph the Earth, National Geographic Society, Washington, DC, 224 p., 1996.

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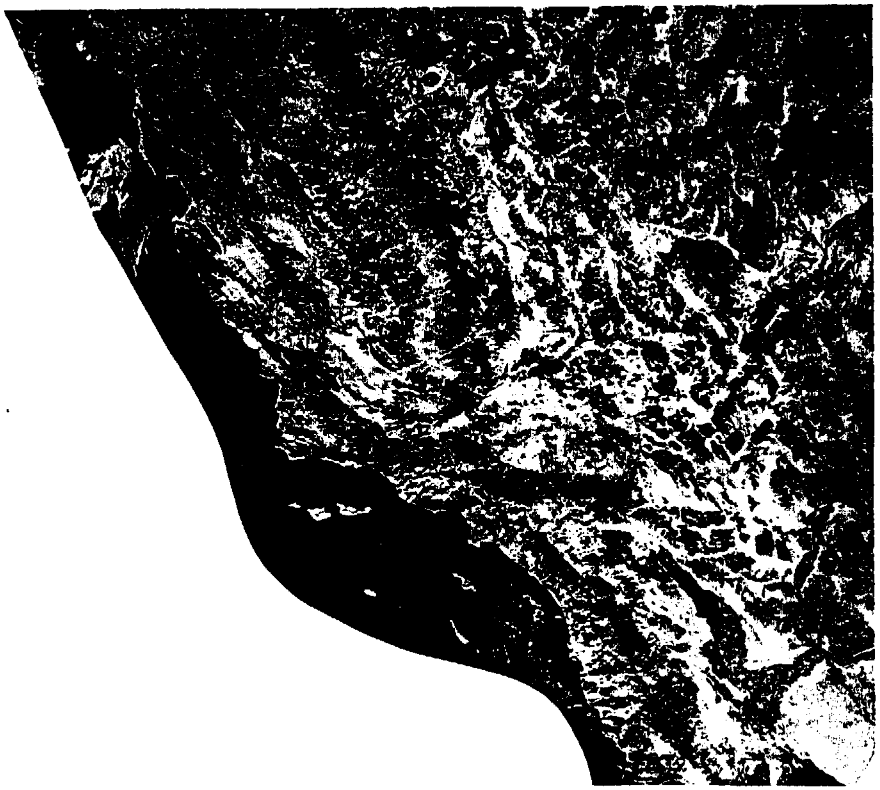
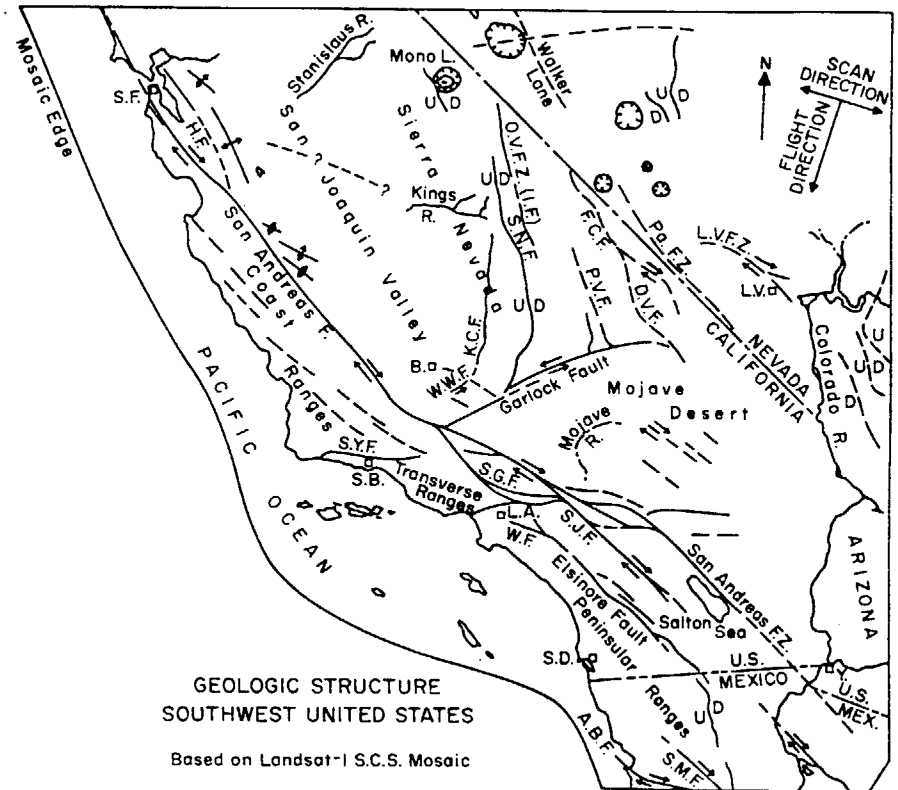




GEOLOGIC STRUCTURE
SOUTHWEST UNITED STATES

Based on Landsat-I S.C.S. Mosaic

Paul D. Lowman

Goddard Space Flight Center

January, 1976

160 Km.
100 Miles

Single MSS Frame Width

Legend

Fault (solid where confirmed, dashed where inferred)

Anticline

Volcanic center

Reference

1. Geologic Atlas of California
2. Tectonic Map of N. America (King, 1969)
3. Rowan and Wetlaufer (1975)

Fig. 2

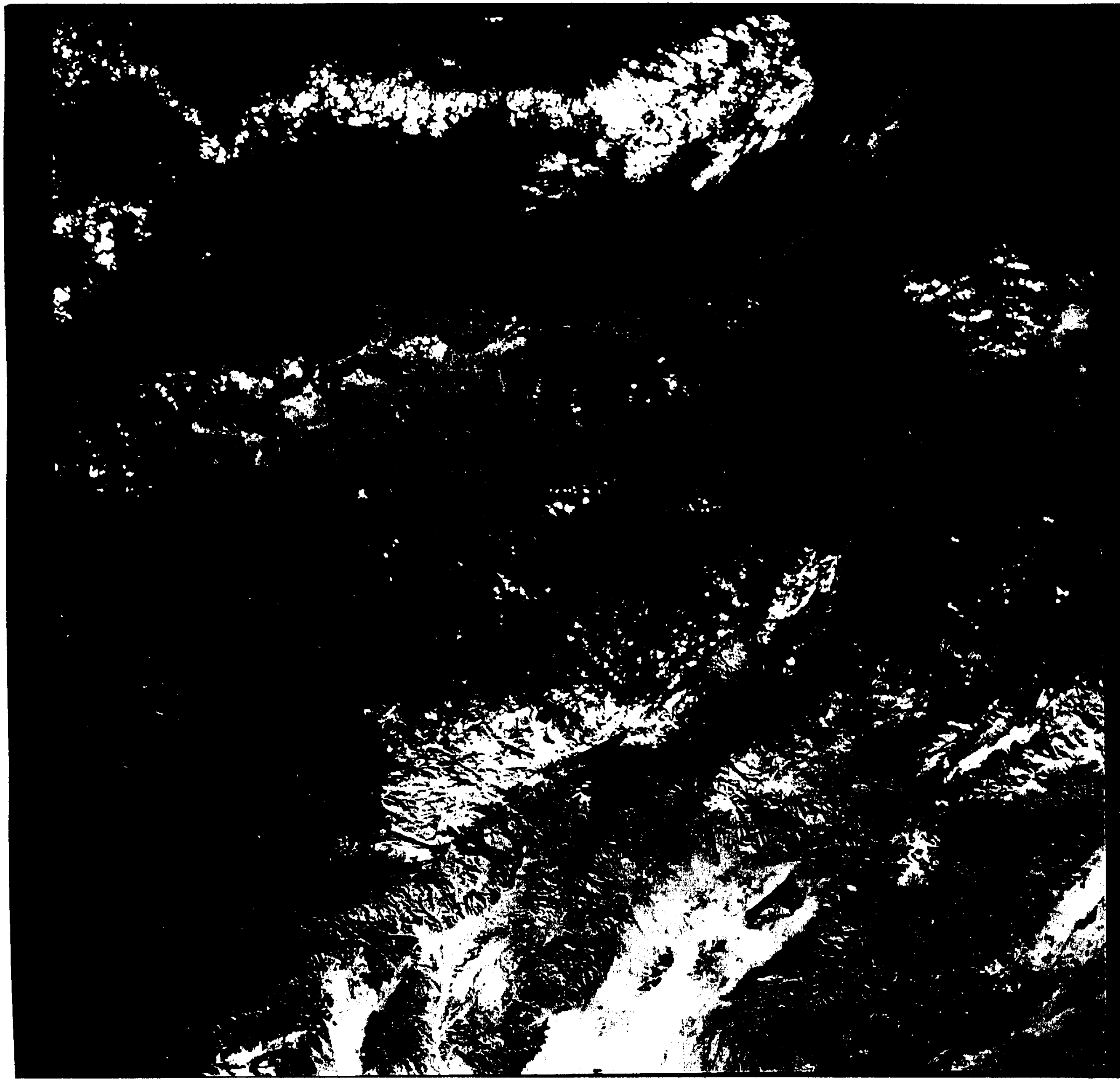
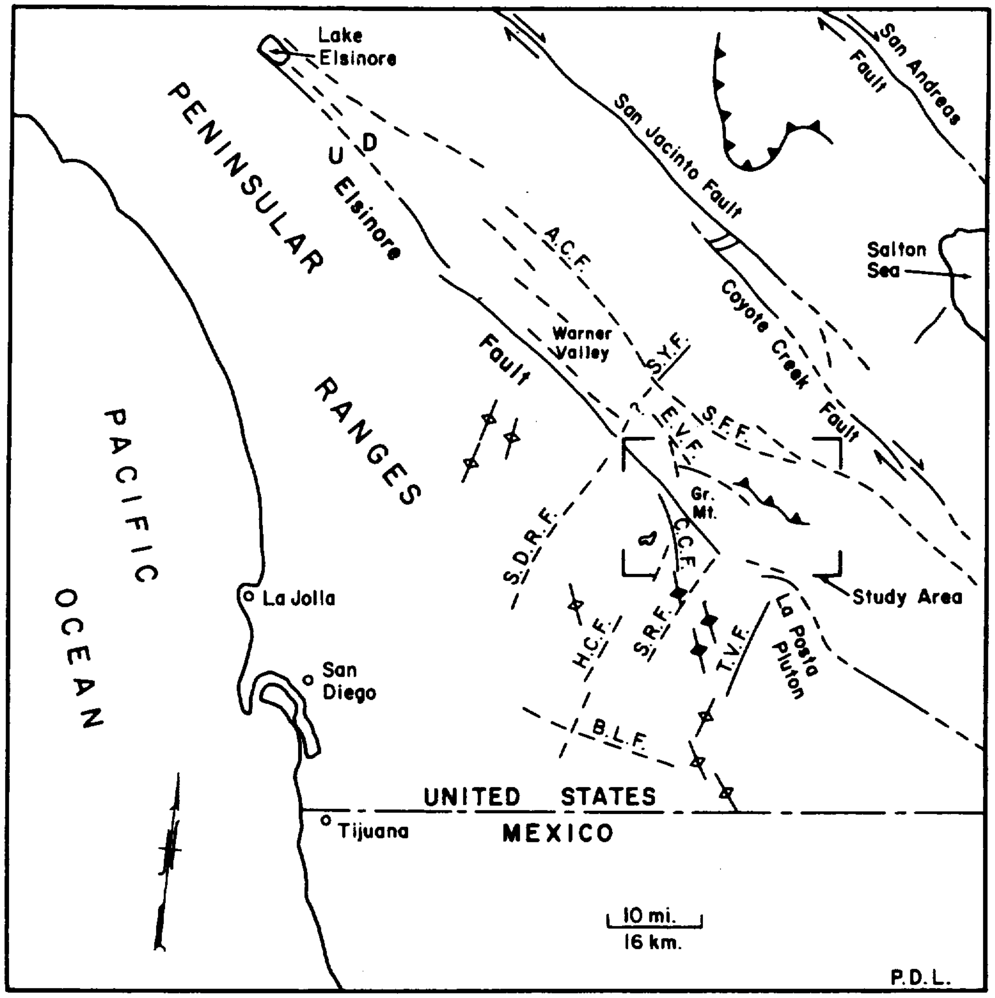


Fig. 3



LEGEND

Major fault:

A.C.F.	Aqua Caliente
B.L.F.	Barrett Lake
C.C.F.	Chariot Canyon
E.V.F.	Earthquake Valley
H.C.F.	Horse-thief Canyon
S.F.F.	San Felipe
S.D.R.F.	San Diego River
S.R.F..	Sawtooth Range
T.V.F.	Thing Valley

Thrust fault; barbs on upper block

Generalized foliation in steeply dipping metamorphic ( ) or igneous ( ) rocks

Fig. 4

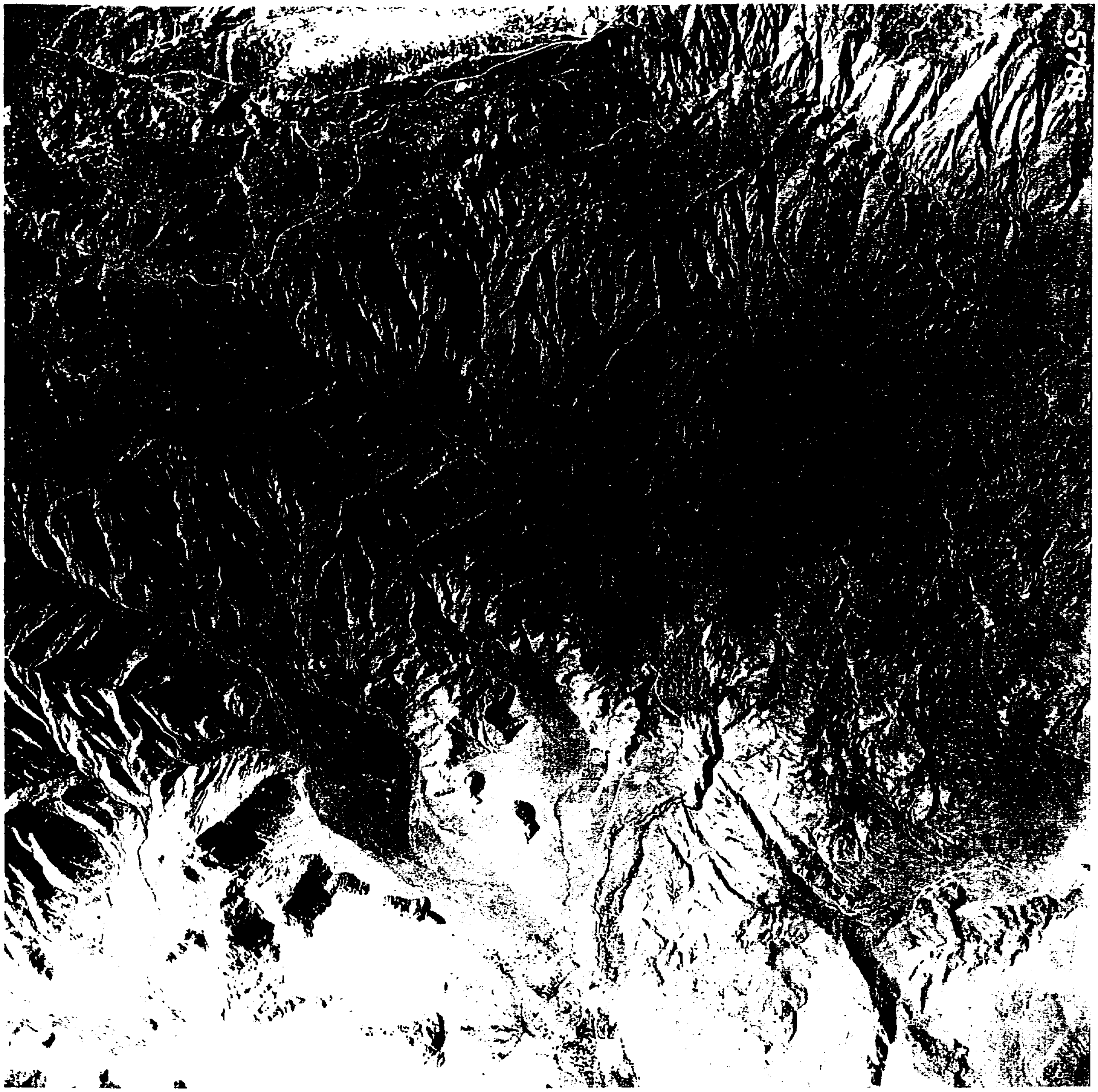


Fig. 5

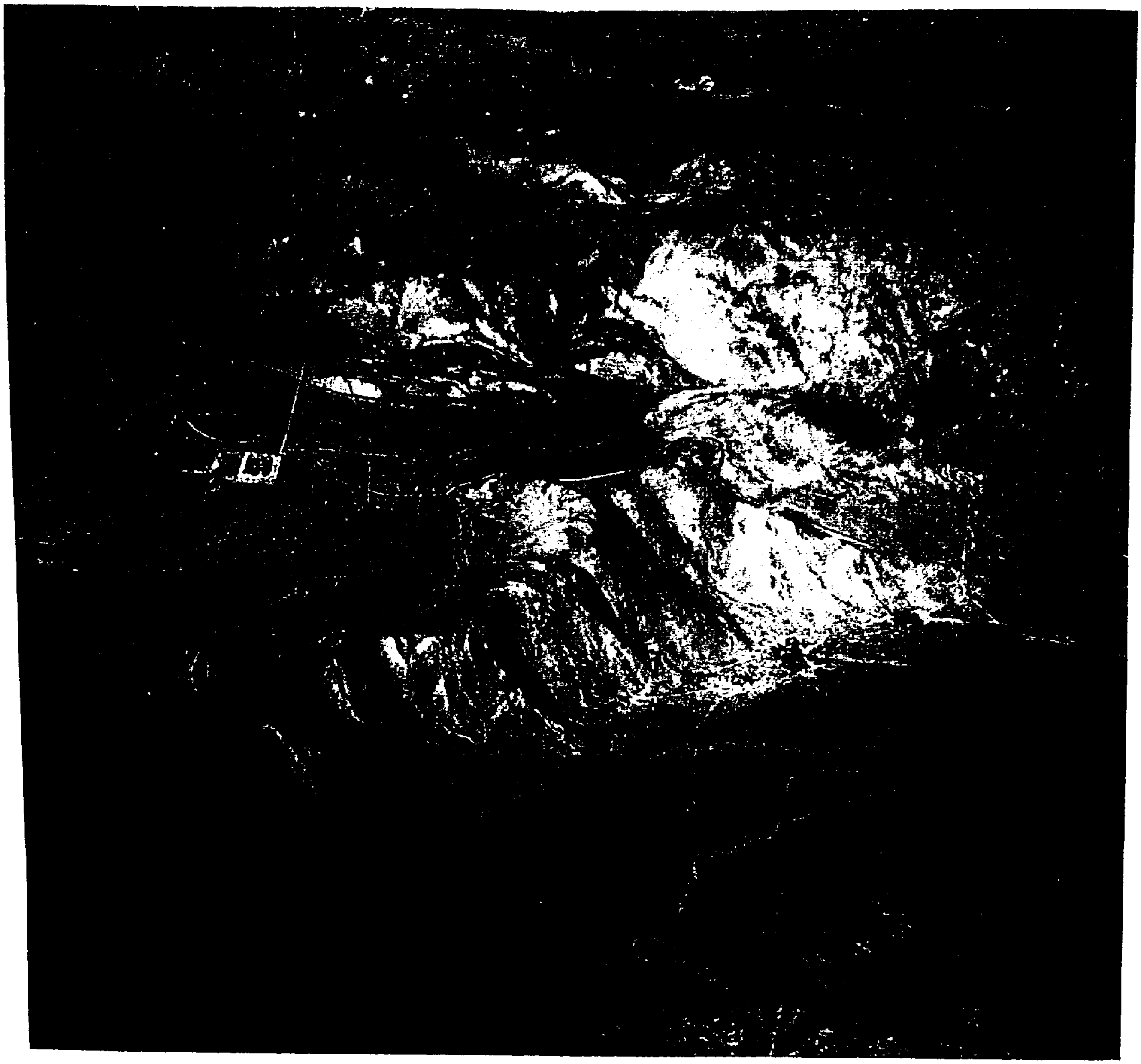
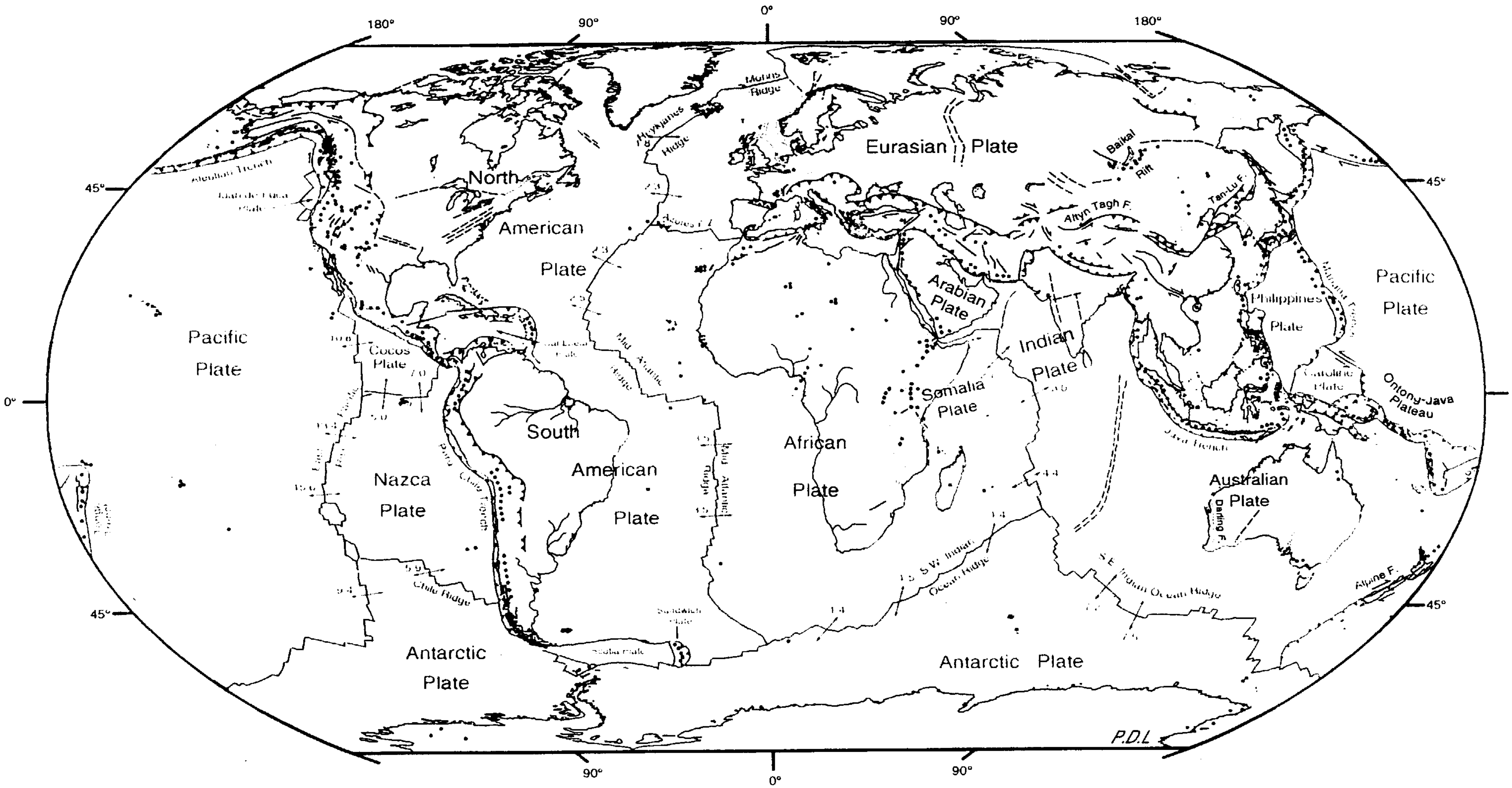


Fig. 6

TOP

Fig. 7



GLOBAL TECTONIC ACTIVITY MAP OF THE EARTH

Tectonism and Volcanism of the Last One Million Years

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Robinson Projection

Mainly oceanic crust

October 1998

LEGEND

- Actively-spreading ridges and transform faults
- Total spreading rate, cm/year, NUVEL-1 model (DeMets et al., Geophys. J. International, 101, 425, 1990)
- Major active fault or fault zone; dashed where nature, location, or activity uncertain
- Normal fault or rift; hachures on downthrown side
- Reverse fault (overthrust, subduction zones); generalized; barbs on upthrown side
- Volcanic centers active within the last one million years; generalized. Minor basaltic centers and seamounts omitted.

Fig. 8

G221.001

Popular Summary

Science Fairs and Observational Science: A Case History from Earth Orbit
(In Press, The Science Teacher, October 2002 issue)

This article discusses the prevailing practice in American schools of requiring student science fair projects to follow "the scientific method," involving formulation of a hypothesis and testing of this hypothesis. The article points out that this is actually just one research approach, the experimental method, that neglects the most important part of science: recognition of a scientific problem in the first place. Much research is actually observational rather than experimental, astronomy being the obvious example. Most space research is also observational.

The author summarizes an observational study of his own, carried out between 1966 and 1980, using orbital photographs from Gemini and Apollo missions to study the Elsinore Fault of California. The Elsinore Fault was generally considered to be slipping horizontally, like the nearby San Andreas fault. However, the author noticed that several geologic structures crossed the Elsinore Fault but were not offset horizontally. Recognition of this problem triggered a 14 year investigation that eventually showed the Elsinore Fault to have moved vertically, not horizontally.

The article suggests that similar observational science fair projects might be carried out by students using NASA material, from the Earth Observatory, the Space Shuttle Earth Observation Program, and the EarthKAM Project. All three produce imagery available from the Internet,and URLs are given for each Website.

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