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ACTIVE FAULTS AND PRELIMINARY EARTHQUAKE EPICENTERS (1969-1970) IN THE SOUTHERN PART OF THE SAN FRANCISCO BAY REGION

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INTRODUCTION

Earthquakes are both abundant and frequent in the San Francisco Bay region. Most of them are so small that they are detected only by sensitive seismographs. Only rarely is one large enough to be felt, and still more rarely is one large enough to cause noteworthy damage. Great earthquakes like that which struck northern California in 1906 are so infrequent that only 2 or 3 are known from California in the last 150 years--the time span for which we have reliable historic records.

The abundance of small, instrumentally detectable earthquakes permits a wide range of seismologic and geologic studies to proceed without waiting for more damaging earthquakes. This opportunity is being exploited in the San Francisco Bay region by several cooperating scientific organizations that have installed and maintain sensitive seismometers to record small earthquakes. The data from this network of seismograph stations are the basis for many research investigations, most of which have a direct bearing on earthquake risks in the San Francisco Bay region.

EPICENTER DISTRIBUTION AND ITS RELATION TO ACTIVE FAULTS

This map is one product of the continuing research on small earthquakes in the San Francisco Bay region. It shows both the preliminary epicenter location and the magnitude of earthquakes greater than 0.5 magnitude on the Richter scale for the period January 1, 1969 to December 31, 1970. A few of the symbols on the map may indicate two or more epicenters located at exactly the same point. Also, because of technical problems that are discussed later, a large number of epicenters near Danville are not shown. Their inclusion would not significantly alter the patterns shown on the map nor the conclusions drawn from that pattern.

The map also shows the location of faults that are historically active or that show evidence of geologically young surface displacement (Brown, 1970). These faults can be recognized by such linear but discontinuous topographic anomalies as narrow elongate depressions, sag ponds, offset streams, and scarps. Most of the recent surface fault breaks shown on the map have been verified by field investigations, but a few, shown as dashed on the map, are based solely or largely on photogeologic interpretation of aerial photographs.

Earthquakes occur throughout the entire San Francisco Bay region, but as the map shows they are not randomly distributed. Most of them are within three northwest-trending, nonparallel belts. Each of the plotted epicenters is, by definition, that point on the earth's surface that is vertically above the source of an earthquake (fig. 1), so the belts of epicenters shown on the map actually represent zones of earthquake activity that extend deep within the earth's crust.

Where the epicenters are numerous the belts are narrow and clearly evident, even though the belt boundaries are somewhat irregular or indefinite. The belts are about 2 miles wide or less in most places, and nowhere are they wider than about 4 miles. This narrow map pattern indicates that earthquake activity is localized along zones that are vertical or that dip very steeply, for although many of the earthquakes represented by the plotted epicenters are miles below the surface, all of them in any one belt fall within a mile or so horizontally of a centrally located vertical plane.

The three zones of earthquake activity approximately coincide with four known fault zones. These are, from southwest to northeast, the San Andreas, the Sargent, and the Calaveras and Hayward faults. The San Andreas, the Calaveras, and the Hayward faults were known to be active even before the 1906 San Francisco earthquake. Each of these has generated major earthquakes with measurable amounts of surface fault displacement in historic time. Locally, there is movement, or creep, along each fault within the area of this map. Although average creep rates are only fractions of an inch a year, they are great enough to adversely affect some manmade structures. Those segments of the faults that exhibit tectonic creep are chiefly within the zones of greatest small-earthquake activity.

Not shown on the map, but determinable from the same seismic data as that on which the map is based, are several other earthquake characteristics, among them depth to the hypocenter and the nature of the movement that produced the earthquake. These characteristics are known for a representative sample of the plotted points. They show that most of the earthquakes are no deeper than 10 miles below the surface of the earth, and none are deeper than 15 miles. The fault movements producing most of the earthquakes are right lateral and in the same sense as the 1906 movement on the San Andreas fault--that is, rock masses seaward of such northwest-trending faults as the San Andreas, Hayward, and Calaveras move relatively toward the northwest and move almost purely in the horizontal plane. Locally, as along the Sargent fault and at a few other points where faults branch or splay, the fault movements may be more complex and show different orientations and substantial components of vertical movement. Nevertheless, the dominant pattern of movement recorded from earthquakes agrees with that observed in active fault displacements and from displaced rock units in the San Francisco Bay region.

San Andreas fault.--The most southwesterly of the three zones of earthquake activity extends from a point about 5 miles north of Watsonville to the southeast corner of the map. Data from beyond the map area (Lee and others, 1970) show that this zone of small-earthquake activity extends for many tens of miles to the southeast and that, for all this distance, it follows or closely parallels the surface trace of the San Andreas fault.

The belt of epicenters shown on this map does not exactly coincide with the line of mapped surface fault breaks, but lies generally 2 or 3 miles southwest of it. The map location of the surface fault breaks is known to be accurate and is the locus of past fault movements as well as of modern tectonic creep. Although the epicenters are not so precisely located, they are thought to be accurate to within a mile of their true position. If so, they indicate that the fault surface at depth lies to the southwest of its surface trace. This condition could result from a steep southwesterly dip on the surface fault, from a

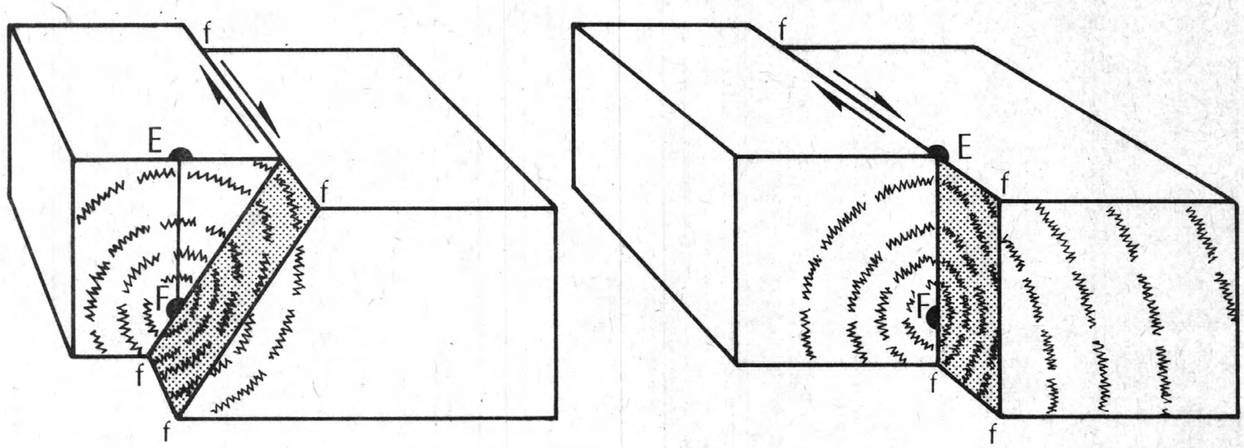

Figure 1. BLOCK DIAGRAMS SHOWING THE RELATIONSHIP BETWEEN:

F, earthquake focus or hypocenter: that point, generally at some depth within the earth's crust, from which the seismic energy appears to radiate; E, earthquake epicenter: a point on the earth's surface that is vertically above the source of the earthquake; f, fault surface (shaded): a fracture surface along which failure and accompanying dislocation have displaced adjacent blocks of the earth's crust. In both diagrams arrows indicate a right-lateral strike-slip sense of movement, as on the San Andreas fault.

series of discontinuous vertical fault surfaces stepped deeper towards the southwest, or from a more complicated fault zone geometry. Some such variation with depth is reasonable, in view of the complexity and variations in trend of the mapped surface fault breaks. However, we cannot entirely eliminate the possibility that much of the apparent discrepancy is due to systematic error arising from incorrect assumptions regarding seismic velocities in the earth's crust near the fault zone. Current research on crustal structure is aimed at resolving this problem.

Whatever the reason for the inexact match between surface faulting and epicentral locations, the small-earthquake activity is clearly related to the San Andreas fault, showing that this segment of the fault is now moving and, at least to some extent, is relieving crustal strain. Corroborative evidence of fault activity on this segment of the San Andreas fault is afforded by measurements of tectonic creep, which show that the blocks on opposite sides of the surface fault break are gradually moving apart at rates as great as a half an inch per year (R. O. Burford, written commun., 1971). The sense of movement is such that the block southwest of the fault moves horizontally towards the northwest relative to the opposing block, as shown in figure 1. Similar small-earthquake activity and tectonic creep at even greater rates occur along the San Andreas fault for nearly 70 miles to the southeast (Steinbrugge and Zacher, 1960; Brown and Wallace, 1968), so that in all, the actively moving segment of the fault is more than 100 miles long.

North of the junction with the Sargent fault, about 5 miles north of Watsonville, the San Andreas shows only sporadic earthquake activity. This activity is inadequate to show any well-defined linear trend, but four broad clusters of earthquake epicenters lie on or near the fault: one in the Pacific offshore from San Francisco, another about 2 miles south of Portola Valley, a third about 3 miles west of Cupertino, and a fourth in the Santa Cruz Mountains near Lake Elsman about 18 miles northwest of Watsonville.

The cluster offshore from San Francisco agrees with previous earthquake data which show relatively abundant epicenters in the same area for the years 1942-1957 (Tocher, 1959a, p. 48) and 1962-1965 (Bolt and others, 1968, p. 1737 and plate 1). The epicenter for the magnitude 5.3 earthquake that caused damage in the northern San Francisco Peninsula on March 22, 1957 was located nearby, as were the aftershocks of that earthquake (Tocher, 1959b).

The cluster of epicenters near Cupertino may be related to an unnamed southwesterly dipping reverse fault mapped by T. W. Dibblee, Jr. (1966), rather than to the nearby San Andreas fault. The location of the epicenters, the focal depth of these earthquakes, and the nature of the fault movement as determined from the seismic data favor an origin on the reverse fault, and suggest that at the depths at which the earthquakes occur (about 3 miles) the fault is moving. At the surface, rock units as young as Pleistocene are faulted, but Holocene and late Pleistocene alluvial deposits are not noticeably affected along the trace of the fault (T. W. Dibblee, Jr., oral commun., 1971).

More data may show a different distribution of epicenters along the San Andreas fault north of its junction with the Sargent fault, but the northern part of the San Andreas is clearly behaving differently from the segment south of the Sargent fault. Available data on historic seismicity (Tocher, 1959a; Niazi, 1964; Allen, 1968; Bolt and others, 1968) suggest that these differences have persisted over a much longer time period than that covered by the map. The absence of measurable tectonic creep on the San Andreas north of Watsonville since 1906 is added corroboration that the difference in abundance and distribution of small earthquakes is real and significant.

Calaveras and Hayward faults.--A second well-defined belt of abundant earthquake epicenters follows or closely parallels surface fault breaks along the Calaveras fault zone from its junction with the San Andreas fault 6 miles south of Hollister to a point about 5 miles east of Fremont. Farther north, the epicenters are much less abundant, but they appear to define a trend diverging northwestward from the Calaveras fault and merging with mapped surface breaks along the Hayward fault zone north of Fremont. This belt of less abundant earthquake activity roughly follows the Hayward fault nearly to San Pablo Bay.

Where earthquake epicenters are most abundant along the Calaveras fault, between Pacheco Creek north of Hollister and Calaveras Reservoir, they define a linear belt that lies a mile or so northeast of the mapped sursurface fault breaks of Radbruch (1968b). The mismatch between the belt of epicenters and the surface fault is similar but in the opposite direction to the mismatch observed on the San Andreas fault south of Watsonville. As with the San Andreas, the reason for lack of precise agreement between the surface fault and the belt of epicenters is not known. It may indicate a real divergence of the subsurface fault zone from the surface break, it may be related to unrecognized variations in seismic velocities in the earth's crust, or it may be due to a combination of causes. Despite the present uncertainty about the cause of the divergence, the belt of epicenters is clearly related to the Calaveras fault in much the same way as the San Andreas and the epicentral belt southeast of Watsonville are related.

The line of epicenters that connects the southern part of the Calaveras fault to the Hayward fault north of Fremont closely follows the Mission fault. This fault cuts rocks of Pleistocene age (Hall, 1953), but it exhibits little other evidence of recent surface displacement.

Indirect evidence, as yet incomplete, also suggests that the Hayward and Calaveras faults may be connected, for both faults show evidence of tectonic creep. Fault slippage, or creep, has been documented along the Calaveras fault from Hollister to a point about 15 miles north of Hollister (Rogers and Nason, 1971; R. O. Burford, written commun., 1971), and along the Hayward fault from Fremont nearly to San Pablo Bay (Blanchard and Laverty, 1966; Bolt and Marion, 1966; Bonilla, 1966; Cluff and Steinbrugge, 1966; Radbruch and Lennert, 1966). Although it has not yet been systematically verified on the Calaveras north of Coyote Reservoir, this segment of the Calaveras fault is less well known and is crossed by fewer structures that permit identification of gradual fault movement. Average rates of tectonic creep are about the same on the Hayward and Calaveras faults: about 0.1 inch per year to as much as 0.6 inch per year, with the greater rates on the southern part of the Calaveras fault north of Hollister.

The migration of small-earthquake activity from the southern Calaveras fault to the Hayward along the trend of the Mission fault is significant because it reflects a different dynamic response from that suggested by surface geologic relations. On geologic evidence the Calaveras fault has been mapped along a nearly straight course from Calaveras Reservoir through Dublin, where a major earthquake in 1861 resulted in at least 5 miles of surface faulting (Radbruch, 1968a) and northward along the San Ramon Valley toward Walnut Creek (Hall, 1958). Except near Dublin, recent surface breaks along the Calaveras fault have not been accurately located, and the exact location of the active zone to the north is uncertain.

For the 2-year period covered by the epicenter map this northern segment of the Calaveras fault does not exhibit the linear concentration of earthquake activity shown along the southern segment. Both the segment of the Calaveras fault that moved in 1861 and the nearby surface trace of the Pleasanton fault were seismically quiet during 1969 and 1970. However, the occurrence of a swarm of small earthquakes 3 miles southeast of Danville in May and June of 1970 (Lee and others, 1970b; Lee and others, 1971) appears to indicate activity on the Pleasanton fault, or possibly on the Calaveras, although this possibility seems less likely because the swarm is about 2 miles east of the projected trace of the Calaveras. North of Danville, and beyond the boundary of this map a diffuse group of epicenters extends northward beneath Walnut Creek and Concord and suggests that the active branch of the Calaveras fault trends toward Suisun Bay and connects northward with the Green Valley fault.

Sargent fault.--This fault is a relatively short (35 miles long) northwest-trending link between the Calaveras fault at Hollister and the San Andreas fault north of Watsonville. Epicenters are closely clustered along the southern half of the surface trace of recent movement and agree closely with the fault trace drawn from topographic evidence (Brown, 1970) south of State Highway 152. To the north, however, there is little evidence of earthquake activity on the Sargent fault during 1969 and 1970.

The distribution of epicenters south of State Highway 152 suggests that the currently active branch of the Sargent fault joins the San Andreas about 5 miles north of Watsonville, or some 15 miles southeast of the junction of recently active surface breaks of the Sargent and San Andreas.

Other concentrations of epicenters.--In several parts of the area covered by this map, less well-defined groups of epicenters suggest current activity on other fault zones. Where there is independent evidence that such fault zones have undergone recent movement, the earthquake epicenters are confirmatory evidence of current fault movements.

Several epicenters indicate a trend southeastward from Point Año Nuevo into Monterey Bay. This trend lies along or near the southeastern extension of the San Gregorio fault, mapped here on the basis of topographic lineaments between Point Año Nuevo and San Gregorio. Because two critical seismograph stations near the San Gregorio fault and its southeastern offshore extension were not installed until mid-1970, the number of events along this trend may be greater than that shown on the map. On geophysical evidence the San Gregorio fault is inferred to continue southeastward into the Carmel Canyon fault (Martin and Emery, 1967, p. 2290), a northwest-trending submarine fault that is south of the map boundary. Recent marine geophysical surveys have confirmed faulting of the sea floor in a wide northwest-trending zone beneath Monterey Bay (Gary Greene, oral commun., 1971) and have provided new evidence that the San Gregorio fault does continue southeastward from Point Año Nuevo (D. S. McCulloch, oral commun., 1971). Geologic evidence for recent movement on the San Gregorio fault is much less clear-cut than on the major fault zones to the east, but the alinement of small earthquakes suggests that this fault is active. Continued seismic surveillance, marine geologic investigations, and on-land geologic studies are needed to better delineate any recent fault traces and to evaluate their level of activity. Some of these studies, now in progress, are expected to provide the necessary data.

A trend indicated by several small clusters of epicenters extends about 18 miles southeastward from San Jose to the Calaveras fault at Anderson Reservoir. This trend locally coincides with a surface lineament that has been interpreted as evidence of recent movement (Brown, 1970) along a known fault in bedrock. Near San Jose, the epicenters, the lineament, and the bedrock fault as shown by Rogers (1966) roughly parallel the Silver Creek fault zone about 1 to 2 miles to the east, but near their junction with the Calaveras fault the two faults merge into a single complex zone. Although the evidence shown on this map indicates a more westerly line of activity, it is possible that the Silver Creek fault is the source of the earthquakes.

Several other groups of epicenters exhibiting short trends are shown on the map. Two such groups of epicenters are near Hollister: one about 5 miles northeast of Hollister suggests a northwest-trending earthquake belt that merges with the Calaveras fault north of Hollister, another about 8 miles southeast of Hollister trends a little north of west. Neither is more than about 10 miles long, nor can either now be confidently related to known surface faulting. A third diffuse but elongate group of epicenters parallels the Calaveras fault zone about 9 miles east of Calaveras Reservoir. It cannot yet be related to any known active fault.

More equidimensional groups of epicenters are evident at several places. Several of these clusters are located at, or near, the junction of active fault zones, and they appear to indicate more abundant and more diffuse activity at such junctions than on less complicated linear segments of fault zones. Clusters of this nature are at the junction of the Calaveras and San Andreas faults about 5 miles south of Hollister and at both ends of the Sargent fault. The cluster near Davnille may be related to similar activity near or at the junction of the Calaveras and Pleasanton faults, but this possibility is difficult to assess because of uncertainty as to the exact position of these two faults.

Some small clusters of epicenters or single epicenters may be related to quarry blasts or other manmade earthquake-like events. All known events of this kind have been deleted from the map, but because of the large numbers of epicenters it is not feasible to check each one individually. Despite the almost certain inclusion of some manmade events in the epicenter map, it is unlikely that any of the preceding geologic interpretations are seriously biased by shocks other than earthquakes. This is simply because the number of known tectonic earthquakes is relatively great as compared with the possible number of manmade events that have not been recognized and excluded from the map.

IMPLICATIONS OF THE MAPPED ACTIVE FAULT AND EPICENTER RELATIONSHIPS

The implications of the data shown on the map are clear. Those faults along which small earthquakes are recurring are active. They are potentially capable of generating much larger and more damaging earthquakes, some of which may be accompanied by sudden and extensive surface faulting.

What may not be so apparent from the map is that seismically quiet parts of these faults pose an equal or greater potential risk. North of its junction with the Sargent fault the San Andreas shows notably fewer small earthquakes than it does to the south. This represents a real difference in seismic activity for the time period covered by this map, one which also seems to be shown by longer term records. A similar decrease in activity northward along the Calaveras and Hayward faults is probably also real, and representative of long-term seismic activity. Each of these relatively quiet fault segments exhibits geologic evidence of repeated sudden fault displacements, and each has generated one or more major earthquakes during historic time. Some geologists (Allen, 1968; Brown and Wallace, 1968; Wallace, 1970) have noted that, throughout California, those segments of the San Andreas fault that are the quietest now are the ones which have been the site of one or more great earthquakes. They suggest that these segments are characterized by long periods of seismic quiescence (and strain accumulation) followed by relatively large earthquakes. The data are inadequate to evaluate this interpretation completely, but whether it is right or wrong, the absence or relative scarcity of small earthquakes on these known active fault zones clearly does not diminish the risk and, indeed, may increase it.

Perhaps the most optimistic interpretation of the uneven distribution of epicenters is that it is due to the short period of time represented by the sample. In this view, the lack of current seismic activity is nonrepresentative and will appear less significant as longer periods of record become available. This interpretation does not seem to be supported by earlier (pre-1969) seismic monitoring of the Bay region (Niazi, 1964; Bolt and others, 1968), which shows patterns similar to those evident in this map. However, modern seismic techniques have been available only for about 50 years at the most--hardly long enough to provide a truly representative sample of deformation on a fault system that has been active for at least 25 million years.

Besides the implications for future large earthquakes, the map relations together with other evidence indicate a current, and probably continuing, problem arising from gradual creep or slippage along some parts of known active faults in the San Francisco Bay region. The data that are available now show a close agreement between the most active linear seismic belts and fault segments that are undergoing creep. Systematic investigations of this relationship are now underway, but the current evidence, cited earlier in this report, suggests that creep at measurable rates is a potential risk along those segments of Bay area faults that display notably high levels of seismic activity. On this basis, fault creep is a real or potential problem on: 1) the San Andreas fault south of a point about 5 miles north of Hollister, 2) the Sargent fault southeast of State Highway 152, 3) the Hayward fault, and 4) all of the Calaveras fault south of Calaveras Reservoir.

Known average rates of fault creep in the Bay area are generally less than an inch a year, but higher rates are possible and short-term fault slippage with rates equivalent to 1 1/2 in./yr. are known from the San Andreas fault south of the map boundary (Burford, 1971). Even the lower average rates in the San Francisco Bay region are sufficient to damage many manmade structures and to warrant regular surveillance of tunnels, dams, pipelines, aqueducts or other vital structures that cross seismically active fault segments.

Some fault segments that exhibit abundant seismic activity and measurable tectonic creep are known to have ruptured abruptly during previous large earthquakes. Examples are the Hayward fault north of Fremont, which exhibited fault rupture in 1868 (Radbruch, 1968b), and the San Andreas fault north of San Juan Bautista, which exhibited fault rupture in 1906 (Lawson and others, 1908). These examples suggest that large earthquakes and abrupt surface movement may sometimes occur on fault segments where part of the strain is being relieved by small earthquakes and tectonic creep. Consequently, the presence of creep or abundant small earthquake activity cannot be considered a safeguard against larger and more catastrophic earthquakes.

HOW THE MAP WAS MADE

To understand the significance of the data and also something of their limitations, it is important to know how this map was made. The basis for the mapped active fault breaks has been discussed and is shown in the explanation. The epicenter locations were obtained by about 70 sensitive seismograph stations. These stations are distributed to provide the maximum efficiency and accuracy in monitoring seismic activity on known and suspected active faults in the south Bay region, especially those that are part of the San Andreas fault system. Most of the stations are operated by the U.S. Geological Survey and are connected by leased telephone lines to a data-collection and data-processing center in Menlo Park, California; but some data are obtained from seismographs of the University of California and from those of the Earthquake Mechanism Laboratory of the National Ocean Survey, National Oceanic and Atmospheric Administration.

Besides the relatively permanent stations operated by the U.S.G.S. and other research organizations, temporary field seismograph nets are operated for periods of days, weeks, or months in order to study aftershock sequences or to make more detailed local studies of seismicity. One such local network of field seismographs operated in the Danville area during the aftershock sequence that followed the May 26, 1970 earthquakes. Some of the output from that network is incorporated in this map and is easily recognized as a cluster of closely plotted epicenters about 3 miles southeast of Danville. Of the Danville earthquakes, 426 are not shown, because the computer plotting of all events in so small an area would have damaged the paper on which the initial compilation was made.

A thorough discussion of the theoretical basis and procedures for epicenter location is beyond the scope of this report, but a general concept of the technique helps to understand the map and its significance. The method used here is a simple one. It depends upon determination of the exact time of arrival of the first seismic wave ("P wave") at the seismograph station. At each U.S. Geological Survey station a seismometer monitors the vertical component of ground motion. Simultaneously, precisely timed signals for calibration of the ground motion record with Greenwich Mean Time are continuously recorded. If the velocity of the seismic wave is constant between the epicenter and each recording station, the wave will be detected earlier at near stations than at distant ones, and if enough stations record the event its epicenter can be calculated from the arrival time data and from the known geometry, or map distribution, of the recording stations.

The calculation of epicentral locations is actually much more complex, largely because the earth's crust is not homogenous and because seismic wave velocities vary with changes in crustal properties. In general, deeper crustal layers conduct seismic waves at greater velocities than do shallow layers. By painstaking analysis of many seismograms, seismologists can interpret deep crustal structure and can postulate theoretical models of the crust which provide a reasonably good fit to observed data. Where such models are available and where they accurately represent actual crustal conditions, earthquakes can be very accurately located.

The model used to determine the epicenters on this map assumes four different horizontal layers and four corresponding velocities in the uppermost 15 miles of the earth's crust. Deeper layers of the crust play an insignificant role in the location of the local earthquakes, and the most critical depths are those shallower than about 9 miles. The model is a reasonable one for average crustal properties in the area of this map, but locally crustal structure and seismic velocity may depart significantly from that assumed.

The error in location due to inaccuracies in the velocity model and to other causes may amount to as much as a mile or two for the earthquake epicenters shown on this map, although most epicenters are probably more accurately located. Such errors tend to shift the epicenter pattern while preserving the relative distribution of earthquakes.

Earthquake magnitude, shown on the map by the symbol locating each epicenter, is a function of the amount of energy released by an earthquake. It is

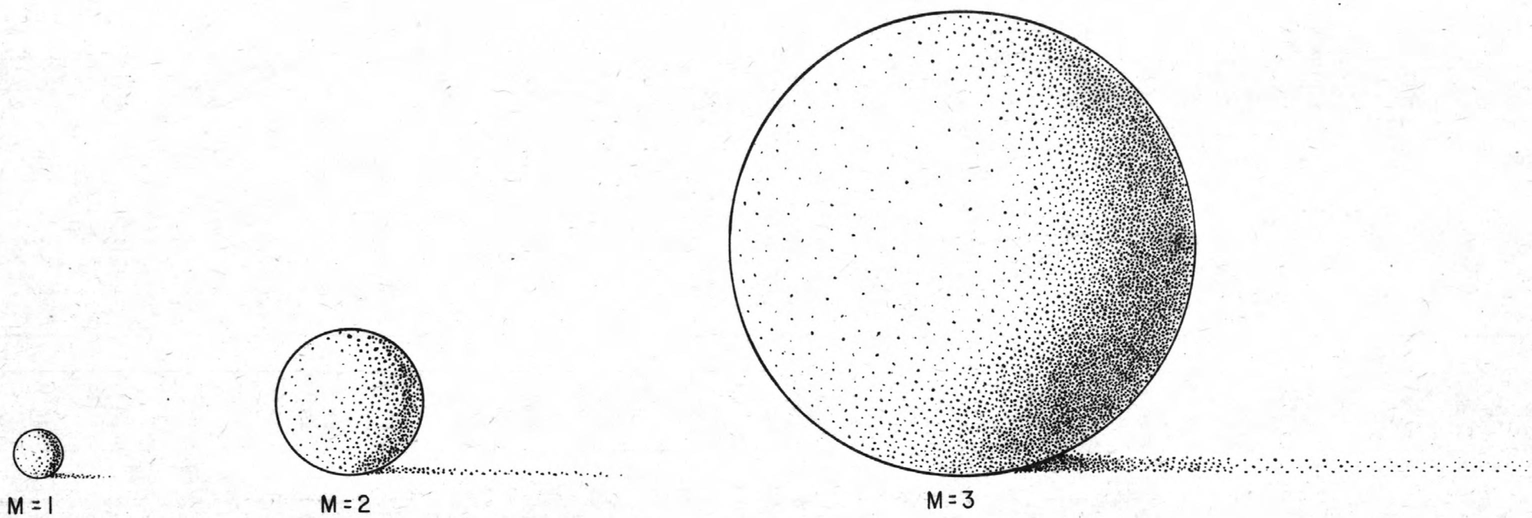

Figure 2. RELATIONSHIP BETWEEN EARTHQUAKE MAGNITUDE AND ENERGY

The volumes of the spheres are roughly proportional to the amount of energy released by earthquakes of the magnitudes given, and illustrate the exponential relationship between magnitude and energy. At this same scale the energy released by the San Francisco earthquake of 1906 (M=8.3) would be represented by a sphere with a radius of 110 ft.

determined by noting the amount of deflection of a seismogram trace at a known distance from the epicenter, and relating this deflection to a set of standards devised by C. F. Richter. It is important to recognize that the magnitude scale varies logarithmically and that each whole-number step in the scale represents about 30 times more energy than the preceding one (fig. 2). With very few exceptions, the plotted epicenters represent earthquakes that are thousands of times smaller, in terms of energy released, than the minimum shock that would be likely to cause damage to manmade structures, and they are hundreds of thousands of times smaller, in terms of energy released, than major earthquakes.

All of the earthquake epicenters as well as the magnitude determinations shown on this map were calculated and plotted by a computer. Earthquakes that occur within the net of dense seismograph stations can be relatively accurately located, and all those greater than 0.5 magnitude that are within the net are shown, except for those previously noted near Danville. An unknown number of earthquakes outside the net were not located by the network stations, even though they were 0.5 magnitude or greater. Thus areas that are distant from the seismometer net and that appear on this map to be seismically quiet may have considerable small earthquake activity.

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