AN EXPLANATORY TEXT TO ACCOMPANY THE 1:750,000 SCALE FAULT AND GEOLOGIC MAPS OF CALIFORNIA

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- FAULT PATTERNS
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  Formations
  Source Data

BULLETIN 201

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BULLETIN 201

AN EXPLANATORY TEXT TO ACCOMPANY THE 1:750,000 SCALE FAULT AND GEOLOGIC MAPS OF CALIFORNIA

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PREFACE

This bulletin was prepared after the GEOLOGIC MAP OF CALIFORNIA was published in 1977. The parts dealing with hot springs and wells, and with source data, now included in the appendices to this bulletin, were prepared in draft form in conjunction with the FAULT MAP OF CALIFORNIA published in 1975. Most of the text was written in 1978 and a first draft was reviewed at that time. After several delays the manuscript was approved for publication in 1981.

The data in Appendix B, Tabulated List of Thermal Springs and Wells have been incorporated in the U.S. Geological Survey GEOTHERM data bank and later the California Division of Mines and Geology, Geologic Data Map No. 4, GEOTHERMAL RESOURCES OF CALIFORNIA. It is included in this bulletin as documentation for the locations of thermal springs and wells shown on the FAULT MAP OF CALIFORNIA, WITH LOCATIONS OF VOLCANOES, THERMAL SPRINGS AND THERMAL WELLS, Geologic Data Map No. 1.

The Source Data Index (Appendix D), although somewhat outdated, is still the best guide to the most useful and available areal geologic mapping in California to approximately 1972, and its annotations indicate the sources used to classify the recency of activity of faults in California. The Source Data Index also contains some data to 1975.

This bulletin reviews the history and development of geologic and fault maps of California. The author has taken this opportunity to articulate various ideas and speculations pertaining to the geology and structure of California that have occurred to him over the years he has spent compiling maps published by the California Division of Mines and Geology.

ABSTRACT

The latest in a series of State Geologic Maps of California was published in 1977, and a Fault Map of California was published in 1975. Bulletin 201 attempts to put these maps in historical perspective by describing in chronological order the earlier state maps of both these types. The bulletin explains various uses for these maps and also discusses precautions against their misuse.

This volume is divided into three parts. The first deals with the Fault Map of California. The evolution of fault maps of California is described beginning with the first fault map of the state (published in 1908), and ending with a detailed description of the 1975 Fault Map of California. Emphasis is placed on historic and Quaternary faults and the criteria used to classify them. Fault patterns recognized in California are discussed, and structural provinces of the state, as defined by predominant fault trends, are proposed. The limitations in the use of the Fault Map of California for land-use planning are reviewed. Finally, a discussion of the volcanoes and thermal springs and wells that are plotted on the Fault Map concludes the first part of Bulletin 201.

The second part of the bulletin, pertains to State geologic maps of California. A brief historical account of early geologic maps of the state is followed by a discussion of the 1977 edition. The objectives and contents of the map are described, and considerable explanation is given to the compilation method and the physical appearance of the map, including a discussion of the choice of colors, patterns, and symbols. A brief explanation of batholiths and other plutons, as well as the offshore geology, follows.

The third part of the bulletin consists of reference data organized in four appendices. Appendix A is an index to the 272 fault names shown on the Fault Map of California. In addition, a procedure for the naming of faults that would avoid repetition and confusion is suggested.

Appendix B consists of a tabulated list of 584 thermal springs and wells, organized by 1° x 2° State Map Sheet units. This list contains location and temperature data, and pertinent references. For the thermal wells, total depth and year drilled are also given. The location of each thermal spring and well is shown on the index maps to the source data in Appendix D.

Appendix C is an index to the over 1,000 geologic formations grouped within the units portrayed on the 1977 Geologic Map of California.

Lastly, Appendix D is an extensive index to the source data used to compile the Geologic Map and for classifying the faults on the Fault Map. This index is keyed to 28 maps showing in detail the area covered by the references listed in the bibliographies.

Bulletin 201 consists of 197 pages, including 16 figures, 15 tables, and two plates. The Bulletin was designed to accompany the Fault Map of California (1975) and Geologic Map of California (1977), and hopefully will enhance the usefulness of these maps by providing additional explanation and background data.

AN EXPLANATORY TEXT TO ACCOMPANY THE 1:750,000 SCALE FAULT AND GEOLOGIC MAPS OF CALIFORNIA

BY CHARLES W. JENNINGS

INTRODUCTION

The Fault Map of California (1975), the Geologic Map of California (1977), and this bulletin culminate nearly ten years of extensive research. To a degree these maps represent the "state-of-the-art" in California regional geology. They supersede the Preliminary Fault and Geologic Map of California on the same 1:750,000 scale, published by the California Division of Mines and Geology in 1973.

The Geologic Map of California presents an overview of the geology and structure of the state with sufficient detail to be useful for many purposes. It should fill the need for a modern geologic wall map showing the distribution of the major rock types and the major structural elements of the state. The Fault Map of California, on the other hand, emphasizes fault activity in the state and differentiates faults according to time of activity. The fault map also shows the locations of the numerous recent volcanoes in California and the locations of all known thermal springs and wells.

This bulletin was prepared to accompany the Fault Map and the Geologic Map and is intended to enhance their usefulness by providing additional explanation. This report also describes the historical antecedents of these two maps, the latest in a sequence of state geologic maps that was started in 1891. No attempt has been made to write a comprehensive "Geology of California"—so much is now known and the problems are so complex that California geology, for most intents and purposes, has become the field of specialists. Nor has the writer attempted to summarize or generalize the basic facts of California's geologic history because at least two effective overviews have been published in recent years: G.B. Oakeshott's "California's Changing Landscapes" (1971 and 1978), and Norris and Webb's "Geology of California" (1976). Readers are referred to these texts, as starters, if they are unfamiliar with the geologic setting in California. For more advanced considerations of California geology, the recent literature abounds with outstanding papers. Some of the most instructive are the outgrowth of symposia on various topics, or field trip guides to specific areas within the state. To list these would require much space; however, the reader is referred to the "References Cited in Parts I and II" on pages 69-74 wherein many useful papers are included.

Bulletin 201 consists of two main parts and four extensive appendices. Part I is a detailed explanation of the Fault Map of California and Part II is a discussion of the Geologic Map of California. Part III contains four appendices: (1) an index to the faults shown on the 1975 edition of the Fault Map, (2) a tabulated listing of data for the thermal springs and wells depicted on the Fault Map, (3) an index to the geologic formations grouped within each of the units shown on the Geologic Map of California, and (4) a detailed bibliography keyed to 27 index maps identifying all of the source data used to compile the Geologic Map and Fault Map.

The Geologic Map of California and the Fault Map of California are syntheses of the available information on the geology and structure of California. An attempt was made to summarize and incorporate some of the currently accepted conclusions regarding the geologic evolution of California, for example, depiction of the Coast Range thrust fault as the upper boundary of a late Mesozoic subduction zone; however, little attempt was made to devise a uniform structural interpretation of the entire state. Uniformity is certainly desirable; however, it was believed that to achieve it on a map of a state as large and complex as California would be a difficult and time-consuming task and might even prove to be of dubious value. It was decided, therefore, to concentrate more intently on the basic data, namely the distribution of the various rock units, and generally to use the structural interpretations shown by the authors of the source data.

In synthesizing data from individual maps, an attempt was made to follow the field geologist's interpretation as closely as possible, but in order to harmonize one map with another, it was often necessary to be arbitrary in the selection of what is most significant. No two compilers will make identical decisions; however, at the onset of this project, guidelines were established and followed by all those who assisted in the compilation. In the final map-synthesis, the writer tried to view the state as a whole and tried to give the compilation a certain balanced judgment. Thus, in the resulting maps, the depiction of faults, especially *recent faults,* was considered more important than the portrayal of rock types. In congested areas, faults may have sometimes been exaggerated by connecting several segments, or by generalizing the local geology.

Purpose and Uses

The primary purpose in preparing the Geologic Map of California was to show clearly the regional relationships of rock and time-rock units in California, and of the Fault map of California, to depict the faults as to their recency of movement. The maps summarize up-to-date geologic information on California for use in applied and theoretical geology.

These are multipurpose maps. The Geologic Map portrays the geologic setting of mineral deposits of California and can be used in planning mineral resources investigations. It is helpful in making regional land-use plans, soil surveys, and in locating and planning large-scale civil engineering projects such as roads, dams, tunnels, and canals. The Fault Map is an inventory of faults in the state and can be useful in preliminary earthquake hazard evaluations. A preliminary version of this map was published to aid local governments in preparation of seismic safety elements required by California law as part of the general plans (or master plan) for cities and counties. The Fault Map is also useful as a guide to Quaternary and recent volcanism and thus is useful in consideration of possible volcanic hazards. Lastly, the locations of thermal springs and wells shown on the Fault Map are indications of abnormally high temperature gradients and are useful in the exploration and development of geothermal power. The Geologic Map of California and the Fault Map of California are also useful in classrooms for those teaching and studying geology, seismology, and geophysics, as well as related fields such as geography, oceanography, ecology, and soils.

Value of Map Compilations

A compilation is no better than the data sources from which it is compiled, which usually vary from detailed to general maps. A compilation, however, can go beyond the scope of the source maps and reveal broader relationships, by virtue of the capability of synthesizing individual areas and thereby revealing important regional trends. A careful synthesis thus reveals new concepts, which because of their magnitude, may be more important than the details.

Base Map

The base map used on the Fault Map of California and the Geologic Map of California is a reduction of the two-sheet 1:500,000 scale Map of California published in 1970 by the U.S. Geological Survey. These two sheets were reduced to 1:750,000 scale and joined to make a single map 4 ½ by 5 feet. The use of a single large-size sheet instead of two separate sheets eliminated problems in registration and matching of colors from sheet to sheet and, most important of all, allowed the faults, geologic formations, and structures to be displayed with uninterrupted continuity.

The base map indicates county boundaries in green; cities and towns, highways and roads, railroads, and the township-and-range boundaries in black; and rivers, streams, and other water features, including ocean depth curves at 100 fathom intervals, in blue. Contours, at 500-foot intervals with 100-foot supplementary intervals, are shown in brown on the Fault Map and are available on the Geologic Map (part of the first printing of the Geologic Map was without contours). The base map is a Lambert conformal conic projection, based on standard parallels 33° and 45°. The highways shown are correct to 1969.

Source Data

In a state as large and geologically complex as California, the quality and accuracy of the geologic mapping varies. In general, the latest information available was used. The 1:250,000 scale Geologic Atlas of California was the principal source, but extensive revisions were made and nearly 900 new references were added, approximately 30 percent of which were from unpublished sources.

The continual progress and rate of growth in preparation of published and unpublished geologic maps in California are shown in Figures 1 and 2.

Among the unpublished data, besides geologic theses and dissertations, some company and consultant reports are included and unpublished maps by geologists of the California Division of Mines and Geology and other State and Federal agencies, especially the California Department of Water Resources, and the U.S. Geological Survey. Extensive reconnaissance maps of parts of the northern Coast Ranges, which were made by the Department of Water Resources in connection with proposed dams and tunnel routes, were very useful in revising the Ukiah Sheet area, and the extensive work by the U.S. Geological Survey in the San Francisco Bay Region Environment and Resources Planning Study was invaluable in the revision of several Bay area sheets.

Unlike the extensive mapping done by the staff of the Division of Mines and Geology for the preparation of the State Geologic Atlas, most of the Division maps used in the 1:750,000 scale compilation were taken from projects such as the urban mapping cooperative projects with cities and counties and from the completion of 15-minute or 7 ½-minute quadrangle projects. The preparation of a totally revised 1:250,000 scale Death Valley sheet (Streitz and Stinson, 1977) was especially useful, and indeed, was done in part to aid the 1:750,000 scale compilation. Work done by the Division specifically for the 1:750,000 compilation included extensive photo-interpretation of Quaternary faults in northeastern California and field evaluations of selected faults to determine their extent or recency of movement.

Preparation of the 1:750,000 scale map began in 1969, and revisions were added to keep the work sheets current until about 1972. An extensive review of the product was then undertaken with the help of many geologists both inside and outside the Division of Mines and Geology. As a result, numerous changes and additions were made to the compilation. After 1974, while the maps were being drafted for publication, no attempt was made to keep the compilation current, because of lack of time and the difficulties of making piecemeal revisions of areas which had already been drafted. However, some later data, especially newly recognized faults, or data affecting the fault classification, were incorporated. The offshore area was the largest single area thus affected, because of the vast amount of new data released by the U.S. Geological Survey. All reference data used in the compilation are indexed by atlas sheets, and shown in Appendix D.

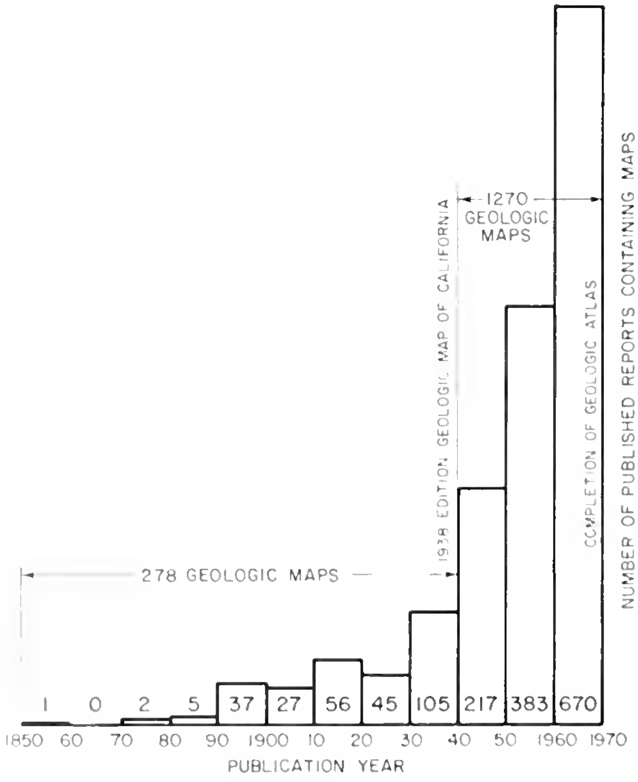

Figure 1. Increase of published geologic map data for California.

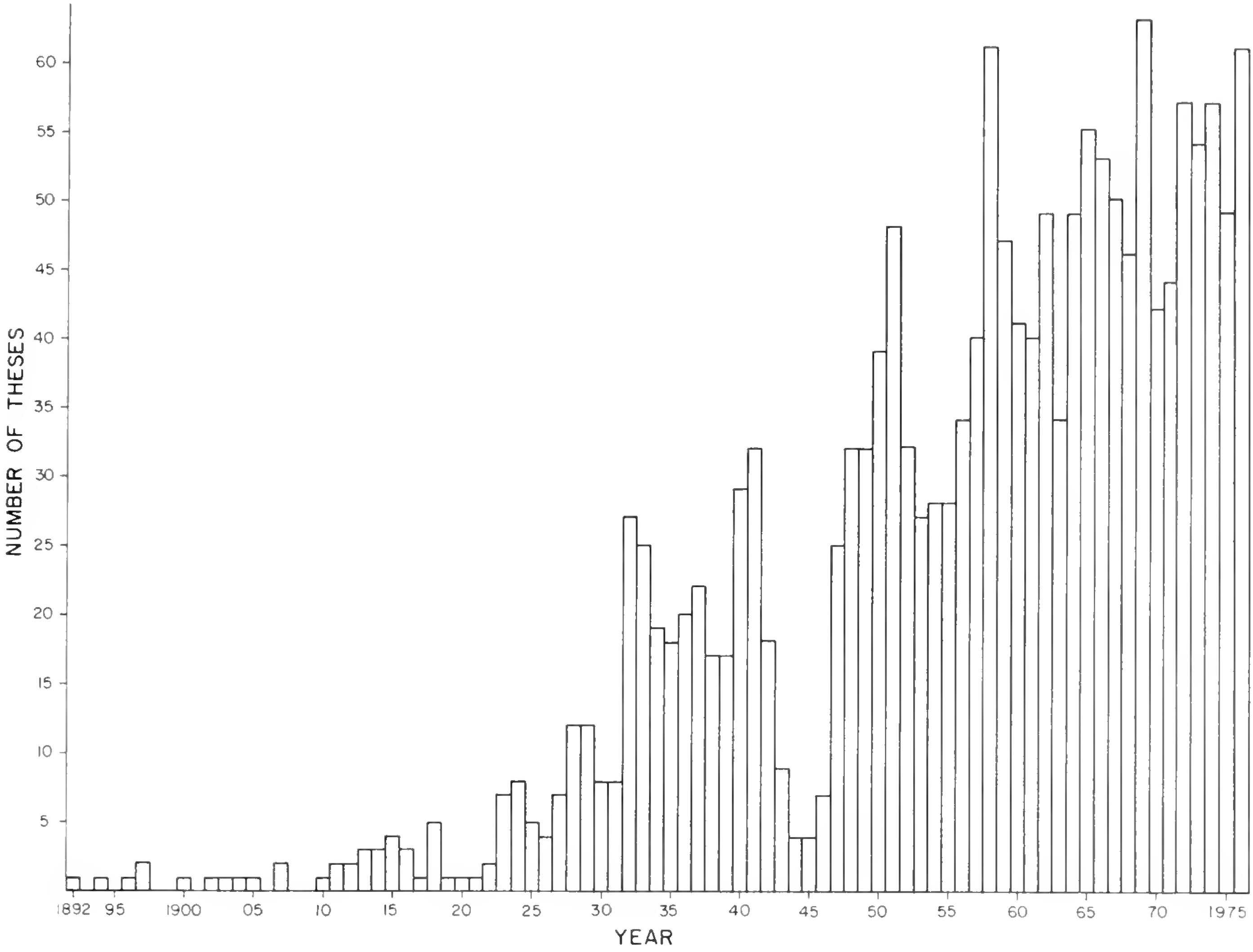

Figure 2. Theses on California geology 1892-1976 (exclusive of topical and broad regional studies).

Acknowledgments

The Fault Map of California and the Geologic Map of California are based on the work over many years by a vast array of geologists and institutions. In a way, these two maps represent about 150 years of geologic exploration and mapping since Lieutenant Edward Belcher first surveyed the "Port of San Francisco," which became in 1839 the first published geologic map of any part of California. Acknowledgment therefore goes to all the geologists down the years who have mapped in California, for only by drawing on this collective body of knowledge have we arrived at our present level of understanding of the state's rocks and structure.

Within the Division of Mines and Geology, the writer is especially grateful to R.G. Strand and T.H. Rogers for their assistance in compiling and revising the 1:250,000 scale work sheets during the first stages in the preparation of the compilation. M.C. Stinson in the later stages helped revise the depiction of selected Quaternary and historic faults, and J.L. Burnett prepared a photogeologic interpretation of Quaternary faults for the northeastern part of the state. J.E. Kahle provided valuable assistance in the location of historically active faults, and his unpublished catalog of "Earthquakes with Surface Faulting or Ground Breaks and Creep Events" was particularly valuable. R. Streitz and M.C. Stinson substantially improved the representation of the geology in the Death Valley Sheet area by the preparation of a new compilation of this sheet (Streitz and Stinson, 1977). Robert Switzer assisted in the interpretation of some of the latest geologic data used in updating the compilations and also in making numerous corrections immediately prior to submittal of the maps to the printer. The painstaking task of coloring the preliminary compilation, photographic prints of which were used in the reviewing process, was done by my daughter, Marcia Jennings.

The compilations benefited greatly by the comments and new data generously provided during careful review of this map by members of numerous federal and state agencies, as well as independent geologists familiar with California geology. At the risk of appearing partial, I would like to mention the following geologists who made particularly constructive suggestions or contributed new data covering large areas of the state: E.H Bailey, E.E. Brabb, T.W. Dibblee, Jr., P.E. Hotz, W.P. Irwin,

R.D. Nason, H.C. Wagner, C.M. Wentworth, and J.I. Ziony, all of the U.S. Geological Survey; Professors C.R. Allen, California Institute of Technology; J.C. Crowell, University of California, Santa Barbara; C.A. Hall, University of California, Los Angeles; B.M. Page, Stanford University; C. Wahrhaftig, University of California, Berkeley; and M.L. Hill and A.O. Woodford, Pomona College, Claremont, California. To all these geologists and many other unnamed contributors, the State is especially grateful.

Of all the individual contributors to the geologic mapping of California, surely Thomas W. Dibblee, Jr. warrants special recognition and appreciation. A vertiable one-man geological survey, he mapped and published more than eighty-four 15-minute and thirty-five 7 ½-minute quadrangles. In addition, Mr. Dibblee has numerous geologic quadrangles that he has mapped but not published.

The immense task of scribing and preparing the plates for publication was expertly done by R.R. Moar, R.T. Boylan, and R.A. Switzer of the Division. The Fault Map of California and The Geologic Map of California could not have become a reality without the ready help of Merl Smith, Publications Supervisor of the California Division of Mines and Geology. His sage advice in lithographic matters and his assistance in obtaining the type of map we desired are especially recognized.

The maps were printed by the Williams and Heintz Map Corporation of Washington D.C., under the masterful supervision of William Heintz. Mr. Heintz's keen interest, cooperation, and patience were demonstrated time after time while we experimented with different colors, shades, patterns, and formats.

In the preparation of this manuscript, two of the four appendices—the Tabulated List of Thermal Springs and Thermal Wells and the Source Data Index—could not have been possible without the extensive help of John Sackett, Duane McClure, Melvin Stinson, and Robert Switzer, who plotted most of the thermal springs and wells; David Peterson, who assisted in the preparation of the source data index; and Robert Switzer, who drafted most of the plates. The initial manuscript was edited by Virginia McDowell. Dorothy Hamilton carefully and cheerfully typed and proof-read this manuscript, including all the extensive listings, and all the revisions.

Special thanks are due B.W. Troxel, R.D. Nason, J.W. Williams, G.B. Oakeshott, D.L. Wagner, S.J. Rice, R.G. Strand, and C.R. Real, who read all or parts of the manuscript and generously aided with constructive criticism.

To all those mentioned above, and all the unnamed individuals who over the years contributed or encouraged the preparation of these two maps and this bulletin, I wish to express deepest thanks and appreciation.

PART I
FAULT MAP OF CALIFORNIA

He looketh on the earth, and it trembleth:
He toucheth the hills, and they smoke.

—-Psalm 104
Verse 32

FAULT MAP OF CALIFORNIA

INTRODUCTION

The 1975 Fault Map of California depicts the most recent knowledge on the distribution and nature of faults in California. It also indicates as factually as possible the activity of the faults. Indications of the degree of activity on faults that have been mapped in the state are based on the recency of the last recognized movement.

The following section briefly discusses when faulting was recognized as the principal cause of earthquakes and how faults were considered on early California geologic maps. The evolution of fault maps of the state is then presented before going into a detailed discussion of the present Fault Map of California. Regional fault patterns are discussed, and the writer then presents his concept of structural provinces of California based on the predominant fault directions recognizable in the state. The relationship of faults to patterns of seismicity is discussed. Lastly, other features depicted on the fault map, such as volcanoes and thermal springs and wells, are described and related to faults where appropriate.

RECOGNITION OF FAULTING AS CAUSE OF EARTHQUAKES

The understanding of earthquakes has come a long way since Josiah Whitney, early State Geologist of California, considered that ground fractures associated with the great 1872 Owens Valley earthquake were of small importance. The prevailing thought at that time was that ground fractures were the result, not the cause, of earthquakes.

As a matter of historical interest, it was not until 1819, in connection with the Cutch, India earthquake of that year, that surface faulting itself was first recognized *and well documented* as accompanying an earthquake. In California, the first descriptions of ground displacements associated with major earthquakes were in 1836 on the Hayward fault and in 1838 and 1857 on the San Andreas fault. However, descriptions of ground displacements during these earthquake-events were in newspaper accounts and were not made by trained observers. In fact, it was not until many years later that the connections between these earthquakes and these specific faults were recognized (Lawson, 1908; Louderback, 1947).

In California it probably was LeConte who first proposed the idea of faulting as a *cause* of earthquakes. In his article "On the Structure and Origin of Mountains," LeConte (1878, p. 101) considered readjustment along the fault at the eastern base of the Sierra Nevada as the cause of the Owens Valley earthquake. Later, LeConte (1886, p. 179) stated that "With every readjustment and increase of fault [movement] there is probably an earthquake." Worldwide, according to Davison (1927), the first person to attribute an earthquake to the movement along a fault probably was Rev. Fisher (1856) in his description of the Visp, Switzerland earthquake.

What we now take for granted, that movement along faults is the cause of most earthquakes, did not become generally accepted until after the 1906 California earthquake and H.F. Reid's (1910) precise theoretical formulation of the elastic rebound theory. However, the English engineer Milne, anticipated Reid's elastic rebound theory by 24 years (but, without of course, the benefit of Reid's rigorous analysis of accurate triangulation surveys across the San Andreas fault):

> The ground is broken and slips either up, down, or sideways, as we see to have taken place in the production of faults. Here we get distortion in the direction of the movement, and waves are produced by the elastic force of the rock, causing it to spring back from its distorted form (Milne, 1886, p. 47).

Though faults had long been noted in older rocks, as in the case of displaced beds, early geologic maps mostly ignored fault features or only noted an occasional fault. Individual U.S. Geological Survey folios for California (from 1894 to 1914) show no faults, or at most two or three on a folio map before 1909. Fairbank's San Luis Folio (1904) shows several faults on a cross section, but the faults are not shown on his geologic map. However, it appears to have been early U.S. Geological Survey policy not to show faults on the folio maps even if the geologists had mapped them as Fairbanks had done (Olaf P. Jenkins, personal communication, 1957). In 1909, the Santa Cruz folio by Branner, Newsom, and Arnold was published, and it displayed many faults. Perhaps the Geological Survey changed its policy for this folio because the area it maps blankets a segment of the San Andreas fault zone, the importance of which had been dramatically demonstrated by the 1906 California earthquake. The San Francisco folio by A.C. Lawson, published in 1914, also portrayed many faults on the maps and on the cross sections. However, no faults are shown on Lawson's map of the San Francisco Peninsula, published in the 15th Annual Report of the U.S. Geological Survey (1893-94), although in the text the San Andreas and other faults are discussed at considerable length.

A perusal of other early geologic maps of areas in California also reveals few mapped faults. The earliest volumes of the University of California Publications in Geology show but few faults, albeit more than on the early U.S. Geological Survey folios. Apparently, in early geologic mapping more attention was given to plotting the rock distribution than in trying to resolve geologic structure.

EVOLUTION OF FAULT MAPS OF CALIFORNIA

First Fault Map of the State—1908

The atlas of the State Earthquake Investigation Commission report (Lawson and others, 1908) contains a map of California and the adjacent states, showing the more important known faults. This report and atlas were the result of the monumental investigation of the 1906 California earthquake which did such heavy damage in north coastal California. The fault map in the atlas is the first attempt to depict faults in California statewide (Lawson and others, 1908, p. 346). The scale of the map is approximately 1 inch equal to 30 miles, and the title is: "Geomorphic Map of California and Nevada with portions of Oregon and Idaho showing the diastrophic character of the relief, the steep descent from the sub-continental shelf to the floor of the Pacific, and the more important faults"—a cumbersome but accurate description of the map. Plate 1A (pocket, herein) is a reduced version of this map identifying the faults described in the Lawson report.

Lawson's map is very interesting, for some of the faults shown on it were subsequently, and mistakenly, ignored on later maps. On Plate 1A, the San Andreas fault is shown extending about as far south as San Gregorio Pass. The prominent portion of the San Andreas fault in the Mecca Hills, on the east side of Coachella Valley and on the east side of Salton Sea, had not been discovered. To the north, however, the Shelter Cove fault rupture of 1906 is joined to the San Andreas where it leaves the mainland at Point Arena. This speculative connection, concealed by the waters of the ocean and requiring a broad curve in the otherwise long straight stretch of the fault, was later thought to be unreasonable, and the segments were not joined together on most subsequent maps. This lack of connection persisted until 1967 when sonic profiling at sea showed that the San Andreas fault does indeed swing back to shore at Shelter Cove (Curray and Nason, 1967).

The Sierra Nevada fault is shown on Lawson's map as being cut off at its southern end by the San Andreas fault at Gorman. Actually the Garlock fault, as we know it today, intersects the San Andreas fault at Gorman and also intersects the Sierra Nevada fault northeast of the town of Mojave. The Garlock fault also extends far eastward into the southern Death Valley area. The Mojave Desert on Lawson's map is, as we might expect, shown as being devoid of faults, for little of the desert land had been explored or even mapped topographically by 1908. The northern extent of the Sierra Nevada fault is shown as an almost continuous trace following the eastern side of the Sierra Nevada crest past Lake Tahoe and into Plumas County. Modern detailed mapping shows that this continuity is a gross oversimplification.

Lawson described (p. 19) a "San Gabriel branch of the San Andreas fault" in southern California heading westward to the ocean at Carpinteria. This fault line quite accurately connects what are now known as the Cucamonga, Sierra Madre, Santa Susana, and Oakridge faults. What is mapped as the San Gabriel fault today lies farther north, within the San Gabriel Range, and then heads northwestward, joining the San Andreas near Gorman.

The San Jacinto and Elsinore faults are crudely depicted on Lawson's map, but the Whittier and Malibu-Santa Monica faults are quite accurately drawn.

The Kern Canyon fault is quite accurately located, and Lawson's map, unlike several succeeding maps, shows its full northern and southern limits. A prominently depicted fault west of the Kern Canyon fault is not recognized on later geologic maps.

Some other important faults in the southern part of the state that were mapped at that time (at least in part) include the San Clemente Island, Santa Ynez, and Nacimiento faults.

In central California, Lawson (1908, p. 19) described a "Santa Lucia fault" as "one of the dominant structural lines of the Coast Ranges at the base of the Santa Lucia Range on the border of Salinas Valley." Today we know the northern part of this structural line as the King City fault. Lawson shows this fault continuing southeastward to San Miguel. This part is incorrect according to modern maps, which show the King City fault as a possible continuation of the Rinconada fault somewhat farther to the west.

In the San Francisco Bay area, the Hayward fault is correctly depicted, but its north-bay counterpart, the Rodgers Creek-Healdsburg fault, is missing. However, in the text, Lawson (1908, p. 17-18) discusses the prolongation of the "Haywards" fault on the east side of the Santa Rosa and Russian River Valley northward to about Cloverdale. The Calaveras fault is not well located, but the shorter Concord and Green Valley faults are recognized. Other faults correctly mapped in the Bay area are the San Gregorio fault and the San Bruno fault. A strange fault is shown directly cross-cutting the San Andreas at Pajaro Gap and is described by Lawson (p. 19) as: (1) lying approximately on the axis of the geosyncline of Monterey Bay, (2) transverse to the San Andreas and intersectng it, and (3) near the place where the 1906 surface rupture ceased.

In the east central part of the state, the White Mountains fault is recognized and extended as far south as the Coso Mountains. In northern California, the Mother Lode faults are totally absent, but probably this was because of their great antiquity and complexity. The Mother Lode fault system was also not recognized on several subsequent geologic maps of the state, including the 1938 Geologic Map of California.

The fault along the Chico monocline is correctly depicted from its southern extent near Paradise, but it is drawn too far north. By the time the second fault map of California was published (Willis, 1922), only a small segment of this fault (east of Red Bluff) was shown (as a probable fault). When the next map (Jenkins, 1938) was published, no faults were shown in this area. Mapping for the Chico Sheet of the Geologic Atlas rediscovered these faults (Burnett, 1963). Admittedly, the faults only show small displacements, but their continuity and abundance on the crest of the monocline are very striking on aerial photos and are also very interesting in that they are aligned with the active Foothills fault system to the southeast.

Lawson correctly shows the Honey Lake fault and the Surprise Valley fault in northeastern California. He also noted other important faults in this part of the state, but owing to lack of adequate maps and only crude reconnaissance studies, misconnections were made. The same is true of the northwestern part of the state. The Orleans fault was recognized at its northernmost extent (where it crosses into Oregon), but unlike the simple curving line depicted, the Orleans fault to the south is now known to take a much more circuitous route, befitting a low-angle thrust fault, before continuing for many miles to the southeast. Actually the southern two-thirds of this fault, about 145 km (90 miles), in extremely rugged terrain, is quite correctly located on Lawson's map. Just west of this fault, is O.H. Hershey's "Redwood Mountain" fault (Lawson and others, 1908, p. 17). This corresponds to the South Fork Mountain fault of the Geologic Atlas.

It is interesting to note that faults were not depicted on any of the state geologic maps preceding Lawson's 1908 fault map (see Section II, herein), nor were they shown on the 1916 geologic map of California. G.A. Waring (1915), in describing the springs of California, tried to show the relationship of springs to faults in the state, but a note on his map indicates that the faults were taken from the atlas accompanying the 1908 State Earthquake Investigation Commission report.

In 1916, Harry O. Wood, in a study of faults in California as generators of earthquakes, published a modified version of Lawson's 1908 fault map (Wood, 1916). This map, (Plate 1B, herein), confined itself to California, but omitted a number of valid faults shown on Lawson's map. Wood added five faults or "lines" which he considered "generatrices of earthquakes." Perhaps the most interesting (and prophetic) was his so-called "Eureka-Ukiah-San Pablo line." This appears as a northwestward continuation of the "Haywards" fault along the Rodgers Creek, Healdsburg, and Maacama faults, extending all the way to Eureka as similarly proposed by Herd (1979) and Jennings (herein). Two other lines, lying offshore, Wood referred to as the Monterey and San Pedro submarine fault zones, but they do not correspond to any of the offshore faults recognized in recent years by acoustical profiling. Wood's "Mare Island-Nevada-Carson line" was delineated on the basis of rather inaccurate location of earthquakes, but this northeasterly trend does not correspond to any faults known in the surface or subsurface today. It is, however, parallel in part to the subsurface Stockton fault across the Great Valley. The fifth feature or "line" added by Wood is the "Great Valley axis" lying on the east side of the Valley and approximately bounding the Sierra Nevada block. "This line," Wood (1916, p. 79) states, "is not considered to delineate, even crudely, any fault zone or chain of faults,—simply to bring to notice the tendency for certain meizoseismal areas to cluster in line along the Valley." An inspection of recently published earthquake epicenter maps, however, does not seem to bear out Wood's statement.

Second Fault Map of California—1922

Bailey Willis, Professor of Geology at Stanford University, and H.O. Wood, Research Associate in Seismology of the Carnegie Institution of Washington, prepared a new fault map of California that was published by the Seismological Society of America in 1922 as a separate publication. The map was compiled at 1:506,880 scale (1 inch equals 8 miles). A reduced version of this map is portrayed in Plate 1C (in pocket). The Willis-Wood map is evidence of the growing concern about earthquakes in California; Willis (1923a) reports that the businessmen of San Francisco subscribed $1,600 for the publication of the map. The publication of the map was followed by a text (Willis, 1923b) which attempts to explain the rationale in compiling the faults and includes a brief discussion of earthquakes and their relationship to faults. (Willis' strong feeling on the importance of this relationship is evident in the opening sentence of his text, which reads: "Another title, and perhaps a more obvious one, would be 'Earthquake Map of California.' ") A large part of the report is also given to description of various fault features, which includes a particularly long treatment of the physiography observed along the San Andreas rift.

Willis was responsible for compiling the northern part of the state, that is, the part north of San Luis Obispo, while Wood prepared the southern part (Willis, 1923, p. 4). An attempt was made to identify "active faults," "probably active faults," and "dead faults." However, Willis' criteria for classifying faults were not the same as Wood's criteria. Willis considered any fault related to "a growing mountain" as a reasonable subject for an active fault. The method, as he explains, was based on observation of "mountain forms" and the interpreted age of topographic surfaces and old landscapes. In this way, he classified numerous mountains as being bounded by active faults. Wood, on the other hand, considered active faults as those that are known to have had some movement during historic time or those for which there is evidence of recent surface dislocation. The map has two different legends for the three sectional sheets of the state to clarify this difference in interpretation of "active faults." The northwest sheet (which was entirely the work of Willis) and the southwest sheet (a joint effort) contain the following note in the legend:

> North of San Luis Obispo faults are shown as active if there has been an earthquake during historic time and also wherever they define valleys, ridges, or ranges which are now growing, even though there is no record of an earthquake on that particular fault during historic time.

Consequently, that part of the map compiled by Willis shows many more "active" and "probably active" faults than the area compiled by Wood. In the central Coast Ranges, for example, more than half of the faults are shown in the "active" fault category. The legend for the southeast sheet specifies that the "active faults" have "earthquakes recorded on lines so marked." Such faults indicated include the Owens Valley, San Andreas, Newport-Inglewood, San Jacinto, and parts of the Elsinore and Chino faults. The "dead faults" are designated as "not known to have been active during historic time."

Plate 1C is a greatly reduced and somewhat generalized version of the Willis and Wood map, but it accurately represents most of the faults shown on the 1922 map. In many ways the detail of the Willis and Wood map goes far beyond Lawson's 1908 map, not only by virtue of the much larger scale, but more importantly because, during the 14 years following the Lawson map, faults and the problem of locating and understanding them received much more attention than before, not only from seismologists, but also from geologists searching for petroleum and other mineral resources and from geology professors and their students in the two leading academic institutions then in the state, the University of California and Stanford University. Unfortunately, the map is totally blank in the northernmost part of the state where the earlier map by Lawson showed a surprising amount of information on faults that has, in most instances, withstood the test of time. Willis (1923, p. 6) justifies the absence of fault delineation north of the latitude of Santa Rosa by explaining that topographic maps showing sufficient detail and accuracy of the landscape did not exist and that, therefore, it was impossible to follow and plot the faults except by an expenditure of time and money beyond the project's means. Willis intentionally disregarded Lawson's map. (Perhaps his professional feud with Lawson influenced his decision—this is suggested by his reference to the map in Lawson's Earthquake Commission report of the 1906 earthquake as "a map of the principal earthquake faults of California but on a small scale and not complete enough to be of practical use.")

The Willis and Wood fault classification was highly interpretive and commonly went beyond the data at hand. The attempt was certainly too ambitious; even today, distinguishing between "active" faults and "probably active" or "dead" faults may still be beyond our means. Nevertheless, as a map showing the location of faults known in the state at that time, the 1922 map contains a wealth of information, some of which even goes beyond maps published later.

The remarkable advancement in fault mapping represented by Willis and Wood's 1922 fault map (Plate 1C) becomes readily apparent when it is compared to Lawson's 1908 map (Plate 1A). In the Coast Ranges province, for example, the 1922 map shows numerous faults—including the Rodgers Creek-Healdsburg, the Tolay, the Burdell Mountain, the Pilarcitos, the Butano, the Ben Lomond, the Tesla, the Ortigalita, the Sur, the Tularcitos, the Rinconada, the Ozena, the Little Pine, and the Pleito faults—which are not shown on the earlier map. Also, in this province, such unnamed faults as those at Dunnigan Hills and in Capay Valley are correctly shown on the 1922 map but not on the earlier one.

Willis and Wood's map remains an informative source even today. The map shows, for example, an "active fault, uncertainly located," lying west of and parallel to the San Andreas fault and coincident with the straight coastline from Bodega to Point Arena. Today the existence of this fault is a likely possibility, although confirmation of it is still lacking. Another interesting feature shown, in a critical area, is the Dry Creek fault at the Warm Springs dam site. According to Willis and Wood, this is an "active, well located" fault which connects (to the north as well as to the south) with "probable faults, character and location uncertain." Today part of this fault is recognized and appears on recent U.S. Geological Survey maps (Blake and others, 1974), although the connection between the Dry Creek fault and the active Rodgers Creek fault, which is shown on the 1922 map, has not been verified. To the north, faults are shown in Anderson Valley and along the Navarro River—areas which since 1922 have not been critically evaluated for active faults. To the south, the Quaternary faults now recognized at San Simeon are shown as "active." Interestingly, an "active fault, well located" is shown in the San Luis Range, at Diablo Canyon; however, recent investigations in this area have not confirmed it. The Hayward, Calaveras, and parts of the Nacimiento fault zones are shown much as they have been mapped since then. The major Quaternary faults in the central and southern Coast Ranges as we now know them were all recognized by Willis and Wood, perhaps with the exceptions of the San Juan fault and the full extent of the Rinconada fault zone. Of course, they had no idea of the offshore continuations of the Seal Cove-San Gregorio-Palo Colorado faults or the Hosgri fault zone lying offshore of San Luis Obispo County. Also, they did not always recognize certain Coast Range faults as being young faults, for some are shown as "dead" faults.

Of all the areas shown on the 1922 map, the Transverse Ranges and the Los Angeles basin are depicted in greatest detail. Therefore, the 1922 map shows numerous faults in these areas not recognized on Lawson's map, including the northern part of the San Gabriel, the San Francisquito (site of the St. Francis Dam failure), the Arroyo Parida, the Red Mountain, the Simi, the Newport-Inglewood, the Palos Verdes, the Cucamonga, and the Sierra Madre faults. On Willis and Wood's map the Pacifico and Santa Ynez faults are shown more accurately than on Lawson's map (although still somewhat crudely). The Liebre and Clearwater faults are recognized but incorrectly joined together. Willis and Wood classify the faults shown in the Transverse Ranges as "dead" with the exception of the San Andreas fault (which transects the Transverse Ranges) and a concealed fault in the Alamo area along San Antonio Creek in the Santa Maria basin. This latter fault, shown as an "active fault, uncertainly located," is not recognized by later mapping in the area (for example, Woodring and Bramlette, 1950) and therefore, is not shown on the 1975 Fault Map of California. The fault was apparently based on a doubtful fault hypothesized by Arnold and Anderson (1907) and was probably viewed by Willis and Wood as the cause of the rather severe 1902 and 1915 "Alamo" earthquakes. Willis and Wood likewise classify as "dead" all the faults in the Los Angeles basin, with the exception of the Newport-Inglewood and Chino faults.

On close inspection, one can make out the San Fernando fault, on which the disastrous earthquake of 1971 occurred. However, Wood has identified this fault as a "probable fault, character and location uncertain." Nevertheless, other available geologic maps of the San Fernando area prior to the 1971 earthquake show little indication of a San Fernando fault.

In the Peninsular Ranges a large number of faults are shown. Among these, the San Jacinto, Elsinore, and Whittier faults are better defined than on the 1908 fault map. The Chino fault is depicted as a "probable active fault," presumably on the basis of earthquake epicenters. A probable fault is correctly shown in the upper part of the San Diego River, but many other "probable faults" in the southern California batholith are today considered to be joints in granitic rocks and not faults (on the basis of a close examination showing that they have no displacements). The Cristianitos fault and a fault in Palm Canyon by Palm Springs are mapped more or less as they would be today.

The Mojave Desert is shown largely devoid of faults. The northern boundary, the Garlock fault, is recognized, but the rest of the area is still largely unmapped on the 1922 map, as it was in Lawson's time.

North of the Garlock fault, in the southern Sierra Nevada, the Sierra Nevada-Owens Valley faults are quite accurately located; the Kern Canyon fault, however, is incorrectly shown as being shorter than depicted by Lawson; and the White Wolf fault, which ruptured during the 1952 Arvin-Tehachapi earthquake, is shown, although only as a "dead, well-located fault." East of the Sierra, only a part of the Death Valley, Panamint, and Furnace Creek faults are recognized. Several other probable faults are shown bounding valleys and steep mountain fronts, but few of these have been confirmed by later mapping.

Like Lawson's map, Willis and Wood's map shows no faults in the Mother Lode of the northern and central Sierra Nevada. This is interesting because a close examination of the text of some of the U.S. Geological Survey Mother Lode District folios —for example, Ransome (1900)—reveals that early geologists were aware of abundant faults in the area and that, furthermore, some believed that such faults were possibly still active. For example, Ransome (1900, pp. 7-8) writes:

> It appears highly probable that much of the movement which has affected the Sierra Nevada since the close of Jurassic time...has resulted in the linear fissure system of the Mother Lode.
>
> The dislocations by which the fissures were originally opened, were of the kind known as thrust faults.* The present structure of the veins shows that the original displacement was followed at intervals by further movement of the same kind. There has very probably been subordinate displacement of reverse character, i.e., downward movement of the hanging wall relative to the foot wall, producing local crushing of earlier-formed veins, and resulting in more bodies of irregular and brecciated character. There is evidence that this latter movement is still in progress, producing the gouges and slickensided surfaces which accompany most of the veins.
>
> The fissures which the veins fill were formed after the post-Jurassic folding in of the bed-rock complex and after the granitic and dioritic intrusions. They have probably continued to be a zone of movement and readjustment ever since their first dislocation, and such movements are still in progress.

Why the Mother Lode faults and "fissures" were not plotted on the folio maps—whether because of U.S. Geological Survey policy or because of difficulties in mapping the structural complexities—is not known. In any event, no attempt was made to show this important and extensive fault system, even in a most general way, on any regional map until very much later (see p. 11).

Faults Shown on Geologic Map of California—1938

A far more accurate depiction of faults in California appears on the 1938 Geologic Map of California, compiled by Olaf P. Jenkins at a scale of 1:500,000. This outstanding map of its time, however, followed conventional compilation practice, whereby all faults are treated alike and historic or recently active faults are not distinguished from any other faults shown on the map.

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*We would refer to these faults today as high-angle reverse faults

Plate 1D is a reduced version of the 1938 geologic map showing just the faults.

Jenkins did not refer to either the Lawson fault map or the Willis and Wood map, because he had much more recent data to choose from for most parts of the state. In some cases he could have profited by selective use of certain faults from these earlier fault maps, but he may have chosen not to do so because of possible problems with harmonizing the earlier mapped faults with the geologic contacts he was depicting. Jenkins rightly could not mix faults and geologic contacts without additional field evaluation, for which he had neither the time nor the funds. In addition, the small scale of the Lawson map and its crude shaded-relief base, would have posed serious problems in some places in locating features on the larger and much more accurate 1938 base map.

A comparison of the 1938 map with the 1922 map shows that in the Coast Ranges, a few faults that were not shown on the 1922 map were added, but others were omitted. The major Rodgers Creek-Healdsburg fault is missing, but the less pronounced Tolay fault is shown. The Hayward fault falls short of San Pablo Bay at its north end. The Concord fault is shown as before, but its counterpart north of Suisun Bay, the Green Valley fault, is missing. The Palo Colorado and Sur faults were added, and the controversial King City fault was omitted.

Some of the more important faults in the northern part of the state that the 1938 map shows, but that the 1922 map does not, include the Surprise Valley and Honey Lake faults and the faults of the Lake Tahoe graben. Absent from the 1938 map are the series of faults now known to be associated with the Chico monocline, which are indicated on the 1922 and 1908 maps.

In the Transverse Ranges, the Santa Ynez fault is better defined, as is the Clearwater, but the Big Pine fault still had not been discovered. The San Gabriel fault is correctly shown at its north end, disappearing under the Frazier Mountain thrust fault, and the south end is correctly shown terminating at Mt. Baldy. The Malibu-Santa Monica fault (shown on the 1922 map) is left off, but the Raymond Hill fault is correctly shown, as well as the Sierra Madre-Cucamonga faults. A vast improvement is shown where the San Andreas splits into two branches and becomes entwined with the Banning fault. Also, the Pinto Mountain fault was recognized for the first time, and the Santa Rosa Island and Santa Cruz Island faults were added.

On the 1938 map the myriad of joints shown in the Peninsular Ranges on the 1922 map have been omitted although the Temescal fault has been preserved. It is difficult to see the Newport-Inglewood and the Palos Verdes faults, which are there, at least in part. The submarine San Clemente Island fault, although known at the time, is not shown, probably because no faults were shown off the coast on the 1938 map except where they happened to intersect islands. A more correct orientation of the Rose Canyon fault near San Diego is shown.

Some faults are shown in the Mojave Desert, signaling the beginning of recognition of a strong northwest structural grain, but the area at this time was still largely unmapped.

Very little of the configuration of the Sierra Nevada fault shown on the 1922 map is shown on the 1938 map, and definition of this fault's southern end is almost nonexistent. The faults in Owens Valley (except for the 1872 break at Lone Pine) are not as completely defined as on the 1922 map. The northern extent of the Kern Canyon fault, correct on Lawson's map, falls far short on the 1938 map. Not until new mapping by the Division of Mines and Geology for the Fresno Sheet of the Geologic Atlas was this fault depicted correctly again on any published map (Matthews and Burnett, 1966).

As mentioned in a preceding section, faults in the Mother Lode still were not depicted. By this time, such prominent geologists as Knopf (1929) and Ferguson and Gannett (1932) had not only recognized the abundant fault fissures in which the gold-quartz veins were emplaced, but also had talked about the existence of a major through-going reverse fault bordering the Mother Lode region on the east. These faults are not shown on any of their regional maps but the segments which lie in the areas that they mapped in detail are shown. Then, in 1944, King and others defined a highly generalized fault trace identified as the "Mother Lode mineralized fault" on the Tectonic Map of the United States. Sixteen years later, Lorin Clark, taking the findings of the early gold-belt workers and adding his detailed observations, prepared a regional map defining the Foothills fault system (Clark, 1960). His map shows the Foothills fault system bounded on the east and west by what he named the Melones fault zone and the Bear Mountains fault zone, respectively. Several years later Lorin Clark's fault system appeared on the Basement Rock Map of the United States, compiled by the U.S. Geological Survey and the University of Texas (Bayley and Muehlberger, 1968)—although mislabeled as the "Mother Love Belt"! The recency of fault activity on faults within the Melones fault zone, was recognized on the detailed maps by Eric and others, (1955, Plate 1 and p. 27). They note that movement took place following the formation of the Table Mountain Latite, suggesting late Pliocene or even Pleistocene activity. Much more recent investigations involving trenching (Alt and others, 1977) have shown that Holocene activity, including fault-displacement of soils has taken place. Thus, Ransome's intuitive observations 77 years ago concerning the recency of fault movement mentioned earlier, have proved to be correct.

Combined Wood and Jenkins Fault Map of The Southern Half of the State—1947

In 1947, Harry Wood published in the Bulletin of the Seismological Society of America a paper entitled "Earthquakes in Southern California with Geologic Relations." In it he tried to correlate earthquake origins in California with geologic faults. To illustrate his ideas, he took the faults shown on the southern half of the 1938 Geologic Map of California and supplemented it with faults he had shown in the same area on the 1922 Fault Map of California. Wood also added certain faults not known by him before and also not shown on Jenkins' 1938 map. Wood, being primarily a seismologist, had J.P. Buwalda, Professor of Geology at the California Institute of Technology (with which Wood was then associated), critically examine the resulting fault map. The published map, from which Plate 1E is patterned, was then used to plot epicenter locations, their relation to the faults serving as the basis for the paper. Choosing an approach to fault classification more cautious than the one used by Willis and Wood on the 1922 map, with its "active," "probably active," and "dead" designations, Wood designates the faults on his map as "major faults" and "other faults," and classifies each fault as "well located," "approximately located," or "uncertain."

A comparison of Wood's 1947 map with both Jenkins' 1938 map and Willis and Wood's 1922 map shows that Wood resurrected possibly significant faults from the 1922 map which do not appear on the 1938 map and also that he added some faults that do not appear on either the 1938 or the 1922 maps.

Among the features that Wood carried over from the 1922 map but that do not appear on the 1938 map are the King City fault and faults in the vicinity of Diablo Canyon and Los

Alamos.* The joints in the southern California batholith east and northeast of San Diego are retained as probable faults, but later investigators have found no evidence for displacement on most of these features and have concluded they are not faults. The fault in Palm Canyon, by Palm Springs, which the 1938 map does not show, is correctly retained from the 1922 map.

Among the significant omissions on the 1947 map are the Big Pine fault and the San Juan fault—both known today as major Quaternary faults. The configuration of the Banning and Mission Creek faults is much improved in the manner of the Jenkins' compilation, but a significant departure exists with the projected location of the San Andreas fault in the Salton Sea area (which still is largely a matter of conjecture). The Inglewood fault is more continuous on the 1947 map, and the Palos Verdes fault is shown as a splinter off the Inglewood fault. The Imperial fault, with offset along some 64 km (40 miles) of the fault trace during the May 1940 earthquake, is added. Many other differences in detail occur between this map and the earlier ones, and the 1947 map is without doubt the best fault map of the southern part of the state published up to that time.

Earthquake Epicenter and Fault Map of California—1964

In 1964, the California Department of Water Resources compiled a fault map of California using mainly the published and unpublished 1:250,000 scale geologic atlas sheets of the California Division of Mines and Geology (Hill and others, 1964). Although this map depicts faults, its primary purpose was to show epicenters, and the bulk of the report accompanying the map consists of a catalog of epicenters (magnitude 4 and greater, from 1934 to 1961). The faults shown were divided crudely into "active faults" (after C.F. Richter's textbook "Elementary Seismology," 1958), and "other faults, activity not ascertained." The criteria used to distinguish between these two classes are not indicated on the map, nor are they explained in the text. All the faults on this map are shown in red and, according to the legend, the two classes of faults are represented by two different line-widths; unfortunately, the map shows a range of line-widths, making it difficult to determine in some cases whether the fault was meant to be designated as active or not.

The map was published on three sheets at 1:500,000 scale and is included in the pocket of the California Department of Water Resources Bulletin 116-2. The map and report were prepared as part of a "crustal strain and fault movement investigation," for use in planning studies and final design stages of water resources development in the state. The report recognized the usefulness of such data in preparing estimates on the probability of earthquake occurrence and the magnitude of the damaging earthquake forces that should be anticipated at sites proposed for construction of authorized State water facilities.

Earthquake Epicenter Map of California —1978

The California Division of Mines and Geology published an earthquake epicenter map of California, known as Map Sheet 39 (Real and others, 1978). This 1:1,000,000 scale map shows all epicenters of magnitude 4 or greater from 1900 through 1974. Faults shown on the map are reduced from the Division's 1975 Fault Map of California. The map, which represents all faults with thin blue lines, does not distinguish among the faults as far as recency of movement is concerned. It is a product of the Division's Earthquake Catalog Program. A short text is included on the face of the map.

Small-Scale Fault Maps of California

Several page-size and smaller outline maps specifically showing the major and/or active faults of the state have been published over the years. Some of the more noteworthy ones are listed below:

- Richter, C.F., 1958, Elementary seismology, W.H. Freeman and Co., and Francisco, p. 441 (Figure 27-3).
- Dickinson, W.R., and Grantz, A., 1968, Historically and recently active faults of the California region, *in* Proceedings of conference on geologic problems of San Andreas fault system: Stanford University Publications in the Geological Sciences, v. XI, (map and list following p. 374).
- U.S. Geological Survey, 1970, Active faults of California, (map and text, p. 15), information pamphlet (revised and updated periodically; latest revision, 1974).

The scale of these maps and the grossly simplified bases used, however, make it almost impossible to locate the faults except in the most general way.

In addition to the small-scale maps discussed above (faults of which are almost all well documented), an interesting fault map of the state, particularly of the Coast Ranges, was published by Bruce Clark in the Bulletin of the Geological Society of America (1930). Clark, a Professor of Paleontology at the University of California, Berkeley, was intrigued with the tectonics of the Coast Ranges, which he interpreted as a complex series of faulted blocks. To illustrate his ideas he prepared a map of what he considered to be the "principal known primary faults" in the Coast Ranges (Figure 3).

As was common in those days, Clark interpreted the faults in the Coast Ranges, not as large-scale strike-slip faults, as we do today, but as bounding a series of raised and depressed blocks. Clark indicates in his text that the data for his map came from various published and unpublished maps and that a large number of the fault lines were studied in the field by either himself or his assistant James Fox. Clark states (p. 70) that "only faults which we considered definitely proven, by either direct or indirect methods, have been included." Of course, "indirect methods" leaves much room for interpretations that may not always be accepted by other geologists. A close look at the map shows, however, that solid lines represent "accurate" faults and that these comprise less than half of the faults shown on the map. Dashed and dotted lines indicate "approximate" and "buried" faults, respectively, and most of these must have been determined by Clark's "indirect" methods. Many of them, in light of later detailed field mapping, have been modified or discredited, but some have proved to be correct or are still considered possible. For example, his interpretation of a Salinas Valley (his no. 10) and King City (no. 11) faults as branches of the San Andreas (1) has not held up. But his extension of the unnamed fault known today as the White Wolf fault across the southern San Joaquin Valley to the San Emigdio fault (23) was substantiated in a dramatic way by the occasion of the Arvin-Tehachapi earthquake of 1952 and the associated ground rupture. In like manner, Clark's northward extrapolation of the Hayward fault (3)

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*The Los Alamos fault is also named on an accompanying map by Wood (this map No. 4); here, although shown concealed, it is identified as one of the major faults of the state. Perhaps this suspected fault was given such prominence on the basis of the significant earthquakes reported in the vicinity of Los Alamos in 1902 and 1915.

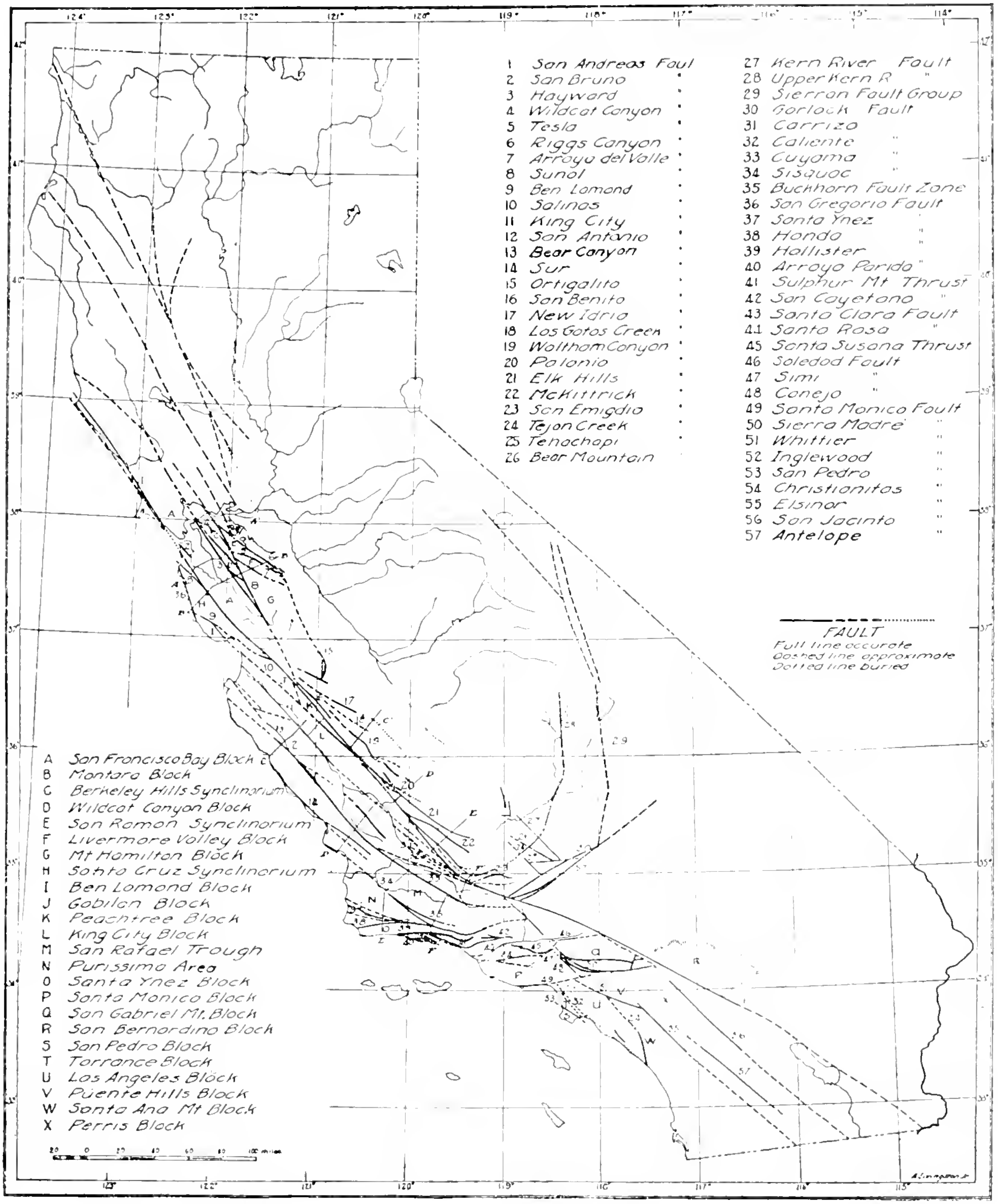

Figure 3. Bruce Clark's 1930 map of California showing "principal known primary faults". (*From Geological Society America Bulletin, V. 41, pl. 16*).

into Marin and Sonoma counties is recognized today, although his northernmost arcuate extension into Mendocino County may not exist, or if it does, at least not as part of the same Hayward-Rodgers Creek-Healdsburg-Maacama fault trend we know today.

As an interesting sidelight we might point out that what is now known as the South Branch Garlock fault was earlier known as the Antelope fault (57). Note also that Clark's Sisquoc fault (34) extrapolation to the San Luis Hills area across the Santa Maria Valley resembles Clarence Hall's east-side bounding fault of his proposed Lompoc-Santa Maria pull-apart basin (Hall, 1978). The reader can make other interesting comparisons with earlier and later fault maps illustrated in this bulletin.

Preliminary Fault and Geologic Map of California—1973

As an integral part of the new 1:750,000 scale Geologic Map of California, which was planned in 1965, the writer proposed that faults be emphasized and that relatively recent faults (those with known historical movement or with known offset of Quaternary beds) be appropriately indicated. This innovation in depicting faults was designed to help satisfy the numerous requests the Division was receiving for a map showing the "earthquake faults in the state." Thus a three-fold fault classification system, based on recency of movement, was devised and utilized. In an attempt to be as specific as possible and to avoid the problems arising from various definitions and understandings of the term "active fault," faults were subdivided into three categories, based on the time-scale universally used by geologists and seismologists. It was felt that this system was commensurate with the scale of the map used and was also realistic within the time-frame considered for preparing a statewide compilation. The three categories of faults chosen for the statewide compilation were: (1) faults along which historic displacement has occurred (red color), (2) faults having Quaternary displacement, but without an historic record of movement (orange color), and (3) faults that are pre-Quaternary in age or for which no Quaternary movement has been recognized (black). This fault classification system made this the first statewide map to depict faults by recognized recency of movement.

In 1971, a preliminary version of the geologic map including classified faults was completed. It appeared as two sheets in the pocket of a limited edition of a report financed by the U.S. Department of Housing and Urban Development entitled "Urban Geology Master Plan for California" (Bruer, 1971).* This highly preliminary map was then revised, and review copies were prepared in 1972. After the reviewing process was completed and changes and additions were made to the compilation, a preliminary version of the map was prepared and published rapidly in order to satisfy the growing demands for fault information by the cities and counties that were faced with the preparation of a new seismic safety element for their General Plans, as required by the State. As a result, Preliminary Report 13, "Preliminary Fault and Geologic Map of the State of California" was published in 1973.

The map was printed on two sheets at 1:750,000 scale (1 inch = 12 miles). The map showed faults offshore as well as on land. Special symbols and notations on the map indicated: (1) segments of faults with observed historic surface displacement, (2) points of fault creep slippage, (3) direction of fault dip, (4) direction of relative lateral movement along faults, and (5) relative up or down movement of individual faults. The map proved to be useful not only to planners but also to geologists and seismologists, engineers, and others involved in assessing the possibility of future fault activity and ground rupture in various parts of the state.

FAULT MAP OF CALIFORNIA —1975 EDITION

The Preliminary Fault and Geologic Map of California, 1973, proved to be in such great demand that the printed supply was soon exhausted. In the meantime, the fault information on the preliminary map was further edited for a new edition, and new data were added in several areas, especially offshore. Then the locations of some 584 thermal springs and wells were added. The resulting new edition measured about 1.4 by 1.5 meters (4.5 by 5 feet) and was printed in six colors. Each historic fault, shown as a red line on the map, was emphasized with a narrow pink band. Among the Quaternary faults, shown as orange lines, pale

Table 1. Summary of published fault maps of California.

TITLE	SCALE	TOPOGRAPHY	COMPILER
Map of faults accompanying State Earthquake Commission report (Map No. 1 in Atlas)	1 in.=30 mi.	Shaded relief	Lawson (1908)
Fault Map of California	1:506,880 (1 in.=8 mi.)	Shaded relief	Willis and Wood (1922)
Earthquake epicenter and fault map of California	1:500,000 (1 in.=8 mi.)	500 foot contours	Hill and others (1964)
State of California, preliminary fault and geologic map	1:750,000 (1 in.=12 mi.)	No topography	Jennings (1973)
Fault map of California	1:750,000 (1 in.=12 mi.)	500 foot contours	Jennings (1975)
Earthquake epicenter map of California (on fault base)	1:1,000,000 (1 in.=16 mi.)	No topography	Real and others (1978)

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*In this same report, a page-size provisional fault map of the state was included as Figure A-6 (original compilation scale was 1:1,000,000). This map, compiled by J.E. Kahle, attempted to document the type and kind of surface faulting associated with historic ground breaks.

orange bands were added to identify the *major* Quaternary faults. The map was published in 1975 in a new series. It was designated as Geologic Data Map No. 1, and entitled "Fault Map of California, with Locations of Volcanoes, Thermal Springs, and Thermal Wells."

Depiction of Faults

Among the multitude of faults shown on the State Fault Map, many have lengths of tens or hundreds of kilometers, and cumulative displacements of kilometers or even scores of kilometers. For example, there is considerable evidence to postulate hundreds of kilometers of right-lateral displacement on the San Andreas fault since its inception, and 25 to 64 km (16 to 40 miles) of left-lateral displacement on the Garlock fault. Also, we know that the Sierra Nevada block was raised several thousand meters during the late Cenozoic era. In addition, it appears that, as a result of subduction, rocks of the Franciscan Complex have been dragged far below the rocks of the Great Valley Sequence along the Coast Range thrust.

On the other hand, many other well-known faults have relatively small displacements, even though the fault length is measurable in tens or hundreds of kilometers. Furthermore, many of the faults shown on the Fault Map are comparatively minor. Some geologists have questioned the advisability of showing minor fault features, contending that they contribute little information and "clutter" the state fault map. These suggestions are valid for certain map uses, but they are not in keeping with the original map objective of recording all fault features in as much detail as our data allowed and within the limits of legibility. In this way the map would serve as a dependable source of background fault data for the state as a whole, which could be evaluated and interpreted in the future by more detailed studies.

Further, it was felt that by recording faithfully all mapped faults, no matter how short or isolated they might appear, future mapping might show possible fault extensions or reveal a fault zone. The writer has been impressed ever since his student days that there are many faults that are plainly visible in underground mine workings that cannot be detected on the surface even after close scrutiny. Indeed, the discovery of many previously unknown faults during exploratory trenching shows that there are many more faults in California than heretofore expected.

The prime users of such a statewide inventory of faults are engineering geologists and others who have responsibility for siting critical structures such as dams, nuclear power plants, and any other large, potentially hazardous engineering works. However, land-use planners and lay people concerned with active faults and earthquakes are also interested in such data. The numerous calls and inquiries for additional information about the faults shown on the map are continual testimony to the correctness of our decision to show faults in such detail.

In addition to showing the location and extent of faults with lines color-coded to indicate recency of activity, the map indicates the relative movement on faults (where this is known) with symbols. Arrows indicate the direction of relative lateral fault slippage; the letters U and D indicate relative vertical (up and down) fault slippage; and barbs on a fault indicate the upper plate of low-angle reverse or thrust fault. An arrow at right angles to the fault trace indicates the direction the fault surface dips. Dates placed alongside the historic faults indicate when earthquakes occurred that were accompanied by fault rupturing, and symbols indicate the extent of the earthquake fault rupture. Lastly, red dots on faults indicate where fault creep has been or is being measured. All these special notations are described in more detail below.

Fault Classification

In 1965, when plans were being made for a 1:750,000 scale geologic map, it was decided to show more than the usual information about faults on a state map by indicating some information about each fault's history. A way of doing this would be to classify faults according to their recency of activity. At that time (as at present), there was little agreement as to what "active faults," "potentially active faults," and "inactive or dead faults" were, so these terms were deliberately avoided.* In their place, a fault classification system was developed that permitted the presentation of fault information that was as factual as the geologic data would permit and that still included some indication of the relative degree of fault activity.

The three-fold fault classification scheme devised distinguishes faults entirely on the basis of recency of movement. The first category includes those faults on which recorded displacement of the surface of the earth has taken place in historic time during earthquakes or by fault creep. In California, historic time is about two hundred years, a very short interval indeed, in any geologic sense. The historically active faults are shown in red with a pink border for emphasis. The second category includes those faults that have displaced Quaternary deposits (the latest geologic epoch, which includes approximately the past two million years), but that have no historic record of surface displacement. These Quaternary faults are shown in orange, with the *major* faults and fault zones emphasized by a pale orange band. Faults in the third category, designated by heavy black lines on the map, are those without *recognized* Quaternary displacement. Probably most of these are Pliocene or older; but many are of unknown age, and some of these may have had unrecognized Quaternary movement.

The pink and orange bands on the historic and major Quaternary faults are for emphasis only. The width of the bands has no particular significance. They are *not* to be confused with the special studies zones of the Alquist-Priolo Special Studies Zones Act, which requires the State Geologist to delineate zones encompassing all potentially and recently active faults. (These study zones maps are available separately from the California Division of Mines and Geology.)

Fault Definitions

Before proceeding further, it will be useful to discuss the definition of "fault" and such terms as "active," "potentially active," and "capable," because these terms are often used without a clear understanding of them. In recent years, especially since the siting of nuclear power plants, consideration of potentially hazardous faults are of special concern (and the subject of extensive investigations, reports, and hearings). A definition of terms, therefore, is essential to make common understanding possible, not only among geologists, but also between geologist and lawyer or geologist and lay people involved in planning decisions. Numerous reports contain fault definitions, and some of the most pertinent definitions recently have been summarized by Slemmons and McKinney (1977).

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*Many definitions of these types of faults have been published, some of which are widely and even legally recognized. However, in most of these cases a *purpose* has to be stated first—for example, construction of a nuclear power plant, a large dam, or a hospital—before a specific fault definition can be applied. This problem is discussed more fully in the following section.

In defining the term "fault," geologists have no significant disagreement; the various definitions differ only in the elaboration. All agree in defining a fault as a tectonic fracture[*] or break in the earth's crust along which displacement (horizontal, vertical, or diagonal movement) has taken place. In elaborating, some definitions further specify (1) that the fracture or break may be either a discreet surface *or* a wide zone of fractures; (2) that the fault may be a result of repeated displacements which took place suddenly or very slowly as a result of creep slippage; and (3) that the cumulative displacement may be measurable in fractions of an inch (centimeters) or in miles (kilometers).

The use of the designation "active fault" on a map in this country (and probably in the world) began with the publication of the Willis and Wood "Fault map of California" (1922). Unfortunately, two different sets of criteria were used in different parts of the state by the two compilers. Willis designated an "active fault" as one on which slip is likely to occur and a "dead fault" as one on which no further movement may be expected. His criteria for distinguishing between the two, however, were quite vague and his active faults were based primarily on a "growing mountains" theory. Wood, who compiled the southern part of the state, was more factual and designated his "active faults" as those which have shown activity in historic time, or which have physiographic evidence of recent surface dislocation. Wood's definition of an active fault is thus based on observation and has survived through the years with only slight modification. The main changes to Wood's definition have been: (1) the addition of other criteria, principally seismic, for identifying active faults, and (2) the addition of a specific time frame since the last fault movement for separating "active" from "inactive" faults (possible because of the modern capability of deteriming the time of movement on them).

All definitions of "active faults" in common use imply *future movement* commonly constituting a geologic hazard. In recent years, specialized definitions vary according to the type of structure to be built in the vicinity of a fault and the degree of risk acceptable for a particular type of structure. The most conservative definition is that of the U.S. Nuclear Regulatory Commission (NRC, formerly U.S. Atomic Energy Commission). In defining fault activity for its special uses, the NRC sought to avoid the misunderstanding that might arise from its use of the term "active" by using the term "capable" in its place. A "capable fault" is defined as a fault that exhibits one or more of the following characteristics: (1) movement at or near the ground surface at least once within the past 35,000 years, or movement of a recurring nature within the past 500,000 years; (2) macroseismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault; (3) a structural relation to a fault deemed "capable" such that movement on one can be reasonably expected to be accompanied by movement on the other.

In California, special definitions for active faults were devised to implement the Alquist-Priolo Special Studies Zones Act of 1972, which regulates development and construction in order to avoid the hazard of surface fault rupture. The State Mining and Geology Board established Policies and Criteria in accordance with the Act. They defined an "active fault" as one which has "had surface displacement within Holocene time (about the last 11,000 years)" (Hart, 1980, p. 21). The State Geologist, who has the responsibility under the Alquist-Priolo Act to delineate special studies zones (i.e., regulatory zones) to encompass potentially hazardous faults, has adopted additional definitions based on wording in the Act. A "potentially active fault" was defined as any fault that "showed evidence of surface displacement during Quaternary time (last two to three million years)" (Hart, 1980, p. 5). On the 1974 and 1976 editions of the Special Studies Zones maps, such faults, including the San Andreas, Calaveras, Hayward and San Jacinto faults and their branches, were zoned unless it could be demonstrated that specific fault strands were inactive during all of Holocene time. Because of the large number of potentially active faults in California, the State Geologist adopted additional definitions and criteria in an effort to limit zoning to only those faults with a relatively "high" potential for surface rupture. Thus, the term "sufficiently active" was defined as a fault for which there was evidence of Holocene surface displacement. This term was used in conjunction with the term "well-defined," which relates to the ability to locate a Holocene fault as a surface or near-surface feature. All faults zoned since 1977 have had to meet the criteria of "sufficiently active and well-defined" (Hart, 1980, p. 5-6).

Another special definition is used by the U.S. Water and Power Resources Services (formerly the U.S. Bureau of Reclamation) in the design of dams. To this agency, any fault exhibiting relative displacement within the past 100,000 years is an active fault (Slemmons and McKinney, 1977, p. 19.)

Table 2 is a summary of the fault definitions in common use and the factors on which they are based. Each of these definitions is concerned with future fault activity and this is based on the recent history of the fault. Depending on the type of structure being planned and the acceptable risk to be taken, the definition of an active fault may be based on the last 11,000 to 100,000 years or on repeated movements during the past 500,000 years. The recent history of movement on a fault can be determined by use of geological or historical criteria. A summation of these criteria is presented in Table 3.

Of recent concern is the possibility that faults, even geologically ancient ones (that is, pre-Quaternary), can be reactivated by the influences of man. For example, there are now several authenticated cases showing that the filling of a reservoir can induce fault activity and earthquakes of significant size. In this way, what may have been considered "inactive faults" can become "active faults."

The term "active fault" is best avoided altogether when seismic risk is not a consideration. For simply describing the characteristics of faults, such terms as "historic fault," "Holocene fault," "Quaternary fault," "pre-Quaternary fault," or "seismically active fault" are preferable. With these designations, a project geologist, after confirming the designation of a fault, can then go on and make his own determination of its activity relative to the type of structure to be built and the acceptable risk.

Historic Faults, Earthquakes, and Creep

Faults along which displacement has occurred during historic time are shown in red on the Fault Map of California. A fault was classified as historic if it had (1) a recorded earthquake with surface rupture, (2) recorded fault creep, or (3) displaced survey lines. A fourth criterion was considered, namely seismicity, but this was ultimately rejected for the 1975 map (for reasons explained in a later section).

Earthquakes With Surface Rupture

The historic record of earthquakes in California goes back slightly more than 200 years to the Portola expedition of 1769, when violent earthquakes were felt in the Los Angeles region and recorded in the diaries of these explorers. However, no record of

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[*] A tectonic fracture is distinguishable from nontectonic fractures such as subsidence fractures, landslide fractures, et cetera, by having its origin deep in the earth

Table 2. Comparison of various commonly used fault definitions.

	Design structure	Fault term	Time of last displacement on fault	Other criteria
NRC (U.S. Nulcear Regulatory Comm.) 1975	Nuclear power plants	Capable	1) at least once within past 35,000 yrs. *or* 2) two or more times within past 500,000 yrs.	1) Macro-seismicity relatable to specific fault. 2) Structural relationship to a capable fault such that movement on one could cause movement on another.
CDMG (Calif. Div. Mines & Geol.) 1976	Structures for human occupancy	Active	Within Holocene (11,000 yrs.)	
		Potentially active	During Quaternary (last 2-3 million years).	
USBR* U.S. Bur. Reclamation) 1976	Dams	Active	Within past 100,000 yrs.	
New Zealand Geol. Survey 1976	Town planning	Active	Since last glaciation (50,000 yrs.) *or* repeated movement in last 500,000 yrs.	
Grading Codes Board (Assoc. Eng. Geol.) 1973	Not specified	Active	Historic.	
		Potentially Active	No historic evidence but strong evidence of geologically recent activity.	
		High Potential	Holocene.	a) Ground water barrier or anomaly within Holocene deposits b) Related earthquake epicenters.
		Low Potential	Pleistocene (less than 1,000,000 yrs.).	
Louderback 1950	Not specified	Active	Historic or Recent (i.e. Holocene).	Related earthquake epicenters.

Table 3. Evidence used for determining fault history.

Criteria	Evidence For Recent Displacement
Geological	1) Geomorphic evidence of fresh or youthful appearance (e.g., fault scarps, triangular facets, markedly linear and steep mountain fronts, and shutterridges, i.e., ridges blocking normal stream drainage). 2) Alignment of horizontal depressions that are not the result of differential erosion (e.g., sag ponds, saddles, troughs, valleys). 3) Displaced or deformed deposits of Holocene or Pleistocene age (e.g., faulted alluvium, alluvial fans, terraces, and other recent geologic formations). 4) Offset Holocene or Pleistocene ridges or stream courses (offset systematically in the same direction.) 5) Ground water barriers in alluvium (often marked by contrasts in vegetation or determined by well-log records).
Historical	Recorded accounts of: 1) actual ground breakage. 2) distributed earthquake damage permitting reasonable reference to a particular fault.

Criteria	Evidence For Current Displacement
Geological	1) Creep slippage. 2) Surface features in modern alluvium or in soils (e.g., open fissures, mole tracks, pressure ridges).
Seismological or Geodetic	1) Alignment of earthquake epicenters including microearthquakes (<M3.0) 2) Displaced survey lines.

ground displacement was reported by the expedition for this event, although the intensity of the quake at their camp was considerable.

As far as can be ascertained, the first record of ground displacement in California was associated with the Hayward fault during the earthquake of 1836. About 30 subsequent earthquake events have occurred in California that have well-documented ground breakage. These events are listed in Table 4, Part A, and are shown on Figure 4 and the Fault Map of California.

During the 1952 Arvin-Tehachapi earthquake, many widespread and well-defined surface breaks or cracks developed which were *not* part of the causative White Wolf fault. These ground breaks were the result of ground failures during the shaking of this event. Because of the extensive distribution and possible significance of the cracks to future land-use planning, some of these breaks are shown on the Fault Map. Likewise, small breaks were associated with the 1971 San Fernando earthquake that were probably due to severe ground shaking. Some of these breaks also have been shown on the map.

It should be noted that the dates of the earthquakes associated with fault rupture are indicated on the Fault Map of California in red. Red triangles are placed along the historic faults to indicate the terminating points of observed surface displacement. Most of these points are well established, but unfortunately, the records are not always good enough to know for certain what the extremities were in the case of several earlier earthquakes having ground ruptures. Today, when an earthquake occurs, numerous geologists and seismologists swarm into the area to study and map the effects, but before 1906 the relation between faulting and earthquakes was not recognized and little or no attempt was made by early-day scientists to record such data. For example, Josiah Whitney, the State Geologist of California, was the first scientist on the scene after the great 1872 Owens Valley earthquake, but he made no effort to record the ground ruptures. Hence the full extent of these ruptures is still imperfectly known. What is known has been learned by modern interpretive techniques. The 1872 scarps at the few populated areas where the ground ruptures are well known (because of reports of associated damage) were observed, and low sun angle aerial photographs were scrutinized closely to distinguish scarps with features characteristic of the known 1872 scarps from older, more eroded scarps in the area.

The extent of the ground rupture associated with the 1857 earthquake on the San Andreas fault poses still another problem. In this case, the accounts of rupture were based on newspaper reports made by untrained observers. Thus the southern end of the break is reported in two different places, one near San Bernardino and the other in the Colorado Desert. A study of the relative youthfulness of fault features on the San Andreas, many of which are still preserved in this semi-arid climate of southern California, suggests that the southern extent of the 1857 event was at Cajon Pass and that the fault features traceable into the Colorado Desert should be attributed to some earlier pre-historic event. The northern extent of the 1857 rupture is also in doubt because of vague reports. Attempts to reinterpret its northern limit have not been successful because of subsequent earthquakes and fault breaks in the same region.

There is great uncertainty about the location of the 1852 earthquake ruptures in southern California. Newspaper accounts of this event describe the occurrence in a sparsely inhabited Lockwood Valley, but because there are two Lockwood Valleys in the state that are astride major fault zones (the Big Pine fault and the Rinconada fault), there is considerable uncertainty about which remote area suffered the reported 30 miles of ground breakage. Until recently, the Big Pine fault was believed to be the site, but closer scrutiny suggests that the fault features along the Big Pine fault are probably not of historic origin.

Ground rupture associated with the 1966 Truckee earthquake in the Boca Reservoir area north of Lake Tahoe, is not completely understood. The area is dominated by northwest-trending faults, but the concentration of ground breakage resulting from this earthquake was along a northeasterly trending zone 16 kilometers long. This suggests that it may be related to a subsurface northeast-trending fault (Kachadoorian and others, 1967). Whether the surface earthquake effects mapped on and adjacent to this probable fault were due to tectonic movement or to ground shaking could not be determined (Carter, 1966).

The San Jacinto fault is one of the most seismically active faults in southern California. The fault has a record of historic fault displacement along its southernmost portion; for example, breaks were associated with the 1968 Borrego Mountain earthquake and a 1934 earthquake in the Colorado River Delta area of Baja California. However, no verified fault displacements have occurred on its northern section although numerous earthquakes have been associated with it. Some reports of ground breakage on the northern part of the San Jacinto fault during an 1899 earthquake were published by Daneš (1907), in an Austrian geological publication, but these reported ruptures could have been caused by landsliding (Allen and others, 1965, p. 767; Sharp, 1972).

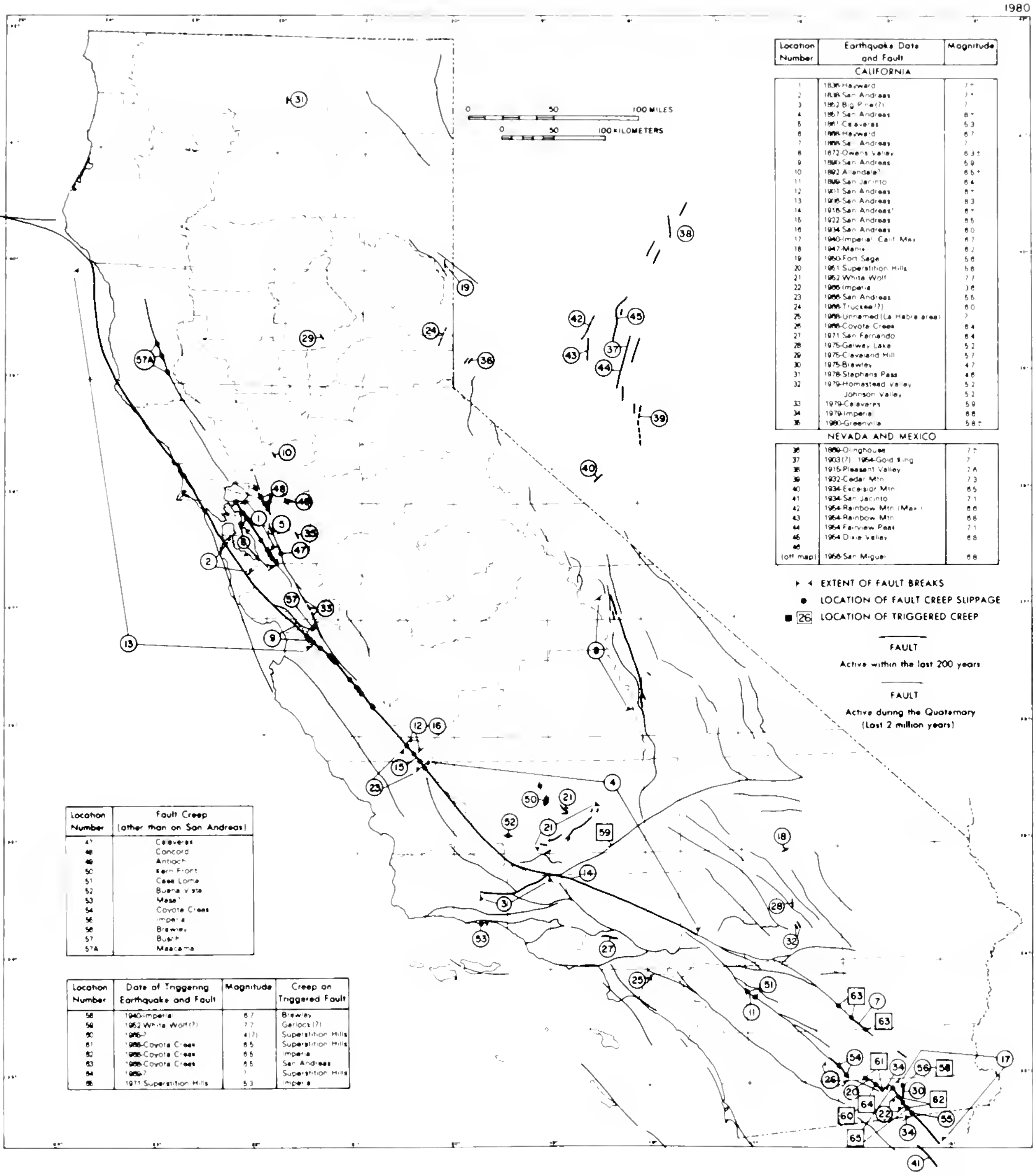
Recorded Fault Creep

Fault creep is described as slow ground displacement usually occurring without accompanying earthquakes. It was first recognized on the Buena Vista fault, in an oilfield near Taft, California (Koch, 1932). It was later recognized on the San Andreas fault at a winery south of Hollister, (Steinbrugge and Zacher, 1960), and since then has been found on several other faults in California. It is apparently a relatively rare phenomenon outside of California. Creep may have preceded the 1959 Montana earthquake (Myers and Hamilton, 1964). Outside the United States it has only been reported in Turkey. On the Fault Map of California, fault creep has been used as the sole criterion for classifying the six following faults as having activity during historic time: Concord, Antioch, Kern Front, Casa Loma, Buena Vista, and Mesa (see Table 4, Part C).

Fault creep of tectonic origin is often difficult to distinguish from nontectonic ground displacement resulting from groundwater or oil withdrawal. In fact, creep on the Buena Vista fault, as well as on the Kern Front fault, is today generally attributed to withdrawal of oil. Creep on the Casa Loma fault is considered by some to be a result of ground-water withdrawal. The creep shown on the Mesa fault is questionable, and there are now indications that earlier reports of creep may have been in error. The places where fault creep has been observed and recorded are shown on the map with red dots on the fault. These locations include both tectonic and nontectonic creep.

Fault creep has been noted on some faults in areas where the ground has been previously broken by historic earthquakes (for example, on segments of the San Andreas, Hayward, Coyote Creek, and Imperial faults). But fault creep has also been observed on other segments of active faults that have had no record of earthquake ground ruptures during historic time (for example, certain parts of the San Andreas and Calaveras faults).

Since 1975, when the Fault Map of California was published, fault creep in places on the Imperial fault has been reported (Gilman and others, 1977). A segment of the Brawley fault (not



Location Number	Earthquake Date and Fault	Magnitude
	CALIFORNIA	
1	1836-Hayward	7+
2	1838-San Andreas	7+
3	1852 Big Pine(?)	?
4	1857 San Andreas	8+
5	1861 Calaveras	6.3
6	1868-Hayward	6.7
7	1868-San Andreas	?
8	1872-Owens Valley	8.3±
9	1890-San Andreas	6.9
10	1892 Allendale?	6.5+
11	1899-San Jacinto	6.4
12	1901 San Andreas	6+
13	1906-San Andreas	8.3
14	1916-San Andreas?	6+
15	1922 San Andreas	6.5
16	1934 San Andreas	6.0
17	1940-Imperial Calif. Mex.	6.7
18	1947-Manix	6.2
19	1950-Fort Sage	5.6
20	1951 Superstition Hills	5.6
21	1952 White Wolf	7.7
22	1966-Imperial	3.6
23	1966-San Andreas	5.5
24	1966-Truckee (?)	6.0
25	1968-Unnamed (La Habra area)	?
26	1968-Coyote Creek	6.4
27	1971 San Fernando	6.4
28	1975-Galway Lake	5.2
29	1975-Cleveland Hill	5.7
30	1975-Brawley	4.7
31	1978-Stephens Pass	4.6
32	1979-Homestead Valley	5.2
	Johnson Valley	5.2
33	1979-Calaveras	5.9
34	1979-Imperial	6.6
35	1980-Greenville	5.8±
	NEVADA AND MEXICO	
36	1869-Olinghouse	7±
37	1903(?) 1954-Gold King	?
38	1915-Pleasant Valley	7.6
39	1932-Cedar Mtn.	7.3
40	1934-Excelsior Mtn.	6.5
41	1934-San Jacinto	7.1
42	1954-Rainbow Mtn. (Max.)	6.6
43	1954-Rainbow Mtn.	6.6
44	1954 Fairview Peak	7.1
45	1954 Dixie Valley	6.8
46 (off map)	1956-San Miguel	6.8

▸ ◂ EXTENT OF FAULT BREAKS

● LOCATION OF FAULT CREEP SLIPPAGE

■ 26 LOCATION OF TRIGGERED CREEP

FAULT
Active within the last 200 years

FAULT
Active during the Quaternary
(Last 2 million years)

Location Number	Fault Creep (other than on San Andreas)
47	Calaveras
48	Concord
49	Antioch
50	Kern Front
51	Casa Loma
52	Buena Vista
53	Mesa?
54	Coyote Creek
55	Imperial
56	Brawley
57	Busch
57A	Maacama

Location Number	Date of Triggering Earthquake and Fault	Magnitude	Creep on Triggered Fault
58	1940-Imperial	6.7	Brawley
59	1952 White Wolf (?)	7.7	Garlock (?)
60	1966-?	4 (?)	Superstition Hills
61	1968-Coyote Creek	6.5	Superstition Hills
62	1968-Coyote Creek	6.5	Imperial
63	1968-Coyote Creek	6.5	San Andreas
64	1969-?	?	Superstition Hills
65	1971 Superstition Hills	5.3	Imperial

Figure 4. Map of California and adjacent terrane showing major Quaternary faults and identifying historic fault breaks, occurrences of fault creep, and triggered creep.

Table 4, Part A. *Historic surface faulting associated with earthquakes in California.*

Earthquake			Fault					Reference[3]
Year	Location	Magnitude	Name	Location number (See Fig 4)	Length surface rupture (kilometers) [miles]	Maximum displacement and type of slippage[1]	Repeated fault breaks during historic time[2]	
1836	San Pablo to Mission San Jose	*	Hayward	1	61 (?) km 38 (?) mi	No data	First	Bonilla 1970, Louderback 1947 Slemmons 1967
1838	San Francisco to Mission Santa Clara (?)	[illegible] *	San Andreas	2	40 (+) km 25 ± mi	No data	First	Louderback 1947, Slemmons 1967
1852	Lockwood Valley	No data	Big Pine (?)[4]	3	48 (?) km [30 (?) mi]	No data		Townley and Allen 1939 (p 28-29) Vedder and Brown 1968 (p 256)
1857	Fort Tejon	8 +	San Andreas	4	322 ± km [200 ± mi]	RL 9m (?)	Second	Bonilla 1970, Slemmons 1967, Wood 1955
1861	Dublin	5 3	Calaveras	5	No data	No data	First	Radburch 1968 (p 52-53), Toppozada and others 1979 (p 15)
1868	Oakland to Warm Springs	6 7	Hayward	6	48 ± km [30 ± mi]	RL 0 9m V 0 3m	Second	Bonilla 1970, Lawson and others, 1908, Toppozada and others, 1979 (p 17)
1868	Dos Palmas	No data	San Andreas	7	"Long fissure"	No data	Third	Townley and Allen, 1939 (p 50)
1872	Big Pine to Olancha	8 3 ±	Owens Valley	8	97 + km [60 + mi]	RL 6m[5] Some LL V 7m		Bonilla 1970, Knopf 1918, Hobbs 1910
1875	Honey Lake (Clio)[5]	6 0	Honey Lake[6]		No data	No data		Toppozada and others, 1979 (p 19), Bonilla, 1970
1890	Chittenden	5 9	San Andreas	9	8 ± km [5 ± mi]	0 3m? lateral	Fourth	Holden 1898 (p 150), Lawson and others, 1908 (p 110), Toppozada and others, 1979 (p 23)
1892	Allendale (Sacto Va)	6 5 ±	Unnamed[7]	10	0 3 to 0 6km [0 5 to 1 0 mi]	No data		Toppozada and others, 1979 (p 24)
1899	S E of San Jacinto	6 4	San Jacinto[8]	11	3 2 (?) km [2 (?) mi]		First (?)	Bonilla, 1970, Danés, 1907, Slemmons, 1967, Toppozada and others, 1979 (p 26)
1901	Parkfield	6 ±	San Andreas	12	"Several miles"	V 0 3m	Fifth	Lawson and others, 1908 (p 40), Townley and Allen, 1939, Brown and others 1967 (p 10)
1906	Shelter Cove-San Juan Bautista	8 3	San Andreas	13	432 km [270 mi]	RL 6m V 0 9m	Sixth	Bonilla, 1970, Lawson and others, 1908
1916	Gorman	6 ±	San Andreas[9]	14	No data	No data	Seventh (?)	Branner, 1917, Richter, 1959 (p 134)
1922	Cholame	6 5	San Andreas	15	0 4 (?) km [0.25 (?) mi]	No data	Seventh	Townley and Allen, 1939, Richter, 1958 (p 533)
1934	Parkfield	6 0	San Andreas	16	3 km [2 mi]	No data	Eighth	Byerly and Wilson, 1935 (p 233), Richter, 1958 (p 534)

1940	Calif.-Mexico	6.7[10]	Imperial (San Jacinto F.Z.)	17	64+ km [40+ mi]	RL 5.8m V 1.2m	First	Bonilla, 1970, Hileman and others, 1973, Ulrich, 1941
1947	Mojave Desert	6.2	Manix	18	1.6 km [1 mi]	LL 7.6cm		Bonilla, 1970, Hileman and others, 1973, Richter, 1958
1950	Honey Lake Valley	5.6	Fort Sage	19	8.9 km [5.5 mi]	V 20 cm		Bonilla, 1970, Gianella, 1957
1951	Imperial Valley	5.6	Superstition Hills (San Jacinto F.Z.)	20	3.2± km [2± mi]	RL slight		Bonilla, 1970, Allen and others, 1965.
1952	Arvin-Tehachapi	7.7 6.4 6.1(2)	White Wolf	21	53.1 km [33 mi]	LL 0.76 m V 1.22 m		Bonilla, 1970, Hileman and others, 1973, Buwalda and St. Amand, 1955.
1966	El Centro	3.6	Imperial (San Jacinto F.Z.)	22	9.7 km [6 mi]	RL 1.5 cm	Second	Bonilla, 1970, Brune and Allen, 1967
1966	Parkfield	5.5	San Andreas	23	37 km [23 mi]	RL 17.8 cm[11] V 5 cm[11]	Ninth	Bonilla, 1970, Brown and others, 1967
1966	Truckee	6.0	Not named[12]	24	16.1 km [10 mi]	No data		Carter, 1966, Kachadoorian and others, 1967
1968	La Habra[13]	?	Unnamed	25	32 km [0.2 mi]	LL 5 cm		Yerkes, 1972 (p. 31), Lamar, 1972
1968	Borrego Mtn	6.4	Coyote Creek (San Jacinto F.Z.)	26	31 km [19 mi]	RL 38+ cm	Second	Allen and others, 1968, Hileman and others, 1973, Clark, 1972
1971	San Fernando Valley	6.4	San Fernando	27	15.3 km [9.5 mi]	LL 1 m V 1 m		USGS, 1971 (p. 55), Allen and others, 1975 (p. 257), Hileman and others, 1973
1975	Mojave Desert	5.2	Galway Lake	28	6.8 km [4.2 mi]	RL slight		Hill and Beeby, 1977
1975	Oroville	5.7	Cleveland Hill	29	1.7-3.0 km [1-2 mi]	RL 4 cm V 5 cm		Hart and Rapp, 1975, p. 61
1975	Imperial Valley	4.7	Brawley[14]	30	10.4 km [6.5 mi]	V 0.2+ m		Sharp, 1976
1978	E. of Mt. Shasta	4.6	Stephens Pass	31	2+ km [1.2+ mi]	V 15± cm		Bennett and others, 1979
1979	Mojave Desert	5.2	Homestead Valley	32	3.25 km [2 mi]	RL 10 cm V 4 cm		Hill and others, 1980.
			Johnson Valley		1.45 km [0.9 mi]	RL 1 cm V 1 cm		
1979	Coyote Lake	5.9	Calaveras	33	39 km [24.2 mi]	RL 6+ mm	Second	Uhrhammer, 1979, Lee and others, 1979, Armstrong, 1979
1979	Imperial Valley	6.6	Imperial (San Jacinto F.Z.)	34	30 km [18 mi]	RL 0.8 m	Third	Real, McJunkin and Leivas, 1979, Sharp, 1979
1980	Livermore	5.8+	Greenville	35	5+ km [3.0± mi]	RL 2.5+ cm		Bonilla, 1980

Table 4, Part B. Historic surface faulting associated with earthquakes in Nevada and Baja California.

Earthquake			Fault				Reference[3]
Year	Location	Magnitude	Name	Location number (See Fig. 4)	Length surface rupture (kilometers) [miles]	Maximum displacement and type of slippage[1]	
1869	Nevada	7.0 *	Olinghouse	36	No data	No data	Slemmons, 1967
1903(?)	Nevada	No data	Gold King (Also see 44)	37	19 km (?) [12 mi (?)]	No data	Bonilla, 1970, Slemmons and others, 1959, Tocher and others, 1957
1915	Nevada	7.6	Pleasant Valley	38	32-64 km [20-40 mi]	N 4.6m	Bonilla, 1970, Jones, 1915
1932	Nevada	7.3	Cedar Mountain	39	61.2 km [38 mi]	RL 8.5 m V 1.2m	Bonilla, 1970, Gianella and Callaghan, 1934
1934	Nevada	6.5	Excelsior Mtn	40	1.5 km [0.9 mi]	LL slight N 1.2cm	Bonilla, 1970, Callaghan and Gianella 1935
1934	Mexico	7.1	San Jacinto	41	Faulting inferred from aerial photos	RL (?)	Bonilla, 1970, Kovach, 1962
1954 (July)	Nevada	6.6	Rainbow Mtn	42	17.7 km [11 mi]	N 3.1cm	Bonilla, 1970, Tocher, 1956
1954 (Aug.)	Nevada	6.8	Rainbow Mtn	43	30.6 km [19 mi]	N 0.76m	Bonilla, 1970, Tocher, 1956
1954	Nevada	7.1	Fairview	44	58 km [36 mi]	RL 4.3 m N 3.7m	Bonilla, 1970, Slemmons, 1957
			Gold King		Part of Fairview F.Z.	RL little or none, V 2 feet	Slemmons and others, 1959
1954	Nevada	6.8	Dixie Valley	45	61.2 km [38 mi]	N 2.1+ m (4.6m scarp)	Bonilla, 1970, Slemmons, 1957
1956	Baja, Mexico	6.8	San Miguel	46	19+ km [12+ mi]	N 1m RL 0.8 m	Bonilla, 1970, Shor and Roberts, 1958

Table 4, Part C. California faults displaying fault creep slippage not associated with earthquakes.

Fault	Location number (see Fig. 4)	Reference[3]
San Andreas[*]		Nason and others, 1974
Hayward[*]		Nason and others, 1974
Calaveras	47	Nason and others, 1974
Concord	48	Sharp, 1973
Antioch (?)	49	Burke and Helley, 1973
Kern Front	50	Manning, 1968 (p. 132-139)
[illegible] (F.Z.)	51	Fett and others, 1967 (p. 22, 25, 27, 28)
Buena Vista	52	Koch, 1933, Manning, 1968 (p. 133-134), Nason and others, 1968 (p. 100-101)
[illegible] (?)	53	Wood, 1972; [illegible], 1973, pers. comm.
[illegible] (?)	54	Clark, 1972 (p. 73)
[illegible]	55	[illegible] and others, 197[illegible]
[illegible][*]	[illegible]	Sharp, [illegible] (p. 1153)
[illegible]	[illegible]	Rogers, [illegible]
[illegible]	[illegible]	[illegible]

Table 4, Part D. Triggered creep along faults with earthquakes in California.

Earthquake Fault			Triggered Fault				Reference[3]
Year	Location	Magnitude	Name	Location number (See Fig. 4)	Length surface rupture	Maximum displacement and type of slippage[1]	
1940	Imperial	6.7[10]	Brawley[17]	58	No data	V 25.4 cm	Sharp, 1976 (p. 1152)
1952	White Wolf (?)	7.7	Garlock (?)	59	122 meters [400 feet]	No data	Buwalda and St. Amand, 1955 (p. 53), Clark, 1973
1965	No data	4.0 (?)	Superstition Hills (San Jacinto F.Z.)	60	1 km [0.6 mi]	No data	Allen and others, 1972 (p. 94)
1968	Coyote Creek	6.5	Superstition Hills (San Jacinto F.Z.)	61	7.7 km [4.8 mi]	RL less than 2.5 cm	Allen and others, 1968
			Imperial	62	19.3 km [12 mi]	RL less than 2.5 cm	Allen and others, 1968
			San Andreas	63	No data	RL less than 2.5 cm	Allen and others, 1968
1969	No data	No data	Superstition Hills (San Jacinto F.Z.)	64	No data	No data	Allen and others, 1972 (p. 94)
1971	Superstition Hills	5.3	Imperial (San Jacinto F.Z.)	65	27.4 km [17 mi]	RL 1.5 cm	Allen and others, 1972 (p. 89), Kahle (pers. comm.)

FOOTNOTES FOR TABLE 4 (PARTS A THROUGH D)

[1] Abbreviations: RL = right lateral, LL = left lateral, V = vertical, N = normal, m = meters, cm = centimeters.

[2] Multiple fault ruptures on the same fault, but not necessarily at the same place.

[3] See references cited (at end of Part II) for complete bibliographic description.

[4] Location of 1852 earthquake is questionable (see text p. 18).

[5] May represent two (possibly three) events (Nason, R.D., 1980, personal communication).

[6] The 1875 earthquake, until recently, was thought to have occurred in Mohawk Valley as shown on Fault Map of California (1975). Some 22 years after the event, Turner (1897), in talking with local residents, thought he could locate ground ruptures for this event near Clio. New data and isoseismal maps (Toppozada and others, 1980) indicate the earthquake probably was centered in the Honey Lake area, probably on the Honey Lake fault.

[7] Two early newspaper accounts recently uncovered (Toppozada and others, 1980) describe a fissure 0.5 to 1 mile long near Allendale, 5 miles west of Dixon. [Not plotted on Fault Map of California (1975).]

[8] Questionable fault rupture—may have been landslides (Allen and others, 1965; Sharp, 1972). Not plotted on Fault Map of California, nor on Figure 4.

[9] Questionable fault rupture—cracking may have been caused by shaking only.

[10] Widely listed as magnitude 7.1—recalculated by C.I.T. to be 6.7 (Hilman and others, 1973)

[11] Displacement given includes tectonic creep that occurred within 50 days following main shock.

[12] Surface fault rupture not conclusive.

[13] Some uncertainty regarding earthquake associated with 1968 ground rupture near La Habra (Yerkes, 1972).

[14] Brawley fault of R.V. Sharp (1976) is not shown on the Fault Map of California (1975 ed.) because it was reported after the Fault Map was published. Sharp's "Brawley fault" is oriented somewhat differently than the fault by the same name shown on the Fault Map of California based on Elders and others, 1972.

[15] Numerous occurrences of creep along this fault; see Figure 4.

[16] Not plotted on Fault Map of California because first reported in 1977

Evidence of some surface ruptures in 1940 at the time of the Imperial earthquake according to report in R.V. Sharp (1976, p. 1152) and suggestions of creep over an extended period of time (1976, p. 1153). Not plotted on Fault Map of California because first reported in 1976.

shown on the Fault Map of California) is also undergoing fault creep (Sharp, 1976).

Fault creep is not well understood. It may signify a building of stress along a fault or it may indicate a releasing of stress. Research into fault mechanics may eventually explain its causes.

Another type of creep, designated "triggered creep," has been observed in recent years. This type of creep occurs on a fault after it has been triggered by a strong earthquake on some other fault. The 1968 Borrego Mountain earthquake, for example, which is centered on the Coyote Creek fault, triggered movement on the Superstition Hills, Imperial, and San Andreas faults. Other triggered creep has been noted on the Imperial fault in 1971 and on the Superstition Hills fault in 1965 and 1969. Table 4, Part D lists all the known triggered creep events along faults associated with earthquakes in California. On the Fault Map of California, red squares are plotted where triggered fault creep has occurred, and the date of the causative earthquake is indicated.

Displaced Survey Lines

The third criterion recognized for designating faults with historic ground displacement is measured displacement across survey lines. In compiling the Fault Map of California, this criterion served mostly to corroborate other evidence for historic activity (earthquake ground rupture or fault creep slippage). However, one location in the San Bernardino Valley, on the San Jacinto fault, was shown to have historic ground displacement based solely on the repeated surveys of the Rialto-Colton triangulation network.

Seismicity

A fourth criterion, active seismicity, was considered in classifying faults with historic activity. This criterion was used on a preliminary unpublished compilation but not on the final map. An attempt was made to classify a fault as having historic activity in cases where there appeared to be a close correlation between the epicenter locations of earthquakes and a specific fault. Both macroseismic and microseismic activity were considered, and all types of events were evaluated—whether they were repeated earthquakes over a period of years, aftershocks of a larger event, or microearthquakes detected by extensive continuous monitoring by close seismic survey networks. The guiding factor was whether or not an alignment of epicenters appeared to be clearly related to a specific fault. This criterion was used most sparingly because of imprecise location of epicenters (especially with older data). In this way several faults that otherwise had no observable historic surface fault displacement were tentatively classified with the group of historic faults. These included the Newport-Inglewood, Palos Verdes, Mendocino, Sargent, Mission Creek, Palo Colorado-San Gregorio faults, the northern part of the San Jacinto fault, and the southern part of the Healdsburg fault. However, because of disagreement among seismologists about the significance of microearthquake alignments, and because of the uncertainties involved with ascertaining alignments among the random distribution of macroearthquakes, a decision was made not to include seismicity with the other widely recognized geologic and historic criteria used in making this official fault map of the state.

The uncertainty of relating individual macroearthquakes (magnitude 3 or greater) to specific faults in cases where there is no ground displacement is well known among seismologists, although sometimes overlooked by geologists. The problem lies with the accuracy of epicenter locations. "Without a group of several good stations, velocities and crustal structures are uncertain and location of epicenters is unreliable" (Richter, 1958, p. 315). Well-recorded earthquakes may be located accurately within 5 km. (3 mi.), but most epicenter maps include locations with far less accuracy. Also, there are instances in which well-located earthquakes do not line up with known faults.

In recent years, the sensitivity of seismograph networks has been greatly increased. As a result, a remarkably close relation between microseismicity (magnitudes less than 3) and specific faults in certain parts of the state has been confirmed. Figure 5 shows how a section of the San Andreas fault, and the Hayward, Calaveras and Rodgers-Creek faults are clearly outlined by the alignment of very small earthquakes. However, historically active faults may for periods of time show no microseismic activity; thus, a lack of microearthquakes is not conclusive evidence that a fault is dead. For example, north of San Francisco, where a long stretch of the San Andreas fault ruptured in 1906, no recognizable microseismicity or macroseismicity has occurred since 1906.

Quaternary Faults

A Quaternary fault is any fault that shows evidence of having been active during approximately the last two million years. The Quaternary period therefore encompasses those historic faults just described in the previous section. The Fault Map of California, however, treats the two terms as mutually exclusive time intervals, that is, a Quaternary fault is any fault *not considered an historic fault* that shows evidence of having been active during approximately the last two million years. Quaternary faults are indicated by orange lines, historic faults, as we have seen, are indicated by red lines.

Faults designated by heavy black lines are those without *recognized* Quaternary displacement, faults in this category are discussed later in the section entitled "Pre Quaternary faults."

Identification

Quaternary faults are recognized by various criteria. Because some of the evidence becomes destroyed with time and is not always clearly recognizable, geologists try to utilize as many bits of evidence as they can accumulate in their interpretation. Some of the most commonly used criteria include the following:

(1) Scarps in alluvium, terraces, or other Quaternary units;
(2) Lateral offsets in Quaternary units;
(3) Stream courses offset in a systematic direction;
(4) Alignment of fault-caused depressions, such as sag ponds, fault troughs, and fault saddles;
(5) Markedly linear and steep mountain fronts that appear to be associated with a bordering concealed fault trace;
(6) Ground-water barriers in Quaternary sediments caused by faults (such barriers may be evidenced by vegetation contrasts, alignment of springs and seeps, or by well data showing comparable water tables at different levels).

Problems

Using the above criteria, numerous faults can be shown to have Quaternary activity; however, as with any classification, there are situations where it is difficult to decide whether to designate the fault movement as being Quaternary in age.

In northeastern California, for example, a large group of faults within Quaternary volcanic rocks have been shown as orange lines on the Fault Map. However, in the same area and on the same trend, many other faults that occur wholly within somewhat older volcanic units have been shown as black lines. These faults may have formed at the same time as those faults in the Quaternary units, but without further evidence they cannot be classified as Quaternary. The faults in this area were largely determined by photo interpretation and only a limited amount of field checking. Further field work may reveal evidence of Quaternary displacement on many of these faults in the older rocks.

In various parts of California extensive nonmarine deposits were laid down over a long period of time ranging from late Pliocene well into the Pleistocene. These Plio-Pleistocene deposits (such as the Paso Robles and Santa Clara Formations in the central Coast Ranges) generally lack fossils, so the Pliocene portion of the rocks can rarely be separated from the Pleistocene rocks. Where these beds are cut by faults, geologists cannot readily determine whether the faults were active during Pliocene or Pleistocene time. A decision therefore had to be made by the compiler as to whether they should be designated as Quaternary. In order to avoid overlooking possible Quaternary faults, it was decided to include these faults within the Quaternary category.

For dating the faults shown on the Fault Map of California, the Quaternary rocks depicted on the new State Geologic Map were used as a guide. Although some of these age designations are probably incorrect, they were the most useful guide we had at the time. Even if the rocks shown as Pleistocene are somewhat older—that is, Pliocene—faults cutting such rocks could be post-Pliocene, nonetheless. In fact, if the rocks cut by a fault are *late* Pliocene in age, then the fault is most likely Quaternary.

Some dotted faults are shown as being Quaternary in volcanic terrain such as at Mount Shasta and in Owens Valley where there are alignments of Quaternary volcanic cones. These concealed "faults" may actually be fissures or fractures along which

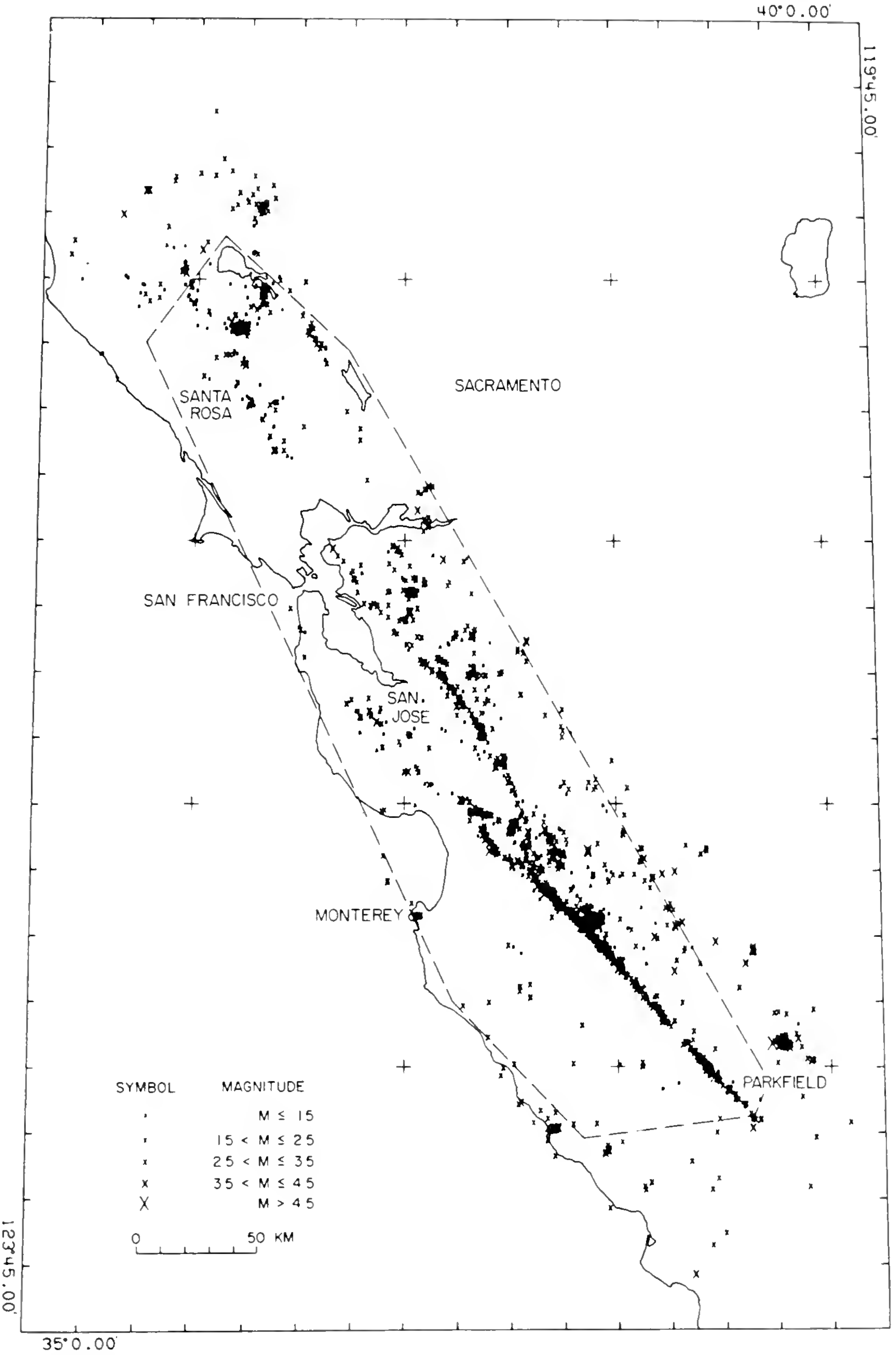


Figure 5. Map showing small-magnitude earthquake epicenters reported during 1975. Earthquakes in the region enclosed by the dashed line are generally well recorded and located. Note the alignments developed along parts of the San Andreas, Hayward, Calaveras and Rodgers Creek faults. *(From McHugh and Lester, U.S. Geological Survey, Open File Report 78-1051.)*

lava was extruded, and may in themselves have little or no displacement. But because these volcanic rocks are Quaternary in age and occur in an area where known Quaternary fault structures exist, these structures are interpreted to be of early Quaternary age also.

Faults that were determined solely on the basis of geophysical interpretations have been used, but with caution. The same is true of Quaternary faults located on the basis of well-log data. The quality of the logs and the well spacing were critical factors that were considered. With geophysical interpretations (especially those made by geologists), the date of the survey and the experience of the interpreters were considered, and consultation with Rodger Chapman, the Division's geophysicist, was sought before deciding whether to use certain fault interpretations based on geophysical data.

In cases where a geologic map indicates a fault separating bedrock from alluvium, especially along a mountain front, it is often difficult to determine what age the geologist considered the fault to be. Sometimes the map's scale is such that it cannot show a fault or fault zone in bedrock close to the alluvium contact. Sometimes, when a mapper interprets a mountain front as an eroded fault-line scarp, the geologist may not be particularly concerned about the age of the fault he is depicting and simply neglect to show it as a dotted line in the alluvium paralleling the mountain front. If such a fault is not discussed in the text, it is impossible to know whether it was considered to be a young or an old feature. This problem most commonly occurs in the Basin and Range and Mojave Desert provinces. In compiling the Fault Map of California, if a bedrock-alluvium fault relationship was not clear from the source data, the fault was usually shown in black—not to indicate that the fault movement was necessarily pre-Quaternary, but that the age of movement was undetermined.

In many cases, it is difficult to recognize Quaternary displacement along a fault when the fault lies wholly within rocks older than Quaternary. This is especially true in areas of great rainfall where subtle geomorphic evidence is easily destroyed or covered by vegetation. Also, some faults have been designated by geologists as Quaternary solely on the basis of photo-interpretation of suspected geomorphic features. Later field investigation, including trenching, may disprove the Quaternary designation or, in some cases, the existence of a fault.

Some faults that may actually have been active in historic time are shown as Quaternary because the activity went unobserved or unrecorded. It is not surprising that such activity on faults located in sparsely populated, remote areas such as in the deserts or in the heavily forested mountains would go unnoticed or, if noticed, never be recorded.

Plio-Pleistocene Boundary Controversy

The duration of the Quaternary period is not well defined, and the position of the Pliocene-Pleistocene time boundary in California has been considered at different places by various experts in recent years. The Pliocene-Pleistocene boundary is generally based on paleontological concepts and the first evolutionary appearance of certain species (Bandy and Wilcoxon, 1970, p. 2939). The paleontological evidence is correlated to magnetic events, paleo-climatic cycles, glacial events, and radiometric age determinations. Because of worldwide problems in correlation and disagreements among the experts, the duration of the Quaternary period has been variously reported as being from one million to three million years. The longer time interval has now been largely discredited (Bandy, 1969, also Bandy and Wilcoxon, 1970, p. 2939), and an age closer to two million years is more widely accepted. However, because three million years was the accepted age for the Quaternary period while some of the State Atlas sheets were being compiled, certain volcanic rocks of that age (determined radiometrically) were classified as Quaternary. Some faults within these volcanic rocks could thus be older than the age implied on the Fault Map of California.

Major Quaternary Faults

Quaternary faults are abundant and widespread in California. Many are short minor breaks, but others consist of numerous small segments that define major structural trends. Some Quaternary faults are extensive, but are largely concealed under alluvium. In order to emphasize the major Quaternary faults or fault zones, a pale orange band has been superimposed on the map portrayal of the fault. Certain criteria were used to decide which Quaternary faults should be selected for such emphasis. To be considered "major," a Quaternary fault had to be characterized by one or more of these factors:

(1) The fault is of considerable length (for example, usually more than 30 miles [48 km]).

(2) The fault is associated with an alignment of numerous earthquake epicenters (such as with the Sargent and Newport-Inglewood faults).

(3) The fault trace is continuous with segments that have historic displacement (for example, the Green Valley fault).

(4) The fault is associated with youthful major mountain scarps or mountain ranges (for example, Surprise Valley, Honey Lake, and Panamint Valley faults).

(5) The fault is associated with strong geophysical anomalies (for example, the Likely, Surprise Valley, San Clemente, and Mendocino faults).

Certain faults near the California-Nevada border that are shown as major Quaternary faults appear to be short. These faults, however, continue for many miles into Nevada and are, therefore, major structural features.

As with any classification, cases arose where the data were not clear-cut, and it was necessary to decide somewhat arbitrarily whether to include a fault as major. In general, the policy was to keep the number of emphasized faults to a minimum. If one were to extrapolate segments of faults across greater distances, many more Quaternary faults could be shown as major, but the writer preferred to await additional information in such cases.

Philisophy of Conservatism

In general, a "philosophy of conservatism" was followed in depicting the *extent* of Quaternary faulting; that is, where local evidence indicated that a fault has had displacement during Quaternary time, the entire length of the fault was shown as Quaternary unless contrary evidence indicated otherwise. This "philosophy," which has also been expressed by the U.S. Geological Survey (Wentworth, Ziony, and Buchanan, 1970, p. 4-5), takes into account the desirability of calling possible geologic problems to the attention of decision-makers *before* critical structures are built. If possible problems are known, they can be investigated, and their presence or absence be established, so that appropriate modifications of plans can be made in advance of siting or before detailed design and construction. Omission of the possible geologic hazards might lead users of the map to an erroneous conclusion that none existed. The maps that were compiled by Wentworth, Ziony, and Buchanan of several coastal areas in southern California were used in the preparation of the Fault Map of California, and in these areas their philosophy was directly incorporated. Elsewhere in the state, this conservative philosophy was followed, but perhaps not as rigorously because of the vastly greater area covered and the less specific character of the information available. The U.S. Geological Survey practice is to include some questionable information as long as it has some basis and is reasonable (Wentworth and others, 1970; Ziony and others, 1974). Hence, individual faults and connections between faults were shown where they were considered reasonable, even though conclusive evidence for their existence may be lacking.

On the Fault Map of California, aligned faults were generally not connected unless the gap between was too narrow to represent adequately at the map's scale; instead, an attempt was made to follow the source data as closely as possible. However, because of an extensive review of the Fault Map by many geologists, both the location and the extent of Quaternary faults shown on the Fault Map were carefully considered and many modifications were made. As a result, the 1975 Fault Map of California is the most complete and accurate portrayal of faults known in the state at the time of publication. The data on faults of California are constantly being evaluated and re-evaluated and, as time passes, new information will support or modify the Fault Map. It is obvious, therefore, that the map should be periodically revised and new editions published.

Pre-Quaternary Faults

Pre-Quaternary faults are shown by heavy black lines on the Fault Map of California. They are defined as faults that are older than Quaternary (older than two million years) or faults without recognized Quaternary displacement. There may be instances in which the youthfulness of a fault is not recognized for several reasons:

(1) The fault may not affect Quaternary rocks because none were present or, if ever present, they have since been removed by erosion.

(2) The fault may not retain evidence of youthful displacement because such evidence has been destroyed by erosion or covered by vegetation. This is especially true in areas of high rainfall.

(3) The stratigraphic or geomorphic evidence may have been removed or covered by works of man, such as in urban areas.

(4) The fault may not have been studied in sufficient detail to ascertain when displacement last took place.

Therefore, many of the faults shown as heavy black lines may be young and possibly may become active. An example of this is the Cleveland Hill fault, which ruptured in the August 1975 Oroville earthquake. Subsequent studies have shown that the fault lies within the Foothill fault system, which extends for more than 240 km (150 miles), but prior to the 1975 earthquake, most geologists viewed this system as a very ancient and "seismically dead" fault zone. Also, it must be stressed again that many faults have been included with the faults designated as pre-Quaternary because of a lack of age data.

Accuracy of Fault Locations

Fault traces are indicated in the same way on the Fault Map of California and the Geologic Map of California. The faults are indicated by solid lines where the location of its trace is accurate, by dashed lines where they are approximately located or inferred, and by dotted lines where covered by younger rocks or concealed by lakes or bays. The fault traces are queried where their continuation or existence is uncertain.

The accuracy of fault locations depends on the area studied and on the confidence that the geologists have in their work. A geologist may show a fault as solid or dashed depending on such factors as how well the feature is exposed, the scale of the map, the amount of time spent in the field, the extent of vegetative cover, and the complexity of the geology. With such variables, the degree of certainty in fault depiction varies greatly on a map compilation such as the Fault Map of California. However, even though the degree of certainty may not be uniform, the map accurately reflects the source data (within the limits of scale) and gives the map-user an indication of the degree of certainty on the location shown for the various faults within the state. Thus, the map-user should be able to distinguish those faults that are well located (shown by a solid line) from those that have some degree of uncertainty in location or existence (shown by dashed or queried lines). Of course, to be more precise, a map-user should refer to the larger scale maps from which the compilation was prepared (Appendix D).

The map-user must keep in mind three factors regarding the accuracy of faults portrayed on the Fault Map. First, a fault is not usually a simple, continuous feature; more often than not it is a zone or feature made up of discontinuous segments. Secondly, geologic features are mapped in the field by "eye" as they relate to topographic and cultural features. Where a fault crosses a featureless or gently undulating region, or where the land is densely vegetated, the mapped fault traces may be off by significant distances. Thirdly, on the 1:750,000 scale map, the width of a scribed fault line (0.012 of an inch) represents in itself about 232 meters (760 feet).

Depiction of concealed faults poses a special problem, particularly for the faults in the Great Valley. Here the fault evidence is taken largely from oil company maps of selected subsurface horizons, and many of the faults shown are at great depth. If a fault is vertical, its projected surface location lies directly over the fault at depth. However, if the fault is inclined, as commonly happens, the vertical projection of the fault to the surface is not directly over the fault. Such projections shown on the Fault Map can only be approximate and may indicate fault trends only. The main purpose of showing the faults is to indicate that the Great Valley is *not* an area devoid of faults. More subsurface information would undoubtedly show that the Great Valley harbors many more faults than the Fault Map of California now indicates.

Faults such as the San Andreas, Hayward, San Jacinto, White Wolf, and San Fernando, which have ruptured during historic time, and the Garlock fault, so well exposed in the semi-arid desert of southern California, have all been mapped in great detail. These studies show that the faults occur as a series of multiple breaks, rather than as a single continuous fracture. Large-scale strip maps of these faults were used in our compilation as the source data for showing more meaningfully the actual nature of these important California faults.

Offshore faults that are concealed beneath the ocean (they are discussed in the next section) are shown as dashed lines on the compiled map to indicate that their location is generally less accurate than is the location of faults mapped on land. Such faults are located by acoustic-reflection profiling from shipboard, and the problems of ship position and record interpretation naturally introduce certain inaccuracies.

Offshore Structure

A.C. Lawson (1893) was one of the first to point out diastrophism along the coast of southern California based on an analysis of the topography of the Channel Islands. He noted that the prominent marine terraces at San Pedro Hill on the mainland and on San Clemente Island do not exist on Santa Catalina Island. He attributed this to submergence of Santa Catalina Island. Later he made structural interpretations of the California coastal area from bathymetric charts. He concluded that "portions of the (continental) slope where the contours are crowded together...can scarcely be interpreted as other than fault scarps," and he compared them with the fault-scarp of the eastern front of the Sierra Nevada (Lawson and others, 1908, p. 13-15).

One of the most detailed fault maps of the southern California offshore, based chiefly on sea floor topography, was made by K.O. Emery (1960, p. 79). However, with modern sparker profiling, knowledge of offshore structure has increased so rapidly that faults and also folds can be based on much more than inferences made from the configuration of bathymetry. Unfortunately, much of this new information is retained in oil company exploration files and is thus unavailable, but the broader aspects of these data are occasionally released, as for example in the paper on northern and central California offshore petroleum geology published by the American Association of Petroleum Geologists(Hoskins and Griffiths,1971). Most of the available information, however, comes from recent studies and publications by the U.S. Geological Survey and various universities and institutions, especially the University of Southern California and the Scripps Institute of Oceanography.

Although the quality and quantity of data are not uniform in the offshore area, an attempt was made to acquire all data that were available and to show at least some structural data for the entire California coastal area. Thus, for the first time, the Fault Map of California depicts offshore faults (and on the Geologic Map of California, offshore folds as well).

Most of the offshore structures record late Cenozoic tectonism which may in fact, be of Quaternary age. As incomplete as these data are, one is struck by the activity and mobility of the continental shelf area. By the depiction of offshore structure, one can see the continuity of such major faults as the San Andreas fault, the Seal Cove-San Gregorio-Palo Colorado-Hosgri fault zone, and the Newport-Inglewood-Rose Canyon fault zone as they leave land and reenter at more distant points. One can also recognize the characteristic northwest-trending structural imprint of the Coast Ranges and the Peninsular Ranges provinces on the adjacent continental shelf area and the west-trending structural continuation of the Transverse Ranges province offshore. Also, a part of the anomalous west-trending Mendocino fault zone can be seen offshore. This feature actually extends westward for more than 3700 km (2300 miles) and one can ponder the character of this structure as it impinges on the continent at Cape Mendocino. Menard (1955) pointed out that this is the only one of the several offshore fracture zones that offsets the continental slope, but the fault has no clear topographic or fault continuation where it comes ashore at Cape Mendocino.

Recognizing these offshore structural features is very important because of their role in the siting of critical engineering facilities along the coast, and in the evaluation of offshore mineral resources

Coast Range Thrust

The Coast Range thrust, first described by Bailey, Blake, and Jones (1970), is depicted by open barbs. This fault marks the upper boundary of a long-active, late Mesozoic subduction zone extending from Oregon nearly to Santa Barbara. In most cases, the fault surface is now very steep, but locally it is flat or has been folded into prominent hooks (Blake and Jones, 1977, p. 6). It is best exposed in northern California and becomes more difficult to follow in its central and southern part because of modification by later vertical and strike-slip faults or because it is concealed by younger rocks.

E.H. Bailey and other geologists of the U.S. Geological Survey at Menlo Park were most helpful in identifying this structure on the 1:250,000 scale work sheets so that it could be more accurately portrayed on the 1:750,000 scale maps of the state.

The Coast Range thrust brings together the Mesozoic rocks of the Franciscan Complex and the Mesozoic rocks of the Great Valley sequence. The contact is easy to recognize where the ophiolitic rocks (a sequence of ultramafic rocks with mafic rocks above) that occur at the base of the Great Valley sequence are in contact with the Franciscan Complex. However, if the Franciscan rocks are in fault contact with *strata* of the Great Valley sequence, one cannot be sure whether the contact is the Coast Range thrust or a later vertical or strike-slip fault. Also, if the Franciscan rocks border serpentinite, which is itself not overlain by other ophiolitic rocks or strata of the Great Valley sequence, one cannot be sure whether the contact is the Coast Range thrust. Such stratigraphic problems made the plotting of the Coast Range thrust very difficult in many places. Additionally, the scale of the map is such that details of the pertinent stratigraphy do not always show.

These newer concepts were not used in the older mapping. In fact, faults on old maps were sometimes shown or omitted on the basis of now-outmoded interpretations. For example, ultramafic rocks that would be interpreted today as klippen of Great Valley ophiolite were mapped with intrusive, non-faulted contacts.

The Coast Range thrust interpretation gives us an explanation of the heretofore inexplicable juxtaposition of the two great belts of coeval Mesozoic strata: the largely chaotic and rarely fossiliferous Franciscan Complex; and the orderly and abundantly fossiliferous Great Valley sequence. The serpentinite lying immediately above the Coast Range thrust, previously thought to have been intruded into a fault zone, is now interpreted as part of the Mesozoic oceanic crust on which the Great Valley sequence was deposited. More recent work in the Coast Ranges has expanded the concept of subducting plates into a more complex pattern [for example, see Blake and Jones (1974) on the origin of Franciscan melanges as imbricate thrust sheets], but this work was done after the compilation of the 1:750,000 scale geologic and fault maps of California and hence could not be utilized on these maps.

Circular Fault Structures

Two very interesting circular and elliptical fault structures lie on the east side of the Sierra Nevada, just south of Mono Lake (Figure 6). The larger of the two is the Long Valley Caldera, a 16- by 31-km (10- by 19-mile) elliptical depression. This feature has been mapped in part by surface exposures, but the connections and complete closure have been determined from geophysical studies, especially gravity surveys (Pakiser and others, 1964). The caldera has been studied by several geologists over the years, and has recently received many detailed geological,

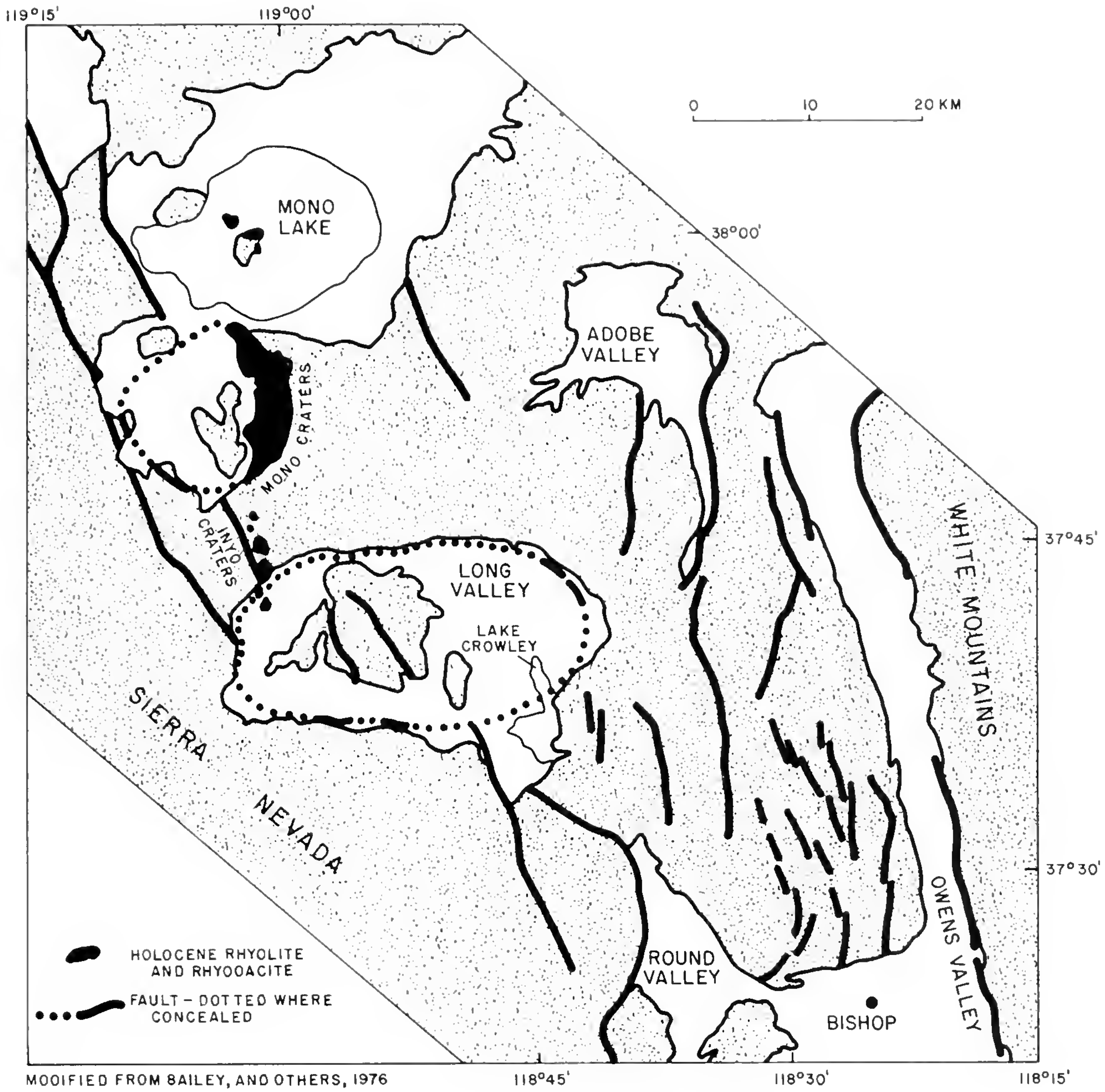


Figure 6. Generalized map of the Long Valley-Mono Craters area showing location of faults.

geophysical, and geochemical investigations as a result of a geothermal study program. According to Bailey and others (1976), the Long Valley structure is a volcanic caldera left by the eruption of the Bishop Tuff some 0.7 million years ago. As a result, the Long Valley magma was partially emptied, and its roof collapsed along arcuate ring faults.

The Mono Craters, to the north, between Long Valley and Mono Lake, are another ring-fracture zone of nearly circular configuration. It is even younger (Holocene) than the Long Valley caldera. However, according to Kistler (1966), the arcuate fault trace of the Mono Craters is probably the protoclastic border of a quartz monzonite pluton.

Future Changes in Fault Depiction

Most of the geologic maps that were used in compiling the Fault and Geologic Maps of California probably show only a small fraction of the faults that actually exist in the area of the maps. This is illustrated dramatically in mine mapping where many more faults are commonly visible in underground workings than are apparent at the surface. On older maps, faults of small displacement have often been ignored and dismissed as merely local features of little significance in the tectonics of the area. While it may be true that such features have had little effect on past geologic history, such faults, especially in young rocks, might be harbingers of a developing stress system and could provide important clues to future tectonic activity. In recent years, much more attention is being paid to subtle geomorphic features that may be evidence of Quaternary faulting. Thus, inconspicuous geomorphic features in the topography of valley alluvium, like those along the pre-earthquake San Fernando fault, will hopefully be detected and allowed for in planning decisions.

Active faults and earthquakes are now the subject of intensive research which will improve the interpretations shown on the Fault Map of California. Since its publication in 1975, many new data have been collected, and future detailed fault studies will require many changes on the Fault Map. Thus, the length or location of certain faults will be modified, and the class of activity for some faults will be changed. Some faults that are now shown as pre-Quaternary (or age unknown) will be changed to Quaternary as evidence for Quaternary movement is discovered. It is less likely that faults now shown as having affected Quaternary rocks will be changed by further studies unless the age of the rocks was originally misinterpreted. It is also expected that additional mapping will reveal new, as yet unsuspected faults of both Quaternary and pre-Quaternary ages. Mapping tools being used widely today that only a few years ago were seldom utilized in fault evaluation—for example, trenching, boreholes, detailed geomorphological studies, and radiometric age determinations—are continually providing new data.

Hopefully, future work will be able to determine the age of faults more accurately within the Quaternary period, so that those faults that have affected rocks of the late Quaternary or Holocene epoch can be shown separately. A better knowledge of where faulting has occurred within the most recent geologic past should be helpful in inferring what is likely to happen in the future. Thus, succeeding editions of the Fault Map of California should attempt to distinguish those faults with recognized Holocene movement, as well as Quaternary and historic designations.

The Fault Map of California, 1975 edition, is a provisional inventory of faults in the state, which should be revised periodically to keep abreast of the vast amount of new data being generated. Such information is vital to geologists, seismologists, engineers, planners, and others who use these data in their work.

FAULT PATTERNS

The Fault Map of California depicts many fault types and many major and minor faults. On close analysis, a characteristic orientation of fault traces over large segments of the state is apparent. Some faults stand out because of their great length, or because they separate vastly different rock types (as is apparent on the companion Geologic Map of California), or bound or terminate major mountain ranges. The San Andreas fault is considered the master fault in California, and is now recognized as one of the major faults in the world, separating two of the earth's major plates. Conjugate to the San Andreas are the Garlock fault and its probable offset western counterpart, the Big Pine fault. The Big Pine fault, together with the prominent Santa Ynez fault and the Malibu-Santa Monica-Raymond Hill faults, form part of the boundaries of the east-trending Transverse Ranges province in southern California. The Sierra Nevada-Owens Valley fault zone defines a north-trending zone and, unlike the earlier described strike-slip faults, is the most conspicuous normal fault zone in the state and perhaps in the western Cordillera.

Further consideration of the Fault Map of California suggests certain unfaulted areas, such as the Great Valley and Sierra Nevada provinces. This is partly misleading. Intensive exploration in the oil and gas fields of the Great Valley has revealed that numerous faults lie within the sedimentary strata of the valley at various horizons, indicating faulting at different times in the past. It is also suspected that extensive faults exist in the basement rocks underlying the Great Valley.The Sierra Nevada, principally a huge batholith consisting largely of ancient multiple intrusions, however, is apparently devoid of large faults except in two places. The first place is near its southern margin, where the Kern Canyon fault lies exposed in granitic rocks and is prominently emphasized in places by Pleistocene glaciation. The second place is at the western margin of the batholith where the Foothills fault system lies in old, pre-batholith rocks. The well-developed faults in the pre-batholith rocks suggest that the *site* of the batholith was earlier extensively faulted, perhaps forming a weak area in the earth's crust that the magma could easily invade during Mesozoic time.

Structural Provinces

An analysis of the structural features of the state reveals certain trends and patterns which appear to define *structural provinces*[*] and specific blocks. Each structural province is characterized by faults of a predominant trend or pattern, or in some cases, by two or more intersecting trends. Folds within these structural provinces are similarly related, and together, faults and folds are the result of stresses acting on and within each block in each province. As will be shown, an understanding of the distribution and nature of Quaternary faults in California should be a clue in the understanding of present stress fields.

No attempt will be made in this paper to analyze these stress fields. Such analysis requires an understanding of the structural blocks which respond as units to any applied stresses and the effort here is to recognize and describe the component blocks.

Each of the crustal blocks is of irregular shape and interacts with neighboring blocks in a complex fashion, much more complicated than the model envisioned for the conventional stress ellipsoid type of analysis. Furthermore, the blocks are highly fractured internally and thus are not homogeneous. Nonetheless, an understanding of the stresses on each individual block would be helpful in predicting where and to what extent future fault ruptures and earthquakes might take place. An understanding of the distribution and nature of Quaternary faults in California is one clue in the understanding of present day stress fields.

As a result of some 140 years of geologic mapping in California, we now have much empirical data about the geologic effects of the stress in most parts of the state as recorded in the rocks in the form of faults and folds. Because California has had a long and changing structural history since Precambrian time, and because so many of the structures revealed in the rocks are a reflection of long-since departed or reoriented stress fields, focus is here made on the most recent sequence of events and on the patterns of faults within the provinces and blocks that are defined largely by major Quaternary structures. Some of these structural boundaries are covered by alluvium or young rocks, and so sometimes it will be necessary to consider earlier structural patterns that may control later patterns. In some parts of the state, boundaries are not well defined because of incomplete geologic mapping; in these isolated cases, the boundaries suggested may need later modification.

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[*] These structural provinces should not be confused with the geomophic provinces by which the state is often described. Some of the structural province boundaries coincide with the geomorphic provinces, but others do not

Interaction between and among the blocks has caused secondary stresses within individual blocks. The internal shearing and rupturing caused by these stresses have resulted in the formation of many sub-blocks. Thus, the crust of California is comprised of several structural provinces which form a mosaic of blocks and sub-blocks of varying sizes and shapes interacting in a complex fashion.

Various geologists have noted fault patterns and structural blocks in different parts of California. For example, Cummings (1976) and Garfunkel (1974) discussed the pattern of Cenozoic faults in the Mojave Desert block, and Wright (1976) discussed the late Cenozoic fault patterns and stress fields in the Great Basin. In this Bulletin, however, the writer points out fault patterns and blocks throughout the state.

In this discussion, the state is divided into eight structural provinces, containing 16 blocks and 24 sub-blocks, which are defined on the basis either of predominant fault trends or of the characteristics of faults they contain. The reader is asked to refer to Plate 2 as the following structural blocks and sub-blocks in California are defined and discussed.

Predominant Fault Trends Defining Structural Provinces

The Quaternary faults in California can be grouped into specific structural provinces according to the predominant trend of the faults. Four of these provinces seem to be limited to specific areas with rather definite boundaries, while four additional structural provinces are bounded by somewhat less definite boundaries, and contain within them complex or multiple fault trends rather than a single dominant fault trend. The first four structural provinces are subdivided into a number of blocks and many of these can be further subdivided by subparallel boundaries into elongate slices or sub-blocks.

Major Structural Blocks With Predominantly Northwest Faults

The Coast Ranges block(Ia) and the Peninsular Ranges block(Ib) (as well as their component sub-blocks) comprise Structural Province I, which is characterized by faults with a strong northwest orientation exemplified by the trend of the San Andreas fault. These faults interestingly, all display right lateral slip (usually with a vertical component). These northwest-trending faults and blocks, however, are interrupted in the southern part of the state by faults having a strong eastward trend or transverse direction, which define Structural Province II.

Coast Ranges Block

The eastern boundary of the Coast Ranges block lies beneath the alluvium of the Great Valley, and the western boundary is concealed by the waters of the Pacific Ocean. In the northern part of the Coast Ranges block where the east-trending Mendocino fault aligns with the Eel River basin, the relationships appear to be very complex and may form a small intervening block. However, everywhere else the Coast Ranges block is dominated by a strong northwesterly structural pattern. The southern boundary of the Coast Ranges block is abruptly terminated by the Big Pine fault and by the transverse Structural Province II.

Peninsular Ranges Block

The eastern boundary of the Peninsular Ranges block is defined by the Dillon fault, which closely parallels the San Andreas fault zone, and its southeast projection through the Orocopia and Chocolate Mountains (fault 1A on Plate 2A). This fault also marks a separation between the prominent northwest trending faults of the Peninsular Ranges block and either the east-trending faults in the Pinto Mountains sub-block (II$_5$) or the diverse pattern of faults in the Sonoran Desert block (V). The western boundary continues offshore, probably as far as the Santa Rosa-Cortes Ridge. The southern boundary lies in Baja California.

Major Structural Block Having Predominantly East-Trending Faults

Transverse Ranges Block

A predominant east-trend or transverse fault trend is characteristic of Structural Block II. This block is composed of the Santa Ynez, the San Gabriel, the Banning, the San Bernardino, and the Pinto Mountains sub-blocks. All the major faults within these sub-blocks are left lateral and/or reverse faults.

Santa Ynez and San Gabriel Sub-Blocks

The Santa Ynez sub-block (II$_1$) is bounded sharply on the south by the Santa Monica-Raymond Hill fault zone and on the north by the Big Pine fault and its westward projection. The San Gabriel sub-block (II$_2$) is bounded by the San Andreas, the Cucamonga, and the San Gabriel-Sierra Madre faults. The Santa Ynez and the San Gabriel sub-blocks very abruptly terminate the northwest-trending faults of the Peninsular Ranges block and those in the southernmost part of the Coast Ranges block.

Banning Sub-Block

The wedge-shaped Banning sub-block (II$_3$) is enclosed by parts of the San Andreas, the San Jacinto, and the Banning faults. Both the east-trending Cucamonga and the Pinto Mountains faults abruptly terminate against this sub-block.

San Bernardino Sub-Block

The San Bernardino sub-block (II$_4$) and the Pinto Mountains sub-block (II$_5$) appear to be offset right laterally from sub-blocks II$_2$ and II$_1$ by the San Andreas fault zone. The San Bernardino sub-block is bounded on the north by an east-trending thrust fault, on the west by the San Andreas fault, and on the south by the Pinto Mountains fault. The eastern side of this sub-block is not well defined by any mapped fault but is marked by the termination of the San Bernardino Mountains. Cummings (1976) included this sub-block with his Mojave Desert block, but its internal transverse structure could exclude it from the Mojave Desert block, at least in recent geologic time.

Pinto Mountains Sub-Block

The Pinto Mountains sub-block (II$_5$) is bounded by the east-trending left-lateral Pinto Mountain and Chiriaco faults. Midway between these faults lies another left-lateral fault, the Blue

Cut fault, which may be considered as further subdividing the Pinto Mountains sub-block (Plate 2A). The Dillon fault clearly forms the western boundary. The southern boundary may extend farther south toward the Chocolate Mountains where certain east-trending faults are known. However, this area has not been mapped in detail, so the southern and southeastern boundaries are not precisely defined.

Major Structural Blocks Characterized By Northeast-Trending Fault Boundaries

The Garlock and White Wolf faults are the two most significant northeast-trending faults in the state and define Structural Province III, which consists of two blocks.* These faults are characteristically left-lateral, but may also have a minor reverse slip component.

Mojave Block

The Mojave block (IIIa) has been recognized as a separate entity for a long time and was discussed in some detail by Hewett (1954) and several others since then. The wedge-shaped Mojave block is bounded by the Garlock and the San Andreas faults and on the south by east-trending faults. The eastern boundary has not been mapped in detail, but appears to be defined by the junction of the predominantly northwest-trending faults within the Mojave block and the diversely oriented faults in the Sonoran Desert block to the east. Within the Mojave block, northwest-trending right-lateral faults are certainly common and conspicuous, although the northeast portion of the block is dominated by east-trending faults and may be a separate sub-block as suggested by Garfunkel (1974, p. 1938).

Tehachapi Block

The Tehachapi block (IIIb) is included in this report as part of the same structural province as the Mojave block because it is bounded on two sides by northeast-trending faults—the Garlock and the White Wolf faults. It is mostly comprised of granitic and metamorphic rocks like the Sierra Nevada, but is offset to the southwest from the main Sierra Nevada block.

Major Structural Blocks Characterized by North-Trending Faults

The fourth fault direction in California, that gives rise to Structural Province IV, is north-trending. The most important structure of this trend is the Sierra Nevada-Owens Valley fault zone. Several subparallel major faults of this same orientation (actually, slightly west of north) make up several blocks within this structural province. All these north-trending faults are normal faults, and any lateral component of slippage is usually right lateral.

Kern Canyon Block

One of the blocks is the Kern Canyon block (IVa), which lies between the Kern Canyon fault and the Sierra Nevada-Owens Valley fault zone. Its southern end is uncertain but is possibly bounded by a northeastern extension of the White Wolf fault trend (Plate 2A). Faults within this block, especially in the Owens Valley-Bishop area, are numerous and trend almost always north. In addition, these faults align with the long north-trending zone of active faults in Nevada which extends from Owens Valley into Nevada through Cedar Valley, Fairview Peak, and Dixie Valley.

Panamint and Death Valley Blocks

Due east of the Kern Canyon block are the Panamint and Death Valley blocks (IVb and IVc). They are more crudely defined than the other blocks of the structural provinces but are well expressed in part by the north-trending Panamint Valley and Death Valley fault zones. Within these blocks are numerous short faults which characteristically trend northwest and northeast. These conjugate fault directions appear much more numerous when we include the faults designated as "pre-Quaternary or age unknown" (Figure 7); perhaps some or many of these "older" faults may also be found on closer analysis to be of Quaternary age. In any event, the conjugate faults within these blocks bounded by north-trending faults collectively make a pattern with a preferred northwest and northeast orientation, with no sign of an east-trending direction. Interestingly, this area appears to be the only place in the state where this northwest-northeast conjugate system is so well developed—a fact suggesting that it is acting as a unit to a specific stress system.

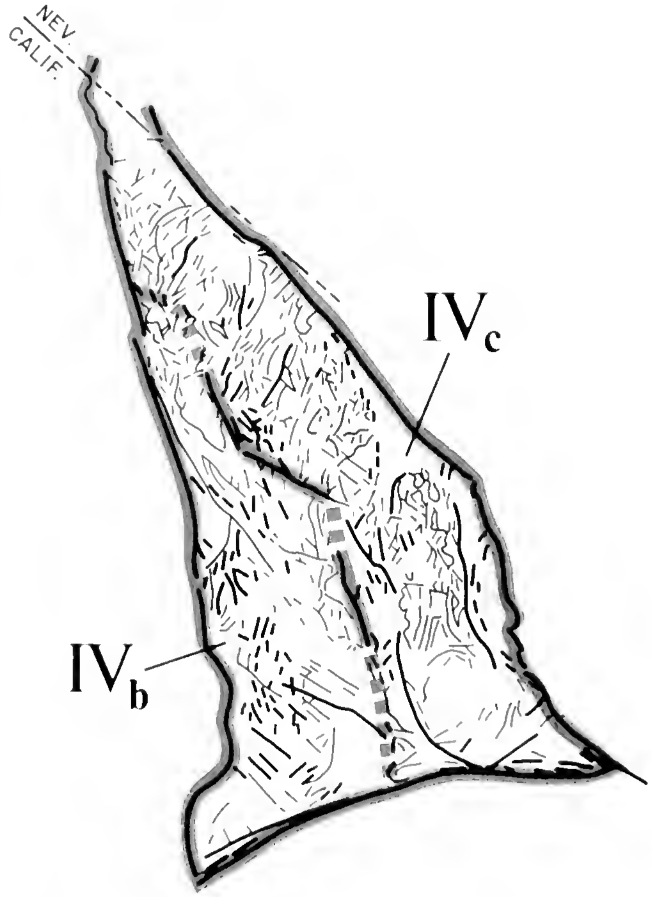

Figure 7. Numerous short NW and NE conjugate faults characteristic of the Panamint and Death Valley blocks. (thick lines = Quaternary faults; thin lines = pre-Quaternary or undated faults)

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*An ancient northeast trending fault, the Stockton fault, lies in the subsurface beneath the Great Valley, but has no apparent relationship to the Quaternary tectonics discussed here.

Warner Block

Another prominent block with characteristic north-trending faults is the Warner Block (IVd) in the northeastern corner of the state. Most prominent is the Surprise Valley fault and the block-faulted Warner Range.

East Sierra Block

The East Sierra block (IVe) has a well-defined boundary on the west side formed by the main Sierra Nevada block, but only a vaguely defined boundary on the east side at the Walker Lane in Nevada. This block is characterized by block-faulting with strike-slip shearing.

Cascade Block

The Cascade block (IVf), in the northern extremity of California, is the southern tip of an elongate north-trending block which continues for many miles into Oregon and Washington. It is principally defined by a north-trending series of volcanoes that may be controlled by deep faults or fractures along which these volcanoes and lavas have erupted.

Gorda Block

Finally, offshore of northwestern California lies another block with north-trending faults. This appears to be part of the eastern edge of the subducting Gorda block (IVg).

Major Structural Blocks Characterized By Other Types Of Faults

The state contains four other structural provinces, which are in general less well defined, especially by Quaternary structures, but which nevertheless form specific areas that have their own special characteristics.

Sonoran Desert Block

Structural Province V forms a rather large region which is fairly well defined on the west, but extends eastward into Nevada, Arizona, and Mexico, where its boundaries have not been studied in detail. Geomorphologically, this region is considered part of the Mojave and Basin Ranges geomorphic provinces, but structurally it appears to form a separate province—here called the Sonoran Desert block. Its eastern boundary may be defined by the Walker Lane in Nevada and Arizona, wherein lies another structural province with north-trending faults. Thrust faults are known in the Sonoran Desert block, but their extent has not been determined. In fact, much of this area has only been mapped by reconnaissance, and so further analysis at this time is not feasible.

Sierra Nevada Block

Structural Province VI consists of the Sierra Nevada block, which has long been recognized as a major structural feature. Certainly this large batholith forms a resistant block and serves in some places as a buttress and elsewhere as a ram on adjacent blocks. Its western boundary lies beneath the Great Valley. Its eastern boundary is clearly marked by an immense scarp in some places and by the faulted terrane of Structural Province IV. The northeastern boundary with the Modoc block was shown by Durrell (1965, 1966) as a separation of an area of relatively young block faulting from a more stable mass. The northwestern boundary is a complicated and vaguely defined junction of at least four blocks. Further work in this area should help to clarify the inter-relationships. This northwestern portion of the Sierra Nevada block also contains a large mass of the older, pre-batholith rocks through which trends the well-developed fault zone of the Melones and Bear Mountain faults. At the south end, these faults have a prominent northwest trend; they turn due north in the central region and then swing northwest again at the north end. This fault zone widens northward and splits into several branches. The faults were formed in pre-batholith times but renewed activity has been noted along parts of this ancient zone of weakness (Alt and others, 1977). The Oroville earthquake of August 1975, with associated ground rupture, for example, illustrates the effects of a modern stress field acting on a very old zone of crustal weakness.

Klamath Block

Impinging on the northwestern end of the Sierra Nevada block is Structural Province VII, the Klamath block. This structural unit is typified by numerous ancient thrust faults. No Quaternary faults are known within this area of resistant granitic and metamorphic rocks.

Modoc Block

Lastly, the Modoc block forms the irregular, anomalous Structural Province VIII. It is characterized by numerous Quaternary faults, most of which trend northwest, but with some conjugate faults that trend northeast, and, in one part of this province, with some seemingly arcuate faults. The faults are largely in young volcanic rocks, but their relationship to this outpouring of lava is not understood. Two long and significant faults appear within this unit—the Likely and the Honey Lake faults. The Likely fault appears to have a right-lateral strike-slip component, while the Honey Lake fault is mostly normal dip-slip. Northwest-trending fault segments line up with the Honey Lake fault, and they may be part of the same fault zone extending toward Oregon. This northwest trend may be a reflection of an underlying structural province hidden beneath the Modoc lavas, or it may be the result of a totally new stress field. It should be pointed out that only reconnaissance mapping has been accomplished in most of this area and that most of the faults were largely unrecognized as recently as 20 years ago.

Coast Ranges Sub-Blocks

Within the Coast Ranges block, seven sub-blocks are recognized. Four of these sub-blocks are well-defined and are bounded by well-known faults. The faults are parallel for the greater part of their length, and are abruptly terminated at the southern end by the Transverse Ranges block. In central California, several adjacent faults converge with one another forming blocks having remarkable mirror-image symmetry.

Santa Lucia and Gabilan Sub-Blocks

The King City-Rinconada fault separates the Santa Lucia and the Gabilan sub-blocks (Ia_1 and Ia_2). The Santa Lucia sub-block is bounded on the west by the inter-connection of the Seal Cove, the San Gregorio, the Sur, and the Hosgri faults, and the Gabilan sub-block is bounded on the east by the San Andreas fault. Note that the Seal Cove fault converges with the San Andreas to the north. Likewise, a short extrapolation of the northwest-trending King City fault coincides with similarly oriented faults under Monterey Bay, which in turn are aligned with a northwest-trending portion of the Santa Cruz County coastline that is probably fault controlled, and thus converges with the San Gregorio fault. To the south, both of these sub-blocks terminate against the transverse Big Pine fault and its westward extrapolation.

San Francisco and Berkeley Sub-Blocks

The San Francisco and Berkeley sub-blocks (Ia$_3$ and Ia$_4$) are separated by the Hayward-Rodgers Creek-Maacama fault zone. The San Francisco sub-block is bounded by the San Andreas fault on the west; the Berkeley sub-block is bounded by the Calaveras-Green Valley fault zone on the east. The Hayward fault appears to converge with the Calaveras fault to the south, and likewise the Calaveras fault converges with the San Andreas fault to the south. It is interesting to note the symmetrical relation between sub-blocks Ia$_3$ and Ia$_4$, north of the San Andreas fault, and sub-blocks Ia$_1$ and Ia$_2$ south of the San Andreas fault.

Diablo and Great Valley Sub-Blocks

The next sub-block to the east is the Diablo (Ia$_5$), defined in part by the Ortigalita fault and its extrapolation to the north. Its southern boundary and its boundary with the Great Valley sub-block (Ia$_6$) to the east, are hypothetical; they have been drawn largely on the basis of the equidistant fault spacing concept discussed later.

Stonyford Sub-Block

Lastly, the Stonyford sub-block (Ia$_7$) is the anomalous northeast corner of the Coast Ranges block. Older faults have made the breaks dividing this corner from the main block. Although the Bartlett Springs fault on the west side of this sub-block has now been recognized as a Quaternary fault (Hearn and Donnelly, personal communication, 1977), the faults within the Stonyford sub-block appear to be characterized by ancient thrust faults. On the basis of photo interpretation and prominent lineaments, it appears that the Bartlett Springs fault connects with the Grogan fault farther north, which may in turn join with a prominent Quaternary fault offshore.

Peninsular Ranges Sub-Blocks

The Peninsular Ranges block, in the southern part of the state, is readily divisible into eight sub-blocks. These eight northwest-trending sub-blocks, without exception, terminate against the Transverse Ranges block lying to the north. All the Peninsular Ranges sub-blocks in California and offshore are remarkably parallel, and all extend southward into Baja, California.

Three of the Peninsular Ranges sub-blocks lie almost totally offshore of California, and definition of their boundaries is largely dependent on the offshore geophysical work that has been accomplished in recent years. Although the Peninsular Ranges sub-blocks illustrated on Plate 2A are defined by Quaternary faults, the boundaries are re-enforced by the patterns of the older faults. It would not be surprising if additional offshore faults in the continental borderland shown on the Fault Map of California are determined to be Quaternary upon further investigation; in any event, all these offshore faults shown are at least of late Tertiary age.

San Clemente and Catalina Sub-Blocks

The San Clemente sub-block (Ib$_1$) is well defined on the east by the San Clemente fault and faults lying on the same strike to the north. The western boundary appears to lie among the faults along the Santa Rosa-Cortes Ridge. The Catalina sub-block (Ib$_2$) is bounded on the east by the Thirty Mile Bank and the Catalina Island faults and on the west by the San Clemente fault (faults 5, 5A, and 6 on Plate 2A).

Palos Verdes and Inglewood-San Diego Sub-Blocks

The Palos Verdes sub-block (Ib$_3$) is bounded by the next major northwest-trending Quaternary fault to the east, the Palos Verdes fault and its offshore extensions on strike to the south. The Inglewood-San Diego sub-block (Ib$_4$) is defined by the Quaternary Newport- Inglewood-Rose Canyon fault zone on the east and the Palos Verdes fault on the west.

Santa Ana, Riverside, and San Jacinto Sub-Blocks

The Santa Ana (Ib$_5$), Riverside (Ib$_6$), and San Jacinto (Ib$_7$) sub-blocks have remarkably distinct boundaries formed by the Quaternary Elsinore fault, the San Jacinto fault, and the San Andreas fault on the east side of each. A possible eighth, narrow-sub-block may lie east of the San Andreas, bounded by the Dillon fault and other somewhat older faults along the southeast-trend of the Dillon fault (fault 1A on Plate 2A).

Sub-Blocks Within The Modoc Block

The Modoc block (VIII) in the northeast corner of the state is irregularly shaped, and it seems to be characterized by numerous Quaternary faults. Many of these faults trend northwestwardly, but some also strike in other directions. Mapping of this area has been mostly reconnaissance, but even so, the fault patterns suggest some tentative subdivisions that are shown on Plate 5. These are identified as the Alturas, Eagle Lake, Diamond Mountains, and Medicine Lake sub-blocks.

Summary

From the preceeding discussion and by consideration of the Structure Map of California (Plate 2A), the basic concepts concerning predominant fault trends and the structural provinces they define may be summarized as follows:

1. The state is divisible into eight structural provinces, each containing faults and folds of a characteristic trend or pattern, or, in a few cases, two dominant conjugate directions.

2. The structural provinces are also divisible, so that the state appears to be broken into a complicated mosaic of fault blocks.
   (a) Each block appears to be acting as a unit, but also interacting with adjacent blocks.

   (b) Stresses within each block (particularly the larger blocks) develop secondary faults which define sub-blocks.
   (c) The blocks and sub-blocks appear to be best defined in the southern part of the state where the rocks are well exposed and where the most detailed mapping has been done. The blocks in the northernmost part of the state are less well defined; where the forest cover is most dense and the mapping less detailed, the block boundaries are least known.

3. Most of the blocks are bounded and characterized by major Quaternary faults of great linear extent. In a few cases, major pre-Quaternary structures define blocks having common structural characteristics.

4. With only a few exceptions, all Quaternary and older faults and folds within a block or sub-block are confined to that block and never cross its boundaries, even when the fault or fold may cross the entire block or sub-block.

5. The most common fault trend in California is northwest with east being secondary. Northeast-trending faults are relatively few but include two major faults—the Garlock and the White Wolf. North-trending faults are not common and usually form more complex, segmented features.

6. (a) All major northwest-trending Quaternary faults are right lateral (usually with a vertical component).*
   (b) All major east-trending Quaternary faults are left lateral and/or are reverse faults.
   (c) All major northeast-trending Quatenary faults are left lateral and/or are reverse faults.
   (d) North-trending Quaternary faults are normal faults (with mostly right lateral components).

FAULT COUPLES

An interesting observation about sub-blocks can be noted. An apparent "couple effect" is generated in the block between two parallel strike-slip faults. In this situation, diagonal breaks occur between the bounding faults, forming a family of diagonal faults with a consistent orientation. Good examples of this can be seen in the northern Coast Ranges between the San Andreas and the Rodgers Creek-Healdsburg faults or in the Transverse Ranges between the San Andreas and San Gabriel faults (Figures 8 and 9). Still other examples can be seen in other parts of the state, especially in the western part where the major faults are strike-slip. It appears that most of the diagonal faults have no Quaternary displacement and that the bounding faults do have Quaternary displacement. Perhaps this is because the diagonal faults are activated only after a long period of time when the confining stress finally exceeds the strength of the crustal materials. If so, the stress on the diagonal faults is intermittantly accumulated and relieved, while the confining parallel faults undergo more frequent strike-slip movement. Hence, it should not be surprising if an occasional stress release occurs on some of these diagonal faults—in fact, many of the earthquake epicenters not lying on major faults could represent release of stress on such diagonal faults (Plate 2D).

There are places between major parallel strike-slip faults where no diagonal fault pattern has developed—for example, between the northern parts of the Elsinore and San Jacinto faults or between the Elsinore fault and the Newport-Inglewood-Rose Canyon fault zone. However, an examination of the Geologic Map of California at these places reveals the presence of extensive bodies of Mesozoic and older granitic and metamorphic rocks. These rocks probably would tend to resist such diagonal shearing and focus the release of stress along the block boundaries. Another place where the absence of diagonal faults is especially noticeable is in the Gabilan block, which has virtually no intra-block faults and which is characterized by the granitic rocks of the Gabilan Range between the strike-slip San Andreas and King City-Rinconada faults (Figure 10). Southeast of the exposed granitic rocks of the Gabilan Range, there is also a virtual absence of faults, but the rocks here consist mostly of a thin layer of late Tertiary sedimentary rocks overlying the rigid granitic rocks. Here, however, gentle folds in the overlying sedimentary rocks, exhibit north northwest-trending axes along the direction of the expected diagonal faults.

EN ECHELON FAULTS

Within the northern Coast Ranges, the major Quaternary strike-slip faults which bound certain sub-blocks commonly display a remarkably consistent right-stepping en echelon pattern. For example, the Hayward, the Rodgers Creek, the Healdsburg, and the Maacama faults each appear to be a successive right-stepping continuation of a principal fault zone bounding the eastern edge of the San Francisco sub-block. And the Calaveras, the Concord, the Green Valley, and the unnamed faults to the north appear to be a successive right-stepping continuation of another major fault zone bounding the eastern edge of the Berkeley sub-block. Both of these sub-blocks are characterized by diagonal shear faults. In a similar fashion, the Bartlett Springs fault lines up with right-stepping lineaments northward into Trinity and Humboldt counties; this alignment suggests the location of heretofore unrecognized faults bounding the Stonyford sub-block.

REGULARITY OF FAULT SPACING

The spatial geometry of the major Quaternary faults reveals another interesting relationship. This concerns their remarkable parallelism and uniformly spaced intervals over great distances. This is particularly evident in the sub-blocks of the Coast Ranges and Peninsular Ranges structural blocks. In the Coast Ranges block, the spacing between the major faults bounding the sub-blocks ranges from approximately 33 to 39 km along lengths of well over 240 kilometers (Plate 2B). Within the onshore portion of the Peninsular Ranges block, three sub-blocks vary from 37 to 42 km in width (except for the southern part of the Santa Ana block, which is as much as 72 km wide; however, there the southern California batholith widens to its greatest extent). Offshore the spacing interval is 32 to 42 km with the Palos Verdes fault appearing to divide a 32 km wide block into two sub-blocks.

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*At first glance, it appears that the family of short northwest-trending faults in northern California known as the Paskenta, Elder Creek and Cold Fork faults, which displace Lower Cretaceous and Jurassic rocks left laterally, is an exception to the basic concept presented here about northwest-trending faults being right lateral. However, if these faults are interpreted as tear faults off the Coast Range thrust, where the Coast Range thrust loops around the Klamath Mountains before heading south, then these northwest faults are a special case and are behaving as tear faults of this orientation would be expected to. In addition, these faults are very old and have no recognizable Quaternary displacement (Jones and Irwin, 1971).

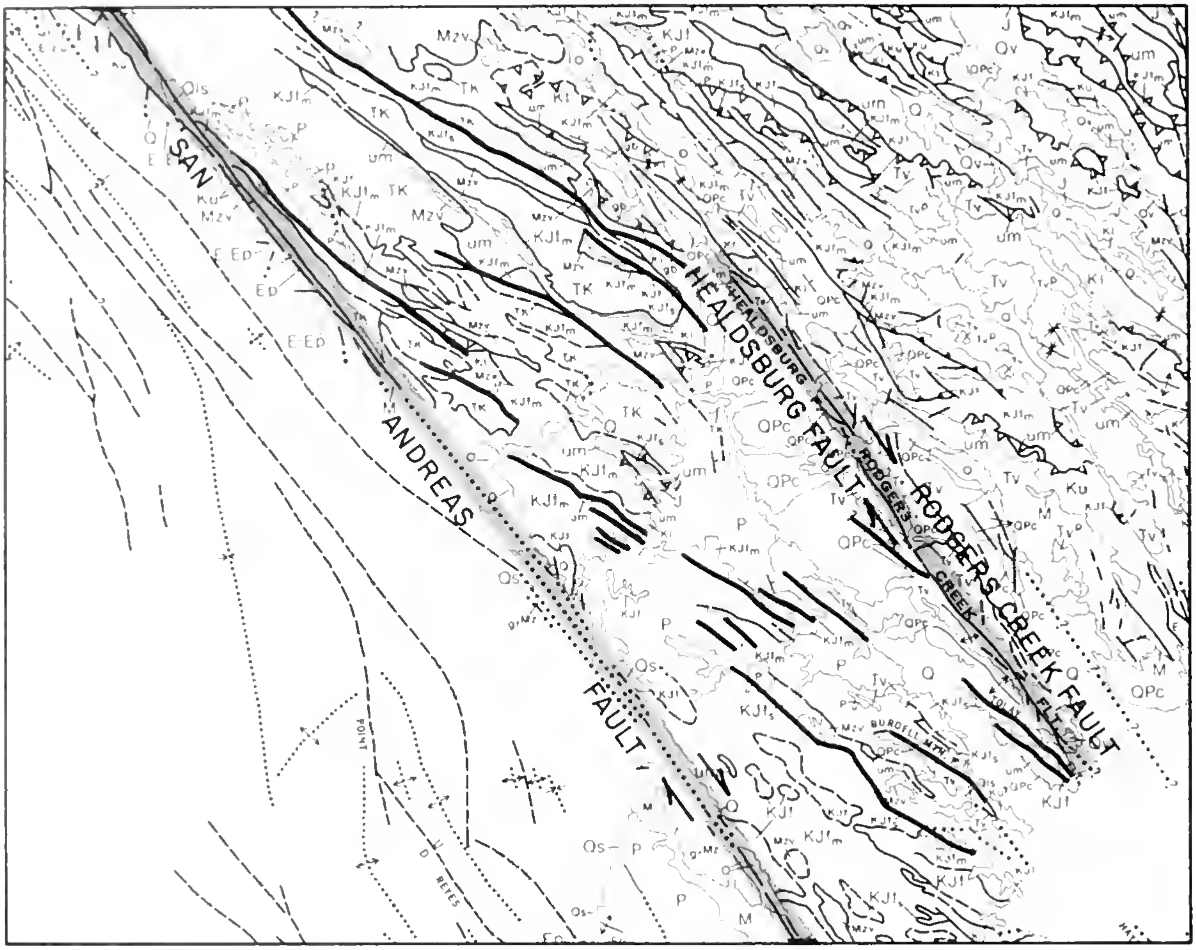

Figure 8. Diagonal faults formed between two major strike-slip faults, the San Andreas and the Rodgers Creek-Healdsburg faults.

The major faults bounding the three adjacent north-trending structural blocks—Kern Canyon, Panamint, and Death Valley—also display roughly equidistant spacing. Two of these blocks are about 50 to 53 km wide, while the third is about 42 km wide over distances of over 160 km.

It appears that regularity of spacing between major faults, repeated in many parts of the state, must be more than a coincidence. It suggests that the rigidity of the earth's crust is behaving in some consistent fashion related to the strength of the crustal or even sub-crustal materials and to the direction of deep stresses applied to the structural blocks.* If such be the case, then the existence of faults in unmapped areas (such as some offshore areas) and in incompletely mapped areas (such as in northwestern and southeastern California) might be predicted by extrapolation of known faults by maintaining equidistant spacing between them. For example, the northwestward continuation of the San Francisco and Berkeley sub-blocks into Mendocino County would therefore be expected, by extension of the Maacama and Bartlett Springs faults (with right-stepping en echelon offset). The continuation of an accompanying diagonal fault system between these strike-slip faults would also be anticipated; and, in fact, topographic lineaments and incompletely mapped faults (see Fault Map of California) strongly suggest such a continuation of both the strike-slip faults and the diagonal fault system.

To extend precisely the mapping of faults paralleling the San Andreas trend northward into the terra incognita of the northern Coast Ranges block will be difficult because of the existence of numerous and gigantic landslides. However, one thing is certain—the major faults coming up from the south must continue into this landslide terrane. Indeed, many of the landslides are in all probability a reflection of the weak rock crushed by the suspected faults. The strong northwest-trending lineaments, expresed by the major river drainages, are an indication of the structural grain of the country. Unfortunately, the river-undercutting of the steep slopes in this high rainfall area, releases the landslides which can easily mask fault traces.

Twenty-five years ago, H.W. Menard (1955, p. 1172) noted the regularity of fault spacing in the ocean floor off California and, on the basis of this regularity, predicted the existence of additional offshore fracture zones. "Four fracture zones have been discovered," writes Menard, "and others may be found as more echograms become available from other regions in the Pacific." Figure 11 is Menard's map showing the location of

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*Upon completion of this manuscript, in which the writer independently developed the ideas of equidistant fault spacing in California, he came upon foreign reports describing this phenomenon in other parts of the world. Especially noteworthy are papers by J. Kutina (1968) and Radan Kvĕt (1974). In these papers the authors describe examples of equidistant rupture systems in Czechoslovakia, Austria, Scotland, and Sardinia.

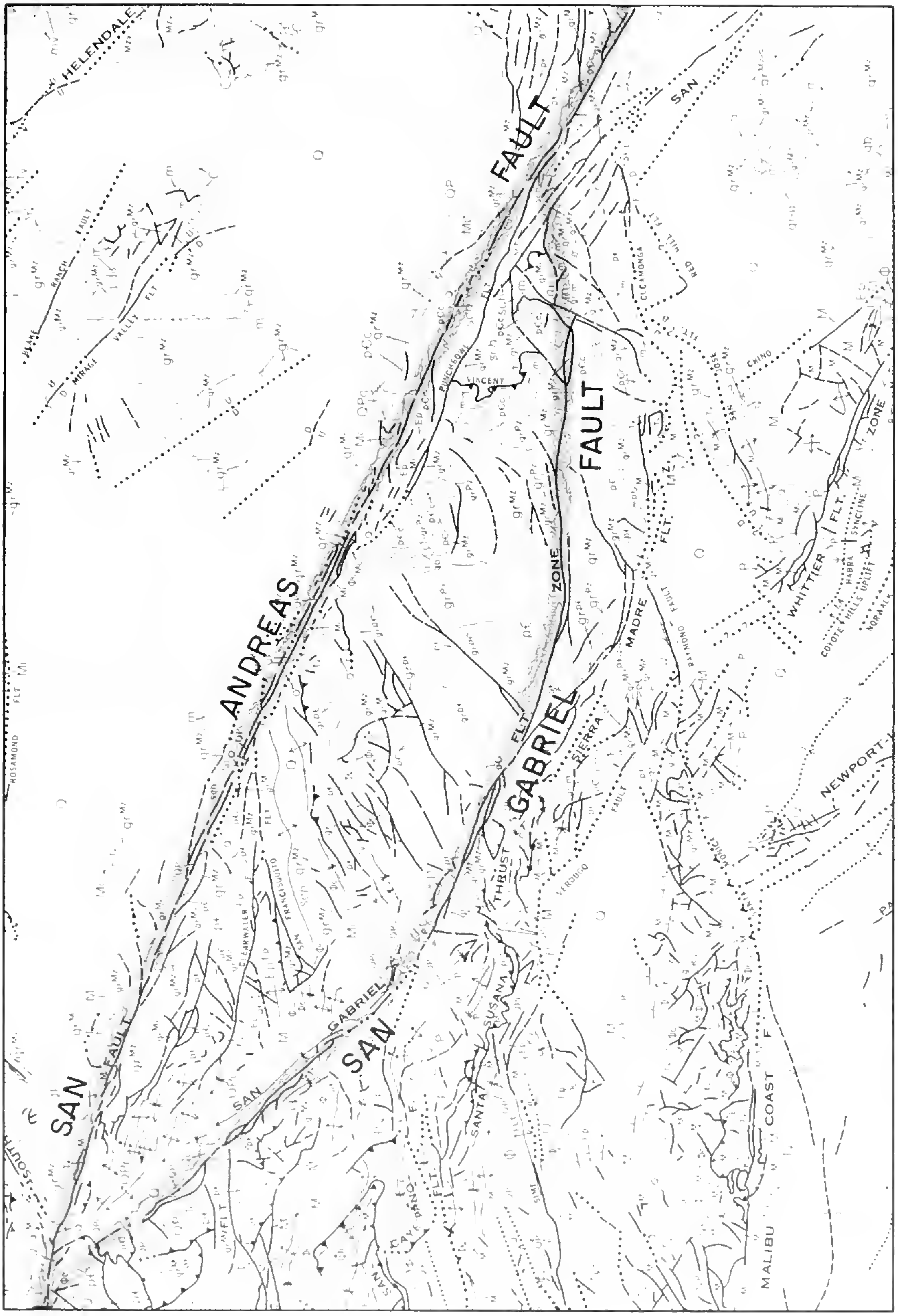

Figure 9. Diagonal faults formed between the strike-slip San Andreas and San Gabriel faults.

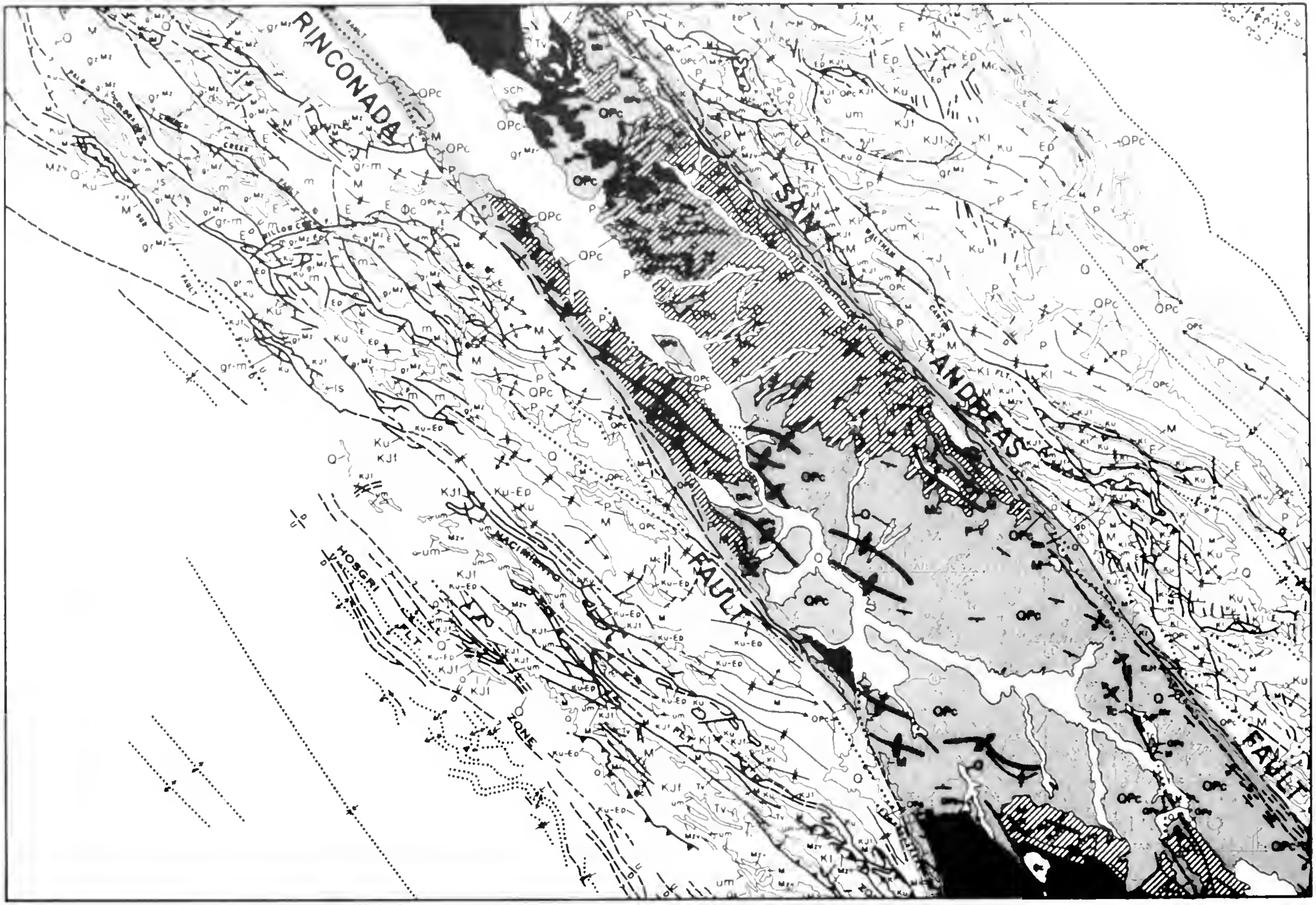

Figure 10. Diagonal folds formed between the San Andreas and Rinconada faults in thin sedimentary cover overlying granitic basement rocks (black area on map). QPc = Plio-Pleistocene nonmarine sedimentary rocks (light gray area), P and M (diagonal pattern areos) = Pliocene and Miocene marine sedimentary rocks. (Also note the diagonal faults and folds formed between the Rinconada and Hosgri-Sur offshore strike-slip fault zone).

these four fracture zones. Speaking of other likely fracture zones, Menard (p. 1172) writes:

> Possible locations are about 600 miles north of the Mendocino fracture zone, midway between the Murray and Clarion fracture zones, and about 600 miles south of the Clipperton fracture zone. These positions are suggested by the regular spacing of the zones.
>
> The most probable position for another fracture zone is midway between the Murray and Clarion fracture zones. A zone at this location would give a regular unit spacing for all the zones from Mendocino to Clipperton rather than a unit spacing between the northern and southern pairs and double the unit spacing between the middle pair.

As a matter of fact, later work has proved Menard's prognostication correct. Figure 12 shows the configuration of the same area as Menard's, but is based on much additional data collected at a later date. Note how the equally-spaced faults have been discovered. Of course, the offshore crustal blocks between Menard's fracture zones are several orders of magnitude larger than the sub-blocks herein described for onshore parts of California. The offshore blocks are merely presented here as an example of crustal materials undergoing stress, which deform in a more or less uniform, predictable fashion.

Menard also saw some possible correlation between the offshore fracture zones and the geologic provinces on the continents. He felt it was particularly significant that the Great Valley and the Sierra Nevada, as well as other geologic provinces south of California, all appeared to be terminated at their northern and southern ends by the onshore continuation or projection of offshore fracture zones.

SUMMARY ON FAULT GEOMETRY

The following facts can be stated about the geometry and distribution of sub-blocks, fault couples, and fault-spacing regularity:

1. Each sub-block has remarkably parallel boundaries for great distances.
2. (a) Each sub-block in the southern Coast Ranges abruptly terminates against the Transverse Ranges block.
   (b) Each sub-block in the northern Peninsular Ranges likewise abruptly terminates against the Transverse Ranges block.
   (c) The northern termination of two Coast Ranges sub-blocks (I_1) and Ia_2) by convergence is symmetrical with the southern termination by convergence of two other contiguous central Coast Ranges sub-blocks (Ia_3 and Ia_4), that is, the Seal Cove-San Gregorio fault converges with the San Andreas and with the projected Rinconada-King City fault zone, while the Green Valley-Calaveras fault zone converges with the San Andreas and with the Rodgers Creek-Hayward fault zone.
3. (a) Most sub-blocks bounded by strike-slip faults contain diagonal faults that may be a result of a couple effect whereby diagonal shears are formed in the block between the bounding strike-slip faults.
   (b) Where diagonal faults do not develop, or are not well developed, between parallel strike-slip faults, the reason could be that resistant granitic and metamorphic rocks lie at or near the surface between the bounding strike-slip faults.
4. Major Quaternary strike-slip faults bounding sub-blocks in the central Coast Ranges display a consistent right-stepping en echelon pattern.
5. Spacing between the major parallel Quaternary faults shows a remarkably uniform interval.
   (a) In the Coast Ranges block this equidistant spacing interval in five sub-blocks ranges from 33 to 39 km over distances in excess of 240 km.
   (b) In the Peninsular Ranges block, the equidistant spacing interval ranges from 32 to 42 km in five sub-blocks.
   (c) Where spacing intervals appear to vary, they occur as a multiple of, or equal fractional parts of, the regular interval.
   (d) Three adjacent north-trending blocks east of the Sierra Nevada block approximate equidistant spacing, two being about 52 km wide and the third 42 km wide.
   (e) Regularity in fault spacing has been noted before in offshore California areas by Menard and served as a useful concept in correctly predicting the existence of additional offshore fracture zones.

FAULTING AND PATTERNS OF SEISMICITY

California is situated within a mobile belt of rocks on the boundary between the Pacific and North American plates. Here the rocks are highly folded as well as faulted, and in places are marked by numerous volcanoes, some of which have been active in historic time. The state is also part of the well-known circum-Pacific earthquake belt, now recognized as coinciding with interconnecting plate boundaries around the Pacific Ocean. As such, it should be no surprise that California has had, and will continue to have, numerous earthquakes.

Relationship of Epicenters To Faults

Various inaccuracies are inherent with epicenter maps, and most epicenter patterns appear more or less randomly positioned in relation to individual faults. However, with care, some relationships can be observed between faults and earthquake epicenters of certain magnitudes. For example, almost all of the earthquakes of magnitude 6.0 and greater in the last 75 years (see Plate 2C) have epicenters that are on or near major Quaternary faults. In a few cases where this relationship does not seem to exist, the epicenter locations could be suspect, for they may have been far from the seismic networks existing at the time. (These earlier locations are often rounded off to the nearest degree, half-degree, or quarter-degree latitude and longitude).

Two earthquake events in the magnitude 6 range that may not be related to major Quaternary faults are the 1947 Manix and the 1966 Truckee earthquakes. Although the magnitude 6.2

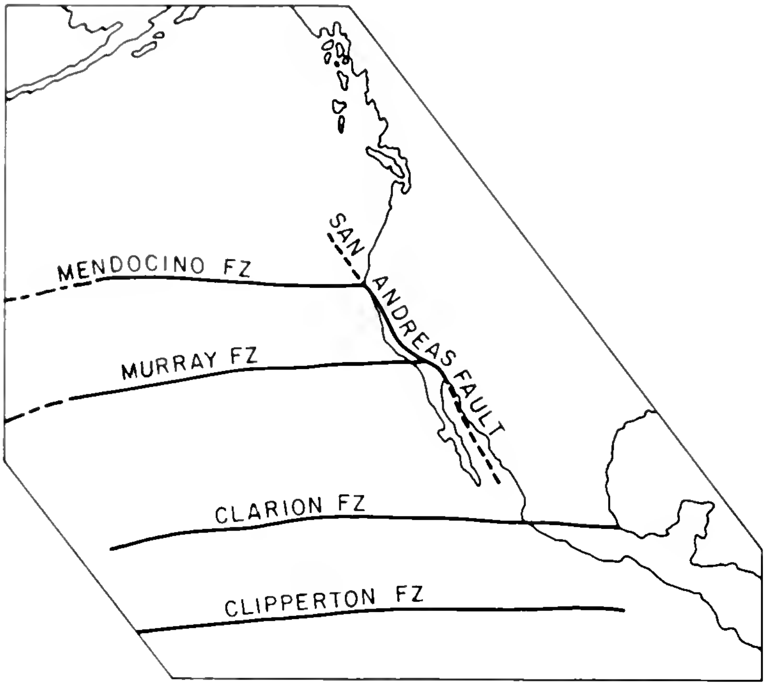

Figure 11. Fracture zones illustrated by Menard (1955).

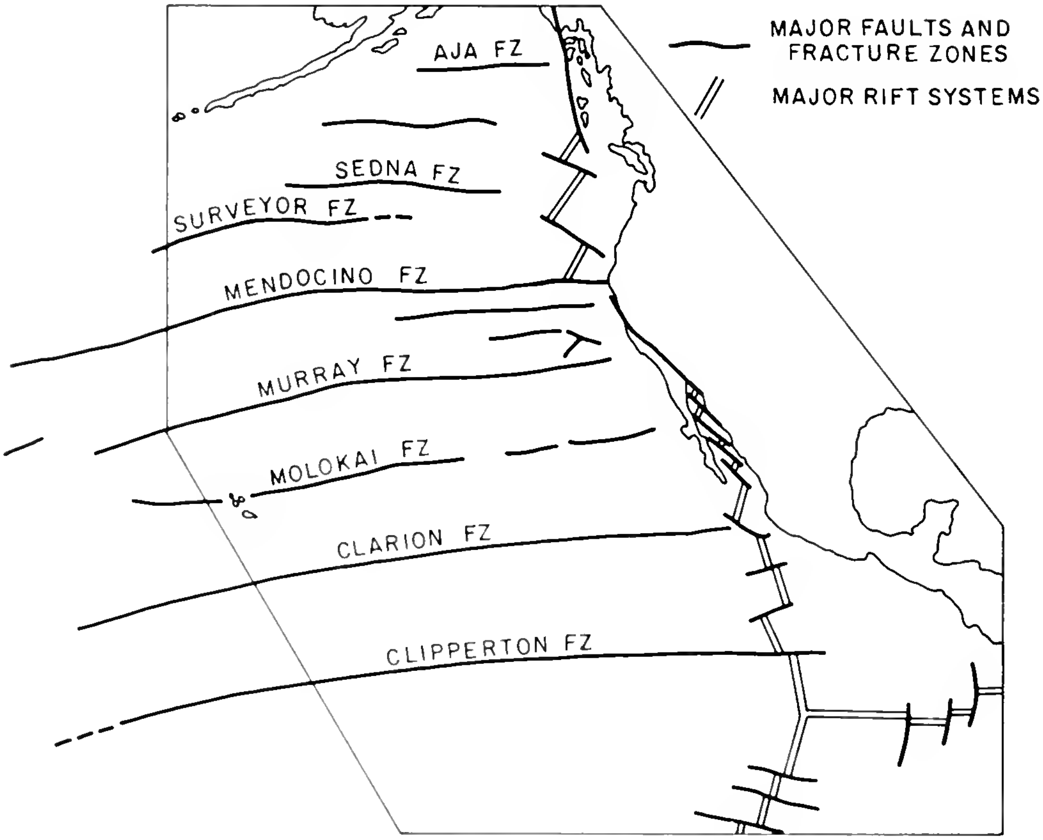

Figure 12. Part of a tectonic map of the world (Condie, 1976) including the same area illustrated by Menard 25 years previously (compare with Figure 11). Note nearly equal spacing between Menard's faults and additional discoveries.

Manix earthquake is associated with the Manix fault, along which ground rupture occurred for a distance of about 1.6 km (one mile), the overall length of this fault is probably no greater than 14.5 km (nine miles)—hardly a major California fault. Indeed, from the aftershock distribution, which was nearly at right angles to the Manix fault, Richter (1958, p. 517-518) felt that the ground breaks observed along the Manix fault were actually the effect of the earthquake, and that the earthquake was presumably caused by subsurface movement along a buried fault as defined by the aftershock distribution. The magnitude 6.0 Truckee earthquake is also not clearly associated with a major Quaternary fault, although ground cracking in the area was aligned for about 16 km (ten miles). However, the area still is relatively poorly mapped, and may contain unrecognized faults of significance.

Earthquakes of less than magnitude 6, which of course are far more numerous, show less close correspondence with major Quaternary faults. Reasons for this less frequent relationship include: (a) inaccuracies in location of pre-1932 epicenters, (b) inaccuracy of epicenter locations owing to the great distance from networks existing at the time, and (c) possibility that many of the smaller earthquakes may simply be minor crustal adjustments within the various interacting crustal blocks and subblocks (as described in the previous section on fault patterns p. 31), and hence are not occurring along breaks exposed at the surface. We should also keep in mind that inclined faults, such as thrust faults, do not give rise to epicenters which project vertically to the fault's surface exposure. For example, the epicenters of the main 1971 San Fernando earthquake, and its aftershocks, plot well to the north of the trace of the inclined San Fernando fault.

A study of the fault-epicenter map (Plate 2D) also reveals a certain number of major Quaternary faults without any apparent relation to earthquake epicenters. For example, in the northeastern part of California, there are many Quaternary faults but very few epicenters. This is perhaps because the setting is an area of extensive volcanic outpourings. The extensive faulting here may have originated from a shallow, short-term cause such as local land collapse due to volcanic activity. If so, repeated movements on most of these faults would not be expected.*

Many currently "quiet" faults in other parts of the state, however, are likely to be dormant or "locked" portions of active faults. For example, long segments of the San Andreas fault that broke in 1857 or in 1906 do not today have associated epicenters. We also know from other parts of the world, such as China, Japan, and the Mediterranean, where the seismic record extends over a period of several thousand years (Allen, 1975), that the 200 years of historical record and 90 years of instrumental record of California earthquakes is far from adequate for estimating fault activity. Seismic gaps of several hundreds of years are not uncommon in the long-term records from these ancient cultures, and hence our brief California record must be used with proper caution in evaluating the potential for recurring seismicity on seemingly "dead" Quaternary faults.

Relationship Of Surface Rupture To Earthquake Magnitude

In general, earthquakes in California of magnitude 6 and greater are accompanied by surface fault rupture, but there are exceptions. The data in Table 5 (1900-1974) show a one-to-one relationship between surface faulting and earthquakes for magnitudes 7 and 8. The earlier historical period before 1900 (Table 4, Part A) adds two more earthquakes of estimated magnitude 8 and three estimated magnitude 7 earthquakes associated with surface rupturing. However, of 31 magnitude 6 earthquakes that occurred during the *1900-1974* interval in California (excluding those offshore), only eight are clearly known to have had associated surface ruptures. Of course, most of these magnitude 6 tremors without known surface ruptures occurred in the first part of the century when locating events was less precise. Also, many of the earthquakes occurred in very sparsely populated parts of the state, and could have had surface ruptures that were not observed or reported. In recent years, however, with vastly improved and telemetered seismic networks, any earthquake of the size expected to break ground, no matter in what remote part of the state, is immediately examined by seismologists and geologists from the Division of Mines and Geology and other organizations and institutions.

Table 5. California Seismic Record for 75 Years.

Earthquakes - 1900-1974		Surface Ruptures
Magnitude	No. of Events (Excluding offshore)	No. of Occurrences (See Table 4, Part A)
8+	1	1
7-7.9	1*	1
6-6.9	31	8
5-5.9	238	5
<5	—	2

* The 1940 Imperial earthquake, which for years was reported as magnitude 7.1, has not been included because more recent calculations by the California Institute of Technology show this event as magnitude 6.7 (Hileman and others, 1973).

Below magnitude 6, only a few earthquakes are known to have broken ground even though, on occasion, earthquakes in California of magnitudes as small as 4.7 and even 3.6 have had accompanying surface ruptures (Table 4, Part A). Very recently, earthquakes of magnitude 4 to 4.6 that occurred in the Mount Shasta area produced more than two kilometers (1.2 miles) of discontinuous surface cracks.

Faults With Recurring Earthquake Activity

Table 4, Part A shows that 19 out of 30 well-documented historical earthquakes associated with surface rupture in California have occurred on the San Andreas fault system. They include nine on the San Andreas proper; two each on the Hayward, San Jacinto, and Calaveras faults; three on the Imperial fault; and one on the Superstition Hills fault—all of which are considered part of the right-lateral San Andreas fault system. Of the faults along which occurred the remaining 11 historical earthquakes associated with surface rupture, *none* has had a recurrence. Thus, the San Andreas is by far the most active fault system in the state.

In recent years, it has been recognized that California is dominated by strike-slip faults of which the San Andreas system is pre-eminant. However, as far as seismic hazards are concerned,

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*Certain faults in this region, however, such as the throughgoing Likely fault (which shows evidence of strike-slip movement and for which aeromagnetic data suggest it to be a major fault feature) may behave differently from the regional swarm of faults. Likewise, the Surprise Valley fault, which is a major normal fault with several hundred meters of vertical slip, must have undergone several periods of movement.

one of the largest earthquake events observed in California, the 1872 Owens Valley earthquake, was associated with a fault having a dominantly normal (vertical) displacement history. In addition, two very disastrous earthquakes have occurred on predominantly thrust type faults—the San Fernando earthquake of 1971 and the Arvin-Tehachapi earthquake of 1952.

Patterns of Seismicity

Although earthquake epicenters occur in most parts of California, greater concentrations do appear in certain areas or along certain fault zones. For example, the west-trending Mendocino fault zone clearly marks a boundary between an area of great seismicity on the north and a quiescent area to the south. The San Andreas fault for at least 180 miles (288 km) south of San Francisco, and the Hayward and Calaveras branches are all well marked by numerous epicenters; in fact, microseismic earthquake monitoring by the U.S. Geological Survey, with its close-order network in the San Francisco Bay area, shows an even closer relationship of seismicity to these faults (Figure 5). The San Andreas system in southern California also displays a close relationship to earthquake epicenters, especially the San Jacinto branch and, to a lesser degree, the southern and northern parts of the Elsinore fault. The Newport-Inglewood fault zone is a well-marked trend even though no clearly visible, continuous, historic, or even Quaternary fault rupture is present at the surface. The 1952 Arvin-Tehachapi earthquake and its numerous aftershocks are clearly related to the White Wolf fault when consideration is made for the dip of the fault. There is also a very conspicuous north-trending concentration of epicenters along the 118° meridian from Nevada extending south into the Owens Valley of California, marking the historic ruptures on the Pleasant Valley (1915), Dixie Valley (1954), Rainbow Mountain (1954), Fairview Peak (1954), Cedar Mountain (1932), Excelsior Mountain (1954), the Owens Valley (1872) faults (Table 4, Parts A and B). This particular seismic zone has been noted in previous studies: it was called the "118° Meridian Seismic Zone" by Slemmons and others (1965) and the "Nevada Seismic Zone" by Gumper and Scholz (1971).

The epicenter map shows what appear to be several aseismic areas within the state (Plate 2C and 2D). In the eastern Mojave Desert area, from the Ludlow fault eastward to the Colorado River, there is a total absense of earthquakes of magnitude 4 or greater; in this area, also, almost no faults having evidence of Quaternary movement have been recognized. It may, however, be too early to conclude that this is truly an aseismic area because: (1) our historic record is very short in years; (2) owing to its extremely sparse settlement, the area has until very recently been far from seismic networks capable of recording smaller earthquakes; (3) the short observational period may not reflect the long-term seismic history, and the faults in the area may in fact be temporarily dormant; (4) most of the geologic mapping has only been reconnaissance and was not performed with any special attempt to evaluate recency of faulting. (On the other hand, one would expect that any truly significant, extensive Quaternary faulting would have been recognized, especially in this desert terrane where faults are so well-exposed and geomorphic features endure for a long period of time.)

Another apparent seismically quiet area encompasses the greater part of the Sierra Nevada, except for the southernmost part at the Tehachapi Mountians, and to a much lesser degree, the northernmost part in the Oroville area (Plates 2C and 2D). Only a very few magnitude 4 to 4.9 events occur in the larger central part of the Sierra Nevada block. To the south, the White Wolf-Walker Pass seismic lineament (and perhaps the Kern Canyon fault) form confining boundaries to seismic activity, with much more activity to the east than to the west. West of the Sierra, the Great Valley is also quiet like the Sierra.

Few seismic events have been plotted in the northeastern part of the state, but this apparent lack of historic epicenters may be deceptive because this sparsely settled area is remote from any seismic network. Three major faults with large displacements must have had considerable Quaternary activity—the Surprise Valley, Honey Lake, and Likely faults. Hence, it may be delusive to conclude that the recent history of sparse seismic activity is an indication of an aseismic area.

The western tip of the Mojave wedge, bounded by the Garlock and San Andreas faults, is anomalously free of seismic events of magnitude 4 and greater. Only a few Quaternary faults have been mapped in this area. This may be deceptive because faults could easily be concealed beneath the vast blanket of alluvium in Antelope Valley.

From the foregoing, it can be seen that certain major boundaries of seismic activity appear in the state, such as along the Sierran front, the Mendocino fault zone, and the White Wolf-Walker Pass trend. These correspond to certain boundaries of the structural provinces described in the section on fault patterns. In addition to these there are other seismic boundaries. For example, at the boundary between the Transverse Ranges and the Peninsular Ranges—especially where the Newport-Inglewood and the San Jacinto faults approach the transverse Santa Monica and Cucamonga faults—there appears to be a concentration of seismic activity. Another example is the apparent boundary between the area of extensive seismicity in the Coast Ranges province and the area of extremely low seismicity in the Great Valley province.

In a similar fashion, several of the sub-block structural boundaries described earlier, are well marked by seismic activity. Especially good examples are the sub-blocks marked by the San Jacinto, Elsinore, Palos Verdes, Calaveras, and Hayward faults.

The coincidence of so many of these seismic boundaries and trends, with the structural provinces circumscribed by fault trends, suggests a strong relationship. This relationship supports the idea of the crust being divided into structural blocks and sub-blocks which interact along their boundaries giving rise to the major earthquakes. The vast number of small, apparently random earthquakes in the state may be explained as events occurring *within* these structural blocks and sub-blocks as a response to minor crustal adjustments within the blocks themselves.

CAUTIONS IN USE OF FAULT MAP OF CALIFORNIA FOR LAND-USE PLANNING

The Fault Map of California is a useful tool for considering fault hazards in various parts of the state. However, it cannot be overstressed that the nature and scale of the map pose severe limitations. First of all, more faults exist than are portrayed—the limitations of the map scale alone (in which .32 cm [one-eighth inch] on the map represents about 2.4 km [1.5 miles] on the ground) restricts what can be shown at 1:750,000 scale. Secondly, some faults are hidden beneath alluvium and other surficial deposits, or concealed by water; or they simply have not been recognized because of insufficient geologic investigations. Also, it is important to remember that the map is a product of numerous sources, some of which are more detailed than others, and that some observations were made by geologists whose objectives and purposes may not have included the evaluation of faults. Therefore, the degree of validity for the faults shown on the Fault Map varies from area to area. This is not only true for the existence or extent of some faults, but sometimes in regard to age designations of fault displacement as well. Thirdly, not all the faults shown in black should be assumed to be of pre-Quaternary age. Unfortunately this assumption has been made by some, even though the explanation on the map states that faults shown in black may also signify a "fault without recognized Quaternary displacement." The map explanation also has this to say about faults shown in black:

> Faults shown in this category should not necessarily be considered "dead." Evidence for recency of movement may not have been observed, or it may be lacking because the fault may not be in contact with Quaternary deposits. In many cases, the evidence may have been destroyed by erosion, covered by vegetation, or by works of man.

Above all, the State Fault Map should not be used to replace detailed site investigations for specific undertakings. For engineering purposes, faults at specific sites should be individually examined by detailed surface examination. Trenching, drill holes, and geophysical techniques may be helpful.

Certain precautions must be specifically mentioned concerning the offshore areas. The offshore submarine faults shown have not been directly observed but rather interpreted from various remote-controlled devices. In addition, because of the difficulties in ship positioning, offshore faults may not be as precisely located as those on land. Factors such as the type of geophysical equipment used, the depth to the sea floor, and the character of the rocks and sediments below the sea floor affect the quality of the records obtained.

This map should therefore be used only as an initial guide, or as a first approximation, or for regional fault considerations. Before site-specific decisions are made, more information and maps on a larger scale should be consulted. The Fault Map of California, by virtue of the area covered—an entire state, and a very large and geologically very complex one at that—must be supplemented with additional data. Hopefully this map and this Bulletin (especially the Index to the Source Data, Appendix D) will be useful as an introduction to the pertinent geologic literature and information on faults that were known at the time of the compilation. These references should be considered an integral part in the understanding and use of the Fault Map of California, for by referring to the documentation the reader can evaluate the interpretation given, and may possibly come to a different conclusion, especially if subsequent data have been generated.

This Fault Map of California should not be confused with the "Special Studies Zones Maps" developed as a result of the Alquist-Priolo Special Studies Zones Act of 1972 amended (Hart 1980). The Special Studies Zones Maps, at a scale of 1:24,000, were conceived at a different time and for a different purpose, and may not always agree in detail with the Fault Map of California. The Fault Map of California, together with the Geologic Map of California were developed over nearly a nine-year period largely preceding the Special Studies Zones Maps. It should be clearly understood that no desire or intent is implied in the Fault Map of California to either zone active faults or to predict where earthquakes, with or without ground rupture, might occur.

No attempt is made in this volume to describe the methods geologists use in evaluating fault and/or earthquake hazards. Publications on the subject abound and their numbers continue to increase. The following partial list is submitted as an introductory guide:

Bonilla, M.G., 1970, Surface faulting and related effects, *in* R.L. Wiegel, editor, Earthquake engineering: Prentice-Hall, N.J., p. 47-74.

Borcherdt, R.D., editor, Studies for seismic zonation of the San Francisco Bay region: U.S. Geological Survey Professional Paper 941-A, 102 p.

Cluff, L.S., Slemmons, D.B., and Waggoner, E.B., 1970, Active fault zone hazards and related problems of siting works of man: Proceedings, Fourth Symposium on Earthquake Engineering, University of Roorkee, India, p. 401-410.

Grading Codes Advisory Board and Building Code Committee, 1973, Geology and earthquake hazards, planner's guide to the Seismic Safety Element: Association of Engineering Geologists (Southern California Section), 44 p.

Hart, E.W., 1980, Fault hazard zones in California: California Division of Mines and Geology Special Publication 42 (Revised), 25 p.

Lung, R., and Proctor, R., editors, 1966, Engineering geology in southern California: Association of Engineering Geologists (Los Angeles Section), 389 p.

Nichols, D.R., and Buchanan-Banks, J.M., 1974, Seismic hazards and land-use planning: U.S. Geological Survey Circular 690, 33 p.

Sherard, J.L., Cluff, L.S., and Allen, C.R., 1974, Potentially active faults in dam foundations: Geotechnique 24, no. 3, p. 367-428.

Slemmons, D.B., 1977, State-of-the-art for assessing earthquake hazards in the United States, Report 6, Faults and earthquake magnitudes: U.S. Army Engineer Waterways Experiment Station Miscellaneous Paper S-77-8, 129 p., and Appendix, 37 p.

Ziony, J.I., Wentworth, C.M., Buchanan-Banks, J.M., and Wagner, H.C., 1974, Preliminary map showing recency of faulting in coastal southern California: U.S. Geological Survey Map MF-585, with 8 p. text.

DEPICTION OF VOLCANOES

Distribution And Age

In addition to the faults, some 565 volcanoes are shown on the Fault Map of California. These consist mostly of cinder cones, although volcanic domes and plugs, broad shield volcanoes, and a few strato-volcanoes (composite cones) are included. These volcanic centers are associated with the vast outpourings of relatively young lava and pyroclastic rocks depicted on the Geologic Map of California (1977). The volcanoes shown are almost entirely of Quaternary age. Although volcanism has been very active throughout most of California's geologic history, no attempt has been made to locate the older volcanoes because they were mostly ephemeral structures destroyed during the course of geologic time by erosion.

Of the volcanoes shown on the map, five were the centers of eruption in recent years (Table 6). Many other volcanic centers are probably of Holocene age (less than about 11,000 years). These centers are located in such areas as Medicine Lake Highlands-Lava Beds National Monument (Siskiyou and Modoc counties), Inyo-Mono Craters (Mono County), Clear Lake area

(Lake County), and Amboy-Pisgah Craters (San Bernardino County). Most of the volcanoes shown on the map are older than Holocene but less than two million years old. A few volcanoes shown on Geologic Data Map No. 1 are of Pliocene age (two to five million years old).

Table 6. Observed volcanic events in California (modified after C.W. Chesterman, 1971).

1951	Violent eruption of mud-volcanoes and hot water discharge at Lake City, Modoc County.
1914-17	Eruption of Mt. Lassen, lava flows, ash falls, mud flows, and nuées ardentes.
1890	Eruptions in Mono Lake, including emission of steam, sulfurous fumes, boiling water, and hot mud.
1857	Ash eruption from either Mt. Lassen or Mt. Shasta.
1851-52	Eruption of Cinder Cone and associated lava flows, east of Lassen Peak.
1786	Eruption of steam and ash from either Mt. Lassen or Mt. Shasta (observation of La Perouse while sailing along the California coast).

Relation of Volcanoes to Faults

The relation of volcanic centers in California to faults remains a subject of controversy, although there are certainly several places in the state where there is clear evidence or strong suggestion of such a relationship. For example, Howel Williams (1934, p. 232) pointed out that the alignment of five plug domes, two cinder cones, and one lava cone suggests a through-going fracture passing across the summit of Mount Shasta even though no surface displacements are to be seen along this trend. Similar alignments can be seen on the maps by Gordon Macdonald in the Lassen Peak area. The close alignment of nine cinder cones east of Crater Peak (Manzanita Lake quadrangle), about 19 km (12 miles) north of Lassen Peak, is strongly suggestive of fault or fissure control, as is the alignment of at least 19 cinder cones in the eastern part of Lassen National Park, south-easterly from Poison Lake, on the Harvey Mountain and Prospect Peak quadrangles (Macdonald, 1963, 1964, 1965).

The arcuate alignment of more than 15 volcanic eruptive centers south of Mono Lake, including the rhyolite domes of Mono Craters, is a classic example of fault-controlled volcanoes (Figure 6). Russell (1889) was probably the first to conclude that the Mono Craters were probably localized along faults (related to the faults along the east scarp of the Sierra Nevada). Mayo and others (1936) described the structures in the rhyolite domes south of the Mono Craters and concluded that they are determined by faults in turn controlled by northwest-striking joint sets in the bedrock. Kistler (1966) proposed that the arcuate traces of faults are not related to joint sets but to a zone of weakness thought to be related to the early cooling history along the border of a quartz monzonite pluton. In any event, the existence of a fault control beneath the line of Mono Craters was, in fact, confirmed during the construction of the Los Angeles Water District tunnel (Putnam, 1949, p. 1299).

Another clear example of fault-controlled volcanoes is the Quaternary (possibly 1872) fault scarp that trends between the volcanic cones of Red Mountain and Crater Mountain, in Owens Valley south of Big Pine (Allen, 1965, p. 761; and Mayo, 1941, p. 1065). In fact, Mayo described the fault boundary between the Sierra Nevada and the bedded sediments to the east as a deeply penetrating zone of weakness that opened many channels for the extrusion of lava and the location of volcanoes (Mayo, 1941, p. 1064-1069).

According to Koenig and others (1972, p. 1, 4), the extrusions in the Coso geothermal area, Inyo County, consisting of a mixture of explosion breccia rings, perlite domes, and obsidian sills, are fracture-controlled. Inspection of the geologic map of the Haiwee Reservoir quadrangle (Stinson, 1977) shows conspicuous north and northwest alignments of volcanic centers. These may be fault controlled, perhaps by a buried north-trending fault zone and a northwest-trending fault zone. More recent geologic, geophysical, and geochemical studies in the Coso area suggest that the youngest volcanic rocks, the rhyolitic dome field, and the associated fumaroles lie at the center of a ring-fault structure superimposed on regional fault patterns and overlying a young magma chamber (Duffield, 1975; and ERDA 77-74, p. 65).

Allen and others (1965, p. 761) have shown that Cerro Prieto, a Quaternary cone, 35 km south of the Mexican border, lies squarely athwart the extended trace of the Quaternary San Jacinto fault.

In San Luis Obispo County, 14 intrusive volcanic plugs are aligned over a distance of approximately 32 km (20 miles) (see Figure 13) through the town of San Luis Obispo to Morro Rock (and offshore, according to H.C. Wagner, 1974). These Tertiary plugs, although much older than the Quaternary volcanoes shown on the Fault Map of California, appear to be another example of emplacement of volcanic centers along a zone of weakness that in all probability is a fault even though a fault trace has not been observed in the field.

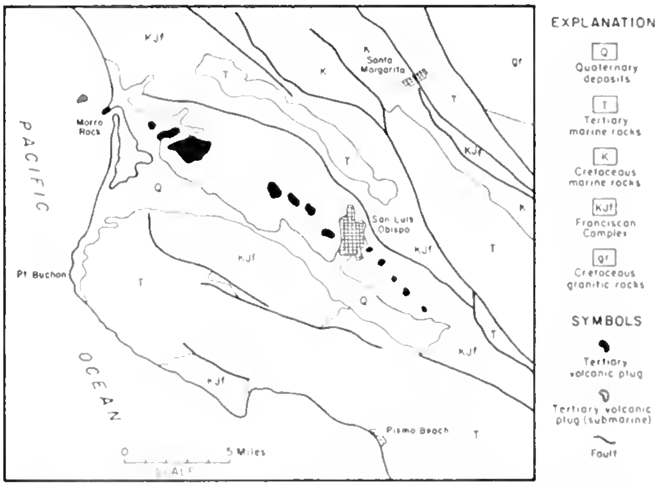

Figure 13. Alignment of Tertiary volcanic plugs near San Luis Obispo along a line of weakness presumed to be an ancient fault.

Volcanic Hazards

Volcanic eruptions have commonly occurred throughout California's long geologic history, and numerous eruptions have occurred in relatively recent geologic time, as indicated by the large number of volcanoes depicted on the Fault Map of California. Volcanism has occurred in California approximately 65 years ago with the violent eruption of Lassen. It would therefore seem reasonable to expect other eruptions in the state, although exactly when or where is uncertain. The most probable centers of future volcanic eruptions are in areas where past eruptions have occurred and particularly at large central-vent volcanoes (Mullineaux, 1976).

The Urban Geology Master Plan for California (Alfors and others, 1973) estimates that losses due to future volcanic eruptions could amount to $50 million between 1970 and the year 2000. The report concludes that major urban areas of the state are relatively safe from the threat of volcanic eruptions.

DEPICTION OF THERMAL SPRINGS AND WELLS

Besides faults and volcanoes, 584 thermal springs and wells are also plotted on the Fault Map of California. Separately identified are the locations of high temperature mud volcanoes and mud pots at Wister (Imperial County), Lake City (Modoc County), and the unusually prolific carbon dioxide springs and wells at Niland (Imperial County) and Hopland (Mendocino County). Many of the hot springs are clearly associated with known faults or volcanic rocks. Where a hot spring is not shown associated with a fault, it may indicate that the area has not been mapped in sufficient detail.

The location of hot springs and wells serves as an approximate guide to areas of anomalously high temperatures present today in the crustal rocks of California. This, of course, is pertinent in the exploration of geothermal power sources. In volcanic areas, the location of hot springs may indicate either a dying phase of volcanism or a precursor of volcanic activity.

Information concerning temperatures, more specific location data, well depths, date drilled, and pertinent references is contained in Appendix B.

Temperature

Following the convention established by G.A. Waring's reports (1915 and 1965), which were the principal sources used when this present compilation was started, the writer considered as thermal only those springs that are more than 15°F (8.3°C) above the mean annual temperature of the air at their localities. In the case of drilled wells, a normal thermal gradient of about 1°F increase for each 100 feet of depth (2°C for each 100 meters) was taken into consideration when determining whether the well should be classified as thermal.

The water from thermal springs may be meteoric—that is, surface water that has percolated downward, been heated, and then ascended to the surface. Or, thermal water may be juvenile—that is, a product from the magma; water which has reached the surface for the first time. Thermal spring waters also may be a mixture of meteoric and juvenile water. Methods of distinguishing between juvenile and meteoric waters by major and minor element chemistry, isotope ratios, and other means are described by White (1969).

The abnormally high temperature of hot springs and wells may fluctuate or even normalize, and some springs and wells may "dry up" or cease to flow. One of the factors commonly accounting for these phenomena in California is the occurrence of earthquakes. Another factor commonly affecting springs is the precipitation of calcium carbonate, which causes clogging, resulting in reduction of flow and ultimately cessation.

Springs close to boiling-point temperatures are found in many localities in the state. Because the boiling point decreases with an increase in elevation, the boiling temperature of springs in California ranges from 212°F (100°C) at sea level to about 185°F (85°C) at 14,250 feet (4377 m). Table 7 summarizes the locations of springs near the boiling point in California.

Mode of Occurrence Of Hot Springs

Thermal springs in California are probably associated with or controlled by one or more of the following geologic conditions:

(1) areas of volcanoes of geologically recent activity

(2) frictionally heated rocks associated with faults

(3) intensely deformed mountains

(4) jointed or faulted batholithic rocks

1. In some areas of volcanic rocks, especially in areas of recently active volcanism, magma or solidified magma, probably lies below the surface that has not cooled to normal temperatures, and water coming near it will be heated. In a few places—at The Geysers area of Sonoma County, for example—it is believed that heat from magma at depth has been transmitted to the overlying rock. Meteoric water penetrating near the hot materials is thus heated. Faults and fractures may serve as conduits bringing the hot water to the surface.

2. Rocks along fault zones are heated considerably by the great pressure and friction that are produced by extensive masses of rock moving past one another. This is evidenced by the presence of fused mylonite or crushed rock along certain fault zones (Wallace, 1976). In an analysis of faulting, McKenzie and Brune (1972) have shown that a temperature of 1000°C can be obtained by frictional heating along a fault, with actual melting taking place along the fault plane. When water comes in contact with a fault zone, fault gouge can act as a barrier to lateral migration, and the crushed zone adjacent to the fault gouge can serve as a conduit for water to reach the surface. Thus, if water passes upward near recently active faults, the water can take up heat by contact with the frictionally heated rocks.

3. It can be reasonably assumed that accompanying intense deformation of crustal rocks by folding and faulting, a considerable amount of thermal energy is generated. Furthermore, a significant portion of the thermal energy is expected to remain stored over a certain interval of geologic time (Chaterji and Guha, 1968). For example, only comparatively recent (Tertiary or post-Tertiary) deformation might be expected to account for the heat-flow of certain thermal springs. A good example of this may be a comparison of the abundant warm springs in the Late Tertiary-Quaternary highly deformed Coast Ranges with the almost total absence of thermal springs in the Klamath Mountains—the intense deformation of the Klamaths having largely taken place in pre-Tertiary time.

4. Deep joints or faults in batholithic rocks, like those in the Sierra Nevada, occasionally give rise to moderately warm springs. Meteoric waters collected in such cracks may be heated by the disintegration of radioactive elements in the granitic rocks (Kiersch, 1964, p. 43).

Distribution Of Hot Springs

Hot springs in California have a wide geographic distribution. Because the state is readily divisible into 11 geomorphic provinces, each reflecting fundamental differences in geology (Figure 14), California's thermal springs will be discussed in relation to these provinces. Although no consistent or clear relation of the

Table 7. Springs near boiling point temperature.

STATE MAP SHEET * LOCATION NO	SPRING	COUNTY	ELEV (feet)	TEMP (°F)	ROCK TYPE	STRUCTURE	NOTES
Alturas							
	Mud volcanoes near Lake City	Modoc	4480	120-207	In alluvium very close to late Tertiary volcanic rocks	Surprise Valley fault zone	A major normal fault in California. Fault probably serves as a conduit for heat below as well as contributing frictional heat
12	Hot Springs near Cedarville	Modoc	4500	200	In alluvium not far from late Tertiary volcanic rocks	Surprise Valley fault trough	Ditto
14	Benmac Hot Springs and Surprise Valley Hot Springs	Modoc	4500 4500	205-207 209	In alluvium not far from late Tertiary volcanic rocks	Surprise Valley fault trough	Ditto
	Kelley Hot Springs	Modoc	4360	204	In close proximity to Pleistocene volcanic rocks	On fault	Fault probably serving as heat conduit from volcanics below
Death Valley							
[illegible]	Devils Kitchen Fumarole	Inyo	4,280	180 to boiling	In Holocene volcanic rocks	Fractured volcanic caldera	Ditto
8	Coso Hot Springs	Inyo	3600	140 to boiling	In alluvium not far from Quaternary volcanics	On Quaternary fault	Ditto
Los Angeles							
	Sespe Hot Springs	Ventura	2850	191-194		In Pine Mtn. fault zone highly folded strata	
Mariposa							
	Pauha Is. springs and steam vents	Mono	6400	203	In lake sediments very close to Pleistocene volcanic rocks		
12	Casa Diablo Hot Springs	Mono	7290	115-194	Pleistocene basalt	Volcanic caldera	Fault acting as conduit from heat below
18	Hot Creek Geysers (springs)	Mono	7040	194-203	Pliocene rhyolite (not far from Pleistocene basalt)	Ditto	Ditto
Salton Sea							
44-45	Mud pots	Imperial	230	[illegible] to boiling	Alluvium-lake beds. Holocene volcanics in vicinity	On or near concealed San Andreas fault extension	Heat from mantle below thin crust?
San Bernardino							
5	Waterman Hot Springs	San Bernardino	1750	123-210	Fractured granitic and gneissic rocks	On branch of San Andreas fault	
6	Arrowhead Hot Springs	San Bernardino	2000	110-202	Ditto	On branch of San Andreas fault	
Santa Rosa							
13	The Geysers	Sonoma	1600 ±	140 to boiling	Jurassic(?) Franciscan rocks. Quaternary volcanic in vicinity	On or close to faults	Faults transmitting heat from shallow magma to overlying rocks
Walker Lake							
2	[illegible]	Alpine	7400	176	Pliocene volcanics overlain by glacial deposits		Heat of the water probable derived from the nearby lava— Waring (1915) p. 132
Weed							
[illegible]	Hot Springs on Mount Shasta	Siskiyou	14,000	184	Pleistocene and Holocene volcanic rocks	Strato volcano	"Possibly fresh magma within the cone" —H. Williams (1934) p. 228
Susanville [illegible]							
4	Tophet Hot Springs (Lassen area)	Shasta	7000	175 to boiling	Pleistocene volcanic rocks not far from Holocene volcanics	Recently active volcano	Part of the water from the springs is probably of juvenile origin derived from an underlying magma or batholith
5	Bumpas Hot Springs	Shasta	8160	boiling	Pleistocene volcanic rocks not far from Holocene volcanics	Ditto	Ditto
7	Growler Hot Springs	Tehama	5120	203 +	Pleistocene volcanic rocks		Ditto
11	Boiling Spring Tartarus Lake	Plumas	5920	170-19[illegible]	Pleistocene volcanic rocks	On small fault	Fault probably serving as heat conduit from volcanics below
[illegible]	Terminal Geyser	Plumas	59[illegible]	120-206	Pleistocene volcanic rocks	On small fault	Ditto
	Wendel Hot Springs	Lassen	4138	206	Alluvial deposits close to Plio-Pleistocene volcanic rocks	On Litchfield fault	Ditto
[illegible]	Amedee Hot Springs	Lassen	4000	178-204	Alluvial deposits close to Plio-Pleistocene volcanic rocks	On Amedee fault	Ditto

*See map sheets in Appendix D and tabluated data in Appendix B hot springs to the four previously mentioned geologic modes of occurrence discussed is always discernable, where these conditions are recognized, they will be briefly described.

The Modoc Plateau in northeastern California is a region of extensive Late Tertiary and Quaternary lava flows and volcanoes. Within these volcanic rocks are hot springs that probably derive heat from the same source as the lava outpourings. Although the area is largely mapped only in a reconnaissance way, often the thermal springs appear to be fault controlled.

Immediately east of the Modoc Plateau is Surprise Valley in the Basin Ranges province, a province characterized by volcanism and block faulting. Here, five boiling springs and four thermal wells are aligned along the Surprise Valley fault, a major Quaternary fault with vertical movement estimated in excess of 1650 m (5500 feet) (Gay, 1959) and associated with prominent gravity and magnetic anomalies. It also has evidence of Late Quaternary activity. Several other springs in California's Basin Ranges province, some at boiling temperature, occur in the Honey Lake volcanic area. The springs are situated along the Quaternary Amedee and Litchfield faults and, farther to the south, in the Coso Mountains, on faults in an area of Quatenary volcanism.

Two of California's most famous volcanoes, Mount Shasta and Lassen Peak, lie in the southernmost end of the Cascade Range province. This province consists of a chain of volcanoes extending into Oregon and Washington. Mount Shasta and Lassen Peak, both active in historic time, are the sites of several hot springs, steam vents, and fumaroles. The associated hot springs are clearly related to recent volcanism and probably to faults.

The Sierra Nevada province is bounded by a profound fault on the east side, which is the loci of several hot springs, especially where geologically recent volcanism has occurred, such as at the Mono Lake, Casa Diablo, and Owens Lake areas. The south-central part of the Sierra Nevada batholith is also the site of several warm springs. Here hot water issues from granitic and metamorphic rocks far removed from young, volcanic rocks. The springs appear to be related to the Kern Canyon fault along which they lie. As suggested earlier, the heat may be derived from the disintegration of radioactive elements in the granitic rock. The Kern Canyon fault, although a major tectonic feature, is probably not active, inasmuch as undisturbed Pliocene volcanic rocks are known to lie athwart the trace of the fault.

Hot springs in the northern part of the Coast Ranges province in California are both numerous and among the hottest in the state. Most of them are associated with the Clear Lake and Sonoma volcanic areas, or lie in the intensely faulted and deformed Mayacmas Mountains. The Clear Lake Volcanics are late Pliocene to Holocene in age (Hearn and others, 1975) and the older Sonoma Volcanics are Pliocene. The Mayacmas Mountains lie between the Clear Lake and Sonoma volcanic areas. Here, in the world-famous area of The Geysers, is the first (and at present, the only) commercially developed geothermal power source in the United States. The Geysers are situated in metamorphosed, sedimentary, and volcanic Mesozoic rocks of the Franciscan Complex, and although no geologically recent volcanic rocks are exposed, the area is marked by numerous fumaroles, steam vents, and other signs of active volcanism. The area is highly faulted, and the source of heat is probably a magma chamber at shallow depth (Chapman, 1957).

Moderately warm springs are scattered in the central and southern parts of the Coast Ranges province in highly folded and faulted Mesozoic and Tertiary strata. Likewise, the Transverse Ranges is a highly folded and faulted province marked by a number of thermal springs, including the near-boiling Sespe Hot Springs in the Santa Ynez Mountains. The Sespe Hot Springs are situated within the Pine Mountain fault zone. In the eastern part of the Transverse Ranges, in the San Bernardino Mountains, are the Arrowhead Springs. This group of boiling springs is also on a fault, probably a splay of the San Andreas fault.

The Peninsular Ranges province, in the southwestern part of the state, has a number of warm springs. These springs lie close to the Elsinore and San Jacinto fault zones. The thermal springs in the Peninsular Ranges province, the central and southern Coast Ranges, and the Transverse Ranges are all outside areas of geologically recent volcanism (although containing volcanic rocks of earlier geologic time). These provinces, however, are among the most active tectonically, and are traversed by numerous major faults. These provinces are also intensely folded and, in places, as for example the western Transverse Ranges, are still undergoing active deformation by folding, uplift, and faulting.

The Salton Trough is essentially a graben or down-faulted block. Numerous mud volcanoes and hot springs are situated principally along or near the active San Andreas fault zone on the east side of the graben. For example, shallow hot water wells occur at Desert Hot Springs, a hot spring is found at Dos Palmas, and numerous mud volcanoes occur at the southeastern end of the Salton Sea. Also in this fault trough, numerous exploratory wells have tapped high temperature steam and brine on some of the largest known geothermal anomalies of the state. One of these geothermal anomalies, at Niland, is associated with relatively young volcanic rocks which are dated at 16,000 years (Muffler and White,1969). Positive gravity and magnetic anomalies suggest the presence of intrusive bodies at shallow depth.

The Mojave Desert province, although containing both extensive volcanic rocks of recent geologic age and numerous extensive Quaternary faults, is nearly devoid of thermal springs. This is probably attributable to the dearth of water rather than to the lack of a subterranean heat source.

The Klamath Mountains province in northwestern California, with abundant water, and lying in an intensely deformed terrain, has only one known abnormally high temperature spring. This may be due to the lack of geologically recent volcanism or to the great geologic antiquity of the deformation, in which case any thermal energy generated from these movements would probably have dissipated during the long period of conduction and radiation. Another possibility might be related to the huge abundance of ground water (one of the highest rainfall areas of the state) that is available to mix with and cool to normal temperatures any hot water that rises from the underlying rocks.

The remaining natural province of the state, known as the Great Valley, is essentially a gigantic alluvial plain containing a tremendous thickness of sediments. It is not surprising that no thermal springs (or thermal wells) occur in this province, for it lacks a known subterranean heat source.

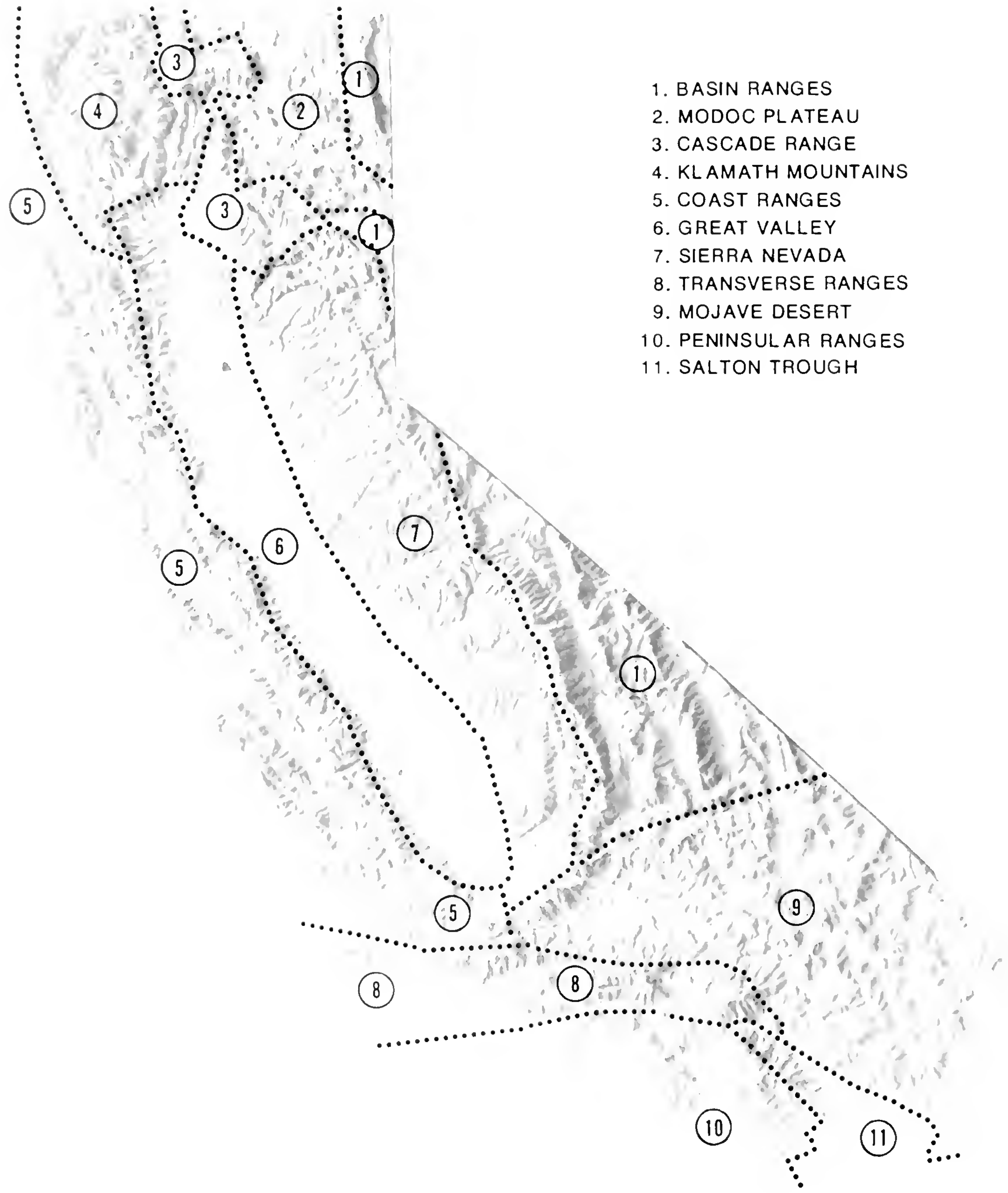

Figure 14 Relief Map of California showing geomorphic provinces

PART II
GEOLOGIC MAP OF CALIFORNIA

The Man with the Hammer

A wanderer—with downcast eyes he looks
For truth 'mid ruins and the dust of Time.
The strata of the mountains are his books
Wherein he reads, as he does slowly climb.

—A.C. Lawson
University of California Chronicle
October 1925

GEOLOGIC MAP OF CALIFORNIA

INTRODUCTION

More than 90 years have passed since the preparation in 1891 of the 1:750,000 scale Preliminary Mineralogical and Geological Map of the State of California. The 1977 edition of the Geological Map of California is the latest in the series of statewide geologic maps published by the State, and represents a great step forward in the mapping and understanding of California's geology. (See Table 8 for list of State geologic maps of California.).

HISTORY OF GEOLOGIC MAPS OF CALIFORNIA

The First Attempts

Geologic mapping in California began about 160 years ago. The first geologic mapping in the state, done by Lieutenant Edward Belcher, a British naval officer, was a remarkably accurate geologic map of the Port of San Francisco. Although Belcher did the surveying for the map in 1826, it was not published until 1839. This map and other early geologic maps of California are described and illustrated in "State Geologic Maps of California—a Brief History" (Jennings, 1966).

Landmarks in the publication of early geologic maps of the entire state begin with the hand-tinted geologic map of California made by W.P. Blake in 1853 and published in Volume V of the War Department's "Report of Explorations in California for Railroad Routes" (Blake, 1857). Utilizing nine geologic units, this 41 x 56 cm (16 x 22 inch) map was the first published geologic map that specifically and exclusively pertained to California. This map was followed by the first color-lithographed map of the state, made in 1867 and published four years later in Paris as part of a report of a French scientific mission to Mexico and the "ancient Mexican possessions of the north" (Guillemin-Tarayre, 1871). The geology is portrayed in a most impressive manner by ten geologic units, and the geologic interpretation is much improved over Blake's map.

The second color-lithographed geologic map of California was prepared by another Frenchman, Jules Marcou (1883), and published in the "Bulletin of the Geological Society of France." The nine geologic units shown were largely based on Marcou's observations while working with the Pacific Railroad Survey in 1854 and the Wheeler Survey West of the 100th Meridian in 1875, both Federal surveys. The map was accompanied by a report on the geology of California.

These early, page-size geologic maps of the state were superseded in 1891 by the first relatively large-scale statewide geologic map.

Preliminary Mineralogical and Geological Map of the State of California—1891

The Preliminary Mineralogical and Geological Map of the State of California, at a scale of 1:750,000 (12 miles equals one inch), was prepared and published in four sections by the California State Mining Bureau. Beginning with this map, the responsibility for preparing and publishing succeeding editions of relatively large-scale geologic maps of California has remained with the State. Only eight geologic units were depicted on the 1891 map; however, their general relations are better shown than on all the previous geologic maps. Special emphasis was given to mineral resources. Such units as auriferous gravel, auriferous slate, and limestone are portrayed, and the locations of known mineral deposits are shown. The map was issued by the State Mineralogist, William Ireland, but the map compiler is not credited on the map. However, the 10th Annual Report of the State Mineralogist (Ireland, 1890, p. 21) states that the topographical and other work on the Preliminary Geological and Mineralogical Map was "being executed by Mr. Julius Henkenius, who received aid in the geological and mineralogical locatings from the Field Assistants."

Geological Map of the State of California—1916

Twenty-five years after the 1891 Preliminary Mineralogical and Geological Map of the State of California, another 1:750,000 scale state geologic map was published by the California State Mining Bureau. This map was prepared by J.P. Smith, Professor of Paleontology at Stanford University, and was accompanied by a brief bulletin describing the geology (Smith, 1916).

The map legend lists 21 geologic units. Although Professor Smith's bulletin clearly explains that certain areas of California were still unmapped, his map, unlike the earlier 1891 edition, shows the entire area of the state covered by colors representing geologic units with delineated contacts. This, unfortunately, leaves the map-user without any clue as to what is known and what has merely been projected. The absence of geologic faults on this map is also somewhat puzzling. Although faults were by this time widely recognized and mapped—as, for example, in the atlas accompanying the "State Earthquake Investigation Commission" report on the disasterous 1906 San Francisco earthquake—not even the San Andreas fault is shown on the 1916 geologic map of California.

By 1916, there was much outstanding geologic mapping to draw upon. U.S. Geological Survey geologists H.W. Turner, Waldemar Lindgren, J.S. Diller, F.L. Ransome, G.H. Eldridge, Ralph Arnold, Robert Anderson, R.W. Pack, and H.W. Fairbanks had completed a number of geologic folios and bulletins on the Sierra Nevada gold belt area, the Coast Ranges, and the oil regions of the state. In addition, many significant contributions had been made by Professor A.C. Lawson and graduate students at the University of California and by Professor J.C. Branner and his students at Stanford University.

The 41-page bulletin, "The Geologic Formations of California," which accompanies the 1916 Geological Map of California, consists of the following: an expanded legend for the reconnaissance geologic map; a description of the geologic record of California as related to the fluctuations of the "Great Basin Sea" and the Pacific Ocean; a description of the "rock-forming agencies of California" wherein the formation of igneous rocks, organic and inorganic sediments, and chemical deposits are briefly discussed; a listing of the sources of data for the geologic map; and, lastly, a listing of the formations included in each geologic unit shown on the map.

Table 8. State geologic maps of California.

DATE OF MAP	TITLE	SCALE	GEOLOGIC UNITS	CONTOUR INTERVAL	COMPILER (PUBLISHER)
1857	Geological map of a part of the State of California	1 in.=38 mi.	9	No contours	W P Blake (U.S. Senate Document)
1867	Carte géologique de la Haute California et de la Nevada	1 in.=64 mi.	10	No contours	Guillemin-Tarayre (Paris. France)
1854-75	Carte géologique de la California	1 in.=95 mi.	9	No contours	J. Marcou (Soc. Geol. France Bull)
1891	Preliminary mineralogical and geological map of the State of California	1 in.=12 mi. (1 750,000)	8	No contours (Shaded relief)	J Henkenius (State Mining Bur)
1916	Geological map of the State of California	1 in.=12 mi (1 750,000)	21	No contours	J P Smith (State Mining Bur)
1938	Geological map of California	1 in.=8 mi. (1 500,000)	81	No contours	O P Jenkins (Calif. Div Mines)
1958-69	Geological atlas of California (27 sheets)	1 in.=4 mi. (1:250,000)	124	200 feet	Jennings. Strand. Rogers et al (Calif Div Mines & Geol.)
1973	State of California. preliminary fault and geologic map	1 in.=12 mi. (1 750,000)	52	No contours	C.W Jennings (Calif Div Mines & Geol.)
1977	Geologic map of California	1 in.=12 mi (1:750,000)	52	500 feet	C W Jennings (Calif Div. Mines & Geol.)

Geologic Map of California—1938

Twenty-two years later, another milestone in California geologic maps appeared in the form of a 1:500,000 scale map published in six sections by the California Division of Mines. This map was prepared by Olaf P. Jenkins, Chief Geologist of the Division of Mines, and represented nine years of careful geological research.

Much larger in scale than any preceding geologic maps of the state, the 1938 map shows much more detail than the earlier maps. The geologic boundaries of the 81 units depicted were drawn with greater precision than before. Care was taken to follow the source data faithfully, and in areas where no geologic maps were available, or where previous maps were too general in nature or at a scale much smaller than the base map, the area was purposely left blank. This portrayal of the geology of the state showed that about 25 percent of the state was unmapped. The largest unmapped areas at that time were in the Klamath Mountains, the northern Coast Ranges, the southern Sierra Nevada, and the desert areas of southeastern California. For the first time, faults were shown on an official geologic map of California.

A brief report heralding the new map was published by Jenkins (1937). It contained a history of previous state geologic maps and a description of the new state map. It also presented a detailed listing of the source data used in the compilation. The 1938 Geologic Map of California was prepared during the Great Depression when funds were in short supply. Fortunately, Dr. Jenkins had the services of a number of fine geologists who were paid by the Federal government under a Public Works Administration (PWA) program. Two PWA geologists in particular, Wayne Galliher and Bert Beverly, did the bulk of the drafting and compilation (Jenkins, 1976, p. 31-32). In addition, the Geology Department at Stanford University provided work space near the Branner Memorial Geological Library.

Geologic Atlas of California—1958-1969

The ground work for the Geologic Atlas of California began in 1951, after the popular 1938 edition went out of print. Great demand prompted Olaf P. Jenkins to set up a program for preparing a new edition of the state map that would incorporate the large amount of new geologic data collected since the earlier map was compiled (Jahns, 1961).

Under Dr. Jenkins' direction, eight preliminary sheets compiled by Charles J. Kundert were issued in 1955. They were printed in black and white, on a new 1:250,000 scale series of Army Map Service base maps. These sheets covered much of the coastal and interior desert regions of southern California. The base maps, however, were very inaccurate, and a few years later, after the Army Map Service had tremendously upgraded the quality of the topographic maps, these eight preliminary geologic map sheets became obsolete.

Work on a new, full-color edition, utilizing the vastly improved Army base maps, was begun in 1956 by Charles W. Jennings. The first map to be completed, the Death Valley Sheet, was published in 1958. The new edition was designated the "Olaf P. Jenkins Edition" in recognition of the stimulus Dr. Jenkins provided to geologic mapping in California during the 29 years he served as Chief Geologist and later as Chief of the Division of Mines, and in recognition of his personal direction of the program at its inception.

The new State Geologic Map sheets were lithographed and published individually in the same order that the new topographic base maps became available. The standard map sheet covers two degrees of longitude by one degree of latitude, but certain sheets bordering the coast or containing irregular areas along the Nevada, Arizona, and Mexican borders were combined to form single oversize sheets. The topography of the land surface is expressed by a 200-foot contour interval, and the Division added the bathymetry from other sources for the offshore area and

Lake Tahoe using 300-foot contours, and for Salton Sea using 10-foot contours.

Shortly before the retirement of Dr. Jenkins, Charles Jennings was put in charge of the map compilation and Rudolph Strand and James Koenig were added as assistants. One of the greatest problems facing the compilation project at the onset was determining the existence of all the new source data. The U.S. Geological Survey's excellent index to published geologic maps of California (Boardman, 1952) was several years out-of-date, and no map index to doctoral dissertations and master's theses specifically on California geology existed at that time.

Largely through the efforts of Rudolph Strand, an index to published geologic maps was prepared. This index updates the Boardman index through 1956. Approximately 256 entries were added, and the boundaries of all the entries were plotted on a new format using the Army Map Service one degree by two degree quadrangle units. The index proved to be so valuable in other areas of the Division's work and to geologists and others outside the Division that it was made available by publication (Strand and others, 1958).

Similarly, an index to graduate theses on California geology was prepared in order to identify and tap the enormous wealth of geologic mapping available from this source. For many areas of the state, unpublished doctoral dissertations and master's theses were the only source of geologic information; hence these were essential to the preparation of the State Geologic Map. The first such index covered the span of time from 1892 (the earliest recorded thesis on a California area) through 1961, and also was published by the Division (Jennings and Strand, 1963).

From time to time various staff members were assigned to the "State Map Project." These geologists worked either on a full-time basis to compile one or more sheets (Table 9), or part-time principally for field mapping to fill in "blank areas" or to prepare additional source data indexes (see "Indexes to published geologic maps" and "Indexes to theses" listed under "Other References" in Appendix D).

Compiling the Geologic Atlas turned out to be more difficult than anticipated. At the outset of the project, the difficulties associated with compiling a geologic map of the entire state, with all of its geologic diversity and complexity, were for the most part recognized, but it was hoped that the abundance of new data on hand would make overcoming these difficulties fairly simple. Actually, the inconsistent nature of these new data made the task more difficult. The source maps for some areas of the state were excellent; in other areas they were very poor, incomplete, or simply nonexistent. Frequently, well-described areas were adjacent to poorly understood, incompletely mapped, or totally unmapped areas. Often, too, there was no continuity between maps for adjacent areas because of differences in geologic interpretation. Thus, the compilation could easily have resulted in a patchwork of data. Fortunately, perhaps, the scale of the atlas made it possible to ignore a multitude of discrepancies. Numerous problems, however, had to be resolved in the field, and almost all blank areas in the state were filled in by a series of reconnaissance mapping programs undertaken by various Division personnel. Nevertheless, in a few areas of complex geology, or where particularly detailed work was surrounded by less detailed mapping, white areas were left around the more detailed area to preserve as much information as possible.

Table 9. Geologic Atlos of Colifornio (1:250,000 scole).

MAP SHEET (by order of publicotion)	YEAR	COMPILER (S)
Death Valley	1958	C W Jennings
Alturas	1958	T E Gay Jr., and Q A Aune
San Luis Obispo	1958	C W Jennings
Santa Maria	1959	C W Jennings
Santa Cruz	1959	C W Jennings and R G Strand
Ukiah	1960	C W Jennings and R G Strand
Westwood	1960	P A Lydon, T E Gay, Jr., and C W Jennings
Kingman	1961	C W Jennings
San Francisco	1961	C W Jennings and J.L. Burnett
San Diego-El Centro	1962	R.G Strand
Long Beach	1962	C.W Jennings
Redding	1962	R G. Strend
Chico	1962	J L. Burnett and C.W Jennings
Trona	1962	C W Jennings, J.L Burnett and B W Troxel
Walker Lake	1963	J B Koenig
Santa Rosa	1963	J B Koenig
Weed	1964	R G Strand
Needles	1964	C C Bishop
Bakersfield	1965	A R. Smith
Fresno	1966	R A. Matthews and J.L. Burnett
Santa Ana	1966	T H Rogers
Sacramento	1966	R G Strand and J B Koenig
San Jose	1966	T H Rogers
Salton Sea	1967	C.W Jennings
Mariposa	1967	R G. Strand
San Bernardino	1967	T H Rogers
Los Angeles	1969	C W Jennings and R G Strand
Geologic Legend and Formation Index	1969	C W Jennings and R G Strand
Death Valley (revised)	1974	R Streitz and M C. Stinson

Blank areas marked on the atlas sheets as "unmapped" or "incomplete" actually amount to a very small percentage of some map sheets and are absent entirely from others. To provide geologic data for the large areas of the state for which there were no published or unpublished maps or theses available, the Division's reconnaissance geologic mapping program was initiated in 1957. The first mapping by the Division for this purpose was done by T.E. Gay and Q.A. Aune. They mapped 5,400 square miles of the Alturas sheet. Later an additional 5,000 square miles were mapped by T.E. Gay and P.A. Lydon for the adjacent Westwood sheet. The mapping of six 15-minute quadrangles for the Chico Sheet by M.C. Stinson and J.L. Burnett completed the coverage for northeastern California.

In the southern part of the state, an area equivalent to about nine 15-minute quadrangles was mapped in the Death Valley-Mojave Desert region largely by B.W. Troxel, C.H. Gray, and L.A. Wright for the Trona Sheet. More than half of the Salton Sea Sheet was previously unmapped when compiling began for this area. However, as the result of a mapping effort continued through several winter seasons in this desert-mountain terrain by C.W. Jennings, P.K. Morton, T.H. Rogers, R.B. Saul, B.W. Troxel, F.H. Weber, and C.H. Gray, this huge "blank" area was covered. Through the efforts of F.H. Weber and P.K. Morton, several 15-minute quadrangle-size areas were mapped in San Diego and Imperial counties. The mapping of these areas completed the map down to the Mexican border. In addition, many smaller areas in the state were studied and mapped by various Division geologists.

Perhaps the most widespread and inaccessible area mapped by the Division lay in the high Sierra, extending from near Lake Tahoe at the north to the Tehachapi Mountains at the south. This mapping provided data for about half of the Fresno Sheet and parts of the Walker Lake, Mariposa, and Bakersfield Sheets. The main objective of this reconnaissance work was to block out the major roof pendants in the Sierran batholith that heretofore had not been mapped, and to delineate the remnants of volcanic deposits and extensive glacial deposits. Much of this area was only accessible by backpack or horse and, because of the high elevation and snow, could only be mapped during the summer. Fourteen Division geologists contributed to this concerted effort before the job was completed, with the major part done by J.L. Burnett, R.A. Matthews, and C.W. Jennings.

The final sheet was completed in 1968 and published in 1969. Collectively, these works make up the Geologic Atlas of California, which consists of 27 sheets, 110 pages of explanatory data, a master legend, and a formation index.

The geologic legend for this atlas consists of 124 cartographic units. In a state as geologically complex as California, with formations representing every geologic period known in the world, the choice of units to show statewide such variety and diversity in a meaningful way required some special innovation. Olaf P. Jenkins worked out an admirable legend for the 1938 map, and this with only a few modifications, was also used for the atlas series. At first glance, the legend appears to be based principally on age, with the exception of two formations, the Franciscan and Knoxville (which are very widespread in the California Coast Ranges). In actuality, the geologic contacts shown are drawn on the basis of rock-stratigraphic units (formations) and not time-stratigraphic units. The procedure followed was to group the numerous formations into "State Map Units" according to (a) their relative stratigraphic position (usually expressed by age); (b) their fundamental rock type (sedimentary, metasedimentary, igneous, and meta-igneous); (c) their environment of sedimentation (marine or non-marine); and (d) their broad modal composition (in dividing volcanic and plutonic rocks such as rhyolite, andesite, and basalt, or granite, granodiorite, and tonalite). Genesis was the basis for subdividing the various Quaternary units (for example, dune sand, salt deposits, lake deposits, glacial deposits, and terrace deposits, with the alluvium of the Great Valley province subdivided into stream channel deposits, fan deposits, and basin deposits—interpreted largely from federal and state soil survey maps).

The more prominent or well-known faults are identified by name; however, no attempt was made to distinguish faults by age of latest movement.

Accompanying each map sheet is an explanatory data sheet that includes an index to the geologic mapping used in the compilation, a table of stratigraphic nomenclature for the units compiled on that sheet, and an index map indicating the U.S. Geological Survey topographic quadrangles within the map sheet area. Aerial oblique photographs of salient geologic features in the map sheet area illustrate most data sheets.

The map is not specifically designed as a wall map of California, but rather as an atlas, suitable for use in the field as well as in the office. Should the entire map be assembled, however, (as has been done in several universities and in the former Division Headquaters office in San Francisco), it covers an area about 4.6 x 4.3 meters (15 x 14 feet). Although the sheets were published individually over a period of 11 years, all the colors and patterns of the geologic units were integrated as closely as possible so that adjacent sheets match in continuity of units and color. Thus, adjacent sheets can be trimmed and joined in any size block, if desired.

Two Small-Scale Geologic Maps of California (1966 and 1968)

Two relatively recent lithographed maps of the state, although of much smaller scale than the previously described maps, should be mentioned. The first of these was compiled jointly by the U.S. Geological Survey and the California Division of Mines and Geology at a scale of 1:2,500,000. It was published by the U.S. Geological Survey (1966) as "Miscellaneous Geological Investigations Map I-512" and has been reprinted or copied in several different formats in various other publications. This highly diagrammatic map vividly portrays the major rock units by 11 subdivisions—three Cenozoic (marine, nonmarine, volcanic), three Mesozoic (principally sedimentary), one Paleozoic (sedimentary and volcanic), one Precambrian (all rock types), a Pre-Cenozoic metamorphic rock unit, Mesozoic granitic rocks, and lastly, ultramafic rocks. Faults are shown with heavy black lines, and direction of apparent movement is indicated by arrows. The base is without roads, and only a few major cities and geographic features are identified. This map effectively displays the most prominent geologic features of the state, and has enjoyed considerable popularity.

The second map was prepared and published by the American Association of Petroleum Geologists (1968) as part of their Geologic Highway Map Series. It includes Nevada as well as California and is at a scale of 1 inch equals approximately 30 miles. Twenty-nine geologic units are depicted, but because their identification is obscure and their description is scattered among five separate legends, five columnar sections, and lengthy explanatory notes, using the map is cumbersome. The back of the map is filled with cross sections, a geologic history, a physiological map, and a tectonic map.

GEOLOGIC MAP OF CALIFORNIA—1977

History of the Project

Even before the 1:250,000 scale Geologic Atlas of California was completed, it was recognized that a smaller-scale map of the state, one that would present an overview of the geology of the entire state, was highly desirable. It had become apparent that the individual atlas sheets, as useful as they were for field and office purposes, were not satisfactory for evaluation of statewide geologic and structural trends. Therefore, late in 1965, plans were made for a 1:750,000 scale map of California (Jennings, 1965).

After consideration of various scales, 1:750,000 was chosen because the resulting size, about 1.4 x 1.5 meters (4.5 x 5 feet) is convenient for fitting on an average office or classroom wall. In addition, this scale is consistent with the first two official geologic maps of California published by the State in 1891 and 1916, and the scale is also sufficiently large to show a significant amount of geologic information.

Almost two years passed, however, before work on compiling this new map could begin. A pilot compilation of the Chico Sheet area, using a newly devised legend, incorporating such new data necessary for classifying the faults, and adding fold axes and other structural data, was then started by C.W. Jennings. It soon became apparent that considerable updating of the geologic data for most of the map sheets would be necessary because many of the published atlas sheets were already several years old and a large quantity of new geologic map data was available for a good part of the state.

At the beginning of the project, it was decided that a multipurpose map of the state would be most desirable. In addition to the geology, the map would emphasize recently active faults, recent volcanic rocks and volcanoes, thermal springs, offshore structures, and major fold axes. Therefore, all these data were plotted on the work sheets; but it became evident that, for publication purposes, it would be much more effective to separate some of this information and make two maps rather than one. Pursuing this concept, it was planned to present a series of maps at the same 1:750,000 scale illustrating various geologic and geophysical parameters that can conveniently be studied individually or in relation to one another. Thus, the first map in this series is the Fault Map of California With Locations of Volcanoes, Thermal Springs and Thermal Wells. The Geologic Map of California is Geologic Data Map No. 2. The third in the series will be a Gravity Map of California, which is nearing completion.* Other maps in the series, such as an epicenter map and aeromagnetic map, are in the planning stage. In addition, consideration is being given to periodically update and revise the Fault Map of California, because of the rapid rate at which new information is being generated and because of the growing demand for such data in city and county seismic safety planning, and in the location of schools, hospitals, nuclear power plants, and other engineering works.

A preliminary draft of the 1:750,000 geologic map was complete in 1971, and it accompanied a report entitled "Urban Geology Master Plan for California" (Bruer, 1971), which was financed by the Federal Department of Housing and Urban Development. Many areas on the map, however, were still shown in a tentative state and the map needed additional work pending receipt of new information. The map also required more editing and generalization in complex areas. This work was accomplished and the compilation was complete in 1972.

Because of the complexity of the map, a hand-tinted copy of the map was carefully prepared and then photographed and full-scale color prints were made. These colored prints proved very helpful in the extensive reviewing process that the map then underwent by more than forty-five geologists conversant with California geology. Reviewers from outside the Division included personnel from the U.S. Geological Survey, universities, other federal and state agencies, and a number of consulting geologic firms. The review was completed in about six months, and extensive revisions and additions were then made to the master compilation. Because of the demand for the information on this map, an uncolored version of the original hand-drafted compilation was published (see "Preliminary fault and geologic map of California—1973" in Part I of this report). Work also began in scribing and preparing the plates for the fault map portion of the compilation. Scribing of the geologic contacts for the "Geologic Map of California" did not begin until January 1975, when drafting help became available. During the final stages of scribing and preparing of the printing plates, some additional corrections of the geology were made, and new data for a few selected areas were added. The bulk of the data shown, however, is only complete to 1973.

Uses Of The Geologic Map

The usefulness of the Fault Map of California, whose intimate relationship to earthquakes is easy to explain, is generally apparent. This is not the case, however, with a geologic map of the state, the use of which is difficult to explain to the nongeologist. Dr. P.B. King and H.M. Beikman of the U.S. Geological Survey discussed this difficulty in their explanatory text for the Geologic Map of the United States (King and Beikman, 1974). Their explanation is succinctly expressed, and because it applies as well to the Geologic Map of California as it does to the Geologic Map of the United States, we quote at length from it here:

> Sometimes, when we explain to nongeologists our project for a Geologic Map of the United States, we are dismayed when asked, "What good is it?" We compilers, enmeshed in our many problems of assembling, collating, and generalizing the source data for the map, find it difficult to produce a ready answer to this question. Nevertheless, the values and uses of an accurate geologic map are manifold, not only to geologists, but to the public at large.
>
> First of all, of course, the map displays the rocky foundations on which our country is built and is a summation of the nearly two centuries of investigation of this foundation by a succession of geologists. It is thus a reference work that present and future geologists of the country can consult and is of prime importance in the education of earth scientists in schools and colleges. Further, it can be consulted by geologists in other countries and continents who wish to learn about the geology of the United States; they will compare the map with similar national or continental maps of their own countries.
>
> In terms of resources useful to man, the Geologic Map lays out accurately the major regions of bedrock in the United States upon which many facets of our economy depend. It illustrates the areas of stratified rocks that are the sources of most of our fuels, and the areas of crystalline, plutonic, and volcanic rocks that contain important parts of our mineral wealth. The map shows areas of complex folding and faulting, parts of which are still tectonically unstable and subject to earthquake hazards. To some extent the bedrock represented on the map also influences the surface soils, which are of interest in agriculture and engineering works.
>
> Beyond this, the practical value of the map is less tangible, although it can be an important tool for the discerning user. Clearly, the map will not pinpoint the location of the next producing oil well or the next bonanza mine, nor will it give specific advice for the location of a dam or a reactor site; these needs can only be satisfied on maps on much larger scales, designed for specific purposes. Nevertheless, the sapient exploration geologist can find upon it significant regional features not apparent to the untrained user. Important mineral deposits cluster along regional tectonic trends or chains of plutons of specific ages. Finally, the Geologic Map will be used in national planning activities in conjunction with other national maps showing environmental features such as climate, vegetation, and land use—for the location of power transmission corridors, highways, National Parks, wilderness areas, reclamation projects, and the like.

In essence, the Geologic Map of California is simply a representation of a part of the earth's surface. It shows the distribution of the rock units that occur at the surface, and tells us something of their composition and origin, as well as their relative degree of hardness—a clue to their resistance to erosion. In addition, the map shows by appropriate symbols where and how the rocks are folded and faulted.

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*Editor's note: Geologic Data Map No. 3, Gravity Map of California and its Continental Margin, and Geologic Data Map No 4, Geothermal Resources Map of California, have been published since this was written

Objectives and Contents

Ideally, the geologic map represents the various features that one would find on a visit to any locality on the map. Of course, the amount of detail that can be depicted is limited by the scale, but the most important geologic features are portrayed. During the compilation this factor was continually kept in mind; where necessary, particularly significant geologic features, even if small, were exaggerated in order to portray them. Likewise, in some places the geology is generalized in order that the most important features are not lost in a maze of detail. The geologic map of the state is first and foremost a factual documentation of the distribution of rocks in the state; it is secondarily an indicator of the presence of major folds and faults where known. As such, the Geologic Map of California should be the kind of data source that can be used to build theory as closely grounded in reality as possible.

Although the Geologic Map of California confines itself within the political boundaries of the state, during its construction attention was given to the geologic data for adjacent areas provided by maps of Arizona, Oregon, Nevada, and Baja California. In the Pacific Ocean area, the map does not attempt to show geologic units (largely because of the unavailability of data). However, the major offshore structural features are shown. Data on offshore faults and folds are rapidly accruing, due largely to the increasing efforts by the U.S. Geological Survey and certain universities and other institutions. Unfortunately, the wealth of offshore knowledge possessed by the petroleum exploration companies is largely unavailable.

Representation of Faults

The location of faults shown on the Geologic Map of California are the same as those shown on the Fault Map of California, but the faults are not color-coded according to recency of movement. Thus, all faults on the Geologic Map are shown as black lines, and no distinction is made between historic, Quaternary, or pre-Quaternary faults. The symbology showing sense of movement on faults is the same for both maps: pairs of half-arrows for direction of lateral displacement along a fault, arrows showing direction of dip of a fault plane or fault surface, and letters U and D for relative up and down movement along a fault.

Representation of Contacts

All contacts between map units are shown on the Geologic Map of California as solid fine lines except where the map units are bounded by faults (depicted by a thicker line), regardless of the reliability of the contact on the original data source. The reader is referred to the 1:250,000 scale Geologic Atlas or to the original source data (indexed in Appendix D) for details as to the nature of the various contacts.

In several places in the Coast Ranges where "Franciscan melange" is depicted, there may be no contact between it and the "undifferentiated" Franciscan Complex because of incomplete knowledge of the area. In such places the pattern alone separates "melange" from undifferentiated Franciscan.

In a few places where mapping or paleontological control is inadequate to distinguish between map units of similar rock types, a combination map symbol has been used. For example, there is shown on the map in the northern Coast Ranges, E-Ep (Eocene-Paleocene marine undifferentiated); in the southern Coast Ranges, Ku-Ep (Upper Cretaceous-Paleocene marine undifferentiated); and on Santa Catalina Island, M + KJf (Miocene marine together with Franciscan rocks). In each case, the color used for the unit is the color of the first indicated symbol, which suggests the more likely or more predominant unit of the combination.

In editing the final map, the writer tried to keep in mind not only the large-scale features that illustrate the geologic framework of the state and that should be apparent even when viewing the map from a distance, but also to retain important details for which the state is noted, and which can be seen on close inspection of the map.

Compilation Method

For those who may be embarking on their own statewide geologic map compilation, and for those who are interested, the method used in compiling and publishing the Geologic Map of California will be described. There are probably as many methods of compiling as there are compilers, each method having its own advantages and disadvantages. The method described here, devised through trial and error, was found suitable for our purposes. The method essentially consists of six steps in compiling followed by two steps for publication outlined as follows:

1. Search and collection of source data.
2. Evaluation and generalization of data.
3. Reduction to the compilation scale.
4. Plotting on the master base.
5. Further generalization and editing.
6. Review and correction.
7. Preparation of printing plates.
8. Final proof and publication.

1. Search and collection of source data: No compilation is better than the sources upon which it is based. For this reason, a large amount of the effort involved in a good compilation is spent searching out the best available data. We in California are fortunate to have a data bank of map sources going back many years. This data bank was started in the 1930s by Dr. Olaf P. Jenkins, Chief Geologist of the Division of Mines, who came to the Division in 1929 to prepare a new geologic map of California. Much of the data contained in Dr. Jenkins' collection of maps has been superseded by more detailed work, but certain data, especially unpublished data covering remote areas of the state, are still useful or valuable for their historical content.

When the preparation of the 1:250,000 scale Geologic Atlas of California was undertaken, the files of Dr. Jenkins were reorganized into 1° x 2° units, corresponding to the atlas sheets, and each piece of information was evaluated and either saved or rejected. As new data were acquired, they were systematically added into the collection. By 1973 the data bank had expanded from less than a single five-drawer file cabinet to six such cabinets and a number of roll-map files—and it is still growing. Then, as now, the amount of new data generated every year was so great (and becoming greater each year—see Figures 1 and 2) that even a brief suspension of data gathering would seriously compromise the usefulness of the data collection.

In order to ensure completeness in gathering published data, one can refer to source indexes such as that published by the U.S. Geological Survey (Boardman, 1952). However, we found that the published indexes lagged far behind publication of new data. Thus, we had to develop our own indexes, and considerable time and effort were expended in this direction (see Strand and others, 1958; Koenig and Kiessling, 1968; Kiessling, 1972; and Kiessling and Peterson, 1977).

We found the largest source of unpublished geologic map information on California in universities and colleges, in the form of theses and dissertations for advanced degrees—especially in the fields of geology, seismology, paleontology, oceanography, geophysics, and geochemistry. Here too, no complete or up-to-date indexes existed, and much time was spent in preparing our own indexes and gathering the data (see Jennings and Strand, 1963; Taylor, 1974; Peterson and Saucedo, 1978).

Other unpublished sources of information include oil company and mining company maps. However, little surface mapping is done in oil exploration today—the bulk of the effort going into subsurface interpretations. The numerous surface maps existing in the older files of oil companies were occasionally used, but all too often gaining access to them was difficult or impossible. Moreover, there was no way to know whether data for certain areas even existed in company files.

Maps by mining companies consist mostly of underground workings. Often their areal coverage is so narrow as to be of limited usefulness for regional compilations. However, regional mining exploration maps have been made for remote areas where mineral deposits occur, and these maps can be very useful. When such maps were known to exist and to be available, they were used.

One other source of valuable unpublished data is work under way, especially work that is nearly complete. Numerous maps of this kind were made available by the U.S. Geological Survey, the Division of Mines and Geology, other state or federal agencies, and universities.

2. Evaluation and generalization of data: Oftentimes more than one interpretation of the geology of a given area exists, and the compiler must choose which to use. Usually, the most recent map is chosen on the premise that the geologist has made use of pre-existing data and has correspondingly improved on that body of information. This is usually the case, but not always. The area of geologic interest or the objectives of later mappers may have been different from the earlier workers, and deliberate omissions in their maps may have been made. The compiler must always be on the lookout for such possibilities.

After the data have been evaluated, a tracing of the mapped area is made for inclusion into the compilation. The tracing is done on an overlay of either good-quality tracing vellum or polyester drafting film. The advantage of using drafting film is that, with its superior transparency, it can be seen through without the use of a light table. Drafting film, of course, is also scale-stable. The original mapped units are combined according to a predetermined legend, and the contacts are then generalized in accordance with the amount of reduction that will be required.

3. Reduction to the compilation scale: The tracings of the combined and generalized units are marked with a bar-scale showing the amount of reduction required to fit the master base map. A few major roads, or intersecting latitude and longitude lines, are drawn on the tracing in order to verify the amount of reduction or to provide control for adjusting any distortion that might exist in the source map. The tracings are then photographically reduced to accurately fit the compilation base map. For the Geologic Atlas, reduction was made to the final publication scale, that is, 1:250,000. In preparing the 1:750,000 scale Geologic Map of California, intermediate-scale work sheets at 1:250,000 scale were prepared and later reduced to the 1:750,000 publication scale.

The photographic reduction technique used most successfully and efficiently by the Division was performed by high-quality engineering reproduction firms equipped with large cameras, vacuum frames, and photographic processing labs. The procedure for this technique consists, first, of making a 105-mm negative of the tracing, utilizing a vacuum frame to ensure a flat surface of the tracing. The negative is then used to photographically print a positive image on sensitized drafting film. At the same time the image is enlarged to the precise size indicated by the bar-scale shown on the tracing.

4. Plotting on the master base: The master compilation base map must be scale-stable material. This is absolutely essential in the publication process following the completion of the compilation. The base map shows at a minimum the roads, railroads, streams, lakes, and topographic contours. These features are printed on the reverse side of the base so that any erasures or changes in the geologic compilation will not destroy the base map features. Showing the culture and topography in one color and the streams and lakes in another makes it easy to distinguish between the two while plotting the geology. The geologic contacts are then drawn onto the master base utilizing black drawing ink and technical pens. A fine point is used for normal contacts and a broader point for fault contacts.

Invariably additional generalization and simplification are required at this stage. Now that these data have been reduced to the actual publication scale, it is possible to visualize the final product and to begin generalizing the data. The compiler's objective is, of course, to present a picture that is as definitive as possible and that has both clarity and intelligent emphasis. To reach this goal, the compiler usually must make compromises dictated by the limits of space and legibility. Often the compiler finds that he has more geologically significant features to portray than space on the map to portray them, and he will have to choose what to show and what to leave out, relying on his interpretation of the relative importance of the available data.

5. Further generalization and editing: After each of the individual reduced segments have been plotted and such inevitable problems as "dangling contacts" and mismatches have been resolved (perhaps by consultation with the individual geologist, by compromises, or by field examination), the map is ready for an overview evaluation. At this point, attention is given to such factors as balance (areas where too much detail is shown), clarity (taking a more detached look at the overall map), and emphasis ("can't see the forest for the trees"). A most useful aid at this step is the preparation of a hand-colored copy of the map. This may be a long and exacting task, but its value cannot be overestimated. With a hand-colored map, consideration of the above mentioned factors is greatly facilitated and many problems become glaringly apparent.

6. Review and correction: Before the compilation is submitted for publication, it is advisable to have the map reviewed by experts conversant with wide areas of regional and detailed geology of the area. During preparation of the Geologic Map of California, we were fortunate to have the benefit of extensive reviews by a wide range of professionals affiliated with the U.S. Geological Survey, and universities, other State of California and Federal agencies, as well as a number of consulting geologists and firms. Each reviewed our maps with great interest and dedication.

Following the review process, the various comments, corrections, and suggested additions are evaluated and the necessary changes incorporated in the master compilation.

7. Preparation of printing plates: After the map compilation is submitted for publication, it becomes a job for the drafting staff and lithographer. However, the responsibility for checking the work submitted to the lithographer still falls on the compiler. Inevitably, no matter how carefully the compilation has been prepared, problems will be encountered which only the geologist-compiler can resolve.

It is usually beyond the knowledge and experience of the geologist-compiler to tell the drafting staff how to make the map ready for the printer. However, the compiler should understand something of the printing procedure in order to recognize some of the problems in preparing the printing plates. A summary of the steps involved in this procedure is as follows: First, the compilation must be photographically transferred to a sensitized drafting film in order that the contacts and faults can be scribed (engraved). These are first scribed solid so that the necessary "peelcoats" for each of the formation colors and patterns can be made by the lithographer. Then the contacts and faults, which were scribed as solid lines, are "dashed" where required by opaqueing, usually utilizing a "visitype" pattern on a transparent overlay sheet. Similarly, overlays are prepared using "visitype" for dotted faults, queried faults and queried contacts, thrust fault "barbs," fault attitudes, formation symbols, volcano symbols, fault names, hot springs and well locations, and any other special symbols. Some of these symbols can be combined on the same overlay, but usually certain ones are kept separate if the map is to be printed in various forms for other purposes where simplication may be required or different colors are to be used—for example, color-coded faults for a fault map and uncolored (black) faults for a geologic map. Lastly, an overlay for the explanation, titles, and other peripheral data is prepared.

The plates and overlays of the contacts, faults, and the formation symbols are then photographically combined, and a film positive is made of the combination. Ozalid prints of this composite plate are made, and these are hand-colored for use as color guides by the lithographer when the peelcoats are made.

8. Final proof and publication: After all the necessary scribed plates and overlays are prepared, the hand-colored guides made, and a color and pattern scheme selected, the "map" is ready to send to the lithographer. In addition to the above, a dummy layout is included, together with instructions concerning the various plates for the base map (previously acquired from the U.S. Geological Survey). After these materials are sent to the lithographer, the job for the compiler and drafting staff does not end, because the extremely important task of proofing is yet to come.

After the lithographer prepares the printing plates, the first color proof will arrive. The compiler will be especially interested in seeing how the selected color scheme appears. Do the colors show up properly? Can units be adequately distinguished? Are the color shades aesthetically pleasing? Changes in colors or patterns may be required before the second proof is prepared. The drafting staff, in the meantime, will make a careful, systematic search for printer's errors in the placement of colors and/or patterns. Everyone, of course, will be interested in how the layout appears, the titles, explanations, and legend. After all the discovered errors have been noted, and instructions to the lithographer for any changes in color and layout have been made, the lithographer will correct and change the printing plates accordingly and a second proof will be prepared. This procedure will be repeated until satisfaction by all concerned is attained. The map is then ready for printing.

Classification of Rock Units and Special Problems

The rock units selected for the new Geologic Map were largely derived from the legend for the 1:250,000 scale atlas sheets. The 124 units shown on the 1:250,000 scale series have been combined into 52 units. Fewer units are used as a result of fewer subdivisions within epochs or periods; for example, Miocene marine sedimentary rocks are shown rather than upper, middle, and lower Miocene marine sedimentary rocks. Table 10 illustrates how the units of the 1:250,000 scale Geologic Atlas of California have been grouped into the new 1:750,000 scale Geologic Map of California.

From Table 10, it might appear that the units shown on the map are defined by time lines, but they are in fact drawn on formation boundaries. For convenience, formations of approximately the same age and origin are grouped under the same symbol. Thus, all the marine formations of Miocene or predominantly Miocene age are shown as "M," and all the volcanic rocks of Miocene or predominantly Miocene age are shown as "Mv." Although the boundaries shown on the map are drawn on the basis of mapped formations, only the Franciscan Complex is separately identified. This exception is warranted because of the Franciscan's widespread extent, its time span of deposition (Jurassic through Cretaceous), and its importance in the understanding of California geologic history.

For reference purposes, a complete listing of all formations grouped within each of the units shown on the Geologic Map of California is included in Appendix C. The Geologic Legend of the map contains brief descriptions of the units indicating the predominant lithologic types. Among the Cenozoic rocks, a statement is also included to indicate the degree of consolidation. This could be useful in estimating relative slope stability, ground shaking during earthquakes, erosion resistance, and liquifaction potential.

The plan for classification of the rock units in the Geologic Legend, which is reproduced in Figure 15, follows a systematic scheme. The rock units have been broadly classified into sedimentary, volcanic, metamorphic, and plutonic lithologic groups, and are arranged in normal stratified sequence with the oldest rocks at the bottom of the chart. Thus, the relative and comparable ages among the lithologic groups are indicated as closely as possible—rocks of approximately the same age being shown on the same horizontal level in the legend. The marine and nonmarine (continental) facies of the Cenozoic sedimentary rocks have also been distinguished.

The Cenozoic rocks, ranging in age from Holocene through Paleocene, have been grouped into: (1) marine sedimentary rocks, (2) nonmarine (continental) sedimentary rocks, (3) volcanic rocks, and (4) plutonic rocks. The nonmarine sedimentary rocks are distinguished from the marine rocks by the letter "c"—for example, "Pc" for Pliocene "continental" rocks. The Cenozoic volcanic rocks have been further subdivided into flow rocks and pyroclastic rocks, the pyroclastic rocks being distinguished by the superscript "p."

The lower half of the Geologic Legend, representing the pre-Cenozoic rocks, is more complex and includes rocks of Precambrian through Mesozoic age. These are grouped into: (1) marine sedimentary and metasedimentary rocks, (2) mixed rocks (of uncertain age, consisting of undivided granitic and metamorphic rocks or undivided metasedimentry and metavolcanic rocks), (3) metavolcanic rocks, and (4) plutonic rocks.

The plutonic rocks are classified by age and by broad lithologic types. For example, the granitic types are the most common in California and are the most amenable to classification by age (mainly on the basis of radiometric data). Among the granitic rocks, the Mesozoic ones have the greatest extent, but Precambrian, Paleozoic, and Cenozoic granitic rocks are also distinguished. These are all identified by the symbol "gr" indicating their basic composition, and the superscripts Mz, pЄ, Pz, and Cz are used to indicate their age. Other major plutonic types are separately identified but not subdivided in detail. For example, the ultramafic rocks (mostly serpentine) are shown as "um" and

Table 10. Derived legend for 1:750,000 scale Geologic Map of California.

CENOZOIC
SEDIMENTARY ROCKS

Unit on 1:750,000 map	Description	Units on 1:250,000 Geologic Atlas
Qls	Selected large landslide deposits	Not shown on Atlas
Q	Alluvium (mostly Holocene, some Pleistocene) Quaternary nonmarine Quaternary marine	Qal, Qsc, Qf, Qb, Qst Ql, Qs (small), Qt, Qc Qm
Qs	Extensive sand dune deposits	Qs
Qg	Glacial deposits	Qg
QPc	Plio-Plestocene nonmarine Pliocene nonmarine	QP Pc, Puc, Pmlc
P	Pliocene marine	Pu, Pml
Mc	Miocene nonmarine	Mc, Muc, Mmc
M	Miocene marine	Mu, Mm, Ml
Φc	Oligocene nonmarine	Φc
Φ	Oligocene marine	Φ
Ec	Eocene nonmarine	Ec
E	Eocene marine	E
Ep	Paleocene marine	Ep
Tc	Tertiary nonmarine, undivided	Tc, Tl, QTc, Epc

CENOZOIC
VOLCANIC ROCKS

Unit on 1:750,000 map	Description	Units on 1:250,000 Geologic Atlas
Qrv	Recent (Holocene) volcanic flow rocks (or predominantly flow rocks)	Qrv, Qrv', Qrv$^{\circ}$, Qrv^{b}
Qrv^{p}	Recent (Holocene) pyroclastic rocks and volcanic mudflow deposits	Qrv^{p},
Qv	Quaternary volcanic flow rocks (or predominantly flow rocks)	Qpv, Qpv', Qpv$^{\circ}$, Qpv^{b}
Qv^{p}	Quaternary pyroclastic rocks and volcanic mudflow deposits	Qpv^{p}
☼	Quaternary and/or Pliocene volcanoes	☼
Tv	Tertiary volcanic flow rocks (or predominantly flow rocks)	Pv, Pv', etc.; Mv, Mv', etc., Φv, Φv', etc.; Ev, Ev', etc.; QTv, QTv', etc.; Tv, Tv', etc.
Tv^{p}	Tertiary pyroclastic rocks and volcanic mudflow deposits	Pv^{p}, Mv^{p}, Φv^{p}, Ev^{p}, QTv^{p}, Tv^{p}
Ti	Tertiary intrusive rocks	Ti, Ti', Ti$^{\circ}$, Ti^{b}

Table 10. Derived legend for 1:750,000 scale Geologic Map of California. (continued)

MESOZOIC-PALEOZOIC-PRECAMBRIAN
SEDIMENTARY AND METASEDIMENTARY ROCKS

Unit on 1:750,000 map	Description	Units on 1:250,000 Geologic Atlas
TK	Tertiary-Cretaceous Coastal Belt rocks	K
K	Cretaceous marine undivided (in part nonmarine)	K
Ku	Upper Cretaceous marine	Ku
Kl	Lower Cretaceous marine	Kl
KJf	Franciscan Complex	KJf
KJf_m	Franciscan melange	not shown
KJf_s	Franciscan schist	ms (in part)
J	Jurassic marine	Ju, Jml, Jk
TR	Triassic marine	TR
Pm	Permian marine	Pm
C	Carboniferous marine	C, CP, CM
D	Devonian marine	D
SO	Silurian and/or Ordovician marine	S, O
€	Cambrian marine	€, €?, (in part)
Pz	Paleozoic marine, undivided	ℙ
P€	Precambrian rocks, undivided	p€, p€g, lp€, ep€, € ? (in part)
ls	Limestone of probable Paleozoic or Mesozoic age	P(ls), m(ls)
sch	Schist of various types and ages (either metasedimentary or metavolcanic)	pSs, ps, pSv, p€s, m (in part) ms(in part)

CENOZOIC-PRECAMBRIAN
PLUTONIC, METAVOLCANIC, AND MIXED ROCKS

Unit on 1:750,000 map	Description	Units on 1:250,000 Geologic Atlas
gr^{Cz}	Cenozoic (Tertiary) granitic rocks	not recognized
gr^{Mz}	Mesozoic granitic rocks	gr, gr^{a}, gr^{g}, gr^{t}
gr^{Pz}	Paleozoic and Permo- Triassic granitic rocks	gr (in part)
$gr^{P€}$	Precambrian granitic rocks	p€gr, p€an
gr	Undated granitic rocks	various gr symbols
um	Ultramafic rocks, chiefly Mesozoic	ub
gb	Mesozoic gabbroic rocks	bi
Mzv	Mesozoic volcanic and metavolcanic rocks; Franciscan volcanic rocks	JTRv, KJfv
mv	Undivided pre-Cenozoic metavolcanic rocks	mv
Pzv	Paleozoic metavolcanic rocks	Pv, Pmv, Cv, Dv, Dv?
gr-m	Granitic and metamorphic rocks, undivided, of pre-Cenozoic age	gr-m
m	Undivided pre-Cenozoic metasedimentary and metavolcanic rocks	m, ms (in part)
p€c	Precambrian igneous and metamorphic rock complex	p€c

gabbroic rocks as "gb." The ultramafic rocks in large part are fragments of mantle material of various ages and rest in their present position by tectonic rather than by magmatic processes.

Rocks of the Franciscan Complex have been separated into three subdivisions. "KJf" is the most widespread, and consists of Cretaceous and Jurassic sandstones with smaller amounts of shale, chert, limestone, and conglomerate. "KJf_m" indicates Franciscan rocks that have been intensely fragmented and sheared into a *melange*. "KJf," is the designation for the metamorphosed part of the Franciscan Complex, consisting largely of blueschist and semi-schist.

A hybrid symbol "SO" is used for Silurian and Ordovician rocks. These rocks are found in California in limited extent and could not be readily portrayed on the present map if shown separately. The rocks occur in narrow bands in the Klamath Mountains, Sierra Nevada, and Basin Ranges geologic provinces.

Because in many places in California the older rocks are devoid of fossils (or the forms found may not be complete enough or diagnostic of age), several broad rock groups have been designated for some of the pre-Cenozoic rocks. For example, the symbols "m," "mv," "gr-m," "sch," and "ls" have been used for rocks whose ages are very uncertain. The symbol "m" is used for undivided pre-Cenozoic metasedimentary and metavolcanic rocks; "mv" for undivided pre-Cenozoic metavolcanic rocks; "gr-m" for a mixture of granitic and metamorphic rocks ranging in age from Mesozoic to Precambrian; "sch" for schist that is believed to be mostly Paleozoic or Mesozoic (although some may be Precambrian); and "ls" for limestone, dolomite, and marble of various pre-Tertiary periods or of uncertain age.

A similar broad rock unit group has also been used in one instance in the Cenozoic section. This is the symbol "Tc," which is used to represent nonmarine sedimentary rocks whose relative age cannot be determined any closer than Tertiary.

Special problems exist in the Cenozoic rocks where it is important to separate the nonmarine from the marine sedimentary rocks. The marine Tertiary rocks lie principally along the western part of the state (coastal ranges). However, in many places within sections of shallow-water marine rocks, there are nonmarine strata—for example, rocks containing coal or lignite, red beds, and sand dunes. These are not shown as nonmarine units if they appear to be very local or limited in area. Likewise, many elevated marine terraces are covered wholly or in part by a thin cover of nonmarine talus debris. These areas also are generally shown as marine to emphasize the geomorphic origin of the unit. Similarly, a unit like the Sespe Formation, which consists predominantly of red beds and other nonmarine deposits, does have marine facies—particularly as the unit is traced westward toward the sea. The Sespe, in addition, poses a problem because its age ranges from late Eocene to early Miocene. In portraying this unit, a compromise has been chosen, and the unit is shown on the map by its predominant characteristics—nonmarine Oligocene.

Among the older (pre-Cenozoic) rocks, the nonmarine facies are usually almost impossible to recognize as mappable units and have only been done so in a few places in California. For example, the Cretaceous Trabuco Formation and the Carboniferous Supai Formation have been recognized as being wholly or in part of nonmarine origin. However, these rocks are exposed only in limited areas in California, and are hence grouped on the 1:750,000 scale map with the marine units.

Metamorphic rocks were the most difficult to denote on the Geologic Map of California. In general, the older rocks show increased evidence of metamorphism, although this might be of a very low grade. Where the age of metasedimentary rocks is known, for example, by their fossil content or by well-defined stratigraphic position, the unit is depicted on the map by the symbol representing the geologic period when it was deposited. If the age of a metamorphic rock unit is uncertain or unknown, we tried to show the rocks by their characteristic field appearance, for example, "sch" (schist of various types) or "ls" (marbleized limestone or dolomite). Where undivided pre-Cenozoic metamorphic rocks have not been mapped by their metamorphic characteristics, they are shown on the compilation simply as "m" (undivided metasedimentary and metavolcanic rocks), or "mv" (metavolcanic rocks). Where the general age of some metasedimentary and metavolcanic rocks is known, the symbols "Pz," "Mzv," and "Pzv" are used to indicate Paleozoic metasedimentary rocks and Mesozoic and Paleozoic metavolcanic rocks.

The map legend also shows that the Geologic Map of California tends to emphasize bedrock rather than surficial geologic units. It can be seen, however, that various surficial deposits of Quaternary age are lumped into the unit "Q." The largest area of such surficial deposits in the state is the Great Valley of California. Smaller deposits occur elsewhere, but they are usually shown only where the area covered is significant. Stream alluvium, fan deposits, salt deposits, Quaternary lake deposits, and Quaternary marine or stream terrace deposits are all included in the unit "Q." Such deposits, however, are not shown if they greatly interfere in the depiction of the bedrock units. An exception to this general rule is the case where a fault intersects or offsets Quaternary surficial units. In such cases, the young surficial unit might even be exaggerated to illustrate this important evidence for recency of faulting.

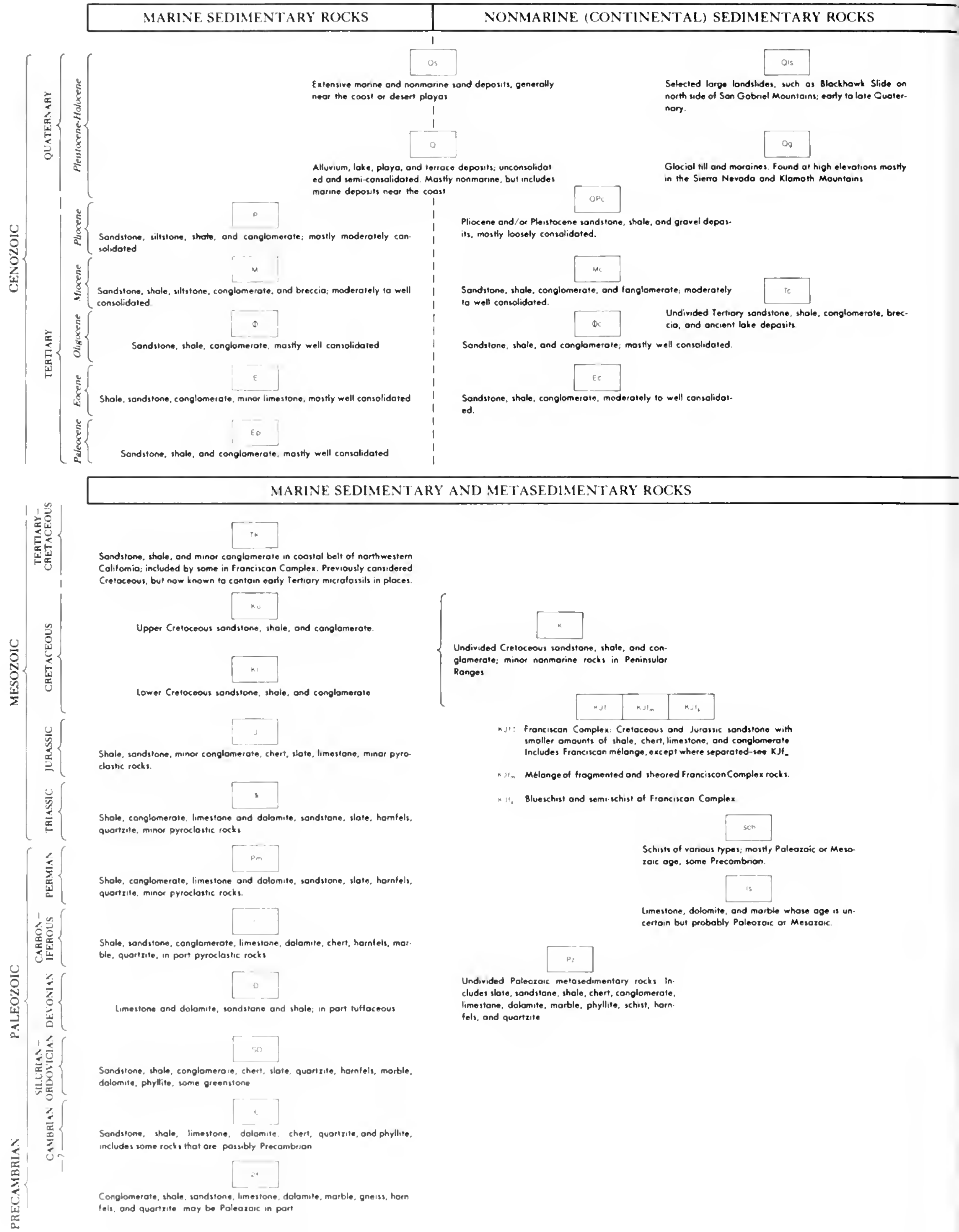
Certain other Quaternary surficial deposits are shown where significantly large. For example, glacial deposits are shown because of their importance to Quaternary chronology, and extensive dune sand deposits are depicted, especially where they occur as rather large areas of possible economic or geomorphological importance. Lastly, some Quaternary landslide deposits are indicated where they are particularly large (for example, Blackhawk and Martinez Mountain rock slides in southern California), or where they drastically obscure the geologic relationships of the bedrock units (for example, Table Mountain serpentine landslides in the central Coast Ranges). Unfortunately, the decision to show landslide deposits was not made until the compilation was well underway; as a result, some truly huge landslides have not been depicted. This is not altogether a shortcoming of the map, however, because if too many large landslides were shown, the bedrock geology would be correspondingly obscured.

Colors, Patterns, Symbols of Rock Units, and Map Appearance

A combination of colors, patterns, and symbols has been used to distinguish the rock units shown on the Geologic Map of California. Each device was chosen to adhere as closely as possible to national or international convention and to best illustrate the complex geology of California.

1. Colors: Worldwide efforts to achieve a systematic scheme of colors for geologic maps began nearly a century ago. The 2nd and 3rd International Geological Congresses made recommendations for international standards in 1881 and 1885, and the World Map Commission made certain modifications in 1958. In this country, attempts to set a national standard of colors for portraying rocks of each geologic age began in 1881 with J.W.

GEOLOGIC



MARINE SEDIMENTARY ROCKS | NONMARINE (CONTINENTAL) SEDIMENTARY ROCKS

Qs Extensive marine and nonmarine sand deposits, generally near the coast or desert playas

Qls Selected large landslides, such as Blackhawk Slide on north side of San Gabriel Mountains; early to late Quaternary.

Q Alluvium, lake, playa, and terrace deposits; unconsolidated and semi-consolidated. Mostly nonmarine, but includes marine deposits near the coast

Qg Glacial till and moraines. Found at high elevations mostly in the Sierra Nevada and Klamath Mountains

QPc Pliocene and/or Pleistocene sandstone, shale, and gravel deposits, mostly loosely consolidated.

P Sandstone, siltstone, shale, and conglomerate; mostly moderately consolidated

M Sandstone, shale, siltstone, conglomerate, and breccia; moderately to well consolidated

Mc Sandstone, shale, conglomerate, and fanglomerate; moderately to well consolidated.

Tc Undivided Tertiary sandstone, shale, conglomerate, breccia, and ancient lake deposits

Φ Sandstone, shale, conglomerate, mostly well consolidated

Φc Sandstone, shale, and conglomerate; mostly well consolidated.

E Shale, sandstone, conglomerate, minor limestone, mostly well consolidated

Ec Sandstone, shale, conglomerate, moderately to well consolidated.

Ep Sandstone, shale, and conglomerate, mostly well consolidated

MARINE SEDIMENTARY AND METASEDIMENTARY ROCKS

TK Sandstone, shale, and minor conglomerate in coastal belt of northwestern California; included by some in Franciscan Complex. Previously considered Cretaceous, but now known to contain early Tertiary microfossils in places.

Ku Upper Cretaceous sandstone, shale, and conglomerate.

Kl Lower Cretaceous sandstone, shale, and conglomerate

K Undivided Cretaceous sandstone, shale, and conglomerate; minor nonmarine rocks in Peninsular Ranges

KJf | **KJf$_m$** | **KJf$_s$**

KJf: Franciscan Complex: Cretaceous and Jurassic sandstone with smaller amounts of shale, chert, limestone, and conglomerate Includes Franciscan mélange, except where separated–see KJf$_m$

KJf$_m$ Mélange of fragmented and sheared Franciscan Complex rocks.

KJf$_s$ Blueschist and semi-schist of Franciscan Complex

J Shale, sandstone, minor conglomerate, chert, slate, limestone, minor pyroclastic rocks.

₮ Shale, conglomerate, limestone and dolomite, sandstone, slate, hornfels, quartzite, minor pyroclastic rocks

sch Schists of various types; mostly Paleozoic or Mesozoic age, some Precambrian.

Pm Shale, conglomerate, limestone and dolomite, sandstone, slate, hornfels, quartzite, minor pyroclastic rocks.

ls Limestone, dolomite, and marble whose age is uncertain but probably Paleozoic or Mesozoic.

Shale, sandstone, conglomerate, limestone, dolomite, chert, hornfels, marble, quartzite, in part pyroclastic rocks

Pz Undivided Paleozoic metasedimentary rocks Includes slate, sandstone, shale, chert, conglomerate, limestone, dolomite, marble, phyllite, schist, hornfels, and quartzite

D Limestone and dolomite, sandstone and shale; in part tuffaceous

SO Sandstone, shale, conglomerate, chert, slate, quartzite, hornfels, marble, dolomite, phyllite, some greenstone

Є Sandstone, shale, limestone, dolomite, chert, quartzite, and phyllite, includes some rocks that are possibly Precambrian

p€ Conglomerate, shale, sandstone, limestone, dolomite, marble, gneiss, hornfels, and quartzite may be Paleozoic in part

Figure 15. Geologic Legend (generalized description of rock types)

LEGEND

VOLCANIC ROCKS

Qrv | Qrv^p

Qrv: Recent (Holocene) volcanic flow rocks, minor pyroclastic deposits

Qrv^p: Recent (Holocene) pyroclastic and volcanic mudflow deposits

Qv | Qv^p

Qv: Quaternary volcanic flow rocks, minor pyroclastic deposits.

Qv^p: Quaternary pyroclastic and volcanic mudflow deposits.

Tv | Tv^p

Tv: Tertiary volcanic flow rocks, minor pyroclastic deposits.

Tv^p: Tertiary pyroclastic and volcanic mudflow deposits.

Ti

Tertiary intrusive rocks, mostly shallow (hypabyssal) plugs and dikes

PLUTONIC ROCKS

gr^{Cz}

Cenozoic (Tertiary) granitic rocks—quartz monzonite, quartz latite, and minor monzonite, granodiorite, and granite, found in the Kingston, Panamint, Amargosa, and Greenwater Ranges in southeastern California.

MIXED ROCKS

gr-m

Granitic and metamorphic rocks, mostly gneiss and other metamorphic rocks injected by granitic rocks Mesozoic to Precambrian

m

Undivided pre-Cenozoic metasedimentary and metavolcanic rocks of great variety Mostly slate, quartzite, hornfels, chert, phyllite, mylonite, schist, gneiss, and minor marble

pCc

Complex of Precambrian igneous and metamorphic rocks Mostly gneiss and schist intruded by igneous rocks, may be Mesozoic in part

METAVOLCANIC ROCKS

Mzv

Undivided Mesozoic volcanic and metavolcanic rocks. Andesite and rhyolite flow rocks, greenstone, volcanic breccia and other pyroclastic rocks; in part strongly metamorphosed Includes volcanic rocks of Franciscan Complex basaltic pillow lava, diabase, greenstone, and minor pyroclastic rocks

mv

Undivided pre-Cenozoic metavolcanic rocks Includes latite, dacite, tuff, and greenstone, commonly schistose

Pzv

Undivided Paleozoic metavolcanic rocks Mostly flows, breccia, and tuff including greenstone, diabase and pillow lavas, minor interbedded sedimentary rocks

PLUTONIC ROCKS

gr^{Mz}

Mesozoic granite, quartz monzonite, granodiorite, and quartz diorite

um

Ultramafic rocks, mostly serpentine Minor peridotite, gabbro, and diabase Chiefly Mesozoic

gb

Gabbro and dark dioritic rocks, chiefly Mesozoic

gr

Undated granitic rocks

gr^{Pz}

Paleozoic and Permo-Triassic granitic rocks in the San Gabriel and Klamath Mountains

gr^{pC}

Precambrian granite, syenite anorthosite and gabbroic rocks in the San Gabriel Mountains, also various Precambrian plutonic rocks elsewhere in southeastern California

Table 11. Comparison of "American" and "International" map colors for sedimentary rocks.

SYSTEM	AMERICAN COLOR SYSTEM			INTERNATIONAL COLOR SYSTEM	
	U.S. GEOL. SURVEY 2nd ANN. REPT. 1881[1]	GEOLOGIC MAP OF UNITED STATES 1974[2]	*GEOLOGIC MAP OF CALIFORNIA 1977*[3]	2nd and 3rd INTERNAT. GEOL. CONG. BOLOGNA AND BERLIN 1881, 1885[4]	WORLD MAP COMMISSION 1959[5]
QUATERNARY	Gray	Gray Pale yellow	*Pale yellow* *Gray*	Undecided	Pale yellow brown
TERTIARY	Yellow	Yellow Pale brown Pale flesh Dark yellow Greenish yellow Orange	*Dark yellow* *Flesh* *Tan* *Greenish yellow* *Yellow green*	Yellow	Shades of yellow
CRETACEOUS	Green	Olive green Yellow green Cool green	*Olive green* *Cool green* *Gray green*	Green	Light greens
JURASSIC		Blue green	*Blue green*	Blue	Shades of blue
TRIASSIC		Peacock blue	*Peacock blue*	Violet	Light purple
PERMIAN	Blue	Cool blue	*Cool blue*	Gray	Warm brown
PENNSYLVANIAN		Gray	*Warm blue*		Dark gray
MISSISSIPPIAN		Warm blue			
DEVONIAN	Purple	Blue	*Dark blue*	Brown	Brown
SILURIAN		Purple	*Lavender*	Greenish gray	Grayish green
ORDOVICIAN		Rose and pink			Medium green
CAMBRIAN		Red and coral	*Dark lavender*		Brownish green
PRECAMBRIAN	Brown	Yellow brown Brown Bluish gray Brick red	*Warm brown*	Rose	Grayish green to Orange pink and Rose

[1] Powell, 1882, p. xl-lv

[2] Jennings, 1977

[3] King and Beikman, 1974

[4] King and Beikman, 1974, p. 27; also see Fraser, 1888, p. 90

[5] Commission for the Geologic Map of the World, 1959

Table 12. Comparison of "American" and "International" map colors for plutonic and volcanic rocks.

ROCK TYPE		AMERICAN COLOR SYSTEM				INTERNATIONAL COLOR SYSTEM	
		U.S. GEOL. SURVEY 2nd ANN. REPORT 1881[1]	GEOLOGIC MAP OF THE UNITED STATES 1974[2]	*GEOLOGIC MAP OF CALIFORNIA 1977*[3]		2nd and 3rd INTERNAT. GEOL. CONG. BOLOGNA AND BERLIN 1881, 1885[4]	WORLD MAP COMMISSION 1959[5]
PLUTONIC	"Granitic"	Shades of red	Random dash-pattern on color assigned to sedimentary rocks of same age		*Shades of red*	Seven tints of red	Shades of bright red to bright red orange
	Mafic		Double dash-pattern on shades of green (Jurassic and Paleozoic). Solid pale red (Triassic).	*GABBRO*	*Light purple*		Shades of purple
	Ultramafic		Dark blue	*PERIDOTITE SERPENTINE (ULTRABASIC)*	*Dark purple*		
VOLCANIC	Cenozoic Volcanic Rocks		Shades of pink and orange (felsic rocks with v-pattern)	*HOLOCENE*	*Orange*		Shades of strong orange (acid) to purplish reds (basic)
				QUAT.	*Pink*		
				TERT.	*Salmon*		
	Pre-Cenozoic Volcanic Rocks		v-pattern on color assigned to sedimentary rocks of same age		*v-pattern on color assigned to sedimentary rocks of same age.*		Pattern of short lines on color assigned to sedimentary rocks of same age.

[1] Powell 1882 p. x lv

[2] King and Beikman 1974

[3] Jennings 1977

[4] Fraser 1888 p. 95

[5] Commission for the Geologic Map of the World, 1959

Powell, Director of the U.S. Geological Survey. For an interesting history of the development of schemes for geologic map colors, the reader is referred to King and Beikman (1974, p. 25-28).

Both schemes proposed that the orderly sequence of sedimentary rock units be portrayed on geologic maps by a prismatic sequence of colors. For example, with the use of yellow, green, blue, and violet, yellow would be younger than green, green younger than blue, and so forth—the darker shades representing progressively older rocks (Table 11). In this way, the map would show at a glance which sedimentary rocks were younger and which were older, and oftentimes, the structures they form would be readily apparent.

In actual practice, most geologic maps follow this principle but with departures because of limitations in contrasting shades of color for areas with numerous units of comparable ages. The "International color system" works well for maps of Europe (where the system was proposed), but it has important deficiencies for geologic maps of the United States. The international scheme, unfortunately, is not entirely suitable for areas where Paleozoic and Precambrian rocks predominate and where they have been subdivided into numerous periods. This was not a problem in Europe where neither the Precambrian nor the Paleozoic is extensive or subdivided as much as in some other parts of the world.

Therefore the map colors proposed by Powell, with subsequent elaborations, have become the "American color system," which is the general model used by the U.S. Geological Survey. The principal differences between the "American" and "International" color systems are shown in Table 11 for the sedimentary rocks and Table 12 for the igneous rocks. Note that in the "American" system the blues and shades of purple extend farther down in the Paleozoic Era, and also note the different treatment of the intrusive and extrusive rocks.

The color scheme chosen for the Geologic Map of California is largely patterned after the "American" system, as exemplified by the U.S. Geological Survey's Geologic Map of the United States (King and Beikman, 1974) for the sedimentary rocks, but a closer adherence to the "International color system" was followed for plutonic and volcanic rocks. Note that bright reds and purples have been reserved on the California map for plutonic rocks. This departure from the "American" system is in keeping with a long tradition of geologic maps of California. The use of bright colors for the plutonic rocks achieves a much better contrast between the vastly different sedimentary and plutonic rock types. A glance at the Geologic Map of California and the bright red color immediately conveys the location of batholithic rocks, and the deep purple color shows the distribution of serpentinite and related ultramafic rocks, which are so important tectonically and economically to California. Following the use of intense red for the deep-seated plutonic rocks, warm shades of pink and orange are used to portray volcanic rocks.

Among the prismatic colors used to portray sedimentary rocks, there is not a large contrast between the yellowish-greens of the Lower Tertiary rocks and the light green of the Upper Cretaceous rocks. This was done purposely, because in many places in California the distinction between rocks of these ages is very difficult to draw. Lithologically, the rocks of these two ages are commonly identical, and the lack or sparseness of fossils makes the separation in many cases almost impossible.

A similar situation exists with the "coastal belt" rocks of northwestern California, shown as "TK." These rocks of lithologic similarity* to the Franciscan Complex (indeed, often shown as Franciscan on some maps) are now known to contain, in the sparse fossil record, early Tertiary microfossils. Hence, these rocks, too, are shown as a transitional green between the Lower Tertiary and Upper Cretaceous colors. Likewise, lithology and other characteristics of Miocene and Oligocene marine sedimentary rocks are often very close and hence are portrayed by similar colors on the map.

2. Patterns: In addition to colors, certain rock units are distinguished by an overprint pattern (Table 13). Basically, all *marine* sedimentary or metasedimentary units, whether Cenozoic, Mesozoic, Paleozoic, or Precambrian, are represented by solid colors without any overprint patterns. *Nonmarine* units (distinguished on this map in the Cenozoic only) are shown by the same color that is used to show their marine counterparts, but with a *stipple pattern* overprint (either blue or red, depending on which shows up better).

Table 13. Patterns used on Geologic Map of California.

UNIT	PATTERN
Nonmarine sedimentary rocks (Distinguished only in Cenozoic)	Stipple pattern on same solid color as marine counterparts.
Marine sedimentary rocks (all ages)	No pattern; solid colors representing appropriate geologic age.
Pyroclastic volcanic rocks (Cenozoic age only)	V-pattern, on appropriate stratigraphic color.
Metavolcanic rocks (Pre-Cenozoic age)	V-pattern, on appropriate stratigraphic color.
Franciscan melange (where mapped)	Random dot pattern on green color of Franciscan Complex rocks.
Highly metamorphosed rocks (schist, gneiss, slate, mylonite, etc.)	Randomly oriented short dashes.
Granitic rocks	Red color with various patterns to distinguish various ages.

Pyroclastic volcanic rocks of Cenozoic age and *metavolcanic* rocks of pre-Cenozoic age are shown with a *v-pattern* overprint on the appropriate stratigraphic color.

A *random dot pattern* overprint is used on the green color of the Franciscan Complex to indicate where areas of *melange* have been mapped. Because melange in the Franciscan has been recognized as mappable units only in the past decade, this information is incomplete. However, because of its importance to structural concepts and its relevance to the stability of slopes, this information is shown where it is known (although often without contacts bounding the unit and with only the pattern to indicate the presence of mapped melange).

Most of the more highly metamorphosed rocks (for example, schist, gneiss, slate, mylonite, etc.) and the *undivided mixed rocks* are shown with an overprint of *randomly oriented short dashes.* Granitic rocks of different ages are depicted with various distinguishing overprint patterns.

3. Symbols: Besides colors and patterns, each geologic unit is identified by a letter or combination of letters in order to aid in matching the colors of map units to units with similar colors on the legend. This is particularly helpful in complex parts of the map where the unit may only be a small patch or a narrow band.

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* Coastal belt rocks, when analyzed carefully, often have a high K-feldspar content, unlike the typical Franciscan rocks.

Symbols become increasingly useful as the map fades with time and makes some color contrasts more difficult to distinguish. We have also found it particularly useful to label every area bounded by contacts with a symbol because it enables the publication of an uncolored edition of the geologic map.

The letter symbols used on the Geologic Map of California were chosen to comply as much as possible with accepted conventions, and also to be simple. Most symbols consist of a single capital letter indicating the geologic epoch or period when the rock formation was formed. In some cases, combinations of capital letters were used where the age of the unit widely transgresses geologic time, for example, "TK" for Tertiary-Cretaceous rocks. Likewise, "SO" was used for Silurian and Ordovician rocks, which because of their limited exposure in California, would not have shown up individually.

Because of the repetition of certain first-letters in the names of several periods and epochs, a number of contrived symbols were utilized. For example, Pliocene, Paleocene, Permian, and Paleozoic, each begin with the letter "P"; therefore, the following symbols were used for these units respectively: P, E_p, Pm, and Pz. This follows the convention used for many years on the Geologic Atlas of California and on some U.S. Geological Survey maps. Cenozoic, Cretaceous, Carboniferous, and Cambrian also posed a problem with the repetition of the first letter "C." This was resolved by using the symbols Cz, K, C, and Є. This has also been common practice on Californian, U.S. Geological Survey, and a number of foreign geologic maps for many years.

Lower case "u" and "l" differentiate upper and lower parts of certain periods, for example, Ku and Kl. Lower case "c" identifies nonmarine ("continental") sedimentary rocks. A lower case "v" is used to denote volcanic rocks, and a superscript "p" is used to distinguish Cenozoic volcanic rocks of pyroclastic origin from flow rocks. Other lower case modifiers used are: "g" for Quaternary glacial deposits (Qg), "i" for Tertiary intrusive rocks (Ti), and "s" for extensive Quaternary sand deposits (Qs).

For plutonic and metamorphic rocks that range widely in age or are of uncertain age, lower case letters or combinations of letters are used to indicate their broad rock classification. For example, "m" is used for undivided pre-Cenozoic metamorphic rocks (where metasedimentary and metavolcanic rocks have not been distinguished); "mv" for metavolcanic rocks; "sch" for schist; "ls" for limestone, dolomite, and marble; "gr" for granitic rocks; "gb" for gabbro; and "um" for ultramafic rocks (mostly serpentinite and related rocks).

4. Map appearance: It is apparent, even from a distance, that the Geologic Map of California shows a major color contrast among certain geologic units. This was purposely intended. For example, the deep-seated batholithic-type rocks shown in bright red hues are easily distinguished from the paler (pastel) hues depicting the sedimentary and metasedimentary rocks (arranged in a prismatic sequence, yellows through lavender with the darker colors being the oldest). Between these two principal color and rock contrasts are depicted the Cenozoic volcanic rocks, shown in shades of warm pink and orange. Thus, at a glance, the map user is able to see the distribution of the granitic rocks, the widespread Cenozoic volcanic rocks, the sedimentary and metasedimentary rocks, and the vast basins of unconsolidated alluvium.

On closer inspection, with attention to various patterns used, the map-user is able to easily differentiate between marine and nonmarine rocks (stipple pattern on the latter); most volcanic rocks (random v-pattern); and metamorphic rocks (randomly-oriented dash pattern). In addition, stratified rocks of similar age and lithologic origin appear as different shades of the same color. In this way, they may appear as one unit from a distance and the major sedimentary groups are emphasized; however on closer inspection, the rock groups can be separated by the more subtle color contrasts.

Geologic Time Scale

In addition to the conventional geologic legend on the Geologic Map of California, in the lower left-hand part of the map is a chart portraying a generalized geologic time scale. This chart is reproduced as Table 14 (but without color).

The purpose of this generalized time scale is to assist those who are not familiar with the geologist's way of depicting relative rock ages. The term "relative geologic time" is used on the chart, for that is how geologists began scores of years ago to depict rock sequences, not knowing the rock's actual age in numbers of years. Of course, with the knowledge of radioactive decay rates and other sophisticated dating techniques, geologists now can determine the actual age of many types of rocks. However, the generalized geologic time scale was devised to put rock ages in some sort of perspective, especially as they relate to the evolution of life on the planet. The same geologic time scale is used universally by all geologists and paleontologists.

The generalized time scale shown on the Geologic Map of California is shown in color to match the major time units of the stratified rocks depicted on the map. Subdivisions of the various periods are, of course, shown on the Geologic Map by shades of the colors shown on the generalized geologic time scale. For example, Upper and Lower Cretaceous are shown in shades of green, and subdivisions of the Paleozoic are shown in shades of blue and lavender.

The colored time scale shows that the colors are arranged as a spectrum with yellow for the youngest rocks, green for Mesozoic, and blue and lavender for Paleozoic. Thus, the map-user can quickly get an approximate idea of the distribution and age of stratified rocks within the state.

Volcanoes

The location of numerous volcanoes of all types (cinder cones, domes, composite or stratovolcanoes) are shown on the Geologic Map of California with the conventional volcano symbol, in the same way that they are shown on the Fault Map of California. Some 565 volcanoes are plotted, most of which are cinder cones. The greatest concentration of volcanoes in California are in the Modoc Lava Plateau, Clear Lake, Owens Valley, and certain southern California desert areas. For more discussion of volcanoes, see pages 43-45.

Batholiths and Plutons

Numerous granitic intrusive bodies are found in California, and many of these have been given specific names as they are studied in detail. Table 15 is a list of all the named granitic intrusive masses shown on the Geologic Map of California, 1977 edition. Additional plutons have been carefully studied and named, but because of their relatively small size or the lack of space available on the map, they are not labeled. Others have been the subjects of careful study, but the results of the studies had not been published at the time the compilation of the map was under way.

The term *batholith* has traditionally been used for large plutonic bodies, usually of granitic composition, that generally cross-cut the structure of the rock they intrude and have steep

Table 14. Geologic time scale.

	RELATIVE GEOLOGIC TIME			TIME in millions of years before present	TIME OF APPEARANCE OF DIFFERENT FORMS OF LIFE
	Era	Period	Epoch		
Age of Mammals	Cenozoic	Quaternary	Holocene		Historic record in California, 200 years
				0.011*	Post glacial period
			Pleistocene	1.5-2	Ice age, evolution of man.
		Tertiary	Pliocene	5-7	Age of mammoths
			Miocene	23-26	Spread of anthropoid apes.
			Oligocene	37-38	Origin of more modern families of mammals, grazing animals
			Eocene	53-54	Origin of many modern families of mammals, giant mammals
			Paleocene	65	Origin of most orders of mammals, early horses
Age of Reptiles	Mesozoic	Cretaceous		136	Appearance of flowering plants; extinction of dinosaurs at end; appearance of a few modern orders and families of mammals
		Jurassic		190-195	Appearance of some modern genera of conifers; origin of mammals and birds; height of dinosaur evolution.
		Triassic		225	Dominance of mammal-like reptiles.
Age of Invertebrates	Paleozoic	Permian		280	Appearance of modern insect orders
		Carboniferous Systems		320	Dominance of amphibians and of primitive tropical forests which formed coal; earliest reptiles.
				345	Earliest amphibians
		Devonian		395	Earliest seed plants; rise of bony fishes.
		Silurian		430-440	Earliest land plants.
		Ordovician		500	Earliest known vertebrates
		Cambrian		570	Appearance of most phyla of invertebrates
	Precambrian				Origin of life; algae, worm burrows.
				4,500	Estimated age of earth.

Modified from U.S. Geological Survey, Geologic Names Committee, 1972, and G. Ledyard Stebbins, Processes of organic evolution, 1966, Prentice Hall, Inc., Englewood Cliffs, New Jersey

* 11,000 years. Ziony et al., 1974, U.S. Geological Survey Map MF 585

walls dipping outward so that the body enlarges downward and has no visible or inferred floor. Often a batholith is a regionally extensive complex body, consisting of many individual intrusive masses of various compositions. The term *pluton* is a noncommittal term for an intrusive igneous body of any shape or size. Also, it is commonly applied to the various separate intrusive masses that make up a batholith. *Stock* is a much more restrictive term for an intrusive igneous body having the features of a batholith, but covering less than 40 square miles (100 km^2).

The largest of the batholilths in the state is the Sierra Nevada batholith, which is at least 644 km (400 miles) long and as much as 80-97 km (50-60 miles) wide. Strictly speaking, the Sierra Nevada batholith is confined to the granitic terrane of the Sierra Nevada (Bateman and others, 1963), and it is labeled this way on the Geologic Map of California. However, in a broader sense the term has been applied by many geologists to include the Inyo batholith and other similar granitic rocks to the east and north, far into Nevada (Crowder and others, 1973, p. 285 and 287).

The terrane shown on the State Geologic Map as the Sierra Nevada batholith is composed of granitic rocks of various compositions and is made up of a number of separate intrusive masses, the limits of which have often not been delineated. Hence, with the exception of a number of satellitic intrusive bodies in the northwestern part of the Sierra, the main Sierra Nevada batholith has not been separated into its component plutons on the 1977 Geologic Map of California. The batholith has been studied most intensely in the central and northern parts by the U.S. Geological Survey (for example, Bateman and others, 1963; Hietanen, 1973). In general, the major plutons in the western part of the batholith are older and more mafic than those in the eastern part. Isotopic ages in the Sierra Nevada batholith range from Late Triassic to Late Cretaceous.

The granitic rocks of the southern California batholith occupy an area about 97 km (60 miles) wide and more than 1610 km (1,000 miles) long extending from Riverside to the southern tip of Baja California. Although this batholith consists of many

Table 15. Batholiths, plutons, and stocks identified on the 1977 Geologic Map of California.

NAME	LOCATION
Batholiths	
English Peak	Klamath Mountains
Hunter Mountain	Inyo Mountains
Inyo	Inyo-White Mountains
Ironside Mountain	Klamath Mountains
Shasta Bally	Klamath Mountains
Sierra Nevada	Sierra Nevada
Southern California	Peninsular Ranges
Wooley Creek	Klamath Mountains
Plutons	
Ashland	Klamath Mountains
Bald Rock	Sierra Nevada
Bucks Lake	Sierra Nevada
Canyon Creek	Klamath Mountains
Caribou Mountain	Klamath Mountains
Cascade	Sierra Nevada
Castle Craggs	Klamath Mountains
Craggy Peak	Klamath Mountains
Deadman Peak	Klamath Mountains
Forks of Salmon	Klamath Mountains
Granite Peak	Klamath Mountains
Grizzly	Sierra Nevada
Heather Lake	Klamath Mountains
Merrimac	Sierra Nevada
Paiute Mountain	Inyo Mountains
Papoose Flat	Inyo Mountains
Pat Keyes	Inyo Mountains
Russian Peak	Klamath Mountains
Sage Hen Flat	Inyo Mountains
Santa Rita Flat	Inyo Mountains
Shelly Lake	Klamath Mountains
Slinkard	Klamath Mountains
Swedes Flat	Sierra Nevada
Wildwood	Klamath Mountains
Stocks	
Mule Mountain	Klamath Mountains
Pit River	Klamath Mountains

separate intrusive masses of various lithologic composition (Larsen, 1951), in general, individual plutons have not been identified. No individual pluton names are therefore shown on the 1977 Geologic Map of California. The southern California batholith is known to be overlain by fossiliferous Upper Cretaceous sedimentary rocks, and the batholith is considered to have been emplaced in early Late Cretaceous time.

Granitic intrusive masses are common in parts of the Coast Ranges west of the San Andreas fault, and although studied in some detail (for example, Compton, 1966), few of the individual plutons have been given formal names. An all-encompassing name of "Coast Range batholith" has been applied in a general sense (Spotts, 1962), but more commonly the granitic terrane is referred to as "granitic rocks of the Salinian Block," or simply by petrographic descriptions at various localities. Determining the age of these granitic rocks is not without problems, but they are generally interpreted to have been emplaced during Cretaceous time (Compton, 1966, p. 277 and 287). Because of the scattered nature of the intrusive masses (they extend from Bodega Head at the north to the La Panza Range at the south, and include the Farallon Islands, Montara Mountain, Ben Lomond Mountain, parts of the Santa Lucia Range, and the Gabilan Mesa), the Coast Range batholith could not meaningfully be identified on the Geologic Map of California by that name.

Most of the granitic masses found in the Klamath Mountains have been studied and named. Some of the larger intrusive bodies are referred to as batholiths; the others are described as plutons and stocks (Irwin, 1966; Davis, 1966). With one exception, all are of Mesozoic age and are generally thought to have been emplaced during the Nevadan (Late Jurassic) orogeny (Irwin, 1966). The only evidence for an earlier intrusion comes from the small Pit River stock, whose age has been determined as Permian, 246 million years (Lanphere and others, 1968), and is shown on the map as Paleozoic granitic rocks.

The granitic rocks of the Transverse Ranges are of various compositions and ages, and the geologic relations among the various granitic rocks are very complex and not completely understood. No batholiths as such have been named, but various areas have been studied in detail. The oldest of the plutonic rocks, in the San Gabriel Mountains, consisting of anorthosite and related rocks, are Precambrian. Also in the San Gabriel Mountains are granitic rocks of Permian-Triassic age, commonly referred to as the Lowe Granodiorite. These represent one of only two occurrences of recognized Paleozoic granitic rocks in the state—the other lying far to the north in the Klamath Mountains, as described previously. Mesozoic granitic rocks are also widespread throughout the Transverse Ranges, extending from the Santa Monica Mountains on the west to the Eagle Mountains on the east.

The numerous scattered granitic plutons in the Mojave geologic province, in general, have not been studied in detail and, as far as the writer knows, none of the plutons have been named. They are mostly Mesozoic in age, although some Precambrian bodies are known. The age of many of the granitic bodies have now been radiometrically determined (Armstrong and Suppe, 1973).

Offshore Geology

Until recently, knowledge of the geology of offshore California has been largely based on the geologic mapping of the offshore islands plus crude extrapolations between the mainland and the islands. There has also been speculation as to the location of offshore faults based on the configuration of sea-floor bathymetry. This is explained on page 28, where a discussion of offshore structural features, as determined by modern geophysical methods, is also included.

The Geologic Map of California shows the same offshore fault locations shown on the Fault Map of the state, but in addition, fold axes are plotted. A separate map of the state showing the offshore surficial geology has been compiled and published by the California Division of Mines and Geology at 1:500,000 scale (Welday and Williams, 1975). This offshore surficial geologic map provides an excellent overview of the distribution of rock and various types of sediments on the ocean bottom.

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PART III
APPENDICES

False facts are highly injurious to the progress of science, for they often endure long; but false views, if supported by some evidence do little harm, for everyone takes a salutary pleasure in proving their falseness.

—Charles Darwin

APPENDIX A

INDEX TO FAULT NAMES SHOWN ON THE FAULT MAP OF CALIFORNIA, 1975 EDITION

NAMED FAULTS SHOWN

A list of all the faults plotted and named on the 1975 edition of the Fault Map of California follows. Because of space problems, not all these faults are named on the Geologic Map of California, 1977 edition, although an attempt was made to identify the major faults on that map.

The faults are listed alphabetically, followed by the name of the State Atlas sheet on which the fault occurs. Many additional named faults occur in the state, and a good number of these are indicated on the sheets of the larger-scale Geologic Atlas of California (see supplemental index to fault names, p. 80).

Many other named faults occur in California, but most of these could not be identified, even on the Atlas sheets, because of the lack of space, or because they had not been formally recognized in a geologic publication.

PROCEDURE FOR NAMING FAULTS

Of course, as time goes on, more and more faults will be mapped and described in published geologic reports. Although no systematic procedure exists for naming faults (such as the "Code of Stratigraphic Nomenclature" devised and periodically expanded by the American Commission on Stratigraphic Nomenclature as a guide for naming formations and other stratigraphic units), it is important for geologists to exercise judgment in devising new fault names. For example, most faults are named after nearby prominent geographic features; this convenient practice should be continued. A notable exception to this practice is the recently named Hosgri fault, located offshore near San Luis Obispo County. The need to name this fault arose when it became a subject of concern during the evaluation of the seismic safety of the adjacent Diablo Canyon nuclear power plant. There was no prominent geographic feature noted on bathemetric charts of the faulted area to name the fault after. In this instance, it was decided that the two geologists who first published a map showing the fault should be recognized in the name. Thus, the fault became known as the "Hosgri" fault—a contraction of the first parts of the geologists' names, Hoskins and Griffiths.

Although naming faults does not require the kind of care and consideration to detail specified for naming geologic formations by the "Code of Stratigraphic Nomenclature," a cavalier approach can easily result in subsequent confusion. In order to avoid confusion, careful consideration should be given to the following principles when naming surface faults.

1. A fault should be given a name only if it has considerable length or offset, or is situated in hazardous proximity to man-made structures, or is of recent origin, no matter the length. For example, any future fault rupture associated with an earthquake (if not on a previously recognized or previously named fault), warrants a name, if only for convenience of reference.

2. The name of a geographic feature on or near the fault should be used to help in visualizing its location or "type locality." This practice reduces the confusion in nomenclature when faults are determined to be connected or separated by further studies. The concept of a type locality for faults was first suggested by H. J. Buddenhagen, M. L. Hill, F. S. Hudson, and A. O. Woodford in 1930 (Bulletin of the American Association of Petroleum Geologists, v. 14, no. 6, p. 797-798). Over the years this practice has not always been followed, but it is strongly recommended that the type locality be an integral part of any description of a newly described fault. The first public description of a fault should include an accurate location of its trace, preferably by an adequate-scale map, and a description of its best exposure ("type locality").

3. As much information as can be determined about the geometry of the fault should be described, including length, direction of prevalent strike, direction and magnitude of dip, and recency of movement as can best be determined. The amount of displacement should be given if it can be reasonably deduced, with careful attention being given to the distinction between separation and slip, that is, the distinction between displacement between the traces of a displaced plane on two sides of a fault and displacement of points that were formerly adjacent (see J. C. Crowell, 1959, Bulletin of the American Association of Petroleum Geologists, v. 43, no. 11, p. 2653-2674). If not enough of these factors can be determined, the naming of the fault should perhaps be delayed until more is known about it.

4. Previously used fault names should not be used for faults in other areas of the state that might have a similarly named geographic feature. To do so creates confusion. For example, we have already three "San Jose Faults" in the state, and four "Hot Springs faults," two of which are less than 25 miles apart! Even though the following indexes of fault names are incomplete, they should be consulted, and similar names should be avoided. As the Division of Mines and Geology publishes updated fault maps of the state, it will incorporate new fault names. It would be helpful and it would ensure completeness if newly described faults are called to our attention and a description provided to this Division. Such information should be addressed to the attention of the State Geologist, California Division of Mines and Geology, Resources Building, Room 1341, 1416 Ninth Street, Sacramento, CA 95814.

5. In recent years, with the advent of strong earthquakes with new (or newly recognized) faults, the intensity of investigation has sometimes resulted in different names being applied

to the same fault by various investigators. It is important that different names for the same fault not enter the literature where future confusion is created. Here again, if the State Geologist is regularly informed before publication, duplicate fault names can be avoided and suitable arbitration can be provided in questions of priority of name, or of naming different traces of the same fault zone.

6. A special problem arises when two or more separately mapped and named faults are found to join, after additional work has been done. When this occurs, giving the fault a new name or applying one of the original fault names to the entire length of the fault may be warranted. If such a change is proposed, the proposal should be accompanied by a detailed analysis of the situation, well documented by maps, fully explained in a text, and the proposal published in a recognized geological journal. A good example of this is the case of the Espinosa, San Marcos, and Rinconada faults, now recognized as the same fault, for which Dibblee has proposed, in U.S. Geological Survey Professional Paper 981, that the name Rinconada be applied to the entire length of the fault.

INDEX TO FAULT NAMES

Faults listed are those shown on the 1975 edition of the Fault Map of California. To aid in their location, the 1° x 2° State Atlas sheet on which the fault lies is indicated in parentheses. Abbreviations of sheet names are identified at the end of the list. An asterisk indicates a fault not shown, or not named, on the 1:250,000 scale Geologic Atlas.

Agua Caliente (SA)
Alamo Mt. thrust (LA)
*Algodones (EC)
Aliso (SA)
*Amedee (Su)
Arroyo Parida (LA)
Bald Mountain (R, W)
Banning (SA, SB)
*Bat Mountain (DV)
Bear Mountain (Sac, SJ)
Bear Valley (SC)
Ben Lomond (SF)
*Big Bend (C)
Big Pine (LA)
Big Spring (SLO, B)
Blackwater (T)
Blake Ranch (SB)
Bloomfield (SR)
Blue Cut (SS, SA)
Blue Rock (SC)
*Bradley Canyon (SM)
*Brawley (EC, SS)
Breckenridge (B)
*Browns Valley (SC)
Buena Vista (B)
Bullion (SB, N)
*Burdell Mountain (SR)
Butano (SJ, SF)
Cady (SB)
Calaveras (SC, SJ)
Calico (SB)
Calico, West (SB)
*Calipatria (EC, SS)
*Camel Peak (C)
Camp Rock (SB)
Cantil Valley (T)
*Carmel Canyon (SC)
Casa Loma (SA)
Cedar Canyon (K)
Chabot, East (SF)
Charnock (LA, LB)
Chino (SA, SB)
Church Creek (SC)
Claremont (SA, SB)
*Clark (SA)
Clearwater (LA)
*Coast Range thrust (LA, SR, R, W, U, SM, SJ, SC, SLO)
Coast Ridge (SLO, SC)
*Cold Fork (R)
*Concord (SR, SJ, SF)
Coyote Creek (SA)
Coyote Lake (T)
Cristianitos (SA)
Cucamonga (SB)
*Cypress Point (SC)
*Dead Mountains (K, N)
Death Valley (see Northern Death Valley-)
Death Valley Graben (DV)
*Death Valley, South (DV, T)
*Del Norte (W)
Dillon (SA, SB)
*Dogwood Peak (C)
Durrwood (B)
Earthquake Valley (SA)
*East Fork (W, R)
Edison (B)
Elder Creek (R)
*El Modeno (SA)
El Paso (T)
Elsinore (SA, SD)
Emerson (SB)
Falor (R)
*Fort Sage (Su)
Franklin (SF, SR)
Freshwater (R)
Furnace Creek (DV)
Garlic Spring (T)
Garlock (B, LA, T)
Garlock, North Branch (LA)
Garlock, South Branch (LA)
*Goat Ranch (B)
Green Valley (SR)
Grizzly Valley (C)
Grogan (W, R)
*Grouse Point (W)
Halloran (K)
Harper (SB, T)
Harris (SA)
Hayward (SF, SJ)
Healdsburg (SR)
Helendale (SB)
*Hidalgo (SB)
Hidden Springs (SS)
Hildreth (LA)
Hilton (M)
Hitchbrook (LA)
Hoadley (R)
Holser (LA)
*Honey Lake (Su, C)
*Hosgri (SLO, SM)
Hot Springs (C, SA-2, SS)
Huasna, East (SLO)
Imperial (EC)
Independence (F)
Ivanpah (K)
Jawbone (B)
Jewett (B)
Johnson Valley (SB)
Jolon (SLO)
Kern Canyon (B, F)
*Kern Front (B)
*Kern Gorge (B)
*King City (SC)
Korbel (R)
*Laguna Salada (EC)
*La Honda (SF)
*La Nacion (SD)
*La Panza (SLO, B)
Last Chance (C)
Lenwood (SB)
Leuhman (SB)
Liebre (LA)
Likely (A, Su)
*Litchfield (Su)
Little Pine (LA, SM)
Little Salmon (R)
Livermore (SJ)

Lockhart (T, SB)
•Lockhart, South (T)
•Los Lobos (SC, SLO)
Los Pinos (SA)
•Lucia (SC)
Ludlow (SB, N)
Madrone Springs (SJ)
Malibu Coast (LA)
Mallethead thrust (W)
Manix (SB)
•Manly Pass (T)
•McCullough (K)
Melones (C, SJ, Sac, Su, M)
•Mendocino (R)
Mesa (LA)
•Mesquite Lake (SB, N)
Midland (Sac, SJ)
Mirage Valley (SB)
Mission Creek (SB, SA)
•Mohawk Valley (C)
•Monterey Bay (SC)
•Monterey Canyon (SC)
Morales (B, LA)
More Ranch (LA)
Morongo Valley (SB)
Mount Poso (B)
Munson Creek (LA)
Muroc (T, B)
Nacimiento (SLO)
Newport-Inglewood (LB, LA, SA)
Northern Death Valley-Furnace Creek (M, DV)
•North Fork (R, W)
Northridge Hills (LA)
Norwalk (LB, SA)
•Oak Flat (R)
Oakridge (LA)
Old Woman Springs (SB)
•Orleans (W)
Ortigalita (SJ, SC)
•Owens Valley (M, F, DV)
Owl Lake (T)
Ozena (LA)
Pacifico (SM)
Paicines (SC)
•Palo Alto (SF)
Palo Colorado (SC)
Palo Colorado-San Gregorio (SF, SC)
Palos Verdes (LB)
Panamint Valley (T, DV)
Paskenta (U, R)
Pastoria (LA)
Pilarcitos (SF)
Pine Mountain (LA)
Pinnacles (SC)
Pinto Mountain (SB, N)
Pinyon Peak (B)
Pipes Canyon (SB)
Pisgah (SB)
Pleasanton (SJ)
Pleito (LA, B)
•Point Reyes (SR, SF)
•Pond-Poso Creek (B)
Porcupine Wash (SS)
Punchbowl (SB)
Raymond (Raymond Hill) (LA)
Recruit Pass (B)
•Red Hill (SB)
Red Mountain (LA)
Refugio (SM)
Reliz (SC)
•Rialto-Colton (SB)
•Rich Bar (Su, C)
Rinconada (SC, SLO, LA, SM)
Rodgers Creek (SR)
Rosamond (LA)
•Rose Canyon (SD, SA)
Salton Creek (SS)
San Andreas (SS, SB, SA, LA, B, SLO, SC, SJ, SF, SR, U, R)
San Andreas, North Branch (SB)
San Andreas, South Branch (SB)
San Benito (SC)
San Bruno (SF)
San Cayetano (LA)
•San Clemente (LB)
•Sand Hills (EC, SS)
San Felipe (SA)
San Felipe Hills (SA)
San Francisquito (SC, LA)
San Gabriel (LA, SB)
San Gregorio (SF)
San Jacinto (SA, SB)
San Jose (LA, SB, SJ, SF)
San Juan (SLO, B)
Santa Cruz Island (LA, LB, SM)
•Santa Maria (SM)
Santa Monica (LA)
Santa Rosa Island (SM)
Santa Susana thrust (LA)
Santa Ynez (LA, SM)
Santa Ynez, South Branch (SM)
Sargent (SC, SJ)
Sawpit Canyon (SB, LA)
Seal Cove (SF)
•Shady Canyon (SA)
•Sheephead (T)
Sierra Madre (LA, SB)
Sierra Nevada (M, F, DV, T, B)
Silver Creek (SJ, SF)
•Simi (LA)
Spring (SB)
•Spring Creek thrust (R)
Springs (B, LA)
•Stanford (SF)
State Line (K)
Stockton (Sac, SJ)
Suey (SM)
•Sulphur Spring (R)
Superstition Hills (SS, EC)
Superstition Mountain (EC)
Sur (SC)
Sur-Nacimiento (SC)
Surprise Valley (A)
Sweitzer (SR)
Tejon Canyon (B)
•Temescal (SA)
Tesla (SJ)
Tolay (SR)
Tularcitos (SC)
Tule Creek (LA)
•Twin Sisters (R, W)
Verdugo (LA)
Vergales (SC)
Verona (SJ)
Vincent thrust (SB)
Walnut Creek (SB)
•Waltham Canyon (SC, SLO)
•White Mountains (M)
Whiterock (B, LA)
White Wolf (B)
Whittier (SA, LB)
Willow Creek (SC)
•Willows (U, C)
•Wilson Canyon (T)
Yager (R)
Zayante (SF, SJ)

Abbreviations of Map Sheets

A = Alturas
B = Bakersfield
C = Chico
DV = Death Valley
EC = El Centro
F = Fresno
K = Kingman
LA = Los Angeles
LB = Long Beach
M = Mariposa
N = Needles
R = Redding
SA = Santa Ana
Sac = Sacramento
SB = San Bernardino
SC = Santa Cruz
SD = San Diego
SF = San Francisco
SJ = San Jose
SLO = San Luis Obispo
SM = Santa Maria
SR = Santa Rosa
SS = Salton Sea
Su = Susanville
T = Trona
U = Ukiah
W = Weed
WL = Walker Lake

SUPPLEMENTAL INDEX TO FAULT NAMES

Faults listed here are not shown on the 1975 edition of the Fault Map of California because of space problems, but they are shown on the individual sheets of the 1:250,000 scale Geologic Atlas of California, O. P. Jenkins edition. The sheets on which the faults occur are indicated in parentheses; abbreviations used are the same as those used in the previous index to faults.

Acton (LA)
Agua Blanca thrust (LA)
Agua Dulce Canyon (LA)
Agua Tibia (SA)
Aguanga (SA)
Aliso Canyon (SA)
Amargosa thrust (T)
Americano Creek (SR)
Arnold Ranch (SA)
Arrastre Spring (T)
Ash Hill (DV)
Avalon-Compton (LB)
Bee Canyon (LA)
Ben Trovato (SJ)
Berrocal (SJ)
Bicycle Lake (T)
Black Butte (SJ)
Black Mountain (SR)
Bolinger (SF)
Brown Mountain (T)
Bryant (SA)
Buck Ridge (SA)
Butte Valley (T)
Cabrillo (LB)
Cajon Valley (SB)
Cameros (LA)
Camuesa (LA)
Carnegie (SJ)
Carneros (SR)
Chabot (SF)
Chalone Creek (SC)
Cherry Hill (LB)
Childers Peak (SR)
Chimeneas (SLO)
Clark Mountain (K)
Cleghorn (SB)
Clemens Well (SS)
Collayomi (SR)
Cook Peak (B)
Cottonwood (LA)
Cox Ranch (SA)
Cull Creek (SF)
Curry Mountain (SC)
Cuyama (SLO)
Cuyama, South (LA)
Diamond Bar (SA)
Doble (SB)
Dos Pueblos (LA)
Dry Creek (LA)
Duarte (SB)
Dublin (SJ)
Eisner (SR)
Espinoza (SC, SLO)
False Cape Shear Zone (R)
Fitch Mountain (SR)
Frazier Mountain, North (LA)
Frazier Mountain, South (LA)
Gandy Ranch (SA)
Garnet Hill (SA)
Glen Anne (LA)
Glen Helen (SB)
Glen Ivy (SA)
Goose Lake (A)
Gravel Pit (SJ)
Green Ranch (LA)
Greenville (SJ)
Handorf (SB)
Harper Lake (SB)
Hillside (SF)
Holmes (SB)
Honda (SM)
Huer Huero (SLO) (now La Panza)
Indian Hill (SB)
Indio Hills (SA)
Juncal Camp (LA)
Keene Wonder (DV)
Kennedy (SR)
Kern River (B) (now Kern Gorge)
Kramer Hills (SB)
Laguna Canyon (SA)
Lancaster (SA)
Las Tablas (SLO)
Las Trampas (SF)
Lavigia (LA)
Lawrence (SA)
Leach Lake (T)
Limekiln (SJ)
Little Oak Canyon (LA)
Little Rock(LA)
Little Sulphur (SR)
Lockwood (LA)
Loma Alta (LA)
Loma Linda (SB)
Lone Tree (LA)
Maacama (SR)
Magic Mountain (LA)
Maguire Peaks (SJ)
Mattole (R)
McWay thrust (SC)
Mecca Hills (SA)
Mesquite (SB) (now Mesquite L.)
Mesquite thrust (K)
Middle (K)
Midway (SJ)
Mill Creek (SB)
Miller Creek (SF, SC)
Mint Canyon (LA)
Mission (SJ)
Mission Ridge (LA)
Mount Diablo (SJ)
Mount Jackson (SR)
Mule Spring (T)
Nadeau (LA)
New Idria thrust (SC)
North (K)
North Fork (SC)
Old Dad (K)
Orocopia thrust (SS)
Overland Avenue (LA)
Palm Canyon (SA)
Park Hill (SA)
Parks (SJ)
Patterson Pass (SJ)
Pelican Hill (SA)
Pelona (LA)
Pick Creek (SC)
Pine Rock (SC)
Pinecate (SC)
Pinole (SF)
Pinyon Hill (LA)
Pole Canyon (LA)
Protrero (LB)
Red Hills (SLO)
Rincon (SJ)
Round Mountain (B)
Russ (R)
San Antonio (SLO)
San Dimas Canyon (SB)
San Guillermo (LA)
San Juan (SA)
San Marcos (SLO)
San Pablo (SF, SR)
Santa Rosa (LA) (now Simi)
Santa Ynez, North Branch (SM)
Seal Beach (LB)
Shannon (SJ)
Sidewinder (SB)
Sierra Azul (SJ)
Soda Creek (SR)
Soda Spring (SJ)
Soledad (LA)
South (K)
South Fork Mountain (R, W)
Southhampton (SR)
St. John Mountain (SR)
Stewart (SA)
Stony Brook (SJ)
Stony Creek (U)
Sunol (SF)
Sycamore (LA)
Temple Hill (SA)
Tenaja (SA)
Thomas Mountain (SA)
Towne (DV)
Tracy (Stockton)(SJ)
Transmission Line (LA)
Tyler Horse (LA)
Tyler Valley (SB)
Valle (SJ)
Vasquez Canyon (LA)
Water Tank (SJ)
Welch (SJ)
West Huasna (SLO)
Wildcat (SF)
Wildomar (SA)
Williams (SJ)
Willow Springs (LA)
Wilson (SR)
Winters thrust (K)
Woods (SR)
Workman Hill fault extension (LA)
Wragg Canyon (SR)

APPENDIX B

TABULATED LIST OF THERMAL SPRINGS AND THERMAL WELLS

The following tabulation provides additional data for the thermal springs and wells shown on the Fault Map of California. These data include information on location, water temperature, references, some notes, and, in the case of wells, the total depth and year drilled.

DATA USED AND ACKNOWLEDGMENTS

Multiple references are often indicated on the tabulated list because in many instances supplementary references can be helpful in locating the spring or well more precisely on a map or in finding it in the field. In addition, many of these references (especially the more recent ones) contain data pertaining to chemistry and physical properties (for example, conductivity, discharge rate, and isotopic analysis). In addition to the published references listed, unpublished data were acquired from Robert W. Rex (Republic Geothermal, Inc.), James B. Koenig (Geothermex), and Sanford L. Werner (California Department of Water Resources). To these, I wish to express my gratitude. Help in plotting and tabulating these data was ably provided by John Sackett, Melvin C. Stinson, Robert A. Switzer, and Duane A. McClure.

LOCATING THERMAL SPRINGS AND WELLS

Locations of many thermal springs and wells, especially many of those listed in the earlier publications, were vague and difficult to plot. A reason for this was the lack of adequate base maps for many parts of the state when these earlier reports on hot springs and wells were made. If later reports did not clarify the locations, county records were examined (old copies of official county maps, as well as early Mines and Mineral Resources Reports by the California Division of Mines and its predecessor, the State Mining Bureau). Particularly useful in locating many early thermal springs and resorts was a book entitled "Mineral Springs and Health Resorts of California" (1892), by Winslow Anderson, Professor of Medicine at the University of California Medical School, San Francisco. Because the early references often did not give the location of the thermal springs and wells by township, range, and section, these data were often determined by the compilers where possible, from 7½- or 15-minute quadrangles. In unsurveyed land, the locations were described by the compilers by latitude and longitude from the published quadrangles.

The thermal springs and wells are shown on the Source Data Index maps (Appendix D) as circles for thermal springs and as squares for thermal wells. These spring and well locations are numbered, starting with "1" (one) for each atlas sheet. These coded numbers refer to the tabulated data in the following Appendix B. On the Fault Map of California, the thermal springs and wells are shown, but are not coded by number.

It should be noted that a number of the thermal springs are actually shallow wells that were dug or drilled for water but came in flowing as artesian wells. Oftentimes such artesian wells were dug for convenience in areas where no springs occur, so both wells and springs are intimately associated and, in fact, on the early records often the two are not clearly differentiated.

Following the convention established in reports by G. A. Waring (1915 and 1965), which were the principal sources used when this present compilation was started, the writer considered as thermal only those springs that are more than 15°F (8.3°C) above the mean annual temperature of the air at their localities. In the case of drilled wells, a normal thermal gradient of about 1°F increase for each 100 feet of depth (2°C for each 100 meters) was taken into consideration when determining whether the well should be classified as thermal.

ALTURAS SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
1	Warm spring	48N	9E	33	MD	Steele Swamp(15')								Pers. comm., J.B. Koenig
2	Pothole Spring	46N	9E	15	MD	Steele Swamp(15')	70			USGS P.P. 492	1965	20	4	
							70			USGS WSP 338	1915	334	Modoc 1	
		46N	9E	15	MD		78							Temp. by Burnett & Jennings 9/71
3	Hot springs on Bidwell Creek	46N	16E	8 or 17	MD	Fort Bidwell(15')	97-108			USGS P.P. 492	1965	20	12	
							108			USGS WSP 338	1915	121-122	Modoc 10	
	Fort Bidwell Hot Springs	46N	16E	8 & 17	MD		109-115			USGS Geoth. Modoc Co. (Open file)	1974	8a		2 springs
	Fort Bidwell Res. Hot Springs	46N	16E	17	MD		111			CDOG TR 15	1975	Table 4a	1	
	Peterson Ranch Well, Buchner's Well, Fort Bidwell Well	46N	16E	8 & 17	MD		97-108			CDOG TR 13	1975	47	1, 2, 3	
4	Spring, north of Big Glass Mtn.	44N	3E	1	MD	Medicine Lake (15')	191			USGS P.P. 492	1965	20	3A	Location vague
5	Spring, near Rattlesnake Creek	43N	12E	22?	MD	Big Sage Res. (15')	80			USGS P.P. 492	1965	20	5	Location vague
							-			USGS WSP 338	1915	120	Modoc 8	
6	Magma Energy Inc. Parman 1	44N	15E	24	MD	Cedarville (15')	283	2150	1959	USGS Geoth. Modoc Co. (Open file)	1974	6a		
	Magma Energy Inc. Parman 2	44N	15E	24	MD		257	1968	1959	USGS Geoth. Modoc Co. (Open file)	1974	6a		
	Magma Energy Inc. Parman 3	44N	15E	24	MD		-	92	1962	USGS Geoth. Modoc Co. (Open file)	1974	6a		Rig destroyed by blowout
	Magma Energy Inc. Phipps 1	44N	15E	24	MD		278	1267	1962	USGS Geoth. Modoc Co. (Open file)	1974	6a		
	Magma Energy Inc. Phipps 2	44N	15E	24	MD	Cedarville (15')	320	4500	1972	USGS Geoth. Modoc Co. (Open file)	1974	6a		
	Wells						320	max. 4500		CDOG TR 13	1975	47	5	
7	Several springs at site of mud "volcanoes"						120-207			USGS P.P. 492	1965	20	14	
	Hot springs north of Lake City						-			USGS WSP 338	1915	122-123	Modoc 11	
	Mud volcano and hot springs	44N	15E	24	MD	Cedarville (15')	118-207			CDOG TR 13	1975	47	4	
	"Lake City mud explosion"						205			CDOG TR 15	1975	Table 4a	2	
8	Boyd Spring	45N	17E	31	MD	Cedarville (15')	70			USGS P.P. 492	1965	20	13	Now only 50°F, Marshal Reed, CDOG, pers. comm. 7/1/74
							67			USGS WSP 338	1915	124	Modoc 12	
9	Hot springs	43N	16E	12	MD	Cedarville (15')	140-149			USGS P.P. 492	1965	20	16	Waring's location (18E) corrected
							-			USGS WSP 338	1915	123	Modoc 14	
		43N	16E	12	MD		185			USGS Geoth. Modoc Co. (Open file)	1974	8a		Several springs
	Seyferth Hot Springs						186			CDOG TR 15	1975	Table 4a	3	
	Seyferth Hot Springs						185			CDOG TR 13	1975	47	9	
10	Leonards Hot Springs	43N	16E	13	MD	Cedarville (15')	106			USGS Geoth. Modoc Co. (Open file)	1974	8a	8	
							149			CDOG TR 13	1975	47	10	
11	Leonards Hot Springs (east)					Cedarville (15')	150			USGS P.P. 492	1965	20	17	Waring's location corrected

* See Appendix D for location.

TURAS SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

P* C. ɔ.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
1	Leonards Hot Springs (east)	43N	16E	13	MD	Cedarville (15')	-			USGS WSP 338	1915	123	Modoc 13	
	Hot springs						143			CDOG TR 15	1975	Table 4a	4	
							150			USGS Geoth. Modoc Co. (Open file)	1974	8a	A	
							144			CDOG TR 13	1975	47	11	
A	Hutchens Well	43N	16E	20	MD	Cedarville (15')	118	400		CDOG TR 13	1975	47	6	
B	Well	43N	16E	20	MD	Cedarville (15')	156	650		CDOG TR 13	1975	47	7	
C	Robison's Well	43N	16E	30	MD	Cedarville (15')	122	250		CDOG TR 13	1975	47	8	
	Hot springs	42N	16E	1	MD	Cedarville (15')	130			USGS P.P. 492	1965	20	18	
							200			USGS Geoth. Modoc Co. (Open file)	1974	8a	D	
							-			USGS WSP 338	1915	123	Modoc 15	
	Hot Springs Motel Well	42N	17E	6	MD	Cedarville (15')	210	90		CDOG TR 15	1975	Table 4a	5	
	Hot Springs Hotel Wells						183-208	-		CDOG TR 13	1975	47	13	
	Magma Energy, Inc., Cedarville #1						129	734	1962	USGS Geoth. Modoc Co. (Open file)	1974	6a		
	Benmac Hot Springs	42N	17E	6	MD	Cedarville (15')	205-207			CDOG TR 13	1975	47	15	
	Surprise Valley Mineral Wells (springs)						209			USGS Geoth. Modoc Co. (Open file)	1974	8a	C	
	Geothermal Resources Int. Kelly Hot Spring 1	42N	10E	29	MD	Canby (15')	230	3206	1969	USGS Geoth. Modoc Co. (Open file)	1974	6a		
	Well	42N	10E	29	MD	Canby (15')	230	3206	-	CDOG TR 13	1975	47	20	
	Kelly Hot Springs	42N	10E	29	MD	Canby (15')	204			USGS P.P. 492	1965	20	8	
							199			USGS WSP 338	1915	118-119	Modoc 4	
							196			CDOG TR 15	1975	29	1	
							198			CDOG TR 13	1975	47	19	
	Warm Springs Valley	42N	10E	13	MD	Canby (15')	81			USGS P.P. 492	1965	20	7	
							81			USGS WSP 338	1915	119	Modoc 5	
	Essex Springs	42N	11E	10	MD	Alturas (15')	80-92			USGS P.P. 492	1965	20	6	
							92			USGS WSP 338	1915	119	Modoc 6	
	Hot Creek Ranch	42N	11E	9	MD		91			CDOG TR 13	1975	47	18	
	Spring near Canyon Creek	40N	11E	22?	MD	Alturas (15')	80			USGS P.P. 492	1965	20	9	Location very vague
							-			USGS WSP 338	1915	120	Modoc 7	
	Spring near Alturas	42N	13E	30	MD	Alturas (15')	72			USGS P.P. 492	1965	20	10	Location vague
							72			USGS WSP 338	1915	323-324	Modoc 9	
	Williams Ranch Well	40N	13E	31	MD	Alturas (15')	110	114+		CDOG TR 15	1975	29	2	
	Old Williams Ranch Well						111	-		CDOG TR 13	1975	47	22	

S Appendix D for location.

ALTURAS SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
21A	New Williams Ranch Well	40N	13E	30	MD	Alturas (15')	84	200		CDOG TR 13	1975	47	21	
22	Warm spring	40N	13E	31	MD	Alturas (15')	75							Pers. comm., J.B. Koenig
23	Menlo Warm Springs	39N	17E	7	MD	Eagleville (7½')	117-125			USGS P.P. 492	1965	20	20	
							-			USGS WSP 338	1915	123	Modoc 16	Location vague
	Menlo Baths	39N	17E	6 & 7	MD		128, 139			USGS Geoth. Modoc Co. (Open file)	1974	8a		
							120			CDOG TR 13	1975	47	16	
	Menlo Hot Springs	39N	17E	7	MD		135			CDOG TR 15	1975	Table 4a	6	
24	Kosk Creek Hot Springs	37N	1W	25-26	MD	Big Bend (15')	100			USGS P.P. 492	1965	20	23	
							-			USGS WSP 338	1915	116-117	Shasta 7	
	Hunt Hot Spring	37N	1W	25	MD		136			CDOG TR 15	1975	29	7	
	Hunt (Kosk Creek) Hot Spring	37N	1W	26	MD		136			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	27		
	F.E. Rayner, Jr.	37N	1W	26	MD		105			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	27		
25	Big Bend Hot Springs	37N	1W	36	MD	Big Bend (15')	100-180			USGS P.P. 492	1965	20	24	
							180			USGS WSP 338	1915	115-116	Shasta 8	
							180			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	27		
26	Little Hot Spring Valley	39N	5E	9	MD	Fall River Mills (15')	127, 170			USGS P.P. 492	1965	20	11	
	Little Hot Spring Valley	39N	5E	9	MD	Fall River Mills (15')	127, 170			USGS WSP 338	1915	118	Modoc 3	
	Little Hot Springs						168			CDOG TR 15	1975	29	3	
							167-171			CDOG TR 13	1975	47	26	
27	Hot springs	37N	6E	28 or 27	MD	Fall River Mills (15')	?							Pers. comm., J.B. Koenig, Q. Aune
28	Bassett Hot Springs	38N	7E	1	MD	Bieber (15')	173			USGS P.P. 492	1965	20	28	
							173			USGS WSP 338	1915	117	Lassen 1	
							174			CDOG TR 15	1975	29	5	
							174			CDOG TR 13	1975	47	24	
29	Stonebreaker Hot Springs	38N	8E	14	MD	Bieber (15')	110-165			USGS P.P. 492	1965	20	29	
							165			USGS WSP 338	1915	117-118	Lassen 2	
	Kellog Hot Spring	38N	8E	15	MD		174			CDOG TR 15	1975	29	6	
	Kellog Hot Spring	38N	8E	14 & 15	MD		172			CDOG TR 13	1975	47	25	
30	Warm spring	39N	13E	22	MD	Tule Mtn. (7½')	?							Pers. comm., J.B. Koenig 6/73
31	Warm spring	38N	14E	6	MD	Tule Mtn. (7½')	70±							Pers. comm., J.B. Koenig 6/73
32	West Valley Res., Hot Spring	39N	14E	29	MD	Tule Mtn. (7½')	171			CDOG TR 15	1975	29	4	
							165			CDOG TR 13	1975	47	23	

* See Appendix D for location.

ALTURAS SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTE
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
33	Hot spring	39N	17E	29	MD	Snake Lake (7½')	120			USGS P.P. 492	1965	20	21	
							-			USGS WSP 338	1915	123-124	Modoc 17	
	Squaw Baths Springs	39N	17E	29	MD		95-109			USGS Geoth. Modoc Co. (Open file)	1974	8a		3 springs
										CDOG TR 13	1975	47	17	
34	Bare Ranch	36N	17E	102	MD	Snake Lake (7½')	70			USGS P.P. 492	1965	20	22	Location vague
							-			USGS WSP 338	1915	124	Modoc 18	

BAKERSFIELD SHEET

MAP* LOC. NO.	NAME	T	R	SEC.	B&M	QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	PUBLICATION	YEAR	PAGE	LOC. NO.	NOTE
1	California (Deer Creek) Hot Springs	22S	31E	31	MD	California Hot Springs (15')	105-126			USGS P.P. 492	1965	23	137	
							120-126			USGS WSP 338	1915	49-50	Tulare 18	
2	Democrat Springs	28S	31E	4-5	MD	Glennville (15')	100-115			USGS P.P. 492	1965	24	152	
							115			USGS WSP 338	1915	51-52	Kern 7	
2A	Hot spring	27S	31E	33	MD	Democrat (7½')	?			USGS Democrat 7½' quad.	1972			
3	Delonegha Springs	27S	31E	26	MD	Glennville (15')	104-112			USGS P.P. 492	1965	24	151	
										USGS WSP 338	1915	51	Kern 8	
4	Clear Creek (Hobo) Hot Springs	27S	32E	15	MD	Glennville (15')	119			USGS P.P. 492	1965	24	150	
	Clear Creek (Hobo) Hot Springs	27S	32E	15	MD	Glennville (15')				USGS WSP 338	1915	51	Kern 9	
5	Miracle Hot Springs	27S	32E	15	MD	Glennville (15')	?			USGS Glennville 15' quad.				
6	Neills Hot Spring	35°37.2'N 118°28.6'W				Isabella (15')	131			USGS P.P. 492	1965	24	149	Shown as Scovern Hot Springs on 1943 topo quad.
							131			USGS WSP 338	1915	51	Kern 10	
7	Hot spring	35°43.7'N 118°24.6'W				Isabella (15')	98 113			USGS P.P. 492	1965	24	148	
							103			USGS WSP 338	1915	50	Kern 11	
8	Williams Hot Springs	29S	33E	6	MD	Emerald Mtn. (15')	60-100			USGS P.P. 492	1965	24	15[illegible]	Shown as Yates Hot Springs on 1943 topo quad.
							97			USGS WSP 338	1915	52	Kern 12	

CHICO SHEET

MAP* LOC. NO.	NAME	T	R	SEC.	B&M	QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	PUBLICATION	YEAR	PAGE	LOC. NO.	NOTE
1	Doyle Hot Springs	24N	12E	24	MD	Blairsden (15')	108			CDOG TR 13	1975	47	44	
2	McLear Sulphur Spring	22N	13E		MD	Sierra City (15')	86			USGS P.P. 492	1965	21	42	
							84-86			USGS WSP 338	1915	[illegible]-284	Plumas 15	
	McLear's Warm Springs						86			CDOG TR 13	1975	48	46	
3	Marble Hot Wells	22N	14E	13	MD	Portola (15')	125-161			USGS P.P. 492	1965	[illegible]	41A	
							125-161		1885-1888	USGS WSP 338	1915	178-179	Plumas 16	Also [illegible]

* See Appendix D for location.

CHICO SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
3	Marble Hot Springs wells	22N	14E	13	MD	Portola (15')	158-163	330		CDOG TR 15	1975	11	1, 2	
							158-163	330		CDOG TR 13	1975	48	35, 36	
4	Viscia Well	22N	14E	25	MD	Sierraville (15')	104	25		CDOG TR 13	1975	48	37	
5	Shallow well	22N	15E	26	MD	Sierraville (15')	131			CDOG TR 13	1975	48	38	
6	W. Hagge well (1)	[illegible]N	[illegible]E		MD	Sierraville (15')	104	699		CDOG TR 15	1975	11	3	
	Hagge Well 1						104			CDOG TR 13	1975	48	39	
7	W. Hagge well (2)	[illegible]N	15E		MD	Sierraville (15')	102	597		CDOG TR 15	1975	11	4	
	Hagge well 2						102			CDOG TR 13	1975	48	40	
8	W. Hagge Well (3)	[illegible]	[illegible]E		[illegible]	Sierraville (15')	111	899		CDOG TR 15	1975	11	6	
	Hagge Well 3						126	909		CDOG TR 13	1975	48	41	
9	G. Filipini Well (1)	[illegible]	[illegible]E		MD	Sierraville (15')	201	1099		CDOG TR 15	1975	11	5	
	Filipini Well 1						201	1080		CDOG TR 13	1975	48	42	
10	G. Filipini Well (2)	[illegible]N	[illegible]		MD	Sierraville (15')				CDOG TR 15	1975	11	7	
	Filipini Well 2						124	399		CDOG TR 13	1975	48	43	
11	Filipini well 3	21N	15E	5	MD	Sierraville (15')	111	600		CDOG TR 13	1975	48	44	
12	Campbell Hot Springs	20N	15E	19	MD	Sierraville (15')	65-111			USGS P.P. 492	1965	21	43	
	Campbell Hot Springs	20N	15E	19	MD	Sierraville (15')	98-111			USGS WSP 338	1915	129-130	Sierra 1	
							100			CDOG TR 15	1975	11	9	
							99-111			CDOG TR 13	1975	48	45	
13	Brockway Hot Springs	16N	18E	30	MD	Tahoe (15')	120-140			USGS P.P. 492	1965	21	44	
							137			USGS WSP 338	1915	131	Placer 8	
							131			CDOG TR 13	1975	48	47	Near Kings Beach
14	Wentworth Springs	14N	15E	31	MD	Granite Chief (15')	60-75			USGS P.P. 492	1965	21	44A	
										USGS WSP 338	1915	235-236	Eldorado 2	Carbonated springs

DEATH VALLEY SHEET

MAP* LOC. NO.	NAME	T	R	SEC.	B&M	QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	PUBLICATION	YEAR	PAGE	LOC. NO.	NOTES
1	Spring in Saline Valley	13S	[illegible]9E	18	MD	Waucoba Wash (15')	100			USGS P.P. 492	1965	23	139	
							warm			USGS WSP 338	1915	136	Inyo 12	
	Lower Warm Spring						110			USGS WRI 33-73	1974	10	90	Also known as Burro Warm Springs
	Palm Springs	1[illegible]	[illegible]9E	18	MD	Waucoba Wash (15')	1[illegible]			USGS WRI 33-73	1974	10	91	
	Upper Warm Spring	[illegible]	[illegible]9E	[illegible]	MD	Dry Mtn. (15')				USGS Dry Mtn. 15' quad.	1957			
4	Keane Wonder Spring	[illegible]	4[illegible]E	[illegible]	MD	Chloride Cliff (15')	8[illegible]			USGS P.P. 440F	196[illegible]	54	1	Depositing travertine

* See Appendix [illegible] for location

DEATH VALLEY SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
4	Keene Wonder Spring	15S	46E	1	MD	Chloride Cliff (15')	80-93			USGS P.P. 492	1965	23	140A	
5	Dirty Socks "Hot Spring"	18S	37E	34	MD	Keeler (15')	?	600	1917	CDMG MIS vol. 17 no. 11	Nov. 1964	202		
6	Hot spring-fumarole	22S	38E	12	MD	Haiwee Res. (15')	150-203			USGS P.P. 492	1965	23	141	
7	Devils Kitchen (fumarole)	22S	39E	7	MD	Haiwee Res. (15')	180 to boiling			USGS P.P. 492	1965	23	141A	
							203			USGS WSP 338	1915	150-151	Inyo 30	
							206			USGS WRI 33-73	1974	6	14	
8	Coso Hot Springs	22S	39E	4	MD	Haiwee Res. (15')	140 to boiling			USGS P.P. 492	1965	23	142	
										USGS WSP 338	1915	149-150	Inyo 31	
	Well						207	106		USGS WRI 33-73	1974	6	12	
	Well						240	375		USGS WRI 33-73	1974	6	13	
9	Warm spring	21S	44E	10	MD	Telescope Pk. (15')	80			USGS P.P. 492	1965	24	144	Shown as Warm Sulphur Springs on 1952 topo. quad.
										USGS WSP 338	1915	136	Inyo 29	

EL CENTRO SHEET

1	C.L. Smith well	16S	10E	5	SB	Painted Gorge (7½')	85	150		Rex unpub.	1972	4	84	
2	J. Green Well	16S	10E	16	SB	Painted Gorge (7½')	85	105		Rex unpub.	1972	4	161A	
3	Dollinger Well	16S	10E	16	SB	Painted Gorge (7½')	86	300		Rex unpub.	1972	4	162	
4	Magma Energy Co. Bonanza 1	15S	14E	22	SB	El Centro (7½')		5024	1973	Werner unpub.	1973	Map	28	
5	Well	15S	15E	18	SB	Holtville West (7½')	100			USGS WRI 33-73	1974	8	57	
6	N. Fifield Well	14S	15E	6	SB	Alamorio (7½')	124	1250		CDOG TR 15	1975	Table 1a	17	
							129	1290		Rex unpub.	1972	1	64	
7	T. Shank Well	13S	15E	32	SB	Alamorio (7½')	111	1006		CDOG TR 15	1975	Table 1a	12	
8	Mamer-Shank Well	14S	15E	9	SB	Alamorio (7½')	68	800		Rex unpub.	1972	3	144	
9	J. Birger Well	14S	15E	9	SB	Alamorio (7½')	89	385		Rex unpub.	1972	3	42	
							88	387		CDOG TR 15	1975	Table 1a	18	
10	Magnolia School Well	13S	15E	33	SB	Alamorio (7½')	124	1337		CDOG TR 15	1975	Table 1a	13	
							127	1389		Rex unpub.	1972	1	1	
11	M. Phegley well	13S	15E	34	SB	Alamorio (7½')	111	950		CDOG TR 15	1975	Table 1a	14	
	Rutherford well						112	954		Rex unpub.	1972	1	4	
12	Fifield Well	13S	15E	34	SB	Alamorio (7½')	112	1045		Rex unpub.	1972	1	111	
11	Orita Stage Station well	13S	15E	34	SB	Alamorio (7½')	110	900		Rex unpub.	1972	1	7	

See Appendix D for location.

EL CENTRO SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
14	Moiola Feed Lot Well (Same as No. 517)	14S	15E	11	SB	Alamorio (7½')	107	654		CDOG TR 15	1975	Table 1a	19	
15	A. Gisler well	14S	15E	15	SB	Alamorio (7½')	117	1172		CDOG TR 15	1975	Table 1a	21	
	Gisler-Bowman Well						121	1165		Rex unpub.	1972	1	35	
16	Mendiburu Feed Lot Well	14S	15E	12	SB	Alamorio (7½')	125	1240		CDOG TR 15	1975	Table 1a	20	
	M-F Feed Lot Well						124	1260		Rex unpub.	1972	1	43	
17	OMITTED													
18	J. Birger well	14S	15E	23	SB	Alamorio (7½')	103	754		CDOG TR 15	1975	Table 1a	22	
	James Birger Jr. We						106	750		Rex unpub.	1972	1	34	
19	J. Birger Well	14S	15E	27	SB	Alamorio (7½')	90	402		CDOG TR 15	1975	Table 1a	23	
	James Birger Jr. Well						90	400		Rex unpub.	1972	3	33	
20	A. Foster Well	14S	15E	28	SB	Alamorio (7½')	88	380		Rex unpub.	1972	3	143	
21	Jenson Well	14S	15E	34	SB	Alamorio (7½')	86	359		CDOG TR 15	1975	Table 1a	24	
22	Gaddis Well	14S	15E	34	SB	Alamorio (7½')	96	613		CDOG TR 15	1975	Table 1a	25	
23	Gaddis-Hanson Well	14S	15E	34	SB	Alamorio (7½')	97	610		Rex unpub.	1972	2	31	
24	Shawner Well	15S	15E	10	SB	Holtville West (7½')	90	463		CDOG TR 15	1975	Table 1a	32	
	Shawner-Harmon We..						90	460		Rex unpub.	1972	3	25	
25	R. Shaffner Well	15S	15E	9	SB	Holtville West (7½')	89	550		Rex unpub.	1972	3	41	
26	A. Barres Well	15S	15E	10	SB	Holtville West (7½')	90	399		Rex unpub.	1972	3	30	
27	C. Allen well	15S	15E	14	SB	Holtville West (7½')	104	864		Rex unpub.	1972	1	24	
							104	869		CDOG TR 15	1975	Table 1a	33	
28	K. Sharp well	15S	15E	1[illegible]	SB	Holtville West (7½')	97	800		Rex unpub.	1972	2	145	
29	J. DeFaoli well	15S	15E	26	SB	Holtville West (7½')	104	954		CDOG TR 15	1975	Table 1a	34	
							106	970		Rex unpub.	1972	1	11	
30	Modern Grocery well	15S	15E	25	SB	Holtville West (7½')	96	850		Rex unpub.	1972	2	14	
31	Holtville Ice Co. well	15S	15E	35	SB	Holtville West (7½')	11[illegible]	11[illegible]		Rex unpub.	1972	1	8	CDOG #35
32	City of Holtville Well	15S	15E	36	SB	Holtville West (7½')	84	850		CDOG TR 15	1975	Table 1a	46	
	Unnamed well	[illegible]	15E	36	SB		109	14		USGS WRI 33-73	1974	8	56	
33	Mazz Strang well	15S	15E	25	SB	Holtville East (7½')	112	873		Rex unpub.	1972	1	150	
34	Spanish Trails Mobil Home Park well	15S	16E		SB	Holtville East (7½')	110	155[illegible]		Rex unpub.	1972	1	172	
35	A. Fuel, Jr. well	15S	16E	[illegible]	SB	Holtville East (7½')	104	918		CDOG TR 15	1975	Table 1a	44	
							114	10[illegible]		Rex unpub.	1972	1	6[illegible]	
36	A. Fuel, well	15S	16E	29	SB	Holtville East (7½')	9[illegible]	5[illegible]		CDOG TR 15	1975	Table 1a	43	

* See Appendix [illegible] for location

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
36	A. Fusi, Sr. Well	15S	16E	29	SB	Holtville East (7½')	88	616		Rex unpub.	1972	3	16	
37	F. Strahm Well	15S	16E	19	SB	Holtville East (7½')	97	839		CDOG TR 15	1975	Table 1a	40	
							98	834		Rex unpub.	1972	2	21	
38	Hooke Well	15S	16E	7	SB	Holtville East (7½')	97	683		CDOG TR 15	1975	Table 1a	37	
	H. Hoke Well						99	695		Rex unpub.	1972	2	28	
39	G. Hoyt Well	15S	16E	8	SB	Holtville East (7½')	89	484		CDOG TR 15	1975	Table 1a	38	
							89	488		Rex unpub.	1972	3	27	
40	F. Grinello	15S	15E	12	SB	Holtville East (7½')	101			Rex unpub.	1972	2	146	
							106			USGS WRI 33-73	1974	10	59	
41	J. Rohrer Well	15S	15E	1	SB	Alamorio N.E. (7½')	100	580		Rex unpub.	1972	2	147	
42	A. Immel Well	14S	16E	19	SB	Alamorio N.E. (7½')	124	1135		Rex unpub.	1972	1	157	
43	F. Axler Well	14S	16E	21	SB	Alamorio N.E. (7½')	96	450		Rex unpub.	1972	2	154	
44	S. Stacey Well	14S	16E	21	SB	Alamorio N.E. (7½')	88	450		Rex unpub.	1972	3	38	
							90	440		CDOG TR 15	1975	Table 1a	30	
45	Singh Well	14S	16E	22	SB	Alamorio N.E. (7½')	96	709		Rex unpub.	1972	2	39	
							117			USGS WRI 33-73	1974	8	58	
	Singh well	14S	16E	22	SB	Alamorio N.E. (7½')	107	706		CDOG TR 15	1975	Table 1a	31	
46	Chopenick Well	14S	16E	16	SB	Alamorio N.E. (7½')	90	450		Rex unpub.	1972	3	155	2 separate wells
	M. Axler Well						78	402		CDOG TR 15	1975	Table 1a	29	
47	F. Borchard well	14S	16E	4	SB	Alamorio N.E. (7½')	102	456		Rex unpub.	1972	2	47	
							100	425		CDOG TR 15	1975	Table 1a	26	
48	F. Borchard Well	14S	16E	4	SB	Alamorio N.E. (7½')	102	457		Rex unpub.	1972	2	46	
							101	460		CDOG TR 15	1975	Table 1a	27	
49	B. Emanuelli Well	13S	16E	32	SB	Alamorio N.E. (7½')	106			Rex unpub.	1972	1	112	
50	Q.O. Cattle Co. Well	13S	16E	28	SB	Alamorio N.E. (7½')	98			Rex unpub.	1972	2	156	
51	Moiola Feed Lot Well	14S	16E	11	SB	Alamorio N.E. (7½')	108	650		Rex unpub.	1972	1	45	
52	U.S.G.S. Oasis Well	14S	16E	11	SB	Alamorio N.E. (7½')	96	287		Rex unpub.	1972	2	65	
53	U.S.-B.L.M. well	14S	16E	11	SB	Alamorio N.E. (7½')	94	287		CDOG TR 15	1975	Table 1a	28	
54	Coons Well	14S	16E	27	SB	Alamorio N.E. (7½')	88			Rex unpub.	1972	3	148	
55	A. Jechims Wells	14S	16E	34	SB	Alamorio N.E. (7½')	92			Rex unpub.	1972	3	149	
56	R. Garewal Well	15S	16E	15	SB	Holtville East (7½')	91	800		Rex unpub.	1972	3	23	
							90	804		CDOG TR 15	1975	Table 1a	39	

* See Appendix D for location.

EL CENTRO SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
57	D. Starr well	15S	16E	22	SB	Holtville East (7½')	98	750		Rex unpub.	1972	2	20	
							94	754		CDOG TR 15	1975	Table 1a	41	
58	L. Foster well	15S	16E	23	SB	Holtville East (7½')	95	561		Rex unpub.	1972	2	18	
							94	544		CDOG TR 15	1975	Table 1a	42	
59	Neldifier well	15S	16E	27	SB	Holtville East (7½')	89	600		Rex unpub.	1972	3	17	
60	C. Ansiel well	16S	16E	4	SB	Holtville East (7½')	102	940		Rex unpub.	1972	2	61	
							94	944		CDOG TR 15	1975	Table 1a	45	
61	Date City Store well	16S	16E	3	SB	Holtville East (7½')	89	596		Rex unpub.	1972	3	133	
62	Magma Energy Inc. Sharp #1	15S	16E	35	SB	Holtville East (7½')		6070	1972	Werner unpub.	1973	Map	17	
							259	6072		USGS Open File (Imperial Valley)	1976	26	215	
63	Lechuga Store Well	16S	16E	17	SB	Holtville East (7½')	104			Rex unpub.	1972	1	136	
64	Alamo School well	16S	16E	15	SB	Holtville East (7½')	99	1000		Rex unpub.	1972	2	29	
65	Masserini well	16S	16E	15	SB	Holtville East (7½')	107	1060		Rex unpub.	1972	1	36	
	Alamo School (ABD.) Well						100	881		CDOG TR 15	1975	Table 1a	47	
	Old Alamo Store Well						118	1177		Rex unpub.	1972	1	26	
66	Watton Labor Camp well	16S	16E	14	SB	Holtville East (7½')	112	800		Rex unpub.	1972	1	15	
	Watton Labor Camp well	16S	16E	14	SB	Holtville East (7½')	109	1134		CDOG TR 15	1975	Table 1a	46	
67	Schneider-Guthrie well	16S	16E	12	SB	Holtville East (7½')	108	825		Rex unpub.	1972	1	137	
68	Linden Gravel well	16S	16E	13	SB	Holtville East (7½')	120	810		Rex unpub.	1972	1	134	
69	U.S.B.R. #6-151 Well	16S	17E	6	SB	Glamis SW (7½')	91	150		Rex unpub.	1972	3	170	
70	U.S.B.R. Mesa 6-1 Well	16S	17E	6	SB	Glamis SW (7½')		8030	1972	Werner unpub.	1973	Map	22	
							395	7960		USGS Open File (Imperial Valley)	1976	30	338	
70A	U.S.B.R. Mesa 6-2 well	16S	17E	6	SB	Glamis SW (7½')		6005	1973	Werner unpub.	1973	Map	31	
							368	5920		USGS Open File (Imperial Valley)	1976	30	339	
71	U.C. Riverside-127 well	16S	17E	17	SB	Glamis SW (7½')	181	1500		Rex unpub.	1972	1	71, 71A	
							186	1363		USGS Open File (Imperial Valley)	1976	30	348	
72	U.S.B.R. Mesa 5-1 well	16S	17E	5	SB	Glamis SW (7½')		6000±	1974	Werner unpub.	1973	Map	34	
73	Smith Bros. well	13S	18E	33	SB	Glamis (15')	160	680		Rex unpub.	1972	1	171	
74	U.S.B.R.-U.C.R. #115	15S	19E	[illegible]	SB	Glamis (15')	212+	350	1971	CDWR-UCR Dunes Report	1973	3, 8, 9		
	DWR Dunes #1 well						212±	1800±	1972	CDWR-UCR Dunes Report	1973	3, 8, 9		
	DWR Dunes #1 well							2007	1972	Werner unpub.	1973	Map	18	
75	Erma Mire well	[illegible]	19E	3	SB	Ogilby (15')	86	700		Rex unpub.	1972	4	2	

* See Appendix D for location.

EL CENTRO SHEET

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
76	Gold Rock Ranch Well	15S	20E	7	SB	Ogibley (15')	98	690		Rex unpub.	1972	2	13	
77	Texaco I-8 Well, Imperial Hwy.	16S	9E	36	SB	Coyote Wells (7½')	91	547		Rex unpub.	1972	3	75	
							85	312		Rex unpub.	1972	4	75	
78	W. Simpson Well	17S	10E	11	SB	Coyote Wells (7½')	85	302		Rex unpub.	1972	4	82	
79	Magma Energy, Inc. Fed-Rite #1 Well	17S	13E	8	SB	Mt. Signal (7½')		5380	1973	Werner unpub.	1973	Map	30	
80	Magma Energy, Inc. Holtz #2 Well	16S	14E	31	SB	Heber (7½')		5000	1972	Werner unpub.	1973	Map	20	
							318	4890		USGS Open File (Imperial Valley)	1976	30	302	
81	Magma Energy, Inc. Holtz #1 Well	16S	14E	32	SB	Heber (7½')		5147	1972	Werner unpub.	1973	Map	19	
							334	5025		USGS Open File (Imperial Valley)	1976	30	304	
82	Chevron Oil Co. Nowlin Part. 1 Well	16S	14E	33	SB	Heber (7½')		5030	1972	Werner unpub.	1973	Map	21	
83	L. Bornt well	17S	16E	9	SB	Bonds Corner (7½')	95	714		Rex unpub.	1972	2	63	
							100	714		CDOG TR 15	1975	Table 1a	48	
84	Mets Feed Lot Well	16S	16E	33	SB	Bonds Corner (7½')	87	800		Rex unpub.	1972	4	135	
85	Magma Energy, Inc. Sharp #2 Well	16S	16E	34	SB	Bonds Corner (7½')		6485	1973	Werner unpub.	1973	Map	29	

FRESNO SHEET

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
1	Kern (Jordan) Hot Spring	36°28.7'N 118°24.2'W				Kern Peak (15')	95-123			USGS P.P. 492	1965	23	135	
							95-123			USGS WSP 338	1915	53-54	Tulare 7	
2	On S. Fork of M. Fork of Tule R.	36°09.2'N 118°39.8'W				Camp Nelson (15')	77			USGS P.P. 492	1965	23	134	Water carbonated
							77			USGS WSP 338	1915	242-243	Tulare 11	
3	Monache Meadows Spring	20S	35E	3	MD	Monache Mtn. (15')	100			USGS P.P. 492	1965	23	136	Water carbonated
										USGS WSP 338	1915	246	Tulare 8	

KINGMAN SHEET

						No thermal springs or wells reported.								

LONG BEACH SHEET

1	Unnamed warm springs, Malaga Cove area.	4S	15W	36	SB	Redondo Beach (7½')	77			Torrance Daily Breeze	1970	9		Jan. 23, 1970, newspaper
2	Whites Point Hot Springs	5S	14W	31	SB	San Pedro (15')	114			USGS WRI 33-73	1974	10	92	
3	Segura Petroleum Co. Segura #1	5S	11W	34	SB	Seal Beach (7½')	425	8340	1920's	CDOG Huntington Beach Map No. 134				CDOG written comm. 7/26/74
4	McCasden Well	6S	11W	10	SB	Seal Beach (7½')	very hot							CDOG written comm. 7/26/74

* See Appendix D for location.

LOS ANGELES SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
1	San Marcos Hot Springs	5N	29W	2	SB	Lake Cachuma (7½')	89-108			USGS P.P. 492	1965	22	102	
	(Mtn. Glen) Hot Springs						-			USGS WSP 338	1915	67-68	Sta. Bar. 2	
	(Cuyama) Hot Springs						110			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-16		
2	Agua Caliente (Big Caliente) Spring	5N	26W	1	SB	Hildreth Peak (7½')	133			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-16		
3	Warm spring	5N	25W	4	SB	Hildreth Peak (7½')	90			USGS P.P. 492	1965	22	104	
4	Warm spring	5N	25W	1	SB	Old Man Mtn. (7½')	90			USGS P.P. 492	1965	22	105	
5	Wheelers Hot Springs	34°30.5'N 119°17.4'W				Wheeler Springs (7½')	62-102			USGS P.P. 492	1965	23	109	
							102			USGS WSP 338	1915	64-66	Ventura 2	
							94, 102			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-18		
6	Willett Hot Springs	6N	20W	30	SB	Topatopa Mtn. (7½')	120			USGS P.P. 492	1965	23	110	
							108			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-19		
7	Sespe Hot Springs	6N	20W	21	SB	Devils Heart Pk. (7½')	191			USGS P.P. 492	1965	23	111	
							194			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-19		
							191			USGS WSP 338	1915	66	Ventura 1	
							191			USGS WRI 33-73	1974	10	87	
8	Elizabeth Lake Canyon Warm Spring	6N	16W	15	SB	Warm Springs Mtn. (7½')	100			USGS P.P. 492	1965	23	112	
	Elizabeth Lake Canyon Warm Spring	6N	16W	15	SB	Warm Springs Mtn. (7½')	-			USGS WSP 338	1915	66	Los Angeles 1	
							92			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-7		
9	Tecolate Tunnel	5N	29W	26	SB	Dos Pueblos Can. (7½')	93			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-16		
10	Montecito (Santa Barbara) Hot Springs	4N	26W	5	SB	Santa Barbara (7½')	111-118			USGS P.P. 492	1965	22	103	
							111-118			USGS WSP 338	1915	66-7	Sta. Bar. 7	
							118			USGS WRI 33-73	1974	10	86	
	Montecito Hot Springs and Arsenic Springs	4N	26W	5 & 6	SB		111, 112			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-15		Arsenic Springs in Section 6
11	Vickers Hot Springs	34°30.1'N 119°20.75'W				Wheeler Springs (7½')	118			USGS P.P. 492	1965	22	106	
							-			USGS WSP 338	1915	62-63	Ventura 3	
12	Stingleys Hot Springs	5N	24W	24	SB	Matilija (7½')	100			USGS P.P. 492	1965	22	107	
							100			USGS WSP 338	1915	63	Ventura 5	
	G.A. Rice						123			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-19		
13	Matilija Hot Springs	5N	23W	29	SB	Matilija (7½')	116			USGS P.P. 492	1965	23	108	
							116			USGS WSP 338	1915	63	Ventura 7	
							109			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-19		
14	Seminole Hot Springs	1S	18W	5	SB	Point Dume (7½')	114	3000±		USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-7		Oil test well

* See Appendix D for location.

LOS ANGELES SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
15	Encino Ranch (Seminole) Hot Springs	34°09.1'N 118°29.0'W				Van Nuys (7½')	85			USGS P.P. 492	1965	23	112 A	
							85			USGS WSP 338	1915	246-247	Los Angeles 8	
16	Radium Sulfur Spring	1S	14W	14	SB	Hollywood (7½')	80			USGS P.P. 492	1965	23	112 B	[illegible]63 Melrose Ave. near Gower St.)
								1000±	CA. 1904	USGS WSP 338	1915	71-72	Los Angeles 10	Oil test well; later bathing resort
17	Bimini Hot Springs	1S	13W	19	SB	Hollywood (7½')	104			USGS P.P. 492	1965	23	112 C	[illegible]rd & Vermont Ave.
							104	1750±	CA. 1903	USGS WSP 338	1915	71	Los Angeles 11	Oil test well; later bathing resort
							104			USGS WRI 33-73	1974	10	75	

MARIPOSA SHEET

MAP LOC. NO.	NAME	T	R	SEC.	B&M	QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	PUBLICATION	YEAR	PAGE	LOC. NO.	NOTES
1	Paoha Island	2N	27E	31	MD	Mono Craters (15')	176			USGS P.P. 492	1965	23	120	
							176			USGS WSP 338	1915	144-145	Mono 7	
							176			USGS WRI 33-73	1974	6	8	
	Springs and steam vents						203			CDOG TR 13	1975	48	55	
2	Geothermal Resources International "State P.R.C. 4397.1" 1	1N	27E	17	MD	Mono Craters (15')	130	4110	1971	CDOG Sum. Op. v. 57, no. 2	1971	13		
	Geothermal Resources International "State P.R.C. 4397.1" 1						129	4110	1971	CDOG TR 13	1975	48	57	Also see p. 35
3	Springs	1N	28E	6	MD	Cowtrack Mtn. (15')	?				1950			Shown as hot spring on Mt. Morrison 30' quad.
4	Benton Hot Springs	2S	31E	2	MD	Glass Mtn. (15')	135			USGS P.P. 492	1965	23	127	
							135			USGS WSP 338	1915	136	Mono 12	
							136			USGS WRI 33-73	1974	6	10	
5	Bertrand Ranch	1S	32E	8	MD	Benton (15')	70			USGS P.P. 492	1965	23	127A	Location somewhat uncertain
										USGS WSP 338	1915	322	Mono 10	
6	Reds Meadows Hot Springs	37°37.1'N 119°04.7'W				Devils Postpile (15')	90-120			USGS P.P. 492	1965	23	128	
							120			USGS WSP 338	1915	55-56	Madera 6	
7	Two fumaroles	T4S	27E	6	MD	Devils Postpile (15')				USGS GQ 437	1965			
8	Fumarole	T4S	27E	7-8	MD	Devils Postpile (15')				USGS GQ 437				
9	Fish Creek Hot Springs	5S	27E	8	MD	Devils Postpile (15')	110			USGS P.P. 492	1965	23	129	
		37°32'N 119°01'W								USGS WSP 338	1915	56	Fresno 2	
										USGS GQ 437	1965			
10	Casa Diablo Geothermal Well	3S	28E	31	MD	Mt. Morrison (15')	128			CDWR Long Valley Invest.	1967	Pl. 2, 107		
	Geothermal well									CDWR Long Valley Invest.	1967	Pl. 2, 107		[illegible]
11	Ritchie wells 1 thru 3	3S	28E	32	MD	Mt. Morrison (15')				CDOG Map G 5-1	1973			
	Bathrick wells 1 & 2									CDOG Map G 5-1	1973	-	-	

* See Appendix D for location.

MARIPOSA SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
11	Magma Power Co. & Assoc. wells	3S	28E	32	MD	Mt. Morrison (15')	Max. 352	Max. 1000	1959-1962	CDOG TR 13	1975	48	60	Also see p. 35 (20 wells)
12	Casa Diablo Hot Springs	3S	28E	32	MD	Mt. Morrison (15')	115-194			USGS P.P. 492	1965	23	123	
							115-194			USGS WSP 338	1915	146-147	Mono 15	
		3S	28E	31	MD		128			USGS WRI 33-73	1974	6	1	
		3S	28E	31	MD		128			CDWR Long Valley Invest.	1967	107		
	Casa Diablo Hot Springs	3S	28E	32	MD		115-194			CDOG TR 13	1975	48	58	
13	Ritchie wells #4, 5, 6	3S	28E	32	MD	Mt. Morrison (15')				CDOG Map G 5-1	1973	-	-	
14	Mono County Sheriffs Substation well	3S	28E	33	MD	Mt. Morrison (15')	79	75	1962	CDWR Mam. Basin Rept.	1974	39		
							91			CDWR Long Valley Invest.	1967	107		
15	Magma Power Co. Chance #2	3S	28E	35	MD					CDOG Map G 5-1	1973	-	-	
	Casa Diablo Hot Pool well						275	805	1961	CDMG SR 75	1963	11	12	
16	Casa Diablo Hot Pool	3S	28E	35	MD	Mt. Morrison (15')	180			USGS P.P. 492	1965	23	124	
							120-180			USGS WSP 338	1915	147	Mono 16	
							165			USGS WRI 33-73	1974	6	4	
							165			CDWR Long Valley Invest.	1967	110		
							180			CDOG TR 13	1975	48	59	
17	Hot spring	3S	28E	13	MD	Mt. Morrison (15')	170			USGS P.P. 492	1965	23	122	
							-			USGS WSP 338	1915	147	Mono 14	
							180			USGS WRI 33-73	1974	6	2	
							174			CDOG TR 13	1975	48	61	
18	Hot springs	3S	28E	25	MD	Mt. Morrison (15')	120-203			USGS P.P. 385	1964	Pl. 1 80-81 fig. 39	5	
							200			CDWR Long Valley Invest.	1967	109		
							200			USGS WRI 33-73	1974	6	3	
	Hot Creek Geysers (Springs)						194-203			CDOG TR 13	1975	48	62	
19	Warm spring	3S	29E	7	MD	Mt. Morrison (15')	100?			USGS P.P. 385	1964	Pl. 1 80-81 fig. 39	10	
20	Whitmore Warm Springs	4S	29E	6	MD	Mt. Morrison (15')	90			USGS P.P. 492	1965	23	126	
							100			USGS WSP 338	1915	147-148	Mono 17	
	Whitmore Hot Springs						91			CDOG TR 13	1975	48	64	
21	Warm spring	3S	29E	31	MD	Mt. Morrison (15')	140			USGS P.P. 385	1964	80-81	8	
							-			USGS WRI 33-73	1974	6	7	
							142			CDWR Long Valley Invest.	1967	112		
	Hot springs						136			CDOG TR 13	1975	48	63	

* See Appendix D for location

MARIPOSA SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
22	Hot spring	3S	29E	29	MD	Mt. Morrison (15')	172			CDWR Mam. Basin Rept.	1973	40		
23	Hot spring	3S	29E	17	MD	Mt. Morrison (15')	131			CDWR Mam. Basin Rept.	1973	40		
24	"The Geysers"	3S	29E	30	MD					USGS P.P. 492	1965	23	125	
25	Dehy Hot Spring	3S	29E	21	MD	Mt. Morrison (15')	128, 134			USGS WRI 33-73	1974	6	5 & 6	
	Hot springs						12B, 132			CDWR Long Valley Invest.	1967	111		
26	OMITTED													
27	OMITTED													
28	Warm spring	37°24.75'N 119°08.35'N				Kaiser Peak (15')	95							Written comm. V.P. Lockwood
29	Mono Hot Springs	7S	27E	16	MD	Kaiser Peak (15')	112			USGS P.P. 492	1965	23	130	
							-			USGS WSP 338	1915	55	Fresno 4	
30	Keough Hot Springs	8S	33E	17	MD	Bishop (15')	130			USGS P.P. 492	1965	23	138	
							130			USGS WSP 338	1915	148	Inyo 1	
							138, 130			USGS WRI 33-73	1974	6	9 & 11	Loc. 9 in error; should be in Range 33
31	Blaney Meadows Hot Springs	BS	28E	23	MD	Blackcap Mtn (15')	110			USGS P.P. 492	1965	23	131	
							118			USGS WSP 338	1915	54-55	Fresno 5	
32	Grapevine Spring	11S	42E	3	MD	Ubehebe Crater (15')				USGS WRI 33-73	1974	10	93	

NEEDLES SHEET

1	Flamingo well	10N	20E	13	SB	Bannock (15')	104	-	-	USGS WRI 33-73	1973	8	30	
2	Ruzicka	1S	24E	9	SB	Parker (15')	90	-	-	USGS P.P. 486-G	1973	111		
3	Ruzicka, Deahring and Fortner	1S	24E	10	SB	Parker (15')	84	290	1959	USGS P.P. 486-G	1973	111		
4	Rio Mesa Ranch #2	1S	24E	10	SB	Parker (15')	86	332	-	USGS P.P. 486-G	1973	111		
	Rio Mesa Ranch #1						86	-	-	USGS P.P. 486-G	1973	111		
5	V. Ruzicka	1S	24E	16	SB	Parker (15')	10B	225	1959	USGS P.P. 486-G	1973	111		

REDDING SHEET

1	Tuscan (Lick) Springs	28N	2W	32	MD	Tuscan Springs (7½')	86			USGS P.P. 492	1965	21	45B	
										USGS WSP 338	1915	289-291	Tehama 5	Saline with H_2S
2	Stinking Springs	27N	8W	3	MD	Colyear Springs (15')	101			USGS Water Res. Div. Open File Rept. (No. Coast and Klamath Mtns.)	1968	33		

SACRAMENTO SHEET

1	Valley Springs	5N	10E	24	MD	Valley Springs (15')	75			USGS P.P. 492	1965	23	113A	
							75			USGS WSP 338	1915	300-301	Calaveras 1	Saline

* See Appendix D for location.

SALTON SEA SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
1	Kaiser North Well	3S	15E	4	SB	Coxcomb Mtn. (15')	85			Rex unpub.	1972	4	186	
2	Thurman Ragsdale well	4S	15E	17	SB	Coxcomb Mtn. (15')	104	600		Rex unpub.	1972	1	193	
3	Desert Center Airport well	5S	16E	8	SB	Coxcomb Mtn. (15')	86	225		Rex unpub.	1972	4	99	Possibly in 5S-16E-Sec. 8
4	Dos Palmas Spring	8S	11E	?	SB	Orocopia (7½')	80			USGS P.P. 492	1965	24	176	
							-			USGS WSP 338	1915	315	Riverside 18	
							84	-		CDWR Bull. 143-7	1970	Pl. 2		
5	Sunland Oil Well	5S	15E	29	SB	Chuckwalla Mtns. (15')	86	650		Rex unpub.	1972	4	177	
6	Div. of Highways, Desert Center Well	5S	15E	27	SB	Chuckwalla Mtns. (15')	89	585		Rex unpub.	1972	3	187	
7	Stanley Ragsdale well	5S	15E	27	SB	Chuckwalla Mtns. (15')	91	600		Rex unpub.	1972	3	176	
8	Trailer Park East and West Wells	5S	15E	23	SB	Chuckwalla Mtns. (15')	93, 94	500		Rex unpub.	1972	3	192, 194	
9	Lazy C Trailer Park well	5S	15E	13	SB	Chuckwalla Mtns. (15')	86			Rex unpub.	1972	4	198	
10	Howard Brown Well	5S	16E	7	SB	Chuckwalla Mtns. (15')	95	650		Rex unpub.	1972	2	185	
11	Wiley well Rest Area	6S	20E	33	SB	McCoy Spring (15')	118	1700		Rex unpub.	1972	1	197	
12	Mesa Verde well	6S	21E	36	SB	Ripley (7½')	88	360		Rex unpub.	1972	3	191	
13	Nicholls Warm Springs	6S	21E	36	SB	Ripley (7½')	91	638	1946	USGS P.P. 486-G	1973	111		
14	Riverside Co. Airport Well	6S	22E	32	SB	Ripley (7½')	88			Rex unpub.	1972	3	183	
15	Ballard's Truckhaven Well	10S	10E	18	SB	Truckhaven (7½')	104			CDWR Bull. 143-7	1970	36	5	
							104			USGS WRI 33-73	1974	8	29	
16	Truckhaven Well	10S	10E	16	SB	Truckhaven (7½')	104	1200		Rex unpub.	1972	2	74A	
17	Truckhaven Well	10S	10E	16	SB	Truckhaven (7½')	90	1200		Rex unpub.	1972	3	74	
18	"Hunter's Spring" New Well	8S	11E	12	SB	Durmid (7½')	90			CDWR Bull. 143-7	1970	36	24	
19	King, Spa well	8S	12E	36	SB	Frink NW (7½')	174	347		Rex unpub.	1972	1	127	
20	New Pilger Hot Mineral Well	8S	12E	36	SB	Frink NW (7½')	180			CDWR Bull. 143-7	1970	36	23	
	Pilger Estates well						180			USGS WRI 33-73	1974	8	25	
21	Hot mineral well	9S	12E	2	SB	Frink NW (7½')	186	300		USGS P.P. 492	1965	24	176A	
	Hot mineral Spa well						190			USGS Water Res. Div. Open File (Colo. Desert)	1969	9		
22	Brashfords well	9S	12E	2	SB	Frink NW (7½')	143	247		Rex unpub.	1972	1	128	
							170-174	325		USGS WRI 33-73	1974	8	27	
23	Youth Spa Well	9S	12E	2	SB	Frink NW (7½')	136	631		Rex unpub.	1972	1	12	
24	Unnamed well	9S	12E	2	SB	Frink NW (7½')	159-174	-		CDWR Bull. 143-7	1970	92		
25	Fountain Youth Hot Mineral well	9S	13E	[illegible]	SB	Frink NW (7½')	140			CDWR Bull. 143-7	1970	36	21	
26	Frink Springs	9S	13E	[illegible]	SB	Frink NW (7½')	75			CDWR Bull. 143-7	1970	36	20	

* See Appendix [illegible] for location.

SALTON SEA SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
27	Mudie, Gravel Co. Well	9S	13E	21	SB	Frink NW (7½')	88			Rex unpub.	1972	3	125	
28	Mud volcano(s)	9S	13E	35	SB	Wister (7½')				Min. survey				So. Pac. Min. Sur. unpub. maps 1961
29	Mud volcano(s)	9S	13E	36	SB	Wister (7½')				Min. survey				So. Pac. Min. Sur. unpub. maps 1961
30	Mud volcano(s)	10S	13E	2	SB	Wister (7½')				Min. survey				So. Pac. Min. Sur. unpub. maps 1961
31	Mud volcano(s)	10S	13E	1	SB	Wister (7½')				Min. survey				So. Pac. Min. Sur. unpub. maps 1961
32	Mud volcano(s)	10S	13E	10	SB	Wister (7½')				Min. survey				So. Pac. Min. Sur. unpub. maps 1961
33	Mud volcano(s)	10S	13E	11	SB	Wister (7½')				Min. survey				So. Pac. Min. Sur. unpub. maps 1961
34	Mud volcano(s)	10S	13E	23	SB	Wister (7½')				Min. survey				So. Pac. Min. Sur. unpub. maps 1961
35	Mud volcano(s)	10S	13E	24	SB	Wister (7½')				Min. survey				So. Pac. Min. Sur. unpub. maps 1961
36	Magma Energy Inc. Dearborn 1	12S	13E	30	SB	Calipatria (7½')		4135	1972			Map	16	S.L. Werner, written comm. 10/25/73.
37	OMITTED													
38	Western Geothermal Sinclair 4	12S	13E	4	SB	Niland (7½')	>212	5306	1964	CDWR Bull. 143-7	1970	45, 87		Also see Pl. 2
							328	4503		USGS Open File (Imperial Valley)	1976	20	70	
39	Western Geothermal Sinclair 3	12S	13E	10	SB	Niland (7½')	-	6922	1962	CDWR Bull. 143-7	1970	45		
							334	4720		USGS WRI 33-73	1974	8	50	
							228	5327		USGS Open File (Imperial Valley)	1976	20	72	
40	Earth Energy Inc., Elmore 1	11S	13E	27	SB	Niland (7½')	536	7117	-	USGS WRI 33-73	1974	8	55	
								7117	1964	CDWR Bull. 143-7	1970	45		
41	Imperial Thermal Prod. I.I.O. 1	11S	13E	23	SB	Niland (7½')	430	5232	1962	CDWR Bull. 143-7	1970	45, 87		
							450	4859		USGS WRI 33-73	1974	8	54	
							334	5232		USGS Open File (Imperial Valley)	1976	18	39	
42	Imperial Thermal Prod. I.I.O. 3	11S	13E	23	SB	Niland (7½')	221	1695	1965	CDWR Bull. 143-7	1970	45, 87		
43	Imperial Thermal Prod. I.I.O. 2	11S	13E	22	SB	Niland (7½')	626	5826	1963	CDWR Bull. 143-7	1970	45, 87		Temp. from Muffler and White (1969)
							660	5600		USGS Open File (Imperial Valley)	1976	18	37	
44	Mud Pots	11S	13E	14	SB	Niland (7½')	100 to boiling			USGS P.P. 492	1965	25	182A	
45	Mud Pot	11S	13E	14	SB	Niland (7½')	100 to boiling			USGS P.P. 492	1965	25	182A	
46	Maisson's Spa	11S	13E	13	SB	Niland (7½')	106			Rex unpub.	1972	1	96	
47	Maisson's Well	11S	13E	13	SB	Niland (7½')	104			CDWR Bull. 143-7	1970	36	19	
48	Earth Energy Inc. Hudson Ranch 1	11S	13E	13	SB	Niland (7½')		6141	1964	CDWR Bull. 143-7	1970	45		
							192	500		USGS WRI 33-73	1974	8	53	
49	Joseph O'Neill, Sportsman 1	11S	13E	23	SB	Niland (7½')	590	4729	1961	CDWR Bull. 143-7	1970	45		Temp. from Muffler and White (1969)
							392	4729	1961			Map	5	S.L. Werner written comm. 10/25/73
							495	3000		USGS Open File (Imperial Valley)	1976	18	40	

*See Appendix D for location.

SALTON SEA SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
50	Earth Energy Inc. River Ranch 1	11S	13E	23	SB	Niland (7½')	653	8100	1963	CDWR Bull. 143-7	1970	45		Temp. from Muffler and White (1969)
51	Mud Pot	11S	13E	24	SB	Niland (7½')	100 to boiling			USGS P.P. 492	1965	25	182A	
	(Mud volcanoes)						100			USGS Water Res. Div. Open File (Colo. Desert)	1969	10		
							100	-		CDWR Bull. 143-7	1970	94		
52	Well	13S	14E	15	SB	Westmorland (7½')	282	8350		USGS WRI 33-73	1974	8	52	
53	C. Bowles Well	11S	14E	14	SB	Iris (7½')	106	920		Rex unpub.	1972	1	101	
54	Camp Dunlop Well	11S	14E	1	SB	Iris (7½')	112	825		Rex unpub.	1972	1	3	
55	J. William Well	13S	15E	5	SB	Wiest (7½')	102	866		Rex unpub.	1972	2	59	
							98	864		CDOG TR 15	1974	Table 1a	7	
56	West Store Well	13S	15E	5	SB	Wiest (7½')	102	812		Rex unpub.	1972	2	60	
							100	797		CDOG TR 15	1974	Table 1a	8	
57	Butters-Rivers Well	13S	15E	3	SB	Wiest (7½')	104	880		Rex unpub.	1972	1	116	
58	Mulberry School Well	13S	15E	3	SB	Wiest (7½')	106	890		Rex unpub.	1972	1	50	
							105	890		CDOG TR 15	1974	Table 1a	6	
59	M. Lunceford Well	13S	15E	16	SB	Wiest (7½')	106	780		Rex unpub.	1972	1	49	
							104	764		CDOG TR 15	1974	Table 1a	9	
60	Theodore Shank Well	13S	15E	22	SB	Wiest (7½')	112	1000		Rex unpub.	1972	1	44	
61	J. Ratliff Well	13S	15E	23	SB	Wiest (7½')	133	1300		Rex unpub.	1972	1	6	
							130	1307		CDOG TR 15	1974	Table 1a	10	
62	Butters-Reese Well	13S	15E	24	SB	Wiest (7½')	112	700		Rex unpub.	1972	1	5	
							109	704		CDOG TR 15	1974	Table 1a	11	
63	Dickerman-Butters	13S	15E	13	SB	Amos (7½')	176			Rex unpub.	1972	1	19	
64	Meyer-Dickerman	13S	15E	12	SB	Amos (7½')	98			Rex unpub.	1972	2	114	
65	Schoeman-Koluyek Well	13S	16E	6	SB	Amos (7½')	92	616		Rex unpub.	1972	3	53	
	F. Schoneman Well						92	619		CDOG TR 15	1974	Table 1a	15	
66	Tom Olesh Well	13S	16E	6	SB	Amos (7½')	90	300		CDOG TR 15	1974	Table 1a	16	
							100	300		Rex unpub.	1972	2	52	
67	OMITTED													
68	Taylor Well	13S	15E	1	SB	Amos (7½')	136	1089		Rex unpub.	1972	1	54	
							132	1089		CDOG TR 15	1974	Table 1a	5	
69	P. Pebrik Well	12S	16E	31	SB	Amos (7½')	107	925		Rex unpub.	1972	1	55	
							102	931		CDOG TR 15	1974	Table 1a	4	

* See Appendix D for location.

SALTON SEA SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
70	Richard Cowell Well	12S	15E	35	SB	Amos (7½')	92	344		Rex unpub.	1972	3	56	
							91	346		CDOG TR 15	1974	Table 1a	3	
71	G. Brownell Well	12S	15E	27	SB	Wiest (7½')	94	430		Rex unpub.	1972	3	58	
							92	429		CDOG TR 15	1974	Table 1a	2	
72	D. Brownell Well	12S	15E	23	SB	Wiest (7½')	88	325		Rex unpub.	1972	3	57	
							90	330		CDOG TR 15	1974	Table 1a	1	
73	L.C. Winters	5S	22E	33	SB	McCoy Wash (7½')	88	380	1962	USGS P.P. 486-G	1973	111		
74	C. Cheely	5S	22E	35	SB	McCoy Wash (7½')	88	450	1965	USGS P.P. 486-G	1973	111		
75	E. Fortner	5S	22E	35	SB	McCoy Wash (7½')	88	405	1964	USGS P.P. 486-G	1973	111		
76	USGS well	6S	22E	9	SB	McCoy Wash (7½')	90	276	1967	USGS P.P. 486-G	1973	112		
77	E. Weeks	6S	22E	15	SB	McCoy Wash (7½')	91	585	1963	USGS P.P. 486-G	1973	112		
78	USGS well	6S	22E	20	SB	McCoy Wash (7½')	88	276	1967	USGS P.P. 486-G	1973	112		
79	Basha #1	6S	22E	28	SB	McCoy Wash (7½')	88	-	1965	USGS P.P. 486-G	1973	112		
80	Bill Passey	6S	22E	32	SB	Ripley (7½')	88	560	1947	USGS P.P. 486-G	1973	113		
81	Basha #3	7S	21E	14	SB	Ripley (7½')	113	1368	1966	USGS P.P. 486-G	1973	113		
82	Southern Pacific Co.	11S	21E	5	SB	Quartz Peak (15')	88	752	-	USGS P.P. 486-G	1973	114		
83	MPC Magmamax #3	11S	13E	33	SB	Niland (7½')	568	3083	1972	USGS Open File (Imperial Valley)	1976	18	46	
	MPC Magmamax #2	11S	13E	33	SB	Obsidian Butte (7½')	533	4360	1972	USGS Open File (Imperial Valley)	1976	18	48	
84	MPC Magmamax #1	11S	13E	33	SB	Niland (7½')	509	2263	1972	USGS Open File (Imperial Valley)	1976	18	49	
	MPC Woolsey #1						236	2340	1972	USGS Open File (Imperial Valley)	1976	18	50	

SAN BERNARDINO SHEET

1	Newberry Spring	9N	3E	32	SB	Newberry (15')	77			USGS P.P. 492	1965	24	157	
							77			USGS WSP 338	1915	317	San Bern. 20	
2	Spring in Deep Creek Canyon	3N	3W	15	SB	Lake Arrowhead (15')	80-100			USGS P.P. 492	1965	24	159	
3	Spring in Deep Creek Canyon	3N	3W	14	SB	Lake Arrowhead (15')	80-100			USGS P.P. 492	1965	24	160	
4	Tylers Bath Spring	2N	6W	26	SB	San Bernardino (15')	92			USGS P.P. 492	1965	24	158	
							90			USGS WSP 338	1915	35	San Bern. 34	
										USGS WSP 142	1905	Plate XII		Location of Hot Spring in Lytle Canyon
5	Waterman Hot Springs	1N	4W	11	SB	San Bernardino (15')	123			USGS P.P. 492	1965	24	162	
							-			USGS WSP 338	1915	33	San Bern. 35	
							210			USGS WRI 33-73	1974	10	66	

* See Appendix D for location.

SAN BERNARDINO SHEET

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
6	Arrowhead Hot Springs	1N	4W	11	SB	San Bernardino (15')	110-187			USGS P.P. 492	1965	24	162	
							202			USGS WSP 338	1915	32-33	San Bern. 36	
							154			USGS WRI 33-73	1974	10	65	
7	Urbita Hot Springs	1S	4W	16	SB	San Bernardino (15')	80-106			USGS P.P. 492	1965	24	162A	
							106			USGS WSP 338	1915	36-37	San Bern. 38	
8	Well	1S	4W	16	SB	San Bernardino (15')	106	175		USGS WRI 33-73	1974	10	70	
9	Well	1S	4W	16	SB	San Bernardino (15')	107	600		USGS WRI 33-73	1974	10	71	
10	Well	1S	4W	22	SB	San Bernardino (15')	112	642		USGS WRI 33-73	1974	10	72	
11	Well	1S	4W	22	SB	San Bernardino (15')	124	852		USGS WRI 33-73	1974	10	73	
12	Well	1S	4W	22	SB	San Bernardino (15')	110	975		USGS WRI 33-73	1974	10	74	
13	Harlem Hot Springs	1N	3W	31	SB	Redlands (7½')	120			USGS P.P. 492	1965	24	161	
							-			USGS WSP 338	1915	35	San Bern. 37	
14	Well	1S	3W	6	SB	Redlands (7½')	110	138		USGS WRI 33-73	1974	10	69	
15	Well	1N	3W	32	SB	Redlands (7½')	130	194		USGS WRI 33-73	1974	10	67	
16	Well	1N	3W	33	SB	Redlands (7½')	124	500		USGS WRI 33-73	1974	10	68	
17	Hot Springs in Santa Ana Canyon	1N	2W	34	SB	Yucaipa (7½')	90			USGS P.P. 492	1965	24	163	
17A	Warm spring at Baldwin Lake	2N	1E	12	SB	Lucerne Valley (15')	88			USGS P.P. 492	1965	24	164	
							88			USGS WSP 338	1915	35	San Bern. 33	
	Pan Hot Springs	2N	1E	12	SB					USGS Topo map	1949			
18	Well	1N	5E	12	SB	Joshua Tree (15')	108	477		USGS WRI 33-73	1974	10	95	
19	Well	1N	8E	2	SB	Twenty Nine Palms (15')	128	-		USGS WRI 33-73	1974	6	17	
20	Well	1N	9E	14	SB	Twenty Nine Palms (15')	146	-		USGS WRI 33-73	1974	6	18	
21	Well	1N	9E	29	SB	Twenty Nine Palms (15')	118	-		USGS WRI 33-73	1974	6	19	

SAN DIEGO SHEET

1	Well	16S	2W	16	SB	La Mesa (7½')	80			CDWR Bull. 106-2	1967	222		
2	Well	15S	1W	14	SB	El Cajon (7½')	87			CDWR Bull. 106-2	1967	208		
3	Aqua Caliente Springs	14S	7E	18-19	SB	Aqua Caliente Springs (7½')	90			USGS P.P. 492	1965	24	180	
							-			USGS WSP 338	1915	46	San Diego 9	
		14S	7E	18	SB		101			USGS WRI 33-73	1974	10	64	
		14S	7E	18	SB		99			Rex unpub.	1972	2	106	
		14S	7E	18	SB		99			USGS Water Res. Div. Open File Rept. (So. Coast, Transv. & Penin. Ranges)	1968	A-13		

* See Appendix D for location.

SAN DIEGO SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
4	Well	18S	2W	28	SB	Imperial Beach (7½')	80			CDWR Bull. 106-2	1967	228		
5	Well	18S	2W	28	SB	Imperial Beach (7½')	97			CDWR Bull. 106-2	1967	229		
6	Well	18S	2W	21	SB	Imperial Beach (7½')	82			CDWR Bull. 106-2	1967	227		
7	Well	18S	1W	31	SB	Imperial Beach (7½')	91			CDWR Bull. 106-2	1967	229		
8	Well	19S	1W	3	SB	Otay Mesa (7½')	83			CDWR Bull. 106-2	1967	231		
9	Well	18S	1W	34	SB	Otay Mesa (7½')	83			CDWR Bull. 106-2	1967	229		
10	Well	18S	2W	14	SB	Otay Mtn. (7½')	80			CDWR Bull. 106-2	1967	233		
11	Well	17S	5E	3	SB	Cameron Corners (7½')	86			CDWR Bull. 106-2	1967	234		
12	Henry Lazare Well	18S	7E	8	SB	Tierra Del Sol (7½')	101	200		Rex unpub.	1972	2	87	
13	Jacumba Springs	18S	8E	7 & 8	SB	Jacumba (15')	94, 96			USGS P.P. 492	1965	25	181	
							96			USGS WSP 338	1915	45	San Diego 19	
							101			USGS WRI 33-73	1973	8	32-3	
14	Raymond Rasco Well	18S	8E	9	SB	Jacumba (15')	87	160		Rex unpub.	1972	4	141	
15	Millers Service Station Well	16S	9E	35	SB	In-ko-pa Gorge (7½')	93	535		Rex unpub.	1972	3	76	
16	H.D. Currey Well	16S	9E	35	SB	In-ko-pa Gorge (7½')	85	350		Rex unpub.	1972	4	159	

SAN FRANCISCO SHEET

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
1	Rocky Point Spring	37°53.5'N 122°37.65W				Bolinas (7½')	100			USGS P.P. 492	1965	22	84	
							-			USGS WSP 338	1915	80-81	Marin 3	Located on the beach at low tide
							90			USGS Water Res. Div. Open File Rept. (No. Coast & Klamath Mtns.)	1968	23		
2	Sulfur Springs	37°55.4'N 122°02.8'W				Walnut Creek (7½')	75-81			USGS P.P. 492	1965	22	85	
										USGS WSP 338	1915	270	Contra Costa 3	

SAN JOSE SHEET

1	Byron Hot Springs	1S	3E	15	MD	Byron Hot Springs (7½')	72-120			USGS P.P. 492	1965	22	86	
							73-122			USGS WSP 338	1915	109-111	Contra Costa 7	
							83-96			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-4		
2	Warm Springs	5S	1E	18	MD	Livermore (15')	85-90			USGS P.P. 492	1965	22	87	
							86-90			USGS WSP 338	1915	80	Alameda 3	
	(Alameda Warm Springs, Mission San Jose Hot Springs.						80			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-7		
3	Alum Rock Park Springs	6S	2E	19	MD	Calaveras Res. (7½')	62-87			USGS P.P. 492	1965	22	88	
							69-87			USGS WSP 338	1915	108-111	Santa Clara 3	
	White Sulphur Spring						84			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-1[illegible]		

* See Appendix D for location.

SAN JOSE SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
4	Gilroy Hot Springs	9S	4E	36	MD	Gilroy Hot Springs (15')	110			USGS P.P. 492	1965	22	89	
							110			USGS WSP 338	1915	79-80	Santa Clara 9	
							106			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-18		

SAN LUIS OBISPO SHEET

1	Paso de Robles Mud Bath Springs	26S	12E	20-21	MD	Paso Robles (15')	55-118			USGS P.P. 492	1965	22	95	
							122			USGS WSP 338	1915	73-75	San Luis Obispo 1	
	(H.B. Jenne)	26S	12E	20	MD		108, 110	-	-	USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-14		Roman type pool in baths
2	Paso de Robles Hot Springs	26S	12E	33	MD		105		c. 1900	USGS P.P. 492	1965	22	96	Vague locations; wells & springs
							105	640		USGS WSP 338	1915	72-73	San Luis Obispo 2	
	(Paso Robles City Baths)						101	400		USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-14		
3	Santa Ysabel Springs	27S	12E	14	MD	Paso Robles (15')	94			USGS P.P. 492	1965	22	97	
							96			USGS WSP 338	1915	76-77	San Luis Obispo 3	
	(Sulphur springs)						92			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-15		
4	Warm Well	26S	12E	26	MD	Paso Robles (15')								Pers. comm. J.B. Koenig, 1972
5	Pecho Warm Springs	30S	10E	36	MD	Morro Bay South (7½')	72, 95			USGS P.P. 492	1965	22	99	
	Pecho Warm Springs	30S	10E	36	MD	Morro Bay South (7½')	95			USGS WSP 338	1915	69-70	San Luis Obispo 7	
6	Cameta Warm Spring	29S	17E	?	MD	La Panza (15')	74			USGS P.P. 492	1965	22	98	Very vague location
							74			USGS WSP 338	1915	77-78	San Luis Obispo 5	
7	San Luis (Sycamore) Hot Spring	31S	12E	32	MD	Arroyo Grande (15')	107			USGS P.P. 492	1965	22	98A	
							107	937	1886	USGS WSP 338	1915	70-71	San Luis Obispo 8	Well drilled for oil
	Sycamore Hot Springs						100			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-15		
8	Hidden Valley Hot Springs	31S	12E	32	MD	Arroyo Grande (15')	135	40-50	1908	USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-15		
9	Newsom's Springs	32S	13E	23	MD	Arroyo Grande (15')	98			USGS P.P. 492	1965	22	100	
	(Arroyo Grande)						100			USGS WSP 338	1915	68-69	San Luis Obispo 9	
							99			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-15		

SANTA ANA SHEET

1	Alvarado Hot Springs well	2S	10W	24	SB	La Habra (7½')	112	5000±	1910	USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-7		
2	La Vida Mineral Springs well	3S	9W	2	SB	Yorba Linda (7½')	110			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-9		Well at or near former springs
3	Well	3S	7W	11	SB	Corona North (7½')	119	917		USGS WRI 33-73	1974	10	89	Drilled in 1925 or earlier
4	Glen Ivy (Temescal) Hot Spring	5S	6W	10	SB	Lake Mathews (7½')	102			USGS P.P. 492	1965	24	167	

* See Appendix C for location.

SANTA ANA SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
4	Glen Ivy (Temescal) Hot Spring	5S	6W	10	SB	Lake Mathews (7½')	102			USGS WSP 338	1915	42	Riverside 3	
							102			USGS WRI 33-73	1974	10	77	
							131			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-11		
5	Pilares Hot Springs	4S	3W	12	SB	Perris (15')	100			USGS P.P. 492	1965	24	171	(Shown as "Bernascone" on Perris 15' quad and "Lakeview" on Perris 7½' quad.)
	(Bernasconi-Lakeview Springs)						-			USGS WSP 338	1915	40	Riverside 7	
6	No name	3S	2W	7	SB	Sunnymead (7½')	104			USGS WRI 33-73	1974	10	84	
7	Hot spring	3S	2W	33	SB	Lakeview (7½')				USGS Lakeview 7½' quad.				No other known reference
8	Eden Hot Springs	3S	2W	23	SB	El Cosco (7½')	90-110			USGS P.P. 492	1965	24	172	
							110			USGS WSP 338	1915	37	Riverside 8	
							109			USGS WRI 33-73	1974	8	35	
9	Highland Springs	2S	1W	25	SB	Banning (15')	112			USGS P.P. 492	1965	24	172A	
							112			CJMG v. 41 No. 3	1945	178		
10	Gilman (San Jacinto, Relief) Hot Springs	4S	1W	9	SB	Banning (15')	83-116			USGS P.P. 492	1965	24	173	
							-			USGS WSP 338	1915	38	Riverside 9	
							117			USGS WRI 33-73	1974	10	85	
11	Soboba (Ritchey) Hot Springs	4S	1E	30	SB	Banning (15')	70-111			USGS P.P. 492	1965	24	174	
	Soboba (Ritchey) Hot Springs	4S	1E	30	SB	Banning (15')	70-111			USGS WSP 338	1915	39	Riverside 10	
							111, 102			USGS WRI 33-73	1974	10	80, 83	2 sites
11A	Well	3S	4E	2	SB	Palm Springs (15')	84			CDMG SR 94	1968	Pl. 1		
11B	Well	3S	4E	2	SB	Palm Springs (15')	84			CDMG SR 94	1968	Pl. 1		
12	Well	2S	5E	29	SB	Thousand Palms (15')	168			CDMG SR 94	1968	Pl. 1		
13	Discovery Well	2S	5E	30	SB	Thousand Palms (15')	146	154	1934	CDMG SR 94	1968	42, Pl. 1		
14	Original Bath House Well	2S	5E	30	SB	Thousand Palms (15')	118	170	pre 1940	CDMG SR 94	1968	42, Pl. 1		
15	Coffee Bath House (4 Wells)	2S	5E	30	SB	Palm Springs (15')	108-116	157	1940-1954	CDMG SR 94	1968	42, Pl. 1		
16	Chandler Well	2S	5E	30	SB	Palm Springs (15')	125	160	pre 1950	CDMG SR 94	1968	42, Pl. 1		
17	Blue Haven Well	2S	5E	30	SB	Thousand Palms (15')	130	140	pre 1950	CDMG SR 94	1968	42, Pl. 1		
18	Realty Co. of Am. Demo. Well	2S	5E	30	SB	Thousand Palms (15')	120	212	1952	CDMG SR 94	1968	42, Pl. 1		
19	Dorsk Well	2S	5E	30	SB	Thousand Palms (15')	120	149	1957	CDMG SR 94	1968	42, Pl. 1		
20	Neone Well	2S	5E	30	SB	Thousand Palms (15')	104	127	1946	CDMG SR 94	1968	42, Pl. 1		
21	Desert Hot Springs Co. Water Dist. #1	2S	5E	30	SB	Thousand Palms (15')	88	92	1941	CDMG SR 94	1968	42, Pl. 1		
22	Desert Hot Springs Co. Water Dist. #6	2S	5E	30	SB	Thousand Palms (15')	88	90	1955	CDMG SR 94	1968	42, Pl. 1		
23	Well	2S	5E	30	SB	Thousand Palms (15')	112-116	300±		USGS P.P. 492	1965	24	174A	8 wells

* See Appendix D for location.

SANTA ANA SHEET

APPENDIX B – TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP LOC. NO.*	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
24	Well	2S	5E	30	SB	Thousand Palms (15')	116			USGS WRI 33-73	1974	8	48	
25	McCullough well	2S	5E	31	SB	Palm Springs (15')	88	220	1940 1954	CDMG SR 94	1968	42, Pl. 1		
26	Desert Hot Springs Co. Water Dist. #3	2S	5E	31	SB	Palm Springs (15')	95	48	1940	CDMG SR 94	1968	42, Pl. 1		
27	Desert Hot Springs Co. Water Dist. #5	2S	5E	31	SB	Palm Springs (15')	95	807	1948	CDMG SR 94	1968	42, Pl. 1		
28	Miracle #2	2S	5E	32	SB	Palm Springs (15')	145	143	1948	CDMG SR 94	1968	42, Pl. 1		
29	Well #8	2S	5E	32	SB	Palm Springs (15')	142	76	1952?	CDMG SR 94	1968	42, Pl. 1		
30	Well #11	2S	5E	32	SB	Palm Springs (15')	146	40	1956	CDMG SR 94	1968	42, Pl. 1		
31	Well #12	2S	5E	32	SB	Palm Springs (15')	134	150	1952?	CDMG SR 94	1968	42, Pl. 1		
32	Well #13	2S	5E	32	SB	Palm Springs (15')	153	165	1952?	CDMG SR 94	1968	42, Pl. 1		
33	Well #15 (Yerxa #1)	2S	5E	32	SB	Palm Springs (15')	122	90	1940	CDMG SR 94	1968	42, Pl. 1		
34	Davis well	2S	5E	32	SB	Palm Springs (15')	102	128	1949	CDMG SR 94	1968	42, Pl. 1		
35	Templeman #17	2S	5E	32	SB	Palm Springs (15')	156	95	1955	CDMG SR 94	1968	42, Pl. 1		
36	Angel View Crippled Childrens Foundation, Inc. #18	2S	5E	32	SB	Palm Springs (15')	136	138	1955	CDMG SR 94	1968	42, Pl. 1		
37	Schwartz #19	2S	5E	32	SB	Thousand Palms (15')	150	54	1955	CDMG SR 94	1968	42, Pl. 1		
38	Well #21 (Yerxa #3)	[illegible]	[illegible]	32	[illegible]	Thousand Palms (15')	[illegible]		1940	CDMG SR 94	1968	42, Pl. 1		
39	Sullivan #22	2S	5E	32	SB	Thousand Palms (15')	166	161	1956	CDMG SR 94	1968	42, Pl. 1		
40	Spring			32		Thousand Palms (15')				CDMG SR 94	1968	42, footnote 3		"only surface water in area"
41	Highlands Desert Hot Springs #9	2S	5E	32	SB	Thousand Palms (15')	120	165	1955	CDMG SR 94	1968	42, Pl. 1		
42	Simone and Babin #10	[illegible]		32	[illegible]	Thousand Palms (15')	112	136	1954	CDMG SR 94	1968	42, Pl. 1		
43	Hubbard #1	3S	5E	5	SB	Thousand Palms (15')	108	16	1946	CDMG SR 94	1968	42, Pl. 1		
44	Hubbard #2 (Bubbling wells)	[illegible]		5	[illegible]	Thousand Palms (15')	108	23	1947	CDMG SR 94	1968	42, Pl. 1		
45	Reeves well	3S	5E	4	SB	Thousand Palms (15')	95	76	1949	CDMG SR 94	1968	42, Pl. 1		
46	Bannon et al well			4		Thousand Palms (15')	90	182	1957	CDMG SR 94	1968	42, Pl. 1		
47	Erwin and Assoc. well	3S	5E	4	SB	Thousand Palms (15')	98	225	1954	CDMG SR 94	1968	42, Pl. 1		
48	Terra Vista Corp. well			[illegible]		Thousand Palms (15')	94	164	1954	CDMG SR 94	1968	42, Pl. 1		
49	Johnson #[illegible]			[illegible]		Thousand Palms (15')	106	147	1955	CDMG SR 94	1968	42, Pl. 1		
50	Holmes well	[illegible]	5E	[illegible]	SB	Thousand Palms (15')	165	80	1951	CDMG SR 94	1968	42, Pl. 1		
51	[illegible] well					Thousand Palms (15')	184	84	1950	CDMG SR 94	1968	42, Pl. 1		See footnote 5, p. 42
							188	157-167	1950	CDMG SR 94	1968	42, Pl. 1		
							200	188-218	1950	CDMG SR 94	1968	42, Pl. 1		
							200	-		USGS P.P. 492	1965	24	174B	

* [illegible]

SANTA ANA SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
52	Young Well	3S	5E	10	SB	Thousand Palms (15')	118	75	1951	CDMG SR 94	1968	42, Pl. 1		
53	Guptill Well	3S	5E	10	SB	Thousand Palms (15')	106	117	1956	CDMG SR 94	1968	42, Pl. 1		
54	Well	3S	5E	10	SB	Thousand Palms (15')	176-208	500±		USGS WRI 33-73	1974	8	39-42	4 wells
55	Well	3S	5E	11	SB	Thousand Palms (15')	190			USGS WRI 33-73	1974	8	43	
56	Well	3S	5E	11	SB	Thousand Palms (15')	178			USGS WRI 33-73	1974	8	44	
57	Langois Well	3S	5E	11	SB	Thousand Palms (15')	175	110	1953	CDMG SR 94	1968	42, Pl. 1		
58	Johnson #1 Well	3S	5E	11	SB	Thousand Palms (15')	175	105	1951	CDMG SR 94	1968	42, Pl. 1		
59	Moody Well	3S	5E	11	SB	Thousand Palms (15')	150	170	1956	CDMG SR 94	1968	42, Pl. 1		
60	Tarbutton Well	3S	5E	11	SB	Thousand Palms (15')	125	210	1955	CDMG SR 94	1968	42, Pl. 1		See footnote 6, p. 42
61	Kiel Well	3S	5E	14	SB	Thousand Palms (15')	103	265	1951	CDMG SR 94	1968	42, Pl. 1		
62	Simone and Babin Well	3S	5E	14	SB	Thousand Palms (15')	130	148	1953	CDMG SR 94	1968	42, Pl. 1		
63	Paddock Well	3S	5E	14	SB	Thousand Palms (15')	134	220	1956	CDMG SR 94	1968	42, Pl. 1		
64	Well	3S	5E	8	SB	Thousand Palms (15')	85	-	-	CDMG SR 94	1968	Pl. 1		
65	Well	3S	5E	17	SB	Thousand Palms (15')	84			CDMG SR 94	1968	Pl. 1		
65A	Well	3S	5E	22	SB	Thousand Palms (15')	89			CDMG SR 94	1968	Pl. 1		
66	Well	3S	6E	17	SB	Thousand Palms (15')	120	-	-	USGS WRI 33-73	1974	8	45	
67	Well	3S	6E	21	SB	Thousand Palms (15')	112			USGS WRI 33-73	1973	8	47	
67A	Palm Springs	4S	4E	14	SB	Palm Springs (15')	100			USGS P.P. 492	1965	24	175	
	(Aguas Calientes)						100			USGS WSP 338	1915	40	Riverside 11	
	Agua Caliente Spring						100			USGS WRI 33-73	1974	10	60	
							104			USGS Water Res. Div. Open File Report (Colo. Desert)	1968	11		
68	Obrien "Porter" 2	6S	11W	2	SB	Newport Beach (7½')	"hot salt water"			CDOG written comm.	1974			CDOG Map 134 Huntington Beach
69	Beloil "Davenport" Well	6S	11W	2	SB	Newport Beach (7½')	"hot water"			CDOG written comm.	1974			
70	Fairview Hot Spring	6S	10W	10	SB	Newport Beach (7½')	96			USGS P.P. 492	1965	24	165	
70A	Well	7S	8W	16	SB	San Juan Cap. (7½')	82			CDWR Bull. 106-2	1967	159		
71	Well	7S	7W	34	SB	Canada Gobernadora (7½')	95			CDWR Bull. 106-2	1967	160		
72	San Juan (Capistrano Hot) Springs	7S	6W	4	SB	Canada Gobernadora (7½')	121-124			USGS P.P. 492	1965	24	166	
	San Juan Hot Springs	7S	6W	3	SB		123			USGS WRI 33-73	1974	8	37	(Loc. corrected)
	San Juan Hot Springs	7S	6W	4	SB		120			USGS Water Res. Div. Open File (So. Coast Transv. & Penin. Ranges)	1968	A-10		
73	Wrenden (Bundys Elsinore) Hot Springs	6S	4W	5	SB	Elsinore (7½')	118			USGS P.P. 492	1965	24	168	Well on site of spring
							112			USGS WSP 338	1915	43	Riverside 4	
74	Elsinore Hot Springs	6S	4W	5	SB	Elsinore (7½')	125			USGS P.P. 492	1965	24	169	Wells on site of spring

* See Appendix D for location.

SANTA ANA SHEET

APPENDIX B – TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
74	Elsinore Hot Springs	6S	4W	5	SB	Elsinore (7½')	125			USGS WRI 33-73	1974	10	76	
							-			USGS WSP 338	1915	42	Riverside 5	
75	Temecula Hot Springs	7S	3W	23	SB	Murrieta (7½')	116			USGS WRI 33-73	1974	8	36	
76	Murrieta Hot Springs	7S	3W	14	SB	Murrieta (7½')	134-136			USGS P.P. 492	1965	24	170	
							136			USGS WSP 338	1915	44	Riverside 6	
							132			USGS WRI 33-73	1974	8	34	
	Murrieta (Ramona) and Bethesda Hot Spring						96-117			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-11		2 springs
77	Well	5S	1W	16	SB	Hemet (7½')	102			USGS WRI 33-73	1974	10	82	
78	Well	6S	1W	4	SB	Hemet (7½')	80			CDWR Bull. 106-2	1967	167		
79	Hot Spring	7S	2E	23 or 26	SB	Idyllwild (15')				Pers. comm. Bob Sharp, USGS	1972			Near border of section 23 & 26
80	Well	5S	6E	24	SB	Palm Desert (15')	182	356		USGS WRI 33-73	1974	6	22	
80A	Well	7S	9E	18	SB	Mecca (7½')	90			CDWR Bull 143-7	1970	88		
81	De Luz Warm Springs	8S	4W	32	SB	Fallbrook (7½')	84-88			USGS P.P. 492	1965	24	177	
							84-88			USGS WSP 338	1915	47-48	San Diego 1	
							85			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-12		
81A	Well	8S	3E	7	SB	Temecula (7½')	85			CDWR Bull. 106-2	1967	165		
82	Agua Tibia Spring	9S	1W	29	SB	Pala (7½')	92			USGS P.P. 492	1965	24	178	
							92			USGS WSP 338	1915	47	San Diego 2	
83	Well	10S	1W	22	SB	Boucher Hill (7½')	80			CDWR Bull. 106-2	1967	188		
83A	Warner (Las Aguas Calientes) Hot Springs	10S	3E	24	SB	Warner Springs (7½')	131-139			USGS P.P. 492	1965	24	179	
							139			USGS WSP 338	1915	45-46	San Diego 4	
84	Well	8S	8E	13	SB	Oasis (7½')	90			CDWR Bull. 143-7	1970	Pl. 2, 90		
85	Well	8S	9E	19	SB	Oasis (7½')	109	387		USGS WRI 33-73	1974	6	23	
86	Well	8S	9E	29	SB	Oasis (7½')	109			CDWR Bull. 143-7	1970	90		
							102			USGS WRI 33-73	1974	6	24	
87	Well	9S	9E	4	SB	Oasis (7½')	115			CDWR Bull. 143-7	1970	91		
							115			USGS WRI 33-73	1974	8	26	
88	Fish Springs	9S	9E	9	SB	Oasis (7½')	90			USGS P.P. 492	1965	25	182	
							-			USGS WSP 338	1915	315	Imperial 1	
89	Holly Hot Wells	10S	9E	35	SB	Seventeen Palms (7½')	138, 142	1980		Rex unpub.	1972	1	73, 73A	2 wells
90	Well	11S	9E	[illegible]	SB	Shell Reef (7½')	136			CDWR Bull. 143-7	1970	Pl. 2, 92		
							136			USGS WRI 33-73	1974	8	31	

* See Appendix D for location.

SANTA ANA SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION T	R	SEC.	B&M	QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations) PUBLICATION	YEAR	PAGE	LOC. NO.	NOTES
91	Well	12S	2W	17	SB	Valley Center (7½')	81			CDWR Bull. 106-2	1967	193		
92	J. Balch, Ironwood Motel Well	12S	8E	6	SB	Borrego Mtn. (7½')	99	335		Rex unpub.	1972	2	124	
93	Theweate, Circle T. Trailer Park, Well	12S	8E	6	SB	Borrego Mtn. (7½')	98	312		Rex unpub.	1972	2	123	
94	M.A. Smith Well	12S	8E	6	SB	Borrego Mtn. (7½')	88	300		Rex unpub.	1972	3	152	
95	C. Peterson Well	12S	8E	8	SB	Borrego Mtn. (7½')	89	285		Rex unpub.	1972	3	120	
96	E. Robinson Wells	12S	8E	9	SB	Borrego Mtn. (7½')	98	209		Rex unpub.	1972	2	85/85A	2 wells
97	A. Williams Well	12S	8E	15	SB	Borrego Mtn. (7½')	96	148		Rex unpub.	1972	2	119	
98	De Anza Trail Inn Well	12S	8E	15	SB	Harper Canyon (7½')	100	215		Rex unpub.	1972	2	89	
99	Cornish Well	12S	8E	22	SB	Harper Canyon (7½')	89	229		Rex unpub.	1972	3	118	
100	A. Toner Well	12S	8E	10	SB	Shell Reef (7½')	89	200		Rex unpub.	1972	3	153	
101	T.M. Jacobs #3 Well	12S	9E	22	SB	Borrego Mtn. SE (7½')	102	1200		Rex unpub.	1972	2	90	
102	T.M. Jacobs #2 Well	12S	9E	23	SB	Borrego Mtn. SE (7½')	86	670		Rex unpub.	1972	4	91	
103	Landmark Co.	13S	9E	2	SB	Borrego Mtn. SE (7½')	95	1185		Rex unpub.	1972	2	151	

SANTA CRUZ SHEET

1	Sargent Estate warm spring	11S	4E	31	MD	Chittenden (7½')	77			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-18		
2	San Benito Mineral Well	13S	6E	7	MD	Tres Pinos (7½')	75			USGS P.P. 492	1965	22	89A	
								286	early 1890's	USGS WSP 338	1915	306-307	San Benito 1	Saline
3	Warm spring	13S	10E	29	MD	Ortigalita (15')	81			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-8		
4	Sulfur hot spring	36°37.1'N 121°50.65'W				Seaside (7½')	100±			USGS Map MF-577	1974	Sheet 2 of 2		Described under Seaside fault
5	Mercey Hot Springs	14S	10E	15	MD	Panoche Valley (15')	79-109			USGS P.P. 492	1965	23	132	water brackish
										USGS WSP 338	1915	78-79	Fresno 8	
							119			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-4		
6	Warm spring	15S	12E	8	MD	Chounet Ranch (7½')	75			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-5		
7	Hot spring	18S	1E	26-27	MD	Big Sur (7½')	114			USGS P.P. 492	1965	22	90	
							114			USGS WSP 338	1915	57	Monterey 1	
8	Paraiso Hot Springs	18S	5E	25	MD	Paraiso Springs (7½')	65-111			USGS P.P. 492	1965	22	92	
							118			USGS WSP 338	1915	60	Monterey 2	
							98			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-8		
8A	Sulphur spring	18S	6E	30	MD	Paraiso Springs (7½')	87			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-8		
9	Slates Hot Springs	21S	3E	9	MD	Lopez Point (7½')	100-121			USGS P.P. 492	1965	22	93	
							110-121			USGS WSP 338	1915	56-57	Monterey 4	

* See Appendix D for location.

SANTA CRUZ SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
9	(Big Sur Hot Springs)	21S	3E	9	MD	Lopez Point (7½')	116-122			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-9		
10	Dolans Hot Springs	21S	3E	24	MD	Lopez Point (7½')	100			USGS P.P. 492	1965	22	94	
										USGS WSP 338	1915	57	Monterey 5	
							98			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-9		
11	Tassajara Hot Springs	19S	4E	32	MD	Tassajara Hot Springs (7½')	100-140			USGS P.P. 492	1965	22	91	
							100-140			USGS WSP 338	1915	57-60	Monterey 3	
							119, 134, 144			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-8		3 springs
12	Fresno Hot Springs	20S	13E	34	MD	Priest Valley (15')	88-97			USGS P.P. 492	1965	23	133	
							-			USGS WSP 338	1915	78	Fresno 9	
	(Coalinga Mineral Springs)						112			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-5		

SANTA MARIA SHEET

MAP* LOC. NO.	NAME	T	R	SEC.	B&M	QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	PUBLICATION	YEAR	PAGE	LOC. NO.	NOTES
1	Las Cruces Hot Springs	5N	32W	22	SB	Solvang (7½')	67-97			USGS P.P. 492	1965	22	101	
							-			USGS WSP 338	1915	68	Sta. Barb. 1	
	Gaviota or Sulphur Hot Springs						99			USGS Water Res. Div. Open File (So. Coast, Transv. & Penin. Ranges)	1968	A-16		
	San Marcos Hot Spring						108			USGS WRI 33-73	1974	10	88	

SANTA ROSA SHEET

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
1	Point Arena Hot Springs	12N	15W	27	MD	Point Arena (15')	110-112			USGS P.P. 492	1965	21	47	
							110-112			USGS WSP 338	1915	82-83	Mendocino 33	
							-			CDMG MIS v. 21, no. 4	Apr. 1968	61	-	
							112			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	24		
2	Old Ornbaun Hot Springs	38°53'N 123°10.4'W 12N	13W	4	MD	Ornbaun (15')				Corps of Engineers Ornbaun 15' quad. 1:62,500 scale	1944			Only ref. to "Hot Spring"
3	Hoods (Fairmont) Hot Springs	11N	12W	14	MD	Hopland (15')	100			USGS P.P. 492	1965	21	70	Location from R.G. Strand, pers. comm. 1968
							-			USGS WSP 338	1915	82	Sonoma 1	
4	Highland Springs	13N	9W	31	MD	Highland Springs (7½')	52-82			USGS P.P. 492	1965	21	52	
							max. 84			USGS WSP 338	1915	183-185	Lake 39	
5	England (Elliott) Springs	12N	9W	8	MD	Highland Springs (7½')	76			USGS P.P. 492	1965	21	53	
							76			USGS WSP 338	1915	186	Lake 40	
										Official Map of Lake County	1909			CDMG SF Map Rm. Map file M-8
6	Kelseyville wells	13N	9W	14	MD	Kelseyville (7½')	78			USGS P.P. 492	1965	21	54A	
							76		before 1915	USGS WSP 338	1915	181	Lake 35	Carbonated
6A	Unnamed Spring	[illegible]	[illegible]		MD	Lower Lake (15')	100			USGS WSP 338	1915	193	Lake 37	

SANTA ROSA SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
6A	Bear Spring	13N	8W	10	MD	Lower Lake (15')				Lake Co. Map	1909			CDMG SF Map Rm. Map file H-8
7	Carlsbad Spring	12N	9W	1	MD	Kelseyville (7½')	66-76			USGS P.P. 492	1965	21	54	
							85			USGS WSP 338	1915	187	Lake 41	
8	Sullivan #1 Well E.B. Towne, Operator	12N	8W	18	MD	Kelseyville (7½')	180	6140	1972	CDMG Geotherm. Hotline	Dec. 1972			
9	Kettenhofen #1 Well	13N	8W	28	MD	Kelseyville (7½')		7822	1972	CDMG Geotherm. Hotline	Nov. 1972			
10	The Geysers Geothermal Field	11N	9W	1, 11, 12, 13, 14	MD	The Geysers (7½') and	-	-	-	CDMG Map G 6-1	Aug. 1974	-	-	
		11N	8W	6, 7, 17-20, 26-30, [illegible]	MD	Whispering Pines (7½')								
11	Rorabaugh A-2 Pacific Energy Corp.	11N	9W	14	MD	The Geysers (7½')	steam	715	1971	CDMG Map G 6-1	Aug. 1974	-	-	One of several Rorabaugh wells
12	Happy Jack	11N	9W	17	MD	The Geysers (7½')	steam	6091	1968	Koenig, J.B., No. Cal. Geol. Soc. Geysers Field Trip	1968	6-7		
13	The Geysers	11N	9W	13	MD	The Geysers (7½')	141 to boiling			USGS P.P. 492	1965	22	72	
										USGS WSP 338	1915	83-88	Sonoma 4	
							112-212			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	32		4 springs listed
14	Signal Oil Co. Cobb Mtn. #1 Well	11N	8W	18	MD	The Geysers (7½')	steam	750	1967	No. Cal. Geol. Soc. Fieldtrip to The Geysers-J.B. Koenig	1968	6-7		
15	**Sulphur Creek**	11N	8W	29	MD	The Geysers (7½')	120			USGS P.P. 492	1965	22	73	Vague location
16	Little Geysers	11N	8W	[illegible] or 28	MD	The Geysers (7½')	110-160			USGS P.P. 492	1965	22	74	Vague location
							160			USGS WSP 338	1915	88-89	Sonoma 5	
17	Gordon Hot Springs	11N	8W	2, 1 or 11	MD	Whispering Pines (7½')	92			USGS P.P. 492	1965	21	60	Vague location
							92, 100			USGS WSP 338	1915	93	Lake 46	
18	**Castle (Mills) Hot** Springs					Whispering Pines (7½')	164			USGS P.P. 492	1965	21	62	
							164			USGS WSP 338	1915	91-8	Lake 54	
	Castle Rock Springs	11N	8W	35	MD		163			CDOG TR 13	1975	49	73	
19	Anderson Springs	11N	9W	25	MD	Whispering Pines (7½')	145			USGS P.P. 492	1965	21	63	
							146			USGS WSP 338	1915	89-91	Lake 55	
		11N	8W	26	MD		128			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	19		
		11N	8W	25	MD		126			CDOG TR 13	1975	49	72	
20	Seigler Springs	11N	8W	24	MD	Clearlake Highlands (7½')	126			USGS P.P. 492	1965	21	59	
							126			USGS WSP 338	1915	96-97	Lake 49	
							126 1[illegible]8			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	2[illegible]		2 springs listed
							1[illegible]4-126			CDOG TR 13	1975	49	69	
20A	Baker Soda Spring	12N	8W	16		Lower Lake (7½')	76			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	[illegible]		
21	Howard Springs	12N	7W		MD	Whispering Pines (7½')	48-[illegible]			USGS P.P. 492	1965	21	5[illegible]	
							117			USGS WSP 338	1915	95-96	Lake 51	

* See Appendix D for location.

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APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION T	R	SEC.	B&M	QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations) PUBLICATION	YEAR	PAGE	LOC. NO.	NOTES
21	Howard Springs	12N	7W	31	MD	Whispering Pines (7½')	95-113			CDOG TR 13	1975	49	70	
	Spiers (Carsey) Springs	11N	7W		MD	Whispering Pines (7½')	78, 84			USGS P.P. 492	1965	21	61	
							74, 78			USGS WSP 338	1915	190-191	Lake 52	
23	Harbin Springs	11N	7W	2[illegible]	MD	Whispering Pines (7½')	90-120			USGS P.P. 492	1965	21	64	
							122			USGS WSP 338	1915	93-95	Lake 56	
							119			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	19		2 springs listed
							120			CDOG TR 13	1975	49	71	
24	Skaggs Springs	10N	11W	24	MD	Skaggs Springs (7½')	12[illegible]-135			USGS P.P. 492	1965	21	71	
							135			USGS WSP 338	1915	81-82	Sonoma 8	
		10N	11W	25	MD		132			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	32		
[illegible]	Mark West Warm Springs	8N	8W	11	MD	Mark West Springs (7½')	60-82			USGS P.P. 492	1965	22	75	
							65-85			USGS WSP 338	1915	115	Sonoma 1	
							87			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	31		
26	Calistoga Power Co. Wells	9N	7W	26	MD	Calistoga (7½')	89	305		USGS WRI 13-73	1973	Table 4 Fig. 3		
27	Well	9N	7W	26	MD	Calistoga (7½')	279	max. 2000	1960-1961	CDMG SR 75	1963	11	8	3 wells
[illegible]	Well	[illegible]N	7W	2	MD	Calistoga (7½')	88			USGS WRI 13-73	1973	Fig. 3		
29	Well	9N	7W	26	MD	Calistoga (7½')	110	207		USGS WRI 13-73	1973	Table 4 Fig. 3		
	Well(s)						333	2000±		CDOG TR 13	1975	48	66	3 wells
	Well	9N	7W	25	MD	Calistoga (7½')	85	149		USGS WRI 13-73	1973	Table 4 Fig. 3		
1	Well	[illegible]N	6W	[illegible]1	MD	Calistoga (7½')	68			USGS WRI 13-73	1973	Fig. 3		
[illegible]	Well	9N	6W	31	MD	Calistoga (7½')	210			USGS WRI 13-73	1973	Table 4 Fig. 3		
	Facheteau's Calistoga Hot Springs (well)						21[illegible]	152		USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	26		
[illegible]	Calistoga Hot Springs	[illegible]N	6W	[illegible]1	MD	Calistoga (7½')	[illegible]6-1[illegible]			USGS P.P. 492	1965	22	91	
							126-173			USGS WSP 338	1915	108-109	Napa 4	
							126-172			CDOG TR 13	1975	48	65	
4	Well	[illegible]N	6W	7	MD	Calistoga (7½')	[illegible]	4[illegible]		USGS WRI 13-73	1973	Table 4 Fig. 3	8	
[illegible]	Well	[illegible]N	[illegible]W	4	MD	Calistoga (7½')	1[illegible]	2[illegible]7		USGS WRI 13-73	1973	Table 4 Fig. 3	3	
[illegible]	Aetna Springs	9N	[illegible]W		MD	Aetna Springs (7½')	[illegible]			USGS P.P. 492	1965	22	80	6 springs
							[illegible]			USGS WSP 338	1915	156-157	Napa [illegible]	2 springs
	[illegible] House						[illegible]			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	26		From old mine shaft
[illegible]	Well	[illegible]	[illegible]	[illegible]	MD	[illegible]	[illegible]			USGS WRI 13-73	1973	Fig. 3		
[illegible]	[illegible]	[illegible]	[illegible]		MD	[illegible]	[illegible]			USGS P.P. 492	1965	[illegible]	83A	

* See Appendix for location.

SANTA ROSA SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
38	Philips Soda Springs	8N	4W	25	MD	Chiles Valley (7½')	-			USGS WSP 338	1915	161-162	Napa 8	
39	Napa Rock (Priests) Soda Springs	8N	4W	25	MD	Chiles Valley (7½')	79			USGS P.P. 492	1965	22	83	
							79			USGS WSP 338	1915	161	Napa 9	
							79			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	26		
40	McEwan Ranch Warm Springs	6N	6W	6	MD	Kenwood (7½')	80			USGS P.P. 492	1965	22	77	
							-			USGS WSP 338	1915	114-115	Sonoma 14	McEwan Ranch on 1908 Sonoma Co. map, CDMG SF map file
							73			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	31		
41	Los Guilicos Warm Springs	6N	6W	5	MD	Kenwood (7½')	78, 82			USGS P.P. 492	1965	22	76	
							78, 82			USGS WSP 338	1915	114	Sonoma 15	
	Los Guilicos (Morton's) Warm Springs						84, 87			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	31		3 springs listed
42	"Eldridge State Home" Warm Springs	6N	6W	22	MD	Glen Ellen (7½')	72			USGS P.P. 492	1965	22	78	
							72			USGS WSP 338	1915	114	Sonoma 16	
	Sonoma State Home Warm Spring						70			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	31		
43	St. Helena White Sulphur Spring	7N	6W	2	MD	Rutherford (7½')	69-90			USGS P.P. 492	1965	22	82	
							max. 90			USGS WSP 338	1915	254-255	Napa 10	
	Spring						90			USGS WRI 13-73	1973	51		
	White Sulphur Springs	7N	6W	2	MD	Rutherford (7½')	96			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	25		
44	Agua Caliente Springs	6N	6W	35	MD	Sonoma (7½')	97-115			USGS P.P. 492	1965	22	79	
							max. 114	300±		USGS WSP 338	1915	113-114	Sonoma 18	Several wells
45	Fetters Hot Springs	6N	6W	35	MD	Sonoma (7½')	100			USGS P.P. 492	1965	22	79	4 wells
							-			USGS WSP 338	1915	114	Sonoma 19	
46	Boyes (Ohms) Hot Springs	5N	6W	1	MD	Sonoma (7½')	114-118			USGS P.P. 492	1965	22	79	Water from 4 wells
							114-118	200±		USGS WSP 338	1915	112-113	Sonoma 20-21	2 wells
							112			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	31		
47	Well	7N	5W	3	MD	Rutherford (7½')	77			USGS WRI 13-73	1973	Fig. 3		
48	Well	7N	5W	15	MD	Rutherford (7½')	70			USGS WRI 13-73	1973	Fig. 3		
49	Well	7N	5W	14	MD	Rutherford (7½')	69			USGS WRI 13-73	1973	Fig. 3		
50	Well	7N	5W	26	MD	Rutherford (7½')	80			USGS WRI 13-73	1973	Fig. 3		
51	Well	7N	5W	26	MD	Rutherford (7½')	85			USGS WRI 13-73	1973	Table 4 Fig. 3		
52	Well	6N	4W	23	MD	Napa (7½')	85			USGS WRI 13-73	1973	Fig. 3		
53	Well	6N	4W	24	MD	Napa (7½')	76			USGS WRI 13-73	1973	Fig. 3		
54	Hot spring	6N	4W	34	MD	Napa (7½')	83							Napa City Water Dept. pers. comm. 5/5/72

* See Appendix D for location.

SUSANVILLE (WESTWOOD) SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
1	Sellicks Springs	31N	15E	7	MD	Karlo (15')	72			USGS WSP 338	1915	324	Lassen 9	
2	Tipton(s) Springs	31N	15E	32	MD	Karlo (15')	70			USGS P.P. 492	1965	20	29A	Location not precise
							-			USGS WSP 338	1915	324-325	Lassen 10	
3	Upper Mill Creek Springs	30N	4E	21-22	MD	Lassen Peak (15')	120-150			USGS P.P. 492	1965	20	25	
										Carnegie Inst. Wash. Pub. 360	1925	90		
4	Tophet Hot Springs	30N	4E	21	MD	Lassen Peak (15')	175 to boiling			USGS P.P. 492	1965	20	26	
	(Soupan, Supan)									USGS WSP 338	1915	141	Shasta 15	
5	Bumpas Hot Springs	30N	4E	14	MD	Lassen Peak (15')	boiling			USGS P.P. 492	1965	20	27	
	(Bumpas Hell)						-			USGS WSP 338	1915	140-141	Shasta 16	
6	Morgan Hot Springs	29N	4E	11	MD	Lassen Peak (15')	90-200			USGS P.P. 492	1965	20	33	
							200+			USGS WSP 338	1915	138-139	Tehama 2	
7	Growler Hot Springs	29N	4E	11	MD	Lassen Peak (15')	203+			USGS P.P. 440-F	1963	40-41	5	
8	Devils Kitchen	30N	5E	21	MD	Mt. Harkness (15')	150-205			USGS P.P. 492	1965	21	34	
							-			USGS WSP 338	1915	141-142	Plumas 1	
9	Hot Spring Valley	30N	5E	22-27	MD	Mt. Harkness (15')	83			USGS P.P. 492	1965	21	35	
							83			USGS WSP 338	1915	227	Plumas 2	Carbonated
10	Drake Hot Springs	30N	5E	22	MD	Mt. Harkness (15')	123-148			USGS P.P. 492	1965	21	36	
	(Drakeshad)						148			USGS WSP 338	1915	142-143	Plumas 4	
11	Boiling Spring Tartarus Lake	30N	5E	27	MD	Mt. Harkness (15')	170-190			USGS P.P. 492	1965	21	37	
							170			USGS WSP 338	1915	143	Plumas 5	
12	Terminal Geyser	30N	5E	36	MD	Mt. Harkness (15')	120-205			USGS P.P. 492	1965	21	38	
	The Geyser						-			USGS WSP 338	1915	143-144	Plumas 6	
13	Geysers Steam Co., Terminal Geyser Well	30N	5E	36	MD	Mt. Harkness (15')	265	1270	1962	CDMG SR 75	1963	11	3	
14	Roosevelt Swimming Pool Well	29N	12E	6	MD	Susanville (15')	96	295(?)		CDOG TR 15	1974	Table 3a	1	
							97			CDOG TR 13	1975	47	27	
15	Church of Latter Day Saints well	29N	12E	6?	MD	Susanville (15')	120	593		CDOG TR 15	1974	Table 3a	2	Location uncertain
	L.D.S. Church well	29N	12E	5?	MD		120	593		CDOG TR 13	1975	47	28	Location uncertain
16	Well	30N	12E	32	MD	Susanville (15')	128							Pers. comm. J.B. Koenig
17	Miller Custom Work well	29N	12E	5	MD	Susanville (15')	116			CDOG TR 13	1975	47	29	
							128?							Pers. comm. J.B. Koenig
18	Chaffer (Brantacks) Hot Springs	29N	15E	23 & 24	MD	Litchfield (15') and Wendel (15')	16?-204			USGS P.P. 492	1965	20	30	Sec. 24 on Wendel quad.
						Litchfield (15') and Wendel (15')	204			USGS WSP 338	1915	124-126	Lassen 16	Sec. 24 on Wendel quad.

* See Appendix C for location

SUSANVILLE (WESTWOOD) SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
18	Wendel Hot Springs	29N	15E	23	MD	Litchfield (15')	205			CDOG TR 13	1975	47	30	
							205			CDOG TR 15	1975	Table 3a	3	
19	Magma Power Co. Wendel Well	29N	15E	23	MD	Litchfield (15') and Wendel (15')	174	630	1962	CDMG SR 75	1963	11	4	
	Well						147	623		CDOG TR 13	1975	47	31	
20	S.P. Railroad Well	29N	16E	30	MD	Wendel (15')	83	305		CDOG TR 15	1974	Table 3a	4	
21	Magma Power Co. Wells	28N	16E	8 & 5	MD	Wendel (15')	220	116	1962	CDMG SR 75	1963	11	5	3 wells
	Wells	28N	16E	4 & 8	MD		225	1102		CDOG TR 13	1975	47	33	
22	Amedee Hot Springs	28N	16E	8	MD	Wendel (15')	178-204			USGS P.P. 492	1965	20	31	
							172-204			USGS WSP 338	1915	127	Lassen 17	
							204			CDOG TR 15	1974	Table 3a	5	
							203			CDOG TR 13	1975	47	32	
23	Warm springs	25N	8E	13-14	MD	Almanor (15')	80-98			USGS P.P. 492	1965	21	40-41	Vague locations
24	Kruger Hot Springs	26N	9E	2	MD	Greenville (15')	90-106			USGS P.P. 492	1965	21	39	Shown as Indian Valley Hot Springs on Greenville quad.
	(Indian Valley)						94			USGS WSP 338	1915	128	Plumas 11	
25	Highrock Spring	28N	17E	25	MD	Doyle (15')	86			USGS P.P. 492	1965	20	32	
							86, 100?			USGS WSP 338	1915	128	Lassen 19	

TRONA SHEET

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
1	Bainter Spring	24S	43E	18	MD	Trona (15')	92			CDWR Bull. 91-17	1969	67		
2	Well	24S	43E	9	MD	Trona (15')	136			CDWR Bull. 91-17	1969	66		
							137	600		USGS WRI 33-73	1974	6	16	
3	Well	24S	43E	22	MD	Trona (15')	90	297		CDWR Bull. 91-17	1969	67		
4	Well	25S	43E	9	MD	Trona (15')	86			CDWR Bull. 91-17	1969	68		
5	Spring	22N	7E	30	SB	Shoshone (15')								Very warm spring, B.W. Troxel pers. comm.
6	Spring	21N	7E	30	SB	Shoshone (15')								Warm artesion spring, B.W. Troxel pers. comm.
7	Tecopa Hot Springs	21N	7E	33	SB	Tecopa (15')	109			USGS P.P. 492	1965	24	146	
							109			USGS WSP 338	1915	137	Inyo 35	
							108			USGS WRI 33-73	1974	10	61	
	Magma Power Co. test well						-	422	1962	CDMG SR 75	1963	11	13	
8	Well	21N	7E	28	SB	Tecopa (15')	118	400		USGS WRI 33-73	1974	10	62	Flowing well drilled by Stauffer Chemical Co., B.W. Troxel pers. comm.
9	Yeoman Hot Springs	21N	7E	1	SB	Tecopa (15')	80			USGS P.P. 492	1965	24	145	
10	Restino Spring	21N	8E	31	SB	Tecopa (15'	80			USGS P.P. 492	1965	24	147	
							80			USGS WSP 338	1915	319-320	Inyo 34	

* See Appendix D for location.

TRONA SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
11	well	26S	39E	19	MD	Inyokern (15')	87	367		CDWR Bull. 91-9	1963	148-149		
12	well	26S	39E	24	MD	Ridgecrest (15')	86-93	825		CDWR Bull. 91-9	1963	151		
13	well	27S	40E	7	MD	Ridgecrest (15')	86	410		CDWR Bull. 91-9	1963	185		
14	well	26S	40E	22	MD	Ridgecrest (15')	90	830		CDWR Bull. 91-9	1963	169		
15	Saratoga Spring	18N	5E	2	SB	Avawatz Pass (15')	82			USGS P.P. 492	1965	24	154	
							82			USGS WSP 338	1915	137-138	San Bern. 3	
16	Magma Power Co. well	29S	41E	25	MD	Klinker Mtn. (7½')	241	772		CDMG SR 75	1963	11	14	
	"Steam Well"						205	415	1920±	USGS P.P. 457	1964	56		Drilled as a prospect for mercury
17	Paradise Spring	12N	2E	7	SB	Lone Mtn. (15')	85-106			USGS P.P. 492	1965	24	155	
							102			USGS WSP 338	1915	52-53	San Bern. 9	
							102			USGS WRI 33-73	1974	10	63	

UKIAH SHEET

MAP* LOC. NO.	NAME	T	R	SEC.	B&M	QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	PUBLICATION	YEAR	PAGE	LOC. NO.	NOTES
1	Sulphur Spring near Laytonville	21N	15W	1	MD	Laytonville (15')	70			USGS P.P. 492	1965	21	45A	Water contains H_2S
							-			USGS WSP 338	1915	259	Mendocino 4	
							70			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	25		
1A	Jackson Valley Mud Springs	21N	15W	19	MD	Cahto Peak (7½')	80			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	25		
2	Crabtree Hot Springs	17N	9W	25/36	MD	Lake Pillsbury (15')	68-105			USGS P.P. 492	1965	21	48	
							105			USGS WSP 338	1915	106-107	Lake 5	
		17N	9W	36	MD		105			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	22		
3	Fouts Springs	17N	7W	5	MD	Stonyford (15')	60-75			USGS P.P. 492	1965	21	48A	
							75			USGS WSP 338	1915	205-207	Colusa 3	Carbonated springs
	(Red Eye Springs)						78			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	16		
4	Orrs Hot Springs	16N	14W	24	MD	Boonville (15')	63-104			USGS P.P. 492	1965	21	45	2 springs
							104			USGS WSP 338	1915	83	Mendocino 20	
	Hot Springs, Alfred Weger						104			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	24		
5	Vichy Springs	15N	12W	14	MD	Ukiah (15')	50-90			USGS P.P. 492	1965	21	46	
							90			USGS WSP 338	1915	171-173	Mendocino 24	
							85			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	24		
6	Wells (Cal. Dri Ice Co.)	13N	12W	1	MD	Ukiah (15')	-	350-790	-	USGS WSP 1548	1965	62		7 wells assoc. with hot ground water; location vague
7	Soda Bay Springs	13N	8W	6	MD	Lucerne (7½')	80-87			USGS P.P. 492	1965	21	55	
							90, 124			USGS WSP 338	1915	191-192	Lake 36	

* See Appendix D for location.

UKIAH SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE (S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
7	(Big Soda Spring)	13N	8W	6	MD	Lucerne (7½')	-			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	20		
8	Spring (unnamed)	16N	8W	35	MD	Clearlake Oaks (15')	90			USGS P.P. 492	1965	21	49	Location vague
9	Newman (Soap Creek) Springs	16N	8W	35	MD	Clearlake Oaks (15')	72-92			USGS P.P. 492	1965	21	50	
							92			USGS WSP 338	1915	202	Lake 8	Carbonated spring
10	Sulphur Bank Springs	13N	7W	5	MD	Clearlake Oaks (15')	83-120			USGS P.P. 492	1965	21	57	
	(Hot Balata)						120			USGS WSP 338	1915	98-99	Lake 38	
	(Borax Springs)						157			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	20		In Sulphur Bank mine
							86-122			CDOG TR 13	1975	49	67	
11	Well (Magma Power Co.)	13N	7W	5	MD	Clearlake Oaks (15')	367	1391	1961	CDMG SR 75	1963	11	6	
							367	5016		CDOG TR 13	1975	49	68	
12	Spring	14N	7W	36	MD	Clearlake Oaks (15')	80			Ciancanelli unpub. map				
13	Spring	14N	7W	14	MD	Clearlake Oaks (15')	66-70			Ciancanelli unpub. map				
14	Chalk Mtn.	14N	7W	12	MD	Clearlake Oaks (15')	67-70			USGS P.P. 492	1965	21	51A	In altered lava
							67-70			USGS WSP 338	1915	196-197	Lake 25	Carbonated springs
15	Complexion Springs	15N	6W	3	MD	Clearlske Oaks (15')	74			USGS P.P.492	1965	21	51	
							-			USGS WSP 338	1915	297-298	Lake 14	Saline springs
	Complexion Springs	15N	6W	3	MD	Clearlske Oaks (15')	-			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	21		
16	Deadshot Springs	14N	5W	6	MD	Wilbur Springs (15')	67-79			USGS P.P. 492	1965	21	65	
							78			USGS WSP 338	1915	195	Colusa 6	Carbonated spring
							60			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	15		
17	Springs at Elgin Mine	14N	6W	13	MD	Wilbur Springs (15')	140-153			USGS P.P. 492	1965	21	69	
							140-153			USGS WSP 338	1915	104-106	Colusa 7	
18	Spring at Abbott Mine	14N	5W	31	MD	Wilbur Springs (15')	79			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	21		Mercury mine
19	Blancks Hot Springs	14N	5W	29	MD	Wilbur Springs (15')	120			USGS P.P. 492	1965	21	66	
							-			USGS WSP 338	1915	104	Colusa 12	
20	Springs on Manzanita Mining property	14N	5W	29	MD	Wilbur Springs (15')	110-142			USGS P.P. 492	1965	21	67A	
							110-142			USGS WSP 338	1915	104	Colusa 10	
21	Wilbur (Simmons) Hot Springs	14N	5W	28	MD	Wilbur Springs (15')	65-140			USGS P.P. 492	1965	21	68	
							140			USGS WSP 338	1915	99-103	Colusa 9	
							120			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	15		3 springs listed
22	Jones Hot Springs	14N	5W	28	MD	Wilbur Springs (15')	125			USGS P.P. 492	1965	21	67	
							-			USGS WSP 338	1915	103	Colusa 11	

* See Appendix D for location.

WALKER LAKE SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
1	Grovers Hot Springs	10N	19E	24	MD	Markleeville (15')	128-146			USGS P.P. 492	1965	23	113	
							128-146			USGS WSP 338	1915	131	Alpine 1	
							147			CDOG TR 13	1975	48	48	
	Fales Hot Springs	6N	23E	24	MD	Fales Hot Springs (15')	97-141			USGS P.P. 492	1965	23	114	
							129-141			USGS WSP 338	1915	132	Mono 1	
							176			CDOG TR 13	1975	48	49	
3	Magma Power Co. Well	6N	23E	24	MD	Fales Hot Springs (15')	-	413	1962	CDMG SR 75	1963	11	9	
4	Buckeye Hot Springs	4N	24E	4	MD	Matterhorn Peak (15')	140			USGS P.P. 492	1965	23	115	
							140			USGS WSP 338	1915	132-133	Mono 2	Extensive lime carbonate deposits
							140			CDOG TR 13	1975	48	50	
5	Travertine Hot Springs	5N	25E	34	MD	Bodie (15')	121-148			USGS P.P. 492	1965	23	116	
							148			USGS WSP 338	1915	133-135	Mono 3	
							122-149			CDOG TR 13	1975	48	51	
6	The Hot Springs	4N	25E	9	MD	Bodie (15')	70-105			USGS P.P. 492	1965	23	117	
							70-105			USGS WSP 338	1915	133	Mono 4	
							95-113			CDOG TR 13	1975	48	52	
7	Magma Power Co. Well	4N	25E	9	MD	Bodie (15')	122	982	1962	CDMG SR 75	1963	11	10	
7A	Magma Power Co. Well	5N	25E	12	MD	Bodie (15')	122	924	1962	CDOG TR 13	1975	48	53	
8	Warm Springs Flat	4N	26E	18	MD	Bodie (15')	100			USGS P.P. 492	1965	23	118	
							-			USGS WSP 338	1915	135-136	Mono 5	
9	Near Mormon Creek	4N	26E	16	MD	Bodie (15')	100			USGS P.P. 492	1965	23	119	
										USGS WSP 338	1915	135-136	Mono 5	
10	Hot spring	2N	26E	11	MD	Bodie (15')	?			USGS Bodie 15' quad.				No other reference
11	Getty Oil Co. "State P.R.C. 4572.1"	2N	26E	24	MD	Bodie (15')	136	2437	1971	CDOG Sum. Op. v. 57 no. 2	1971	13		
							135	2440	1971	CDOG TR 13	1975	48	56	Also see p. 35
12	Mono Basin warm Spring	2N	28E	17	MD	Trench Canyon (15')	90			USGS P.P. 492	1965	23	121	
							80-90			USGS WSP 338	1915	145-146	Mono 8	
	warm spring						91			CDOG TR 13	1975	48	54	

WEED SHEET

1	Bogus Soda Springs	47N	5W	13	MD	Copco (15')	65-75			USGS P.P. 492	1965	20	2A	
							72-76			USGS WSP 338	1915	217-218	Siskiyou 5	Carbonated springs

* See Appendix D for location.

WEED SHEET

APPENDIX B - TABULATED LIST OF THERMAL SPRINGS AND WELLS

MAP* LOC. NO.	NAME	LOCATION				QUADRANGLE	WATER TEMP. (°F)	TOTAL DEPTH (FEET)	YEAR DRILLED	REFERENCE(S) (see list of references for abbreviations)				NOTES
		T	R	SEC.	B&M					PUBLICATION	YEAR	PAGE	LOC. NO.	
1	Bogus Soda Springs	47N	5W	13	MD	Copco (15')	72-76			CDMG Bull. 151	1949	56		
2	Klamath Hot Springs	48N	3W	27	MD	Macdoel (15')	100-152			USGS P.P. 492	1965	20	2	
	(Shovel Creek Springs)						112-156			USGS WSP 338	1915	120-121	Siskiyou 7	
	(Beswick Hot Springs)						152			CDMG Bull. 151	1949	55		
3	Sulphur Springs	15N	8E	29	MD	Ukonom (15')	90			USGS P.P. 492	1965	20	1	
							84			USGS Water Res. Div. Open File (No. Coast & Klamath Mtns.)	1968	28		
4	Hot spring on Mt. Shasta	41N	3W	9	MD	Shasta (15')	184			Zeitschrift fur Vulkanalogie	1934	228		
							-			USGS WSP 338	1915	144	Siskiyou 14	

• See Appendix D for location.

REFERENCES CITED IN APPENDIX B

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Carnegie Inst. Wash. Pub. 360	Day, A.L., and Allen, E.T., 1925, The volcanic activity and hot springs of Lassen Peak: The Carnegie Institute of Washington, Publication 360, 190 p.
Koenig, 1968	Koenig, J.B., 1968, Field trip guide to The Geysers, Sonoma County, California: Northern California Geological Society Field Trip Guide.
Rex, unpub.	Rex, R.W. (Republic Geothermmal, Inc., Whittier, CA), Computer print-out list of data on geothermal wells in Imperial and Coachella Valleys, 1972.
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USGS PP 486-G	Metzger, D.G., Loeltz, O.J., and Irelan, B., 1973, Geohydrology of the Parker-Blythe-Cibola area, Arizona and California: U.S. Geological Survey Professional Paper 486-G, 130 p.
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APPENDIX C

INDEX TO THE GEOLOGIC FORMATIONS GROUPED WITHIN EACH UNIT PORTRAYED ON THE GEOLOGIC MAP OF CALIFORNIA, 1977 EDITION

Obviously, all the individual formations mapped in California, of which there are well over 1,000, could not be depicted on the 1:750,000 scale Geologic Map of California. As explained in Part II of this bulletin, the units portrayed on the Geologic Map are drawn on the basis of formation boundaries, but there are numerous formations contained within many of the mapped units. These formations are not portrayed on the map or named in the geologic legend—only a description of the predominant lithologic types for each mapped unit is given there. For a complete and detailed listing of the individual formational units in California, along with cross indexes by geologic age and by map sheet areas, the reader is referred to the "Geologic Legend and Formation Indexes" which accompany the Geologic Atlas of California. The index of geologic formations presented in the following pages is much more generalized than that of the Atlas; it was designed not to supplant the Atlas index, but rather to provide an easy-to-use listing that is referenced directly to the units portrayed on the 1:750,000 Geologic Map of California.

EXPLANATION

In preparation of the 1:750,000 scale Geologic Map of California, the mapped formations in the state were grouped into 52 units according to lithologic similarities and rock origins, and were also arranged chronologically, according to relative age. The contacts for the units shown on the 1977 map are therefore based on actual formation contacts—if not individual formations—then grouped formations. The following list shows what formations were grouped into each map unit shown by the different symbols on the 1:750,000 scale map. This, of course, is a statewide synthesis, and in any one location either a single formation is represented or two or more formations have been grouped. Because geologic formations commonly transcend time boundaries, many formations listed on the following table do not strictly fit the time interval indicated. It was not only more practical but also more meaningful in compiling the map to conform to formation boundaries, which can be more easily related to the rocks in the field, than to try and "take apart" the geologist's formation and draw "time" lines.

Many formations in the following list are described in parentheses as "(in part)." This was done where a formation is composed of rocks of vastly different lithologies or dissimilar origin. For example, a sedimentary formational unit may have volcanic members within it. In such a case, the volcanic members would be grouped with the volcanic units (of comparable age as the sedimentary unit). Likewise, a marine formational unit may have interbedded nonmarine members, and these would in most cases (if extensive enough to show) be grouped with the nonmarine map unit of appropriate age.

Most of the designated units on the 1977 map contain the formational units depicted on the State Geologic Atlas sheets; however, where subsequent work has shown that certain formations were of a significantly different age than what was previously considered (probably as a result of the discovery of new or more-diagnostic fossils, or by reason of more accurate stratigraphic correlations), the results of this new information were taken into consideration, and the formation was depicted in the most appropriate way on the new State Geologic Map.

Several new geologic units are shown on the 1977 map that were not recognized on the State Geologic Atlas. These include several areas in the southeastern part of the state where Tertiary granitic rocks have been dated (gr^{Cz}); an extensive belt of Tertiary-Cretaceous rocks in the northern Coast Ranges, known as the Coastal Belt rocks or "Coastal Belt Franciscan" (TK); two locations of newly recognized Paleozoic (or Permo-Triassic) granitic rocks (gr^{Pz}), one location in northern California and one in the southern part of the state; and two subdivisions within the Franciscan Complex—a melange unit (KJf_m) and a schist unit (KJf_s).

If the reader would like a more detailed description of the individual formational units listed in the following table, he may refer to the various stratigraphic nomenclature sheets that accompany the individual Geologic Atlas sheets or to the source data from which the Geologic Atlas was derived, as indicated on the explanatory data accompanying each sheet.

For a more detailed explanation of the way in which the rock units were classified, and for a discussion of special stratigraphic problems encountered in preparing the 1:750,000 State Geologic Map, one should refer to pages 58 - 63 in Section II.

INDEX TO
GEOLOGIC FORMATIONS GROUPED WITHIN THE UNITS OF THE 1:750,000 GEOLOGIC MAP OF CALIFORNIA, 1977 EDITION

CENOZOIC - SEDIMENTARY ROCKS

Symbol on 1:750,000 map	Map Unit	Formations Included
Qls	Selected large landslide deposits	"Blackhawk slide"
Q	Alluvium (mostly Holocene, some Pleistocene)	Temescal Fm., Modesto Fm.; Victor Fm.
	Quaternary nonmarine	Alameda Fm., Aromas Red Sands, Bautista Beds, Brawley Fm., Burnt Canyon Breccia, Cabezon Fanglomerate, Campus Fm., Casitas Fm., Chemehuevi Fm., Corcoran Clay, Cushenbury Springs Fm., Dos Picachos Gravels, Dripping Springs Fm., Frazier Mountain Fm., Friant Fm., Harold Fm., Heights Fanglomerate, Hookton Fm. (in part), Huichica Fm., La Habra Fm., Lake Coahuila deposits, Manix Lake beds, Mohawk Lake beds, Montezuma Fm., Nadeau Gravel, Ocotillo Conglomerate, Orcutt Fm., Pacoima Fm., Pauba Fm., Peckham Fm., Pinto Fm., Resting Springs Fm., Riverbank Fm., Rohnerville Fm., San Dimas Fm., Shoemaker Gravel, Temecula Arkose
	Quaternary marine	Battery Fm., Bay Point Fm., Colma Fm., Hookton Fm. (in part), Lindavista Fm., Lomita Marl, Merritt Sand, Millerton Fm., Palos Verdes Sand, San Pedro Fm., Sweitzer Fm., Timms Point Silt
Qs	Extensive sand dune deposits	No named formations
Qg	Glacial deposits	No named formations
QPc	Plio-Pleistocene nonmarine	Arroyo Seco Gravel, Cache Fm., Carlotta Fm., China Hat Gravel, China Ranch Beds, Coso Fm., Funeral Fanglomerate (in part), Furnace Creek Fm., Glen Ellen Fm., Irvington Gravels, Kern River Fm., Laguna Fm., Livermore Gravel, McKittrick Fm., North Merced Gravel, Nova Fm., Packwood Gravels, Paso Robles Fm., Red Bluff Fm., Ricardo Fm. (in part), San Benito Gravels, Santa Clara Fm., Saugus Fm., Tehachapi Fm., Tulare Fm., Turlock Lake Fm.
	Pliocene nonmarine	Alturas Fm. (in part), Anaverde Fm., Canebrake Conglomerate, Chanac Fm., Crowder Fm., Duarte Conglomerate, Esmeralda Fm., Etchegoin Fm., Green Valley Fm., Hathaway Fm., Horned Toad Fm., Hungry Valley Fm., Lockwood Clay, Mecca Fm., Meeke Mine Fm., Mehrten Fm. (in part), Morales Fm., Mount Eden Fm., Mulholland Fm., Neroly Fm. (in part), Orinda Fm., Oro Loma Fm., Painted Hill Fm. (in part), Palm Spring Fm., Panorama Hills Fm., Peace Valley Fm., Petaluma Fm., Potato Sandstone, Purisma Fm. (in part), Quatal Fm., Ricardo Fm. (in large part), Ridge Route Fm., Santa Ana Sandstone, San Timoteo Fm., Siesta Fm., Tassajero Fm., Tehama Fm., Tropico Group, Wolfskill Fm.
P	Pliocene marine	Careaga Fm., Eel River Fm., Etchegoin Fm. (in large part), Falor Fm., Fernando Fm., Foxen Mudstone, Imperial Fm., Jacalitos Fm., Merced Fm., Niguel Fm., Ohlson Ranch Fm., Pancho Rico Fm., "Pico Fm.," Purisma Fm. (in large part), "Repetto Fm.," Rio Dell Fm., San Diego Fm., San Joaquin Fm., Scotia Bluffs Sandstone, St George Fm., Sunshine Ranch Mbr. (of Saugus Fm.), Towsley Fm., Wildcat Gp
Mc	Miocene nonmarine	Barstow Fm. (in part), Bena Gravels, Bissell Fm., Bopesta Fm., Clews Fanglomerate, Coachella Fanglomerate, Fiss Fanglomerate, Mint Canyon Fm., Oso Canyon Fm., Pickhandle Fm. (in part), Punchbowl Fm., San Pablo Group (in part), Santa Barbara Fm., Split Mountain Fm. (in part), Table Mountain Gravels, Tick Canyon Fm., Tropico Group (in part), Valley Springs Fm. (in part)
M	Miocene marine	Agua Sandstone Mbr. (of Temblor Fm.), Alferitz Fm., Altamira Shale Mbr. (of Monterey Fm.), Antelope Shale Mbr. (of Monterey Fm.), Big Blue Serpentinous Mbr (of Temblor Fm.), Branch Canyon Fm., Briones Fm., "Button Bed" Sandstone Mbr. (of Temblor Fm.), Capistrano Fm., Carneros Sandstone Mbr. (of Temblor Fm.), Castaic Fm., Cierbo Sandstone, Claremont Shale, Devilwater Silt-Gould Shale Mbrs. (of Monterey Fm.), Escudo Sandstone, Fish Creek Gypsum Mbr (of Split Mountain Fm.), Freeman Silt, Gallaway Beds, Hambre Sandstone, Hannah Fm., Hercules Shale Mbr. (of Briones Sandstone), Jewett Sand, La Vida Mbr. (of Puente Fm.), Malaga Mudstone Mbr. (of Monterey Fm.), McDonald Shale, McLure Shale Mbr. (of Monterey Fm.), Media Shale Mbr. (of Temblor Fm.), Modelo Fm., Monterey Fm., Neroly Fm. (in large part), Olcese Sand, Oso Mbr. (of Capistrano Fm.), Oursan Sandstone, Painted Rock Sandstone Mbr. (of Vaqueros Fm.), Pismo Fm., Pleito Fm., Point Arena Beds, Point Sal Fm., Puente Fm., Pullen Fm., Quail Lake Fm., Reef Ridge Shale, Rincon Shale, Rodeo Shale, Round Mountain Silt, Salinas Shale, Salt Creek Shale Mbr. (of Temblor Fm.), Saltos Shale Mbr. (of Monterey Fm.), Sandholdt Shale, San Onofre Breccia (in part), San Pablo Group (in large part), Santa Margarita Fm., Santos Shale Mbr. (of Temblor Fm.), Sisquoc Fm., Sobrante Sandstone, Soda Lake Sandstone Mbr (of Vaqueros Fm.), Soda Lake Shale Mbr (of Vaqueros Fm.), Soquel Mbr. (of Puente Fm.), Split Mountain Fm. (in part), Sycamore Canyon Mbr. (of Puente Fm.), Temblor Fm., Tequepis Sandstone, Tice Shale, Topanga Fm., Twisselman Sandstone Mbr. (of Monterey Fm.), Valmonte Diatomite Mbr (of Monterey Fm.), Vaqueros Fm., Vedder Sand, Whiterock Bluff Shale Mbr. (of Monterey Fm.), Wimer Fm., Yorba Mbr. (of Puente Fm.)
Φc	Oligocene nonmarine	Berry Conglomerate, Cedarville Series (in part), Lospe Fm., Plush Ranch Fm. (in part), Sespe Fm., Simmler Fm., Tecuya Fm. (in part), Titus Canyon Fm., Vasquez Fm. (in large part), Weaverville Fm.
Φ	Oligocene marine	Alegria Fm., Church Creek Beds, Gaviota Fm., Kirker Fm., "San Emigdio" Fm., San Lorenzo Fm., San Ramon Fm., Tumey Fm.
Ec	Eocene nonmarine	Ballena Gravels, "Dry Creek" Fm., Ione Fm., Montgomery Creek Fm., Poway Conglomerate

Symbol on 1:750,000 map	Map Unit	Formations Included
E	Eocene marine	Anita Shale, Avenal Sandstone, Butano Sandstone, Canoas Siltstone, Capay Fm., "Coldwater" Sandstone, Cozy Dell Shale, Delmar Fm., Domengine Fm., Gredal Fm., Indart Sandstone, Jameson Shale Mbr. (of Markley Fm.), Juncal Fm., Junipero Sandstone, Kreyenhagen Shale, Llajas Fm., Los Muertos Creek Fm., Lucia Shale, Mabury Fm., Maniobra Fm., Markley Fm., Matilija Sandstone, Meganos Fm., Nortonville Shale Mbr., Point of Rocks Sandstone, Rose Canyon Shale, Sacate Fm., Santa Susana Fm., Santiago Fm., Sierra Blanca Limestone, "Tejon" Fm., Tesla Fm., The Rocks Sandstone, Tolman Fm., Torrey Fm., Tres Pinos Sandstone, Welcome Fm., Yokut Sandstone
Ep	Paleocene marine	Dip Creek Fm., Laguna Seca Fm., Las Virgenes Sandstone, Lodo Fm., "Martinez" Fm., Pattiway Fm., San Francisquito Fm., Silverado Fm., Simi Conglomerate, Vine Hill Sandstone, Yager Fm.
Tc	Tertiary nonmarine, undivided	Avawatz Fm., Bealville Fanglomerate, Borrego Fm., Caliente Fm. (in part), Goler Fm., Old Woman Sandstone, Violin Breccia, Walker Fm., Witnet Fm.

CENOZOIC - VOLCANIC AND PLUTONIC ROCKS

Symbol on 1:750,000 map	Map Unit	Formations Included
Qrv	Recent (Holocene) volcanic flow rocks	Modoc Basalt, Plutos Cave Basalt
Qrv•	Recent (Holocene) pyroclastic and volcanic mudflow deposits	No formations named
Qv	Quaternary volcanic flow rocks	Black Mountain Basalt, Butte Valley Basalt, Lake Basalt, Lousetown Fm., Santa Rosa Basalt, "Warner Basalt" (in part)
Qv•	Quaternary pyroclastic and volcanic mudflow deposits	Bishop Tuff
Tv	Tertiary volcanic flow rocks	Alverson Canyon Fm., Alvord Peak Basalt, Artist Drive Fm., Bald Peak Basalt, Barstow Fm. (in part), Caliente Fm. (in part), Colestin Fm., Conejo Volcanics (in part), El Modeno Volcanics (in part), Funeral Fanglomerate (in part), Gem Hill Fm. (in part), Glendora Volcanics (in part), Greenwater Volcanics, Ilmon Basalt, Leona Rhyolite, Lovejoy Fm., Moraga Fm., Neenach Volcanic Fm., Northbrae Rhyolite, Painted Hill Fm. (in part), Plush Ranch Fm. (in part), Putnam Peak Basalt, Quien Sabe Volcanics, Raymond Peak Andesites, Red Buttes Quartz Basalt, Ricardo Fm. (in part), Roxy Fm., Saddleback Basalt, Shasta Lavas, Silver Peak Andesites, Skooner Gulch Basalt, Sonoma Volcanics, St. Helena Rhyolite, Table Mountain Latite, Tecuya Fm. (in part), Tranquillon Volcanics, Tropico Group (in part), Truckhaven Rhyolite, Tryon Peak Flows, Vasquez Fm. (in part), "Warner Basalt" (in part), Wasson Fm.
Tv•	Tertiary pyroclastic and volcanic mudflow deposits	Alturas Fm. (in part), Bonta Fm., Cedarville Series (in part), Conejo Volcanics (in part), Delleker Fm., El Modeno Volcanics (in part), Gem Hill Fm. (in part), Glendora Volcanics (in part), Ingalls Fm., Jacumba Pyroclastics, Kinnick Fm., Lawlor Tuff, Mehrten Fm. (in part), Nomlaki Tuff Mbr., Obispo Tuff, Penman Fm., Pickhandle Fm. (in part), Pinnacles Fm., Pinole Tuff, Reeds Creek Andesite, Spanish Canyon Fm., Tropico Group (in part), Tuscan Fm., Valley Springs Fm. (in part)
Ti	Tertiary intrusive rocks (hypabyssal)	Bobtail Quartz Latite Mbr. (of Gem Hill Fm.), Fountain Peak Rhyolite, Mountain Meadows Dacite Porphyry, Stoddard Canyon Quartz Monzonite, Sulphur Springs Mountain Andesite
gr^{Cz}	Cenozoic (Tertiary) granitic rocks	Kingston Range Monzonite Porphyry

MESOZOIC - PALEOZOIC - PRECAMBRIAN SEDIMENTARY AND METASEDIMENTARY ROCKS

Symbol on 1:750,000 map	Map Unit	Formations Included
TK	Tertiary-Cretaceous Coastal Belt rocks	"Coastal Belt"
K	Cretaceous marine, undivided (in part nonmarine)	Berryessa Fm., Niles Canyon Fm., Oakland Cgl. Trabuco Fm. (nonmarine)
Ku	Upper Cretaceous marine	Adobe Flat Shale Mbr. (of Panoche Fm.), Asuncion Group, Atascadero Fm., Bald Hills Fm., Chico Fm., Del Valle Fm., Forbes Fm., Funks Fm., Gualala Group, Guinda Fm., Hornbrook Fm., Jack Creek Fm., Jalama Fm., Kione Sand, Ladd Fm., Moreno Fm., Novato Conglomerate, Panoche Fm., Pigeon Point Fm., Rosario Fm., "Salt Creek Conglomerate," Sites Fm., Venado Fm., Williams Fm., Yolo Fm.
Kl	Lower Cretaceous marine Franciscan Complex (assemblage) Franciscan mélange Franciscan schist	Espada Fm., Horsetown Fm., Marmolejo Fm., Ono Fm., Paskenta Fm., Rector Fm., Shasta Series, Toro Fm., Wisenor Fm. Franciscan (sedimentary rocks); Dothan Fm., Honda Fm., San Luis Fm. Franciscan mélange (Blueschist and semi-schist of Franciscan Complex), "Catalina Schist," Kerr Ranch Schist, South Fork Mountain Schist
J	Jurassic marine	Agua Fria Fm., Arvison Fm., Aztec Sandstone, Bedford Canyon Fm., Colfax Fm., Cosumnes Fm., Fant Meta-Andesite, Galice Fm., Hardgrave Fm., Hunter Valley Cherts, Knoxville Fm., Mariposa Fm. (in part), Merced Falls Slate, Milton Fm. (in part), Monte de Oro Fm., Mormon Fm., Potem Fm., Sailor Canyon Fm. (in part), Salt Spring Slate, Santa Monica Slate, Thompson Fm. (of McMath), Trail Fm. (of McMath)

Symbol on 1:750,000 map	Map Unit	Formations Included
TR	Triassic marine	Brock Shale, Butte Valley Fm., Cedar Fm., Chinle Fm., Hosselkus Limestone, Modin Fm., Moenkope Fm., Pit Fm. (in part), Soda Mountain Fm. (in part), Swearinger Fm., Warm Spring Fm. (in part)
Pm	Permian marine	Anvil Spring Fm., Arlington Fm. (of McMath), Bird Spring Fm. (in part), Bloody Mountain Fm., Fairview Valley Fm., Kaibab Limestone, McCloud Limestone, Owens Valley Fm., Reeve Fm. (of McMath), Robinson Fm. (of McMath)
C	Carboniferous marine	Baird Fm. (in part), Bass Mountain Diabase, Bird Spring Fm. (in part), Bragdon Fm., Bright Dot Fm., Furnace Limestone, Keeler Canyon Fm., Lake Dorothy Hornfels, Mildred Lake Hornfels, Monte Cristo Limestone, Mount Baldwin Marble, Oro Grande Series, Peale Fm. (in part), Perdido Fm., Rest Spring Shale, Supai Fm., Tihvipah Limestone, Tin Mountain Limestone
D	Devonian marine	Kennett Fm., Lost Burro Fm., Sultan Limestone
SO	Silurian and/or Ordovician marine	Al Rose Fm., Badger Flat Limestone, Barrel Spring Fm., Convict Lake Fm., Duzel Fm., Ely Springs Dolomite, Eureka Quartzite, Gazelle Fm., Hidden Valley Dolomite, Hilton Creek Marble, Johnson Spring Fm., Montgomery Limestone, Mount Aggie Fm., Mount Morrison Sandstone, Pogonip Limestone, Sunday Canyon Fm., Taylorsville Fm. (in part), Vaughn Gulch Limestone
€	Cambrian marine (and Cambrian?)	Bonanza King Fm., Bright Angel Shale, Cadiz Fm., Campito Fm., Carrara Fm., Chambless Limestone, Cornfield Springs Fm., Death Valley Fm., Good Springs Dolomite (in part), Harkless Fm., Latham Shale, Lead Gulch Fm., Lotus Fm., Monola Fm., Mule Spring Limestone, Nopah Fm., Pioche Shale, Poleta Fm., Prospect Mtn. Quartzite, Racetrack Dolomite, Saline Valley Fm., Tamarack Canyon Dolomite, Tapeats Sandstone, Wood Canyon Fm., Zabriskie Quartzite
Pz	Paleozoic marine, undivided	Bean Canyon Fm. (in part), Blue Canyon Fm., Briceburg Fm., Calaveras Fm. (in part), Cape Horn Slate, Chicopee Canyon Fm., Clipper Gap Fm., Delhi Fm., Garlock Series, Grizzly Fm., Hite Cove Fm. (in part), Kanaka Fm., Maria Fm., Relief Quartzite, Saragosse Quartzite, Shoo Fly Fm., Taylorsville Fm. (in part), Tightner Fm.
ls	Limestone of probable Paleozoic or Mesozoic age	Calaveras Fm. (in part), Gabilan Limestone, Hite Cove Fm. (in part), Riggs Fm., Sur Series (in part)
p€	Precambrian, undivided	Baldwin Gneiss, Beck Spring Dolomite, Crystal Spring Fm., Deep Spring Fm., Essex Series, Fenner Gneiss, Johannesburg Gneiss, Johnnie Fm., Kilbeck Gneiss, Kingston Peak Fm., Marvel Dolomitic Limestone, Mendenhall Gneiss, Middle Park Fm., Mountain Girl Quartzite, Noonday Dolomite, Pahrump Series, Panamint Metamorphic Complex, Pinto Gneiss, Reed Dolomite, Sourdough Limestone, Stirling Quartzsite, Surprise Fm., Waterman Gneiss, Wildrose Fm., World Beater Porphyry, Wyman Fm.
sch	Schist of various types and ages	Abrams Mica Schist, Julian Schist, Mesquite Schist, Orocopia Schist, Pelona Schist, Rand Schist, Salmon Hornblende Schist, Sur Series (in part)
	CENOZOIC - PRECAMBRIAN PLUTONIC, METAVOLCANIC, AND MIXED ROCKS	
gr^{Cz}	Cenozoic (Tertiary) granitic rocks	No formally named units
gr^{Mz}	Mesozoic granitic rocks	Atolia Quartz Monzonite, Barcroft Granodiorite, Big Baldy Granite, Bodega Diorite, Bonsall Tonalite, Boundary Peak Granite, Bradley "Granodiorite", Bridalveil Granite, Burnside Lake Adamellite, Cabin Granodiorite, Cactus Point Granite, Cactus Quartz Monzonite, Cajalco Quartz Monzonite, Carson Pass Tonalite, Cathedral Peak Granite, Clover Creek Granodiorite, Corona Hornblende Granodiorite Porphyry, Cottonwood Adamellite, Cow Creek Granodiorite, Coxcomb Granodiorite, Domenigoni Valley Granodiorite, Ebbetts Pass Granodiorite, El Capitan Granite, Escondido Creek Leucogranodiorite, Estelle Tonalite, Fargo Canyon "Diorite", Green Valley Tonalite, Half Dome Quartz Monzonite, Holcomb Quartz Monzonite, Home Gardens Quartz Monzonite porphyry, Hunter Mountain Quartz Monzonite, Inconsolable Granodiorite, Indian Mountain Leucogranodiorite, Isabella Granodiorite, Johnson Granite Prophyry, Kingston Range Monzonite Porphyry, Lakeview Mountain Tonalite, Lake Wolford Leucogranodiorite, Lamarck Granodiorite, Lar Quartz Diorite, La Sierre Tonalite, Leaning Tower Quartz Monzonite, Lebec Quartz Monzonite, Leidy Adamellite, Liebre Quartz Monzonite, Little Chief Porphyry, Lodgepole Granite, Lookout Peak Tonalite, McAfee Adamellite, Mount Clark Granite, Mount Givens Granodiorite, Mount Hole Granodiorite, Mount Pinos Granite, Palms "Granite" (Quartz Monzonite), Pear Lake Quartz Monzonite, Pellisier Granite, Pohono Granodiorite, Potwisha Quartz Diorite, Rattlesnake Granite, Roblar Leucogranite, Round Valley Peak Granodiorite, Secatar Quartz Diorite, Sage Hen Adamellite, Sands Granite, San Jacinto "Granodiorite", Santa Lucia Quartz Diorite, Sentinel Granodiorite, Stanislaus Meadow Adamellite, Stonewall Quartz Diorite, Taft Granite, Tamarack Leuco-Adamellite, Tejon Lookout Granite, Teutonia Quartz Monzonite, Tinemaha Granodiorite, Tokapah Porphyritic Granodiorite, Tungsten Hills Quartz Monzonite, Weaver Lake Quartz Monzonite, Wheeler Crest Quartz Monzonite, White Tank Quartz Monzonite, Woodson Mountain Granodiorite, Vermont Quartz Diorite
gr^{Pz}	Paleozoic and Permo-Triassic granitic rocks	Mount Lowe Granodiorite, Parker Quartz Diorite
$\text{gr}^{p€}$	Precambrian granitic rocks	Echo Granite
gr	Undated granitic rocks	No formally named units

Symbol on 1:750,000 map	Map Unit	Formations Included
um	Ultramafic rocks, chiefly Mesozoic	No formally named units
gb	Mesozoic gabbroic	Cuyamaca Gabbro, Elk Creek Gabbro, Gold Park Gabbro-Diorite, San Marcos Gabbro, Summit Gabbro
Mzv	Mesozoic volcanic and metavolcanic rocks; Franciscan volcanic rocks	Bagley Andesite, Black Mountain Volcanics, Brower Creek Volcanic Mbr. (of Mariposa Fm.), Bully Hill Rhyolite, Copper Hill Volcanics, Cuesta Diabase, Del Puerto Keratophyre Mbr. (of Franciscan Fm.), Foreman Fm., Franciscan Fm. (volcanic rocks), Gopher Ridge Volcanics, Hinchman Fm., Hull Fm., Kettle Fm. (of McMath), Logtown Ridge Fm., Lotta Creek Tuff Mbr (of Franciscan Fm.), Mariposa Fm. (in part), Milton Fm. (in part), Ord Mountain Group, Oregon City Fm., Osos Basalt, Peaslee Creek Volcanics, Penon (Penyon) Blanco Volcanics, Pit Fm. (in part), Sailor Canyon Fm. (in part), Santiago Peak Volcanics, Sidewinder Volcanic Series, Soda Mountain Fm. (in part), Temescal Wash Quartz Latite Porphyry, Warm Spring Fm. (in part)
mv	Undivided pre-Cenozoic metavolcanic rocks	Hodge Volcanic Fm., McCoy Mountain Fm. (in part)
Pzv	Paleozoic metavolcanic rocks	Baird Fm. (in part), Balaklala Rhyolite, Bass Mountain Diabase, Bean Canyon Fm. (in part), Calaveras Fm. (in part), Copley Greenstone, Dekkas Andesite, Hite Cove Fm. (in part), Nosoni Fm., Peale Fm. (in part), Reeve Fm., (of McMath), Taylor Fm.
gr-m	Granitic and metamorphic rocks undivided, of pre-Cenozoic age	Ash Mountain Complex, Placerita Fm. (in part)
m	Undivided pre-Cenozoic metasedimentary and metavolcanic rocks	Kaweah Series, Kernville Series, McCoy Mountain Fm. (in part), Palm Canyon Complex, Pampa Schist, Placerita Fm. (in part), San Antonio Canyon Group, Stuart Fork Fm., Sur Series (in part)
p€c	Precambrian igneous and metamorphic rock complex	Chuckwalla Complex, Cucamonga Complex, San Gabriel Complex, San Gorgonio Igneous-Metamorphic Complex

APPENDIX D

SOURCE DATA INDEX

Following the format of earlier Division of Mines and Geology indexes to published geologic maps and indexes to theses (see below), this index is organized by State Geologic Atlas sheets (generally 1° x 2° quadrangles). In determining the references used for any particular area on the Geologic Map of California, or the basis on which a fault was classified on the Fault Map of California, the map-user must first determine the State Atlas sheet on which his area of interest lies. If not particularly familiar with these sheets, the map-user should refer to the State Index Map (Figure 16), which shows the boundaries of the individual Atlas sheets. Once the map-user knows the appropriate Atlas sheet, he can use the index map and bibliography for that sheet to determine the source data used.

HOW TO USE THIS INDEX

This index should be used in conjunction with the "Index to Geologic Mapping" accompanying each sheet of the Geologic Atlas of California, 1:250,000 series. It supplements the source data given in the Atlas sheet indexes; only references that were published or acquired *subsequent* to the issuance of the corresponding State Geologic Atlas sheet, as well as additional references that were used in classifying faults, are shown in Appendix D. Some of these references were received late, and may not have been used (or were used only in part) in the compilation of the Fault Map of California and the Geologic Map of California. They are included here because of their potential usefulness to persons seeking more recent references for an area.*

Because the primary purpose of the Fault Map of California is to provide more information on individual faults, especially for active or potentially active ones, particular attention has been given to providing references to the historic and Quaternary faults. For ease in locating references on specific historic or Quaternary faults, the index maps have selectively shown these faults, albeit in a generalized and simplified form (using solid and dotted lines only). For more accurate depiction of these faults, the reader should refer to the 1:750,000 Fault Map of California. If no source data are given for a specific fault shown on the index sheets, then the reference(s) used were taken from the published 1:250,000 State Geologic Atlas sheets, and the reader should consult the Atlas and its accompanying source data indexes.

OTHER REFERENCES

For more extensive references to areal geologic mapping, the reader is referred to the following publications of the California Division of Mines and Geology:

Indexes to Published Geologic Maps

Special Report 52, Index to Geologic Maps of California to December 31, 1956, by R. G. Strand, J. B. Koenig, and C. W. Jennings.

Special Report 52-A, Index to Geologic Maps of California, 1957-1960, by J. B. Koenig.

Special Report 52-B, Index to Geologic Maps of California, 1961-1964, by J. B. Koenig and E. W. Kiessling.

Special Report 102, Index to Geologic Maps of California, 1965-1968, by E. W. Kiessling.

Special Report 130, Index to Geologic Maps of California, 1969-1975, by E. W. Kiessling and D. H. Peterson.

Indexes to Theses

Special Report 74, Index to Graduate Theses on California Geology to December 31, 1961, by C. W. Jennings and R. G. Strand.

Special Report 115, Index to Graduate Theses and Dissertations on California Geology, 1962 through 1972, by G. C. Taylor.

California Geology, February 1978, Index to Graduate Theses and Dissertations on California Geology, 1973 and 1974, by D.H. Peterson and G.J. Saucedo.

California Geology, April 1978, Index to Graduate Theses and Dissertations on California Geology, 1975 and 1976, by D. H. Peterson and G. J. Saucedo.

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*Because of the late publication of this Bulletin (more than ten years after the compilation of the Fault Map of California and the Geologic Map of California), many of the references cited in Appendix D as "work in progress" have subsequently been published. Because of subsequent changes that may have occurred from the "work in progress" stage to the final published work, no attempt has been made to update this Source Data Index with later references. Hence the references cited in Appendix D are largely those that were *actually used* in the compilation of the Fault and Geologic Maps. The source data should be quite complete to approximately 1972. In a few instances this Source Data Index contains some references up to 1975 that were added after the State maps had been compiled and while the text of this bulletin was being written

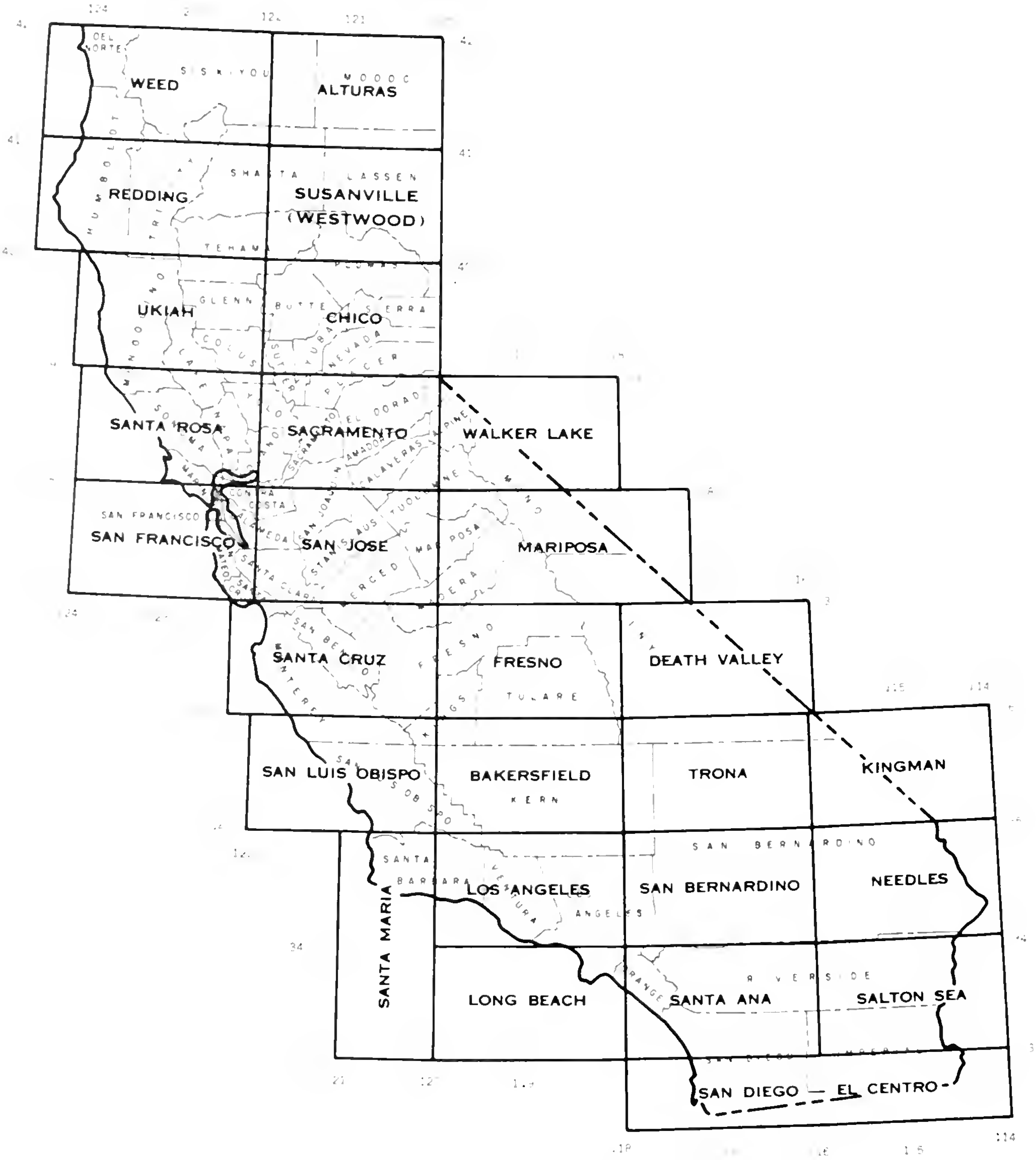


Figure 16. State index map showing the boundaries of the individual Geologic Atlas sheets and the source data index maps in Appendix D.

EXPLANATION OF MAPS

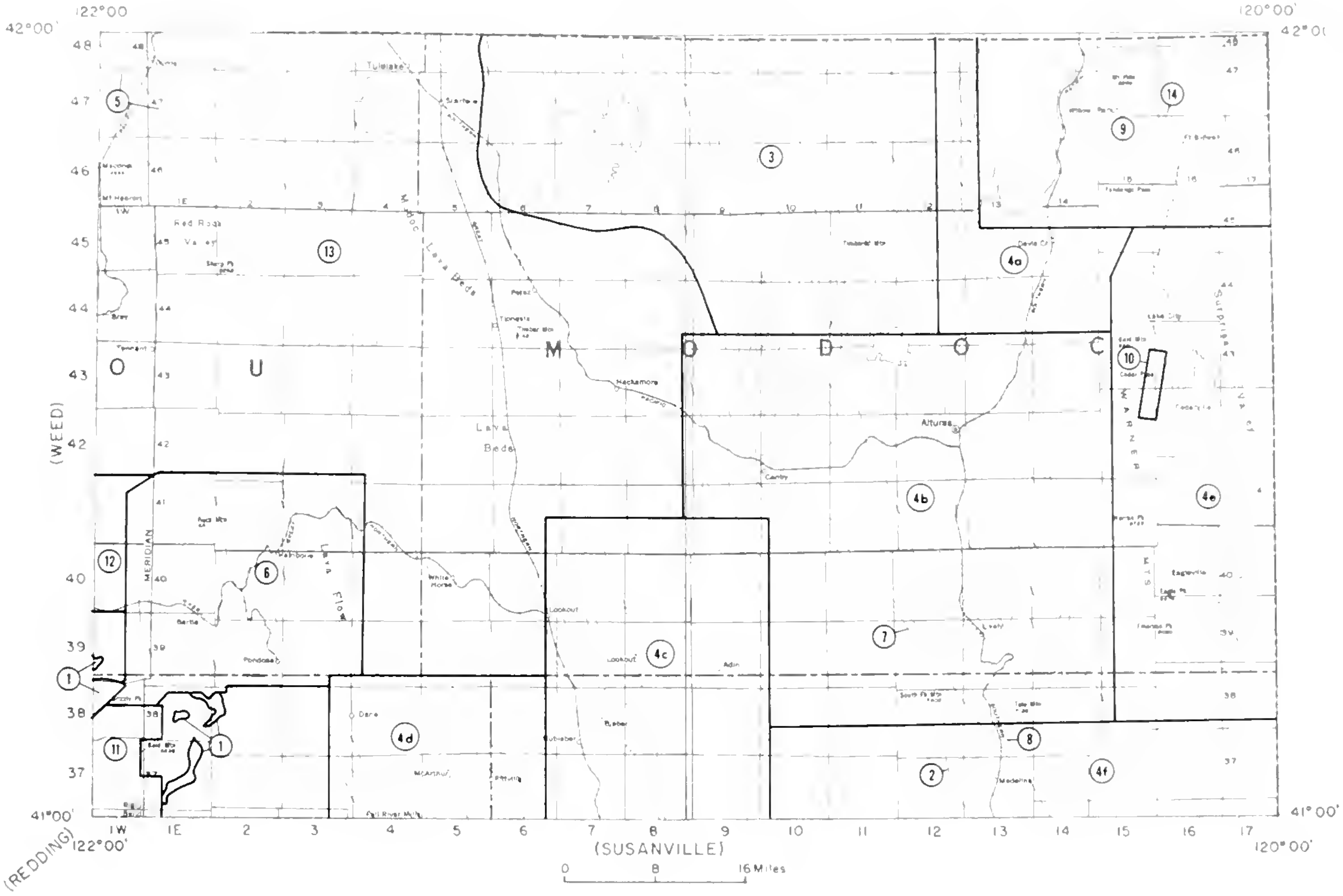
On the following index maps of Appendix D, some of the boundary lines are solid and some are dashed. The dashed boundaries indicate one of the following:

(a) The extent to which a source map was used—that is, that the source map continues farther, but that *other* data were used beyond the dashed boundary.

(b) The area enclosed includes only selected data, for example, fault data only.

(c) The boundary of one map, where two or more maps overlap—in the interest of clarity in cases of overlapping source data.

ALTURAS SHEET



⑤ BIBLIOGRAPHIC DATA REFERENCED ON PAGE BELOW (ALSO SEE EXPLANATION, PAGE 127)

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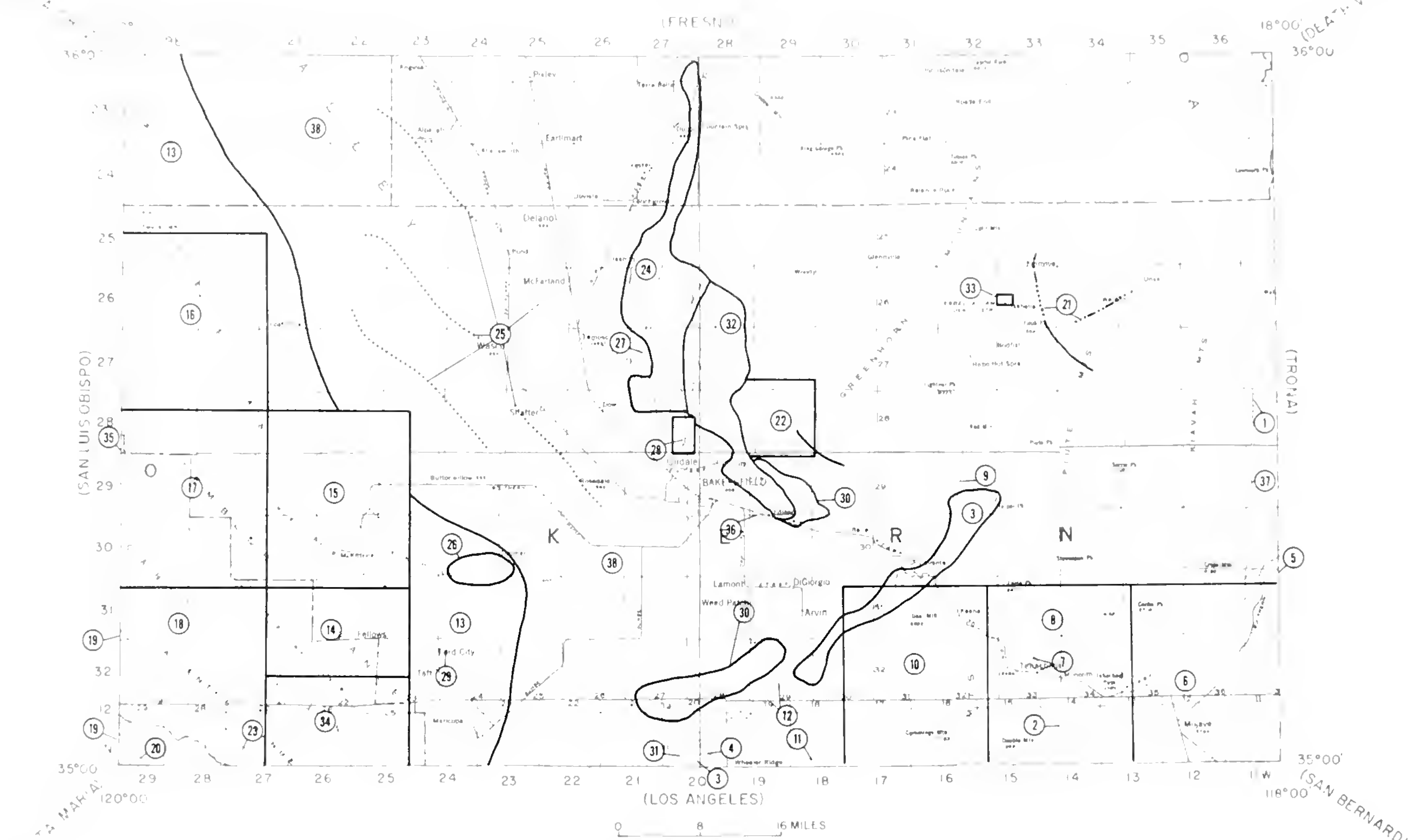

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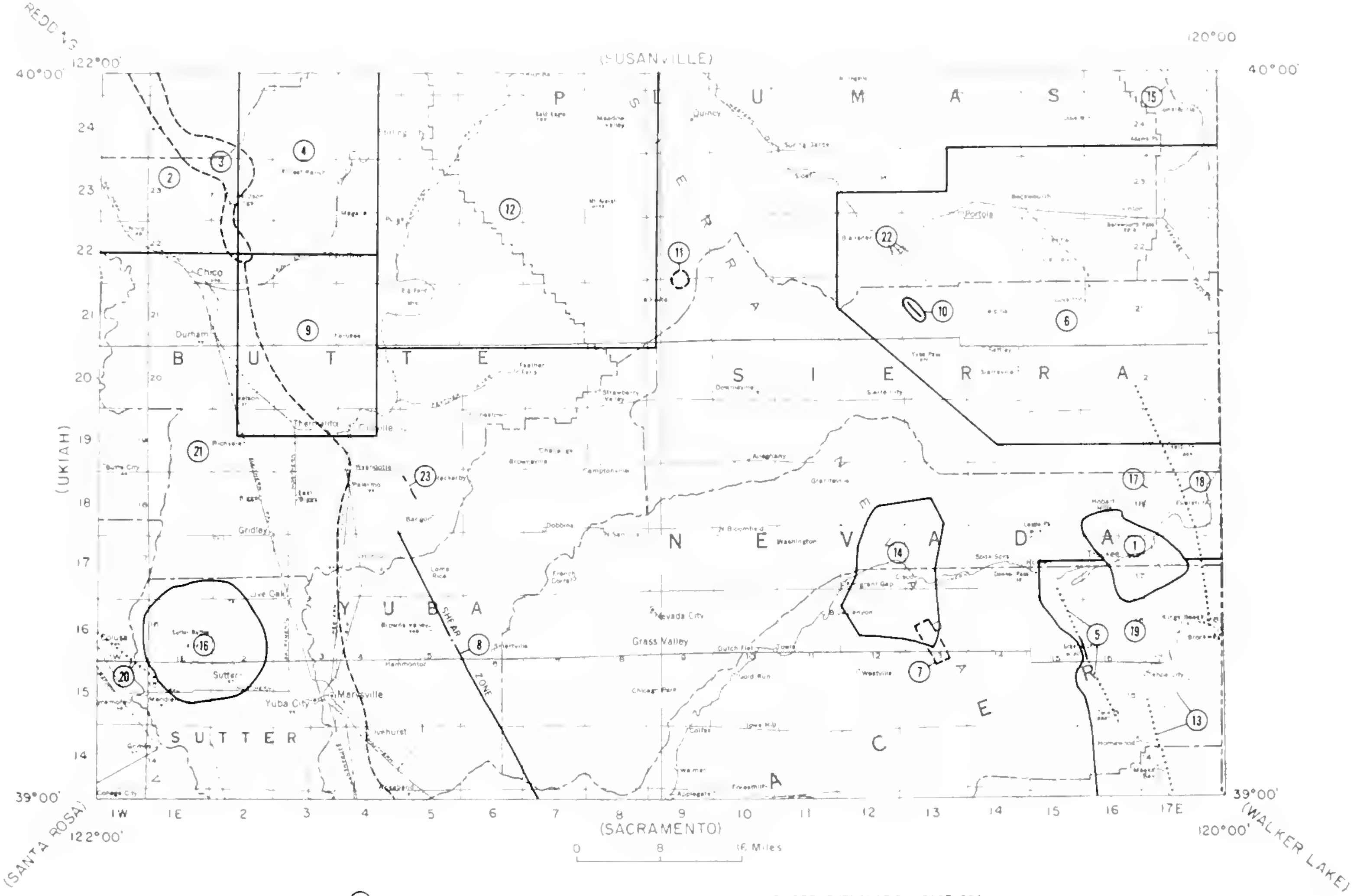

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THERMAL WELL }

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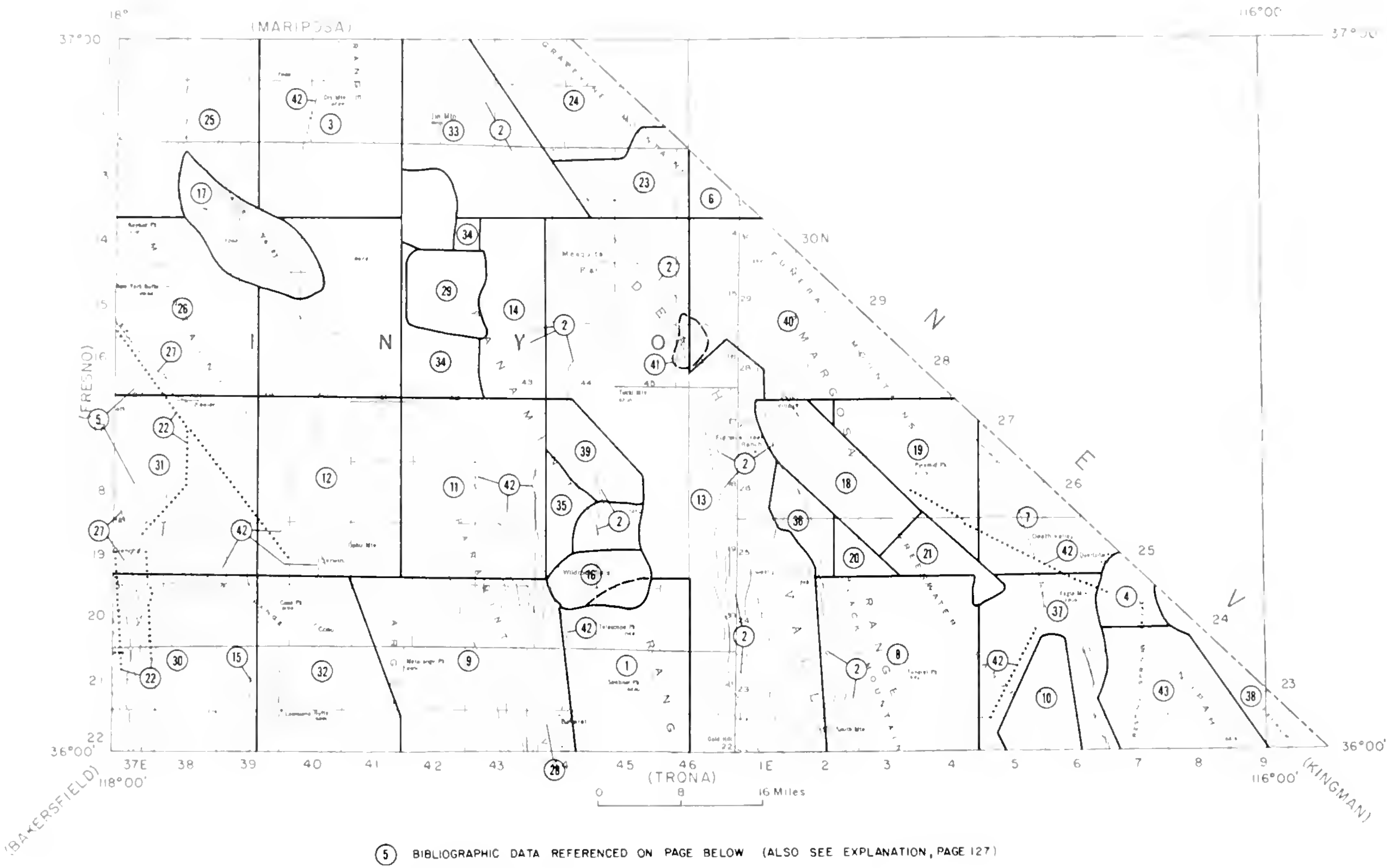

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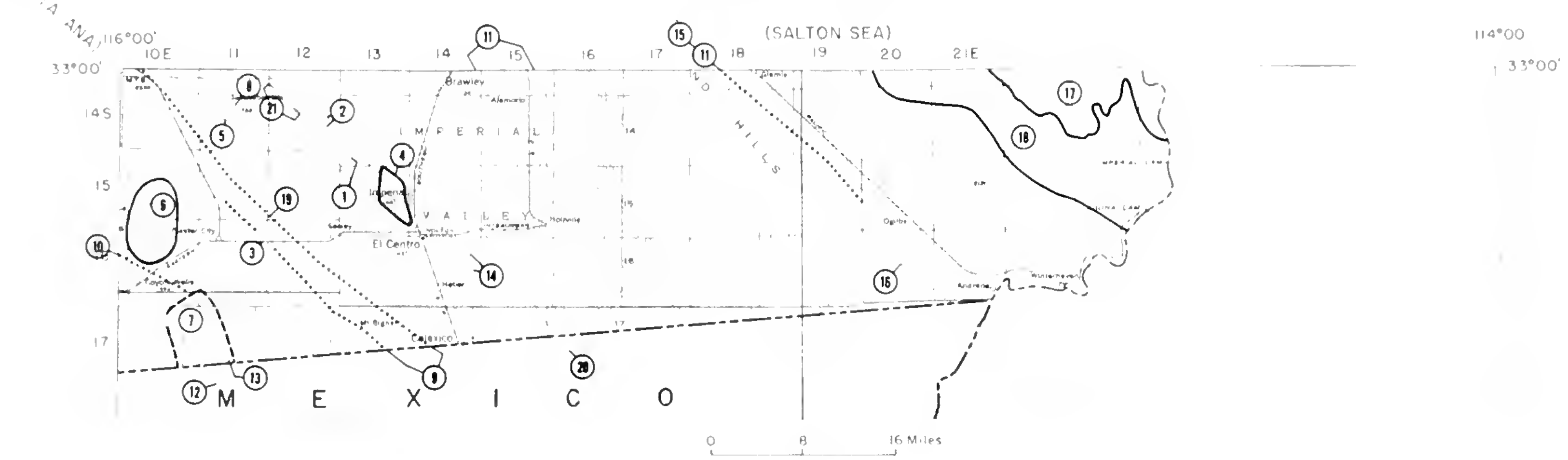

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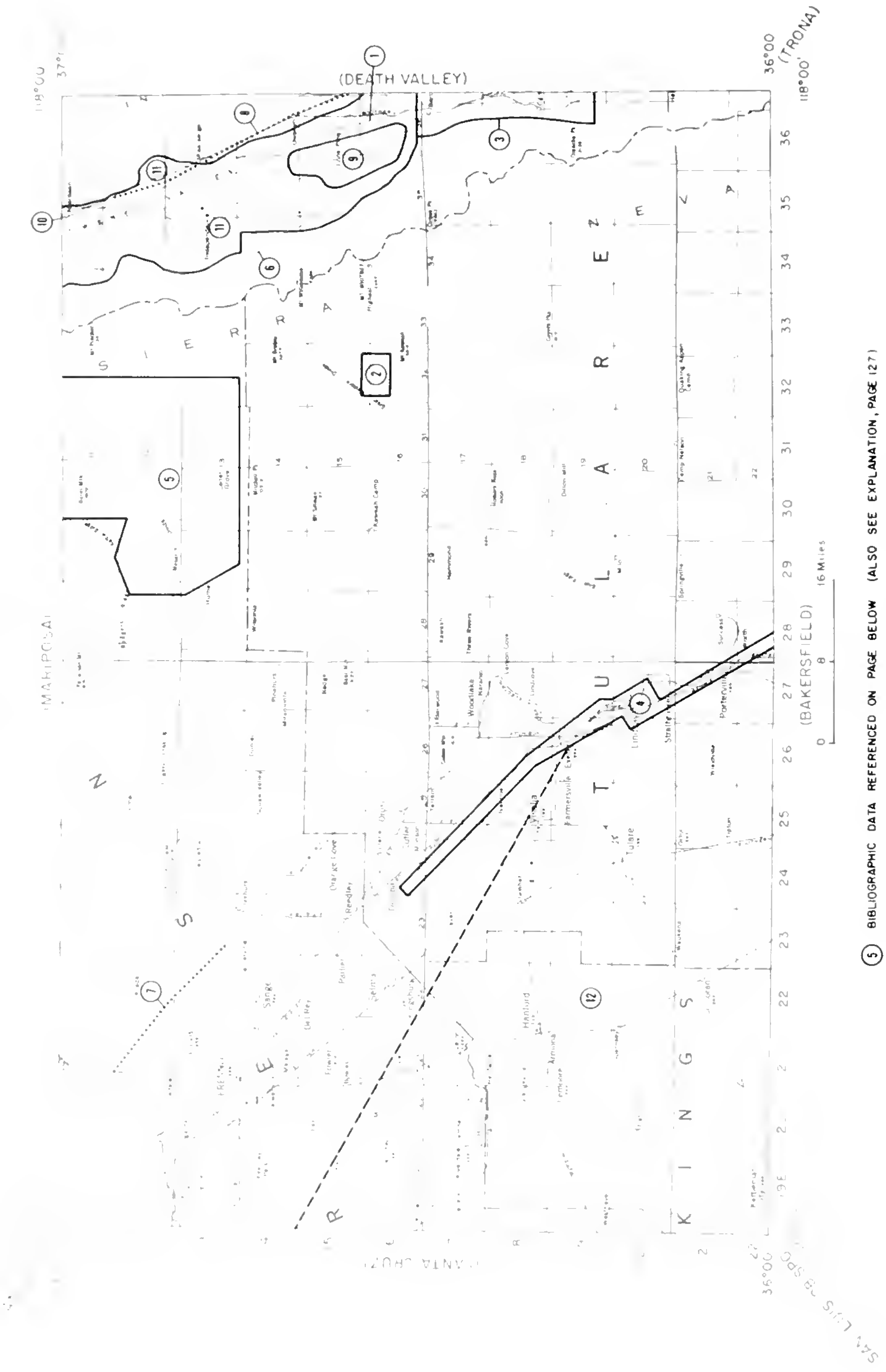

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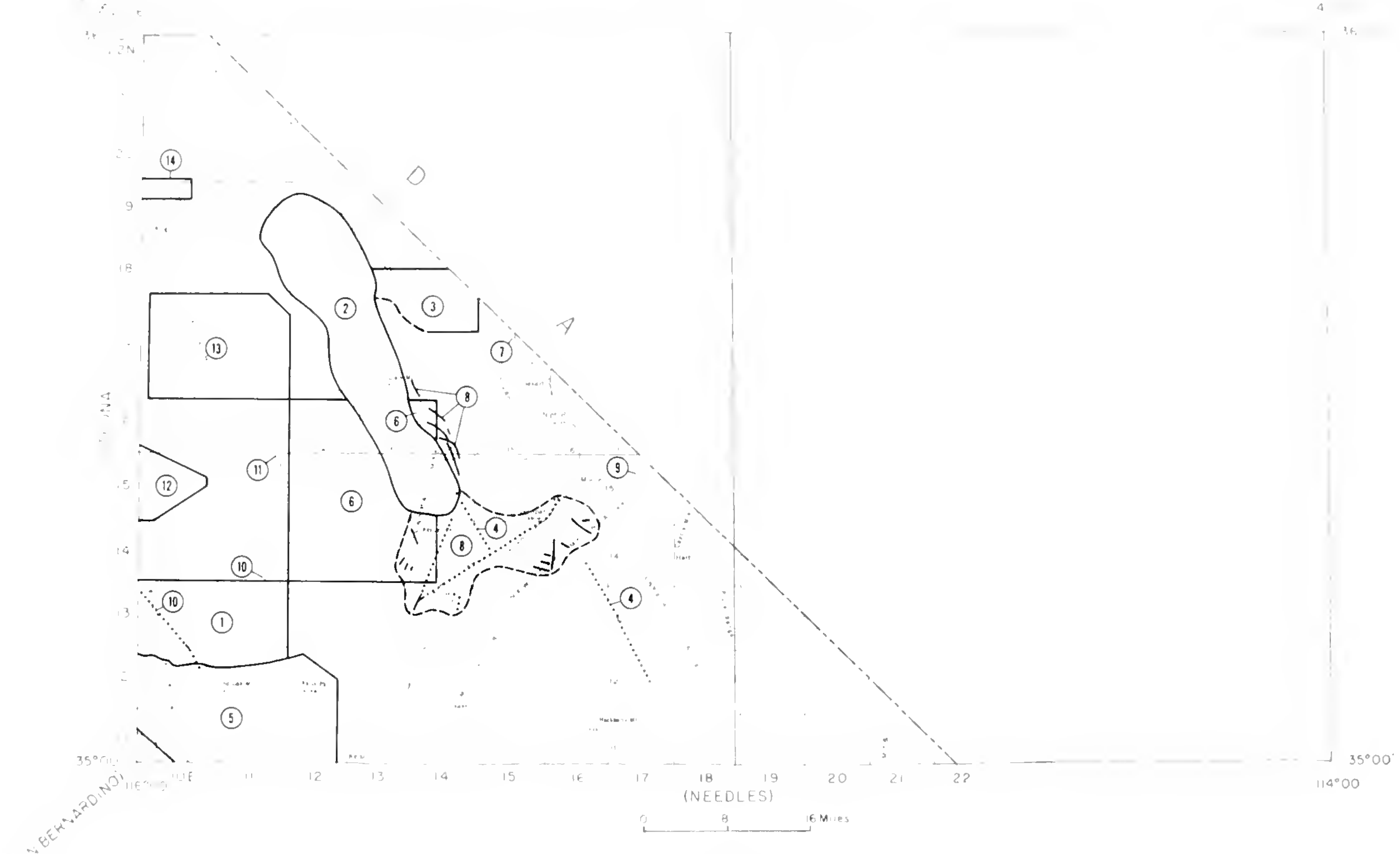

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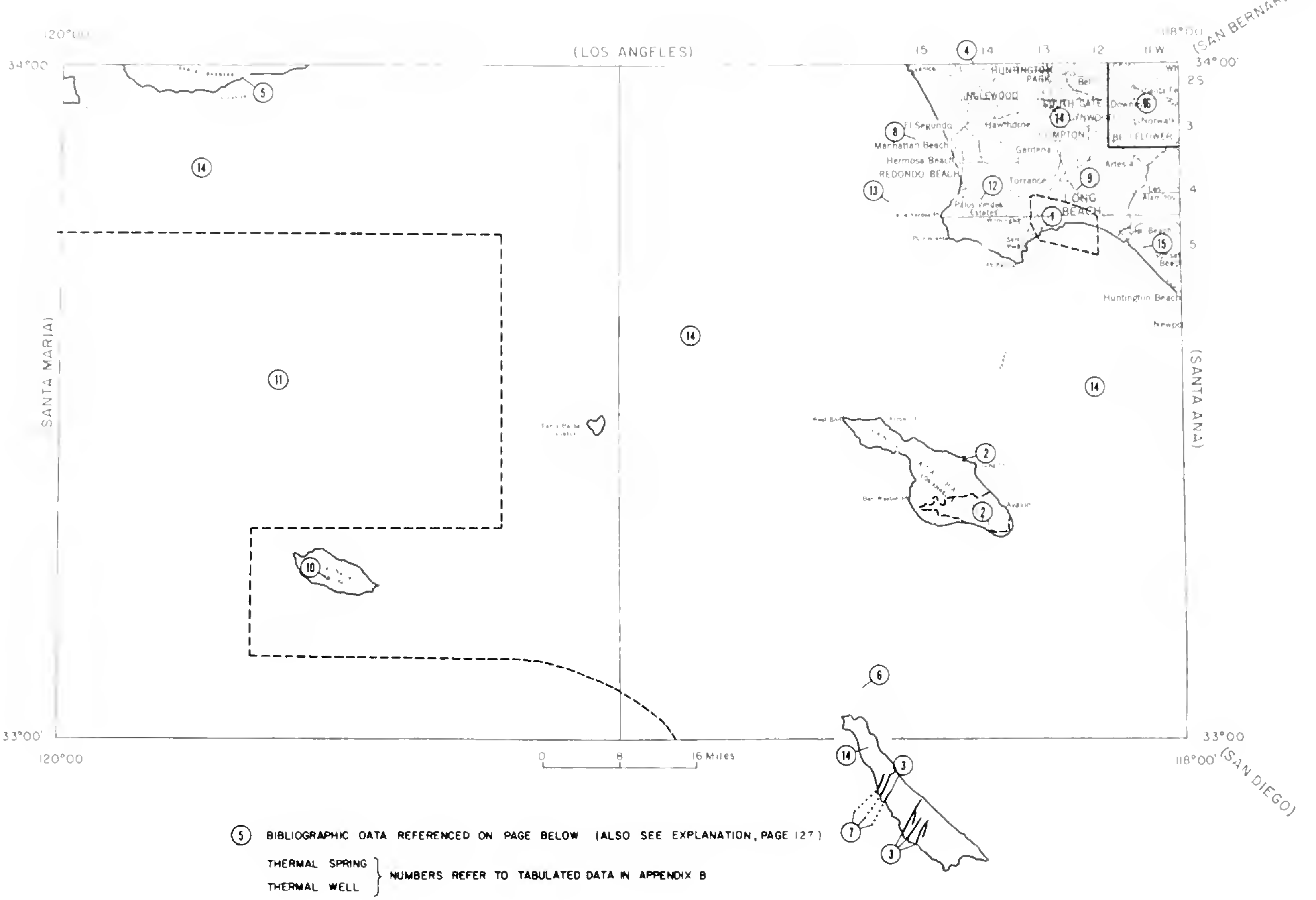

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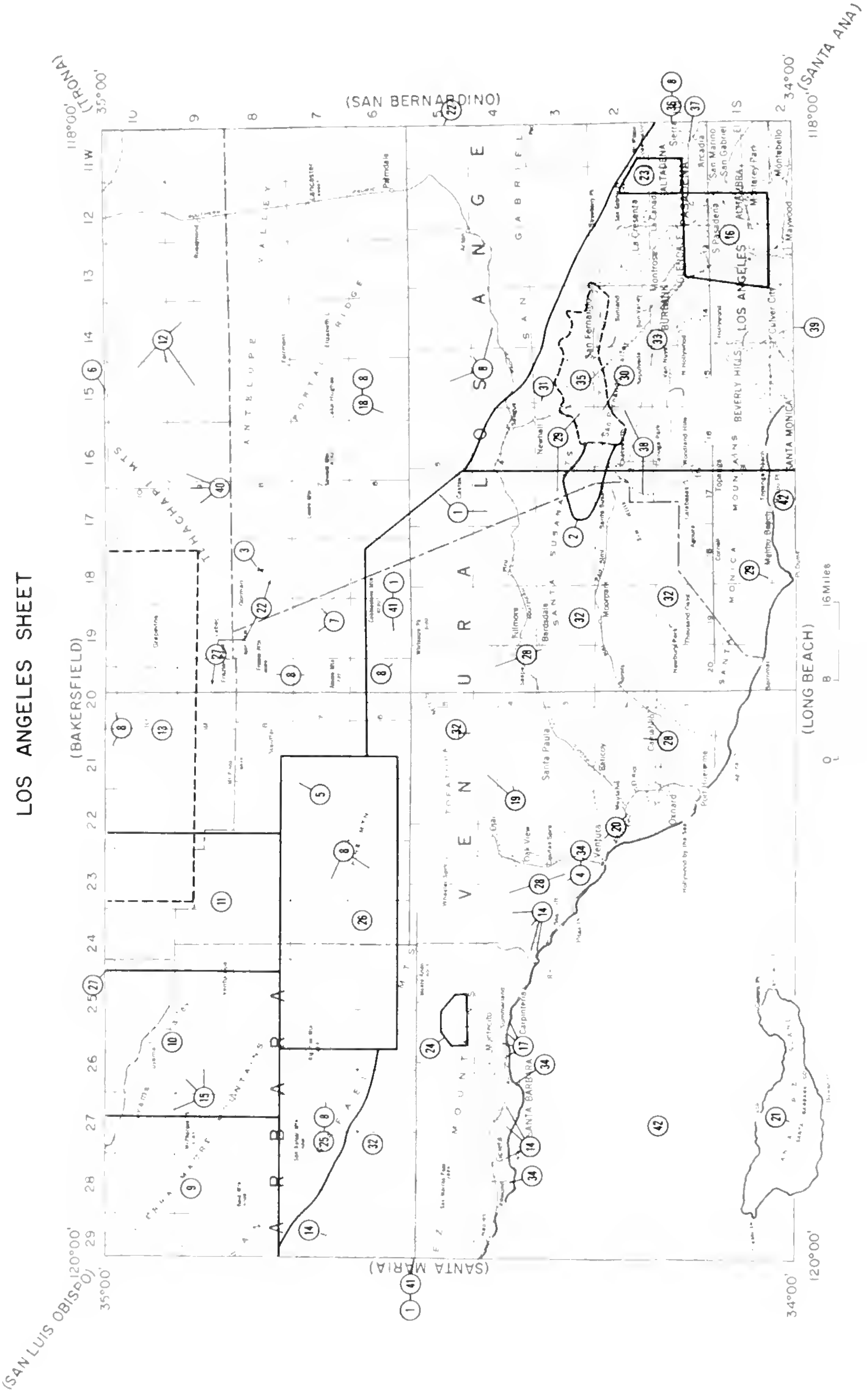

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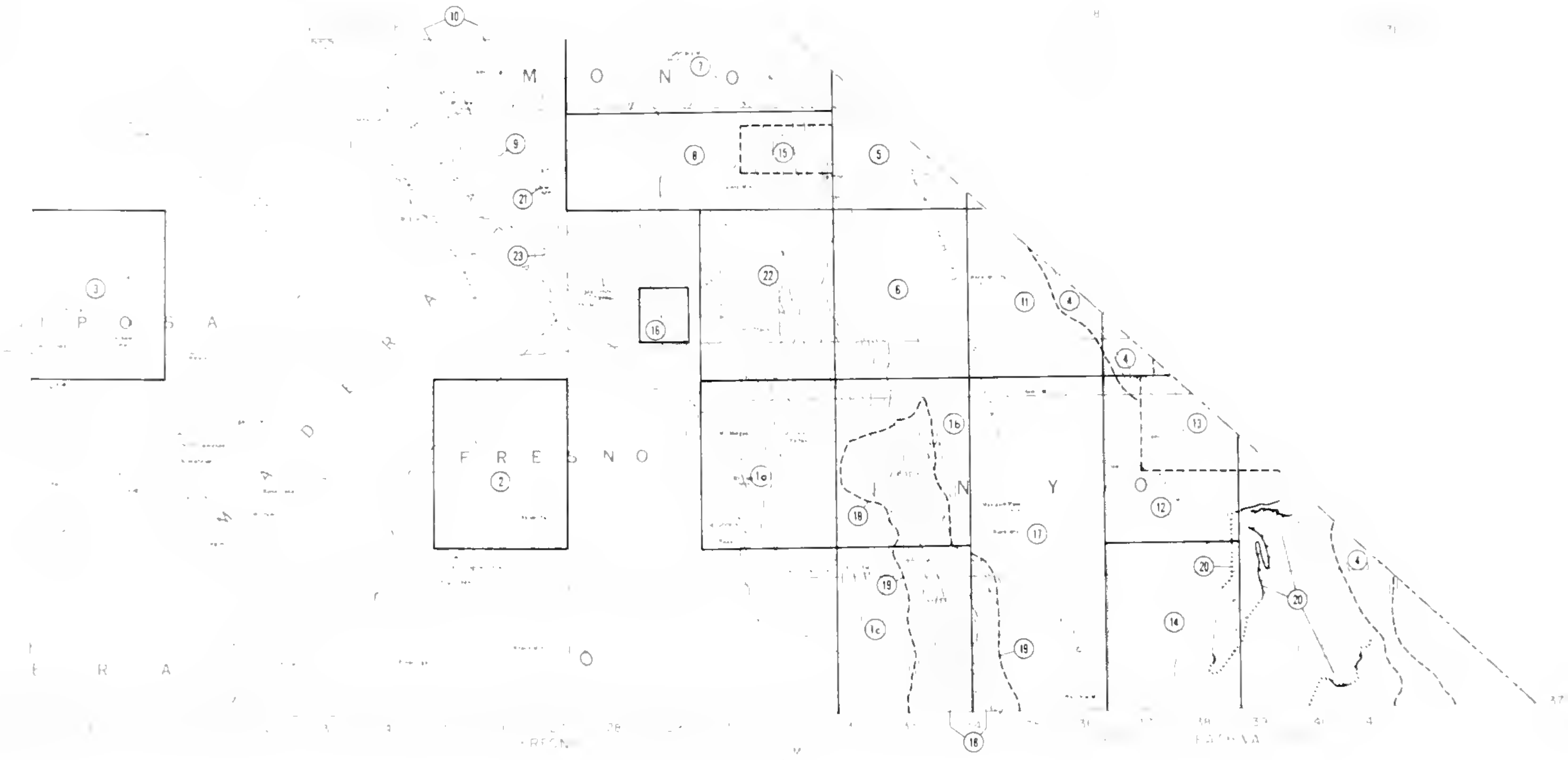

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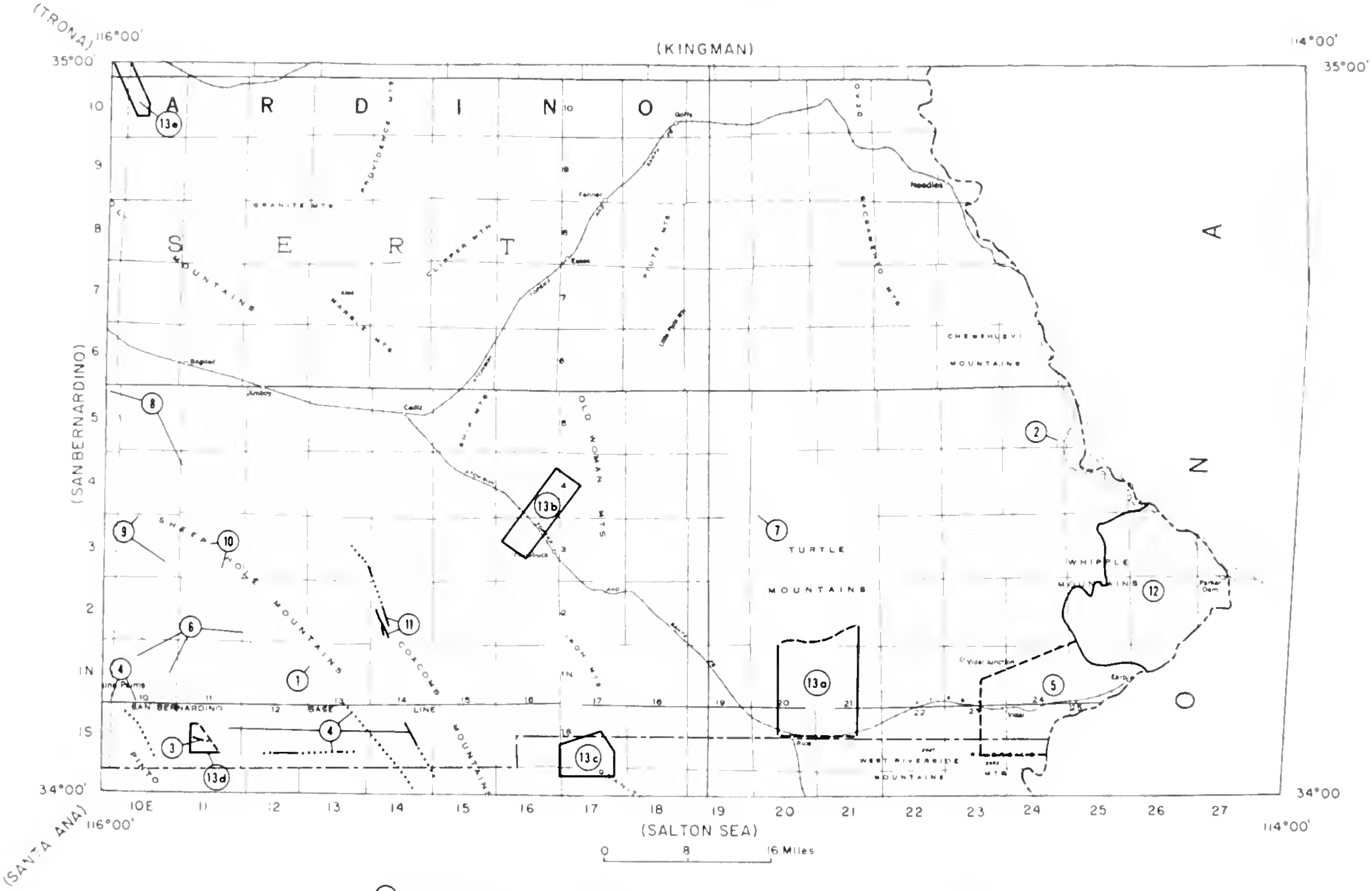

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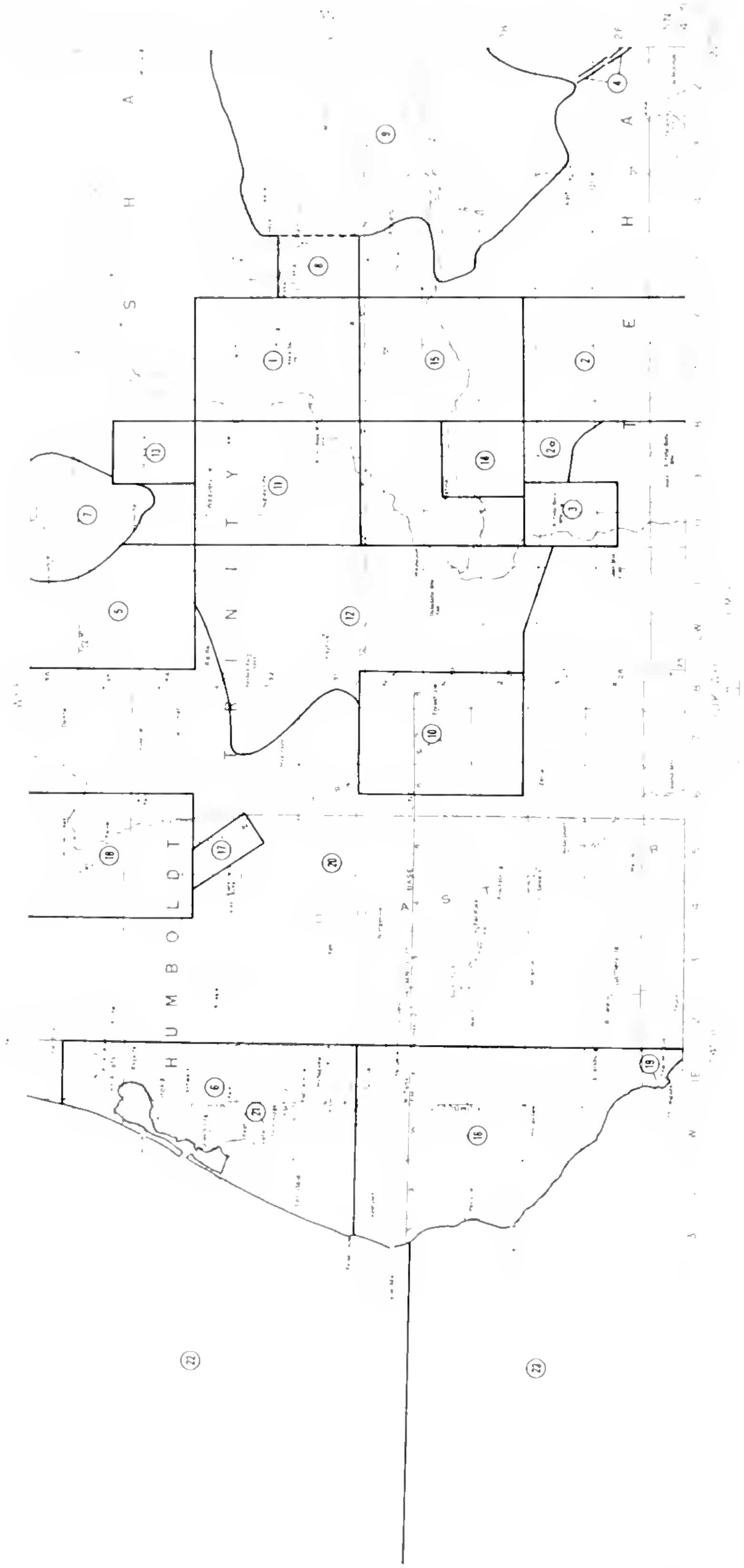

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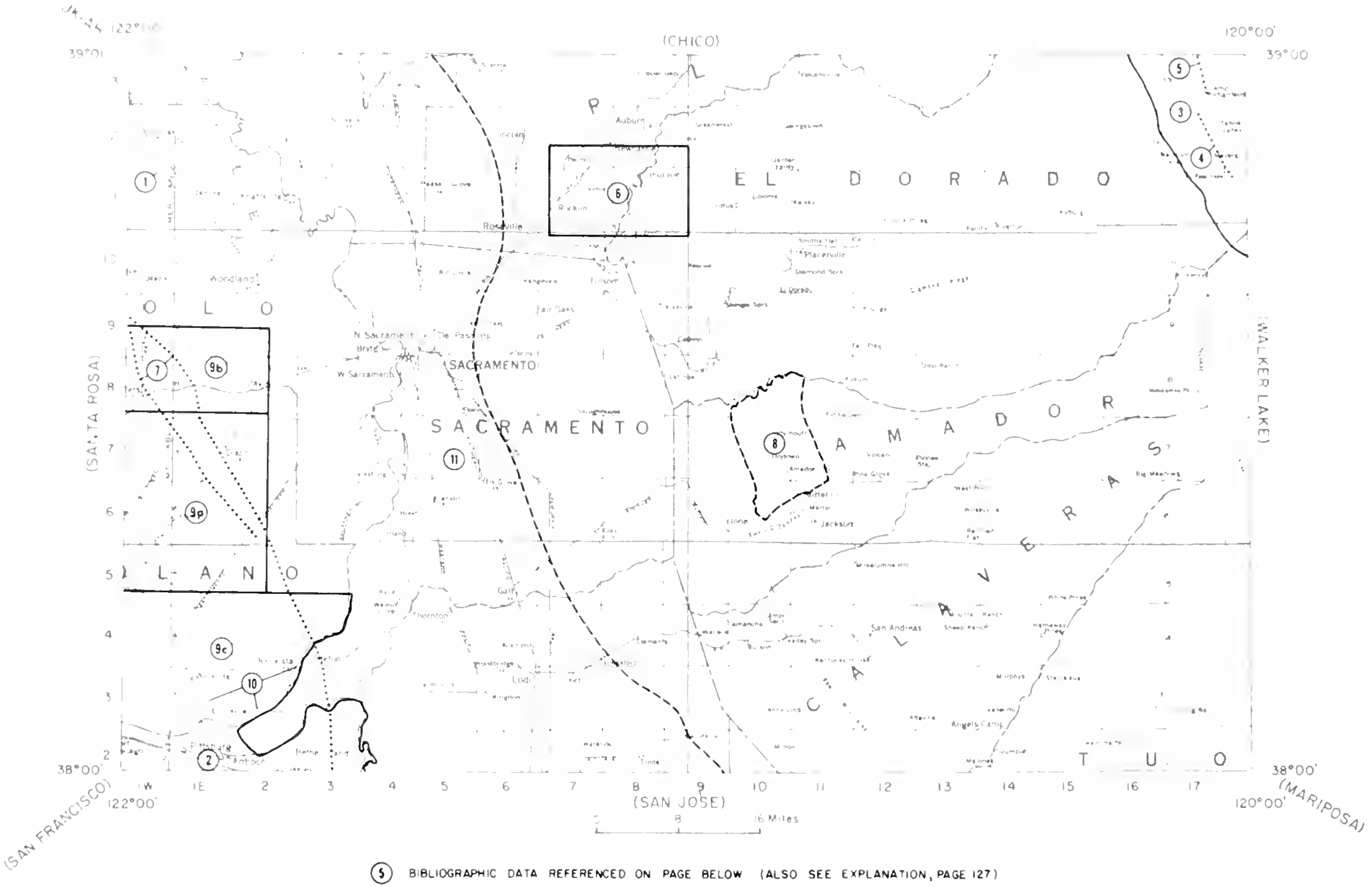

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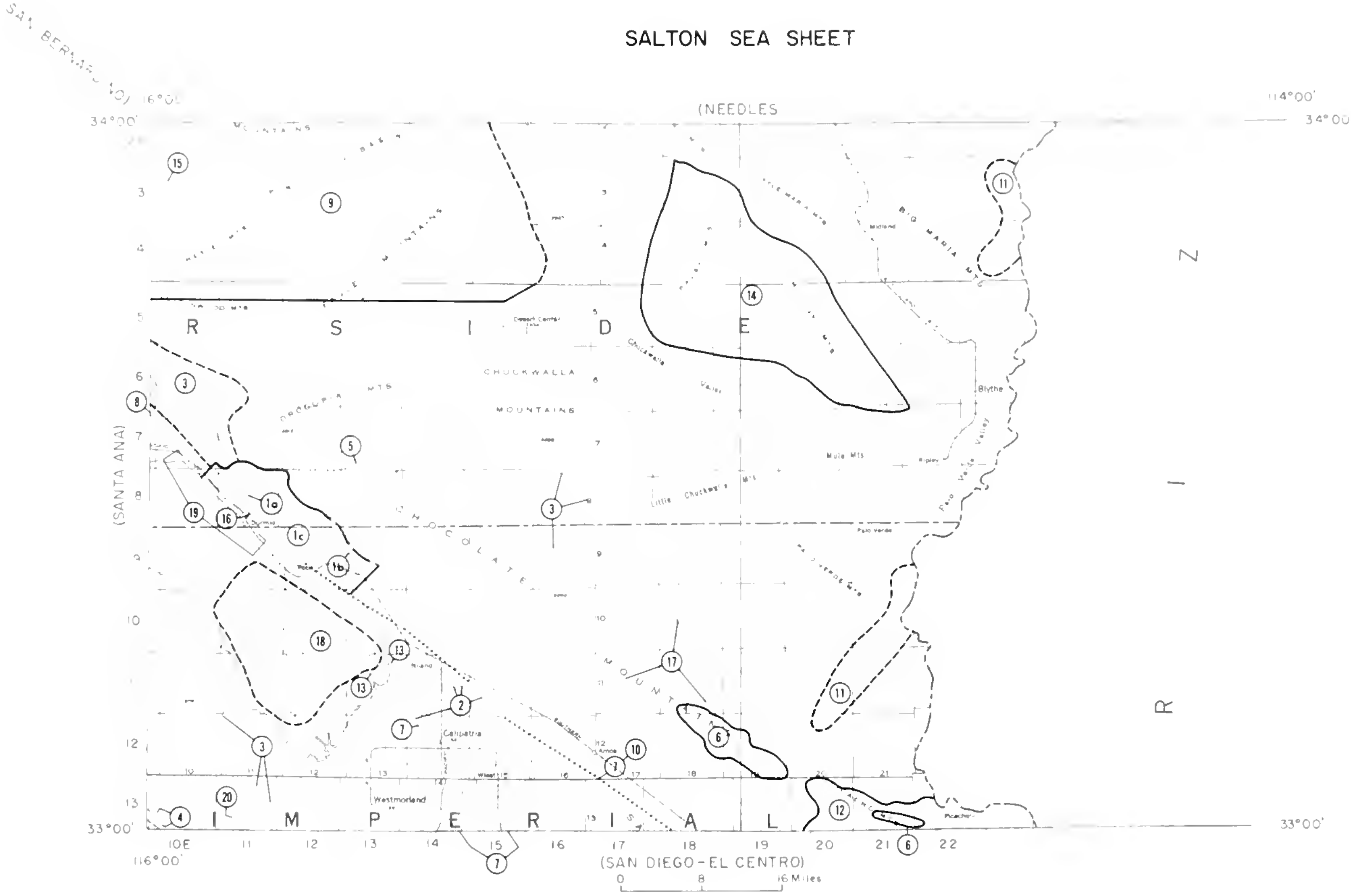

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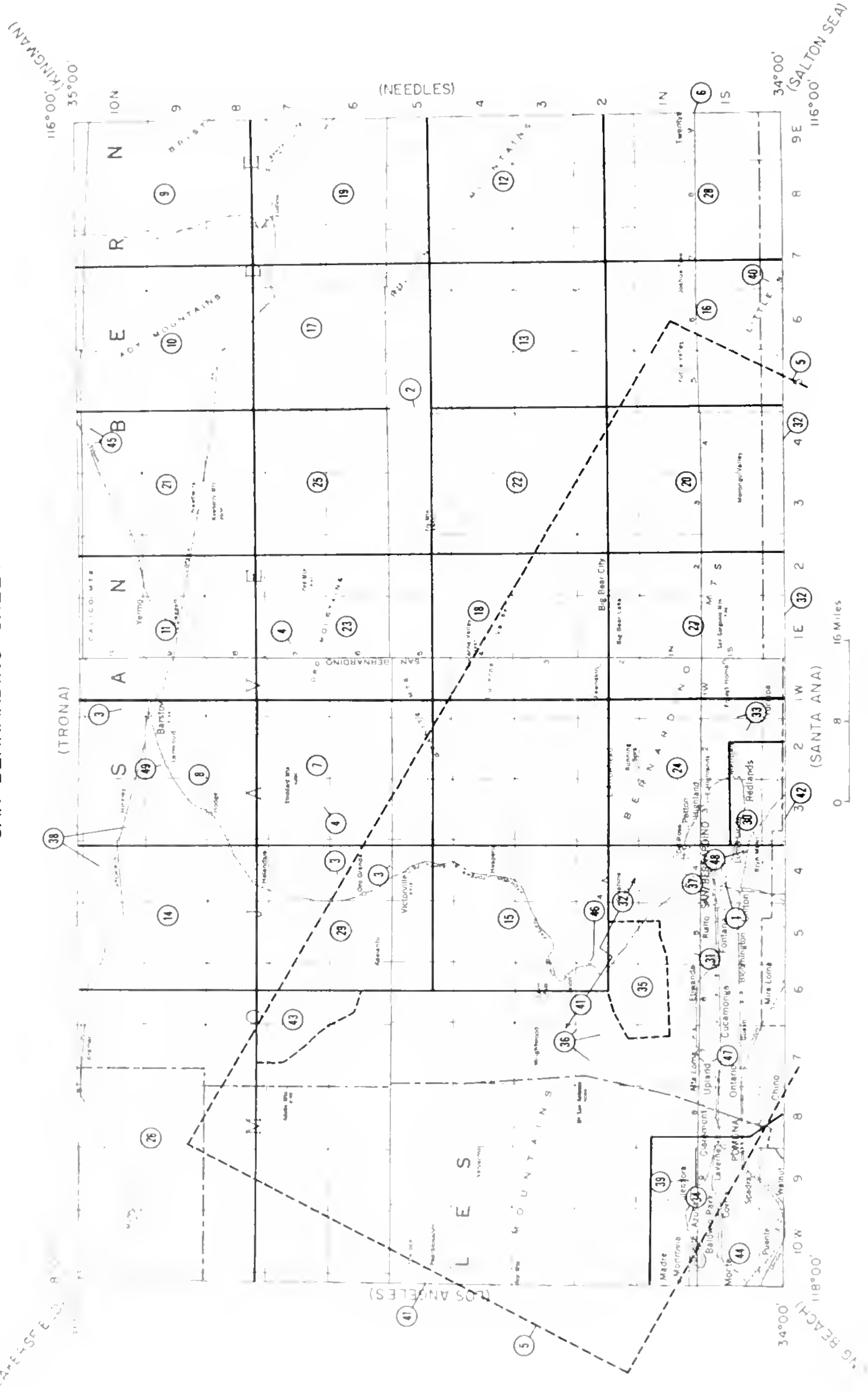

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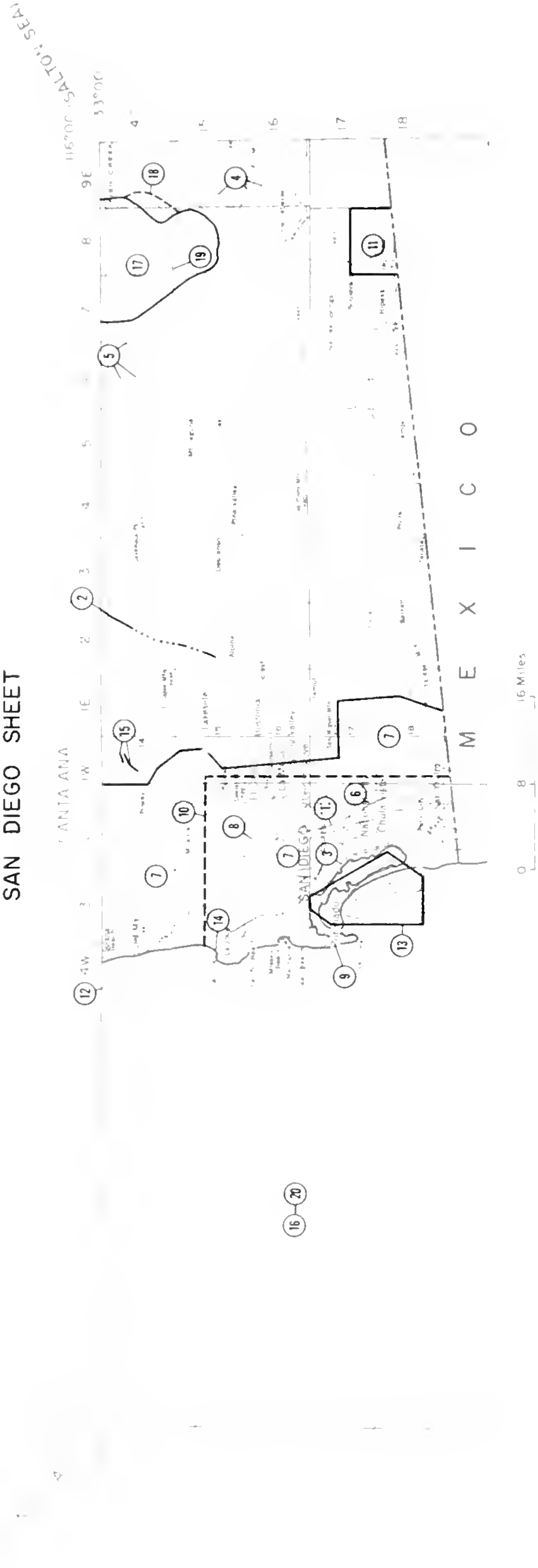

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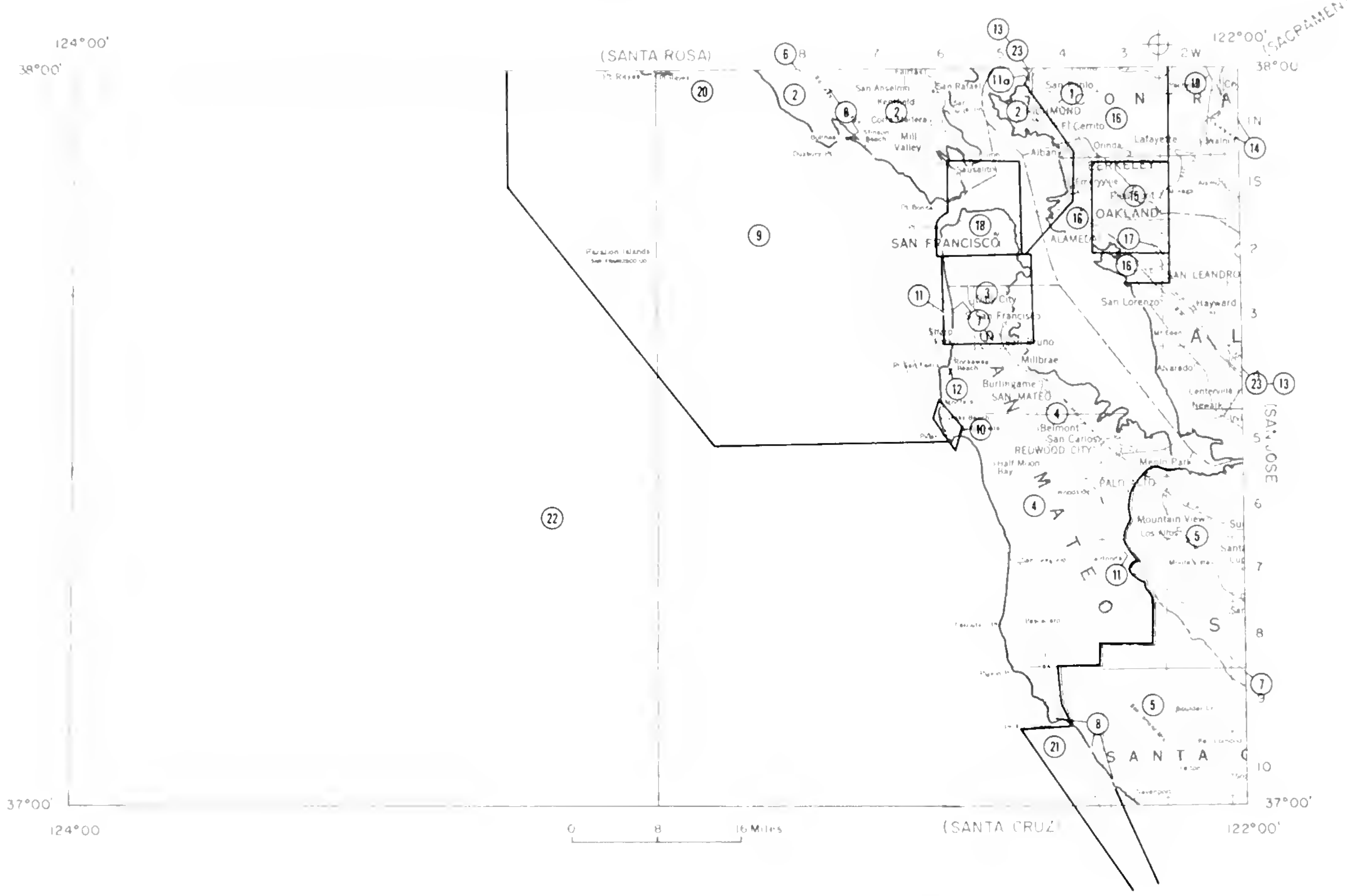

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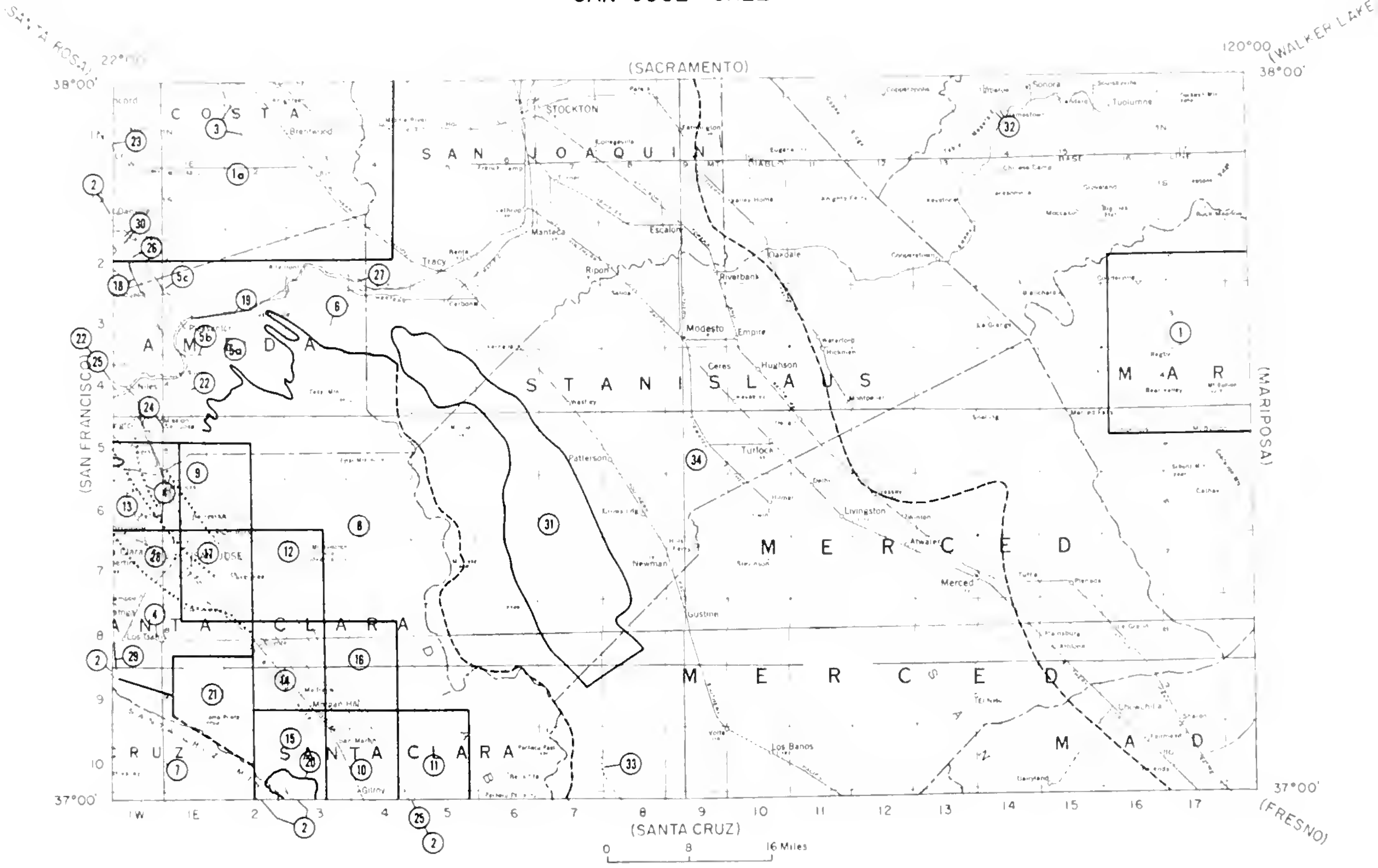

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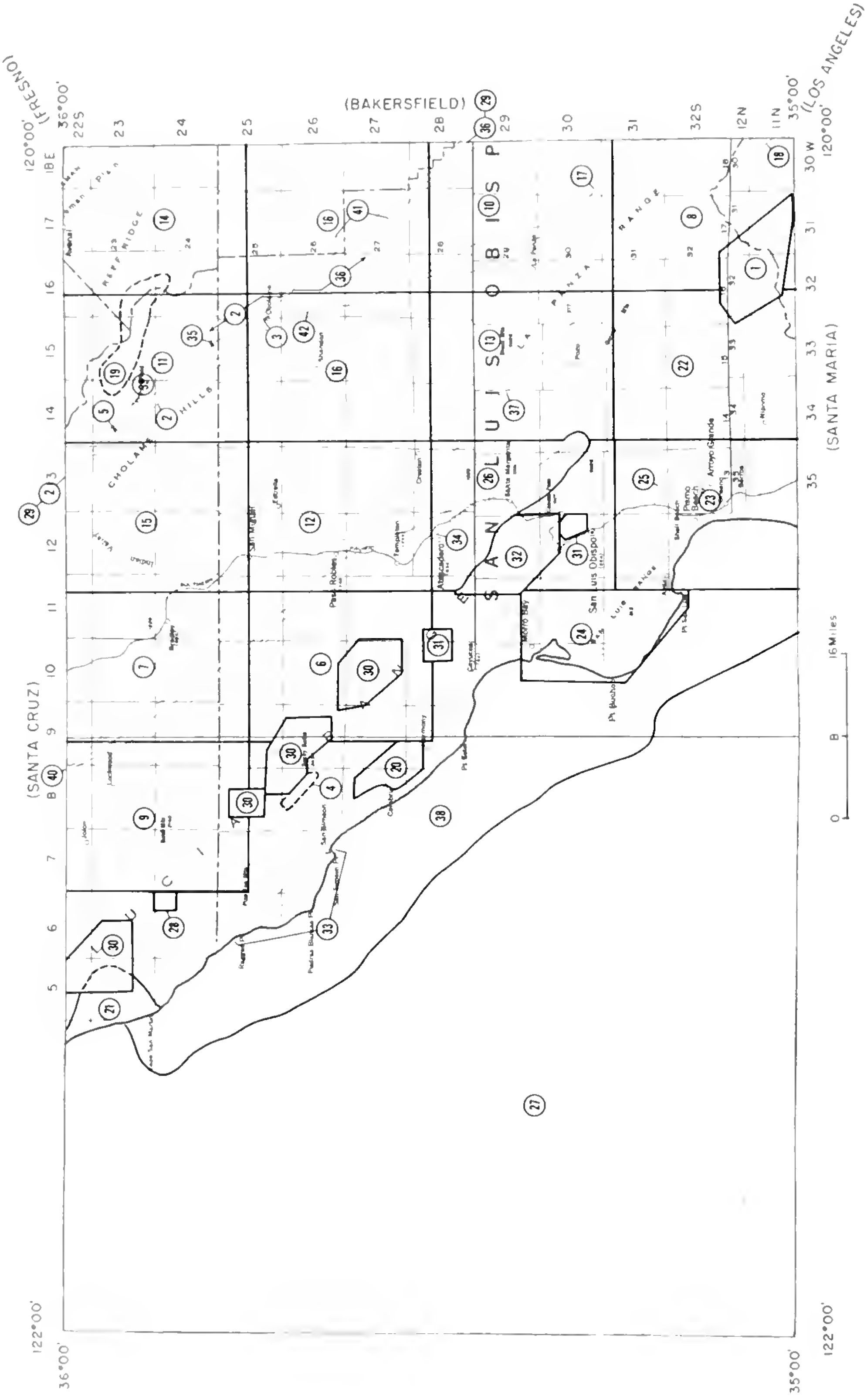

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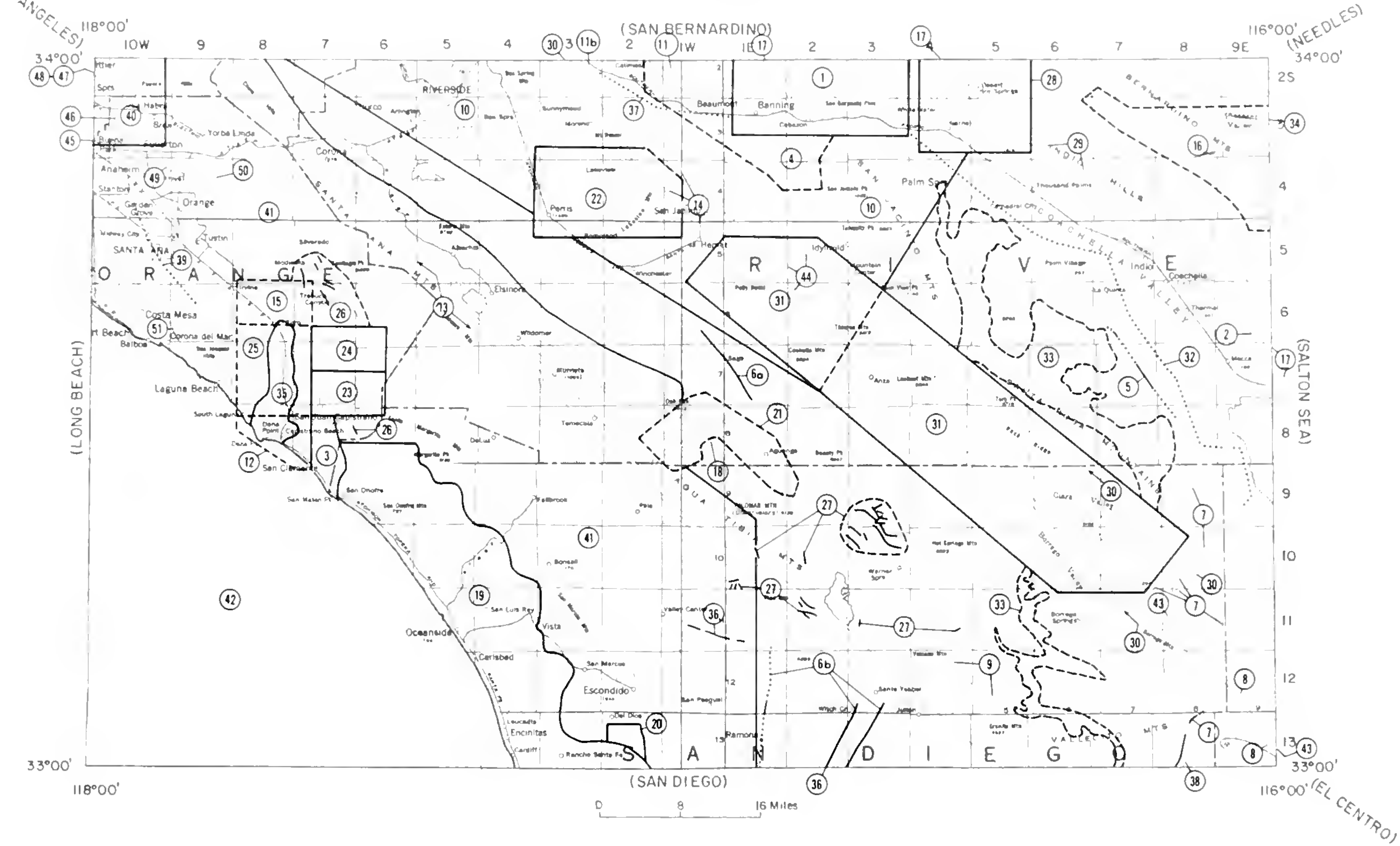

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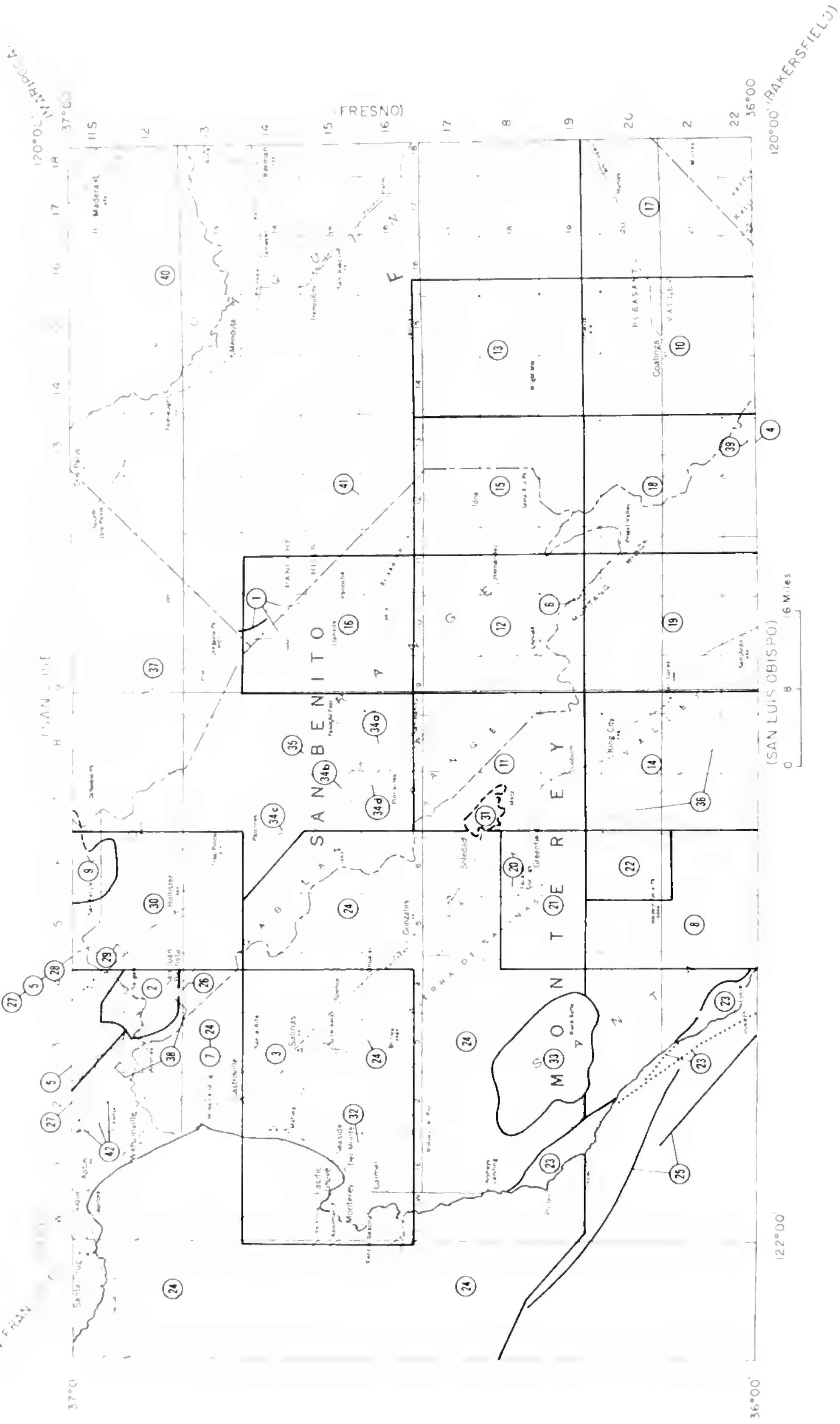

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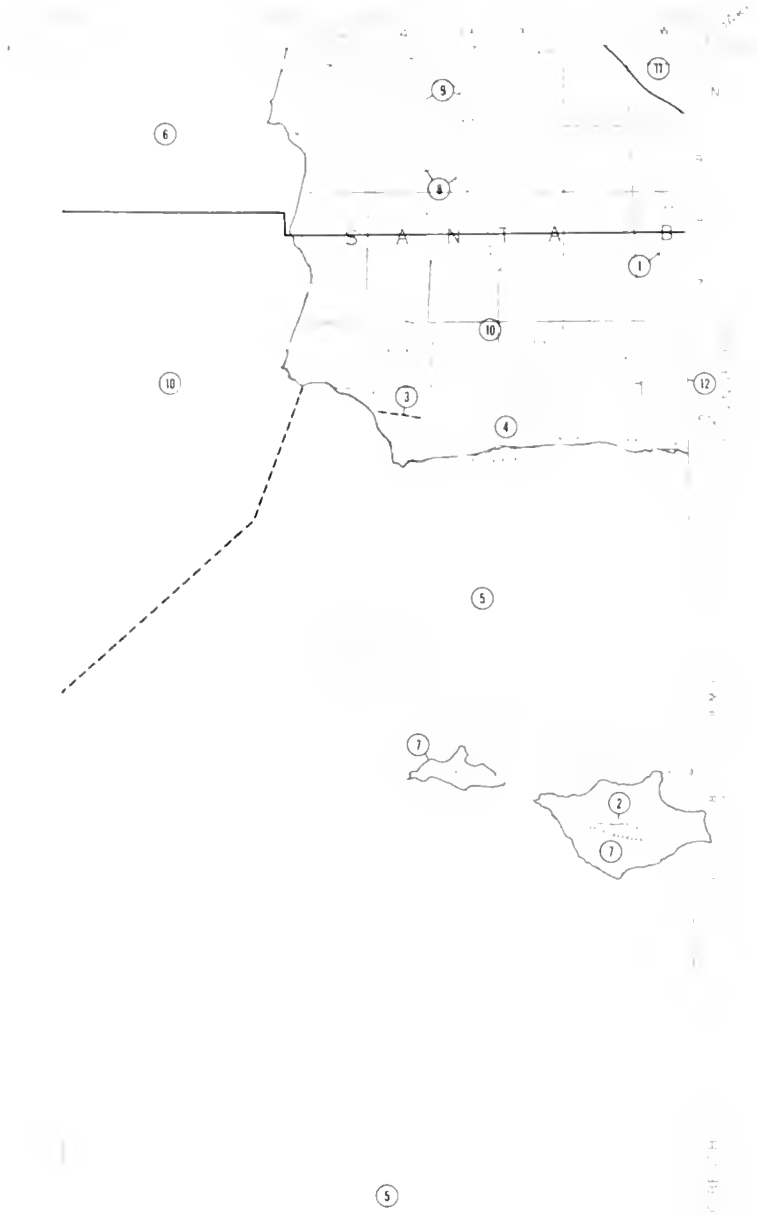

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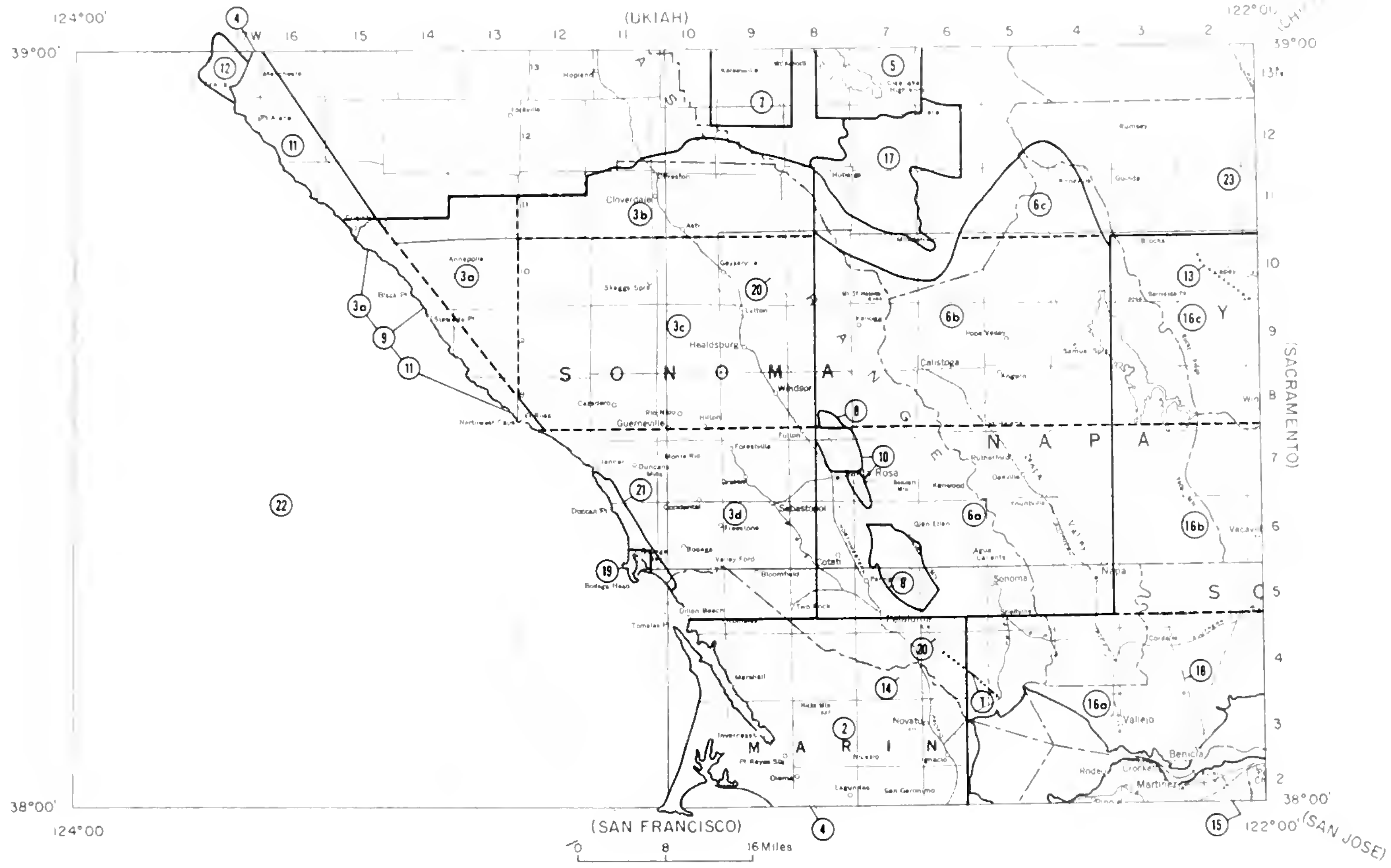

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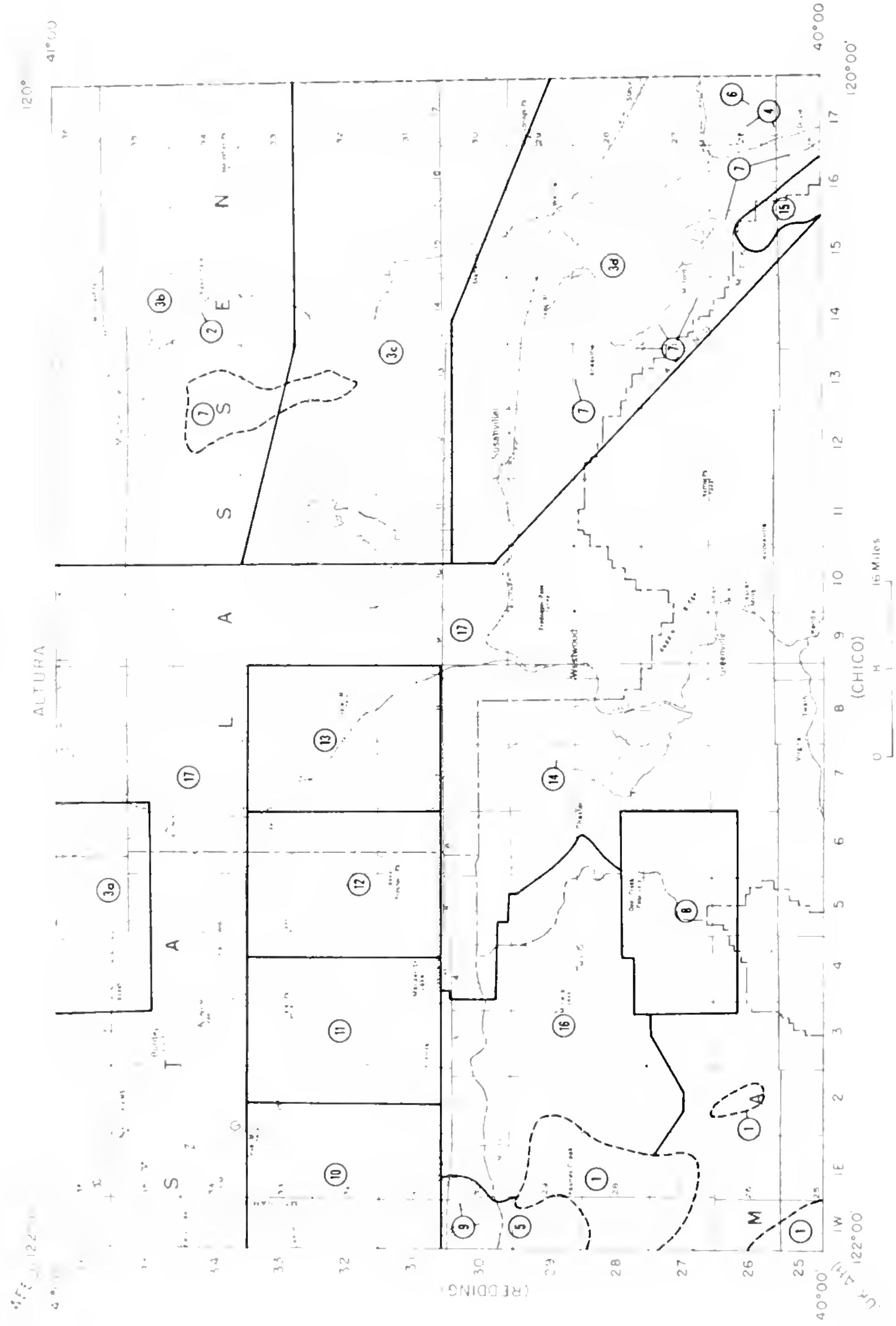

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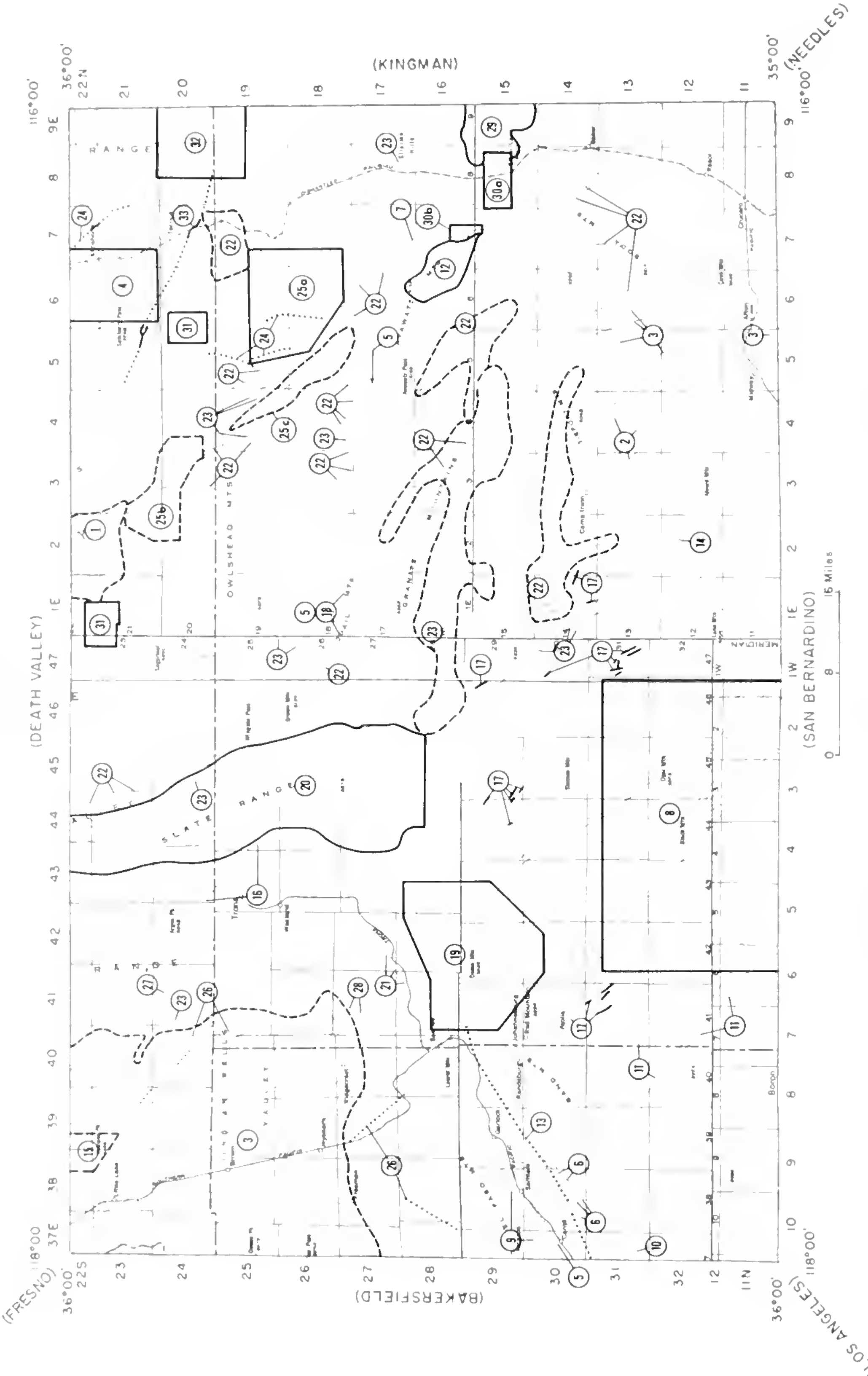

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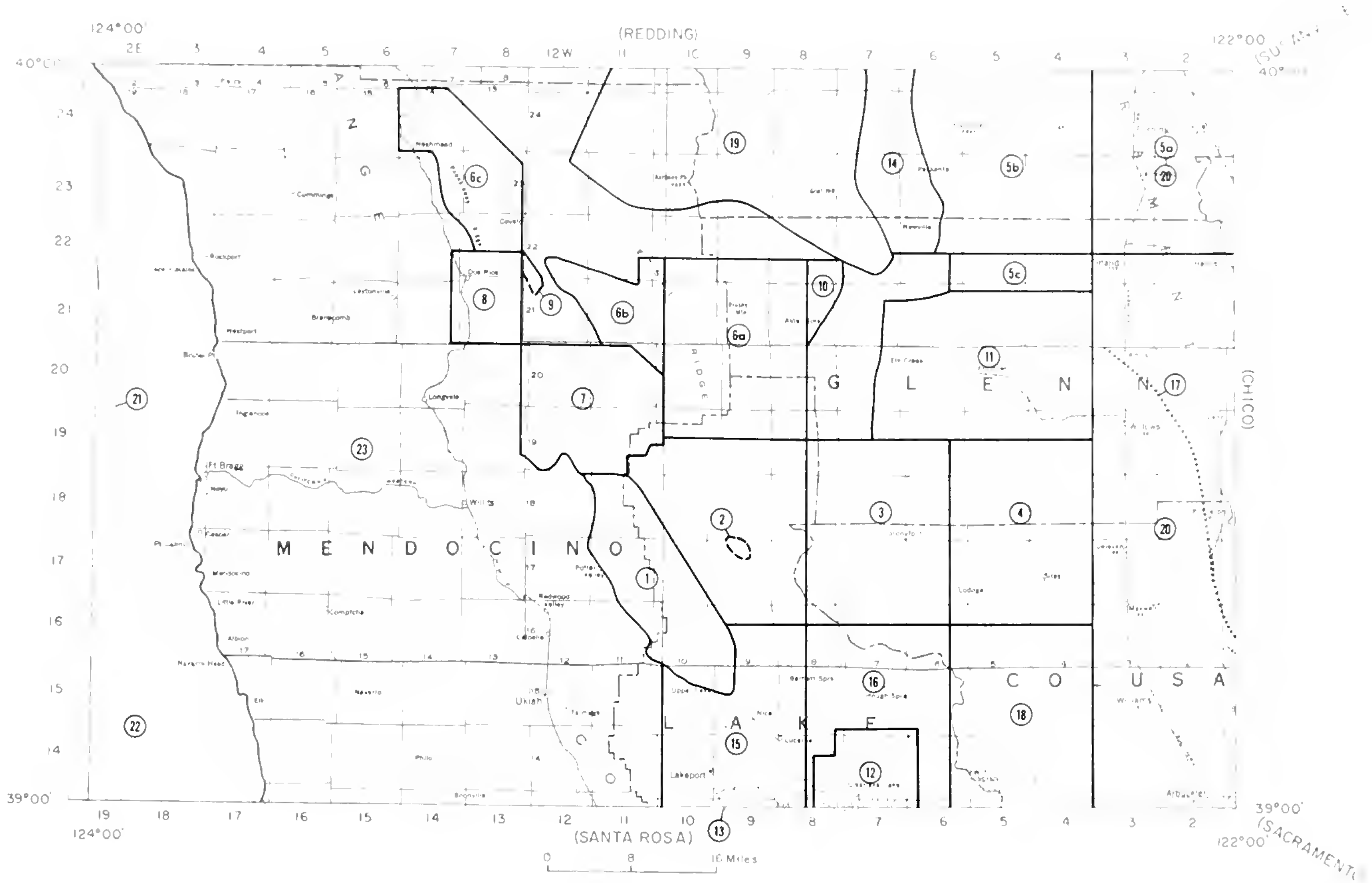

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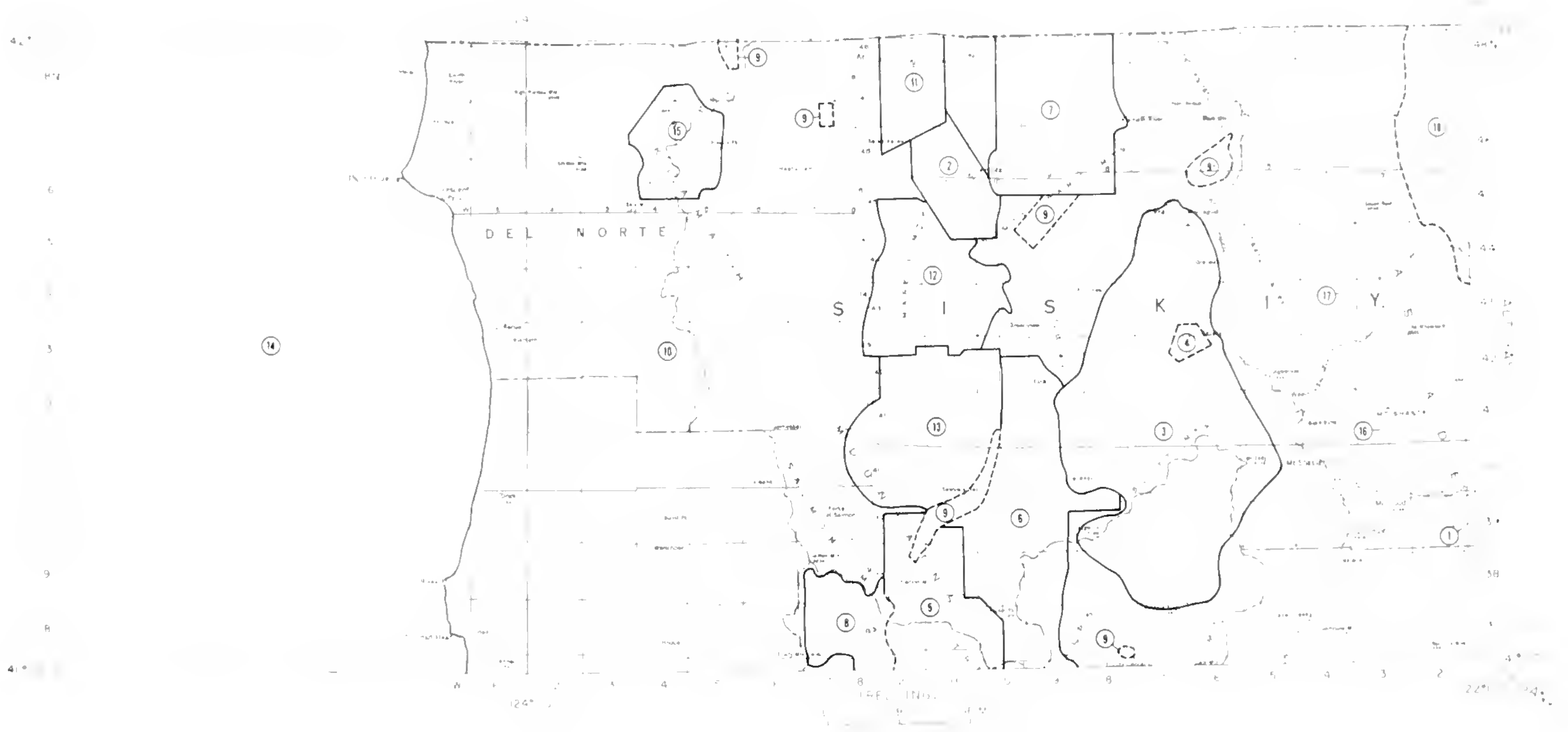

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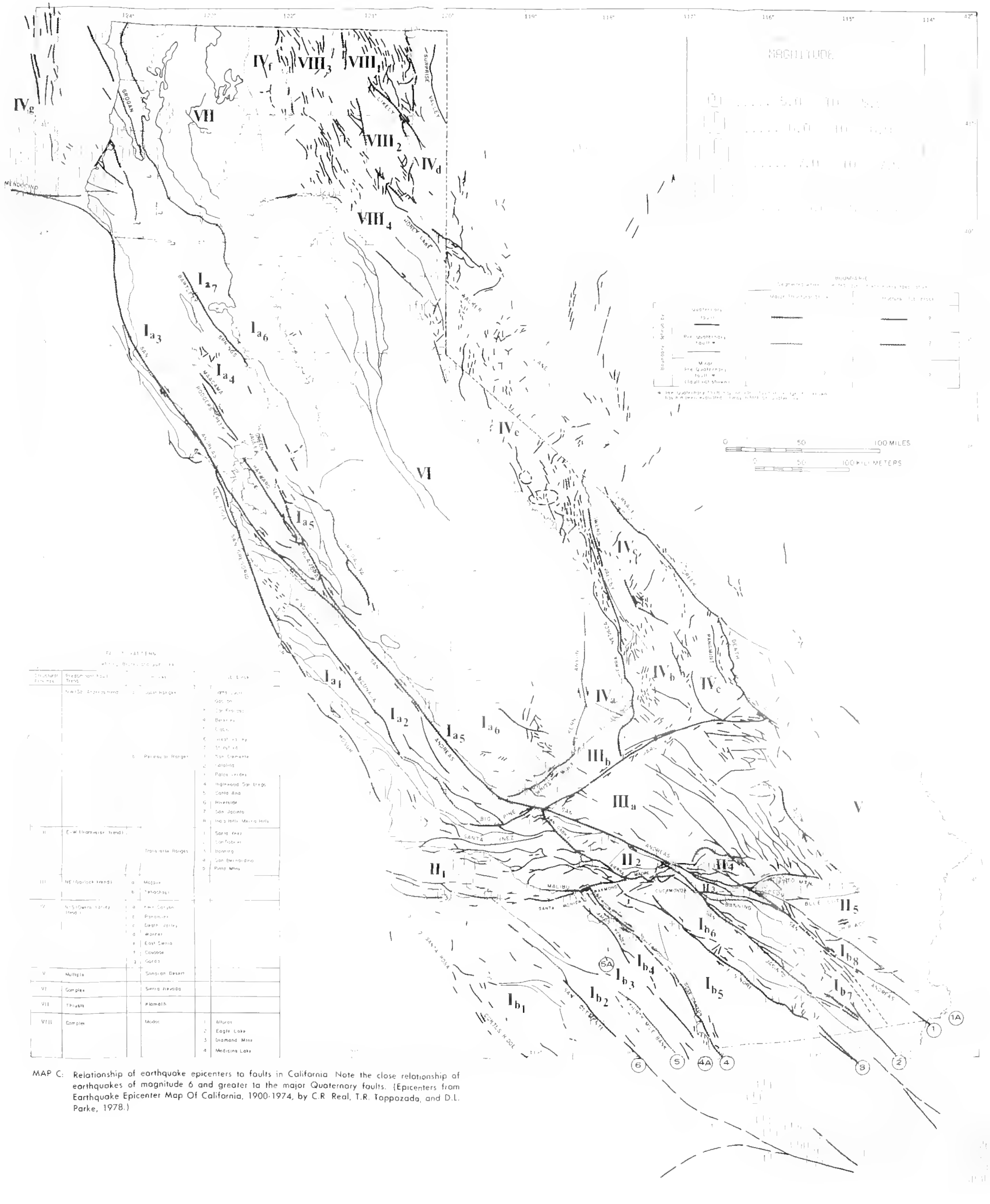
FAULT PATTERNS

Defining Blocks and Subblocks

Structural Province	Predominant Fault Trend		Blocks		Subblocks
I	NW (San Andreas trend)	a	Coast Ranges		Santa Lucia
					Gabilan
				3	San Francisco
				4	Berkeley
				5	Diablo
				6	Great Valley
				7	Stonyford
		b	Peninsular Ranges	1	San Clemente
				2	Catalina
				3	Palos Verdes
				4	Inglewood San Diego
				5	Santa Ana
				6	Riverside
				7	San Jacinto
				8	Indio Hills Mecca Hills
II	E W (Transverse trend)		Transverse Ranges	1	Santa Ynez
				2	San Gabriel
				3	Banning
				4	San Bernardino
				5	Pinto Mtns
III	NE (Garlock trend)	a	Mojave		
		b	Tehachapi		
IV	N-S (Owens Valley trend)	a	Kern Canyon		
		b	Panamint		
		c	Death Valley		
		d	Warner		
		e	East Sierra		
		f	Cascade		
		g	Gorda		
V	Multiple		Sonoran Desert		
VI	Complex		Sierra Nevada		
VII	Thrusts		Klamath		
VIII	Complex		Modoc	1	Alturas
				2	Eagle Lake
				3	Diamond Mtns
				4	Medicine Lake

MAP A: Structural Provinces of California determined by the prominent fault patterns and characteristics of the faults they contain or bound (Encircled numbers in lower part of map identify certain faults referred to in text)

MAP B Parallelism between major Quaternary faults and regularity of fault spacing (Encircled numbers in lower portion of map identify certain faults referred to in the text.)



FAULT PATTERNS

Structural Provinces	Predominant Fault Trend		Provinces		Blocks
I	NW (San Andreas trend)	a	Coast Ranges	1	Santa Lucia
				2	Gabilan
				3	San Francisco
				4	Berkeley
				5	[illegible]
				6	Great Valley
				7	Stonyford
		b	Peninsular Ranges	1	San Clemente
				2	Catalina
				3	Palos Verdes
				4	Inglewood San Diego
				5	Santa Ana
				6	Riverside
				7	San Jacinto
				8	Indio Hills Mecca Hills
II	E-W (Transverse trend)		Transverse Ranges	1	Santa Ynez
				2	San Gabriel
				3	Banning
				4	San Bernardino
				5	Pinto Mtns
III	NE (Garlock trend)	a	Mojave		
		b	Tehachapi		
IV	N-S (Owens Valley trend)	a	Kern Canyon		
		b	Panamint		
		c	Death Valley		
		d	Warner		
		e	East Sierra		
		f	Cascade		
		g	Gorda		
V	Multiple		Sonoran Desert		
VI	Complex		Sierra Nevada		
VII	Thrusts		Klamath		
VIII	Complex		Modoc	1	Alturas
				2	Eagle Lake
				3	Diamond Mtns
				4	Medicina Lake

MAP C: Relationship of earthquake epicenters to faults in California. Note the close relationship of earthquakes of magnitude 6 and greater to the major Quaternary faults. (Epicenters from Earthquake Epicenter Map Of California, 1900-1974, by C.R. Real, T.R. Toppozada, and D.L. Parke, 1978.)

MAP D: Earthquake epicenters of magnitude 4 to 4.9 showing more scatter than for the larger earth quakes, but also suggesting certain areas of low historic seismicity (Epicenters from Earthquake Epicenter Map Of California, 1900-1974, by C.R. Real, T.R. Toppozada, and D.L. Parke, 1978.)