SOURCES OF MIOCENE SEDIMENTS IN SOUTHWESTERN SAN JOAQUIN VALLEY

Thesis by

Willard A. Findlay

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SUMMARY

This investigation constitutes an attempt to determine by studies of heavy minerals, using a statistical approach, the sources of Miocene sands occurring along the southwestern border of San Joaquin Valley, and from a knowledge of these sources to deduce inferences regarding distribution of the sands and Miocene paleogeographic conditions. The method of attack chosen was to compare heavy mineral assemblages of the Miocene sands in question with those (1) of extant possible source areas and (2) of other post-Franciscan sediments the sources of which can be more readily inferred. The method used for sampling possible source areas was to sample fresh Recent sands from streams draining these areas. Miocene samples were discreet "spot" samples. Considerable attention was given to development of laboratory and microscopic technique. The two items in this regard which are considered to represent most progress in technique are (1) use of ruled slides for grain counts, and (2) a method for use in centrifuge separations of heavy minerals. Effective methods of assembling and representing mineralogical results were devised.

Four principal Miocene assemblages have been distinguished. The differences between these are confidently considered to reflect directly difference in source. Three such sources have been postulated; one of the Miocene assemblages is thought to be the result of mixing from two different sources. Interpretation of the specific nature and location of these sources is, however, rendered difficult by the fact that the Miocene assemblages do not in general correspond directly to those obtained from possible source areas. The data are considered nevertheless to admit of valid tentative conclusions in this regard, and of interpretation of differences between Miocene assemblages and source-rock assemblages on the basis of <u>differential mineral decomposition</u>. Thus it is tentatively concluded that the three sources mentioned were: (1) A land area consisting of Franciscan rocks and post-Franciscan, pre-Miocene sediments, and perhaps some granitic rocks, lying northward and westward from Coalinga, which is supposed to have existed during most or all of Miocene time. (2) San Andreas Island, which name is given by the writer to a supposed Miocene land mass lying along what is now the southwest base of the Temblor Range, along the San Andreas Rift, and composed of a distinctive type of granite overlain by metamorphics and sediments. (3) Perhaps other, probably low-lying, short-lived, sediment-blanketed islands in the Miocene seas generally west of San Andreas Island. Expectable distribution of certain Miocene sands is inferred from these paleogeographic considerations.

Considerable knowledge has been accumulated concerning the general heavy mineral constitution of basement rocks (Franciscan and granitic) and pre-Miocene sediments, by the analyses of possible source-rock detritus.

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INTRODUCTION

The problem forming the basis of the present discussion was undertaken in March 1938, under the Standard Oil Company of California Research Fellowship in Geology at the California Institute of Technology. The purpose of the investigation was, as indicated by the title, to determine the sources of Miocene detritus occurring in the southwestern San Joaquin Valley. The ultimate objectives were of course establishment of direction of transportation, and therefore the probable distribution of the detritus, and paleogeographic conditions in general.

Two brief reports on the investigation have been made to the Standard Oil Company by the writer previously: (1) Report of Progress, dated October 8, 1938, and (2) Summary Report on Study of Sources of Miocene Detritus in Southwestern San Joaquin Valley, dated March 28, 1939. The present report is designed to cover the investigation as a whole. It will include all pertinent data of the previous reports. In addition to setting forth discussion and conclusions, and such data as may be necessary for an understanding of these, certain data will be included for purposes of record.

Inasmuch as the location of the area involved in the study, as stated in the title, is well known to California geologists and evident from any map of California, there is no necessity to describe it further than to say that it lies in central California, between and including the vicinities of Coalinga and Maricopa. (See figure 1.)

The problem was limited to Miocene, and particularly to Upper Miocene, beds in the locality mentioned for several reasons: (1) It was desired to include an areal extent sufficient so that differences in source might be expectable. (2) It was proposed to limit the age-range of beds studied so as to avoid mistaking vertical variations for lateral ones, and further because available time required limitation of the field. (3) The problem was of economic significance as applied to these beds. (4) It was desired, incidentally, to provide a check on Reed's conclusion[1] that "the apparently tensional diastrophism of the beginning of the Middle Miocene affected chiefly the Franciscan areas, while the later, apparently compressional disturbances chiefly affected the granitic areas."

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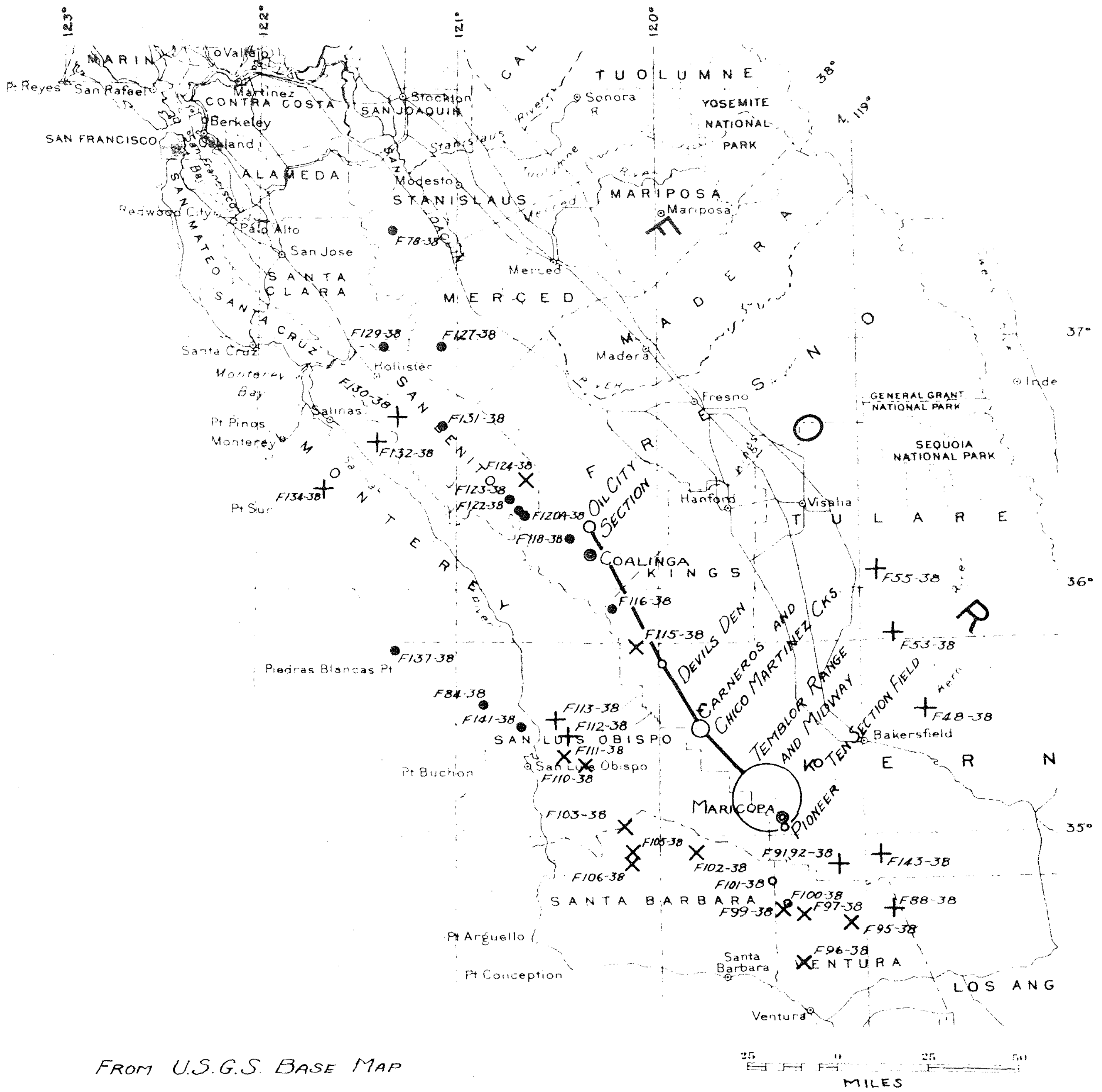
[1] Reed, R. D., and Hollister, J. S., Structural evolution of California, p. 40. 1936.



LOCALITY MAP

MIOCENE SAMPLES are indicated by open circles connected by heavy line. All samples from a given section lie within the circumference of the corresponding circle.

SOURCE-ROCK SAMPLES:

Franciscan ●   Granitic +   Cretaceous or Eocene ×

Figure 1.

The writer's procedure in attacking the problem has been to seek the simplest means of finding the answer to the problem. The methods and practices used in the investigation have been adopted from this viewpoint, without particular regard for conventional methods of study in some of the fields involved. The point of view adopted in discussion and conclusions is to state these definitely and clearly. Although it is believed that considerable progress has been made, it is realized that much further data will be required for final solution of the problem. Consequently most of the conclusions reached are to be considered as tentative. They simply represent the best judgment of the writer on the basis of the data at hand. It must be understood that because a conclusion is concisely stated does not necessarily imply that it is regarded as ultimate knowledge or established and incontrovertible fact.

Materials and data filed with the Division of Geology and Paleontology of the Institute at the conclusion of the work will include: (1) field samples and reference samples; (2) petrographic slides of mineral grain samples, mounted in Canada Balsam, with reference lists; (3) 5" x8" data cards, as discussed below, bearing numerical and graphic representations of grain-counts and most other significant data.

ACKNOWLEDGEMENTS

Grateful acknowledgements are due to Dr. J. P. Buwalda for his continued interest in the work, and to Dr. Ian Campbell for direct supervision of the work and reports and many helpful suggestions. Appreciation is due to the Standard Oil Company of California for sponsoring the investigation. In particular, thanks are due to Mr. G. C. Gester, chief geologist for the company, Mr. S. H. Gester, assistant chief geologist, and Dr. W. S. W. Kew, chief of the Los Angeles geological staff, for the interest they have taken in the problem; and to Mr. W. F. Barbat, in charge of the geological staff at Taft, whose whole-hearted cooperation and aid are greatly appreciated. Thanks are also due to Dr. M. N. Bramlette, of the United States Geological Survey, for his kindness in checking over much of the mineralogical data and discussing at length many phases of the problem, in respect to some of which his first-hand experience is much greater than that of the writer.

LITERATURE

The literature concerning the present problem may be considered under two categories: (1) papers dealing with the sediments studied in the present investigation, and (2) literature having to do with the study of sources of sediments.

R. D. Reed has contributed more extensively to the study of sediments in California than any other person. His interest in the petrology of Californian sediments has extended over a period of many years. Those of his contributions which have a direct bearing on the present problem are as follows:

Reed, R. D., Role of heavy minerals in the Coalinga Tertiary formations. Econ. Geol., Vol. 19, pp. 730-749. 1924.

Reed, R. D., and Bailey, J. P., Subsurface correlation by means of heavy minerals. Amer. Assoc. Pet. Geol., Bull., Vol. 11, pp. 359-368. 1927.

Reed, R. D., Geology of California. 1933.

Reed, R. D., and Hollister, J. S., Structural evolution of Southern California. 1936.

M. N. Bramlette has recently published an important paper dealing with Miocene sediments in the region of the present study:

Bramlette, M. N., Heavy mineral studies on correlation of sands at Kettleman Hills, California. Amer. Assoc. Pet. Geol., Bull., Vol. 18, pp. 1559-1576. 1934.

A short paper by H. W. Hoots has to do with mineralogical data from the Wheeler Ridge area:

Hoots, H. W., Heavy-mineral data at the southern end of the San Joaquin Valley. Amer. Assoc. Pet. Geol., Bull., Vol. 11, pp. 369-372. 1927.

The papers noted above contain some information on the sediments with which the present thesis is concerned. However, these do not deal primarily with sources of the sediments. Few papers have been published which are primarily concerned with the sources of Californian sediments; among these are contributions by A. O. Woodford[1]

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[1]Woodford, A. O., The San Onofre breccia, its nature and origin. Univ. Calif. Publ., Bull. Dept. Geol. Sc., Vol. 15, pp. 159-280. 1925.

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and E. C. Edwards[2]. In addition to those listed above,

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[2]Edwards, E. C., Pliocene Conglomerates of Los Angeles Basin and their paleogeographic significance. Amer. Assoc. Pet. Geol., Bull., Vol. 18, pp. 786-812. 1934.

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there are numerous papers having to do with the geology, stratigraphy, paleontology, etc., of the beds investigated in the present study. The more comprehensive of these are contained in the Bulletins and Professional Papers of the U. S. Geological Survey[3].

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[3]Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, California. U. S. Geol. Surv., Bull. 398. 1910.

Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset Oil region, Kern and San Luis Obispo Counties, Calif. U. S. Geol. Surv., Bull. 406. 1910.

Anderson, Robert, Preliminary report on the geology and possible oil resources of the south end of the San Joaquin Valley, Calif. U. S. Geol. Surv., Bull. 471, pp. 106-136. 1912.

Pack, R. W., and English, W. A., Geology and oil prospects of Waltham, Priest, Bitterwater, and Peachtree Valleys, Calif. U. S. Geol. Surv., Bull. 581, pp. 119-160. 1915.

Anderson, Robert, and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, Calif. U. S. Geol. Surv., Bull. 603. 1915.

English, W. A., G ology and oil prospects of Cuyama Valley, Calif. U. S. Geol. Surv., Bull. 621, pp. 191-215. 1916.

Pack, R. W., The Sunset-Midway oil field, Calif. U. S. Geol. Surv., Prof. Paper 116. 1920.

Hoots, H. W., Geology and oil resources along the southern border of San Joaquin Valley, Calif. U. S. Geol. Surv., Bull. 812, pp. 243-338. 1930.

Woodring, W. P., Roundy, P. V., and Farnsworth, H. R., Geology and oil resources of the Elk Hills, Calif., U. S. Geol. Surv., Bull. 835. 1932.

Literature of the second category, having to do with the study of sources of sediments in general and in other areas is voluminous. The most effective starting point in any survey of this field must be Boswell's book[1], which summarizes and abstracts the previous literature very effectively.

Milner's text-book[2] must also be consulted in this connection.

A wealth of material dealing with the sources of the Paleozoic sandstones of the eastern half of the United

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[1] Boswell, P. G. H., On the mineralogy of sedimentary rocks, a series of essays and a bibliography. London. 1933.

[2] Milner, H. G., Sedimentary petrography. London. 1929. (Sedond Edition).

States, particularly the well-known members such as the Oriskany and St. Peter sandstones, is contained in the Journal of Sedimentary Petrology.

The Reports of the Committee on Sedimentation of the National Research Council, Washington, D. C., constitute most valuable bibliographic sources for studies in this field.

Many investigators have attained a considerable degree of success in studies of the sources of sediments. Some specific instances may be mentioned here:

P. G. H. Boswell[1] briefly discusses a considerable

[1] *Op. cit.*, pp. 47-59.

number of these papers, among which are the following: W. Mackie[2] studied the Old Red Sandstone with a view to

[2] Mackie, W., The principles that regulate the distribution of particles of heavy minerals in sedimentary rocks, as illustrated by the sandstones of the northeast of Scotland. Trans. Edinburgh Geol. Soc., Vol. 11, pp. 138-164. 1923.

determining the source. The same author[3] traced purple

[3] Mackie, W., The source of the purple zircons in sedimentary rocks of Scotland. Trans. Edinburgh Geol. Soc., Vol. 11, pp. 200-213, 1923.

zircons of detrital beds of Scotland to their source in the Lewisian Gneiss. These well-known papers have not been available to the present writer; Boswell's abstracts have been useful in this regard. A. W. Groves' paper[1] on the

[1]Groves, A. W., The unroofing of the Dartmoor Granite and the distribution of its detritus in the sediments of southern England. Q. J. G. S., Vol. 87, pp. 62-96. 1931.

Dartmoor Granite appears to represent a particularly well-executed piece of work. He, as well as most other workers, depended largely upon particular species or varietal characters (zoned zircon in this case) rather than upon statistical data for his conclusions. Among others mentioned and abstracted by Boswell are papers by F. Smithson, H. H. Thomas, and G. C. McCartney.[2]

[2]Smithson, F., The Triassic sandstones of Yorkshire and Durham, their petrography and their relation to the Trias of other parts of the British Isles. Proc. Geol. Assoc., Vol. 42, pp. 125-156. 1931.

Thomas, H. H., The mineralogical constitution of the finer material of the Bunter pebble bed in the west of England. Q. J. G. S., Vol. 58, pp. 620-632. 1902.

McCartney, G. C., A Petrographic study of the Chester sandstones of Indiana. Jour. Sed. Pet., Vol. 1, pp. 82-90. 1931.

Some of the more recent papers in the United States are as follows:

Hans Becker[3] found suggestions, from mineralogical

[3]Becker, Hans, A study of the heavy minerals of the pre-Cambrian and Paleozoic rocks of the Baraboo Range, Wisconsin. Jour. Sed. Pet., Vol. 1, pp. 91-95. 1931.

studies, regarding sources of the old sedimentaries of the Baraboo Range. He used an effective method of graphic presentation of results, similar to that used by the present writer.

M. D. Stearns[1] concluded that the Marshall formation "was derived chiefly from Laurentian and Huronian rocks and the debris therefrom (such as Cambrian and Ordovician sandstones)". A graphic method of presentation of data is considered by the present writer to be a step in the right direction but comparatively ineffective.

E. L. Lucas[2] concludes: "This petrographic investigation yields negative evidence concerning the contribution of sediments from Llanoria to the Ardmore basin during Springer and subsequent time and suggests the Arbuckle Mountains, the Criner Hills and other possible uplifts buried beneath younger rocks as the source of the sediments."

Having concluded that the St. Peter sandstone was derived from preexisting sediments, S. A. Tyler[3] remarks:

[1] Stearns, M. D., The petrology of the Marshall formation of Michigan. Jour. Sed. Pet., Vol. 3, pp. 92-112. 1933.

[2] Lucas, E. L., Petrographic character of the Pennsylvanian sandstones in the Ardmore Basin. Jour. Sed.,Pet., Vol. 5, pp. 96-105. 1935.

[3] Tyler, S. A., Heavy minerals of the St. Peter sandstone in Wisconsin. Jour. Sed. Pet., Vol. 6, pp. 55-84. 1936. (p. 82).

"The Jordan and Franconia sandstones and the Oranto arkose supplied little if any material to the St. Peter. The Bayfield and Hinckley sandstones and the Barron quartzite may have furnished sands to the St. Peter, whereas it is probable that the Mt. Simon sandstone and the Huronian quartzites served either as a partial or entire source." This author obtained interesting data on the ultimate source of the detritus by study of inclusions from quartz grains. He concluded that this ultimate source was granitic.

M. H. Stow[1] has recently studied the Oriskany sandstone.

[1] Stow, Marcellus H., Conditions of sedimentation and sources of the Oriskany sandstone as indicated by petrology. Amer. Assoc. Pet. Geol., Bull., Vol. 22, pp. 541-564. 1938.

METHOD OF ATTACK

When the problem was first surveyed, it appeared that the most profitable method of attack would be to compare the materials of pebbles from the Miocene beds in question with the pre-Miocene rocks which crop out at present in areas which might have served as sources of the detritus. However, the literature indicated that the beds to be investigated would be found to contain an entirely inadequate amount of conglomeratic material for such an attack. Consequently it was decided that a study of the sands of these beds, and in particular the heavy minerals of these sands, would probably furnish the simplest means of approaching the problem.

Therefore the original method of attack was simply to compare heavy mineral assemblages from the Miocene sands in question with the assemblages found in existing areas of pre-Miocene rocks which might have served as sources of the Miocene detritus. A given Miocene assemblage would thus be presumed to have been derived from that one of the potential source-rock types to which the assemblage ~~of which~~ was most similar.

Two assumptions were inherent in the supposition that a given Miocene assemblage would show direct similarity to that of the pre-Miocene rocks now cropping out in the area from which it was derived. One of these was that the rock now cropping out in a possible source area is essentially similar to that in the same area in Miocene time. The fact that Miocene rocks now lap over these possible source rocks indicated that this assumption was a valid one. The results of the investigation also appear to support this.

The second assumption was that Miocene assemblages, as now found, are similar to those of the rocks from which they were derived. The investigation has indicated rather definitely that such similarity is normally considerably impaired by differential decomposition of

~~of~~ heavy minerals of the assemblage since their removal from their source. The result of this decomposition is the disappearance of less stable minerals, such as amphiboles, and eventually epidote, and sphene, from assemblages in which they were originally present.

In view of the fallaciousness of this second assumption, it became necessary to attempt to evaluate the changes undergone by the Miocene assemblages since removal from their source. The principle underlying such evaluations has been to study the present differences between certain assemblages and those of their source rocks, in cases in which the source can be inferred with reasonable certainty. In other words, the principle is to compare Miocene assemblages of unknown source with others (Miocene and older) the source of which is comparatively well known, assuming that assemblages from the same source have undergone similar changes and will therefore appear similar.

Inasmuch as extensive changes in heavy mineral composition due to differential mineral decomposition were not anticipated at the outset of the investigation, samples suitable for the purpose of evaluating these changes are not sufficient for a close evaluation. However it is believed that a close study of the assembled data has shed a good deal of light on the matter, as will be discussed below. Were the investigation to be carried further, considerable effort would go toward study of such "type" samples.

SAMPLES

Descriptions of sample localities are detailed in Appendix A of this report. Brief notations regarding locality and stratigraphic position or source-rock, as the case may be, are given in Plate II (Flood Minerals Chart). Positions of samples relative to the general stratigraphic section are indicated on Plate III (Generalized Sketch of Miocene Stratigraphic Section along Southwestern Margin of San Joaquin Valley). Areal distribution of the samples is indicated in figure 1, Locality Map.

Miocene Samples

Miocene sand samples were taken either from outcrops or from well cores. As regards outcrop samples: They are "spot"[1] samples as contrasted with "composite" samples. In the case of indurated sands they are ordinary hand specimens. In the case of unconsolidated material, they were taken from a volume (in situ) not greater than about 1/4 cubic foot. Sample localities were chosen and samples taken by the writer. Areal and stratigraphic positions of the samples were established by W. F. Barbat.

Miocene core samples were supplied by Barbat, and are presumed to be "spot" samples also.

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[1] Otto, G. H., The sedimentation unit and its use in field sampling. Jour. Geol., Vol. 46, pp. 569-582. 1938.

Source-rock Samples

At the outset of the work it was proposed to follow more or less conventional methods of sampling pre-Miocene rocks in regions which might have served as source-areas for the Miocene beds in question. This would entail as extensive a program as possible of traversing these pre-Miocene rocks and collecting individual or composite samples of the rock, which would be crushed and their heavy minerals concentrated. However, the magnitude of such a task, if it were to be carried far enough to afford any adequate idea of average composition of the heavy mineral assemblages, was soon apparent. On the other hand, it occurred to the writer that samples of fresh Recent sands of streams draining large areas of such rocks would constitute reasonably average samples of these rocks over the whole drainage area of the given stream.

Consequently, the following method of sampling possible Miocene source-rocks was adopted: In a given drainage system a point was chosen upstream from which pre-Miocene rocks of only one type (or possible two, such as Franciscan and Cretaceous or granitic and Eocene) were included in the drainage area. Such points were chosen with the aid of the California State Geological Map (1938). At the chosen point a sample of fresh -- or in any case very recently deposited -- sand was taken. This specific method and its application have not been encountered in the published literature. E. C. Edwards,[1] however, used the

[1] Edwards, E. C., Pliocene conglomerates of the Los Angeles basin and their paleogeographic significance. Unpublished thesis, California Institute of Technology, 1932.

same principle as applied to pebble counts of stream gravels.

It is believed that this method of sampling source-rocks is better adapted for the purposes of the present investigation than any other. Probably a sample taken in this way does not represent a perfectly true average of the parent rocks, since differential decomposition may have affected it; and since probably rock-types at the headwaters of the drainage system are under-represented compared to rock-types drained by tributaries entering immediately upstream from the sample. Other factors probably detract from the perfection of the average. However a sample taken in this manner is probably more closely representative of the Miocene detritus derived from the given rock than any other since they were both derived from the parent mass in the same way.

It is anticipated that the method may be criticized as being unduly susceptible to effects of contamination by detritus from Miocene or post-Miocene rocks, which may have been derived from source-rocks foreign to those which it is desired to represent by a given sample. Such contamination would obviously tend to give a false picture of the composition of the source-rock concerned. The basis of such criticism would presumably be that the State Geological Map is too generalized, in many areas, to furnish reliable data regarding the presence or absence of such contaminating deposits. These possibilities have been borne in mind during sampling and subsequent study, however, and it is the writer's belief that the data of the present investigation have not, in fact, been significantly affected by such contamination. The reasons for this belief are discussed below in connection with the Franciscan source-rock assemblage.

In all sampling, medium to fine grained sands were chosen insofar as feasible, since it was thought this size range would be most commonly available and most convenient for the proposed laboratory work. In some cases, however, coarse sands or even gravels were sampled. All samples yielded sufficient material of -100 -150 mesh size for heavy mineral analysis. It was not necessary to resort to crushing of original grains in any case in order to obtain particles of the desired size.

LABORATORY AND MICROSCOPIC PROCEDURE

As noted above, it was proposed at the outset of the work to approach the problem by means of study of heavy minerals. Therefore the primary object of laboratory and microscopic procedure was always segregation and analysis of these. However, at the beginning of the work it was thought best to retain all materials coarser than 250-mesh and to record all observations on all of this material that could conveniently be obtained in the course of obtaining heavy mineral concentrates. As the work progressed, it became obvious that the greatest returns for the time spent could be best obtained by concentrating effort exclusively on the heavy minerals themselves. Consequently procedure was continuously revised to this end. Among the major items eliminated for these reasons were mechanical analyses, which were completed for the first 30 samples. These appeared to contribute nothing of value to the solution of the problem, and are not included in this report.

It has always been the writer's conviction that the statistical approach, and consequently volume of data, is a vital factor in work of this type; and that, in general, conclusiveness of results will be in direct proportion to this volume. It is further evident that the major factor in increasing volume of data is the reduction of time and tedium, large items at best, in laboratory and microscopic work. Again, it can not be denied that the elimination of the "personal equation" is another most desirable objective. With these considerations in mind, a large amount of time was spent in attempting to improve conventional laboratory and microscopic technique and equipment. As is probably the usual case, many such attempts were unsuccessful. However, it is believed that the positive results of this experimentation are sufficient to justify the considerable time spent on this phase of the problem. The two items of improvement which the writer considers to be of greatest usefulness will be noted here.

The first of these is the use of ruled slides[1]

[1]Ruled slides have long been used in medicine and industrial dust work. However, the application in these fields is somewhat removed from requirements of the present work, since the particle size in medical and dust counts is very much smaller than is the case with mineral grains used in the present investigation. The slides used in these other fields are necessarily accurately and intricately ruled or cross-ruled. They are costly and are used for temporary mounts. Two references to these uses are:

Judson, L. V., New ruling for haemocytometer chambers. Jour. Amer. Med. Assoc., Vol. 84, p. 947. 1925.

Williams, Charles R., A method of counting samples taken with the impinger. Jour. Ind. Hygiene and Toxicology, Vol. 21., pp. 226-230. 1939.

for mineral grain counts. The principal idea involved was to develop~~ment~~ some method whereby every grain on a given microscopic slide could be counted, if desired, and this without danger of counting some grains twice and with a minimum expenditure of time. The great value of <u>counting</u> grains as contrasted with <u>estimates</u> is probably not open to question as a means of eliminating the "personal equation."[2]

[2]Evans, P., Hayman, R. J., and Majeed, M. A., The graphical representation of heavy mineral analyses. World Petroleum Congress, Proc., Vol. 1, pp. 251-256. 1934. (P. 253)

As a means of attaining this end, methods were devised of ruling the slides at such an interval (0.1") that two consecutive parallel rulings would fall within the diameter of the microscope field (using a medium-power objective). In use, the grains are simply counted consecutively along one "lane" (area bounded by two rulings) at a time. This method allows readily of centering a given grain for observation under the high-power objective without loss of continuity of the count, or loss of time. The rulings have the further advantage of affording a means of control in case it is desired to count only part of the grains on a given slide; alternate lanes may be counted, or any number of lanes in any order desired to obtain a probable average count of the slide. A number of methods of so ruling the slides were attempted. The most satisfactory rulings were obtained by coating the slide with paraffine, scratching the desired rulings in the coating, and etching with hydrofluoric acid. The rulings were scratched in the paraffine by means of a crude instrument made by mounting a row of sharp-pointed pins (0.1" apart) in a sheet metal frame, the pins being capable of independent parallel movement, and cushioned at their tops with stopper rubber. Slides could be ruled in this way on an average of about 4 or 5 minutes each, in lots of a few dozen. No such ruled slide is commercially available; and an attempt to have them placed on the market by some of the larger scientific supply companies met with either no success or quotation of fantastic prices for the product. The most rapid means found of making the desired rulings was by the use of an ordinary rubber stamp designed for the purpose, preferably with a quick-drying stamp-pad ink such as is used commercially for stamping bottled and canned goods. These rulings are satisfactory for Canada balsam mounts. They may be dissolved by certain immersion liquids or piperine.

The second of these improvements in technique was made in connection with the use of the centrifuge in heavy liquid separations. The extreme increase in sharpness of separation obtained by use of the centrifuge as compared with use of the conventional funnel arrangement has been demonstrated in practice by other investigators.[1] The

[1]Tyler, Stanley, and Marsden, Ralph W., A discussion of some of the errors introduced in accessory mineral separations. Nat. Research Council, Div. of Geol. and Geog., Annual Rept. for 1936-1937, Appendix F, pp. 4-15. 1937.

Berg, Ernest, A method for the mineralogical fractionation of sediments by means of heavy liquids and the centrifuge. Jour. Sed. Pet., Vol. 7, pp. 51-54. 1937.

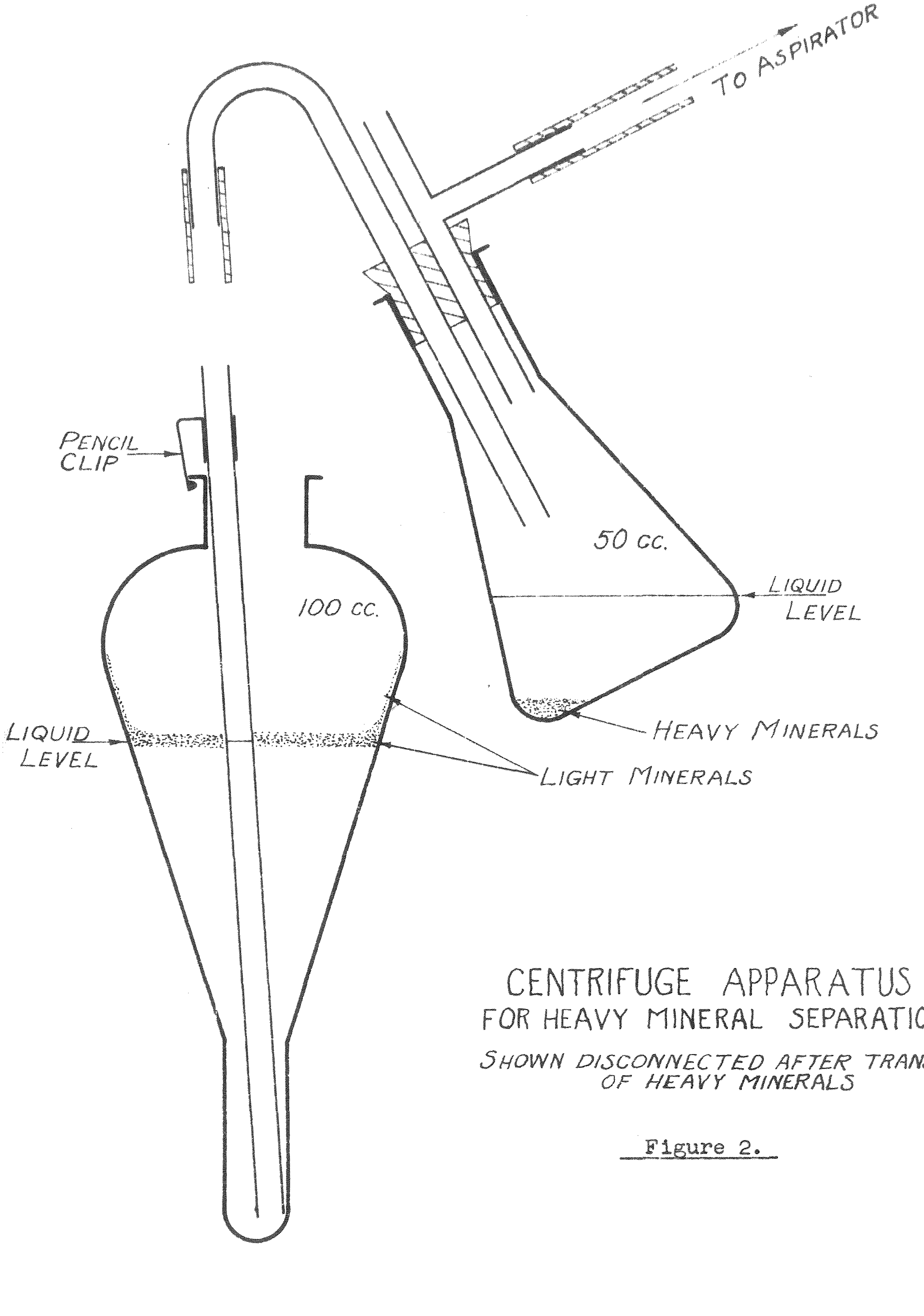
mathematical basis for this increased accuracy is readily apparent from the centrifugal force formula. Whether this extreme sharpness is required for ordinary heavy mineral work will not be argued here. In any case, no method described in the literature for removing either light or heavy fractions from the vessel in which they were separated by centrifuging can compare with the simplicity and ease of manipulation obtained with the ordinary funnel arrangement.[2]

[2]Milner, H. B., _op. cit._, p. 53.

Most of the methods described[1] for centrifuge separations

[1] Krumbein, W. C., and Pettijohn, F. J., Manual of sedimentary petrography, pp. 340-342. 1938.

are unwieldy or intricate or require very special and expensive apparatus. The method devised by the writer avoids all these objectionable features, to his own satisfaction at least, and is nearly as simple and clean in manipulation as the funnel apparatus. The method consists simply of inserting a glass tube into an ordinary "oil tube" (standard centrifuge equipment) containing bromoform, adding the mineral grain sample; centrifuging in the ordinary way; then decanting the accumulated heavy mineral fraction through the tube by connecting this to an Erlenmeyer flask which is placed under a slight vacuum by means of an ordinary aspirator (see figure 2). The glass decanting tube is cut to a length sufficient to allow it to protrude about 1/2" or more from the mouth of the oil tube when resting on the bottom of the latter. Capillary tubing is the most satisfactory for this purpose, but the diameter is not a major factor. No special equipment is required. A glass tee inserted in the stopper of the Erlenmeyer flask and connected with the aspirator serves as a valve for regulating the vacuum, the free end of the tee being opened or closed with the finger. A pencil clip is used to fasten the decanting tube to the lip of the oil tube. This is done in order



CENTRIFUGE APPARATUS
FOR HEAVY MINERAL SEPARATIONS

SHOWN DISCONNECTED AFTER TRANSFER OF HEAVY MINERALS

Figure 2.

to avoid the decanting tube working out of the centrifuge tube during centrifuging. (A tube of ordinary glass will of course float in bromoform.) Many different methods of centrifuging were tried and discarded before discovering this very satisfactory method.

In all experimentation in laboratory methods and equipment the fundamental importance of avoiding variations in treatment of samples which might result in variations of heavy mineral analyses was borne in mind. It is believed that such variations were successfully avoided, since different samples in a given assemblage, as indicated in Plate II, were run at different times, and yet show no significant variations in assemblage. A useful check in this connection might have been to run a completely independent analysis, using the final procedure described below, on one of the samples first analysed. However, observations of the charted data noted above are believed to justify confidence in this regard.

Final Procedure

A detailed outline of procedure in laboratory and microscopic treatment of samples, as finally used follows. The term heavies will be used to designate a concentrate of mineral grains of specific gravity greater than that of bromoform (2.86); likewise, lights will serve to designate concentrates of specific gravity less than that of bromoform.

The present section is limited to a description of the various steps in the procedure. Discussion and comment on the procedure follows, in the section designated "Discussion of Procedure."

(1) Enter all data available on 5"x 8" data card illustrated in Plate I, including sample number, locality, description, megascopic description of the sample, etc. Enter further data as obtained according to the following procedure, including such data as percentage $CaCO_3$ (see below).

(2) Split bulk sample (as taken in the field) to laboratory sample of about 150 grams and disaggregate same with mortar and pestle to pass 9-mesh screen; (avoid crushing any individual+9-mesh detrital particles, which discard). (In case total bulk sample is less than 150 grams, use all for laboratory sample except about 15-20 grams, which retain as reference sample.) File reference sample. In case the laboratory sample contains no oil, treat as per (3) below. If it contains oil, proceed as follows: Place laboratory sample in 300 cc. Erlenmeyer flask and cover with mixture of 50% <u>petroleum</u> <u>ether</u> and 50% <u>carbon</u> <u>disulfide</u>.[1] Close

---

[1]Cf. Tickell, F. G., The examination of fragmental rocks. 1931.

---

flask with cork stopper (rubber will dissolve) and allow to stand, with occasional agitation, for several hours or longer. Wash by decantation with the mixture mentioned, to remove fines (about -250-mesh) and most of the oil. Wash into screened funnel in aspirator bottle (tinned sheet-metal funnel of about 1/2 pint capacity, with disc -- about 1 1/2" diameter -- of 150-mesh screen soldered in place), and wash with above-mentioned mixture until no coloration occurs in the washings. Remove sample from funnel onto paper towel and air-dry; <u>or</u> rewash with acetone and then water and treat directly, without drying, as per (3) below. (Drying time may be eliminated in this way.)

(3) Place laboratory sample from (2) above in 600 cc. beaker and add 250 cc. of water. Bring to gentle boil on hot plate. Add slowly 50% HCl by burette until effervescence subsides. Then add an additional 50 cc. HCl and boil for 10 minutes. If the sample is non-effervescent simply add 50 cc. HCl and boil for 10 minutes. Note total HCl required to eliminate effervescence and calculate (roughly, having estimated weight of laboratory sample) total HCl as $CaCO_3$. The purpose of this calculation is merely to obtain an estimate of the proportion of calcareous cement present in the sample.

(4) Remove from hot plate, dilute with water to 600 cc. and decant HCl and fines. Repeat dilution and decantation once or twice. Add 100 cc. 25% HNO_3 after decantation; boil for 10 minutes (or longer, if brown fumes excessive).

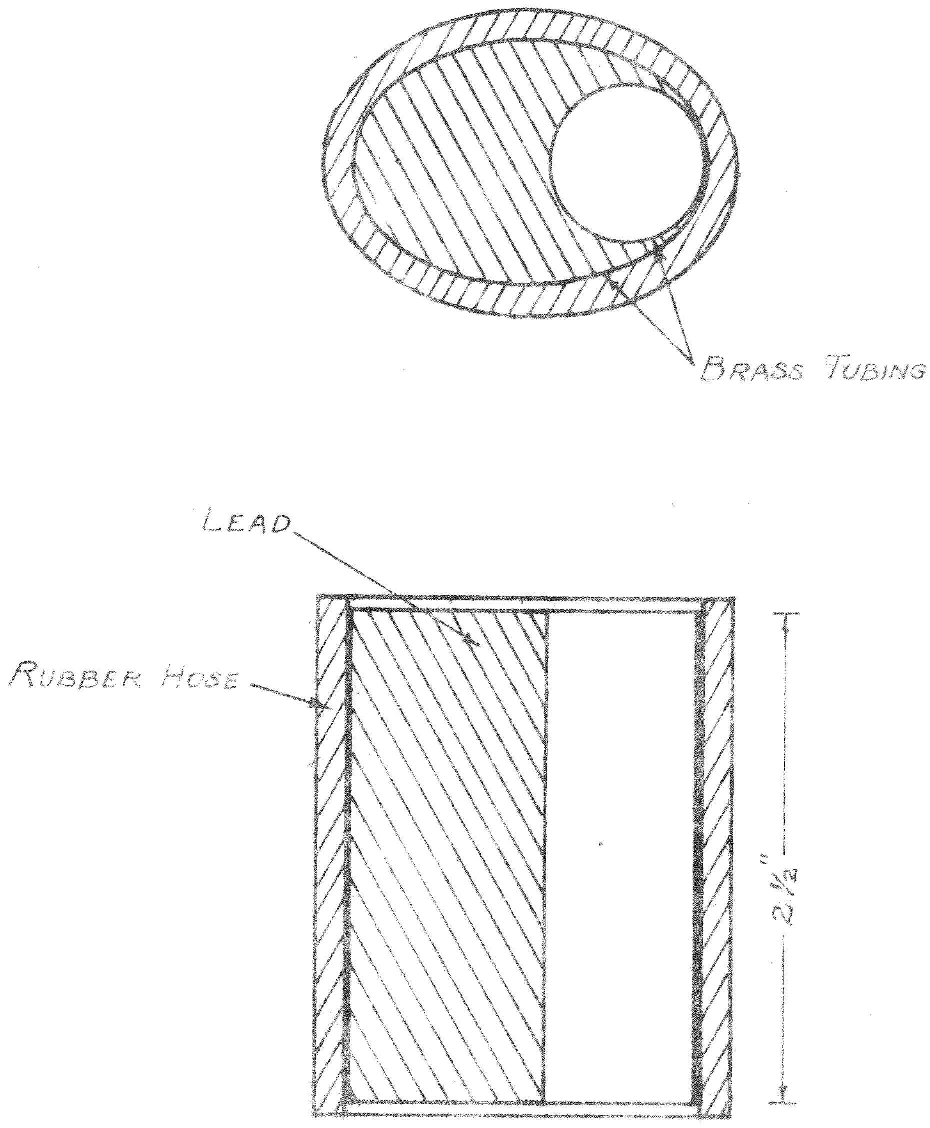
(5) Add 25% NaOH until basic reaction is obtained with red litmus paper.

(6) Wash for 30 minutes in washing machine. A description of the machine used follows:

The machine is of the type commonly used in foraminiferal laboratories, consisting essentially of motor-driven, rubber-covered rollers, on top of and between which glass jars (1-pint Mason jars) containing sample and a tumbler rotate. The tumbler (see figure 3) in the present case, designed and made by the writer, consisted of an elliptical cylinder of brass tubing (1 1/2" round tubing, deformed to elliptical cross section) filled with lead except for the volume of a 3/4" hollow brass tube placed within the larger tube at one end of the major axis of the ellipse. The tumbler was covered with close-fitting radiator hose. Due to the unbalanced eccentric shape of the tumbler, its motion inside the rotating glass jar is partly one of slipping and partly of rotation. It was found very effective in disaggregating detrital particles.

(7) Wash out fines (about-250-mesh) by decantation. Wash with water into screened suction funnel (mentioned in (2) above). Wash until clean. Transfer to paper towel. Any grains adhering to wet funnel or screen can be removed by washing with acetone and drying by suction, if desired. Air-dry the sample.

(8) Screen with Rotap shaking machine through 60-mesh and 150-mesh Tyler Standard 5" sieves for 10 minutes. (Two



SKETCH OF
WASHING MACHINE TUMBLER

Figure 3.

separate sets per run of 10 minutes, two screens, pan and cover per set, separated by 5" copper plate with rims on both sides.) Lump all material except -60 +150-mesh grade and file as "Laboratory Sample Residue."

(9) Perform bromoform separation on -60 +150-mesh grade as follows (four samples per run, with centrifuge having 4-place head, for four tubes):

(a) Fill centrifuge tube (see figure 2, left) to about 75 cc. with bromoform. Insert decanting tube with pencil clip engaging lip of centrifuge tube.

(b) Add mineral grains, or split sample of same if total amounts to more than about 30 grams. (The method of splitting used is to pour the sample in a pile directly over the overlapping edge of a sheet of paper which overlaps a second sheet, and then pick up the top sheet with approximately half of the sample on it.)

(c) Centrifuge (with International Equipment Co. Centrifuge, Improved, Type SB, Size 1) for about 1 minute at about 1000 r.p.m. Stop centrifuge and agitate light minerals by rotary motion of tube. Repeat centrifuging and agitation about 3 times and remove tube to funnel rack adapted to receive it.

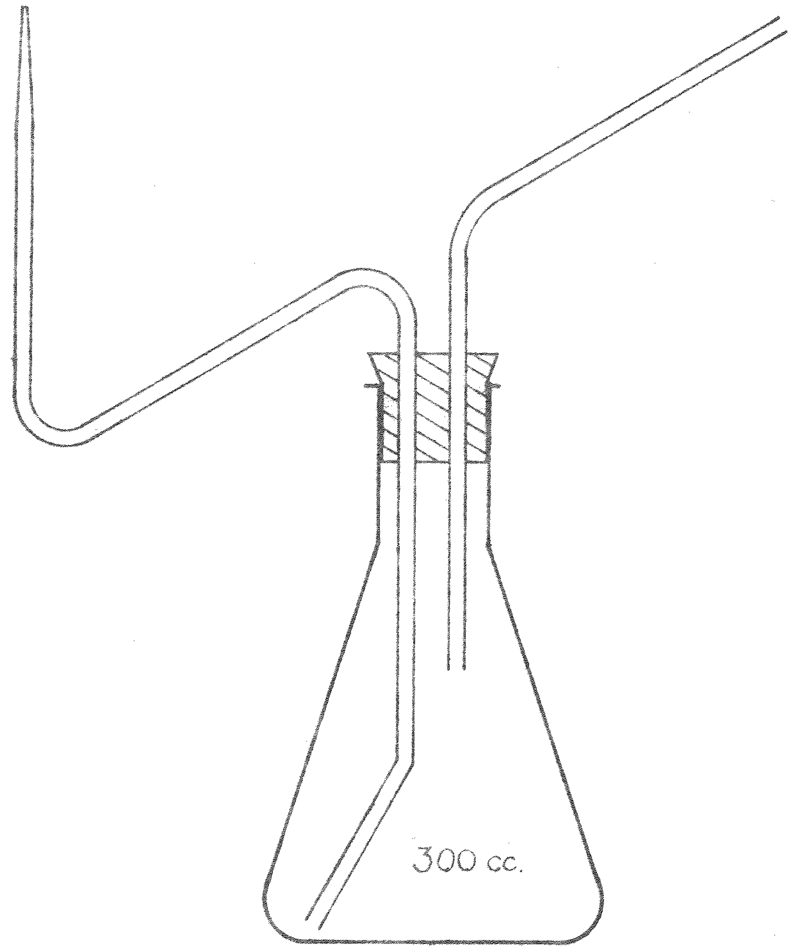
(d) Attach decanting flask (see figure 2, right) to decanting tube and remove heavies from centrifuge tube by applying vacuum from aspirator, regulating vacuum by placing finger over open end of glass tee.

(e) Filter lights and heavies by pouring into separate screened funnels (small tinned sheet-metal funnel with disc of 240-mesh screen soldered in place) placed in bromoform bottles.

(f) After draining, remove funnels from bromoform bottles and place in "washings" bottles. Wash out remaining grains from centrifuge tube and decanting flask into their respective funnels with alcohol or acetone from wash bottles. (A special wash bottle [see figure 4] with V-shaped, rigid nozzle-tube, the open leg of the V being vertical, is easily made and very useful for washing the centrifuge tubes into funnels; while an ordinary wash bottle suffices very well for the Erlenmeyer decanting flask.)

(g) Wash lights and heavies further with alcohol or acetone if necessary. (Acetone is preferable -- being more volatile -- except for its very disagreeable fumes.) After draining, place funnels in rack and dry contents of each by attaching tube from aspirator to small end and pulling air through the funnel. (Drying is very rapid by this method.)

(h) Weigh both lights and heavies and file each in separate glass vial, envelope, or folded paper. (The last method is very satisfactory for the heavies.)



WASH-BOTTLE
FOR CENTRIFUGE TUBES

Figure 4.

Compute percentage heavy minerals as follows:

$$\frac{\text{wt. heavies} \times 100}{\text{wt. heavies} + \text{wt. lights}} = \%\ \text{heavies}$$

("% heavies" is a rough figure, taking no account of losses during separation; but the limits of error of the method used are no doubt within the range of error due to micas remaining one time with the lights and another time with the heavies.)

(10) Prepare permanent mount of sample of heavy crop as follows:

(a) Clean cover glasses (28 x 35 mm.) with xylene if necessary. Place 12 (much time is saved by doing about a dozen at a time in this step) cover glasses on a 6" filter paper covering a 6" (diameter) copper plate with wooden handle. Add to each glass 4 or 5 drops of Canada balsam -- sufficient to cover about 3/4 of the surface of the glass when heated. Place whole on 6" electric hot plate and cook slowly until sample of balsam is almost brittle when removed and cooled on knife blade. Remove copper plate with cover glasses and allow to cool. Unused cover glasses prepared in this way may be kept in a dessicator for several days; but after longer time the balsam will produce bubbles when reheated.

(b) Split -60 +150-mesh heavy mineral crop on glass plate with a razor blade to sample containing about 3000 or 4000 grains and file remainder. Place sample in 1" (diameter) screen stack with 100-mesh and 150-mesh screens (plus cover and pan) and shake by hand by striking bottom on metal block and rotating. (The block need not of course be of metal; but the latter provides a sharper shock.)

(c) Transfer -100 +150-mesh heavies to surface of cold balsam on a cover glass. Discard other sizes unless they represent total remaining heavies, in which case file. Brush heavies on balsam surface into rectangular area occupying about 1/4 area of balsam, near middle, with camels-hair brush.

(d) Place cover glass with balsam and heavies on the filter paper covering hot plate, by means of a cover glass forceps, and heat until heavies sink into melted balsam. Remove cover glass and cool.

(e) Place ruled slide (see page 19), rulings upward, on hot plate and heat.

(f) Take cover glass, with grains embedded in balsam, in cover glass forceps, balsam downward. Touch one end of cover glass to slide, and when balsam begins to melt, lower the glass slowly onto the slide as balsam continues to melt. Remove slide from hot plate with forceps. Work excess balsam out from under cover glass at same time dispersing grains evenly on slide, by pressing and sliding cover glass with handle of camels-hair brush or some similar object. If cooling of balsam is too rapid, it may be reheated on hot plate; but care must be used to avoid overheating and production of bubbles.

(g) Place steel block (about 25x30x10 mm.) on cover glass while balsam is still fluid, and allow to cool.

(h) Clean off excess balsam with knife, wash with xylene and tissue paper, number slide with diamond stylus.

(11) Make heavy mineral count as follows:

(a) Count 100 transparent grains only. About 7 "lanes" will lie within the width of the cover glass; traverse these in the following order, counting the lanes from either side of the slide: 4, 2, 6, 3, 5, 1, 7, as far as may be necessary to obtain 100 clear grains. In case cursory examination indicates that more than 100 clear grains per lane are present, count only the grains in half or a quarter of each lane, splitting the lanes parallel to their length, by inspection. The object of these details of procedure is to obtain the best average representation of the slide. Enter count data on tally sheets as per figure 5. Observe the following pints in making the count:

DATA SHEET FOR HEAVY MINERAL GRAIN COUNTS

****

SAMPLE NO. ____________ SLIDE NO. ______ DATE ____________________

Microsplit: ____

****

Amphiboles
- Actinolite
- Crossite
- Glaucophane
- Hornblende
- Tremolite

Anatase

Apatite

Barite

Brookite

Chlorites

Epidotes
- Epidote
- Zoisite a
- Zoisite b

Fluorite

Garnet

Lawsonite

Micas
- Biotite
- Muscovite

Monazite

Opaque

Pyroxenes
- Augite
- Clinoenstatite
- Diopside

Rutile

Titanite

Tourmaline

Zircon

****

REMARKS:

Figure 5.

1. Exclude micas from the count.

2. Count species only, noting varietal peculiarities, under "Remarks".

3. Make no distinction between basaltic and ordinary hornblende except as noted under "Remarks".

4. Count augite and diopside as augite.

5. Count all glaucamphiboles as such, noting crossite under "Remarks" when present.

(b) In case the full 100 grains are counted, percentages of individual species are given directly. In case less than 100 grains are available, calculate percentages on the basis that total grains counted equals 100%, noting total number of grains counted under "Remarks".

(c) Estimate, by scanning the whole slide, lane by lane, the relative percentages of biotite and muscovite, on the basis that biotite plus muscovite equals 100%.

(d) Note such items as estimated percentage of opaque and altered material, etc., under "Remarks".

(e) Transfer all significant count data from tally sheets to 5"x8" filing cards as per Plate I, completing graphic representation, etc.

(f) Compare assemblages by fastening cards to drafting board in overlapping relationship, with only graphic portion showing.

Discussion of Procedure

The frequent use of decantation methods in laboratory procedure is practically necessitated by considerations of time. Decantation is undesirable from the standpoint of eliminating the "personal equation", but can be used quite successfully for purposes of the procedure used in the present investigation. The method used here was simply to estimate by eye the maximum particle size decanted. Screening, subsequent to use of decantation methods, provided a check on the accuracy of the latter. Measurement of settling times[1] was hardly warranted by requirements of the present problem, and in any case would have been difficult of application in that solutions and mixtures involved in the decantation processes varied widely in physical properties.

The use of funnels with built-in screens eliminated much time in operations which would otherwise be carried out with filter papers. In large-scale laboratory work it might prove preferable, in the case of heavy mineral filtrations, to use sufficiently large batteries of funnels (and filter papers) to avoid wasting time required for filtration and drying.[2] The great advantage in using large

[1] Krumbein, W. C., and Pettijohn, F. J., op. cit., pp. 119-124, 147-150.

[2] Milner, H. B., op. cit.

numbers of funnels is that the slow process of draining of filter papers may take place in one lot of funnels while another operation is being carried out on a second lot, thus avoiding waste of the operator's time. However, in the present case the screened funnels have been found very effective.

The removal of viscous petroleum from core samples was found to be a very tedious process at best. The mixture of petroleum ether and carbon disulphide was very effective (no other effective washing medium was found), especially when used with the screened funnels mentioned. The latter permitted effective final washing.

Time and trouble could probably be saved in step (3) by adding the HCl to the water-covered sample while cold instead of boiling, until effervescence (if any) subsides; then boiling for 10 minutes.

The object of treatment with NaOH is to avoid attack of jar lid and tumbler in the washing machine by acid. If this equipment were acid-resistant this step could be eliminated. However, the time consumed is little, and it is thought that the weakly alkaline solution is effective in cleaning up the detrital grains. The alkalinity is not sufficient to affect silicate minerals or glass jars to appreciable degree.

Scrubbing of some sort, of the acid-treated sample, is necessary to complete disaggregation and cleaning of grains in many or most cases. This is done by hand by many workers, but the washing machine would undoubtedly prove to be indispensable in large scale efforts. The machine could no doubt be improved.

The use of a double set of screens with the Rotap shaking machine represents a saving of time over the usual practice of running one set at a time. It is believed that the ordinary Rotap machine could be quite easily adapted for running four separate sets at the same time. This would obviously represent a further saving in time.

The centrifuge apparatus described above has proved very satisfactory. It is probably true that for general heavy mineral work with sand-size material the increased accuracy of centrifuge separations over the conventional funnel apparatus is not required. Whether the centrifuge would prove more economical in large-scale laboratory work than a battery of funnels is problematical. Certainly the centrifuge method would require less heavy liquid for operation at the same rate of sample output. The immense advantage of the centrifuge in work with silt and clay-size material can hardly be questioned.

A considerable amount of experimentation was done in the matter of preparing Canada balsam mounts of heavy minerals. The two factors most difficult to control are: (1) avoidance of bubbles in the balsam and (2) uniform dispersion of the grains without undue loss of material flowing out from under the cover glass with excess balsam. The method described above is the most effective the writer was able to devise. It was quite satisfactory.

Canada balsam was used rather than kollolith or piperine mainly for the reasons that the balsam is readily obtainable and that much of the determinative criteria from the literature are more easily applied when the mounting medium has the index of balsam; for instance, Tickell's identification tables.[1] The more constant index of kollolith is probably not an important item, as compared with balsam, in work such as that of the present investigation. Piperine, by reason of its relatively high index, might prove to be an effective mounting medium; however, the dispersion effects obtained in its use might prove to be more of a handicap than an advantage.

The method used for splitting down heavy mineral concentrates to samples for mounting is rapid and is thought to be reasonably accurate. To obtain mathematical accuracy, however, a sample splitter such as that of Otto[2] or Went-

[1]Tickell, F. G., op. cit.

[2]Otto, G. H., Comparative tests of several methods of sampling heavy mineral concentrates. Jour. Sed. Pet., Vol. 3, pp. 30-39. 1933.

worth, Wilgus and Koch[1] would be required.

[1] Wentworth, C. K., Wilgus, W. L., and Koch, H. L., A rotary type of sample splitter. Jour. Sed. Pet., Vol. 4, pp. 127-138. 1934.

The use of ruled slides was found to be very effective in making grain counts.

The 1" sieves mentioned in (10), (b) were designed and made by the writer. The bodies of the sieves, pan and top were turned on a lathe from 1" brass tubing with 1/8" wall. Each body, with 1/16" recesses at top and bottom to receive sieves above and below, was made in two pieces which when clamped together with the screen between provided an external V-recess into which the screen protruded, and into which solder was run. These offer a very effective means of screening very small amounts of material. The reason for originally sizing the sands to -60 +150-mesh and subsequently sizing the heavies with 1" screens to -100 +150-mesh was that some of the core samples were small, and it was thought that they might furnish insufficient material of the latter size for analysis, in which case resort could be made to the larger grains without repeating screening and bromoform separation on the Laboratory Sample Residue. Although heavy mineral concentrates were indeed very small in some cases, it did not prove necessary to use the larger grains. In continued practice, it would no doubt prove practicable to use large enough samples to insure a sufficiently large concentrate of the desired size for counting, in which case the material could be originally sized to -100 +150-mesh. This would save time.

The 1" screens are useful also in such work as is represented by the "Check Counts" of Plate II (bottom of chart).

In discussing methods used in making heavy mineral grain counts it will probably be advisable to mention some of the basic ideas involved in the writer's choice of these. As has been mentioned above, one of the main items in the viewpoint adopted in the work was to use the simplest methods by which it was thought a solution of the problem might be found. It was therefore decided to work with mineral <u>species</u> only, making as close an approach to statistical methods as possible, and to avoid attempting to deal particularly with varietal characters. Resort could be made to these latter in case the proposed method did not suffice.

The question of whether to make <u>estimates</u> or actual <u>counts</u> was decided in favor of the latter, for the reason that, while within the limits of any one man's work comparison of estimated assemblages may be quite valid procedure, it is probably not to be expected that estimates made by different men will permit of close comparison. In other words, the "personal equation" must enter into estimates to a greater extent than is the case with counts. One of the ideas maintained during the work, as has been mentioned, was to try to eliminate the personal element from the results. Therefore, while it was realized that actual counting would be slower in the earlier stages of the work, it was thought worthwhile to attack the problem in this way, with a view to developing ways and means whereby actual counts could be made with a rapidity comparable or equal to that attainable in making simple estimates. It was with these considerations in mind that rather extensive experimentation with ruled slides was carried out. It is believed that these slides represent considerable progress in the desired direction.

The procedure of using permanent Canada balsam mounts was adopted rather than that of working with temporary immersion oil mounts by reason of the obviously great advantages of permanence. The original slides could thus be filed and referred to at any moment. Recounts could be made with a minimum expenditure of time. Here again the thought was to choose the procedure which offered the most desirable features, other than that of speed of operation, and attempt to develop a technique sufficiently rapid to justify use of the more desirable method. Another consideration was involved here, namely, whether determinations of species could be made with sufficient certainty in balsam mounts, without the use of immersion liquids. This question is believed to have been answered in the affirmative. In the use of balsam mounts, dependence for diagnostic criteria must be placed largely upon optical characters other than indices of refraction. The technique employed must not depend upon these latter. It is believed that such a technique is entirely practicable. Occasional cases may, of course, arise in which resort to immersion liquids is required. It may be mentioned that, in such a technique, dependence must often be placed upon optic orientation, etc., and that a microscope with revolving, multiple-objective nosepiece possesses a very great advantage.

Another item of microscopic procedure which requires mention is that of counting 100 clear grains only. As regards the counting of clear grains only, the view taken was that these would probably yield more significant data for a given expenditure of time than a study of opaques. It may be mentioned here that a similar view was taken with regard to the magnetic and the light minerals. However, regarding the latter, it is now believed that more extended work might indicate the desireability of at least a cursory examination of the light minerals as a regular item of procedure. Concerning the counting of only 100 grains of the transparent heavy minerals, the number was limited to that figure because it is believed that 100 is adequate to yield percentage data of sufficient accuracy for the present investigation. Confirmation of the adequacy of this procedure would now appear to be forthcoming in the observation that more accurate percentages would apparently furnish no more effective a picture than that represented by Plate II. Further, as regards the "Check Counts" of Plate II, these are taken to indicate that no errors inherent in any part of the procedure employed, including grain counts, are sufficient to minimize or vitiate the conclusions drawn from the data. In other words, the plotted data from any one of the samples of the "Check Counts" appear to be sufficiently similar to warrant confidence in the methods employed. A further consideration in limiting the counts to 100 grains is that the limits of error of this method are probably well within the range of those of field sampling.[1]

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[1]Dryden, A. L., Accuracy in percentage representation of heavy mineral frequencies. Nat. Acad. Sc., Proc., Vol. 17, pp. 233-238. 1931.

The fact that a number of the counts were made on fewer than 100 grains requires notice. The reasons for fewer than 100 transparent, non-micaceous grains being available in these slides are mainly: (1) that the samples contain a very low percentage of heavy minerals, or (2) that the percentage of opaque minerals in the samples is very high, or (3) that the field sample was small. For various reasons, a considerable degree of confidence was felt in the validity of these counts. However, it was realized that, to the general observer of these data, the inclusion of counts based on fewer than 100 grains would probably seem a questionable procedure. Most of these counts included about 50 or more grains; but some included fewer than this. Two of the samples were based upon extremely few grains: 8 in the case of F30-38, and 14 in the case of F84-38. These figures might well seem ridiculously low to the reader. Therefore these two concentrates were resampled and recounted in temporary mounts. In the case of F30-38, 100 grains were available in the recount; in the case of F84-38, 78 grains were available in the slide. In both cases the percentage of opaques in the concentrate was estimated to run over 90%. The recounts checked surprisingly well with the original counts. Consequently it is confidently believed that no significant errors have been introduced into the data by reason of too few grains having been included in any of the counts. The counts of the two samples mentioned are represented in Plate II among the check counts in confirmation of these conclusions.

The order in which the lanes of the ruled slides were counted was designed to give the best average representation of the concentrate.

Micas were excluded from the count because it was believed that their relative abundance among the transparent minerals was of comparatively little significance, except insofar as they might be rare or absent. Moreover, in much of the material the micas were of such great abundance that inclusion of these in the counts would have effectively "flooded out" the other minerals, which would be highly undesirable. Another very major factor in the decision to exclude the micas was the fact that these, by reason of their specific gravity being near that of bromoform, may remain with the light minerals in one case and settle out with the heavies in another case; their frequency relative to the other minerals counted would therefore vary anomalously. However, it was thought that the ratio of abundance of biotite to muscovite might be of interest, and so estimates of this ratio were made. As will be noted below, this ratio has apparently proved to be significant.

The 5"x8" data cards, as per Plate I, were designed by the writer. The objectives were: (1) to obtain a means of assembling concisely all pertinent data; (2) to include at the same time a condensed, graphic representation of the heavy mineral data, and this in a manner such that these data could be readily compared; and (3) to provide for ready reference to the data by making them easily susceptible to filing. The design worked out has proved to be very satisfactory. In use, in comparing assemblages, the complete graphic data for each assemblage requires a space of only 1"x8", which fact obviously allows of comparison of large numbers of counts within a comparatively small space, and permits effective visualization of the data. The effect obtained is that of having the data all plotted on a continuous sheet of cross section paper. Nevertheless, these cards represent a first attempt. Many minor items whereby the design could be revised to the end of improving its usefulness have been noticed. Among these are: (1) "Sample No.", "Slide No.", "Locality", etc., could be placed in the same column as "HEAVY MINERALS", with <u>corresponding descriptions only</u> in the graphic column. (2) "Sp. Gr. greater than 2.86" should be inserted directly under "HEAVY MINERALS." (3) The "HEAVY MINERALS" column could be narrower. (4) A special (logarithmic ?) plotting scale should be used for "Heavy Minerals in Total Grains." It is believed that this design, preferably revised, could be used effectively in coordinating data from great numbers of samples.

As a final remark in connection with procedure in general, it is desired to mention here the writer's belief that in an extended program of work with heavy minerals it would prove feasible to use the methods outlined above for establishing type sections and type assemblages, etc., and that a very large percentage of individual samples could be mineralogically classified by cursory examination in temporary mounts and reference to the type data. Such procedure would permit of rapid classification of data.

In summary, it may be well to repeat that the justification for the considerable time and energy spent on development of technique in laboratory and microscopic work and the matter of assembling and graphically representing data, as well as the present extensive discussion of these, is based upon the writer's conviction that progress in sedimentology itself is vitally dependent on progress along these lines.

EXPLANATION OF CHARTS

Generalized Sketch of Miocene Stratigraphic Section (Plate III)

The object of this chart is to furnish a rough picture of the vertical and lateral stratigraphic relations of the Miocene beds along the southwestern border of San

Joaquin Valley from Coalinga to the Maricopa region, and to indicate the positions in this section of the samples studied.

The data on which the chart is based were furnished almost wholly by W. F. Barbat. The intra-Miocene boundaries are derived from the writer's interpretation of R. D. Reed's classification.[1] The chart has been revised twice, according to Barbat's suggestions, since the original draft was made from his sketches. However, since the chart represents the writer's interpretation of Barbat's data, all responsibility for error is accepted by the writer.

The data shown on the chart are very much generalized. It is intended to indicate stratigraphic relations only. No implications as to structure due to deformation are intended. The intent has been to indicate these stratigraphic relations qualitatively only, not quantitatively. No dimensions, either vertical or horizontal, are drawn to scale.

The geographic positions of the various stratigraphic sections indicated (Oil City, Pioneer, etc.) are shown on the Locality Map, figure 1. Detailed descriptions of sample localities are given in Appendix A.

Details of the mineralogical assemblages are given below and in the Flood Minerals Chart, Plate II,

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[1] Reed, R. D., op. cit. (Geology of California. 1933.)

described below. The distribution of these assemblages indicated in the chart is not to be taken as in any sense complete. That is, the intention has been merely to indicate the assemblages found in the samples analyzed. Inferences regarding the vertical and lateral limits of the assemblages are forthcoming only insofar as inspection of the chart may indicate.

Positions of samples analyzed are only roughly shown. For instance, the fact that most of the Midway samples are plotted toward the southeast ends of the lensing sands has no significance. The relative vertical distribution of the samples is only roughly indicated.

The Stevens sand samples (F144-38, F145-38, F146-38) are not indicated in the chart, since they were taken from the Ten Section field, which lies in the south-central part of the Valley, well removed from the general line of the stratigraphic section represented (see figure 1).

The stratigraphic terminology is that of Barbat[1] and Reed and Hollister.[2] This no doubt corresponds to the terminology used by local petroleum geologists. The terms will probably be understood by the reader insofar as may be

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[1] Barbat, W. F., oral communication.

[2] Reed, R. D., and Hollister, J. S., *op. cit.*

necessary for purposes of this paper, without further definition. Precise definition of the stratigraphic terms involved is beyond the purposes of the present paper.

A few general observations, aside from detailed mineralogical data to be discussed below, may be made from and in connection with a general inspection of the chart. The Coalinga section is largely sandy. No specific section is shown between Coalinga (Oil City) and Devils Den for the reason that the Upper Miocene beds, with which this study is mainly concerned, occurring between these limits, are composed almost entirely of shale, thus offering little suitable material for heavy mineral study. The same is true of the Devils Den section itself, but in this case it was desired to show the positions of a Lower and a Middle Miocene sample studied.

In the Carneros and Chico Martinez Creeks section, beds younger than the middle of the Miocene section are composed entirely of shale except for three thin zones shown on the chart. The lower half of the section contains considerable amounts of sand.

The NE. Temblor Range and Midway section is composed of shale from upper Lower Miocene upward, except for the lensing sands indicated. The same is true of the Pioneer section, although much of the uppermost Miocene is cut out here by unconformity.

A few suggestions are available from these considerations regarding general paleogeographic conditions in these regions during Miocene time. There is a suggestion that land existed nearby in the Coalinga region throughout Miocene time. It is suggested that the same was true during Lower Miocene time throughout the whole region. According to this reasoning, neighboring lands were progressively less in evidence southeastward and later in time. In the Midway region, the suggestion would seem to be warranted that after Lower Miocene time neighboring land masses disappeared and distant land then supplied mud to the area. Subsequently, in Upper Miocene time, it would appear that, while mud (if any detritus at all, much of the shale being organic) continued to come into the area from distant lands, a neighboring land mass (or masses) sporadically shed coarse detritus locally.

Flood Minerals Chart (Plate II)

The purpose attempted in this chart is to assemble in the most condensed and concise form, in the way best suited for comparison and analysis those data derived from the present investigation which are significant to solution of the problem. The chart represents a condensed and simplified compilation of selected material from the more detailed data of the filing cards illustrated by

Plate I. Insofar as the stated purpose of the chart has been fulfilled, it is thought that this selection and simplified presentation of the data is not only justified but highly desirable.

Selections and simplifications of the data with justifications therefor are as follows:

(1) Barite, which was included in the original counts, was calculated out of the assemblages for the reason that it is thought to be largely authigenic. The only specific evidence in support of this supposition is the sporadic occurrence of the mineral, this feature being very striking in some cases. For instance: of two samples otherwise very similar, and referable to the GTZ assemblage (see below), one may have a large amount of barite while another may have none. The suspicion that barite is authigenic in at least some cases, based upon observations such as that mentioned, is considered to constitute sufficient reason for excluding it from consideration as a possible indication of source of detritus. The ratio of barite to total heavies was probably not sufficiently high in any case to seriously affect "% heavy minerals" as plotted.

(2) The observed minerals of the various common major groups were lumped, and calculated and plotted as groups, as follows:

(a) Amphibole, including actinolite, hornblende, tremolite.

(b) Epidote, including clinozoisite, epidote, zoisite.

(c) Glaucamphibole, including crossite, glaucophane.

(d) Pyroxene, including augite, diopside, enstatite, hypersthene, spodumene (?).

The chief justification for this simplification is considered to lie in the observation that there appears to be no assignable significance in differential distribution, among the samples studied, of the minerals of any one group, except as noted below. This observation of course arose from the study of the assembled graphic data of the filing cards. It will perhaps be desirable to discuss the various groups individually in this regard.

The other amphiboles seldom occur separately from hornblende. These all grade into each other, from colorless to deeply colored varieties; and from fibrous to non-fibrous varieties. Sharp distinction between varieties could perhaps be made with detailed study, but such was not considered desirable in the present investigation. Detailed study might reveal that tremolite and actinolite are more prevalent in

Franciscan sources than elsewhere; but since common hornblende is usually the dominant type, large counts and precise optical determination would be imperative. Colorless amphibole (tremolite) was found to occur in notideable quantities in some granitic samples, however.

The epidotes are similar to the amphiboles in these respects. Common epidote is the dominant type. It is very variable in its optical properties. The other epidotes seldom occur independently of common epidote; and appear often to grade into the latter. Again, detailed mineralogical study would be required to establish any significant differential distribution within the group.

Of the two glaucamphiboles recognized, glaucophane is the dominant type (over crossite) by a very wide margin. Although the two minerals are considered by some workers to be difficult or impossible of distinction in grains, the writer has found that they are often quite readily separable on the basis of optic orientation, if not on the basis of color and pleochroism. As a matter of personal interest, many checks as between the two minerals were made in the course of the work. Crossite was found to be comparatively rare, and of no apparently distinctive distribution. Its rarity would in any case eliminate it as a basis for any valid conclusion in this regard, without detailed work.

The case of the pyroxenes is somewhat different than the preceding ones. Enstatite was rarely found, and may in fact have been better classified as hypersthene. A spodumene-like mineral[1] was found in considerable percentage in sample F78-38, although it was counted as augite, as was diopside-like material. There remains the question of the desirability of lumping augite and hypersthene, having grouped all pyroxenes under these two names. There is of course a wide gap optically between the two groups, as contrasted with the amphiboles. In general, there is also a wide gap between the two groups petrographically. The justification for grouping in the case of these two therefore rests solely on the supposition that any differential distribution between them is of no significance in the present problem. It will therefore be pertinent to list the ratios of percentages of augite to hypersthene in all Franciscan and Miocene samples in which either was recognized. These ratios are as follows:

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[1] Index of refraction approx.: $1.670 > N > 1.658$. The occurrence of spodumene in this connection (Franciscan detritus) may appear anomalous. However, it is recorded from the west side of San Joaquin Valley by R. D. Reed and J. P. Bailey, op. cit., p. 363.

FRANCISCAN		COALINGA MIOCENE		OTHERS	
Sample	Ratio	Sample	Ratio	Sample	Ratio
F78-38	36/18	F47-38	10/20	F31-38	4/0
F129-38	50/9	F46-38	2/0	F149-38	1/0
F127-38	54/30	F44-38	14/65	F147-38	5/2 (?)
F131-38	16/3	F42-38	1/1	F152/38	8/0
F122-38	1/0	F39/38	1/1	F150-38	1/0
F120A-38	24/11				
F118-38	19/10				
F116-38	12/0				
F137-38	45/0				
F84-38	51/0				
F141-38	57/0				
F115-38	9/0				

Within the limits of the date furnished by the present investigation, therefore, the only significant suggestion to be derived from differential distribution of the pyroxenes would appear to be that, as between samples containing augite only and others containing both augite and hypersthene, the latter were derived from Diablo Range Franciscan (samples F78 to F116 inclusive) as against derivation from Franciscan of the coastal regions (samples F137 to F115 inclusive). The implication would be Franciscan derivation in either case. However, Bramlette[1] has raised the question as to whether hypersthene found in later Tertiary sediments of the Coalinga region may not have been derived from Sierran andesites. This question will be considered below.

[1] Bramlette, M. N., oral communication.

(3) Having grouped several of the common species as noted above, all minerals recognized in the investigation (except micas) were observed to be divisible into (a) flood minerals and (b) rare minerals. The flood minerals, according to this classification would be:

Amphibole	Pyroxene
Andalusite	Sphene
Epidote	Tourmaline
Garnet	Zircon
Glaucamphibole	

The rare minerals would be:

Brookite	Rutile
Corundum	Sillimanite
Kyanite	Staurolite
Lawsonite	Topaz
Monazite	Idocrase

The flood minerals, as grouped above, occurred often in very high percentages. Of the flood minerals, glaucamphibole showed the lowest maximum percentage among the samples studied: 44%.

On the other hand, none of the rare minerals ever occurred in high percentage. The highest percentage in any sample was shown by rutile: 9%. (Lawsonite, 7%, was next highest.) The excessive gap in range of maximum frequency between the two groups is therefore evident.

These figures are further emphasized by the fact that the flood minerals constitute 98.5% of all grains (except micas) counted in all 89 samples (exclusive of the check counts of Plate II).

The term "flood mineral" is considered to be defined, for purposes of the present paper, by the foregoing discussion. The term is used in the literature differently by different authors but always denotes minerals occurring in abundance, as contrasted with "rare minerals."[1]

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[1]Krumbein, W. C., and Pettijohn, F. J., op. cit.

The rare minerals were excluded from the chart mainly for the following reasons: (a) Their frequency ranges were so small as to indicate nothing more than presence or absence. (b) The presence or absence of any one of these species could well have resulted from, as well as frequency fluctuations been unduly affected by, sampling and counting errors. (c) No data at hand suggested that the presence or absence of any of these species was diagnostic in any way as an indication of source.

In the foregoing the writer has gone to considerable length to demonstrate that no significant data among those obtained have been minimized or discarded in compiling the chart. As a matter of fact it is the writer's belief that no justification would be necessary other than that the data used, regardless of how much might have been discarded, should furnish a picture upon which logical conclusions regarding the problem at hand could be based; provided always that the addition of discarded data would not change the picture in any significant respect. For instance, in a similar study it might prove to be the case that a treatment of the samples as functions of three species, say andalusite, augite and zircon, as independent variables, disregarding any other minerals present as confusing to the data, would be the most advantageous procedure. In the present case, the most convincing justification of the graphic method used appears to the writer to be simply the fact that grouping of the data throughout the chart is a strikingly marked feature, and that it does present a logical picture, regardless of whether or not complete interpretation of the picture can be made at present. Whether or not this picture is the true one can not be finally proved or disproved at the moment. Future investigation will probably answer this question.

A very interesting case, with interesting results, of grouping of a considerable number of minerals from several general rock types into three groups, and use of these three as the independent variables of a triangular diagram, by D. Carrol[1] illustrates some of the ideas expressed above.

[1]Carrol, D., Recording the results of heavy mineral analyses. Jour. Sed. Pet., Vol. 8, pp. 3-9. 1938.

As regards details of calculation and plotting of the graphic portion of the chart:

Percentages of individual "flood minerals" are calculated on the basis that the total of these equals 100% (exclusive of the micas). That is, percentages as plotted, from amphibole to zircon, inclusive, should total 100% for any given sample. The tendency is to exaggerate the smaller percentages for emphasis, but this factor should be of little influence. The total width of a column (bounded by lines separating adjacent flood minerals) equals 100%; each small division horizontally (read across column) equals 10%, except for the "% Heavy Minerals" column. The range of values in percentage of heavy minerals (from about 0.01% to over 10%) required a special method of plotting, the units of which are noted above the head of this column. Percentages in the "% Muscovite" column are estimated on the basis that biotite plus muscovite equals 100%, as discussed previously. Diagonal lines in this column indicate biotite plus muscovite rare or absent. (Note that a blank space in this column indicates 100% biotite, not micas rare or absent.)

As will be observed, samples are grouped as "Recent Sands" from possible source areas, and as "Miocene Sands", the sources of which are in question. The case of samples F100-38 and F101-38 requires special notice. These two are Recent sand samples taken from streams draining Miocene outcrops. Hence they were taken in the same manner as the source-rock samples. All other Miocene samples are "spot" samples, as discussed earlier in this paper.

Under "Recent Sands" the samples are grouped according to type of source rock (Franciscan, granitic, Cretaceous, Eocene). Under "Miocene Sands" the samples are grouped according to their flood mineral assemblages.

A further note is required concerning the usage of the term "granitic". This term is employed in the present paper to refer to the plutonic "basement complex" which constitutes the main bulk of the Sierra Nevada, and to all similar rocks, including those which occur in the Coast Ranges. Scattered masses of ancient, pre-intrusive rocks (gneisses, schists, etc.) are included in the term. The intrusives are of course rarely if ever true granites, being ordinarily more basic.

The "check counts", constituting the lower portion of the chart, were made for the purpose of checking various items of procedure. The first 28 of these were made on 7 different samples, using grains of different sizes obtained in different ways, as noted on the chart. In some of these samples different counts represent separate concentrations, run individually in the laboratory. The counts of these 7 samples used in the main body of the chart are repeated among the check counts for purposes of ready comparison. These data are taken to indicate that those of the main body of the chart are free from significant error due to allowed variations in laboratory and microscopic technique.

The four lowermost counts on the chart are presented as a check on expectable variations due to counting very small numbers of grains. These have been noted above.

MINERALOGICAL NOTES

Amphibole. The amphiboles recognized, exclusive of the glaucamphiboles, were hornblende, actinolite and tremolite. Green hornblende was often found heterogeneously mixed with the brown variety. The green variety was most abundant in granitic assemblages. Apparently continuous gradation between the two types was the rule; the two were not separated in counting. Separation of the two types might have offered significant data, but a detailed mineralogical study of these was not considered advisable. The presence of blue-green hornblende in some of the granites was a very noticeable feature. Detailed study of this item might be also of value in extended study of the problem. Tremolite and actinolite were found to grade into each other and into hornblende, different grains displaying varying degrees of color and fibrousness. As has been mentioned, tremolite (colorless amphibole) was found among the granitic samples as well as in Franciscan assemblages.

Andalusite. The occurrence of this mineral in quantity in some of the Miocene assemblages is very interesting and unexpected. A comparatively few grains displayed marked pleochroism in red shades. Most were colorless.

Epidote. Among this group clinozoisite, common epidote and zoisite were recognized. All gradations between the three were apparently present; that is, grains with characteristics intermediate to those of the three chief types were found. Within the category of material classed as common epidote, wide variations of color, birefringence and pleochroism were observed.

Garnet. Different varieties of garnet were not distinguished in counting except to make general notes regarding the presence of the green garnet discussed by Bramlette.[1] As noted by him, this variety is apparently

[1]Bramlette, M. N., Heavy mineral studies on correlation of sands at Kettleman Hills, California. Amer. Assoc. Pet. Geol., Bull., Vol. 18, pp. 1559-1576. 1934.

confined to Franciscan rocks (among source-rocks). Further, it seems probable that the mineral is more or less confined to the highly serpentinous facies of the Franciscan. Search for spinel indicated that, if present, it was difficultly distinguishable from garnet. If spinel was present, it was counted as garnet.

Glaucamphibole. As previously mentioned, glaucophane and crossite were distinguished, the former being by far the more abundant. It was found necessary to exercise some care in distinguishing between glaucamphiboles on the one hand and blue tourmaline and blue hornblende on the other hand. The distinction is usually simple (by optic orientation, sign, extinction angle, absorption formula, etc.), once the necessity is recognized.

Pyroxene. Augite and diopside were not separated; both are probably present, but all such types were counted as augite. Wide color variations were noted. A spodumene-like mineral (discussed above) found in considerable quantity in one sample was also called augite.

Rare grains called enstatite are probably better classed as hypersthene. The latter frequently showed marked pleochroism, but not invariably.

Sphene. Great variations in color and pleochroism were noted in this mineral also. A notable feature of sphene was what appeared to be an extreme degree of alteration in some samples, especially those derived from Cretaceous and Eocene source-rocks. These samples contained a high percentage of light brownish opaque material, some of which exhibited transparent edges of sphene, of which the opaque material was therefore supposed to be the alteration product. It is possible that the reverse is true: namely, that the sphene is the alteration product of the opaque material.

Tourmaline. The only noteworthy feature of this mineral was its variability in color and pleochroism. The blue varieties were at first confused with glaucamphibole.

Zircon. In contrast to most of the other minerals, zircon displayed no variations. Rounding of the zircons was nowhere marked, although some from the GTZ sands showed a certain amount of wear.

Micas. Variation in the relative amounts of muscovite and biotite proved to be an interesting feature. (See Plate II.) No definite conclusion regarding how much of the muscovite may be of secondary origin is forthcoming.

However, it may be said that the general physical appearance of the grains gave no specific indication of secondary derivation. Chlorites were not counted. Some cases of hornblende altered to chlorite, interesting for their pseudomorphous nature, were noted.

THE SOURCE-ROCK ASSEMBLAGES

Franciscan

The most striking feature of the Franciscan assemblages, as may be observed from a glance at Plate II, is the markedly consistent presence of pyroxenes, often in high percentages. However, Bramlette[1] has raised the question as to whether these pyroxenes (especially hypersthene) are indigenous to the Franciscan rocks, or whether, on the other hand, they may have been originally derived from Sierran andesites, and may therefore be present as the result of some sort of contamination of the present Franciscan samples. If the pyroxenes do represent such contamination, then obviously they may constitute a misleading indication of source when found in Miocene sediments.

The writer believes that these pyroxenes were indeed derived from Franciscan rocks, but since the question

[1] Bramlette, M. N., oral communication.

has arisen, the reasons for this belief merit discussion at this point.

The most convincing evidence available from the present investigation in support of this belief is simply the charted data, showing the striking and consistent presence of pyroxenes, often in large percentage, in the Franciscan samples, and the absence of any such feature in any of the other source-rock samples. The facts that the pyroxenes are so characteristic of the Franciscan samples and so uncharacteristic of samples from other types of source-rocks in the same general region appear to the writer in themselves to constitute very convincing indications in support of his belief.

The original basis for considering that the detritus of these samples was indeed wholly or largely of Franciscan origin was, of course, as mentioned previously, the data of the California State Geological Map. It is unquestionably true that the data of this map are not sufficiently detailed to allow of any certainty that unmapped areas of contaminating material are not present within regions mapped as Franciscan. But that unmapped areas of contaminating rocks of sufficient bulk and similarity to furnish the supposed Franciscan assemblages with the pyroxenes shown should be present consistently within the widely scattered Franciscan areas sampled, and yet not be present and of similar influence in intervening and neighboring sampled areas of other source-rocks, appears to the writer to be highly improbable.

These considerations are instanced as follows: The Chualar Canyon and Pescadero Creek samples (F132-38 and F130-38) of the granitic suite are located roughly on a line between the Franciscan samples from Puerto Creek and Pacheco Creek (F78-38 and F129-38), on the one hand, and from Arroyo de la Cruz Creek (F137-38) on the other hand. (See figure 1.) The Puerto Creek and Arroyo de la Cruz Creek Franciscan samples are located about 125 miles apart, with the granitic samples lying between. Yet the Franciscan samples fall nicely into their suite and the granitic samples into theirs. The pyroxenes are present in marked abundance in the Franciscan samples, while the intervening granitic samples contain negligible amounts. The supposition that the pyroxenes in these samples represent contamination would seem highly improbable to the writer, in the light of the facts enumerated. Similar considerations apply to the source-rock suites in general.

That some of the source-rock samples do involve contamination is obvious from the data of the State Geological Map. That this contamination is of no significant effect is believed to be evidenced by the fact that the assemblages of these samples fit in well with the others of the same suite. One such case is the lower Los Gatos Creek sample (F118-38). The State Geological Map indicates that the major part of the drainage area in this case is underlain by Cretaceous and Franciscan rocks and that roughly 10% of the drainage area is underlain by Pliocene sediments. Yet the analysis fits in with other Franciscan analyses very well. This is the more surprising in view of the fact that the Franciscan rocks, as mapped, constitute but a small percentage of the drainage area, most of which is underlain by Cretaceous beds. There would seem to be two factors mainly accounting for these facts. One of these is that the Franciscan rocks in general show a higher percentage of heavy minerals than samples of sediments. Therefore the Franciscan assemblage might be expected to dominate in the case of mixture with assemblages from sedimentary rocks. The other factor is the probability that the Pliocene rocks themselves were derived in part from Franciscan sources. A glance at Reed's paleogeographic map for Pliocene time[1] will indicate that Franciscan rocks

[1] Reed, R. D., and Hollister, J. S., op. cit., p. 45.

probably were contributing detritus to the area in question. It may be further suggested that similar conditions might hold for possible Pliocene contamination of other Franciscan samples taken in the Diablo Range.

In the foregoing discussion of the pyroxenes of the Franciscan samples no distinction has been made between augite and hypersthene. Much of the discussion applies strictly to augite only, since, as inspection of the augite-hypersthene ratios given earlier in this paper will show, hypersthene is confined to the Diablo Range (among the Franciscan samples). While the writer finds the supposition difficult to accept, the possibility must be recognized that, as far as the hypersthene is concerned, this may have been derived from Miocene volcanics scattered throughout the Diablo Range Franciscan. The State Map shows an area "Miocene Volcanics" as comprising roughly 5% of the drainage area of sample F127-38. Although no similar contamination is indicated for the other Diablo Range Franciscan samples, the possibility that such areas of volcanics may be widely scattered in this general area must be admitted. A further consideration is that these rocks may have been much more wide-spread during later Tertiary time than they are now. However, assuming the existence of these conditions which are admittedly possible, and assuming further that these volcanics are indeed of Miocene or greater age, then interpretations regarding sources of hypersthene-bearing Miocene detritus in the Diablo Range will be the same as if the hypersthene were actually indigenous to the Franciscan. A Diablo Range source will be indicated. Thus the writer sees no probable necessity for appealing to Sierran andesites as a source for hypersthene in this region, of either Miocene or Recent occurrence.

The question as to what specific rock type supplied the pyroxenes, assuming these to have been derived wholly or in major part from the Franciscan complex, naturally arises. To this question the writer can offer no definite answer. The only suggestion that would seem to be available is that the pyroxenes were derived from some of the source-rock types commonly and vaguely referred to as "ultrabasics". That the Franciscan complex contains a very great variety of igneous rocks which have not been comprehensively studied is certain. It does not appear to the writer at all unreasonable to suppose that the pyroxenes may have been derived from some of these. Final solution of these problems will require study of the individual rock types of the Franciscan. A convenient approach to the problem would seem to be to study in thin section the rock types found among the cobbles and boulders of the streams from which the Franciscan samples of the present investigation were taken.

Glaucamphiboles are present in all the Franciscan samples. In all but two of these the percentage of glaucamphibole is comparatively low. These facts would seem to indicate, first, that Franciscan rocks are certainly represented in all these sampes.[1] Second, they would ap-

[1]Detrital glaucamphiboles are considered to be diagnostic of Franciscan source-rocks. Glaucophane and crossite are not known to have been reported from any non-Franciscan igneous or metamorphic rocks in California. Cf.: Reed, R. D., Geology of California. 1933. Pabst, Adolf, Minerals of California. St. of Calif., Div. of Mines, Bull. 113, pp. 263-265. 1938.

pear to offer support to the proposition that no excessive contamination effects are present in that, were such the case, it should be expected that in some cases the glaucamphiboles should be diluted out and that in many others these minerals would be excessively high in percentage. In point of fact, only two samples, which will be mentioned below, show high percentages of glaucamphiboles. The most likely conclusion would seem to be that the glaucamphiboles are derived from comparatively pure Franciscan rocks and that on the average these contain widely scattered occurrences of these minerals. The distribution of the schist areas, to which the glaucamphiboles are probably confined, as observed from cursory field examination, bears out this latter idea. The schists appear to be prevalent mainly in the probable cores of the Franciscan masses.

Two of the Franciscan samples require further notice. These are: F123-38 and F122-38. They are derived from the striking serpentine area near Idria.[2] The charted

[1]The Idria serpentine mass appears to constitute almost wholly a stark, bare, rugged wilderness of ridges and peaks, among which travel along the mountain roads is hazardous on account of the sliding, creeping nature of the serpentine.

data indicate: (1) considerable amounts of garnet in both of these; this is largely the green uvarovite of Bramlette;[1]

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[1] Bramlette, M. N., Heavy mineral studies on correlation of sands at Kettleman Hills, California. Amer. Assoc. Pet. Geol., Bull., Vol. 18, pp. 1559-1576. 1934.

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(2) the presence of an abnormally high percentage of glaucamphibole in one of the samples as compared to the Franciscan samples as a group; (3) the absence of pyroxene in one of the samples and its presence in small percentage in the other. These two samples are markedly exceptional as compared with the group as a whole, with the possible exception of sample F131-38, in which also a high percentage of glaucamphibole will be noticed. Now, if these two were to be taken as typical of true Franciscan rocks, then it would be obvious that the pyroxenes are not characteristic of these, and that something is very wrong with all the other Franciscan samples. However, it is the writer's impression that the Idria mass is not typical of Franciscan rocks as a whole and that these two samples are in fact what they appear to be: exceptions which prove the rule. That the Idria mass is markedly different in field aspect from outcropping Franciscan rocks as a whole seemed obvious from cursory examination during the collection of samples. That this mass represents the exception and not the rule appears to the writer to be a valid conclusion from these field observations.

Two further features of the Franciscan assemblages remain to be mentioned. The first of these is the rarity ~~of~~ or absence of the micas in all samples but one. The second feature is the consistent presence of amphibole, for the most part in substantial percentages. The amphiboles range from brown and green hornblende through actinolite to tremolite. The most noticeable feature of these is the predominance of brown hornblende in some samples.

Granitic

The most obvious feature of the granitic assemblages as a group is the generally overwhelming percentage of amphibole. This is for the most part ordinary green hornblende. However, an interesting blue-green variety, sometimes exhibiting blue tints to a marked degree, was found particularly in the samples from San Emigdio Creek. Micas are ordinarily superabundant in these samples. Biotite is normally greatly predominant over muscovite. The San Emigdio Creek samples are notable exceptions to this rule. The presence of an unusual percentage of garnet in the Grapevine Creek sample may be mentioned.

The La Panza granitic mass, represented by the Pozo-Creston samples, F112-38 and F113-38, is indicated by the charted data to be strikingly abnormal as compared to the other granites represented. The presence of predominant percentages of sphene in these samples is an interesting feature. This is furthef discussed below. The La Panza granite will be referred to in this paper as abnormal granite. This usage is thought to be justified by the data of Plate II, just mentioned.

The general uniformity of the granitic assemblages, from the Sierra Nevada through the San Emigdio Region to the central and coastal Coast Ranges, is a marked feature, the La Panza mass excepted.

Cretaceous-Eocene

These two groups of assemblages will be discussed together, because of their similarities in many respects.

The most marked features of these, as derived from the chart (Plate II) are: (1) generally high percentages of garnet and sphene, (2) sporadically high percentages of epidote, (3) more uniform distribution of tourmaline and zircon, in higher percentages, than in any other group of source-rock assemblages, (4) scarcity or absence of amphibole. As between the two groups, the most noticeable feature is the increase in percentage of garnet in the Cretaceous samples at the expense of epidote and sphene.

Reed[1] conveys the impression that Eocene and

[1]Reed, R. D., Geology of California. 1933.

Cretaceous sediments in general, in central and southern California, were derived from granitic rocks (in the sense in which these are defined in the present paper). This premise is here taken as more or less axiomatic, especially insofar as the samples studied are concerned.

Yet the analyses of Plate II indicate very marked and consistent differences between the Cretaceous and Eocene assemblages on the one hand and the granitic assemblages on the other hand. In particular: (1) the superabundant amphiboles of the granitic assemblages are to be compared with the absence or rarity of amphiboles in the Eocene-Cretaceous assemblage; (2) epidote, garnet and sphene, normally comparatively rare in the granites, are relatively abundant in the Eocene-Cretaceous assemblages; (3) tourmaline and zircon are nearly invariably present, sometimes in considerable percentage, in the Eocene-Cretaceous assemblages, as compared with their frequent absence and never considerable percentage in the granitic assemblages.

The writer's interpretation of these observations is based upon the proposition of <u>differential mineral decomposition</u>. It is proposed to explain the differences between the Eocene-Cretaceous assemblages and those of their parent granitic rocks as being due to elimination, since removal from the parent mass, of certain minerals, principally by chemical decomposition, and survival of others by reason of their greater resistance to such decomposition. It is suggested that during the time elapsed since removal of the detritus from the parent mass amphibole has been largely eliminated by decomposition, and that percentages of epidote, garnet, sphene, tourmaline and zircon have correspondingly increased. From the charted data it is further suggested that percentage of garnet in the Cretaceous assemblages is higher as compared to epidote and sphene than is the case in the Eocene assemblages, by reason of Cretaceous detritus having been removed from the parent mass earlier and therefore having been subject to the processes of decomposition for a longer time. That is, the data suggest that epidote and sphene are subject to a greater rate of decomposition than garnet, and that percentage of garnet will therefore increase with time.

Further discussion of the principle of differential mineral decomposition is presented below, in connection with the Miocene assemblages which form the chief subject of the investigation.

General

In summary, it is desired to direct attention to a few general observations regarding the source-rock assemblages. One of these is the comparative homogeneity within any group. Another is the sharpness of the break in plotted data between the Franciscan and Cretaceous-Eocene groups on the one hand and between the latter and the granitic group on the other hand. The mixed Eocene and and granitic sample, P88-38, fits in nicely with this picture; the mixing being apparent from the assemblage. In contrast to these two sharp breaks, is the absence of such between Eocene and Cretaceous groups. These general considerations are thought to bear out conclusions of this paper.

A further point that may be mentioned here is the writer's belief in the data here presented and in the methods used as a valuable general means of investigating the average mineralogical nature of large areas of rocks. Reed[1] states: "... it is hard to think of any more important task that a petrographer could undertake than this of adding to the quantity and exactness of the data concerning the petrology of areas that were undergoing erosion during the late Mesozoic and Cenozoic time." The general and urgent need for such data can hardly be questioned. In the writer's view, data of the kind here presented, and use of the methods of the present investigation could be of great value in fulfilling this need.

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[1]Reed, R. D., Geology of California, p. 278. 1933.

THE MIOCENE ASSEMBLAGES

Introductory

The assemblages of the Miocene samples studied have been arranged under five groups in Plate II. The grouping is based primarily upon the mineralogy of the assemblages. This same grouping will be observed in the discussion to follow:

(1) Coalinga assemblage.

(2) Garnet-tourmaline-zircon (GTZ) assemblage.

(3) Andalusite-garnet-tourmaline-zircon (AGTZ) assemblage.

(4) Sphene-andalusite (SA) assemblage.

(5) Epidote-garnet-sphene (EGS) assemblage.

Coalinga Assemblage

The stratigraphic distribution of the samples bearing this assemblage is indicated on Plate II. It will be observed that according to this all of Miocene time except the earliest is represented. It must be noted here that Bramlette[1] has questioned the Miocene age of two of

[1]Bramlette, Oral communication.

the higher samples: F47-38, from near the top of the Santa Margarita formation, and F44-38, from near the top of the

Temblor formation. He has suggested the possibility that these may be Etchegoin (Jacalitos) in age; the suggestion arising from their high pyroxene content, particularly hypersthene. The writer's conclusions regarding the source of these sands remain the same, regardless of their age; therefore the main effect of this question in the present discussion is that of eliminating these two samples from unquestioned consideration in the matter of the source specifically of the Miocene beds.

The most marked features of this assemblage are: (1) the presence of glaucamphibole in five of the eight samples, (2) the presence of pyroxenes in five of the eight samples, and its presence in high percentage in two of these, (3) the presence of either glaucamphibole or pyroxene or both in all but one of the samples, (4) the consistent presence of amphibole, often in high percentage, (5) the relatively high percentage of epidote and sphene in the three lower Temblor samples, (6) the heterogeneity of the assemblage as a whole, as compared to the other Miocene assemblages.

The writer's conclusion regarding this material is that the source of most of the sand was probably local, northward and westward from Coalinga, but that the evidence is not sufficiently diagnostic to preclude the possibility that more extensive investigation might prove derivation in part from the Sierra Nevada region. The considerations upon which conclusions have been based are as follows:

The only unquestionable evidence of local derivation of these sands is their content of glaucamphibole. This evidence can not be said to apply to the two Santa Margarita samples, neither of which contain glaucamphibole. It is believed to apply to all others, including F41-38, which does not bear glaucophane, but which is very similar in all other respects to the next two higher Temblor samples, which do bear this mineral. Although the presence of glaucamphibole does not necessarily preclude the presence in these sands of an admixture of Sierran material, yet the fact that Franciscan material from present outcrops in general shows similar small percentages is taken as an indication that any considerable admixture of foreign detritus would have flooded out (diluted out) the glaucamphiboles entirely.

The presence of pyroxene in the two Santa Margarita samples, which lack the glaucamphiboles, is taken as evidence of local derivation of these two. This conclusion is dependent upon the validity of the previously expressed belief that pyroxene is characteristic of Franciscan rocks in general or, possibly, of Miocene volcanics within Franciscan areas. The alternative source, suggested by

Bramlette, is that of the Sierran andesites. The reason for the writer's rejection of this alternative is that the postulation of local(Coast Range) sources seems the more simple and logical conclusion. In addition to the arguments previously set forth as favoring the writer's conclusions, two more may be mentioned in this specific connection. One of these is that it is difficult to suppose that this material was water-borne from the quite distant site of the Sierran andesites across a wide depositional basin to the Coalinga region, while land masses existed relatively close at hand. The material must have been water-borne if of Pliocene age, supposing the andesitic eruptions to have been of Miocene age. The other argument is that, if the pyroxenes were wind-borne during andesitic eruptions, it is difficult to account for their absence from Miocene sediments further southeastward.

It is probably agreed by all investigators that the Big Blue formation was derived largely or wholly directly from the Franciscan serpentine mass near Idria. Pyroxenes are not known to be characteristic, or even present, in the Big Blue. They were not found in sample F45-38, from this formation. Furthermore, pyroxenes were absent from one and rare in another, although comparatively plentiful in the third of the writer's source-rock samples from this mass. These facts constitute one basis for the suggestion by Bramlette to the effect that pyroxenes, and hypersthene in particular, may not be properly considered as indicative of a Franciscan source. However, the writer can not accept this view as being correct, for reasons discussed previously, supporting the idea that the Idria mass is not truly representative of Franciscan rocks as a whole. According to this latter supposition, the Big Blue likewise would not be representative of detritus derived from Franciscan rocks.

A further observation supporting the conclusion that the Coalinga assemblage was derived from local sources is the fact that micas are so conspicuously rare or absent in all these samples. This condition correlates strikingly with the fact that the same feature is found in all but one of the Franciscan source-rock samples (see Plate II).

The relative percentages of amphibole, epidote and sphene in these samples would seem to offer no significant conclusions regarding source. These may have been greatly influenced by differential decomposition and cementation.[1] Much of the hornblende in some of these

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[1] By "differential cementation" is meant simply the condition in which one bed or sample is more thoroughly cemented than another. This is further discussed below in connection with the GTZ assemblage. The term must not be confused with "differential decomposition" which applies to detrital mineral species.

samples is the brown variety, which is more commonly present in Franciscan than granitic detritus. The possibility of derivation of hornblende from Coast Range granites as contrasted with Sierran sources must also be borne in mind. Any Miocene positive areas westward from Coalinga might have included granites, and in these a prolific source of hornblende.

A local land mass such as that postulated for the source of this Miocene detritus would undoubtedly supply material derived from Cretaceous and Eocene rocks as well as from Franciscan types. These other source-rocks no doubt contributed to the heterogeneity of the assemblage as a whole.

In summary, it may be said that while the number of samples studied is entirely too few to establish a final conclusion regarding the source of the Coalinga assemblage, the writer feels a considerable degree of confidence in the tentative decisions reached, these representing his best judgement on the basis of data at hand. At the same time, it can not be claimed that these data permit of exclusion of the possibility of admixture in this detritus of andesitic materials from the Sierra Nevada region, as suggested by Bramlette.

In one of his earlier papers, Reed[1] came to

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[1] Reed, R. D., Role of heavy minerals in the Coalinga Tertiary formations. Econ. Geol., Vol. 19, pp. 730-749. 1924.

essentially the same conclusion as the writer concerning the source of the Coalinga Miocene detritus. It is interesting to note that he found 13% of augite in one and 47% in the other of two samples listed from the Coalinga Temblor. In the second of these he found 4% hypersthene. In a later book, Reed and Hollister[1] appear to have maintained this same view regarding the Lower and Middle Miocene of Coalinga, but to have decided that the Santa Margarita was derived from granitic sources.

[1] Op. cit., p. 40.

Garnet-Tourmaline-Zircon (GTZ) Assemblage

The stratigraphic distribution of this assemblage will be evident to the reader from Plate III, insofar as this has been determined by the present investigation. It will be noted that the assemblage has been found to extend laterally from Devils Den to the Pioneer section. It has been found at various points throughout the vertical extent of the Miocene section; but, obviously from the chart, it appears to be mainly excluded from the upper part of the Upper Miocene.

As is evident from a glance at Plate II, the striking feature of the assemblage is simply the consistent presence in surprising comparative uniformity of garnet, tourmaline and zircon. The sharpness of the mineralogical breaks between this assemblage and others represented in the chart is hardly less striking. Other minerals are either absent from the assemblage or present in relatively insignificant amounts. A further notable feature of the assemblage is the marked predominance of muscovite over biotite.

From study of the charted data it is concluded that the most probable sources of this material were pre-Miocene sediments, largely Cretaceous and Eocene in age. This conclusion is derived from the considerations which follow.

No direct correspondence between this assemblage and that derived from any source rock during the present investigation is evident from the charted data. However, it is assumed for the moment that this detritus must in fact have been derived from either granitic or Franciscan rocks or must represent reworked sediments, mainly Cretaceous or Eocene. Had these sediments been derived from the Franciscan, they should show some similarity to the Coalinga Miocene sands, assuming the correctness, at least in part, of the writer's conclusions regarding the latter. But the striking mineralogical break between these two assemblages is evident from the chart; and possible direct derivation from Franciscan sources is consequently eliminated. Again, assuming the correctness of foregoing conclusions, these

GTZ sands were not derived from granitic sources, since in that case they should be expected to bear marked similarities to the Cretaceous and Eocene source-rock assemblages (assuming these to have been originally derived from granites), or to the EGS assemblage (discussed below). By a process of elimination, therefore, the GTZ sands must have been derived from reworking of Cretaceous and Eocene sediments (or other pre-Miocene post-Franciscan sediments, probably intimately associated with these).

If these GTZ sands were indeed derived from such material as is represented by the assemblages shown on the chart as coming from Cretaceous and Eocene source-rocks, then obviously a large and consistent change has occurred in the assemblage since removal from such sources. Specific items of such change are: (1) Large amounts of epidote and sphene and smaller amounts of amphibole have disappeared. (2) Percentages of tourmaline and zircon have increased greatly. (3) Garnet has decreased in percentage with respect to tourmaline and zircon. (4) Muscovite has increased strikingly as compared with biotite. (5) Percentage of heavy minerals has decreased very markedly.

According to these conclusions and others discussed previously in connection with the Cretaceous-Eocene source-rock assemblages, therefore, material similar to that of the typical granitic assemblage such as, say, sample F48-38, was originally derived from granitic rocks, deposited as pre-Miocene sediments, and reworked and deposited as Miocene beds bearing the GTZ assemblage. This latter assemblage, then, has been derived, by a series of changes resulting from differential decomposition of the heavy minerals, from the typical granitic assemblage. An assemblage originally dominated by amphibole (mainly hornblende) has changed to one in which garnet, sphene and epidote are dominant; and this in turn has changed to one containing almost exclusively garnet, tourmaline and zircon.

Assuming the correctness of these deductions, close study of the charted data indicates the relative resistance of the minerals involved to decomposition to be, beginning with the least resistant: amphibole, epidote, sphene, garnet, tourmaline and zircon. Insofar as this order of resistance is compatible with conclusions expressed by other investigators, it is thought to support the writer's conclusions.

A general examination of the literature, especially papers appearing in the Journal of Sedimentary Petrology, appears indeed to substantiate these ideas evolved by the writer regarding the relative stability of the common heavy minerals, although little work on this specific matter was found.[1] References in the literature

[1] Cf. Boswell, P. G. H., op. cit., pp. 37-46.

invariably agree that tourmaline and zircon are the most resistant of the minerals listed above, no opinion being registered as to which of these two is the more resistant. Except for garnet, all the other minerals listed are usually more or less lumped as being of inferior stability. Garnet has occasioned much discussion regarding its relative stability. Some authors believe that this mineral is often subject to solution by percolating waters; others consider it to be among the most stable of minerals. In all probability its stability varies with conditions. The average of opinion would appear to place the relative stability of this mineral just where it is deduced to be from the present study: between tourmaline and zircon on the one hand and the other minerals listed on the other hand.

A brief review of some of the papers dealing with the stability of garnet, and especially with the solubility of detrital garnet, will perhaps prove useful at this point.

W. Mackie[1] appears to have been the first to

[1]Mackie, W., The principles that regulate the distribution of particles of heavy minerals in sedimentary rocks, as illustrated by the sandstones of the northeast of Scotland. Trans. Edinburgh Geol. Soc., Vol. II, pp. 138-164. 1923.

suggest that garnet may be subject to solution as detrital particles in situ. His paper is not available to the writer, who obtained the reference from a paper by M. N. Bramlette.[1] This author, after discussing various aspects

[1] Bramlette, M. N., Natural etching of detrital garnet. Am. Min., Vol. 14, pp. 336-337. 1929.

of natural detrital grains of garnet showing well developed striations, states: "Some ordinary garnet was crushed and treated with hydrofluoric acid. After several days of treatment in this acid, an etching of the surface of the grains was produced that is identical with that observed in the natural grains from sedimentary rocks. It seems, therefore, evident that this type of detrital garnet is a result of etching. Just what acid or alkaline solution in nature has produced the result is not known, but in many cases at least it is obvious that it is an authigenic change. Some of the grains are etched down by this natural process to delicate almost skeletal forms. It is thus probable, as pointed out by Mackie, that much garnet disappears from sedimentary rocks with sufficient time under certain conditions that are not uncommon."

Arthur Pentland[2] suggests solution effects as an

[2] Pentland, Arthur, The heavy minerals of the Franconia and Mazomanie sandstone, Wisconsin. Jour. Sed. Pet., Vol. 1, pp. 23-36. 1931. (P. 26.)

explanation of anomalously sharply defined faces on detrital garnets.

W. L. Wilgus,[1] after discussing pitting, grooving,

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[1] Wilgus, Wallace L., Heavy minerals of the Dresbach sandstone of western Wisconsin. Jour. Sed. Pet., Vol. 3, pp. 83-91. 1933. (P. 86.)

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and etching of natural detrital grains of garnet and agreeing that solution might be responsible for these, states: "It is possible that the total absence of garnets in the Dresbach at some localities may be explained in this way."

S. A. Tyler[2] discusses and appears to accept the

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[2] Tyler, S. A., Heavy minerals of the St. Peter sandstone in Wisconsin. Jour. Sed. Pet., Vol. 6, pp. 55-84. 1936.

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idea of solution of detrital garnet by circulating solutions, but rejects this agency as being responsible for the comparative absence of garnet in the case of the St. Peter sandstone.

P. G. H. Boswell[3] states: "A large number of in-

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[3] _Op. cit._, p. 44.

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vestigators noted the peculiar etching of garnets, chiefly along the planes of the rhomb-dodecahedron, and many (P. G. H. Boswell, A. Gilligan, H. H. Thomas, W. Mackie, and others) regarded it as evidence of solution of the mineral."

Another marked feature of the GTZ assemblage is the persistent presence of muscovite and its predominance over biotite. This condition, as will be noted from the chart, is comparatively uncommon in both Recent and Miocene sediments, exclusive of the GTZ sands. These facts are taken to substantiate the conception of differential decomposition. It is believed that the hypothesis that muscovite is the more stable of these two micas will not be questioned.

In summary, the writer feels a considerable degree of confidence regarding the principle of differential decomposition of heavy minerals, and its postulated application in the present problem. The question of when and where such decomposition takes place can hardly be approached on the basis of any data deriving from the present investigation. Probably the process goes on both at depth and in the zone of weathering; but no data worthy of note in this regard are at hand. One remark, however, is no doubt justified, namely that, other factors being equal, decomposition is in all probability much less effective in well-cemented sediments as compared with unindurated ones. This probability has been borne in mind in study of the present data. For instance, some samples bearing the GTZ assemblage were highly cemented (calcareous), which indicates that their mineralogy is not largely the result of any undue exposure to agents of decomposition during their Recent history. Again, effects due to differential cementation should not be expected in the Cretaceous and Eocene source-rock assemblages, since each of these represents an average of a considerable area of outcrop, which presumably would include both indurated (cemented) and unindurated material.

Some of the papers which the writer regards as supporting his conclusions concerning the GTZ sands are as follows:

Arthur Pentland[1] states: "The dominant minerals in the Franconia and Mazomanie sandstones are garnet, tourmaline, zircon and mica. This suite of minerals implies derivation from pre-existing sediments."

G. C. McCartney[2] states: "Some of the more resistant minerals, such as tourmaline and zircon, and much of the quartz and feldspar may have been derived, in part, from pre-existing sediments." Again, he states:[3] "Garnet is recognized as a very resistant mineral 1.."

W. L. Wilgus[4]: "The principal heavy minerals are

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[1] _Op. cit._, p. 34.

[2] _Op. cit._, p. 88.

[3] _Ibid._, p. 89.

[4] _Op. cit._

zircon, tourmaline, ilmenite, leucoxene, anatase, and locally garnet, with rutile, brookite, hornblende, staurolite, and diopside found only in one or two samples. ...The physical characters of the heavy minerals, their great durability and small variety suggest sedimentary terranes as the chief provenance for the materials of the Dresbach sandstone."

M. D. Stearns[1] states, regarding Marshall formation: "The eastern assemblage is typical of a reworked sediment, and contains only such resistant minerals as tourmaline and zircon, and the alteration products of less stable species....Unstable minerals such as hornblende and actinolite..."

J. W. Ockerman[2] observes: "The heavy minerals of the Madison and Jordan sandstones suggest that the composing sediments were derived from the re-working of older sediments and not directly from crystalline rocks. As noted above, the sandstones are composed of quartz, a little feldspar, and several heavy minerals, the latter being garnet, zircon, and tourmaline all of which are minerals of high chemical stability."

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[1] *Op. cit.*, pp. 103,104.

[2] Ockerman, J. W., A petrographic study of the Madison and Jordan sandstones of southern Wisconsin. Jour. Geol., Vol. 38, pp. 346-353. 1930. (P. 352.)

S. A. Tyler[1] remarks: "Zircon, tourmaline,

[1] *Op. cit.*

leucoxene and ilmenite compose 97 per cent or more of the detrital heavy minerals of the St. Peter sandstone.....The limited variety and great stability of the allothogenic, heavy minerals suggests a sedimentary terrane as the immediate source of the St. Peter sandstone." This author further concludes that, had the St. Peter sandstone been derived from certain older, highly garnetiferous sediments, the garnet would appear in the St. Peter assemblage, by reason of its great stability. Also, from a study of inclusions in quartz grains, he suggests: "...that the quartz was largely, ultimately derived from a granitic terrane." Again, he states: "A study of the inclusion suite (of quartz) as compared with the detrital suite of the St. Peter sandstone indicates that titanite, hornblende, kyanite, biotite, fluorite and most of the apatite have been largely, if not wholly, eliminated during the history of the sand." The parallelism between Tyler's conclusions and those of the present paper regarding the GTZ sands is evident.

D. D. Condit[2] observes: "There is ample evidence

[2] Condit, D. D., The petrographic character of Ohio sands with relation to their origin. Journ. Geol., Vol. 20, pp. 152-163. 1912. (P. 161.)

that garnet is quite resistant to ordinary weathering processes.....The physical properties of garnet are such that it should withstand the wear of long travel."

R. D. Russell[1] believes: "The absence of the

[1] Russell, R. D., Mineral composition of Mississippi River sands. Geol. Soc. Am., Bull., Vol. 48, pp. 1307-1348. 1937. (Pp. 1343-1346.)

'less resistant' minerals in sediments derived from older sedimentary formations" is not due to any great extent to disintegration during transport, but mainly to chemical decomposition. The writer's views in the matter are based primarily upon Russell's data. The word <u>decomposition</u> is used in this paper, in the term "differential decomposition," rather than <u>disintegration</u> largely because it is inferred from Russell's data that mechanical disintegration during transport has played a minor part in the phenomena discussed here.

Data presented by P. G. H. Boswell[2] and H. B.

[2] *Op. cit.*, pp. 37-46.

Milner[3] are also considered to support the conclusions of the

[3] *Op. cit.*, p. 427.

writer regarding the GTZ sands.

The location of the land mass from which these GTZ sands may have been derived remains to be considered. Again, by a process of elimination, it is concluded that the land mass must have lain to westward or southwestward of the sample localities. Had the parent land mass lain in any other direction, it is very difficult to conceive that the reworked detritus should not be contaminated with granitic or Franciscan material.

In this connection, as well as all others involving location of Tertiary land areas during the present study, Reed's paleogeographic maps[1] have been consulted

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[1]Reed, R. D., and Hollister, J. S., Structural evolution of Southern California. 1936.

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closely and to great advantage. His three maps[2] of Lower,

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[2]*Ibid.*, pp. 37, 39, 41.

Middle and Upper Miocene paleogeography are here reproduced as figures 6, 7, and 8. The Upper Miocene map, figure 8, has been altered by the writer by insertion of "San Andreas Island" which is discussed below. Otherwise these are here reproduced intact, except for insertion of the name "Ynez Island", this being Reed's name[3] (from Loel and Corey).

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[3]Reed, R. D., Geology of California, p. 164. 1933.

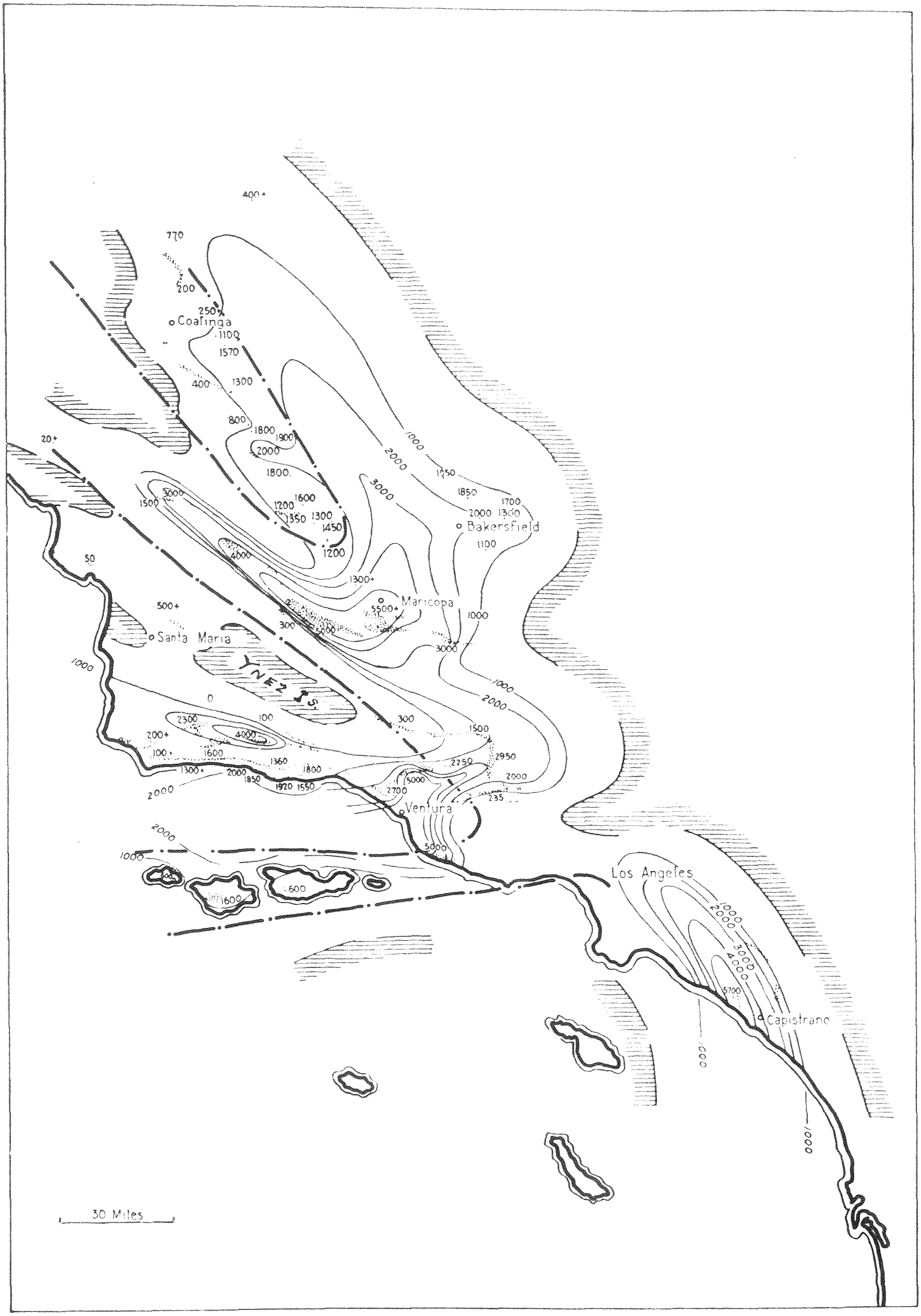

Figure 6. - Lower Miocene Paleogeography. (From Reed and Hollister).

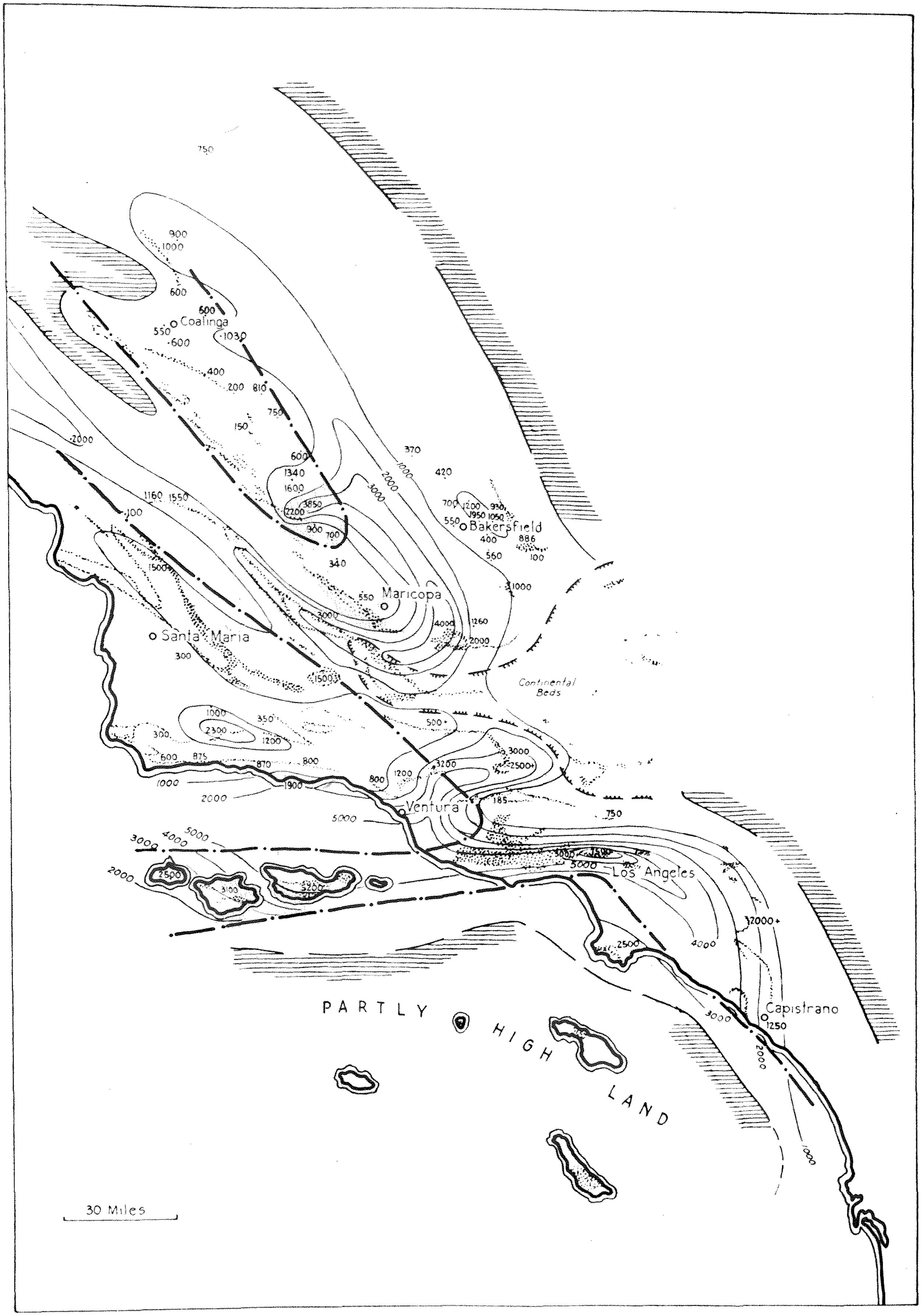

Figure 7. - Middle Miocene Paleogeography. (From Reed and Hollister).

Figure 8. - Upper Miocene Paleogeography. (Modified from Reed and Hollister).

The probability that reworked sediments derived from any direction other than west or southwest, and deposited in the region of the writer's Miocene GTZ sands, would contain evident contamination, as noted above, is derived from study of these maps, the general correctness of which is assumed.

The only likely source-area shown on these maps for the GTZ sands, is Ynez Island, which is supposed according to the maps to have existed only during Lower Miocene time. It was undoubtedly blanketed with pre-Miocene sediments which crop out in this area today. However, Ynez Island was very considerably distant (about 30 miles) from the Miocene outcrops studied here, and the two localities were separated by what must have been a rapidly subsiding basin (see figure 6). That the basin was rapidly subsiding does not of course necessarily indicate that it was deep one. Nevertheless, it seems questionable whether coarse detritus (sand) directly derived from this island source could be expected to have been deposited in open sea this far from the source, and without marked contamination from granitic sources eastward. No plausible southwestern land mass is suggested by the Middle and Upper Miocene maps except for the peculiar tongue presumed to represent land and labeled "Continental Beds". But samples F100-38 and F101-38 were taken from these "Continental Beds" and these indicate a granitic source. The assemblages of these samples do not belong to the GTZ group, which latter it has been specifically argued above was not directly derived from granites.

Two suggestions are here offered in explanation of these difficulties: (1) that San Andreas Island (see below, p. 103) and possibly other islands west or southwest of the GTZ-bearing outcrops, existed continuously or intermittantly as low lands blanketed with Miocene or pre-Miocene sediments previous to middle Upper Miocene time; and that these may have cut off detritus from the "Continental Beds" area from the Maricopa-Devils Den district, and (2) that the peculiar tongue of "Continental Beds" was probably shown on the map by reason of location of their present outcrops, which may have been moved into their present anomalous position by post-Miocene activity along the San Andreas Rift. The fault-movement mentioned may have shifted this "tongue" a number of miles northwestward from the position in which the beds were deposited.

Either one or both of the suggestions offered above may have been operative. The possible San Andreas Rift movement is discussed below, in connection with the source of the SA assemblage.

It remains to point out two possible alternative interpretations of the origin of the GTZ sands. The first of these is the possibility that this assemblage may represent reworking of material such as the Mariposa slates, etc. However, such indications as are at hand, such as overlap of Miocene sediments onto granites in the south end of San Joaquin Valley, tend toward the conclusion that these old formations did not extend much further southward in Miocene time than they do now. It is difficult to understand how, in any case, garnet and tourmaline and zircon derived from these formations could have arrived at the southwest border of the present Valley without marked admixture of other minerals from different sources.

The second possible alternative interpretation which occurs to the writer is the postulation of a very tropical climate and low-lying land in the granitic regions. No such extremely tropical conditions seem probable from the writer's acquaintance with the literature. That the Coalinga assemblage shows no effect of such a climate would seem to corroborate the supposition of its nonexistence. It is to be supposed that such a climate would affect the Coalinga region also, if extant in neighboring areas. Again, the EGS assemblage, supposed to have been derived from granitic sources, indicates that sediments similar to the GTZ sands were not being derived from the granitic areas during Miocene time. No good evidence is known to the effect that the neighboring granitic areas were not low-lying during much or most of Miocene time; in fact, indications are that these lands were low during some parts of the Miocene; but this condition in itself is hardly thought to be sufficient to have produced detritus with a GTZ assemblage.

The Stevens Sand

The Stevens sand samples require special comment. These were taken from the Ten Section oil field, in the south central part of the Valley (see figure 1). This sand is correlated by foraminiferal workers approximately with the Crocker Springs sand, shown in Plate III. The object in studying these samples was the same as for all others: to determine the source of the detritus. However, in this case, the most important specific question was that of the areal distribution of the sand (oil-bearing in the Ten Section field) under the Valley floor.

The assemblages of these samples appear to be obviously of the GTZ type. The source of the detritus is concluded to be the same as for the other sands bearing this assemblage, as discussed above. That is, the Stevens sand is here supposed to have been derived from sources lying westward or southwestward from its site of deposition. Specifically, San Andreas Island is suggested as this source. It is inferred therefore that this sand is most likely to be found at depth westward and southwestward from the sample locality. Its distribution in other directions is inferred to be comparatively limited. While the sand may be discontinuous in the supposed direction of its sources, due to local non-deposition, the probability of its continuity in these directions is greater than for other directions. The general suggestion may be offered that the distribution of this sand within the Valley may lie within a radius of 25 miles, roughly, of San Andreas Island, as shown in figure 8.

The consistent presence, in small percentage, of amphibole, epidote and sphene in these samples offers a definite suggestion of contamination from granitic sources lying southward or eastward from the site of deposition (see Plate II). It is the writer's belief that this contamination probably will be found to have little bearing on the distribution of the sand. However, the possibility that the sand may be continuous eastward and southward, and may grade into wholly granitic detritus in these directions must be admitted, as far as the mineralogical data are concerned.

The conclusion that the Stevens sand in the Ten Section field was probably derived from the west or southwest is somewhat extraordinary in view of the probable proximity of continental land areas east and south of the site of deposition. However, this conclusion appears to the writer as inescapably the most probable interpretation of the data at hand. It has been suggested that San Andreas Island supplied this detritus during the earlier stages of its stripping by erosion. The general picture is that of coarse detritus from the west being intercalated with muds from the east. Perhaps the lack of coarse detritus from granitic areas may be explained on the basis that these did not stand high and that drainage was to a large extent cut off from the sea, as suggested by Reed.[1]

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[1] Reed, R. D., Geology of California, p. 224. 1933.

The origin suggested for the Stevens sand would imply a slightly greater age than that assigned on the basis of paleontological correlations, mentioned above. This observation is based upon the supposition that the Stevens sand was derived from San Andreas Island before the uncovering of andalusite-bearing rocks by erosion. (See Plate III.)

Andalusite-Garnet-Tourmaline-Zircon (AGTZ) Assemblage

This assemblage, the distribution of which will be noted from Plate III, is characterized by abundant andalusite. Otherwise the assemblage is made up mainly of garnet, tourmaline and zircon. These sands are interpreted as probably representing a mixture of detritus from two source-rock types: (1) pre-Miocene sediments as postulated for the GTZ sands, and (2) a metamorphic (probably hornfels) rock type. The latter is supposed to have formed a part of San Andreas Island. The pre-Miocene sediments may have been derived from San Andreas Island or other islands, as discussed above.

Among the reasons for this conclusion are the following: Andalusite is found associated with the SA assemblage, as a source for which San Andreas Island is postulated, as will be discussed below. This mineral is found only very sparingly and rarely in any source-rock studied. The vertical distribution of the assemblage suggests an intermediate phase of denudation of San Andreas Island following stripping of sedimentary cover which may have given rise to the GTZ sands, in part, followed by exposure of granitic types. The lateral distribution of the assemblage indicates a localized source.

<u>Sphene-Andalusite (SA) Assemblage</u>

As will be noted from Plate III, this assemblage is confined to the Sunset-Midway district and to the upper part of the Upper Miocene beds.

The most striking feature of the assemblage is the frequent abundance of sphene. Andalusite is persistently present, although often in small percentage. Garnet is likewise persistently present, usually in small percentage, but in this assemblage garnet is more significant for its scarcity than otherwise. Other minerals are notably scarce.

It is concluded that the most probable source of this material was San Andreas Island (see figure 8), a Miocene land-mass postulated by the writer as the best interpretation of the data furnished by the SA assemblage. This island is supposed to have lain along what is now the southwest base of the Temblor Range. It is presumed to have been made up originally of pre-Miocene sediments, underlain at depth by granitic material of a type abnormal to central California, similar to that now cropping out in the Pozo-La Panza region. It is suggested that metamorphic rocks, probably in the nature of roof material, from which andalusite was derived, were associated with the underlying granites. The land mass is supposed to have come into existence by reason of movements along the San Andreas Rift, which occupies the boundary between the present Temblor Range and the Carrizo Plain. Conclusions regarding the source of this assemblage are based upon field evidence as obtained from reports of the U. S. Geological Survey[1]

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[1]Arnold, Ralph, and Johnson, Harry R., Preliminary report on the McKittrick-Sunset oil region, Kern and San Luis Obispo Counties, California. U. S. Geol. Surv., Bull. 406. 1910.

Pack, R. W., The Sunset-Midway oil field, California. U. S. Geol. Surv., Prof. Paper 116. 1920.

and other sources[1] and from personal field observations,

[1] W. F. Barbat, R. W. Burger, and others. Oral communications.

as well as from the mineralogical data of the present investigation. That the outcrop data of the "Granite Zone" may properly be used in explaining the source of the SA assemblage is evidenced by the fact that correlation between the outcrops and the "Granite Zone" sands in the Sunset-Midway oil field has been established by local geologists[2] and that all these beds bear this assemblage.

[2] W. F. Barbat, oral communication.

Considerations upon which conclusions regarding the source of this assemblage are based are as follows:

Outcrop and drilling data show the coarse beds of the "Granite Zone" to be made up of unsorted granitic and metamorphic detritus ranging in particle size from sand to huge blocks up to 15 feet in diameter. These coarse zones are interbedded with the lower portion of the "Belridge Diatomite", a white or gray diatomaceous shale (see Plate III). It is hardly conceivable in the light of any data known to the writer that the material of these beds could have been derived from a source more distant than a few miles from its site of deposition.[3] Some suggestions

[3] Arnold, Ralph, and Johnson, Harry R., op. cit., pp. 70, 71.

have been made in the literature[1] on this region to account

[1]Arnold, Ralph, and Johnson, Harry R., _op. cit._

for derivation of the coarse detritus from relatively distant sources; among these are that of ice-rafting, which appears to the writer from general considerations to be highly improbable. On the other hand, one writer[2] shows

[2]Pack, R. W., _op. cit._

a rather appalling lack of curiosity regarding the mode of deposition of this detritus. Had this material been derived from a large and distant land mass, it seems most probable that a great deal of finer terrigenous detritus should have accompanied it. On the other hand, the existence nearby of a rising local land mass presenting a fault scarp toward the area would probably permit of a deposition of very coarse material with a minimum of transport as well as a minimum of fine detritus.

Two small granitic masses exist, one on the crest of the Temblor Range and one on its southwest flank, in this general vicinity. These were mapped by Ralph Arnold and Harry Johnson[3] as fault blocks. Brief personal obser-

[3]_Op. cit._

vation indicated that the occurrence on the crest of the range might be interbedded material similar to that of the "Granite Zone" as recognized on the northeast flank of the range. The mass on the southwest flank, near the San Andreas Rift, however, has a much more homogeneous aspect, which fits in well with the idea of its fault block origin. It is supposed that this mass may be a remnant of San Andreas Island.

The field evidence goes to show that the source-rock of the detritus was crystalline, excluding the possibility of reworked sediments, and that the rock was not of Franciscan type. The mineralogical data indicate that this crystalline rock was not of a normal granitic type, such as that of the San Emigdio country, the nearest source of such. Had this been the case, the resulting Miocene assemblage should look like either (a) the typical granitic assemblage from, say, sample F48-38, or (b) the Eocene-Cretaceous assemblages, or (c) the EGS assemblage. The predominance of sphene and the presence of andalusite, sometimes in considerable percentage, in the SA assemblage constitute striking dissimilarities when compared to the three assemblages enumerated.

The persistent presence of andalusite indicates derivation from a rock type not represented at all in the source-rock assemblages studied, nor in other Miocene assemblages except the AGTZ assemblage, which is supposed for this and other reasons to have been derived in part from the same source as the SA assemblage. The inference drawn from this is that the source of the SA assemblage is not exposed at present (except, possibly, for a remnant at the southwest base of the Temblor Range).

The high percentages of sphene indicate derivation from an abnormal granitic source. The only resemblance of the SA assemblage to any source-rock studied is that between the predominant sphene of this assemblage and the similar feature of the La Panza-Pozo granite samples (F112-38 and F113-38) which are taken as representing a markedly abnormal granite.

The inference that the SA assemblage may have been derived from an abnormal granite similar to the La Panza mass is interestingly borne out by the comparative nearness of the two localities. An observation which may be noted in this connection is that a lateral movement along the San Andreas Rift of about 35 miles, relatively northwestward on the southwest side, since Miocene time, would have shifted the present La Panza granite mass from a position opposite the "Granite Zone" outcrops to its present position. Movement of a similar nature on the San Andreas Rift has been suggested in the literature[1] in recent years.

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[1] Reed, R. D., Geology of California, pp. 11-12, 31-34. 1933.
Noble, L. F., The San Andreas Rift and some other active faults in the desert region of southeastern California. Carnegie Inst. of Wash., Year Book No. 25, 1925-1926, pp. 415-428. (P. 420.)

On the other hand, the latest conclusions of some California geologists[1] are to the effect that no extensive lateral movement has occurred along the Rift during Tertiary or later time. The latest expression of opinion known to the writer, however, is that of Eaton[2] in confirmation of ~~the~~ movement of the nature here suggested, in the amount of 25 miles, and further, in precisely the region here involved. Eaton mentions the existence in and near Carrizo Plain of an extensive area of "nonmarine Upper Miocene sediments -- now surrounded by finer-grained marine sediments of equivalent age" which he supposes to have been derived from the San Emigdio granitic mass. A mineralogical study of these sediments should reveal most interesting data, which might well prove conclusive for or against post-Miocene lateral movement on the Rift. It might develop that these sediments were derived from San Andreas Island. The movement suggested would, as mentioned previously, eliminate the incongruous tongue of "Continental Beds" of figures 7 and 8, south of Maricopa.

The presence of garnet, sometimes in considerable percentages, fits in with the ideas expressed above, in that

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[1] Reed, R. D., San Benito Trough. Geol. Soc. Amer., Proc. for 1927, pp. 249-250. 1938. (Abstract)

Telliaferro, N. L., San Andreas fault in central California. Geol. Soc. Amer., Proc. for 1937, pp. 254-255. 1938. (Abstract)

[2] Eaton, J. E., Ridge Basin, California. Bull. Amer. Assoc. Pet. Geol., Vol. 23, pp. 517-558. 1939. (P. 520)

Bramlette[1] mentions having found considerable quantities of

[1] Bramlette, M. N., oral communication.

garnet in hand specimens of the La Panza granite.

The vertical and lateral distribution of the SA sands, insofar as this is known, as shown on Plate III, indicates a local and probably short-lived source for this assemblage. The suggestion that the earlier GTZ and AGTZ sands of the Midway region may represent an earlier stage of stripping of San Andreas Island has been made earlier in this paper (see pages 97,102). The distribution of the AGTZ sands likewise points to a localized source. The occurrence of a GTZ assemblage (Olig sand) and an AGTZ assemblage (Lakeview sand) near the top of the Miocene section, after an interval characterized by the SA assemblage, is presumed to indicate a renewed supply of characteristically earlier detritus, probably by reason of renewed uplift of San Andreas Island or change of drainage or both.

No such element as San Andreas Island appears on Reed's paleogeographic maps of Miocene time, from which the writer's figures 6, 7, and 8 were taken. However, since these are no doubt very generalized, this is thought to constitute no objection to postulation of such a land mass. San Andreas Island has been inserted by the writer in figure 8, as mentioned previously.

Durell[1] came independently to the same conclusion

[1] Durell, Cordell. Oral communication to M. N. Bramlette.

as the writer regarding the location of the source of the "Granite Zone" detritus, on the basis of petrologic studies which brought to light the surprising occurrence of andalusite-hornfels types in this detritus.

Epidote-Garnet-Sphene (EGS) Assemblage

This assemblage is represented by samples F100-38 and F101-38. It is assumed that the detritus of these beds was derived from granitic sources, since they are now intimately associated with the San Emigdio granites, which they probably lap over. These assemblages are taken to illustrate the present appearance of such material, and, by contrast, to indicate that the other Miocene assemblages discussed above were not derived directly from normal granitic sources.

The Miocene data presented by Hoots[2] are regarded

[2] Hoots, H. W., Heavy-mineral data at the southern end of San Joaquin Valley. Amer. Assoc. Pet. Geol., Bull., Vol. II, pp. 369-372. 1927.

similarly to the EGS data. His samples were taken from cores of the Miocene of Wheeler Ridge. An unduly high average percentage of zircon and a correspondingly low average percentage of epidote in Hoots' analyses, as compared to the writer's data, are unexplained by the writer. Otherwise the two sets of analyses are similar, both showing considerable percentages of garnet and sphene.

RESUME

Five distinct Miocene assemblages have been recognized along the southwestern border of the San Joaquin Valley: (1) the Coalinga assemblage, (2) the garnet-tourmaline-zircon assemblage, (3) the andalusite-garnet-tourmaline-zircon assemblage, (4) the sphene-andalusite assemblage, and (5) the epidote-garnet-sphene assemblage (not strictly a Valley assemblage). The foregoing data and discussion are taken to indicate rather conclusively that the differences between these assemblages are directly due to differences in source. A fundamental question at the outset of the work, that of whether or not the Miocene assemblages would display differences diagnostic of different sources, is considered to have been answered in the affirmative. The five assemblages recognized have been tentatively referred to four different sources, one of the assemblages being considered to represent mixing of detritus from two of these sources.

However it has been found that none of the Miocene assemblages is directly comparable to any of the source-rock assemblages studied, with the exception of the Coalinga assemblage, which does display immediate similarities to the Franciscan suite. Two explanations have been proposed to account for this lack of direct correspondence between Miocene and source-rock assemblages: (1) that in some cases (SA and AGTZ assemblages) the source-rocks are not now exposed, and (2) that differential decomposition of the heavy minerals is responsible for the differences in other cases. The principle of differential decomposition of heavy minerals is regarded as having been demonstrated to have been a very significant agent in changing the character of most of the Cretaceous and Tertiary assemblages studied, subsequent to removal from their parent mass, regardless of the correctness of many details of the writer's interpretation.

Conclusions regarding Miocene paleogeography are summarized as follows:

The picture presented by Reed, as indicated in figures 6, 7, and 8, is not essentially altered by the results obtained here as regards the region north and west of Coalinga. It is in fact confirmed except for the suggestion that land existed near Coalinga (northward and westward) during Upper Miocene time. Reed shows no such land. The suggestion by Reed and Hollister[1] that Santa

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[1] Op. cit.

Margarita detritus is mainly of granitic origin is not borne out by the present investigation, as regards the Coalinga region, which these authors presumably included in their statement.

For the region surrounding Maricopa, it has been suggested in this paper that land existed, probably intermittently, westward of southward from Maricopa during Miocene time, in addition to Reed's Lower Miocene Ynez Island, between this and Maricopa. These lands were probably never very high, and for the most part not very extensive. A sharp and localized uplift due to faulting has been postulated to have given rise to San Andreas Island in Upper Miocene time. None of these lands is shown by Reed except Ynez Island.

It has been suggested that the anomalous tongue of Middle and Upper Miocene "Continental Beds" of figures 7 and 8 may in fact have been deposited some 30 miles southeast of its present position.

In conclusion, a few remarks on the present problem and on this type of work in general may not be amiss. At the outset of the work, it was by no means taken for granted that the methods of attack chosen would suffice for a solution of the problem. The writer has been gratified to find that the problem is indeed susceptible to at least partial solution along these lines.

It is keenly realized that the problem as a whole, and many of its details, are still far from a final solution. Nevertheless, it is the writer's belief that the general line of approach employed will prove a powerful tool in eventual solution of this and similar problems. It is believed that the potentialities of this type of work are great, both as regards their scientific and purely commercial aspects.

APPENDIX A

DESCRIPTION OF SAMPLE LOCALITIES

Samples of Miocene Sands

F1-38B *Borophagus littoralis* locality. Crocker Springs Creek, near Crocker Springs. 2700' E. and 900' S. of N. W. corner of Sec. 18, T. 31S., R22E., M.D.B.&M. See U. C. Pub. Bull. Dept. Geol. Sc., Vol. 21, No. 2, pp. 15-24, pls. 1-3; & Vol. 21, No. 3, pp. 25-36, pls. 4, 5, etc., Nov. 5, 1931. (V. L. Vander Hoof; W. F. Barbat, & A. Allen Weymouth.) About 75' stratigraphically below *B. littoralis* skull.

F14-38 Sandstone near top of exposed Miocene section. About 1200' N., 1450' W. of S. E. corner of Sec. 13, T.11N., R.24W., S. B. B. & M.

F16-38 "Vaqueros" ss. In small gulley about 2400' S., 1400' E. of N. W. corner of Sec. 24, T.11N., R.24W., S.B.B. & M.

F17-38 3900' E., 2900' S. of N.W. corner of Sec. 34, T.32S., R.23E., M.D.B.&M. 25 Hill Sand, near top.

F19-38 3800' E., 3550' S. of N. W. corner of Sec. 34, T.32S., R.23E., M.D.B.&M. 25 Hill Sand above middle.

F22-38   1400' W., 200' S. of N.E. corner of Sec. 33, T.32S., R.23E., M.D.B.&M. 25 Hill Sand, near base.

F24-38   750' W., 625' N. of S.E. corner of Sec. 28, T.32S., R.23E., M.D.B.&M. 25 Hill Sand, below middle.

F26-38   "Granite Zone." Sample of matrix. 650' E., 600' S. of N.E. corner of Sec. 20, T.32S., R.23E., M.D.B.&M.

F27-38   Chico Martinez Ck. "Sandy zone" in McLure Shale. East bank of Creek, just S. of S. boundary of Sec. 2, T.29S., R-20E., M.D.B.&M. 4000' E. of S.W. corner of same section.

F30-38   Carneros Creek. About 3' above (unconformable ?) contact with thin bedded clay shales below. About 1600' N., 1400' E. of S.W. corner of Sec. 32, T.28S., R.20E., M.D.B.&M. Approx. 700' upstream from road crossing of Creek. Creek bed.

F31-38   About 3' below unconformity (?) of F30-38. Top of Button Bed?

F32-38   Approx. 7' above contact between Button Bed above and Media Shale below. About 850' upstream from road crossing of Creek. About 1450' N., 1050' E. of S.W. corner of Sec. 32., T.28S., R.20E., M.D.B.&M.

F34-38   Top of Canneros ss. South of Carneros Ck., about 300' N. of road. About 400' N., 1800' E. of S.W. corner of Sec. 32, T.28S., R.20E., M.D.B.&M.

F35-38 Near base of basal Carneros sandstone, south of Carneros Ck. Sec. 5, T.29S., R.20E., M.D.B.&M.; about 1550' S., 1200' W. of N.E. corner of section. On west slope of ridge.

F36-38 3' above glauconitic basal Santos Shale sandstone. About 400' S.W. of F35-38, near gulley. About 1900' S., 1400' W. of N.E. corner of Sec. 5, T.29S., R.20E., M.D.B.&M.

F37-38 Approximately 2' above base of Vaqueros. Gulley south of Carneros Ck. About 600' S.W. of F35-38. About 2150' S., 1600' W. of N.E. corner of Sec. 5, T.29S., R.20E., M.D.B.&M.

F38-38 Approximately 5' above basal contact (with Media Shale) of Button Bed. Main hill of Wagonwheel Mt. About 1300' N., 2650' W. of S.E. corner of Sec. 36, T.25S., R.18E., M.D.B.&M.

F39-38 Carneros Sandstone, about 1/4 total thickness down from top. West of Wagonwheel Mt. About 700' N., 1700' E. of S.W. corner of Sec. 36, T.25S., R.18E., M.D.B.&M.

F41-38 Approximately 3' above base of Temblor (contact with Kreyenhagen). Oil Canyon. 1600' E., 850' N. of S.W. corner of Sec. 20, T.19S., R.15E., M.D.B.&M.

F42-38 On ridge, S.W. side of Oil Canyon. Approximately 1' below base of Indicator Bed., 1500' E., 650' N. of S.W. corner of Sec. 20, T.19S., R.15E., M.D.B.&M.

F43-38 Roadcut. Oil Canyon. About 2' above top of Indicator Bed. 1600' E., 500' N. of S.W. corner of Sec. 20, T.19S., R.15E., M.D.B.&M.

F44-38 Cut bank at junction of gulley, east side Oil Canyon. Approximately 15' below Temblor-Etchegoin (Jacalitos ?) contact. 1700' E., 400' N. of S.W. corner of Sec. 20. T.19S., R.15E., M.D.B.&M.

F45-38 Near top of Big Blue (Santa Margarita overlying). Laval Grade roadcrop. 2550' W., 300' N. of S.E. corner of Sec. 21, T.19S., R.15E., M.D.B.&M.

F46-38 Near base of Santa Margarita (Big Blue underlying). Laval Grade roadcrop. 2475' W., 225' N. of S.E. corner of Sec. 21, T.19S., R.15E., M.D.B.&M.

F47-38 Santa Margarita, about 25' below contact with Etchegoin above. Laval Grade roadcrop. 2400' W., 125' N., of S.E. corner of Sec. 21, T.19S., R.15E., M.D.B.&M.

F100-38 Stream Sand Sample (Miocene sources). Directly above Corral Creek bridge on Highway 399. Near juncture with Cuyama River. T.7N., R.24W., S.B.B.&M. Ventura Co.

F101-38 Stream sand sample (Miocene sources). Quatal Creek at bridge on Highway 399. Near Juncture with Cuyama River. T.9N., R.24W., S.B.B.&M. Santa Barbara Co.

Note: Following samples supplied by W. F. Barbat, from well cores of the Ten Section field and Sunset-Midway district.

F144-38 Shell "KCL-A" #6-29. Sec. 29, T.30S., R.26E., Depth 8969'-8984'. Stevens Sand, near base.

F145-38 Shell "KCL-A" #6-29. Sec. 29, T.30S., R.26E., Depth 8341'-8367'. Stevens Sand, near middle.

F146-38 Shell "KCL-A" #6-29. Sec. 29, T-30S., R.26E. Depth 7805'-7829'. Stevens Sand, near top.

F147-38 Union "Mason" #1. Sec. 36, T.30S., R.22E. Depth 4518'-4525'. Olig Sand, near base.

F149-38 Union "Mason" #1. Sec. 36, T.30S., R.22E. Depth 3904'-3914'. Olig Sand, near top.

F150-38 Standard #~~1733-D~~ 17-33-D. Sec. 33, T.32S., R.24E. Depth 2885'-2904'. Lakeview Sand, near base.

F152-38 Standard #17-33-D. Sec. 33, T.32S., R.24E. Depth 2741'-2749'. Lakeview Sand, near top.

F154-38 M. H. Whittier "Hondo" #16. Sec. 15, T.31S., R.22E. Depth 1063'-1090'. Potter Sand, near middle.

F156-38 Transco "Graham" #4. Sec. 25, T.32S., R.23E. Depth 1540'-1558'. Formax Sand, near base.

F157-38 Transco "Graham" #4. Sec. 25, T.32S., R.23E. Depth 1487'-1507'. Formax Sand, near middle.

F158-38 Transco "Graham" #4. Sec. 25, T.32S., R.23E. Depth 1449'-1466'. Formax Sand, near top.

F159-38 Standard "Mascot" #1. Sec. 26, T.32S., R.23W. Depth 894'-915'. Mascot Sand, near base.

F161-38 Standard "Mascot" #1. Sec. 26, T.32S., R.23W. Depth 650'-671'. Mascot Sand, near top.

F162-38 Gen. Pet. "Moco" #243. Sec. 35, T.12N., R.24W. Depth 1948'-1963'. Webster Sand, near base.

F164-38 Gen. Pet. "Moco" #243. Sec. 35, T.12N., R.24W. Depth 1708'-1725'. Webster Sand, near top.

<u>F165-38</u> Hancock "Maricopa" #1. Sec. 8, T.11N., R.23W. Depth 3148'-3156'. Signal Sand, near base.

<u>F167-38</u> Hancock "Maricopa" #1. Sec. 8, T.11N., R.23W. Depth 3079'-3091'. Signal Sand, near top.

<u>F168-38</u> Doyle Pet. "Weir" #2. Sec. 8, T.11N., R.23W. Depth 3520'-3522'. Weir Sand, near base.

<u>F170-38</u> Doyle Pet. "Weir" #2. Sec. 8, T.11N., R.23W. Depth 3459'-3479'. Weir Sand, near top.

<u>F171-38</u> Gen. Pet. "Mainline" #1. Sec. 6, T.11N., R.23W. Depth 2815'-2827'. O'Brien Sand, near base.

<u>F173-38</u> Gen. Pet. "Mainline" #1. Sec. 6, T.11N., R.23W. Depth 2704' 2714'. O'Brien Sand, near top.

<u>F174-38</u> Standard "Monarch 7" #11. Sec. 7, T.11N., R.23W. Depth 1406'-1408'. Otis Hoyt Sand, near base.

<u>F176-38</u> Standard "Monarch 7" #11. Sec. 7, T11N., R.23W. Depth 1232'-1239'. Otis Hoyt Sand, near top.

<u>F177-38</u> Obispo Oil #12. Sec. 32, T.12N., R.23W. Depth 3810'-3826'. Obispo Sand, near base.

<u>F178-38</u> Obispo Oil #12. Sec. 32, T.12N., R.23W. Depth 3797'-3810'. Obispo Sand, near middle.

<u>F179-38</u> Obispo Oil #12. Sec. 32, T.12N., R.23W. Depth 3766'-3780'. Obispo Sand, near top.

Samples of Recent stream sands derived from possible source rocks of Miocene sediments. (S) indicates distance by speedometer.

F48-38 Small rocky beach on terrace remnant of Kern River 6.5 miles (S) upstream from granite-Tertiary fault contact; 21 miles (S) from Bakersfield South side of River. T.28S., R.30E., M.D.B.&M. Kern Co.

F53-38 About 1/4 mile downstream from White River bridge at White River village. T.24S., R.29E., M.D.B.&M. Tulare Co.

F55-38 Tule River. 6.5 miles (S) from Porterville along Springville road. T.21S., R.28E., M.D.B.&M. Tulare Co.

F78-38 15.2 miles (S) from Patterson on new road up Puerto Creek, upstream from Franciscan-Cretaceous contact. T.6S., R.6E., M.D.B.&M. Stanislaus Co.

F84-38 14.8 miles (S) from intersection of Route 101 and San Simeon road across Lucia Range, on latter road. Paso Robles Creek (?). T.27S., R.10E., M.D.B.&M. San Luis Obispo Co.

F88-38 Piru Creek. 3 miles (S) S.W. of S. Cal. Gas Co. station (which is 2.5 miles (S) from ridge Tavern, 20.2 miles from Castiac, on road branching west from Highway 112). About 6 miles upstream from highway bridge. T.7N., R.19W., S.B.B.&M., Ventura Co.

F91-38 San Emigdio Creek, 50 yards downstream from south-boundary gate of San Emigdio Ranch. About 1 mile upstream from granite-Eocene contact. T.9N., R.21W., S.B.B.&M. Kern Co.

F92-38 San Emigdio Creek; about 1/2 mile downstream from F91-38.

F95-38 Piru Creek. 2.5 miles (S) downstream from Thorn Meadows Ford (where road branching from Ozena-Staufer road crosses Piru Creek). T.6N., R.21W., S.B.B.&M. Ventura Co.

F96-38 Matilija Creek, 1/4 mile above junction with Ventura River, near Matilija Hot Springs. T.5N., R.23W., S.B.B.&M. VENTURA Co.

F97-38 Reyes Creek. Immediately above Reyes Creek public camp. T.7N., R.23W., S.B.B.&M. Ventura Co.

F99-38 Rancho Nuevo Creek near juncture with Cuyama River. T.7N., R.24W., S.B.B.&M. Ventura Co.

F102-38 Green Canyon. West of Cuyama River. 4.8 miles (S) from Cuyama Highway. T.10N., R.28W., S.B.B.&M. SANTA BARBARA Co.

F103-38 Pine Creek at Cuyama Highway bridge. Near juncture with Cuyama River. T.11N., R.31W., S.B.B.&M. Santa Barbara Co.

<u>F105-38</u> North Fork of Labrea Creek. About 1 mile (S) above junction of Bear Creek (Bear Canyon). T.10N., R.31W., S.B.B.&M. Santa Barbara Co.

<u>F106-38</u> 1/4 mile (S) below junction of N. and S. Forks of Labrea Creek. T.9N., R.31W., S.B.B.&M. Santa Barbara Co.

<u>F110-38</u> Salinas River at Pozo-Arroyo Grande road crossing T.31S., R.15E., M.D.B.M. San Luis Obispo Co.

<u>F111-38</u> Salinas River at Pozo-Santa Margarita road bridge. T.30S., R.14E., M.D.B.&M. San Luis Obispo Co.

<u>F112-38</u> Stream bed beside road. 9 miles (S) from Creston on Pozo road. T.29S., R.14E., M.D.B.&M. San Luis Obispo Co.

<u>F113-38</u> Stream bed near road about 3 miles (S) from Creston on Pozo road. T.28S., R.13E., M.D.B.&M. San Luis Obispo Co.

<u>F115-38</u> Stream terrace about 4' above stream bed. Cottonwood Canyon, at about 1000' contour, 1/2 mile upstream from McLure Valley alluvium contact. 12.1 miles (S) from Cholame on Highway 41. T.25S., R.17E., M.D.B.&M. Kings Co.

<u>F116-38</u> Avenal Creek. 13.5 miles from road turnoff from Highway 41 near mouth of Cottonwood Canyon. End of road at quicksilver mine on Avenal Creek. 0.2 miles (S) from turnoff to Kings quicksilver mine. T.23S., R.16E., M.D.B.&M. Kings Co.

<u>F118-38</u> Los Gatos Creek. 8 miles (S) from Coalinga. T.20S., R.14E., M.D.B.&M. Fresno Co.

<u>F120A-38</u> Near mouth of main gulley heading northeastward. Head of Los Gatos Creek, 26 miles (S) from Coalinga. Old road running up gulley toward serpentine mass from Los Gatos Creek road. T.19S., R.12E., M.D.B.&M. Fresno Co.

<u>F122-38</u> San Benito River about 1/4 mile upstream from crossing of Coalinga-Hernandez road, 31 miles (S) from Coalinga. T.19S., R.12E., M.D.B.&M. San Benito Co.

<u>F123-38</u> 5 miles (S) from Hernandez on Idria road up Clear Creek. About 1/2 mile (S) above Clear Creek mine. T.18S. R.11E., M.D.B.&M. San Benito Co.

<u>F124-38</u> 3 miles (S) from New Idria on San Joaquin Valley road. Stream draining Idria mine dumps. T.17S., R.12W., M.D.B.&M. San Benito Co.

<u>F127-38</u> Los Banos Creek, about 1/4 mile upstream from bend at Franciscan Cretaceous contact. About 11 miles (S) from turnoff from Pacheco Pass Highway. T.11S., R.8E., M.D.B.&M. Merced Co.

<u>F129-38</u> 1.2 miles (S) toward Pacheco Pass from Gilroy-Hollister "Y" (highway branching). Pacheco Creek. Santa Clara Co.

F130-38 South Fork of Pescadero Creek, near junction with North Fork. About 4 miles S.W. of Paicines. T.14 S., R.6E., M.D.B.&M. San Benito Co.

F131-38 Tres Pinos Creek at road crossing 11 miles (S) from Paicines on Llanada road. T.15S., R.8E., M.D.B.&M. San Benito Co.

F132-38 Chualar Canyon 5.5 miles (S) from Chualar. T.15S., R.5E., M.D.B.&M. Monterey Co.

F134-38 Carmel River on Martin Flavin property, 1 mile (S) downstream from Nason Ranch Camp at juncture of Cachagua Creek. T.17S., R.3E., M.D.B.&M. Monterey Co.

F137-38 Arroyo de la Cruz Creek just above Highway 1 bridge, 31.2 miles (S) S.E. of Lucia village. San Luis Obispo Co.

F141-38 2.8 miles from Highway 101 at Atascadero. Stream bed beside Morro Rock road. San Luis Obispo Co.

F143-38 Grapevine Creek, 1 mile (S) above Grapevine village, directly above old highway bridge. Kern Co.