GEOCHEMICAL STUDIES OF THE
EPITHERMAL DEPOSITS AT GOLDFIELD, NEVADA.

by

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ABSTRACT

The Applied Research Laboratories grating spectrograph and a technique of quantitative spectro-chemical analysis are described. This method of analysis may show twenty or more elements present in vein and wallrock samples in quantitatively measurable amounts.

Approximately fifty samples of vein material and wallrock from the ore deposits of Goldfield, Nevada were analyzed quantitatively to determine whether the quantitative distribution of the elements would give some clue to the loci of mineralization. It has been established that three elements, bismuth, silver, and tin are genetically associated with the gold values in the deeper veins at Goldfield and that these elements are determinable even in very low grade ore. It is probable that a further study of their distribution would shed much light on the problem of determining the loci of mineralization.

The quantitative variations of some of the elements in the wallrock have been determined and these variations give some hope of an economic application in determining the distance of a given wallrock sample from a vein.

A vertical zoning of tin is present at Goldfield and some suggestion has been found of a zoning of bismuth and perhaps of the whole type of mineralization.

The present work has shown that the spectrograph is very useful in the study of geochemical problems and several possible problems for study are suggested.

INTRODUCTION

Preliminary Statement.

Spectroscopy had its beginning in 1666 when Newton first observed that white light passing through a prism was dispersed into a spectrum. Wollaston and Fraunhofer (1802 - 1817) first used a narrow slit for the illumination source and Fraunhofer first applied the principles of refraction of light from a ruled grating and was able to assign actual wavelength values to the spectral lines he identified.

Many applications have been found for the spectroscope since this early work. It has been used extensively in the study of the physical properties of matter, in the study of the chemical constitution of the sun, stars, and other bodies both celestial and terrestial, and in the qualitative and quantitative analysis of materials.

Quantitative spectro-chemical analysis however has had its great development in the last decade. The spectrograph has been developed so that a bright line spectrum may be photographed and the intensity of the lines of the spectrum are used to obtain quantitative values for the amount of any element present in the spectrum.

Although the spectrograph has been used in geological research for many years, very little has been done with quantitative spectrochemistry. In the following pages an attempt is made to discuss some of these applications and to indicate other lines of research which may be of further interest.

Statement of the Problem.

Quantitative spectrochemical analysis not only offers a rapid means of obtaining accurate chemical analyses, but more particularly accurate quantitative analyses of the rarer elements found in veins and rocks may be easily obtained.

The present work was begun with the hope that the quantitative distribution of these rarer elements, or perhaps even some of the commoner elements if enough samples were analyzed, would give some clue to the loci of mineralization. Two methods of attack on this problem are immediately apparent; first, the study of the distribution of elements along a vein as an ore shoot is being approached, and second, a study of the changes in the amounts of the elements in the wallrock at various distances from a vein to see if it is possible to determine how far a given wallrock sample is from the vein.

Since no mention of such a study has been found in the literature, this research was undertaken with the idea that in all probability it would only show whether there are any possibilities in such a method of attacking the problem of the search for ore, and whether such research should be continued. It is also hoped that it will show some of the problems involved in such a study and some of the additional data that may be obtained in the study of veins and wallrock with the spectrograph.

Method of Attack.

Since there were many variations in the technique of spectrochemical analysis depending upon the type of material to be analyzed and the type of spectrograph to be used, a standardized technique of silicate analysis had to be decided upon. The geological department of the California Institute of Technology possesses an Applied Research Laboratories grating spectrograph so that a technique of silicate analysis suggested by Dr. M. F. Hasler of the Applied Research Laboratories was adapted for use with this instrument. In the first part of this thesis the spectrograph is described and the technique of analysis, the settings of the various accessories, and the constants for the calibration of the film are given.

Before attacking the problem for any specific disctrict, preliminary qualitative analytical work was carried out on may quartz samples to see if the quartz contained a large enough variety of elements to give the method some chance of success. After this preliminary work showed that quartz which carried no visible impurities contained many elements detectable with the spectrograph, a number of miscellaneous samples of vein material from Goldfield, Nevada were obtained and analyses showed that these samples contained approximately twenty elements that could be determined by the spectrograph. The ore in the Goldfield district very often occurs in rich pockets which are found only by extensive development work, so it was believe that this district would be suitable for this problem.

Before any samples could be collected from the Goldfield district the method of sampling had to be decided. Many methods of sampling were possible, but owing to the time available a single method had to be decided upon and it is realized that other methods might or might not have proven more successful. It was decided that the samples would be channel samples of from 5 to 10 pounds taken over a width of about three or four feet, or in the case of a narrow vein, over the whole width of the vein. The samples were taken approximately ten feet apart. Since the samples were collected in this manner, the analytical results are for the vein as a whole, including the quartz and all the ore minerals in the vein.

Two field trips of about four days each were made to Goldfield in the spring of 1940 to collect samples and to become familiar with the local geology and the character of the ore deposits. Suites of ore and wallrock were collected from two of the veins that were still accessible. Another suite of ore samples was collected by Dr. H. J. Fraser from one of the mines during the following summer and was made available for study.

Quantitative spectroscopic analyses were made of these samples and the results of these analyses and conclusions to be drawn from them are presented in the second part of this thesis.

Acknowledgements.

The work for this thesis has been carried forward under the supervision of Dr. H. J. Fraser of the California Institute of Technology. I wish to thank Dr. Fraser for the suggestion of the problem and for many helpful suggestions during the course of the work. Dr. Fraser and Dr. Ian Campbell have critically reviewed the manuscript.

It is a pleasure to acknowledge the kind assistance of Mr. H. P. Kervin of the Goldfield Operators mining company who made the field trips to Goldfield possible and obtained permission for me to inspect and collect samples from some of the mines at Goldfield.

Dr. M. F. Hasler of the Applied Research Laboratories, Los Angeles, suggested the technique of quantitative analysis described in the first part of this thesis and I should like to thank Mr. W. F. Nash of the metallurgy department of the California Institute of Technology for several suggestions regarding the operation of

the spectrograph.

PREVIOUS USES OF THE SPECTROGRAPH IN GEOLOGICAL PROBLEMS

The following cannot be regarded as a complete presentation of the applications of the spectrograph to geological problems since many of the publications in which the references may be found are not available, but it does include the important papers.

Fitch (1) wrote a short book on Spectrum Analysis in Mineralogy. This work contains a description of various methods of analysis and discusses analysis of minerals, mineral concentrates, rocks, and meteorites. It contains an excellent bibliography of the work done on this type of spectrochemical analysis up to 1930.

Hartley and Ramage were two of the earliest workers on spectroscopic analysis of minerals. They simplified the methods of analyzing minerals and made many mineral analyses. Fitch's bibliography contains the references to the work of these two men.

De Gramont was another early worker in quantitative spectrochemistry as applied to mineralogy. His numerous works are also listed in Fitch's bibliography.

V. M. Goldschmidt (2) and his associates used quantitative spectrochemical analyses extensively in their work on the geochemistry of the occurrence of the elements in rocks and minerals. Their principal use of the spectrograph was in determining small quantities of the various elements in the minerals and in checking their chemical analyses by spectrographic analyses.

Graton and Harcourt (3) by means of the spectrograph found the presence of comparable quantities of the same relatively rare elements in the sphalerite of the Mississippi valley type of ore as compared to the quantities of those elements which occur in the sphalerite of deposits now generally accepted as of magmatic origin. They also discuss the geochemistry of the individual elements.

Sahama and Rankama (4) working on the granite of Finland are attempting to divide the granites into certain provinces which show marked similarities when characterized by the content of their rarer elements. They conclude that it should be possible to separate granites by this method although they mention that some granites may originate by partial refusion of the older rocks.

These two authors along with Vahalto have also worked on the rare earth content of many rocks and minerals, (5), (6), (7).

Kenard, Howell, and Yaekel (8), (9), (10), have done research on the color of minerals using the spectrograph. They have been attempting to find if the colorsof certain minerals are due to small quantities of rare elements. They found that the color of blue halite and the blue color and brown color of zircons to be structural rather than pigmental, but the dark smoky quartz always contained less lithium than colorless and pale smoky quartz. They also give a method for preparation of samples and an improved spectrographic technique to avoid contamination.

Clausen (11) analyzed qualitatively about five samples each of galena, sphalerite, and pyrite and gave a table of results.

Newhouse (12) used Claussen's spectroscopic results along with his own chemical results to show that vanadium, molybdenum, chromium, and tungsten in oxidized zones of lead deposits are probably from hypogene minerals containing small percentages of these elements.

Schneiderhohn (13) did a great deal of work on the geochemical occurrence of platinum and some of the other elements in the mines of South Africa. He found that chromite and the silicates of the pyroxenites and Merensky "Reef" are free from platinum and other precious metals. The amount of platinum decreases with decreasing age of the sulphides, and the last two sulphides, chalcopyrite and millerite, contain no platinum metals.

Moritz (14) gives details on methods and practical applications of the spectroscope. An excellent bibliography is also found in this paper.

A recent book by Brode (15) on chemical spectroscopy describes the various types of spectrographs and methods of analysis and gives data for the setting up of working curves. It also contains tables of the principal lines of the elements and has an excellent bibliography on spectro-chemistry.

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PART I QUANTITATIVE SPECTROGRAPHIC PROCEDURE

Introduction.

Since the technique of quantitative spectrographic analysis is still in the experimental stage and the equipment used is undergoing rapid improvements, modifications, and changes, the development of a method of analysis for any problem involves much preliminary research. In the following pages there is presented a description of the equipment used during this investigation and a discussion of the analytical methods.

The instrument described herein is a grating spectrograph made by the Applied Research Laboratories, Los Angeles.

The sample is excited in a carbon arc. The light from the arc passes through a slit, is dispersed by a ruled grating and the spectrum is recorded on photographic film. The quantitative estimation of the elements is made by determining the intensity of the lines produced on the photographic film since the intensity of a line is determined by the concentration of the element in the sample.

The darkening on the film is measured by a densitometer employing a photoelectric cell. However, the amount of the darkening of a line on the photographic film is not only controlled by the concentration of the element, but also by the time of development. The development factor is eliminated by the use of a gamma curve which relates the transmission value of a line as read on the densitometer, to the true intensity of the line.

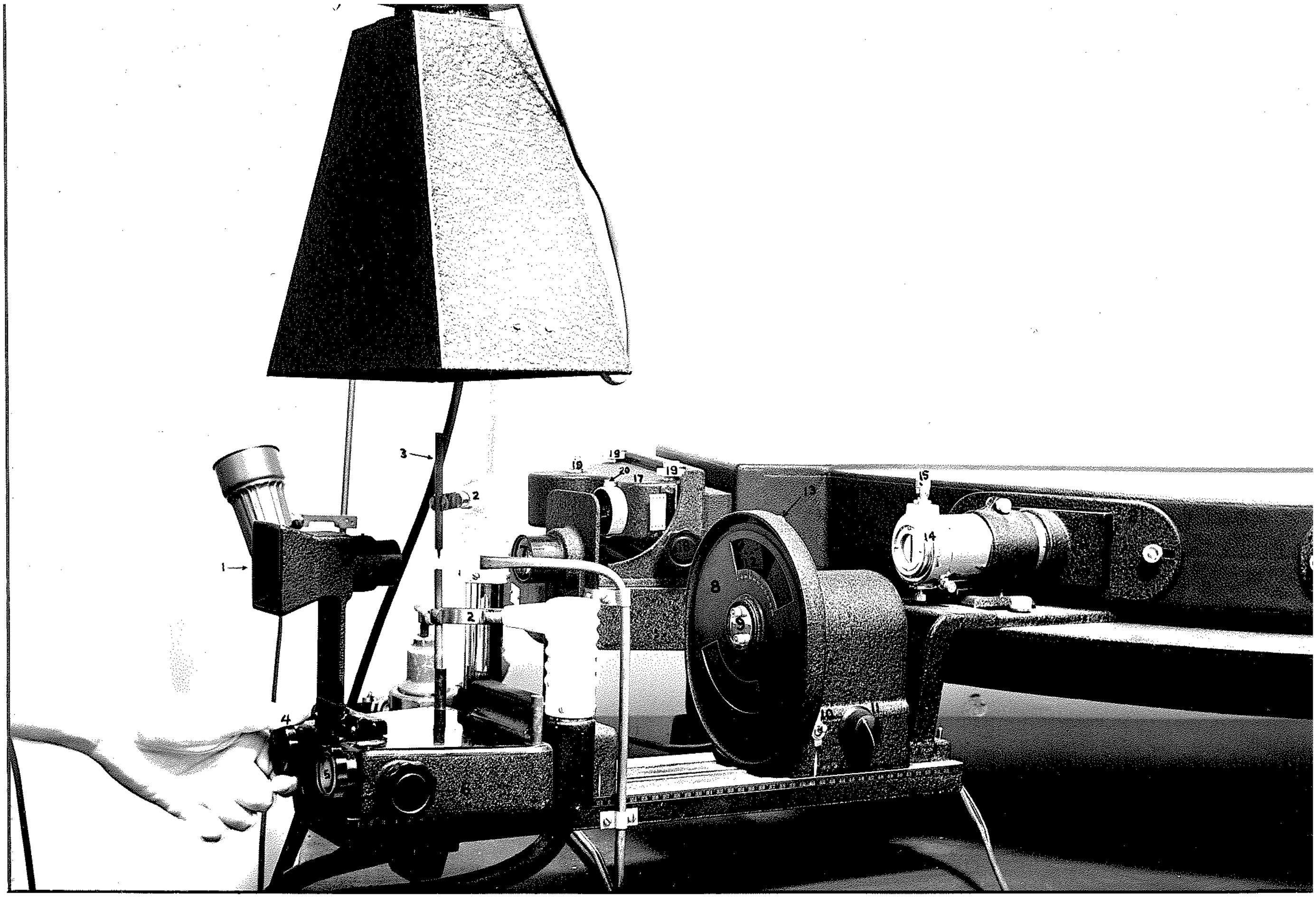
Description of the Apparatus.

(a) The spectrograph.

The spectrograph is shown in Figs. 1 and 2. In the following

Fig. 1. - View of the front part of the spectrograph

Fig. 2. - The spectrograph.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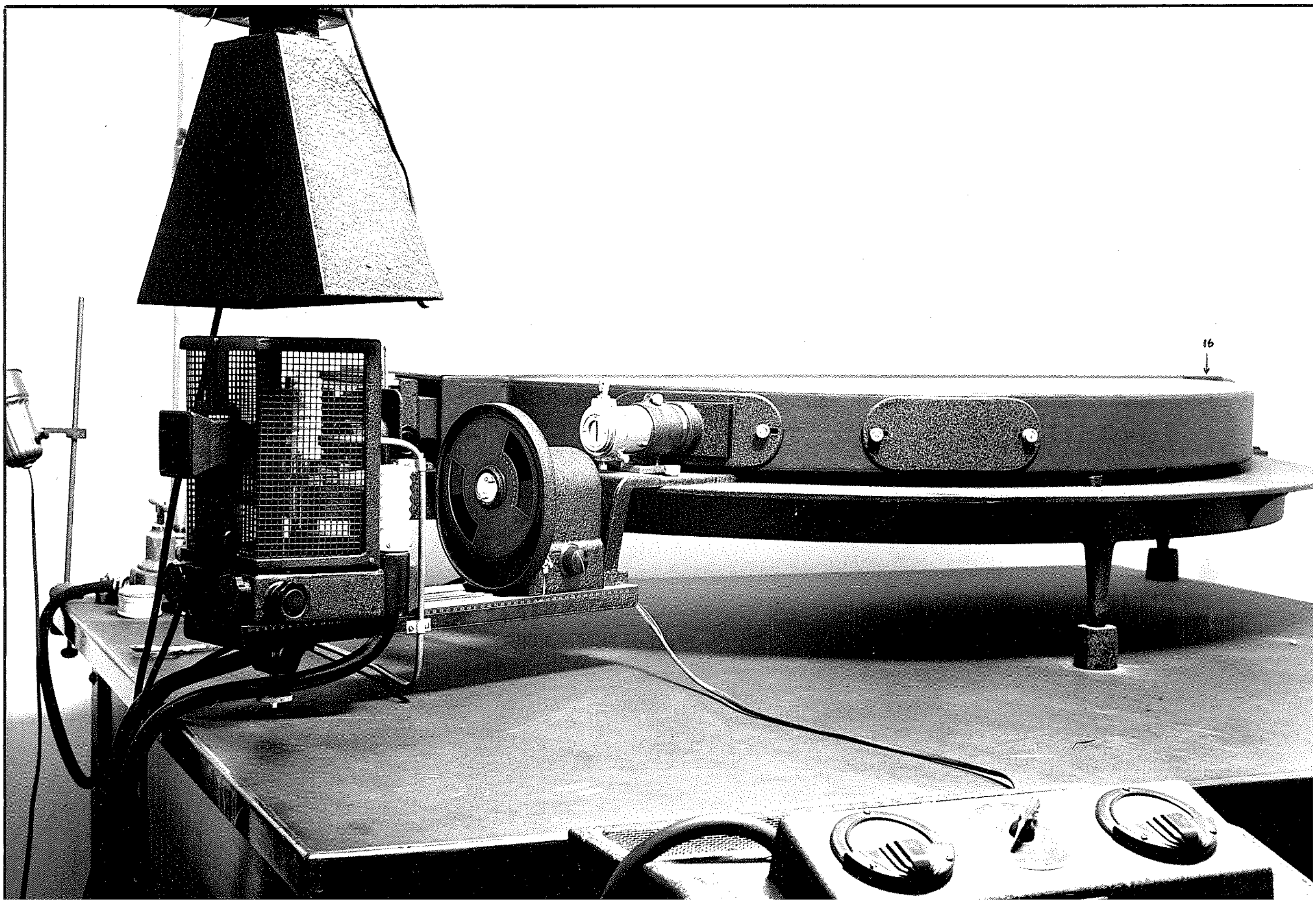
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description of the instrument the numbers refer to the parts of the instrument and the accessories as indicated in the figures.

(1) Ground glass plate for the alignment of the electrodes. The inverted image of the two electrodes is reproduced on this ground glass plate by a lens mounted between the electrodes and the plate. A vertical line is ruled on this screen and the electrodes must be centered by aligning them with this line. Other horizontal lines may be marked on this glass plate to indicate desirable arcing positions for various types of work.

(2) Electrode holders. These holders are constructed to hold $\frac{1}{4}$" electrodes.

(3) Electrodes. Various types of electrodes are used and will be described later.

(4) This knob is used to raise and lower the upper electrode.

(5) This knob raises and lowers the lower electrode.

(6) This knob moves both electrodes simultaneously in a horizontal direction so that the arc may be kept centered on the vertical line on the ground glass alignment plate.

(7) Quartz condensing lens to focus the light from the arc on the slit (14).

(8) The rotating sector. This sector is placed at the secondary focal plane of the spectrograph. It is constructed so that it may be used as a step sector or merely as a rotating sector to reduce the exposure.

The step sector is cut such that when rotating, it exposes a $\frac{1}{4}$" strip on the film at four different intensity levels. These intensity values have a relation to each other of 1: $\frac{1}{2}$: $\frac{1}{4}$: 1/8.

In addition to the step sector two openings on the sector plate cut the exposure in half when fully opened. One of these openings is graduated in a scale from 1 - 100, and a mask may be moved into place over these openings by rotating the small plate (9) by the two handles provided.

The rotating plate may be raised or lowered depending upon whether the step, or ordinary sector is desired.

(10) Starting switch for the rotating sector.

(11) Rheostat to control speed of the sector.

(12) A diaphragm is placed behind the rotating sector. The condensing lens (7) focuses the light from the arc on this diaphragm. The opening of the diaphragm selects the central portion of the arc which is projected on the slit (14).

The diaphragm has four different openings controlled by the knob (13). The number two opening exposes a 1/16" strip of film and is used in quantitative work. The number 4 opening exposes a ½" strip and is used for the step sector. The number 1 and 3 openings are used for qualitative work.

(14) The slit. It is the replica of this slit that is photographed on the film. The slit may be opened from .01 mm to .1 mm., the opening being controlled by the spindle (15) which is graduated from 1 - 10, 1 corresponding to .01 mm., and 10 to 1. mm.

(16) The grating. The grating disperses the light of different wavelengths. The radius of curvature is so designed as to give a uniform dispersion on the film and consequently all measurements along the spectrum areof equal value and the wavelengths of the lines may be easily measured and compared with an iron spectrum on a master plate in the projector.

(17) The camera. The camera uses motion picture film obtained in 100' lengths. Each exposure is $12\frac{1}{2}$ inches long. Nine spectra may be photographed on each strip of film, so that on a single strip it is possible to photograph four samples arced in duplicate, and an iron spectrum to be used in the construction of the gamma curves.

The camera is racked up and down by the knob (18). The screws (19) are used to hold the film firmly in the camera. The middle screw is always left loose, but the outer screws are tightened except when a strip of film is being removed. The screw on the left hand side is always tightened first after a strip of film has been withdrawn from the camera to prevent the possibility of a short piece of film at the end of a roll being left in the camera and to insure the film being tightly stretched across the camera. When a strip is removed its length may be gauged by pulling it about $1\frac{1}{2}$" past the left hand screws (20). The film is then cut near the camera with a pair of scissors. It is much easier to cut the film if the camera is racked as high as possible. A red safe light may be used with motion picture film.

The screws (20) are to hold the camera in place and must be removed to reload the camera with a fresh roll of film.

(21) and (22) are two settings of the instrument to photograph different portions of the spectrum. In Fig. 1 the setting is for the 2380A° - 4600 A° region in the ultra violet. If setting (22) is used the region photographed is from 4580 A° - 6800 A°. The setting from 2380 A° - 4600 A° is generally used, the higher one being used only in the case of one or two elements that have more sensitive lines in that region.

(b) Arc Rectifier Unit.

The current to produce the arc is supplied through an arc rectifier unit (Fig. 3). The amperage may be directly controlled over a range of 3 - 15 amperes, by the reactor wheel at the front of the case. During arcing the voltage varies from 50 - 60 volts.

The unit contains a timer which automatically breaks the circuit and thus extinguishes the arc at any predetermined time up to three minutes.

(c) Projection Comparator and Densitometer.

The spectral lines are identified by comparison with known lines marked on a master plate in the Projection Comparator. The transmission value of each line can be measured by the densitometer.

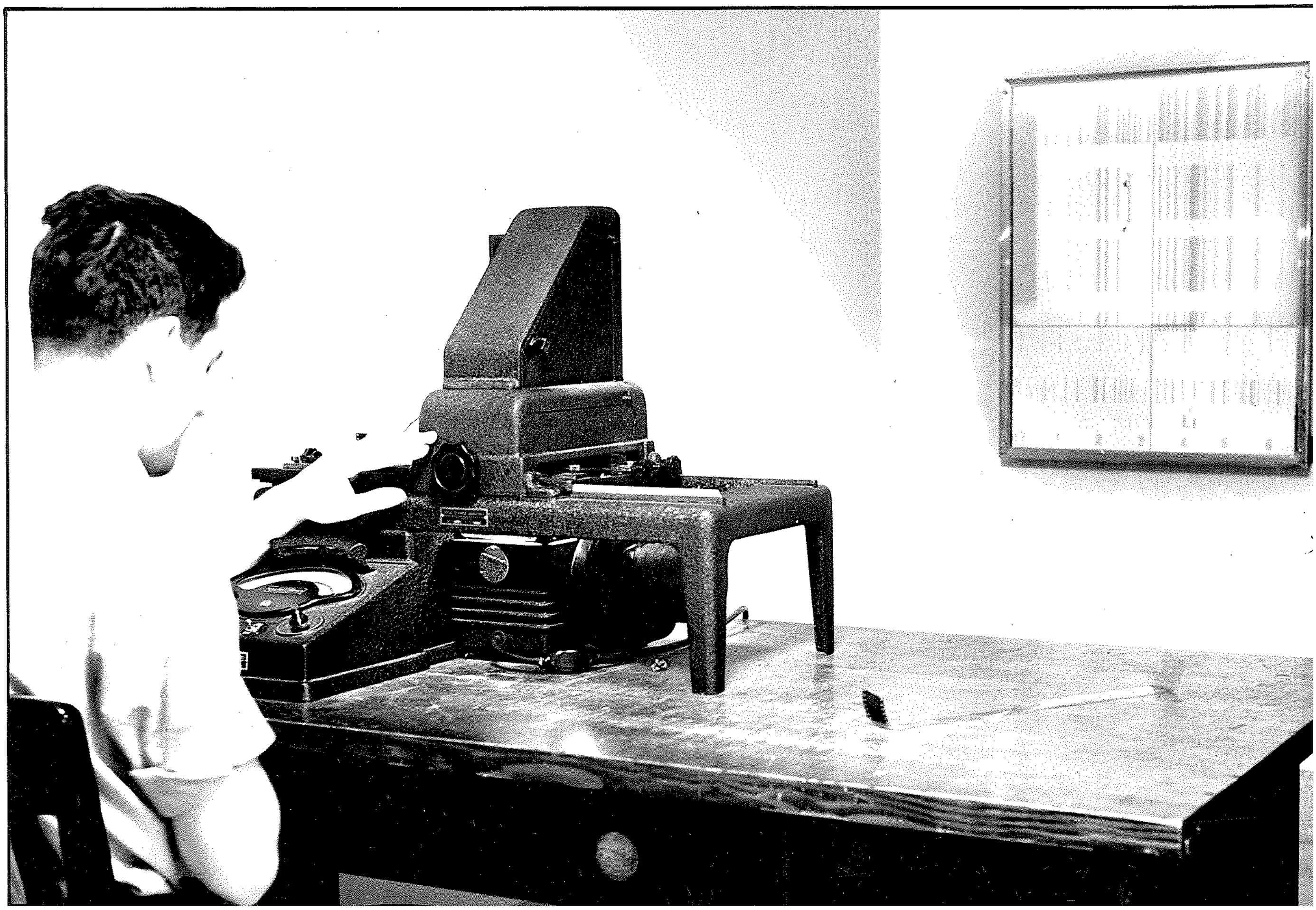
When a film is placed in the projection comparator the spectra on the film are projected on a screen simultaneously with the field (Fig. 4). On this master film there is recorded an iron spectrum, the more persistent lines of the other elements, and a wavelength scale. The iron spectrum of the film may then be aligned with the iron spectrum of the master spectrum and the unknown elements in the sample may be determined by either comparison with the recorded lines on the master film or by measurement of the actual wavelengths. The wavelength of a line not marked on the master plate may be determined to an accuracy of 0.2 A^o by means of the wavelength scale on the master plate and a scale on the screen; and may be identified by the use of a set of tables.
The tables used are the M.I.T. Wavelength Tables.

M.I.T. Wavelength Tables, Compiled by G. R. Harrison, John Wiley and Sons 1939.

Fig. 3. - Arc rectifier unit.

Fig. 4. - Projection comparator, Densitometer, and Screen.


APPLIED RESEARCH LABORATORIES
LOS ANGELES



The transmission value of the lines is read on the densitometer. When the button next to the large knob at the rear of the housing of the projection comparator is pressed, a small shoe is moved rapidly out of a protecting recess on to the film. The shoe contains a slit, whose width is only a small fraction of the width of the lines on the film, and a light- pick-up tube. The shoe is automatically moved across the film by a synchronous drive motor so that as the slit moves slowly across a line the darkening of the line is measured by a photoelectric cell and read on a meter. As the slit scans the line, the pointer sweeps slowly across the scale of the meter and reaches a minimum value, then as the line is passed by the slit, the pointer swings back to higher values. The scale on the meter is graduated from 1 - 100, and the minimum value, which represents the transmission value of the line in percent, is read to the nearest 1/10 of a division.

Full instructions as to the assembly and use of the machine are given in the "Applied Research Laboratories Grating Spectrograph Instructions" supplied by the Applied Research Laboratories.

THE GAMMA CURVE

As mentioned earlier, the transmission value of a line depends not only on the concentration of the element, but also on the amount of development of the film. Variations in this development factor between different films must be cancelled out to determine the true intensity of the line. This is done by using a curve called the gamma curve, which relates the transmission value of the lines to their true intensity.

This gamma curve is obtained by using the step sector and an iron spectrum. The step sector allows each line of the spectrum to be photographed at four different exposure intensities on the same film. The sector is cut such that the four intensity ratios are 1 : 1/2 : 1/4 : 1/8, hence these rations may be plotted as true intensities for the line. It is necessary that the light be uniform over the whole field so that the four ratios will be photographed at their true intensities. The uniformity of the field may be checked by photographing the spectrum through the 1/4 inch opening and measuring the transmission value of several lines to see if they are constant over their whole length.

The transmission values of the four different intensities are read on the densitometer and plotted against the intensity values. A curve is thus obtained relating the transmission value of any line to the true intensity of the line. This curve is known as the gamma curve.

The curve is plotted on logarithmic 2 cycle by 3 cycle graph paper. The transmission values, from 1 to 100 are plotted as the ordinates; and the intensities, from .01 to 10 as the abscissas.

The gamma curve is a straight line for transmission values from 1% to between 20 and 40%, and in practice should have a slope of $45^0 - 55^0$. The curve flattens out in a smooth curve for higher transmission values.

A single sectored line on the film gives only four points on the curve. To get the slope of the gamma curve, several neighboring lines are plotted and the average of their slopes is used as the slope of the curve. The slopes obtained from different lines in the same portion of the film should vary only about two degrees, with the exception of an occasional line which may give a radically different slope, this last type of line being disregarded in the average.

When the slope is obtained the curve can be extended in the following manner. The slope as determined, is drawn on the graph paper with the unity point of the intensity, that is, intensity of one, passing through a given transmission value.

This transmission value is determined for different films by selecting a definite iron line which gives a consitently good curve on every film and using the transmission value of the darkest segment of that line. The reason for selecting this definite point is to relate different films to one another so that the resulting intensities will be comparable.

Neighboring iron lines can be used to extend the curve when this unit point is determined and the slope is plotted. This is done by taking another 3 cycle log scale similar to that used as the abscissa for the gamma curve with intensity values from .01 to 10. The intensity values of 1, 1/2, 1/4 and 1/8 are marked on this second scale. The intensity of one on this second scale is placed on the curve already constructed at the transmission value for the darkest exposure of any neighboring line. The three remaining transmission values of that neighboring line are then plotted at the 1/2, 1/4 and 1/8 intensities on this second scale, and these points will be additional points on the gamma curve.

The construction of the gamma curve is shown in the following example. Table #1 gives the transmission values of six iron lines in the 4000 A^{o} region, at the four different intensity levels.

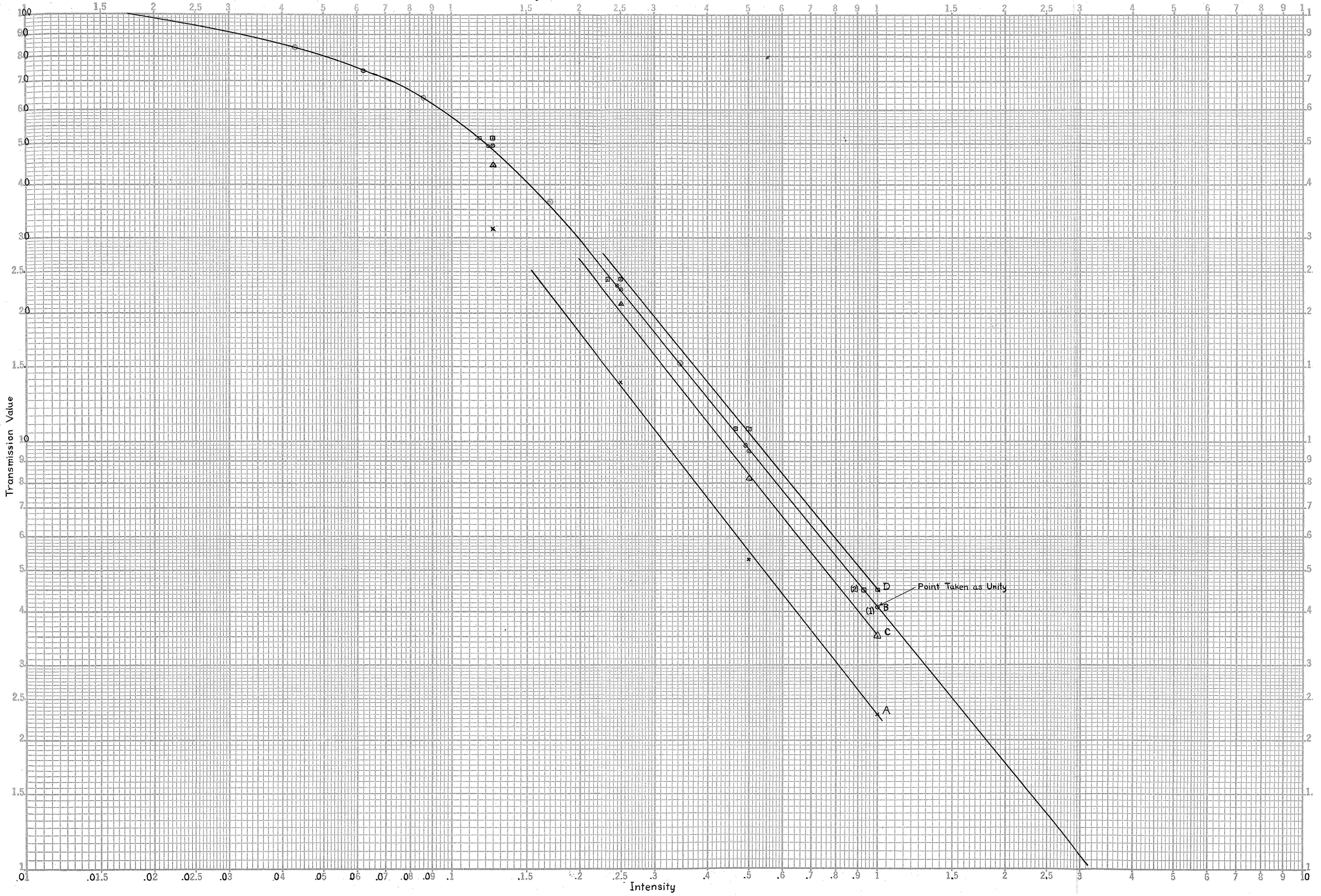
The transmission values of lines A, B, C, and D are first plotted on the graph, Fig. 5. The three lower points of each line are joined to give four straight lines which represent the slope of the gamma curve. The highest transmission values are above the value where the gamma curve begins to flatten out hence cannot be joined by a straight line to the other three points.

The slopes of the four lines, A, B, C, and D, are averaged and line B was found to have the average slope (about 51°). The wavelength of this line (line B) was noted and the unity point of this line (1) was then selected as the point through which the gamma curve of each film must pass. This point will vary from film to film according to the transmission value of the line.

The gamma curve passes through the four intensity values of line B. Other points on the gamma curve may then be plotted as shown in Fig. 5. For example, the values of line D are plotted by black squares. The lowest value of line D (i.e. 4.5) is then plotted at its correct transmission value on the gamma curve passing through the points of line B, that is, at position (2). Then by taking the other log scale and placing its unity value at this point (2), the other intensity values, 1/2, 1/4, and 1/8 are plotted and are shown on the graph (Fig. 5) by red squares. These four points then represent points on the gamma curve.

Similarly for lines E and F (Table 1) the intensity values are plotted by putting the highest intensity value on the curve already constructed and calling this value unity on the movable

Fig. 5 - Construction of a Gamma Curve



log scale, and plotting the other three values at the 1/2, 1/4, and 1/8 intensities on the movable scale. These points are shown as blue circles (Line E) and green circles (Line F). The gamma curve is then extended to pass through these points.

TABLE #1

INTENSITIES AND TRANSMISSION VALUES FOR CONSTRUCTION OF GAMMA CURVE

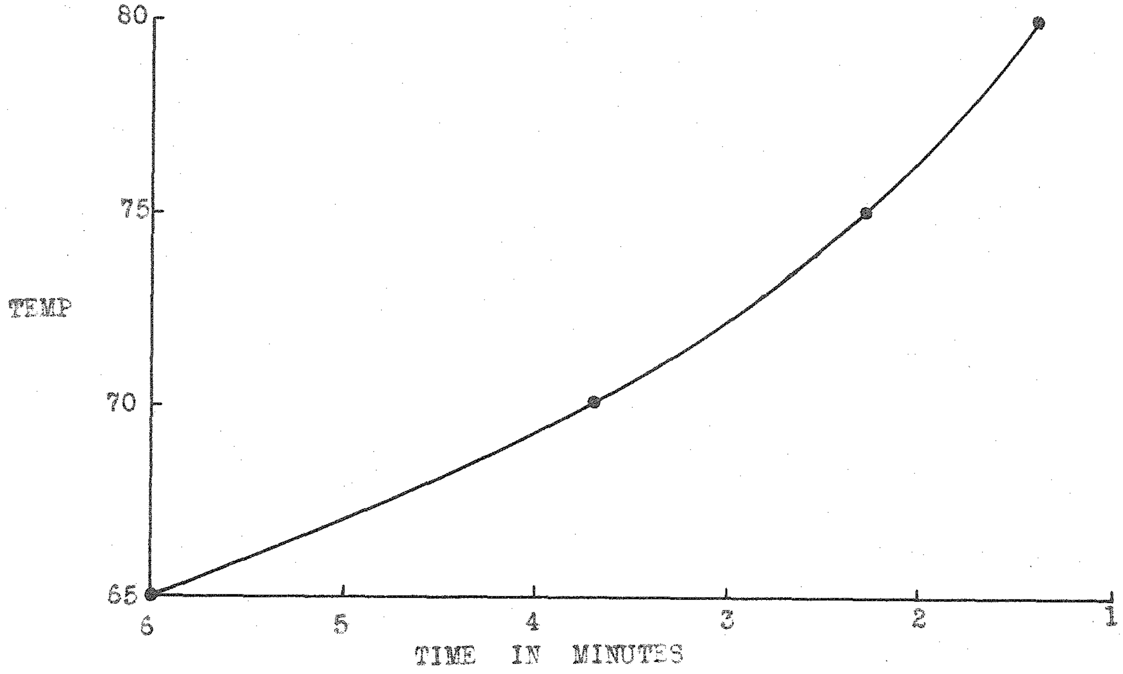
	Line A	Line B	Line C	Line D	Line E	Line F
1	2.3	4.1 (1)	3.5	4.5	9.8	15.3
1/2	5.3	9.5	8.2	10.7	23.2	36.5
1/4	13.8	22.9	21.2	24.0	49.1	64.0
1/8	31.5	49.6	44.3	51.6	74.0	84.3

The slope of the gamma curve is found to change slightly for different portions of the same film. Four gamma curves are drawn for each film because of this change of slope; one for each of the 2800 A$^{\circ}$, 3200 A$^{\circ}$, 3600 A$^{\circ}$, and 4000 A$^{\circ}$ regions. The various lines of the elements are then referred to the nearest curve. If the analysis is for a single element, the curve may be constructed from lines in the immediate neighborhood of that element.

The development of the film is kept as uniform as possible so that the slopes of the curves will remain nearly constant. The slopes of the gamma curves in different portions of a film should be kept as nearly parallel as possible. This is done by using a time-temperature curve to control the time of development of a film at a given temperature. This curve (Fig. 6) was constructed by Mr. W. F. Nash.

<u>Type of Arc for Iron Sector</u>. The iron spectrum is obtained by

Fig. 6
TIME - TEMPERATURE CURVE FOR DEVELOPING FILMS WITH D 11



arcing a lower iron electrode with an upper carbon electrode. These electrodes are shaped as in Fig. 7A. The carbon electrode is made by inserting a 1/8 inch carbon electrode in a hole bored in a 1/4 inch carbon electrode. The electrodes are set 3/8 inch apart.

The arcing conditions are as follows:

Sector - - - - - - - - - - #4
Slit opening - - - - - - 6
Sector opening - - - - - step
Amps - - - - - - - - - - 5
Time - - - - - - - - - - 3 seconds
Screen - - - - - - - - - In
Condensing Lens- - - - - In

IRON CALIBRATION CURVE.

The step sector method of constructing the gamma curve is time consuming and takes up three of the nine exposures on a strip of film. Another method of constructing the gamma curve has been described by the Applied Research Laboratories.

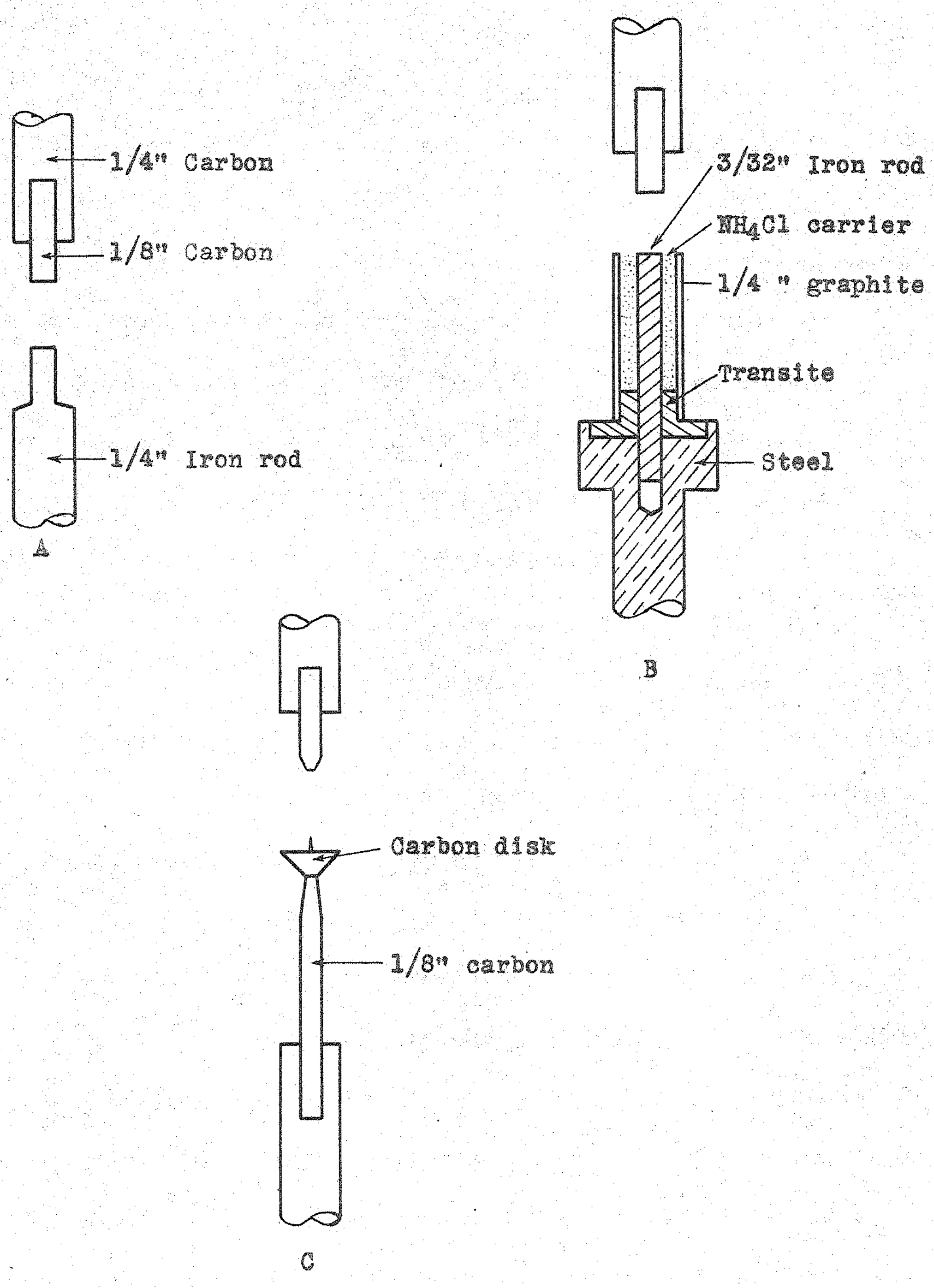
This method depends upon the sector method but is much faster and has the advantage of taking up only one exposure per film, instead of three.

The method as developed by the Applied Research Laboratories is quoted directly:

Photographic Densitometry in Quantitative Spectrochemistry. Spectro-Chemical Advances #3. Applied Research Laboratories. Sept. 1940.

Fig. 7

ELECTRODES



"Due to the differences of film stock sensitivity and contrast in different batches, and under different developing conditions, and in different regions of the spectrum, it is apparent that a system must be devised that allows calibration at several wavelengths throughout the spectrum and then interrelates these calibration curves to give true intensity ratios between lines widely separated in the spectrum. Such a system would also cancel out differential changes of a spectrograph's speed in different regions of the spectrum and thus, most important of all, would allow under certain conditions a direct comparison of intensity ratios between different laboratories. This in turn would allow a new era in spectrochemistry in which all systems of analysis could be interchanged without the tedious repetition of standardization now in vogue."

" The calibration method developed with the above considerations in mind makes use of a high streaming velocity arc similar to that described in "Spectrochemical Advances #2". Since it is an iron arc it serves a twofold purpose in establishing both a wavelength scale and a density scale. A 3/32" iron peg 7/8" long is used in the standard arc base composed of a steel pedestal, transite bushing and graphite sleeve. The carrier employed is ammonium chloride. Carbon does not furnish a sufficient gas stream to prevent the peg from forming a bead and touching the carbon sleeve. With ammonium chloride however, a 3/8" arc started at 7-1/2 Amps. will function steadily for the five second period used. With the Applied Research Laboratories arc rectifier the current may be adjusted before arcing by setting the current to 10.6 Amps. with the electrodes short circuited. The arc should of course be opened rapidly to 3/8 ths of an inch by moving the upper electrode up to its stop. The

Procedure described above, concerning uniformizing the sectored field by adjusting the vertical positions of the arc should be followed when introducing this system.

"Four groups of lines are tabulated below by wavelengths and relative intensities. The lines chosen as unity in each case are not necessarily equal in intensity. They merely represent an arbitrary choice of unit intensity in each region of the spectrum. However, since their relative intensities are always maintained constant in this type of an arc, they serve as a means of interrelating the four calibration curves"

The relative intensities of the iron lines are found to differ slightly from those of the spectrograph used at the Applied Research Laboratories, hence new intensities were determined. Several additional lines were used in redetermining the intensity values and a few of the lines used by the Applied Research Laboratories were found to be unsatisfactory due to differences in the speed of the gratings. All lines used have been checked against the M.I.T. Wavelength Tables and found to be free of interfering lines. The values as determined have been found to give satisfactory gamma curves. Table II gives the wavelength of the lines and their relative intensities.

TABLE II

Relative Intensities of the Iron Lines For the Construction of the Iron Calibration Curve

Wavelength	Intensity	Wavelength	Intensity
2792.4	.284	3175.5	1.98
2788.1	1.97	3173.7	.51
2786.8	.21	3172.1	.336
2786.2	.134	3171.4	.58
2781.8	.583	3168.9	.346
2778.8	.45	3167.9	.51
2772.8	1.14	3166.4	1.00
2767.5	1.00	3165.9	.66
2764.3	.88	3164.3	.187
2763.1	.82	3163.9	.235
2762.0	1.5		

Wavelength	Intensity	Wavelength	Intensity
3667.3	1.2	39[illegible]3.8	.246
3666.2	.605	3946.8	2.44
3664.7	1.00	3948.1	1.50
3661.4	.33	3947.5	1.00
3660.3	.406	3947.0	.74
3659.5	2.36	3945.1	.93
3658.5	.33	3943.4	.43
3657.9	.62	3942.4	1.48
3657.1	.63	3941.7	.581
3656.2	.91	3940.9	1.43
3655.5	1.85	3940.0	.145

"Four gamma curves are now readily established by reading the four steps of the unity lines. By calling their darkest step one in each case, the four curves can be plotted about a vertical line designated as $I = 1$ on a log scale abscissa. Log ordinates are convenient for plotting transmission values. Different colored pencils readily distinguish the four regions of the spectrum. Other lines in each group can be used to extend these curves to higher and lower transmission values. In doing this, the relative intensity values between the lines given can be checked and any difference tabulated.

"Once these relative values are known, with considerable accuracy a double check on the drawing of gamma curves is available as the step intensities must fit the curve at 1, 1/2, 1/4 and 1/8, and I_1/I_2, I_1/I_3, etc. must be maintained.

"A still more important use of the data is to use the relative intensities of the lines and their transmission values to plot gamma curves independently of the rotating sector. This method proves to be highly successful as it can be made more practical in operation than the rotating sector method. However, it must necessarily always depend upon the rotating sector method, as the relative intensity values utilized must be determined in all their final accuracy at each installization.

"The procedure in this case is to operate the arc at 18 cm on the optical bench scale and not use any condensing lens. The rotating sector opening is adjusted to obtain transmission readings on the listed lines covering the range of transmission values usually employed. A regular 1/16" spectrum suffices and thus provides both a wavelength scale and a density scale. This allows a calibration spectrum and eight or nine sample spectra to be recorded on a single film.

"It will be noted that the lines listed are adjacent to each other in the spectrum. Thus by starting at the line having the highest wavelenths the whole group may be read one after the other several at a time. This minimizes errors in reading lines and makes for even faster reading than with the stepped sector. Also the main error occurring in stepped sector work, namely non-uniformity of sectored field does not enter into this method.

"Referring now to the four gamma curves obtained by either the stepped sector method directly or the relative method; these curves do two things. First they establish the films transmission intensity scale for each region of the spectrum separately, and second, they establish a relative film sensitivity wavelength scale that may be used to compare lines in widely different regions of the spectrum.

"For cases where the line of the element to be measured and the internal standard line are within a few hundred angstroms of each other the appropriate gamma curve relating to that region of the spectrum allows their intensity ratios to be calculated directly in the usual manner. This is most easily done by making the internal standard line unity and reading the lines to be compared to it as a fraction of that line. This gives I_1/I (standard) directly.

"However, the case where the lines to be compared are separated by more than several hundred angstroms requires the use of two gamma curves. The procedure is identical to the previous one except that each line is read on the gamma curve pertaining to its region of the spectrum. This introduces an arbitrary constant into the intensity ratio, namely the intensity ratio of the iron lines called unity used to set up the gamma curves, but as this constant is automatically absorbed into working curves relating intensity ratios to concentration this does not complicate matters. Further, since this procedure corrects for practically all variations in film's and spectrograph's characteristics it is well worth applying consistantly to all work covering much of the spectrum.

"If the gamma curves obtained in various regions of the spectrum are parallel or almost so, the above method of film calibration is very satisfactory. However, if curves relating to adjacent regions of the spectrum are very different in slope then the determination of intensities of lines of intermediate wavelengths will be uncertain. Thus, the general aim should be to employ film stock and developer that gives reasonably parallel gamma curves throughout the analytical range."

The lower electrode used in this calibration is shown in Fig. 7B. A #6 finishing nail is suitable for the iron peg. The ammonium chloride used as a carrier must be kept dry in a dessicator.

Application to C. I. T. Spectograph.

The procedure of determining the new values for the iron calibration curve was as follows:

The best position for the electrodes had to be determined since with the condensing lens removed the intensity of the lines varies with the position of the electrodes. To do this, three 1/4 inch exposures were made on a film with the condensing lens removed. One of the exposures was made with the electrodes centered on the sights on the ground glass plate, one with the electrodes 1/8 inch above the sights, and the other with the electrodes 1/8 inch below the sights. The lines were measured on the densitometer to find the electrode position which would give the most constant transmission value over 1/16 inch of any line. This position was determined as 1/8 inch above the sights and the positions of both electrodes were marked on the ground glass plate by two small arrows.

Several arcings with different exposures were made to determine the proper arcing conditions for the calibration. It was found that one tenth of the exposure used by the Applied Research Laboratories gave about the right transmission values for the spectrograph used.

The arcing conditions as determined are:

Sector number - - - - - - - - - - - - 2
Slit Opening- - - - - - - - - - - - - 6
Sector Opening- - - - - - - - - - - - 5
Amperes - - - - - - - - - - - - - - - 10.6 with electrodes short circuited.
Time- - - - - - - - - - - - - - - - - 5 sec.
Screen- - - - - - - - - - - - - - - - Out
Condensing lens - - - - - - - - - - - Out

The time should be very carefully controlled, a watch being used rather than the timer, which occasionally does not start for two or three seconds after the arc is struck.

The relative intensities of the lines were determined by photographing an iron sector and six iron spectra on a single film. The gamma curves for the four regions of the film were determined from the sectored spectrum as already described. One of the iron lines to be used for the iron calibration curve was then selected as having an intensity of one, and the gamma curve was drawn to pass through the transmission value of that line. The relative intensities of the other lines of the same exposure could then be determined by reading their transmission values on the gamma curve and determining their relative intensities from the graph. This was done for all six exposures on the film and the relative intensities were averaged. The same procedure was repeated with two more films and only those lines whose intensities closely agreed on all three films and all eighteen samples were selected to be used.

The values as determined are given in Table II. The technique of arcing these samples for the iron calibration curve must be kept very constant as it has been found that slight changes in the technique affect the relative intensities markedly. Several films were exposed before any constant values were obtained, but once the technique is mastered the method gives excellent results for the construction of the gamma curves. The lines used run in series which are quickly recognized and may be read in a very few minutes.

In reading the lines for the iron calibration the background of the film is disregarded.

THE INTERNAL STANDARD

The darkening of the lines of an element on a film depends not only on the concentration of the element, but also on the amount of exposure of the film, the amount of sample used, and other variables that may enter into the arcing of a sample; so that these variables must be cancelled out if any accurate analyses are to be made. The internal standard is used to eliminate irregularities due to varying amounts of sample and variations in the arcing of the sample.

The internal standard is an element that is present in a constant amount in every sample. It may be either added, or present naturally in the sample. Since this element is present in a constant amount, it should always have the same intensity, but in actual practice the intensity will vary depending upon how much of the sample is arced, how long it is exposed, the amount of current used, and other arcing variables; so that the actual intensity of the internal standard line gives a measure of the sum of the variables due to the arcing of the sample.

These variables may then be eliminated by expressing all the intensities of the other elements as a ratio of the intensity of the internal standard. For example, if a lithium line was being used as the internal standard it might give an intensity of say one, but if the exposure was doubled its intensity would be two. The intensity of the unknown element, say iron, might be four in the first case, but when the exposure was doubled its intensity would be eight. The intensity ratio then would cancel out this error of double exposure, since

$$\frac{I_{Fe}}{I_{Li}} = \frac{4}{1} = \frac{8}{2} = 4$$

Exposures should be kept as uniform as possible and the amount of sample to be arced should be weighed to ±1mg.

The intensity ratio under these carefully controlled conditions has a direct relation to the percentage of the element present in the sample.

The internal standard element used may be the major constituent of the sample if that element is present in amounts over 80%. If no constituent is present in this amount, then a known amount of some element that is not present in the sample may be added.

It is preferable to mix this element in solution, but in the case of ore samples this is impractical, so that the sample and the internal standard material must be thoroughly mixed and the ground together in an agate mortar.

In the case of the analyses in the second part of this thesis, the internal standard used is lithium which is added to the sample in the form of lithium carbonate. The internal standard line used is the 2475 A° lithium line.

For vein quartz samples with 80% or more silica, the procedure is very much simplified as silicon may be used as the internal standard. In this case the 2443.4 Ao silicon line is suitable for the internal standard line.

PREPARATION OF THE SAMPLE

The samples from Goldfield are channel samples weighing from 5 - 10 lbs. These samples were crushed to minus 1/2 inch in a jaw crusher. After coning and quartering, one quarter of the original sample was ground to about 200 mesh in a Braun Chipmunk pulverizer.

The pulverized sample was split into two parts by a Jones sample splitter. From each of these halves one sample was further split for arcing, so that each original sample was arced in duplicate.

Each sample was split to about 60 grams using the same Jones sample splitter, and the iron from the crushing and grinding was removed by an electromagnet. The sample was further ground for about three minutes in an agate mortar until all grains passed through a 200 mesh screen, and then split to 30 - 60 mg. by an Otto microsplit.

Thirty milligrams of the sample were accurately weighed on a chemical balance and mixed with 30 mg of the carbon carrier and 60 mg of lithium carbonate for the internal standard. The mixture was first mixed on a piece of paper, then ground for about three minutes in an agate mortar. Eighteen milligrams were weighed accurately on a chemical balance and this was the sample arced.

The carbon carrier is used to keep the arc burning smoothly as otherwise the sample may spatter out of the electrode and cause errors. The carbon is prepared by burning carbon electrodes and filing off the burned carbon with a file that is used for that purpose only.

Samples which have over 80% silica would be prepared in the same way except that no lithium carbonate needs to be added and the carbon-sample proportions might be changed.

ARCING

A disk type of electrode (Fig. 7C) is used to arc rock samples. The advantage of this disc electrode is that it allows the sample to be completely burned since the arc is not broken until after the carbon disc and all of the sample on it have been completely consumed in the arc. Because the sample is burned completely, even the refractory elements are completely volatilized and there are no errors due to a fractional distillation of the sample. In quantitative arcing, care should be taken that none of the sample spatters out of the electrode without being completely volatilized. Spattering causes major errors and of course duplicate samples will not check.

The disks are cut and drilled on alathe and the central post is sharpened with a pencil sharpener. A bushing with an 1/8 inch hole is placed in the opening of the pencil sharpener to adapt it to the 1/8 inch carbon rods. The upper electrode is the same as that used in the preparation of the gamma curve (Fig. 7A). It has been found that if the tip of the upper electrode is slightly sharpened in the pencil sharpener, none of the sample spatters out of the disc when the arc is struck.

The electrodes are placed 3/8 of an inch apart. They are at the proper position for arcing when the flat part of the disc is placed on the upper sight of the ground glass plate, and the upper electrode is placed at the ink mark just above the lower sight.

Each of the duplicate samples is divided into approximately three equal parts. Each part is arced on a separate disk, but the three arcings go on the same exposure. As all rock samples are run in duplicate, six arcings and two exposures on the film are made for each channel sample. The upper electrode is changed with each different rock sample, that is, after every six arcings.

The arcing conditions for the rock samples using Li as the internal standard are:

Sector number - - - - - - - - 2
Slit opening - - - - - - - - 6
Sector opening- - - - - - - - 10
Amps. - - - - - - - - - - - - 10 amps. with electrodes short circuited
Time - - - - - - - - - - - - arced until disk completely burned. (about 40 sec.)
Screen- - - - - - - - - - - - Out
Lens - - - - - - - - - - - - In

The "electrode polarity" switch is thrown so that the lower electrode is positive for all this work.

The amperage is set with the electrodes short circuited before the arc is struck and is not changed while the arc is burning.

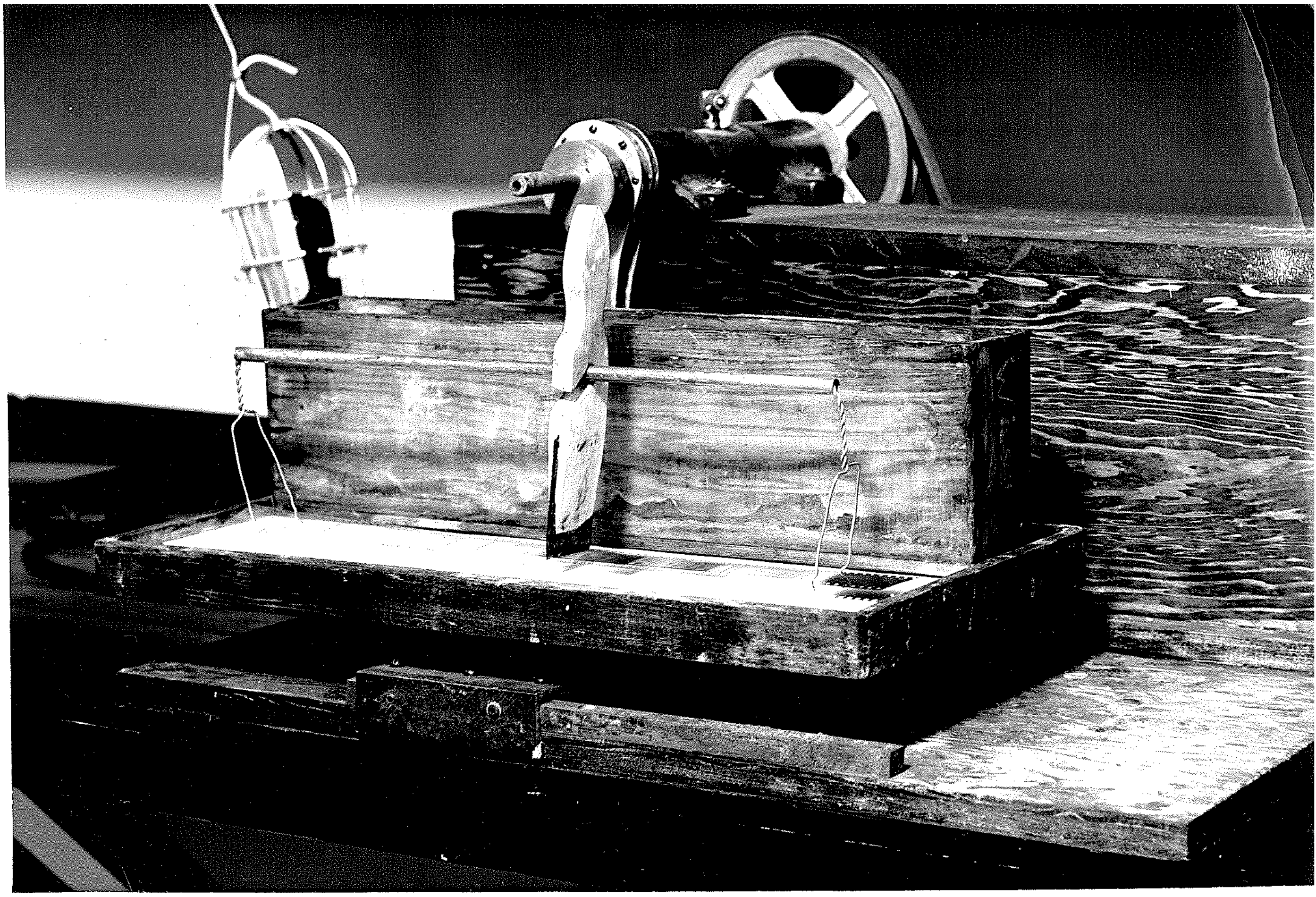
Each foot of film is marked by the manufacturer with a footage number and we use this number as a record of the film.

DEVELOPING THE FILM

The films are developed in paraffin covered wooden tanks 17" long, 2" wide, and 4-1/4" deep. The films are placed on a wire holder and the developer solution is agitated with a paddle (Fig. 8).

The film is developed in half strength D 11 developer, the development time being determined from the time-temperature curve. About 650 cc. of developer are used, and for quantitative work, new developer is used with every three strips of film. This "used " developer may be saved to develop films for qualitative analysis.

Fig. 8. - Developing box, film holder, and paddle.



After development the film is treated for about one minute in short stop (SB 1), fixed for 15 minutes in hypo (F 1), and washed for about 30 minutes.

READING FILM

Each element usually has several lines present within the range of the film, but the intensity of these lines may vary within wide limits. For best quantitative results, a line should be chosen which gives a transmission reading between 10% and 50%, if possible. When a line is too heavy it may undergo self absorption and the transmission values will not be accurate. The gamma curve is not as accurate for lines with a transmission value over 50% so these are poor lines to use.

In the case of the samples analysed in the second part of this thesis, B and Zr always had transmission values of over 50%, but since these were the most sensitive lines they had to be used. The transmission values were occasionally under 10% for some of the elements, but these values were used so that the intensity ratios obtained for elements varying widely in amount would be comparable. When the transmission value became too low the elements were reported as having an intensity ratio of greater than 100.

The meter of the densitometer should read zero when no light is being admitted. This adjustment is made by the left hand knob on the densitometer. The button placing the slit on the film is then pressed with the slit set over a clear, unexposed place on the film. The pointer on the densitometer is then adjusted to read 100% transmission by the use of the right hand knob on the densitometer. This adjustment to 100% should be made every time the spectrum is shifted about 100 A°.

In operating the densitometer, care should be taken to always turn on the left hand switch first and to turn off the right hand switch first. Otherwise the meter bearings may be damaged.

When reading a line to determine the transmission value of an element, both the transmission value of the line and the neighboring background must be read, since the transmission value of the line is actually the transmission value of the line plus the background. The intensities of both (line plus background) and background are determined from the gamma curve. It is necessary to subtract the intensity of the background from the line plus background to obtain the true intensity of the line.

ie. $I_{\text{line background}} - I_{\text{background}} = I_{\text{line}}$

The intensity ratio is obtained by dividing the intensity of the element by the intensity of lithium.

Table III and Fig. 9 give an example of how the intensity ratio of an element is obtained. In Talbe III A transmission readings of lithium and iron are given. The intensities (Table III B) are obtained by plotting the transmission values on the gamma curve (Fig. 9) and reading off the intensity values. The intensity ratio is then obtained from these intensities.

The whole film must be read in the same day since the film may fade slightly and cause some change in the slope of the gamma curves.

TABLE III

EXAMPLE OF THE DETERMINATION OF THE INTENSITY RATIO

Film # C 49830.

*Table III A.

Transmission Values.

Element		Sample No. G 55 A	G 55 B
Li (2475 A°)	Background	97	93
	Line + Back.	60.8	64
Fe (2813.3 A°	Background	95	95
	Line + Back.	11.8	15.3

*Table III B.

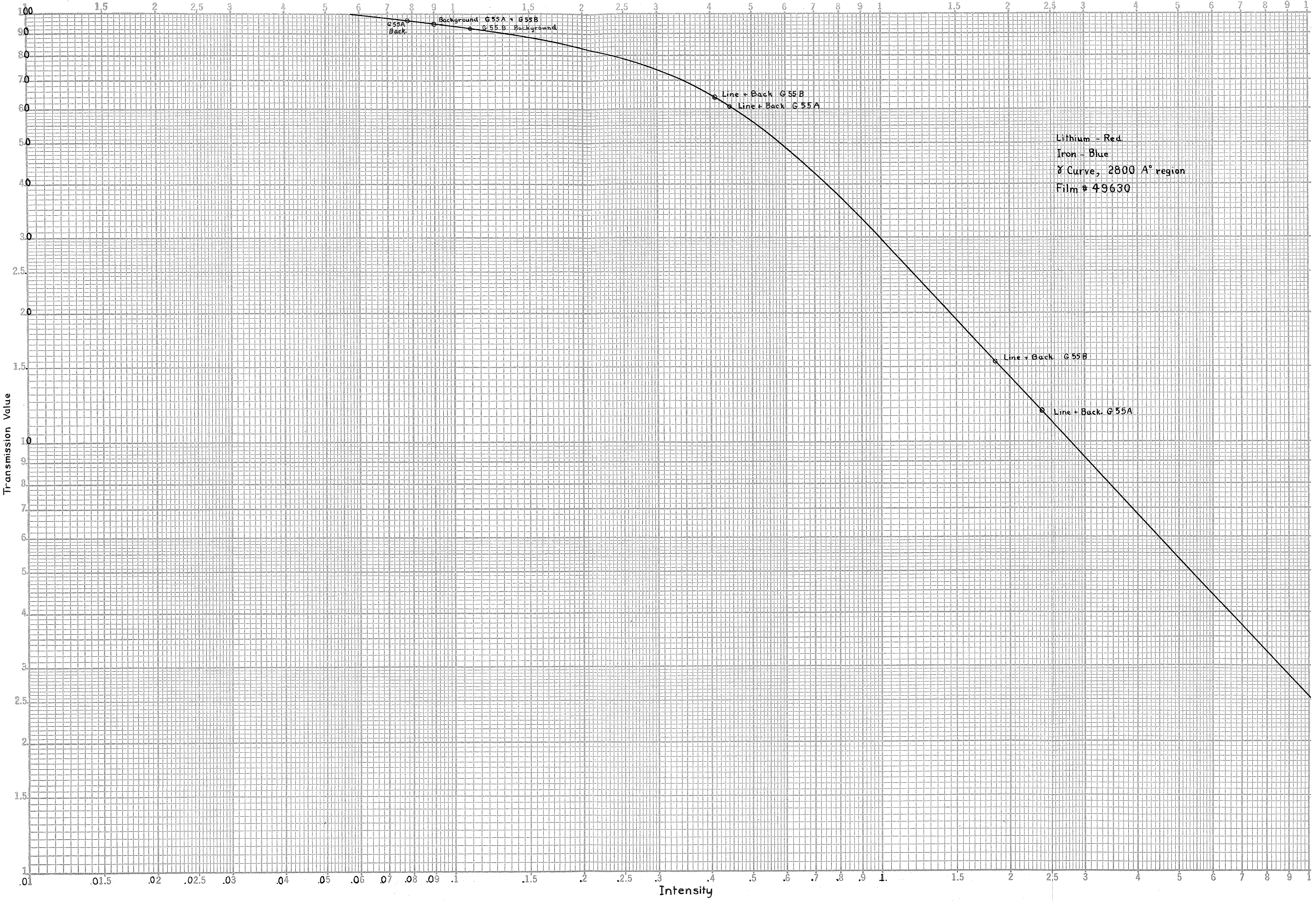
Intensity

Element		Sample No. G 55 A	G 55 B
Li (2475 A°)	Background	.08	.11
	Line + back	.445	.41
Fe (2813.3 A°)	Background	.09	.09
	Line + back	2.38	1.85

		G 55 A	G 55 B
$I_{Li} / I_{line+back} - I_{back}$	=	.365	.30
$I_{Fe} / I_{line+back}\ I_{back}$	=	2.29	1.76

		G 55 A	G 55 B	Ave. G 55
$\frac{I_{Fe}}{I_{Le}}$	=	6.3	5.9	6.1

Fig. 9. - Method of determining the Intensity Ratio of an Element.



RELATION OF INTENSITY RATIO TO ACTUAL PERCENT

All analyses in this thesis are expressed as Intensity Ratios. The intensity ratio is directly related to the percentage of the element present in the sample. For small quantities of an element it is a straight line relation as in Fig. 10.

However, when a line becomes too strong, it undergoes self-absorption with the result that its intensity is not as high as it should be for the percentage of the element present, hence for higher transmission values the curve tends to flatten out as in Fig. 11. This does not take place until the transmission value is below 10%.

The procedure to construct the curve relating intensity ratios to actual percentage is to prepare standard samples by mixing known amounts of an element with a sample and determing the intensity ratios. These intensity ratios may then be plotted against the known percentages and the curve may be established. Unknown samples may then be referred to this curve and the percentages determined.

This is a time consuming procedure so it was felt that for the purpose of this thesis, the intensity ratios would give the same results as the actual percentages in showing whether the method is applicable to geological problems.

ACCURACY OF ANALYSES.

To check the accuracy of the method a single sample was split into four parts and it was found that the results checked to within 10% of the average value. The same procedure was repeated with two additional films to check the difference from film to film and it was found that the results remained within the error stated above.

Fig. 10

RELATION OF INTENSITY RATIO TO ACTUAL PERCENT FOR LINES WITH 10% - 50% TRANSMISSION VALUE

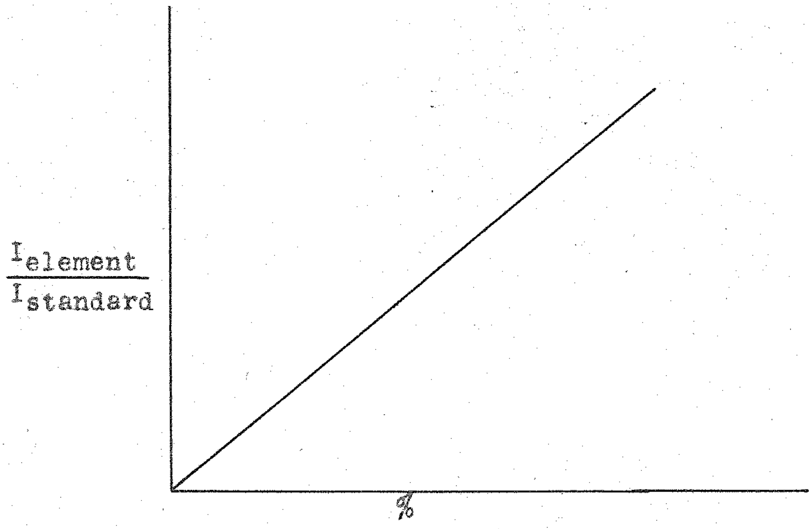
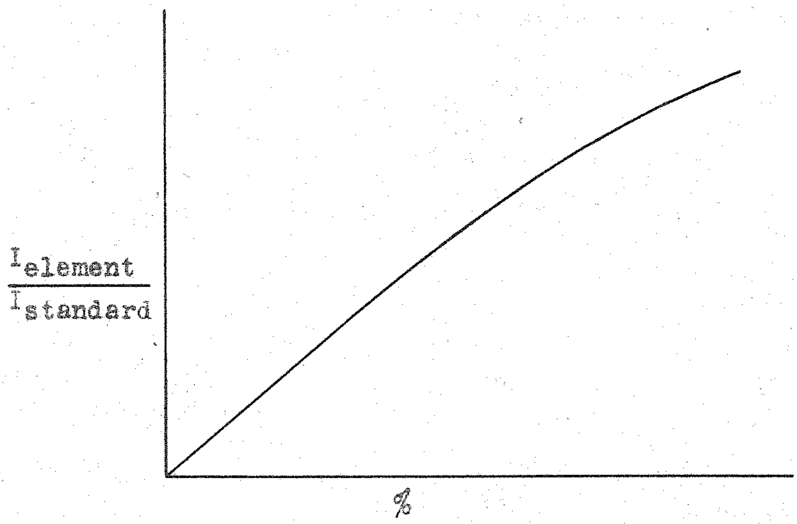


Fig. 11

RELATION OF INTENSITY RATIO TO ACTUAL PERCENT FOR HEAVY LINES WHICH UNDERGO SELF ABSORPTION



It may also be noted that this error is the same whether the element exists as .001%, .01% or 1%.

The duplicate samples checked to within the above limits even in the few cases where the transmission value was under 10. A straight line relation between intensity ratio and percent probably does not exist for these low transmission values as the curve would tend to flatten off ~~off~~ due to self absorption of the lines. Higher intensity ratios however do indicate an increase in percentage of the element, in fact a unit increase in these higher values would be greater than a unit increase in the lower values, due to the flattening of the curve.

As with the iron calibration method it has been found that accuracy increases with the experience of the operator.

The accuracy of this method compares favorably with the accuracy of chemical methods of analysis when the elements are present in amounts ranging from 1% to 5% of the sample. The spectroscope is more accurate for values below 1% and will detect smaller amounts than chemical methods. The chemical methods are most accurate for amounts over 5% as then a 10% error becomes appreciable. For example a 5% result might be between 4.5% and 5.5% when determined by the spectoscopic method.

Umpire assays for silver were available for some of the samples and the intensity ratios for silver checked well with these assays.

SENSITIVITY

Nothing has been done during the course of this work on the sensitivity of the method since no actual percentages were determined.

However a rough approximation of the sensitivity may be given by what is known of the percentage of silver present as shown by the assay values and the intensity ratios of the silver obtained from the spectrograph.

This seems to show that the lower limit of silver detectable is about 1 part in 2,4000,000 parts of sample. The valuesobtained by the Applied Research Laboratories for qualitative analysis show a sensitivity of roughly two to four times greater, since there is no dilution with lithium caronate and carbon carrier. From this comparison the order of the sensitivity of the elements in this method may be determined from the sensitivity of the elements as determined by the Applied Research Laboratories for the qualitative analysis method. It is emphasized that these are only approximations.

Table IV gives the approximate limits of sensitivity for the Lithium Dilution method.

Seventy of the ninety-two elements may be detected by this spectrograph. The undetectable elements include the halogens, the gases, carbon, sulphur and selenium.

TABLE IV

Table showing sensitivity of the elements for Lithium Dilution Method.

.0001 - .001%	.001%	.001 - .01%	.01%	.01 -1%	.1 - 1%	1 - 10%
Ag, Ba, Cu, Ga, Mg, Sr.	Mo, Mn, Cr, Ni,	Al, Au, B, Be, Bi, Ca, Cd, Co, Fe, Ge, In, Pb, Pt, Ph, Sn, Ti, V.	Li, Na, Sb, W, Zn, Cb, Os, Pd, Si, Rare earths.	As, K, Ta, Zr,	Hg P	U

By changing the instrument to the other setting Na and K could be determined to about .0001%.

IMPURITIES AND THEIR SOURCES

Acheck was made on the purity of the reagents by arcing the lithium carbonate and carbon carrier and it was found that impurities present in the electrodes, the lithium carbonate, and the carrier, were negligible as far as this problem was concerned.

The pulverizer plates proved to be a major source of impurities. The plates were analyzed and found to be principally a chrome-manganese steel containing about 1% Cr, 1-10% Mn and 1% Si. The electro-magnet, which uses 100 volts and 2 amps., removed most of the steel from the pulverized samples, but tests showed that enough steel remained to affect determinations for small amounts of Cr. Mn, and Si, as well as Fe.

The removal of steel by the electromagnet is shown in the intensity ratios in Table V, for sample G 79.

TABLE V

REMOVAL OF STEEL BY THE ELECTROMAGNET

	Steel not Removed by Electro-magnet	Steel Removed by Electro-magnet
Element	Intensity Ratio	Intensity Ratio
Fe	6.9	3.4
Mn	24.	3.9
Cr	22.	4.7

The analysis of a hard quartz sample (G 118) which was ground by the pulverizer and had the steel removed by the electromagnet is shown in Table VI, column A. The same sample ground in an agate mortar is shown in column B. Columns C and D are analyses of a soft, altered wallrock sample showing that much less steel is left in a soft sample.

TABLE VI

IMPURITIES INTRODUCED BY PULVERIZER

	A	B	C	D
	G 118 ground in pulverizer	G 118 ground in agate mortar	G 22 ground in pulverizer	G 22 ground in agate morter
Element	Intensity Ratio			
Fe	3.0	1.45	3.8	1.5
Mn	6.4	1.7	3.0	2.3
Cr	8.1	2.7	2.4	1.6

In actual percentage these steel impurities after treatment with the electromagnet might amount to; iron .1 - 1%, and Cr, Mn and Si, to the order of .01% of the total sample. In the rock analyses in this thesis this amount of impurity is sufficient to have a material effect on the ratios of iron and chromium, and consequently these elements cannot be used for correlation. The manganese impurities are sufficient to effect the manganese ratios of the veins so that they cannot be used, but it is not sufficient to effect the differences in the ratios in the altered wallrock.

Grinding samples with an agate mortar is impracticable as it is such a slow process for even very small amountsof material.

The steel remaining in the samples may occur as very small fragments ground into the rock fragments, or possibly some of the steel was oxidized by the heat of the pulverizer and so not removed by the magnet.

If analyses for very small amounts of Mn and Cr were desired it might be possible to remove the steel remaining in the samples by an acid leach if the steel is still in the metallic form.

If analyses were made for .5% or more of Mn, Cr, and Si, the impurities left by the pulverizer would be negligible. None of the other elements were affected by impurities from the pulverizer plates.

ELEMENTS PRESENT BUT NOT ANALYZED QUANTITATIVELY

Ba and Sr are present in all samples, but the most sensitive line of each element is too strong to give any transmission value and the next most sensitive line is too weak to appear. These elements could be determined by cutting down the exposure but this would require at least two, and perhaps four more exposures for each sample analyzed in duplicate.

Potassium is also present, but is too weak to be measured. It could be determined by making a much stronger exposure or by changing the whole apparatus to photograph a different part of the spectrum where there is a more sensitive potassium line.

Gallium is present in most samples, but is too weak to give good quantitative values.

When copper is reported as having an intensity ratio of greater than 100, it likewise could be determined by making a reduced exposure. No other copper line is strong enough to appear at the exposure used in this work.

High magnesium values can be determined by using one of the many weaker magnesium lines that appear at this exposure.

SPEED OF THE ANALYSIS.

The quantitative analytical procedure outlined in the preceding pages requires a total of about nine hours for the determination of four samples, i.e. one film. A quantitative determination in duplicate for eighteen elements is obtained for each sample. Any further elements that were present would require but a few more minutes.

The preparation of the samples, including crushing, grinding, splitting, andmixing with the internal standard, has been found to consume the greater portion of the time. The actual analysis, including the arcing, developing, reading the film and calculating takes about four hours per film, that is, an average of one hour per sample when several samples are being run.

It is probable that the procedure could be speeded up a great deal, if the work was being done for commercial purposes on a large scale and with the proper equipment, housing, and division of labor. Standards would have to be set up for the determination of percentages of the elements, but once this was done, the standars would be good for all analyses.

PART II A SPECTROSCOPIC STUDY OF SOME ORES AND WALLROCK FROM GOLDFIELD, NEVADA.

INTRODUCTION

In the second part of this thesis the general geology and the geology of the ore deposits at Goldfield are treated briefly. The location of the samples collected, their occurrence, and petrography are described in some detail. The tables of the rock analyses are followed by descriptions of the occurrence and relationships of the individual elements, and the results of the study and possible future studies with the spectrograph are summarized.

GEOLOGY OF GOLDFIELD, NEVADA.

General Geology.

The following is a short abstract of the general geology of the Goldfield district as described by Ransome.

Ransome, F.L., Geology and Ore Deposits fo Goldfield, Nevada.
U.S.G.S. Prof. Paper 66, 1909.

Goldfield lies near the eastern border of Esmeralda County in southeastern Nevada, on the south rim of one of the typical desert basins of the region. The hills in the vicinity of Goldfield form an irregular group, have no definite, trend and belong to no recognized mountain range.

"The district is essentially a low, domical uplift of Tertiary lavas resting upon a foundation of ancient granitic and metamorphic rocks. The erosion of this flat dome has exposed the pre-Tertiary rocks at a number of places in the central part of the district and these outcrops are surrounded by wide concentric zones of successively younger formations. Some of the later lavas were erupted after the dome had been elevated or truncated."

The basement consists of granite intruded into Cambrian shales. Several rhyolite flows lie on this basement; then come flows of andesite or latite into which is intruded a thick sheet of dacite. Lake beds and flows of late basalt lie upon the andesite. The lava flows and intercalated lacustrine beds probably range from Eocene to latest Pliocene.

Ore Deposits. The Goldfield deposits have been classified by Lindgren as Gold-Alunite Epithermal Deposits.

The greatest part of the ore in the district has been found in the dacite but it is also known to occur in the rhyolite and latite, and in the shale near the latite contact.

The ore deposits occur in "ledges". Structurally the ledges are "irregular masses of altered and mineralized rock traversed by small, irregularly intersecting fractures, such fracturing passing in many places into thorough brecciation." The ledges are usually intensely silicified and the ore occurs in shoots and pockets within these ledges.

Fig. 12 is a diagrammatic sketch of some of the principal "ledges" or veins of the Goldfield district. The greatest part of the gold and silver production of the district has come from the Consolidated ledge which contained the rich ore shoots of the Mohawk, Florence, Red Top, Jumbo Ex and several others. The

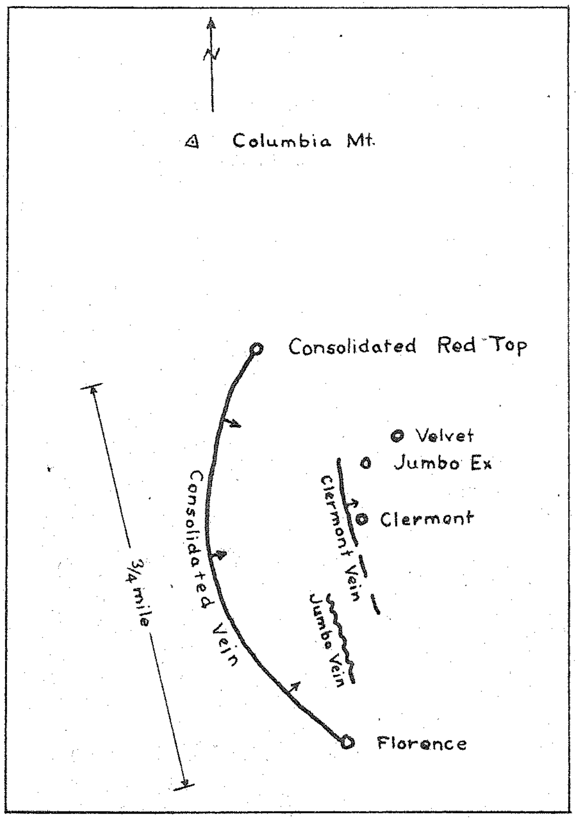


Fig. 12. Diagrammatic sketch of the veins at Goldfield

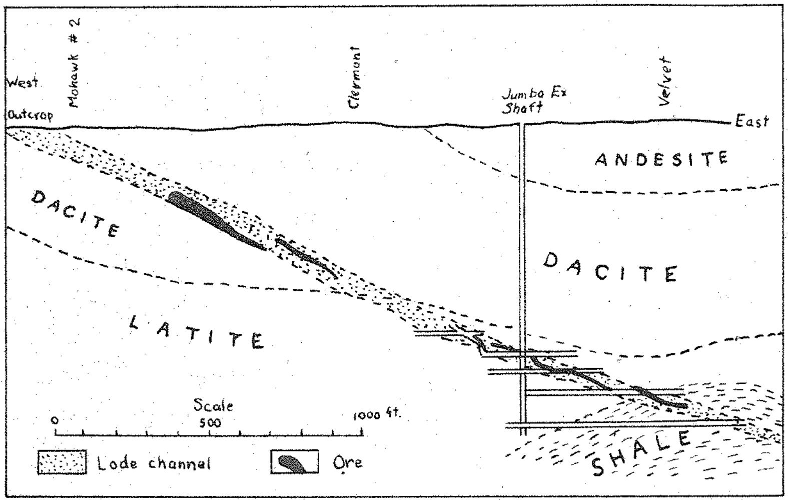


Fig. 13. - Vertical section of Consolidated ledge.

(After J. K. Turner)

ledge has a crescent shaped outcrop and dips towards the east. It is irregular and varies from a few feet to possibly 300 feet in width. A vertical section of the Consolidated ledge is shown in Fig. 13.

The Jumbo vein trends roughly north, but has many sharp angled bends. The vein ranges from about four to ten feet wide and dips almost vertical. It has been stoped laterally for about 400 feet and to a depth of from 200 to 300 feet. The vein may connect at depth with the Consolidated vein and if continued along strike would join the main Consolidated "vein" near the Florence shaft.

The Clermont vein, like the Consolidated vein, dips to the east, but due to the irregularity of the vein its exact dip is not known. The Clermont vein cuts across the Jumbo Ex shaft and may possibly join the main Consolidated vein near the 830-foot level of the Velvet shaft.

Mineralogy. The mineralogy of the Goldfield district has been described by Hastings and Berkey.

Hastings, J. B. and Berkey, C. P., The geology and Petrography of the Goldfield Mining district, Nevada. Trans. A.I.M.E., vol 37, 1907, pp. 140 - 159.

Ransome, U. S. G. S Prof Paper 66, and Tolman and Ambrose.

Tolman, C.F. and Ambrose, J. W., The rich ores of Goldfield, Nevada. Econ Geol. vol 29, pp 255 - 279, 1934.

The gangue minerals in the veins consist of quartz, chalcedony, alunite, kaolinite, zircon, epidote, and sometimes opal.

Ransome has recognized three types of wallrock alteration in the district. The first and most intense type is when the rocks have been changed to porous, fine grained aggregates consisting essentially of quartz which composes the characterisite ledges of the district. The second is one in which the rocks have been changed to a comparatively soft, light colored mass of quartz, kaolinite, alunite, and pyrite. The boundary between these first two types of alteration may be very sharp, but all gradations may be found between the two types when the area is considered as a whole. The third type of alteration is not so closely associated with the ores and is propylitic in character since it consists of the development of calcite, quartz, chlorite, epidote, and pyrite from the original rock. This third type of alteration is quite different from the alunitic type and the two types are rarely found together. Alunite is not found in the prophylitic type and calcite is not found in the alunitic type.

As summarized from Tolman and Ambrose, the ore minerals include:

<u>Pyrite</u>. Commonly associated with alunite and characteristic of most of the ores.

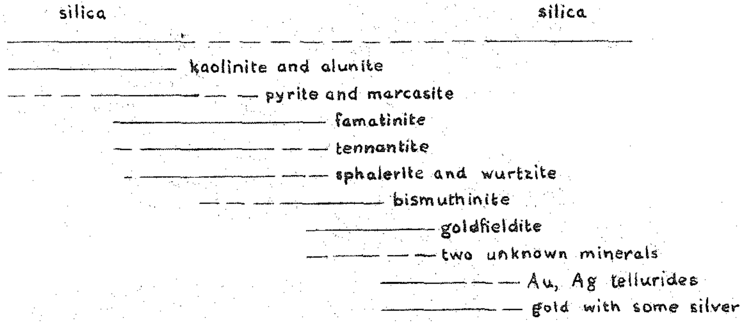
<u>Marcasite</u>. Minor in amount, occurring similar to pyrite.

<u>Sphalerite</u>. Reported in small amounts by Ransome, but Tolman and Ambrose found it abundantly in the Mohawk Mine.

<u>Wurtzite</u>. Primary mineral associated with sphalerite.

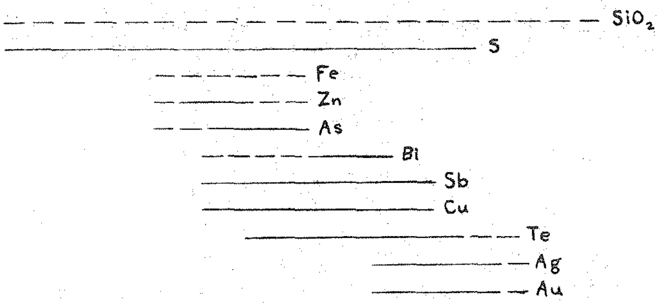
<u>Tennantite</u>. Present in considerable amounts in some mines.

TABLE VII



Paragenesis of minerals at Goldfield
(After Tolman and Ambrose)

TABLE VIII



Paragenesis of elements at Goldfield
(After Tolman and Ambrose)

Famatinite. The predominating metallic mineral in the ores.

Bismuthinite. Associated with famatinite and goldfieldite.

Goldfieldite. Occurs in relatively small amounts intimately associated with other minerals.

Gold-silver tellurides. Petzite, hessite, and sylvanite. Occur in minute amounts intimately intergrown with one another and with goldfieldite and/or bismuthinite.

Gold. Two types of gold present; a bright yellow gold and one with a distinct reddish color.

A tin sulpho-salt has also been found in the Jumbo Ex mine in the course of the present investigation.

Tolman and Ambrose have given two tables for the sequence of mineralization. These are reproduced in Table VII and Table VIII.

LOCATION AND DESCRIPTION OF THE SAMPLES FOR STUDY

Part of the samples from the Goldfield district were collected in the spring of 1940, while others, notably those from underground in the Jumbo Ex mine were collected during the summer. The samples collected in the spring wereprincipally from the 225-foot level of the Clermont mine andfrom the Jumbo vein near the surface.

Jumbo Ex vein.

A suite of samples from the Jumbo Ex mine, comprising samples G 101, G 103, G 105, G 108, G 109, G 110, G 112, G 113, and G 118, were taken along the vein to determine the behavior of the elements in the vein itself. The samples are channel samples ten to twenty feet apart collected across the width of the vein on the 830-foot level. The sample map with assays as drawn by Dr. H. J. Fraser who collected the samples is shown in Fig. 14.

A thin section of a typical sample (G 11) shows very fine grained quartz with a clear coarser quartz deposited along small fractures which occasionally widen to form small vugs. One or two percent of sulphide is present in addition to the quartz. The silicification has completely destroyed all traces of any original rock texture. Apparently this is a good example of Ransome's first type of alteration where the rock has been completely silicified.

Clermont vein.

The suite of samples from the 225-foot level of the Clermont vein, consisting of samples G 47, and G 50 - G 79 inclusive was collected to represent a suite of samples from the vein around a good ore shoot, and a series of wallrock samples from both the hanging and footwall sides of the vein. A sample of the silicified outcrop of the Clermont vein (G 96) was taken directly over the ore shoot about 40 - 50 feet above the top of the ore. Sample G 94 is a vein sample from the 150-foot level of the vein.

This ore shoot of the Clermont vein is a nearly vertical pipe about 20' in diameter extending from a depth of about 450 feet below the surface to within 50 feet of the surface. At the 225-foot level three or four branch pipes have separated from the main pipe. The ore shoot, mined during 1937, produced about $700,000 in gold.

A sample map of the 225-foot level is shown in Fig. 15. The boundaries between the vein and highly altered wallrock, and between the highly altered wallrock and fresher wallrock are sharp and may be easily recognized underground.

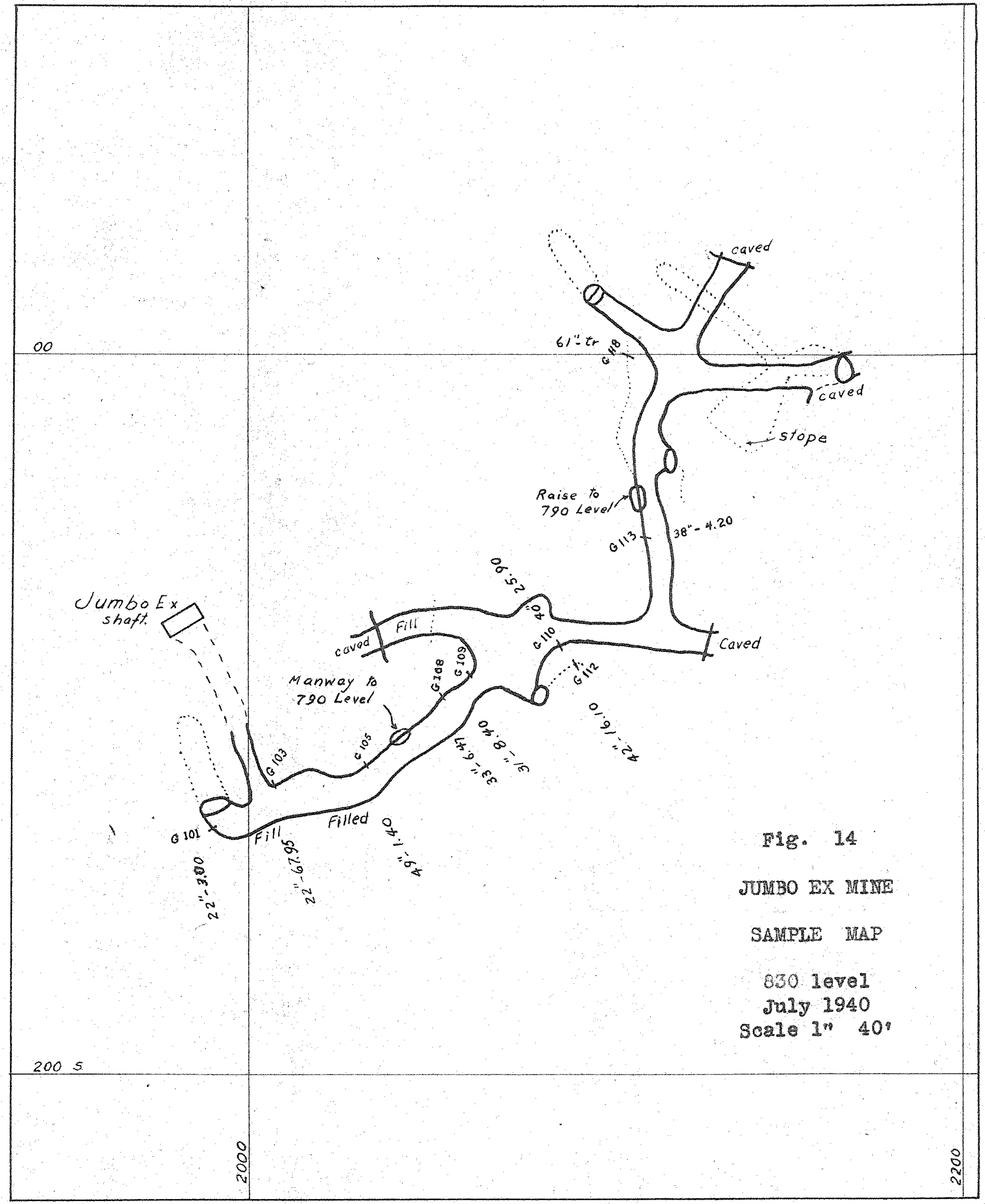


Fig. 14

JUMBO EX MINE

SAMPLE MAP

830 level
July 1940
Scale 1" 40'

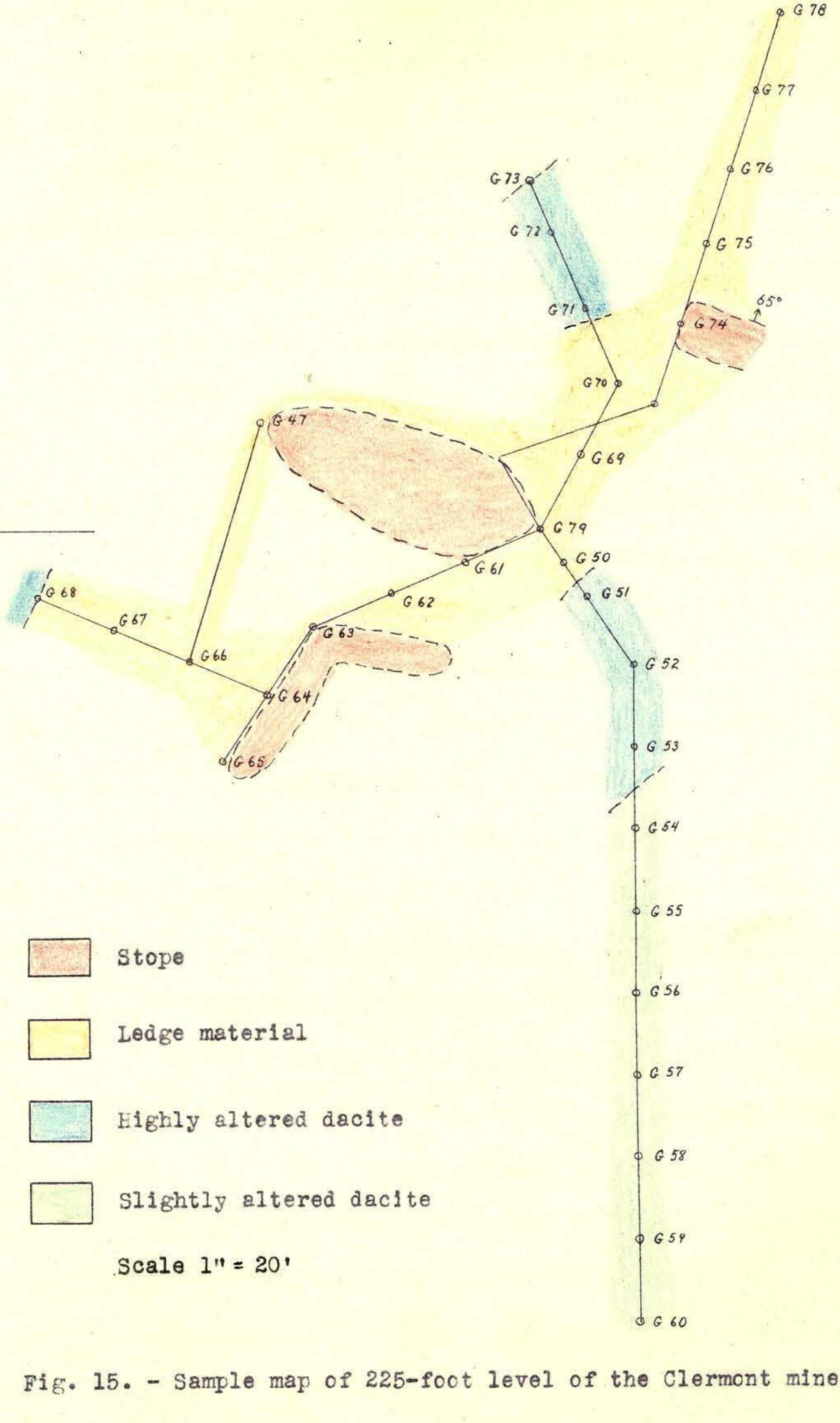


Fig. 15. - Sample map of 225-foot level of the Clermont mine.

Three of these samples, i.e., G 61, G 52, and G 56, were selected as typical samples of vein material, highly altered wallrock and fresher wallrock and were studied under the microscope.

The vein sample (G 61) consists almost entirely of very fine grained silica. A few large grains of unstrained quartz, probably original phenocrysts in the dacite, are in various stages of replacement by the later quartz. Pyrite occurs in small amounts, usually as very fine particles. The vein material on the 225-foot level of the Clermont vein is therefore very similar to the vein material on the 830-foot level of the Jumbo Ex mine. It represents Ransome's first, and most intense type of alteration although some of the original quartz phenocrysts are not completely altered.

In the sample of the highly altered dacite (G 52), only a few quartz phenocrysts remain to show the original texture of the rock. The groundmass is a partially iron stained, fine grained mass of alunite, quartz, kaolinite, and pyrite. The quartz phenocrysts show attack by the altering solutions and some pyrite has been deposited along the fractures in the quartz. Zircon occurs as an accessory mineral throughout the section. This soft highly altered wallrock near the vein represents a very advanced stage of Ransome's second or alunitic type. The soft highly altered wallrock grades within a foot or two into a harder, fresher appearing dacite.

In the fairly fresh sample of wallrock (G 56), the original texture of the dacite is well preserved and even some of the labradorite appears quite fresh although most of the crystals have been partially altered to alunite. The ferromagnesians have been completely altered and only patches of pyrite and alunite remain as pseudomorphs. The quartz phenocrysts are quite fresh and quartz also occurs in small veinlets. The groundmass is altered to quartz, alunite, kaolinite, and pyrite. Pyrite is very abundant.

The 225' level is below the zone of oxidation which according to Ransome extends about 150' below the surface, so that surface oxidation has not affected these samples.

Jumbo vein.

The suite of samples from the Jumbo vein, comprising samples G 10, G 15, G 18, G 19, G 22 and G 26, were taken from the hanging wall (west) side of the vein to determine the changes in the dacite wall as a vein was approached on or near the surface. The wallrock samples of the dacite, including G 15, G 18, G 19, G 21, and G 22 were taken from an adit running perpendicular to the vein about 20' below the surface. The samples were taken 6', 16', 25', 45', and 60' respectively away from the vein. A sample of relatively fresh dacite (G 27) was collected several hundred feet back in the footwall of the Consolidated ledge to determine the difference between fresh and altered dacite near the surface. A sample (G 10) was taken from the hanging wall contact of the ledge and the dacite country rock and contains both ledge material and wallrock. The Jumbo vein has been stoped out, but a sample (G 26) of the silicified ledge where it is too low grade to be classed as ore was obtained within a few feet of the start of the wallrock suite.

The ledge material is a light brown, brittle, siliceous appearing rock with many tiny vugs. In thin section it is composed largely of extremely fine grained quartz and a few quartz phenocrysts embayed by the late silicification. A few straight edged patches of fine grained silica and pyrite suggest original phenocrysts, probably of some ferromagnesian mineral, now completely altered. The small vugs are lined with quartz crystals that are somewhat coarser grained than the general groundmass. This ledge is similar in composition to the ledges of the 225-foot level of the Clermont mine and the 530-foot level of the Jumbo Ex mine.

A thin section of sample G 10 shows the contact of the vein and dacite wallrock to be fairly sharp. The gradation from vein material to wallrock occurs in about one millimeter. Both vein and wallrock are very fine grained, but in the wallrock pyrite and alunite are more abundant and some of the pyrite occurs in larger patches as pseudomorphs after ferromagnesian minerals. An increase in the number of quartz phenocrysts in the wallrock is also apparent. Pyrite and alunite occur in small amounts and in small fragments in the vein material. Small veinlets and cavities are filled with opal. No alunite was found in the ledge material of G 26.

Megascopically, the altered wallrock in this suite shows little apparent change over the 60' sampled. It has a chalky white groundmass with whiter feldspar phenocrysts and dull greenish grey phenocrysts that were apparently ferromagnesians. In thin section the groundmass consists of quartz, alunite, kaolinite and pyrite. Quartz phenocrysts remain, but the feldspars are completely altered to quartz, alunite, and kaolinite. The ferromagnesians are completely altered to epidote and pyrite with quartz, kaolinite, and alunite scattered through them. This altered wallrock then is in a fairly advanced stage of Ransome's second, or alunitic, type of alteration. It is much more highly altered than the fresher wallrock on the 225-foot level of the Clermont vein and is much closer in degree of alteration to the most highly altered wallrock of that vein.

The relatively fresh dacite taken several hundred feet back in the footwall of the Consolidated ledge (G 27) has a grey groundmass with small quartz phenocrysts and light grey phenocrysts of fresh appearing feldspars showing the feldspar cleavage faces.

In thin section it is seen that this rock is still within the zone of alunitization, but it is only slightly altered when compared with the other wallrock specimens. Labradorite is clear and fresh, but cut by small veinlets of alunite. Many of the labradorite phenocrysts show the characterisitic border of glass inclusions mentioned by Ransome. Some biotite remains, but it is highly altered to pyrite. The quartz phenocrysts are unaltered. The groundmass is partly altered to the typical quartz, alunite, kaolinite, pyrite mass, but is much fresher than that observed in other specimens of the altered wallrock.

An ore sample (G 43) was taken from a vein in the rhyolite on the east side of Columbia mountain. This sample was supposedly of ore grade and was collected to show the character of ore near the surface.

TABLES OF THE ANALYSES OF THE GOLDFIELD SAMPLES

In the following tables of the quantitative spectro-chemical analyses of the samples from Goldfield, Nevada, the results are tabulated in the form of intensity ratios. As already explained these intensity ratios have a direct correlation with percentage. The intensity ratios for each element were all determined on the same spectral line, so that all intensity ratios for a single element are comparable. The wavelength of the lines used is given in Table IX.

Table XIV gives the gold and silver assay values of some of the samples from the 225' level of the Clermont mine and three check assays for samples from the Jumbo Ex mine.

TABLE IX

WALL ROCK ANALYSES - CLERMONT VEIN, 225' LEVEL

Wave-length	Element	Intensity Ratio									
		G 51	G 52	G 53	G 54	G 55	G 56	G 57	G 58	G 59	G 60
2497.7	B	.40	.28	.20	.21	.47	.14	.48	.48	.48	.46
2652.5	Al	4.6	5.3	5.2	4.4	3.3	2.5	2.7	3.4	4.2	4.0
2802.7	Mg	60.	58.	46.	100.	100.	100.	100.	100.	100.	100.
2813.3	Fe	8.5	7.2	3.4	9.6	6.1	5.6	5.0	5.7	6.7	6.8
2833.	Pb	-	-	-	-	-	-	-	-	-	-
3067.7	Bi	-	-	-	-	-	-	-	-	-	-
3175.0	Sn	-	-	-	-	-	-	-	-	-	-
3184.	V	1.6	1.4	2.3	1.2	1.3	.98	1.05	1.4	1.4	1.4
3274.	Cu	4.1	3.4	3.3	2.8	3.1	2.4	3.0	7.3	4.5	3.8
3280.7	Ag	-	-	tr	-	-	.22	-	-	-	-
3302.3	Na	2.8	2.4	5.1	9.8	14.	11.	14.	14.	18.	22.
	Zr	tr	tr	tr	tr	tr	tr	tr	tr	.63	.60
3414.8	Ni	.90	.77	1.03	1.02	.80	.76	.60	.58	.89	.79
3453.5	Co	3.9	2.6	2.0	1.9	1.1	1.2	1.1	1.1	1.2	1.2
4030.8	Mn	8.1	10.	6.8	>100.	>100.	>100.	>100.	>100.	>100.	>100.
4254.3	Cr.	1.9	1.7	2.4	2.0	1.6	2.3	1.5	1.6	2.3	2.6
4295.7	Ti	1.2	1.2	1.7	1.2	1.2		1.1	1.1	1.4	1.4
4283.0	Ca	5.6	6.4	6.4	9.9	6.2	7.8	8.0	14.	10.	11.
2516.1	Si	maj	maj	major	major	major	major	major	major	major	major
2943.6	Ga	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr.
3446.4	K	wk	wk	wk	wk	wk	wk	wk	wk	wk	wk
4534.0	Ba	st	s	s	s	s	s	s	s	s	s
4077.7	Sr	s	s	s	s	s	s	s	s	s	s

TABLE X

ANALYSES OF VEIN SAMPLES - CLERMONT VEIN, 255' LEVEL

Element **Intensity Ratios**

	G 47	G 50	G 61	G 62	G 63	G 64	G 65	G 66	G 67
Ag	1.8	.24	2.0	-	-	-	-	-	-
Al	3.1	3.8	.52	1.8	1.4	1.7	1.8	1.8	1.2
B	.42	.26	.33	.46	.36	.38	.38	.22	.32
Bi	tr	tr	tr	-	-	-	-	-	-
Sn	-	-	-	-	-	-	tr	tr	tr
Ca	6.8	5.6	4.8	5.6	5.2	7.6	4.4	2.8	2.8
Cr	6.4	1.5	2.4	5.0	4.0	5.4	4.3	5.0	3.6
Co	1.1	1.2	1.2	.86	.96	1.0	.84	.88	.87
Cu	9.8	26.	13.	4.7	4.6	6.7	4.4	7.4	5.4
Fe	6.0	7.2	2.3	2.8	2.0	2.1	1.8	2.8	2.4
Mg	2.6			4.2	4.2	4.5	3.2	1.6	4.8
Mn	8.3	5.1	4.3	5.2	4.4	4.8	3.5	4.2	5.4
Na	3.4	2.2	1.5	2.3	2.4	3.0	1.7	5.6	3.0
Ni	1.8	.88	1.4	.90	.72	.67	.42	.58	.62
Pb	.68			.22	.20	.55	.23	.51	.25
V	1.1	1.1	.42	.57	.44	1.4	.62	1.2	.44
Zr	.46			.18	.20	.12	.25	-	.28
Si	major	major	major	major	major	major	major	major	major
Ga	tr	tr	tr	tr	tr	tr	tr	tr	tr
K	wk	wk	wk	wk	wk	wk	wk	wk	wk
Ba	S	S	S	S	S	S	S	S	S
Sr	S	S	S	S	S	S	S	S	S

TABLE X (cont)

ANALYSES OF VEIN SAMPLES - CLERMONT VEIN, 225' LEVEL (Cont)

Element	Intensity Ratios								
	G 68	G 69	G 70	G 74	G 75	G 76	G 77	G 78	G 79
Ag	Tr	.61	.72	1.6	.62	.18	-	.24	.57
Al	1.9	2.2	1.7	3.5	3.6	3.8	2.8	4.8	2.0
B	.16	.24	.30	.22	.24	.21	.30	.24	.39
Bi	-	tr	tr	tr	tr	tr	tr	tr	tr
Sn	tr	-	-	tr	-	-	-	-	-
Ca	2.8	3.9	4.0	4.0	4.8	4.3	4.0	4.2	3.3
Cr	2.6	3.9	7.8	2.8	5.5	2.4	4.0	2.7	22.
Co	.93	.92	.92	1.2	1.0	.70	.86	1.0	.84
Cu	19.5	5.6	15.0	30.	16.	3.2	6.4	15.	22.
Fe	1.9	3.9	4.4	6.8	7.4	8.4	5.8	6.2	6.9
Mg	2.4	3.1	2.7				3.6		6.2
Mn	2.1	3.2	6.0	3.3	4.1	3.2	3.8	4.1	24.
Na	11.	1.5	1.8	1.4	1.6	2.4	3.2	3.0	2.5
Ni	.93	.42	.69	2.3	2.6	2.8	.52	2.0	1.4
Pb	.34	-	.56				tr		tr
V	.80	.90	.88	1.2	1.2	1.2	1.0	1.5	.82
Zr	-	.42	.38				.66		.64
Si	major	major	major	major	major	major	major	major	major
Ga	tr	tr	tr	tr	tr	tr	tr	tr	tr
K	wk	wk	wk	wk	wk	wk	wk	wk	wk
Ba	S	S	S	S	S	S	S	S	S
Sr	S	S	S	S	S	S	S	S	S

TABLE XI

ANALYSES OF JUMBO VEIN - NEAR SURFACE.

Intensity Ratios

	Ledge	H.W. 0'	6'	16'	25'	45'	60'	Pure dacite
	G 26	G 10	G 15	G 18	G 19	G 21	G 22	G 27
B	.63	.61	.64	.63	.48	.38	.66	.42
Al	.19	1.14	4.3	3.2	4.6	3.1	3.6	4.4
Mg	4.5	2.7	72.	26.	35.	31.	68.	>100.
Fe	.85	5.9	2.7	1.8	4.2	5.1	3.8	6.0
Pb	tr	-	.53	-	-	-	-	-
Bi	tr	-	-	-	-	-	-	-
Sn	-	-	.55	.23	-	-	-	-
V	.58	.70	2.8	1.5	1.9	2.2	1.8	1.2
Cu	3.8	6.3	4.6	3.7	3.0	2.5	3.4	3.6
Ag	.30	-	-	-	-	-	-	-
Na	2.4	2.8	4.7	4.9	4.4	19.	14.	23.
Zr	1.0	.33	1.1	.36	.72	.46	.40	.50
Ni	.68	.60	.34	.26	.33	.42	.42	.58
Co	.91	.88	1.1	1.15	1.1	1.0	.88	.91
Mn	3.8	3.6	7.3	3.1	2.1	2.3	3.0	>100.
Cr	3.5	3.8	2.5	2.5	2.2	2.3	2.4	2.6
Ca	4.6	4.0	4.0	3.7	3.2	3.2	3.8	10.8
Ti	2.6	1.5	2.4	2.0	1.8	1.5	1.9	1.3
Si	major	major	major	major	major	major	major	major
Ga	tr	tr	tr	tr	tr	tr	tr	tr
K	wk	wk	wk	wk	wk	wk	wk	wk
Ba	s	s	s	s	s	s	s	s
Sr	s	s	s	s	s	s	s	s

TABLE XII

ANALYSES OF SAMPLES FROM JUMBO EX MINE, 830' LEVEL

Elements	Intensity Ratios.								
	G 101	G 103	G 105	G 108	G 109	G 110	G 112	G 113	G 118
B	.39	.35	.44	.28	.61	.24	.66	.50	.44
Al	3.0	2.7	2.0	4.1	2.2	3.1	2.9	4.3	3.6
Mg	3.4	3.1	2.2	8.0	2.8	2.0	2.6	2.4	1.6
Fe	4.8	2.8	3.6	6.4	4.2	6.8	4.1	5.4	3.0
Pb	1.5	1.9	1.5	.84	1.7	1.2	1.4	1.25	.78
Bi	2.3	12.5	1.2	1.75	5.3	10.0	8.0	2.8	.76
Sn	.65	2.2	.48	.38	1.4	2.4	2.0	.75	.32
V	1.2	1.6	.90	1.0	.84	1.2	1.1	1.8	1.35
Cu	>100.	>100.	>100.	>100.	>100.	>100.	>100.	50.	10.
Ag	1.8	16.5	.70	1.0	3.3	8.8	7.0	2.4	.40
Na	3.0	4.4	4.3	5.9	7.5	3.8	5.3	2.7	3.4
Ni	.86	.78	.70	.55	.68	.92	.56	.72	.68
Co	.97	1.0	.80	.80	1.08	.94	1.05	1.04	1.02
Mn	2.2	2.3	3.4	5.0	4.2	13.5	5.0	10.0	6.4
Cr	1.4	2.1	3.1	8.3	5.0	20.5	6.4	14.0	8.1
Ca	3.0	4.1	4.2	4.6	4.0	4.4	5.1	7.5	5.0
Zr					.29	tr	tr	wk	tr
Ti					.90				
Si	major	major	major	major	major	major	major	major	major
Ga	tr	tr	tr	tr	tr	tr	tr	tr	tr
K	wk	wk	wk	wk	wk	wk	wk	wk	wk
Ba	s	s	s	s	s	s	s	s	s
Sr	s	s	s	s	s	s	s	s	s

TABLE XIII

ANALYSES OF WALLROCK
CLERMONT VEIN 225-FOOT LEVEL

OTHER SAMPLES

Elements Intensity Ratios

Elements	G 71	G 72	G 73	G 43	G 94	G 96
B	.55	.63	.50	.60	.74	.66
Al	4.2	5.3	4.0	1.0	2.3	3.1
Mg	37.	66.	100.	4.4	4.0	5.1
Fe	5.4	4.7	7.2	2.2	4.2	3.5
Pb	-	-	-	1.7	.84	-
Bi	-	-	-	-	-	-
Sn	-	-	-	-	-	-
V	1.5	1.8	1.2	.92	.95	1.6
Cu	6.7	3.2	4.2	5.4	7.4	3.4
Ag	-	-	-	.96	-	-
Na	4.8	11.5	18.	4.2	4.8	12.5
Zr	.52	.49	.65	tr	.74	.34
Ni	.74	.90	.76-	.52	.81	.78
Co	1.7	1.45	1.5	.85	.98	1.00
Mn	4.0	5.0	100.	3.8	6.7	5.0
Cr	2.0	1.9	1.7	3.3	5.8	3.1
Ca	3.0	4.4	10.4	4.0	5.0	6.9
Ti	1.3	1.6	1.1	.43	2.1	1.7
Si	major	major	major	major	major	major
Ga	tr	tr	tr	tr	tr	tr
K	wk	wk	wk	wk	wk	wk
Ba	s	s	s	s	s	s
Sr	s	s	s	s	s	s

TABLE XXV

ASSAYS OF GOLDFIELD SAMPLES

(UMPIRE ASSAYS)

Sample No.	Gold Ounces	Value	Silver Ounces	Value
*G 101	.08	$ 2.80	.28	$ .20
*G 108	.18	6.30	.24	.17
G 47	1.60	56.00	.40	.28
G 50	.01	.35	Trace	-
G 61	.08	2.80	.23	.16
G 69	.07	2.45	.12	.09
G 70	.04	1.40	.10	.07
G 74	.03	1.05	.27	.19
G 75	.02	.70	.10	.07
G 77	.01	.35	.02	.01
G 78	.01	.35	.03	.02
G 79	.03	1.05	.10	.07

*Check assays of samples shown in Figs. 14 and 15.

SYSTEMATIC DESCRIPTION OF THE ELEMENTS

In the following section the occurrence and the relationships of each element found in the Goldfield samples are discussed. Since all values in the tables of the analyses of these samples are given in the form of intensity ratios of the elements, approximate percentages of many of the elements in the different types of rock are given in this section to give the reader some idea of the abundance of the element being discussed.

Aluminum.

The aluminum content of the Goldfield samples varies from 1 to 10% with the exception of sample number G 26 from the highly silicified ledge of the Jumbo vein in which aluminum is probably not over .1%.

The analyses show no significant change in the amount of aluminum in the wallrock. There seems to be as much aluminum in the highly altered dacite as in the nearly fresh dacite. The average amount of aluminum in the veins or ledge material is somewhat lower than that of the wallrock. If the ledges are considered as being almost completely altered and silicified dacite, as they seem to be, then some leaching of aluminum has taken place. The leaching is not marked however, except in the case of the Jumbo ledge where aluminum is extremely low.

Barium.

Barium is present in all samples, but since none of the barium lines were suitable for the determination of the element at the exposure used, no effort has been made to study its distribution.

Bismuth.

Bismuth is one of the significant elements which might be used as an indicator of ore bodies in this district. A definite relationship exists between the amounts of bismuth, gold, silver, and tin in the vein on the 830-foot level of the Jumbo Ex mine. The close association of these four elements in this vein is illustrated in the graphs of Figs. 16, 17, 18, 19 and 20.

In Fig. 16 the intensity ratio of bismuth is plotted against the intensity ratio of silver. The figure shows that this is a straight line relationship meaning that with an increase of bismuth in the veins there is a relative increase in silver.

Fig. 17 is similar to Fig. 16 except that the intensity ratio of bismuth is plotted against the intensity ratio of tin. Again a straight line relationship exists between the quantities of the two elements so that an increase in bismuth is accompanied by a relative increase in tin.

In Fig. 18 the intensity ratios of bismuth, of silver, and of tin, are plotted against the value of the ore in dollars. Since the value of the ore is almost entirely due to gold, this graph actually shows the relationship between the silver and gold, bismuth and gold, and tin and gold. The three graphs in Fig. 18 are smooth curves, and hence the gold content is related to the content of silver, bismuth and tin. Only one of these vein samples (G 108) was found to be an exception to this rule as the gold value in this sample dropped far below the value expected from the content of bismuth, silver and tin.

Fig. 19 shows the intensity ratios of silver, bismuth, tin, and cobalt plotted against the value of ore in dollars using log scales. When a log scale is used the graph gives almost a straight line relationship between the intensity ratios of these elements and the value of the ore.

The distribution of bismuth, silver, and tin along the 850-foot level of the Jumbo Ex vein is shown in Fig. 20. The association of these three elements is again apparent in spite of their erratic distribution.

The bismuth content of the vein samples from the Jumbo Ex mine may be as much as a few tenths of one percent. Bismuth is present in only minute traces in the samples analyzed from the 220-foot level of the Clermont vein, and from near the surface in the Jumbo vein and the vein on the side of Columbia mountain. No relationship seems to exist between bismuth, silver, tin and gold on the 225-foot level of the Clermont vein or in the veins at the surface. This suggests a zoning in the deposits with bismuth being more abundant, and associated with silver, tin and gold in the deeper levels.

The close relationship between the quantities of silver, bismuth, tin, and gold in the Jumbo Ex vein seems to imply that the four elements are genetically associated and were probably being carried in the ore solutions at the same time, and that they were deposited contemporaneously by the same precipitating agent. It is hardly possible thatsuch a relationship could be developed where one metal replaces another.

Since bismuth, silver, and tin are related to the value of the ore, they would be the logical elements to look for if any further work was done on the ores of the deep veins at Goldfield.

Fig. 16

Bi - Ag relation in Jumbo Ex vein

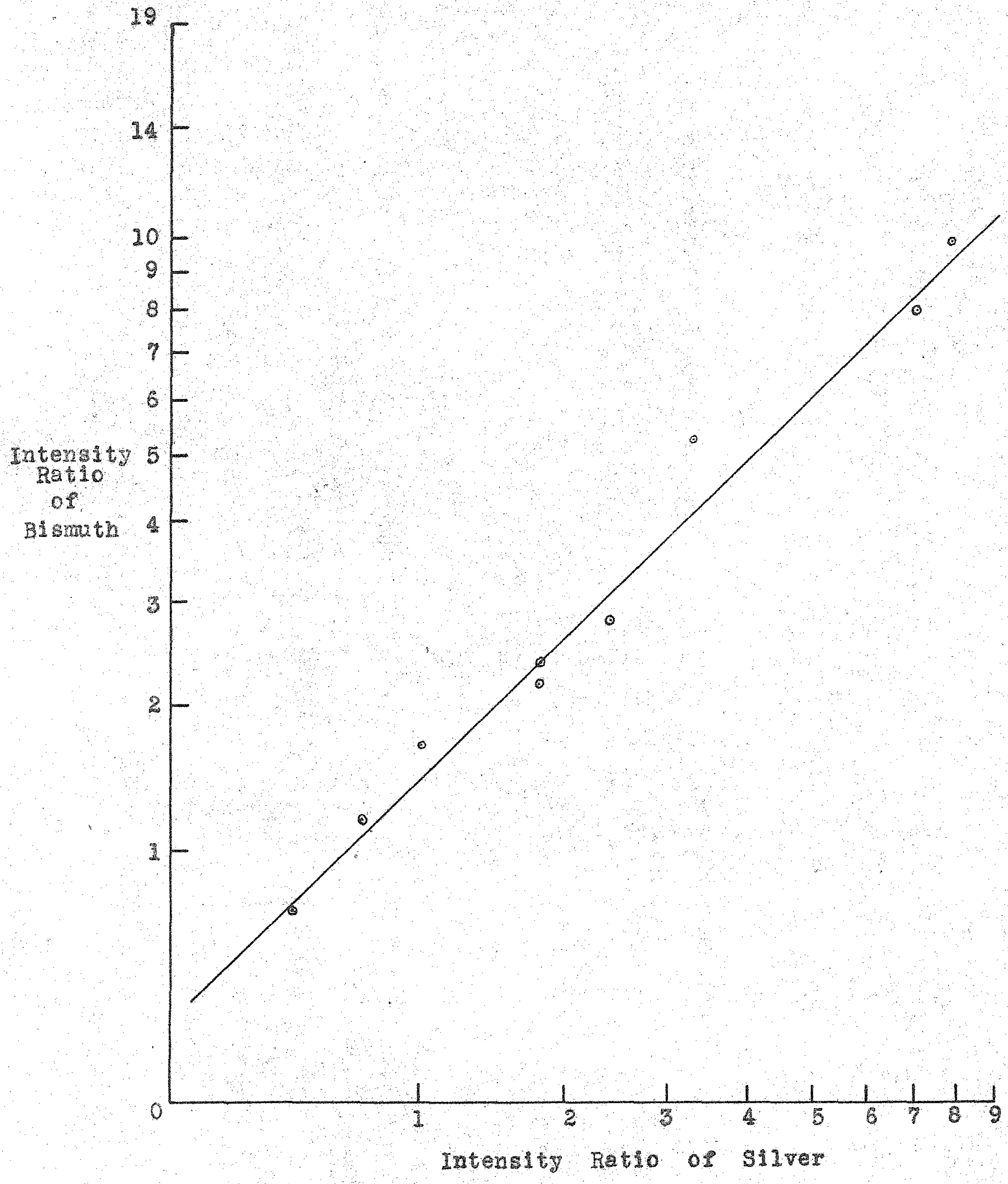
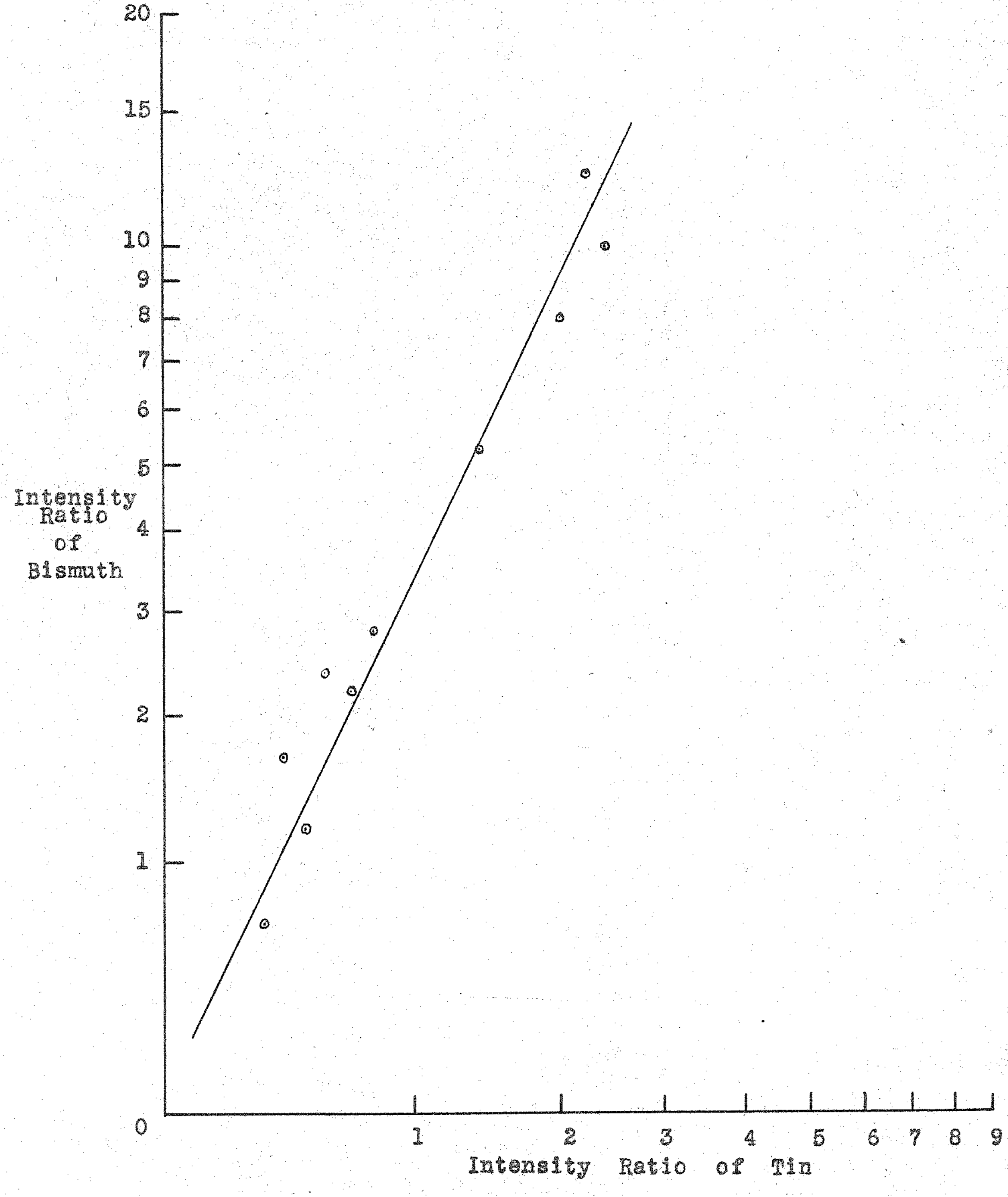


Fig. 17

Bi - Sn relation in Jumbo Ex Vein



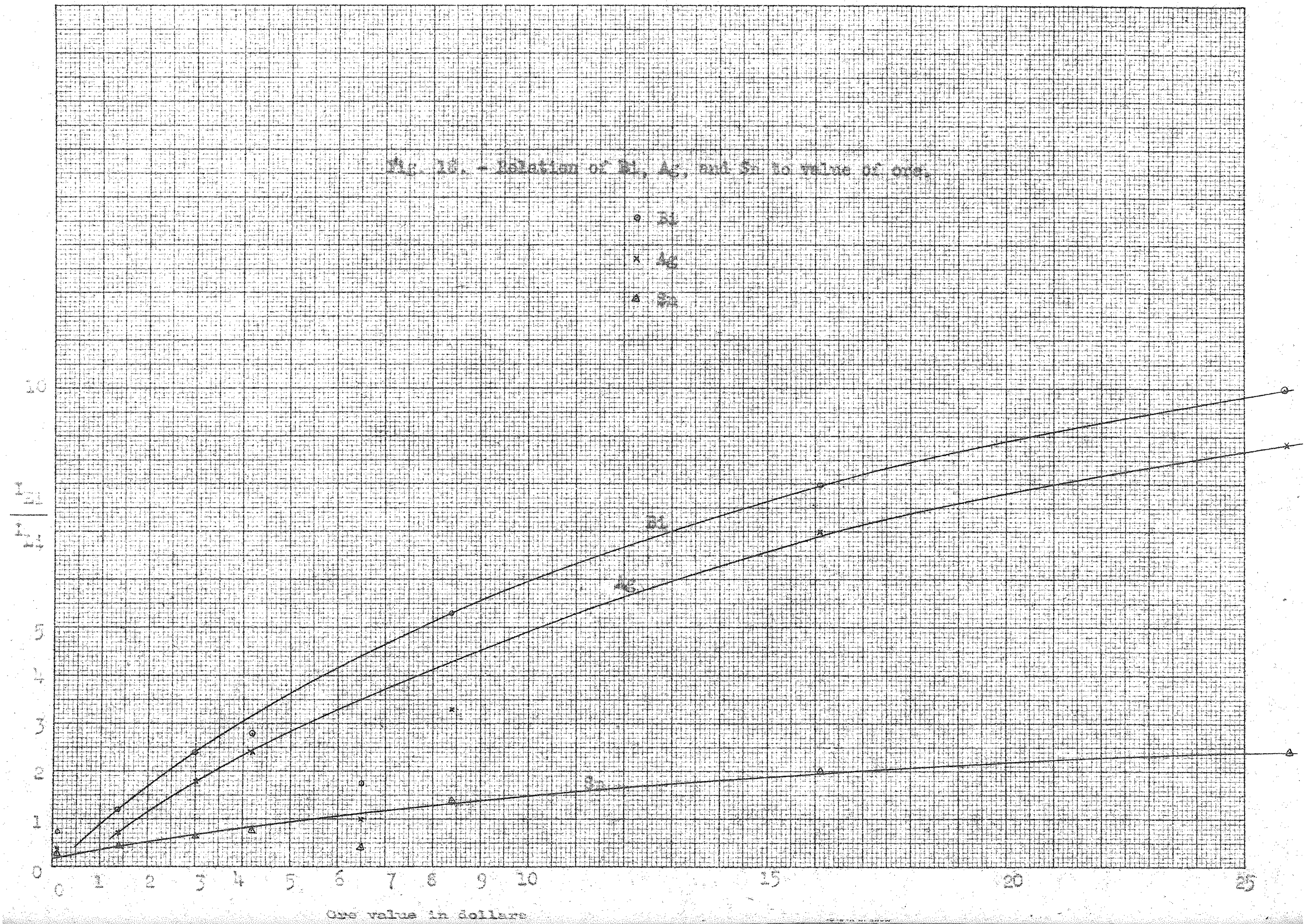


Fig. 18. - Relation of Bi, Ag, and Sn to value of ore.

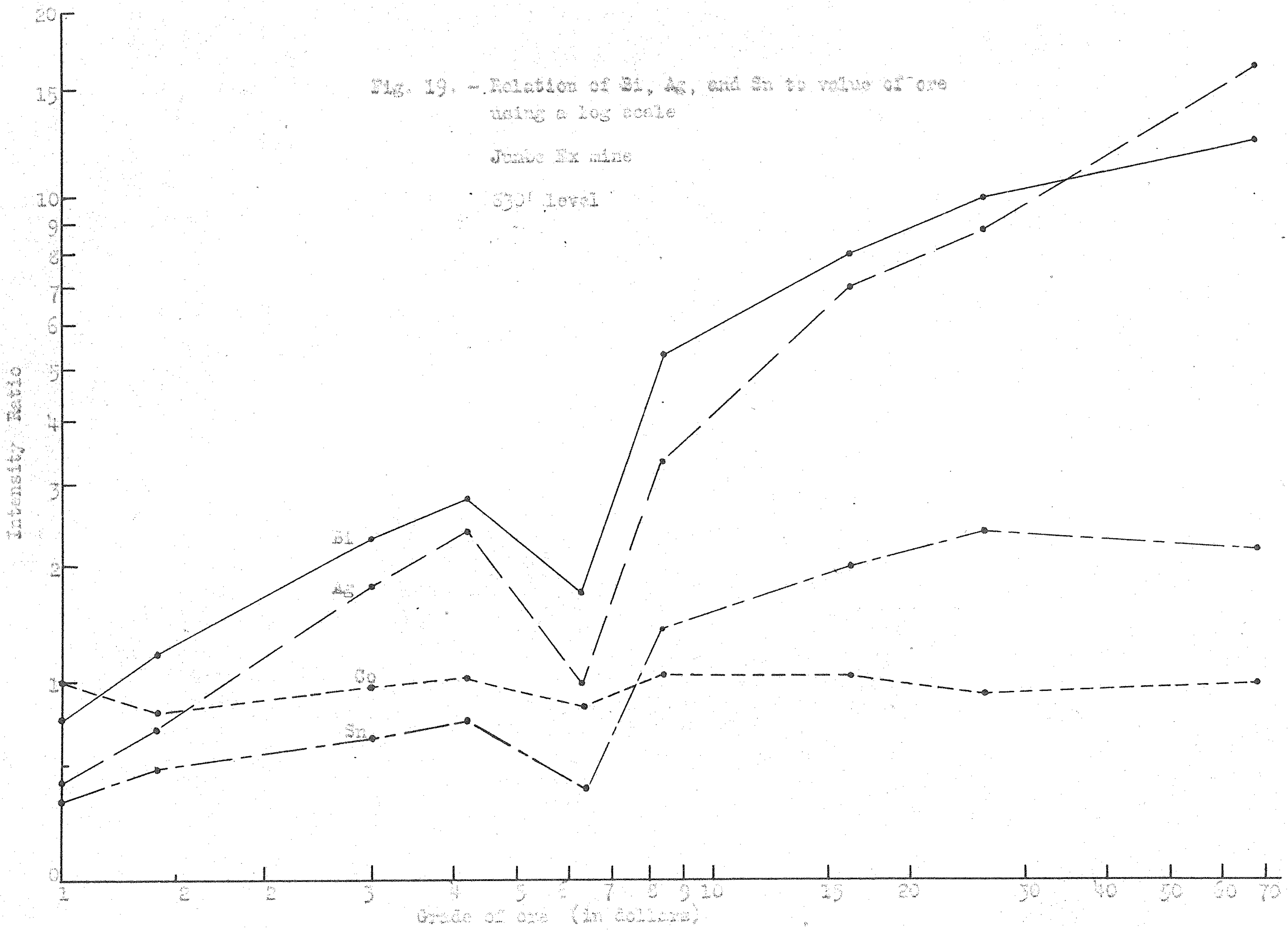
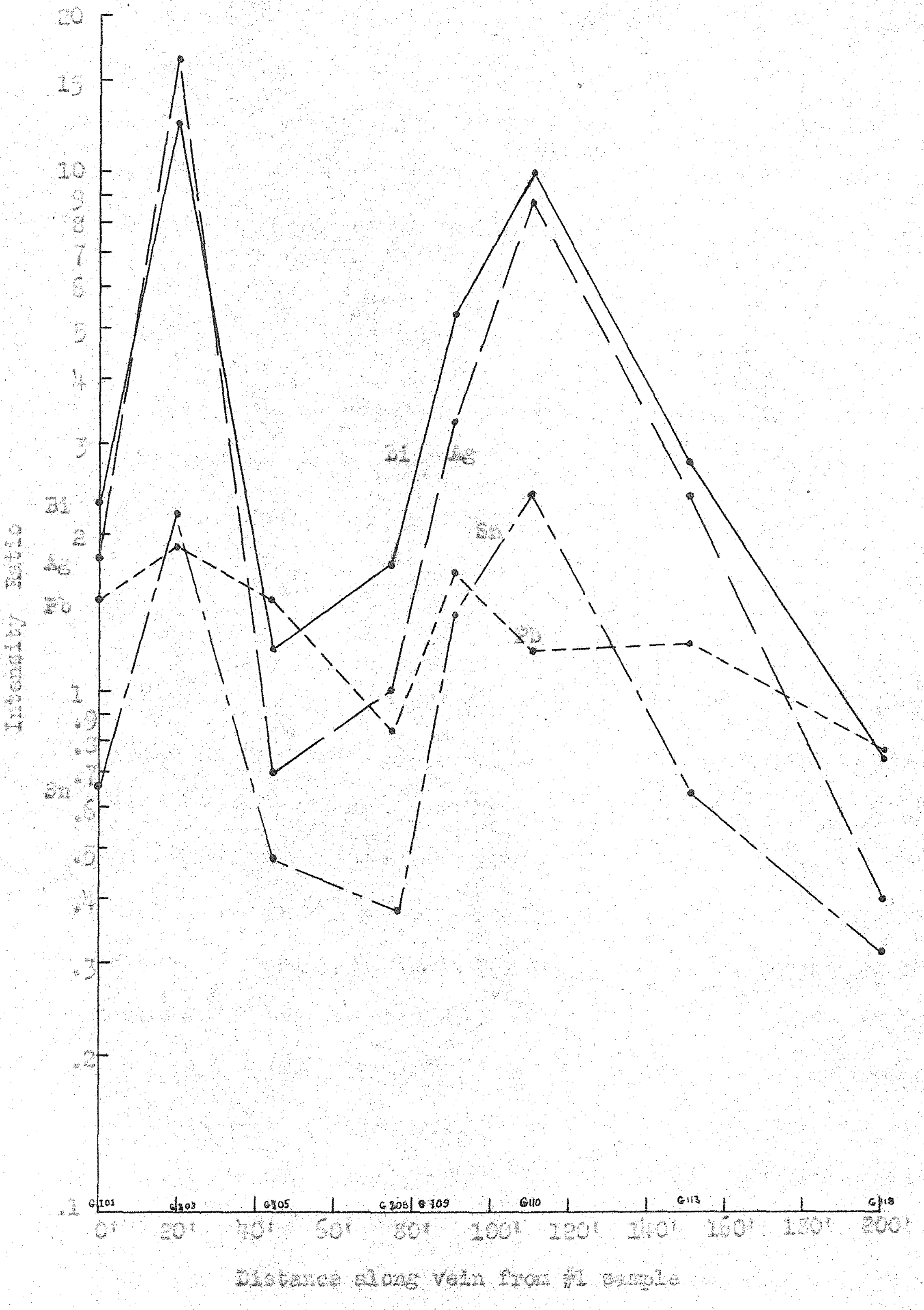


Fig. 19. - Relation of Bi, Ag, and Sn to value of ore
using a log scale

Jumbo Ex mine

630' level

Fig. 20. - Distribution of Bi, Ag, Sn, and Pb along vein of Jumbo Er mine



Only nine vein samples were analyzed from the 830-foot level of the Jumbo Ex mine but these samples showed that a relationship between some of the more abundant elements in the vein and the gold values does exist. The occurrence of the elements along the vein as shown in Fig. 20 is very erratic , but the samples are widely spaced and if they were taken at smaller intervals and over a much larger area, it might be possible to work out a pattern of the distribution of the elements in the vein and to use this pattern in the search for more ore bodies.

Boron.

Boron occurs in small amounts ranging from .001% to .01% in all samples. Little significance is seen in the distribution of boron in any of the rock types.

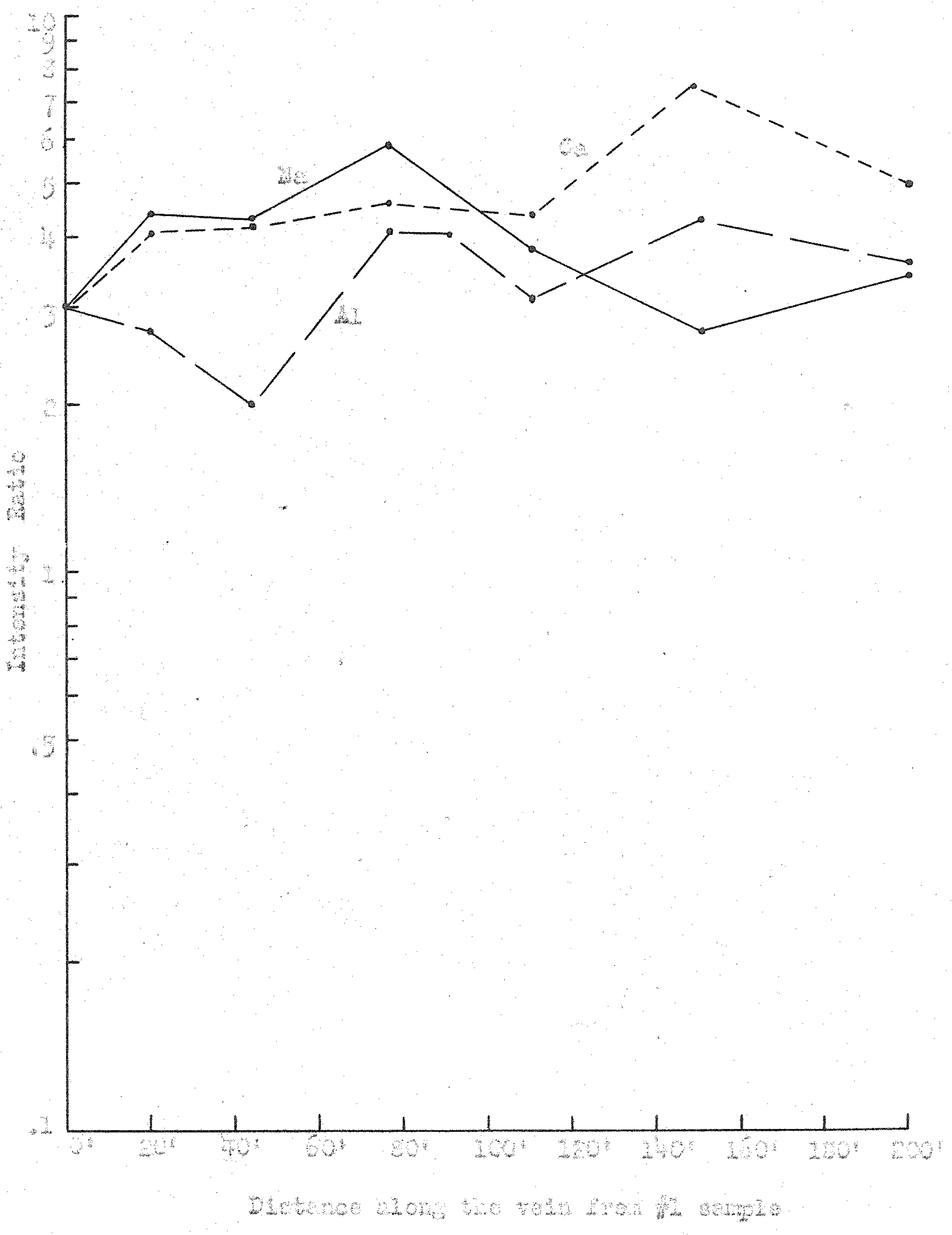
Calcium.

The amount of calcium in each vein sample and in the samples from different veins never varies much from the average of all vein samples, and as shown in Fig. 21, there is little variation in calcium along the vein in the Jumbo Ex mine. The veins contain about the same average amount of calcium as the very highly altered wallrock of both the 225-foot level of the Clermont vein and the Jumbo vein near the surface.

Some leaching of calcium has taken place in the wallrock as shown in Figs. 22, 24, and 26, in which the intensity ratio of calcium in the wallrock samples is plotted against the distance of the sample from the vein.

In Fig. 22, the leaching of calcium seems to be gradual. No

Fig. 21. - Distribution of Ca, Mg, and Al along vein of Jumbo Ex mine



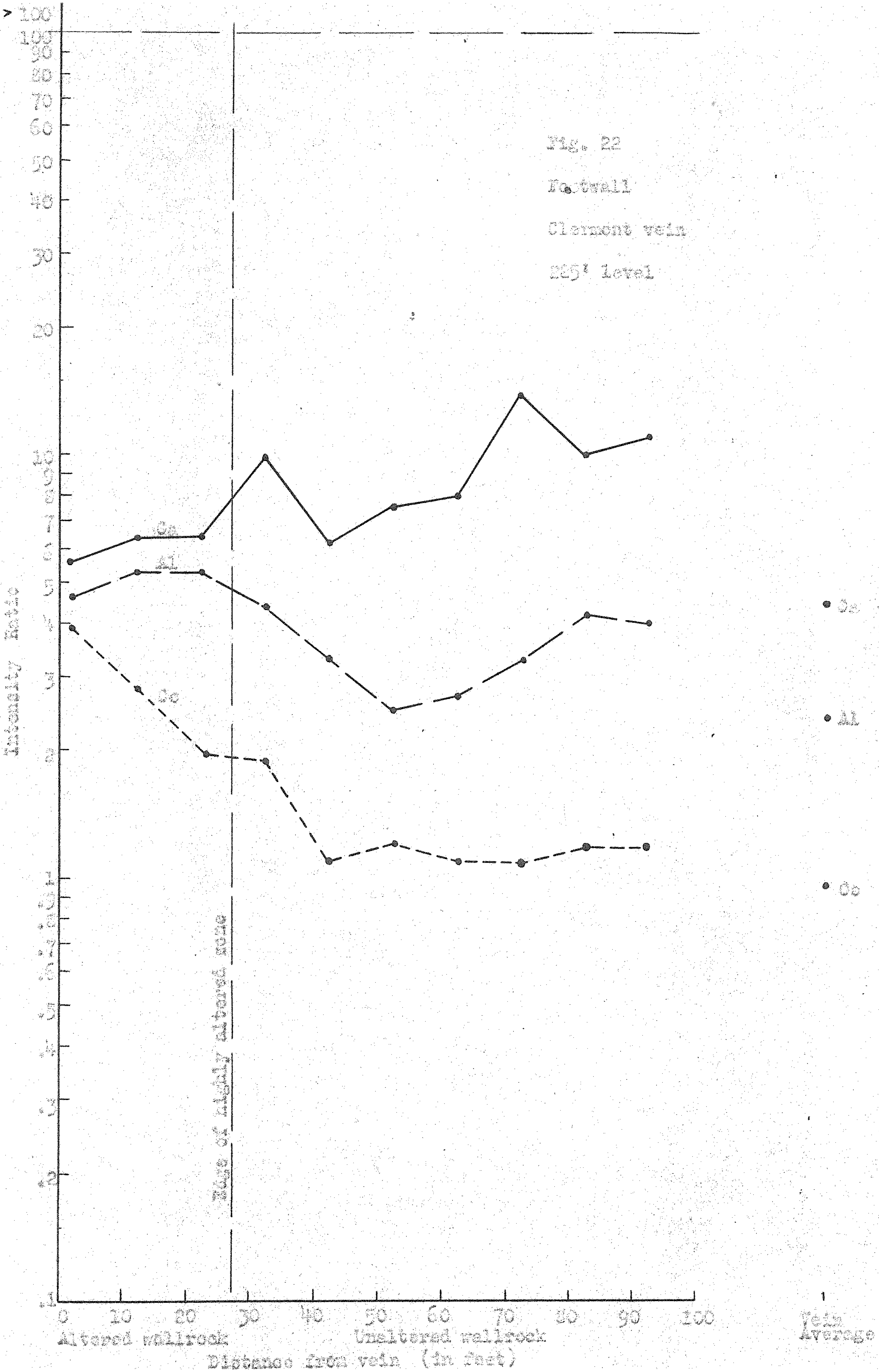


Fig. 22

Footwall

Clermont vein

825' level

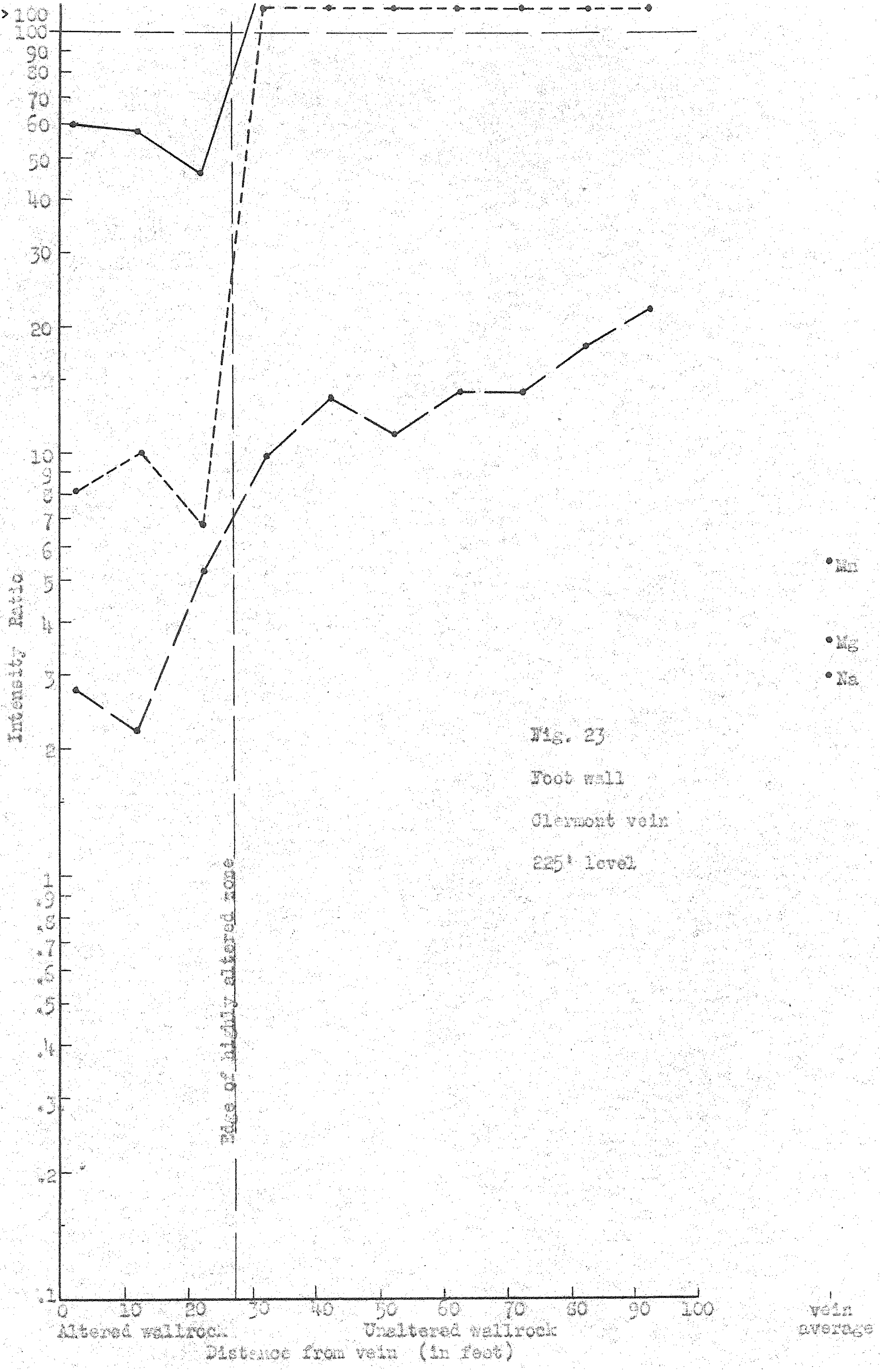


Fig. 23

Foot wall

Clermont vein

225' level

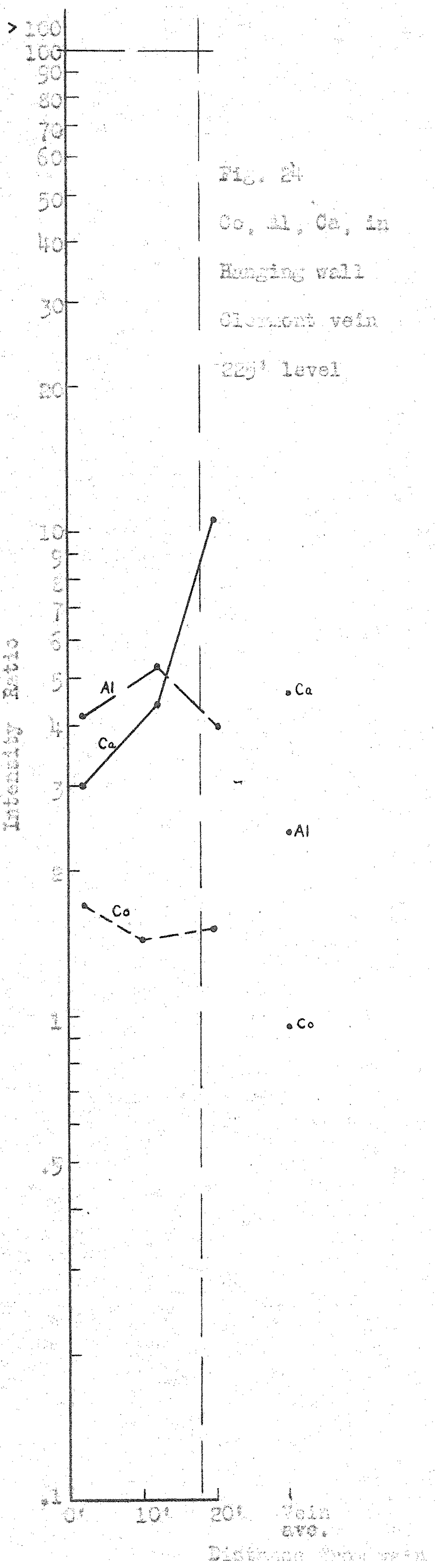


Fig. 24

Co, Al, Ca, in

Hanging wall

Clermont vein

225' level

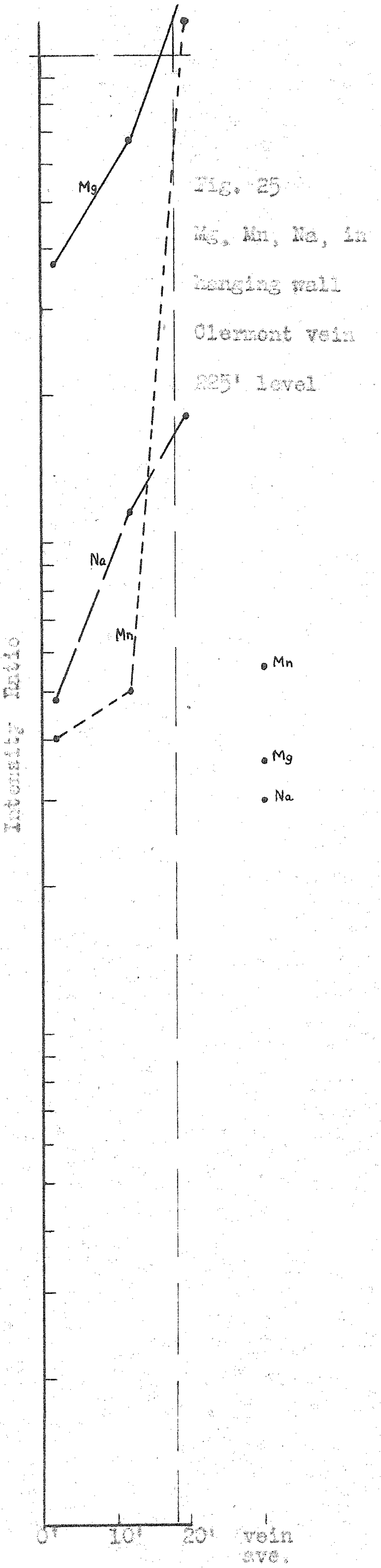


Fig. 25

Mg, Mn, Na, in

hanging wall

Clermont vein

225' level

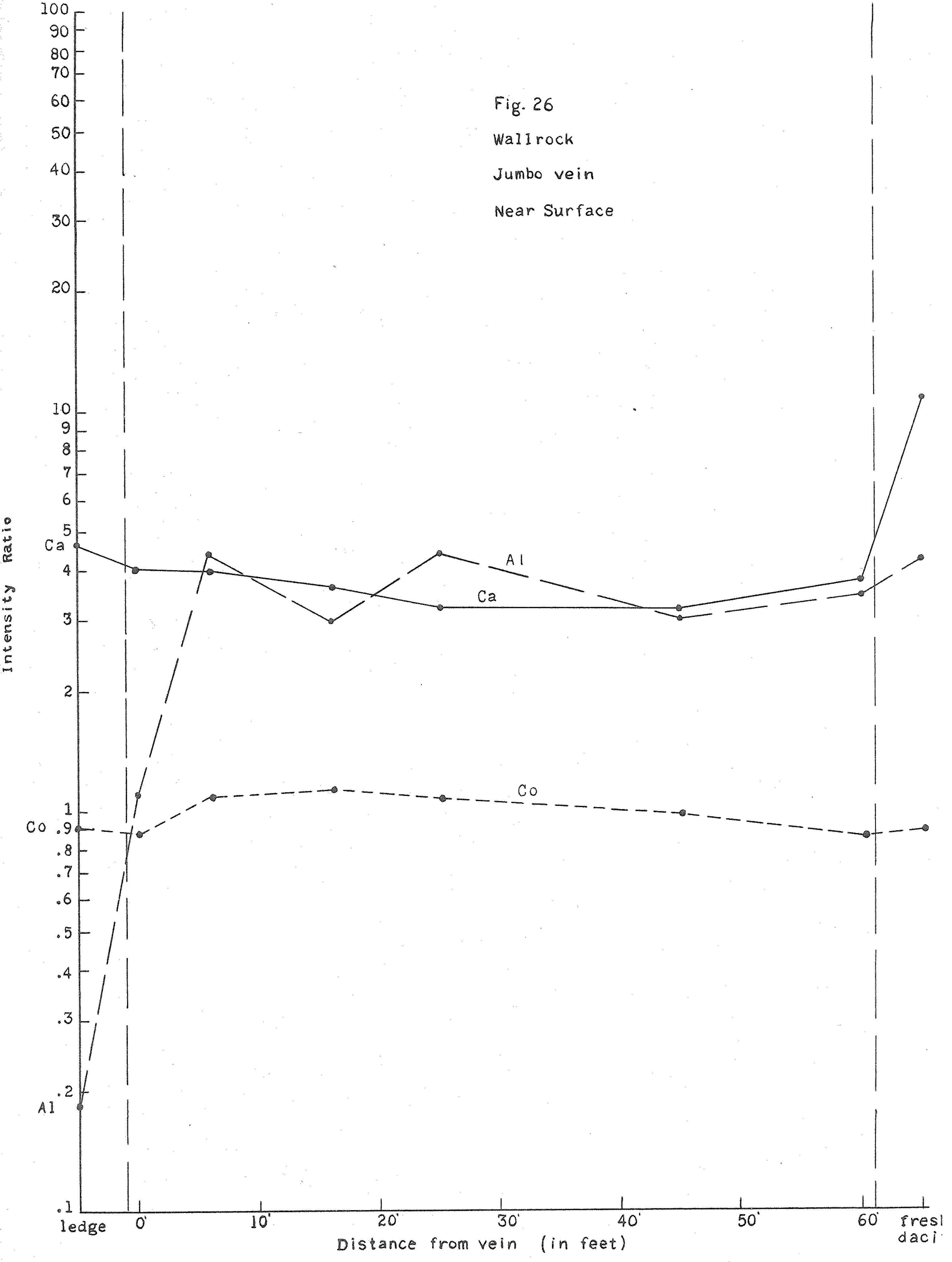


Fig. 26
Wallrock
Jumbo vein
Near Surface
Intensity Ratio
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
Ca
Al
Ca
Co
Co
Al
ledge
0'
10'
20'
30'
40'
50'
60'
fresh dacite
Distance from vein (in feet)

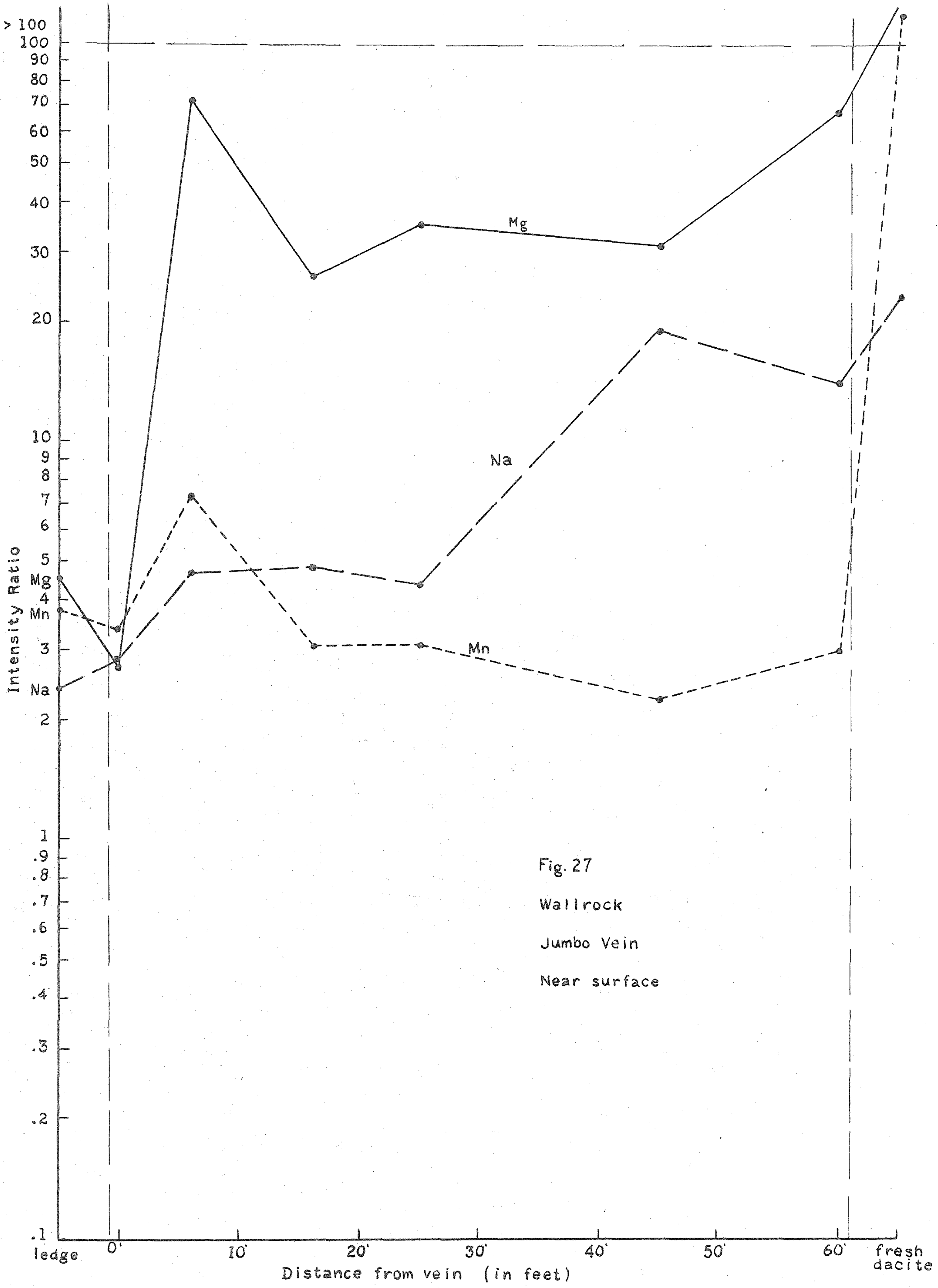


Fig. 27

Wallrock

Jumbo Vein

Near surface

marked increase in the amount of calcium occurs in passing from highly altered to altered wallrock. In Fig. 24, however, the increase at this boundary is more noticeable. Fig. 26 shows a general leaching of calcium over the whole distance sampled in the wallrock of the Jumbo vein, as compared with the amount of calcium in the fresh dacite.

Calcium, although showing a definite decrease due to the alteration, is not as highly leached as some of the other elements.

The range in amount of calcium in the samples is of the order of .5% to 10%.

Chromium.

Any interpretation of the variations in chromium content is complicated by the impurities introduced by the pulverizer plates as discussed in the firstpart of this thesis.

The relative variations of manganese and chromium in the vein samples are very noticeable, but it is believed that this is probably due to introduced impurities rather than to any actual relationship of the two metals in the mineralization of the vein.

Cobalt.

A few thousanths of one percent of cobalt is present in the veins andin most of the wallrock and the fresh dacite. In some of the wallrock near the veins, however, a concentration of cobalt has taken place, and there may be as much as a tenth of one percent.

Cobalt is remarkable for its occurrence in such a constant amount throughout the veins, as shown in Fig. 19, and in the analyses of the vein samples on the 225-foot level of the Clermont vein.

Cobalt is the only element showing enrichment in the wallrock. Figs. 22 and 24 show an enrichment of Cobalt in the wallrock of the Clermont vein with the enrichment gradually decreasing until the amount of cobalt becomes constant between thirty and forty feet from the vein.

Except for the enrichment in the wallrock near the Clermont vein, cobalt is very constant in all the wallrock samples examined. The amount in the wallrock is slightly greater than in the veins.

Copper.

The copper content of the samples from the Jumbo Ex mine may amount to more than one percent. In other samples the copper content ranges from .01% to .1%.

The average copper content of the "below ore grade" ledge material is somewhat greater than that of the wallrock, but in many individual samples the ledgematerial contains less copper than the wallrock.

Copper occurs in sporadic concentrations through the ledge and offers little hope of being much of a guide to ore, at least in the upper levels.

No good indications of leaching or enrichment of copper in the wallrock were found.

As famatinite is very often associated with good ore in the Jumbo Ex mine, it is suspected that some relationship may exist between the amount of copper and the amount of Ag, Sn, Bi, and Au, but the high percentages of copper in the samples prevented quantitative estimations being made with the exposure used in photographing the spectrum.

Gallium.

Gallium occurs in traces in many of the samples, but seems to have no particular significance as it occurs in all types of samples.

Iron.

Iron impurities introduced by the pulverizer plates prevent any good interpretation of the analytical results.

Lead.

Lead occurs in amounts up to a few hundreths of one percent in the vein material. The lead mineralization shows only a slight relationship to the mineralization of Ag, Au, Bi, and Sn. It seems to be enriched in the same part of the vein as the other four elements, Fig. 20, but the relative proportion of lead to the proportions of these other elements is not nearly as marked. This might indicate that the lead mineralization was not contemporaneous with the mineralization of the Ag, Au, Bi, and Sn, but that it may have followed almost the same channels of mineralization in the vein.

No evidence of a lead zoning with depth is found in the analyses and no lead enrichment seems to take place in the wallrock.

Magnesium.

The concentration of magnesium ranges from about .1% in some of the vein samples to several percent in the fresh dacite.

Magnesium shows very pronounced leaching due to the alteration of the wallrock, and the amount of magnesium in the silicified ledge material is much less than that in the highly altered wallrock.

The leaching of magnesium apparently advanced in a wave as shown by the magnesium graphs of Figs. 23 and 25 which show the sudden increase in magnesium when one passes the contact from the highly altered to the fresh wallrock.

Manganese.

The manganese content ranges from .01% in some of the vein samples to between .5 and 1% in the fresh dacite.

Manganese behaves very similar to magnesium in the wallrock alteration. It is highly leached in the highly altered wallrock (Figs 23 and 25), then suddenly increases as soon as the boundary between the intensely altered wallrock and altered wallrock is passed.

The apparent relation between manganese and chromium has already been discussed.

Nickel.

Nickel occurs in small amounts from a few ten thousandths to a few thousandths of one percent in all samples. The results show nothing significant about the behavior of this element.

Potassium.

Potassium occurs in all samples, but as explained in the first part of this thesis the element could not be determined quantitatively with the exposure used in arcing the samples.

Silicon.

Silicon is the major element in all samples, but its percentage of the total sample was too great to permit any determination of significant variations by this method.

Silver.

The silver content of the samples ranges from undetectable amounts to almost three ounces per ton in sample G 47 from the Clermont mine.

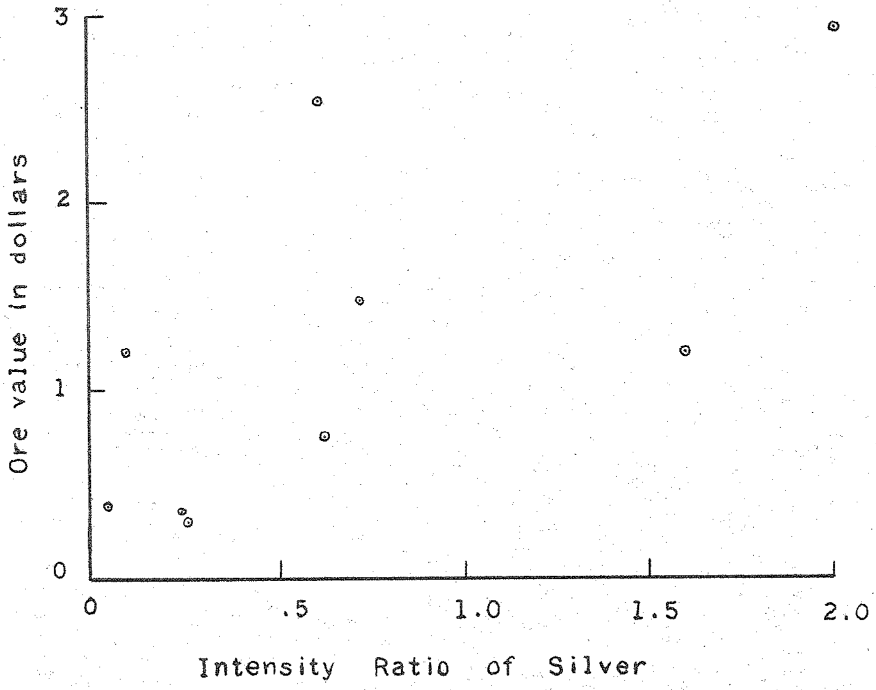
The relationship of Ag to Au, Bi and Sn in the Jumbo Ex mine has already been discussed. No such relationship exists between the four elements in the Clermont vein at the 225-foot level. Tin and bismuth are either absent or occur in very faint traces even in such a high grade sample as G 47. The intensity ratio of silver is plotted against ore value in Fig. 28. and while in general higher silver values mean higher grade ore, that is, higher in gold, no constant relationship exists between gold and silver as in Fig. 18 for the Jumbo Ex mine. Sample G 47 is very high in gold, but very low in silver. Assay results (Table XIV) check with the spectroscopic results to show a lack of any relation between the ore value (or gold content) and the silver content.

It would seem therefore that some change has taken place in the mineralization between the 830-foot level of the Jumbo Ex mine and the 225-foot level of the Clermont mine.

Sodium.

Sodium is present in the samples analyzed in amounts ranging from .1% to 5%.

Fig. 28.- Relation of Ag to Ore Value on 225' level of Clermont mine



The analyses of the various vein samples from all levels show that the vein contains about the same amount of sodium as the highly altered wallrocks near the ledges. In the wallrock itself, however, sodium shows a definite decrease due to the wallrock alteration, but the leaching seems to be different from that of magnesium and manganese. Figs. 23, 25 and 27, showing the occurrence of sodium in the wallrock suggest that instead of a sharp rise in the amount of sodium at the boundary between the highly altered and altered wallrock, sodium increases gradually as the distance from the vein increases.

The wallrock from the Jumbo vein (Fig. 27) was all highly altered, but unlike magnesium and manganese which were very highly leached over the whole distance sampled, sodium had reached a nearly constant value about 40 feet away from the vein and samples further than 40 feet had almost the same amount of sodium as the fresh dacite.

Strontium.

Strontium is present in all samples, but like barium, had no line suitable for quantitative analysis at the exposure used.

Tin.

The relationship between Sn, Ag, Au, and Bi, in the jumbo Ex mine has already been discussed.

A definite depth zoning of tin seems to be present at Goldfield. The samples from the 830' level of the Jumbo Ex mine contained from .01 to 1% tin, and assays containing as much as 3%

tin have been obtained from sulphide concentrates of ore from the Jumbo Ex mine. The samples of ore analyzed spectroscopically from the upper levels contain only a faint trace of tin and previously tin has never been reported from the upper levels of Goldfield.

The relationship between tin and silver occurring in the Jumbo Ex mine is not present in the samples analyzed from the 225-foot level of the Clermont mine.

Titanium.

Titanium is present in all samples in amounts ranging from .1 to 1%. It occurs in about equal amounts and with little variation in both the veins and wallrock.

Vanadium.

The vanadium content ranges from about a hundredth to one or two tenths of one percent. The veins have a lower vanadium content than the wallrock, but no significant change in vanadium content has been noted in the wallrock alteration.

Zinc.

Sphalerite has been reported from Goldfield, but the zinc lines of the samples studied were very faint so that only a few hundredths of one percent of zinc is present.

Zirconium.

As much as .1% of zirconium is present in some of the samples. It occurs in varying amounts in both veins and wallrocks and little significance can be attached to its occurrence. The presence of this element is expected since zircon occurs as an accessory mineral in most of the thin sections.

SUMMARY OF WALLROCK ALTERATION

Analyses of the wallrock show a great diversity in the change in distribution of the constituent elements during the process of mineralization and the accompanying alteration of the adjacent rocks. Some elements, such as manganese and magnesium, show a sharp quantitative change between highly altered and altered wallrock, while others, such as sodium and sometimes calcium completely fail to show any change within this zone.

Going from the vein into the wallrock, little change is apparent in the manganese and magnesium content of the wallrock until the contact between the highly altered wallrock and less altered wallrock is reached. At this contact, the amount of manganese and magnesium suddenly increases tremendously, then shows little additional change at a greater distance from the vein. On the other hand the leaching of sodium and sometimes calcium gradually decreases away from the vein with no marked boundary such as occurs with manganese and magnesium.

The wallrock of the Jumbo vein shows that magnesium, manganese, and calcium have been differentially leached over the entire distance investigated, but sodium is only leached for about 40 feet from the vein and at greater distances from the vein the highly altered wallrock contains almost the same amount of sodium as the fresh dacite.

Many other elements such as B, Co, Cu, Ni, Ti, and Zr show no evident change due to the wallrock alteration. Al and V show little evidence of change in the wallrock itself, but have been leached to a large degree in the highly silicified ledge of the Jumbo vein, which Ransome would consider the most exteme type of dacite alteration.

Cobalt showed an increase in the altered wallrock near the vein at the 225-foot level of the Clermont mine. The enrichment continued outward for thirty to forty feet from the vein.

The spectroscopic technique seems to be applicable to the investigation of wallrock alteration. Quantitative determinations of many elements may be made as accurately as by chemical analysis. Since this spectrographic procedure is such a quick method many samples at various distances from the vein may be analyzed and the behavior of many elements can be studied in detail. Standards for determining the actual percentages of the various elements could be set up and from the percentages the results could be calculated to determine which elements have been added to or subtracted from a unit volume of fresh rock in order to produce a given alteration product.

A combinedpetrographic and spectrographic study of many wallrock samples from some district would undoubtedly yield much new data on the geochemical behavior of the elements during wallrock alteration. It should show to what extent the elements were leached or added to the wallrock, whether the leaching or addition was gradual, or wavelike with a sharp contact between altered and unaltered wallrock, and which elements behaved similarly during the alteration.

SUMMARY OF ECONOMIC APPLICATIONS

This investigation was started with the purpose of determining whether some element or group of elements could be found which would give some clue useful in determining the location of ore bodies. If such an element or group of elements could be found to grade away from good ore shoots these elements could be used in exploration work for new ore. The channels of gold mineralization might also be traced by the more abundant non-economic elements associated with the gold as such a pattern of mineralization would undoubtedly be useful in search for new ore bodies.

While this work is only a first attempt at such a study and relatively few samples have been analyzed, the method gives hope of some success. It has been established that certain non-economic elements are associated with ore and that these elements may be determined by spectroscopic analysis.

In the vein of the Jumbo Ex mine bismuth appears to be the most promising associated element. It is present in sufficient amounts to be determinable with the spectrograph even in extremely low grade ore. Moreover in similar samples the sensitivity of bismuth could be increased two to four times by using silicon as the internal standard instead of diluting the samples with lithium. The lithium dilution method was used in this work to make the analytical results (intensity ratios) of the vein material comparable with those of the wallrock in which silica was not sufficiently constant to be used as an internal standard. If actual percentages were determined there would be no need of using the same method of arcing since standards would be set up for each method.

Silver and tin are also useable in determining the changes in the pattern of mineralization along the vein. Silver, although occurring in small quantities, is very sensitive to this method of analysis. The sensitivity of both silver and tin could be increased by using silicon as the internal standard.

The study of wallrock alteration should also have an economic application. For example, near the Jumbo vein the wallrock is extensively altered over a wide area and a sample a hundred feet from the vein looks very similar megascopically to a sample only a few feet from the vein. Spectroscopic analysis however, shows that sodium gradually begins to decrease about 40 feet from the vein.

If such changes in the wallrock were found to be fairly constant in any given district, or even if a certain element began to decrease as a vein was being approached, the fact should be a great aid in exploration. For example, drill samples could be analyzed to determine if any vein was near at hand, but was missed by the drill hole, and the approximate location of the vein might be determined by analyses from different portions of the core.

Elements, such as cobalt, in the Goldfield district, which are enriched in the wallrock close to the veins would also be very helpful.

It is realized that relatively few samples of the Goldfield district were analyzed and that further work would quite probably yield much additional information. In addition ~~to~~ the samples actually represented only three rather widespread localities in the district. An active district where ore samples could be obtained along several veins or parts of a single vein would be more suitable for study than a district such as Goldfield where most of the ore has been mined out.

SUMMARY OF ZONING

A change in the character of the mineralizing solutions has taken place between the 830-foot level of the Jumbo Ex mine and the 225-foot level of the Clermont mine.

Silver, gold, bismuth, and tin show a close association in the Jumbo Ex mine, but in the Clermont mine bismuch and tin are almost absent and silver shows no direct relationship to gold. A sample taken from a surface vein on the east side of Columbia mountain shows some silver, but only traces of tin and bismuth.

Tin gives the best indication of vertical zoning at Goldfield as it is fairly abundant in the lower levels (830-foot level) but has never been reported from the upper levels and the spectrograph showed only faint traces of tin in the upper levels sampled for this study. Bismuth seems to show a vertical zoning in the samples studied for this work, but bismuthinite is found in the upper levels of some of the mines so that without a more detailed study of its occurrence little can be said of whether a true zoning is present.

PROBLEMS FOR STUDY WITH THE SPECTROGRAPH

Many problems in geochemistry have been suggested by this essentially preliminary work. The most important problem would seem to be an attempt to trace the actual paths of the ore solutions in a vein by the distribution of all the elements to see which elements travelled the same channels and in general to obtain more detailed information on how mineralization actually takes place. Much might be learned about the deposition or the elements and what happened above, below, and laterally from ore shoots.

The spectrograph should be useful in the study of depth and lateral zoning of metals. It would not only show the zoning of the major elements but would pick up changes in the minor elements as well.

Some of the problems of unmixing and paragenesis might be solved. When elements are related to one another as are silver, bismuth, gold, and tin in the Jumbo Ex mine it appears that their deposition must have been nearly contemporaneous. If two or more elements or minerals were suspected to have exsolved from solid solution rather than being replacents, it might be proven to be solid solution by showing a definite relation between the amounts of the elements in the veins.

Much work could be done on the behavior of the elements in various types of wallrock alteration, and certain elements might indicate the proximity of a vein.

The validity of many of these statements and the degree to which many of these proposed applications can be utilized must await the accumulation of a large quantity of reliable analytical data.

STRATIGRAPHY OF THE CRETACEOUS AND EOCENE ROCKS OF THE SANTA MONICA MOUNTAINS.

by

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A Thesis Submitted in Partial Ful-
fillment of the Requirements
for the Degree of Doctor
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ABSTRACT

The problem consisted of separating the Upper Cretaceous from the Eocene rocks in the eastern part of the Santa Monica mountains; determining the local stratigraphy of the Upper Cretaceous and Martinez; and attempting to correlate the Cretaceous section with other sections in California.

Results:

(a) The Upper Cretaceous stratigraphy in descending order is as follows:

E. Upper arkose and conglomerate, 1500 feet.

D. Fine grained, fossiliferous sandstone, 300 feet.

C. Cobble conglomerate with some arkose in lower part, 3500 feet.

B. Coarse arkose with some shale and conglomerate, 2500 feet.

Unconformity.

A. Lower soft red conglomerate.

(b) The lower conglomerate lies unconformably on metamorphosed Santa Monica slates of Triassic (?) age. The Martinez overlaps the Cretaceous with a distinct erosional unconformity although no great angular unconformity has been found. In some places the Cretaceous is overlapped by the Modelo and faulted against Topanga sandstone in others.

(c) The lower red conglomerate has similar lithology and occupies the same relative position as the Trabuco formation of the Santa Ana mountains, so that it may well represent the same formation.

Member D is correlated with the Williams formation in the Santa Ana mountains and with the Metaplacenticeras beds of the Dayton canyon section in the Simi Hills on the basis of the fauna.

(d) The Martinez section in the Eastern part of the Santa Monica

mountains is about 3500 feet thick. The lower 2000' consists of brown shale with reefs of white algal limestone and the upper 1500 feet is more than half coarse white arkose and conglomerate, but contains considerable shale and some algal limestone.

INTRODUCTION

Upper Cretaceous deposits in the Santa Monica mountains were recognized and outlined in a sketch map by Waring in 1917. Hoots mapped the area in more detail, but owing to poor exposures, did not separate the main body of Upper Cretaceous and Lower Eocene (Martinez) rocks which occur in the Topanga Canyon quadrangle. The stratigraphy of the Upper Cretaceous and Eocene rocks of the Santa Monica mountains was not well known.

Since Hoots worked in the area, many new road cuts have been made and better exposures are available. The present work was begun therefore with the hope that with a more detailed study of these rocks, the Martinez could be separated from the Cretaceous and that some idea of the stratigraphy of these Eocene and Cretaceous rocks could be obtained.

It was also hoped that the Cretaceous rocks of the Santa Monica mountains would yield a more abundant invertebrate fauna than has hitherto been described, and that this fauna would lead to a correlation with the Cretaceous section of the Santa Ana mountains and the Cretaceous of other parts of California.

CONDUCT OF THE RESEARCH

The base maps used were airplane photographs with an approximate scale of 1" = 2000'. Problems of structure and physiography are treated only insomuch as they have been necessary in working out the stratigraphy of the area. The fossil localities are located exactly on the aireal photographs and an attempt has been made to place the collections from these localities in their correct place in the stratigraphic section.

Acknowledgements.

This problem was suggested to me by Dr. W. P. Popenoe of the California Institute of Technology and the work has been carried on under his supervision. I have received much advice in the field from Dr. Popenoe, and he has aided me materially in the collection of the fossils and given me much assistance in their identification and their relations to the other Upper Cretaceous faunas of the Pacific coast. Dr. Popenoe has also critically reviewed the manuscript and given many helpful suggestions for its improvement.

I should also like to thank Mr. J. M. Tate, engineer of the Los Angeles Mountain Park Company, for his kindness in giving me permission to enter the properties of the company and to use their private roads.

HISTORY OF PREVIOUS WORK

The first reference found to the Cretaceous of the Santa Monica Mountains was that of Waring (1).

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(1) Waring, C. A., Stratigraphy and Faunal Relations of the Martinez to the Chico and Tejon of Southern California. Proc. Cal. Acad. Sci., 4th Ser., Vol VII, pp 53 - 56, 1917.

Waring outlined a wedge-shaped area of Cretaceous rocks east of Topanga canyon on his sketch map. This area roughly corresponds to the area of Cretaceous and Martinez rocks discussed in this thesis. Waring gives the following Cretaceous section: lower 1500' of sandstone with dark micaceous shale interbedded; 4000' of well consolidated conglomerate with interbedded sandstone and shale, the pebbles of which vary from one inch to four or five inches in diameter; the upper division consists of 1200' of shale and light colored, fine grained, medium bedded sandstone. Scattered over the surface of this Cretaceous area are remnants of Martinez strata .

Hoots (2) in mapping the eastern part of the Santa Monica mountains separated the Martinez from the Cretaceous in the Reseda quadrangle but in the Topanga Canyon quadrangle these formations were not mapped separately. He also epparated the Cretaceous ("Chico") into a lower member of soft red conglomerate and an upper member of conglomerate, sandstone, shale and limestone. Faunal lists and localities were given for both the Chico and Martinez formations.

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(2) Hoots, H. W., Geology of the Eastern Part of the Santa Monica mountains, Los Angeles Co., California. U. S. G. S. Prof Paper 165 - C, 1930.

Hoots also makes a brief mention of these rocks in Guidebook 15, Excursion C-1, XVI International Geological Congress.

W. P. Popenoe (3) using collections made by himself, H. W. Hoots, and W. P. Woodring, believedthat the Metaplacenticeras beds of the Santa Monica mountains were probably correlative with the Williams formation of the Santa Ana mountains. He also suggested that the lower red conglomerate member of the Chico in the Reseda quadrangle is a possible correlative of the Trabuco formation of the Santa Ana mountains.

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(3) Popenoe, W. P., The Upper Cretaceous Stratigraphy and Paleontology of the Northern Santa Ana mountains. Ph.D. Thesis, Calif. Inst. of Tech., 1936.

GENERAL GEOLOGY

Location.

The Santa Monica mountains trend in an east-west direction with the eastern end of the range directly north of Los Angeles. The area mapped in the course of this research is north and northwest of the city of Santa Monica and extends from Topanga canyon about three miles west of Santa Monica to the small canyon just to the west of Sepulveda canyon, at the eastern end of the city. Cretaceous rocks outcrop from the south side of the Santa Monica range almost to the north side.

The Cretaceous and Eocene rocks mapped cover an area of about twelve square miles in the Reseda, Topanga Canyon, and Sawtelle quadrangles. No attempt has been made to map the Cretaceous rocks in, and to the west of, Topanga canyon.

Vegetation and Culture.

Most of the area is covered by a dense growth of heavy brush and with the exception of small gardens in the lower reaches of the canyons above Santa Monica, no cultivation has been attempted. Some of the dense, well cemented sandstones are being quarried for rip rap and road metal in Santa Ynez canyon. Limestone was formerly quarried from thick beds of algal limestone.

Mulholland Highway, an excellent public highway along the crest of the range, crosses the northern part of the area; and fireroads on most of the ridges between the larger canyons, connect Mulholland Highway with roads in Santa Monica. These roads not only made the area very accessible, but many excellent exposures are found in the road cuts.

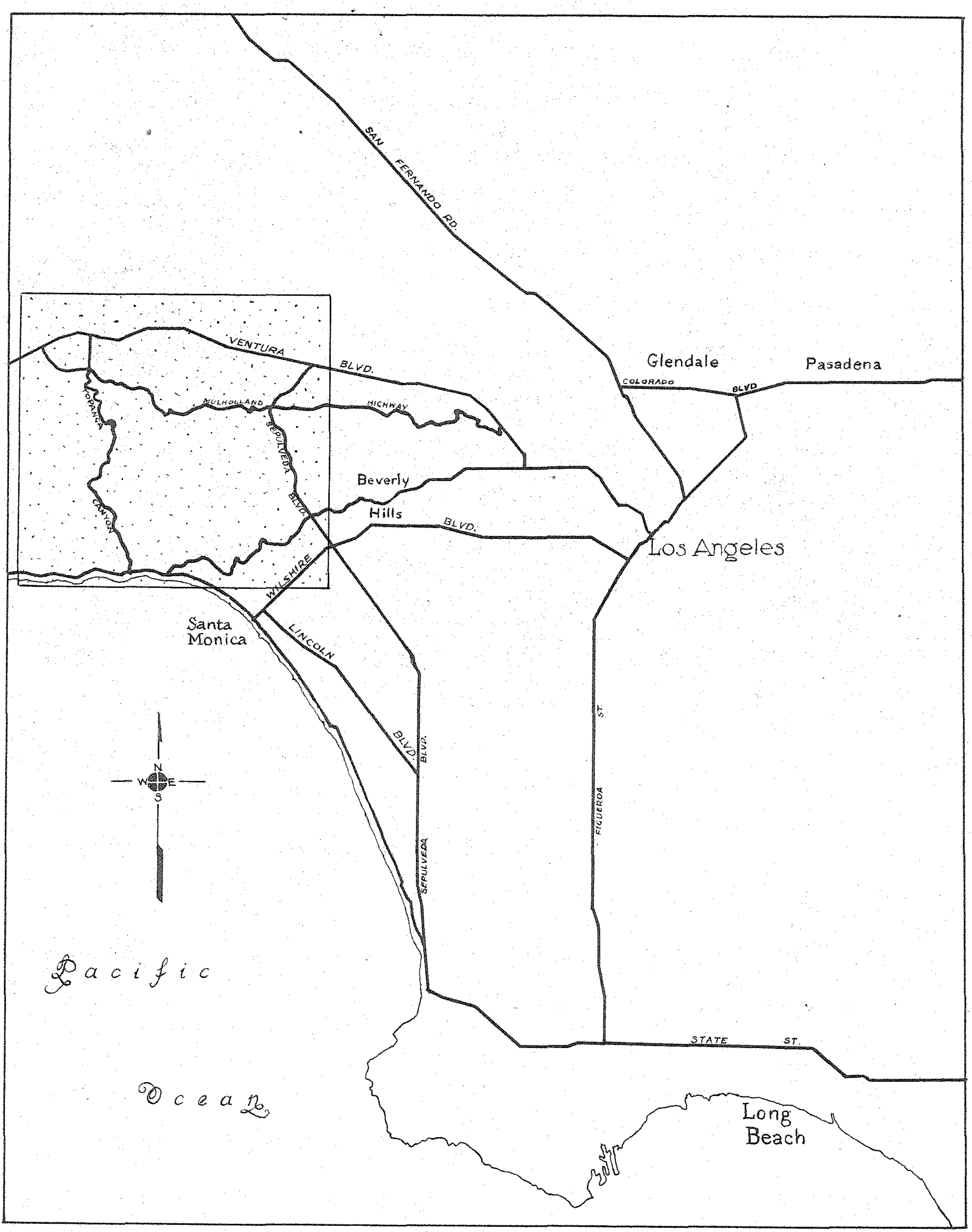


FIG. 1
INDEX MAP OF LOS ANGELES DISTRICT
SHOWING THE POSITION OF THE AREA

Physiography.

The Santa Monica mountains are not high mountains, the highest elevation in the area mapped being 2110 feet. The western part of the range rises directly from the Pacific ocean, while the eastern part, from Santa Ynez canyon eastward, rises above the Los Angeles plain. San Fernando valley lies to the north of the mountains.

The crest of the range lies near the north side of the mountains and the streams of the south side usually flow in straight, evenly spaced, very steep sided canyons, down to the Pacific ocean and Los Angeles plain. Quaternary terrace deposits which extend eastward from Topanga canyon at the base of the south side of the range have been deeply incised by the streams as they come out of the canyons. The streams, at least in the area mapped, show little structural control as their straight courses cut across the strikes of most of the rocks, and the canyons do not follow faults or specific rock formations. Some badland topography is found in the Vaqueros(?) rocks in part of Santa Ynez canyon.

Structure of the Cretaceous and Eocene Beds.

The anticlinal nature of the Santa Monica mountains has been recognized for many years. In the eastern part of the mountains a core of highly metamorphosed, probably Triassic, rocks called the Santa Monica slates has been cut by intrusions of granite. The Cretaceous and Eocene rocks lie in a half circle around this core of metamorphic rocks. For the most part Cretaceous rocks lie unconformably on the Santa Monica slates and dip away from the central core, forming a large anticline plunging towards the west. The dip of these Cretaceous rocks ranges from 15° to 50°. The angle of dip is usually low near the slate contact, but rapidly steepens to 40° to 45° one or two thousand feet away from the contact and then remains nearly constant.

The anticline has been complicated by faulting near the crest of the structure and Eocene and Cretaceous rocks are in fault contact with the Santa Monicaslate near this crest.

The Cretaceous rocks on the north side of the anticline are overlapped by Modelo to a large extent and little can be seen of the Cretaceous structure except that the beds dip 30° to 45° to the northwest. If faulting is present, the faults are not well exposed.

Faults of various magnitudes are found on the crest and south flank of the anticline. Many of the faults that can be mapped on the south flank of the range are steeply dipping, easterly trending normal faults with the downthrow on the north. About halfway between the source and mouth of Temescal canyon, a large easterly trending fault has dropped Eocene shales on the north against Cretaceous conglomerate on the south. Similar relations are shown on the fault between Temescal and Santa Ynez canyons, and on another fault near the big bend of the lower part of Santa Ynez canyon where Vaqueros(?) rocks on the north are dropped against Cretaceous sandstones.

Other smaller eastward trending normal faults in the vicinity of Rustic canyon have brought small patches of Cretaceous and Miocene rocks in contact with Triassic(?) and Cretaceous rocks respectively in such a manner that the north side is the downthrown side.

The northward trending faults such as the Santa Ynez canyon fault and the fault just west of Temescal canyon also dip steeply and have the west side dropped down.

As the traces of many of the faults on the south flank of the mountains bend almost at right angles, the movement must have been largely dip slip. Since the faults are normal and the faulting was probably caused by vertical forces.

Large irregular shaped plugs of gabbro of supposedly the same age as the Topanga formation are found in the central part of the range and in the general area between Santa Ynez and Topanga canyons. Many basalt dikes cut the Cretaceous sediments. Between Temescal and Mandeville canyons on the south side of the range these dikes have an easterly strike and dip to the north, in some cases at angles as low as 20° or 30°. In places dikes have come up along the faults. Many of these dikes are highly sheared and brecciated suggesting a close association of the faulting with the igneous activity. The character of the faults and their associations with the intrusions seem to suggest a general sinking of the central part of the range with that part nearest Topanga canyon sinking the most. This in turn might suggest that the subsidence was due to the extrusion of lava and the general cooling of the igneous mass. If this is true, the question arises as to whether the original uplift of the Cretaceous rocks was due to vertical forces related to the incoming of this intrusion. The basic plugs however, seem to be west of the centre of uplift so no generalization can be made.

At least one and perhaps more later periods of faulting and folding have affected the Santa Monica mountains as the later Miocene and Pliocene rocks have been deformed along the fringes of the range and Quaternary terraces have been uplifted very recently.

THE UPPER CRETACEOUS STRATIGRAPHY OF THE SANTA MONICA MOUNTAINS

General features.

The Upper Cretaceous rocks occur in several disconnected fault blocks with the result that many of the contacts are fault contacts. The thickest and most complete section of Upper Cretaceous is on the south side of the mountains between Temescal and Mandeville canyons.

The section may be divided into five members consisting in descending order of:

E. Upper arkose and conglomerate.
D. Fine grained fossiliferous sandstone.
C. Cobble conglomerate with some massive arkose beds.
B. Coarse arkose with interbedded shale and conglomerate.
A. Lower red conglomerate.

The Upper Cretaceous rocks are almost entirely coarse clastics although a few thin shale beds are found usually in the lower part of the section. The arkoses and conglomerates are characterized by rapid variations in thickness and sometimes by rapid changes from arkose to conglomerate along the strike. These changes suggest rapid deposition of the sediments.

Detailed Stratigraphy.

Introduction.

In this section the numbers I, II, III, and IV refer to the numbers of the four different areas of Cretaceous rocks as marked on the map and the columnar sections. The letters A, B, C, D, and E refer to the five members differentiated in the main area of Cretaceous rocks (I) between Temescal and Mandeville canyons. It has not been possible to draw contacts between all the members, but the location of each member is shown on the map as closely as possible by the above letters.

The stratigraphy of area I is described in detail in the following pages. The smaller Cretaceous areas are then described and an attempt is made to correlate them with the section of area I.

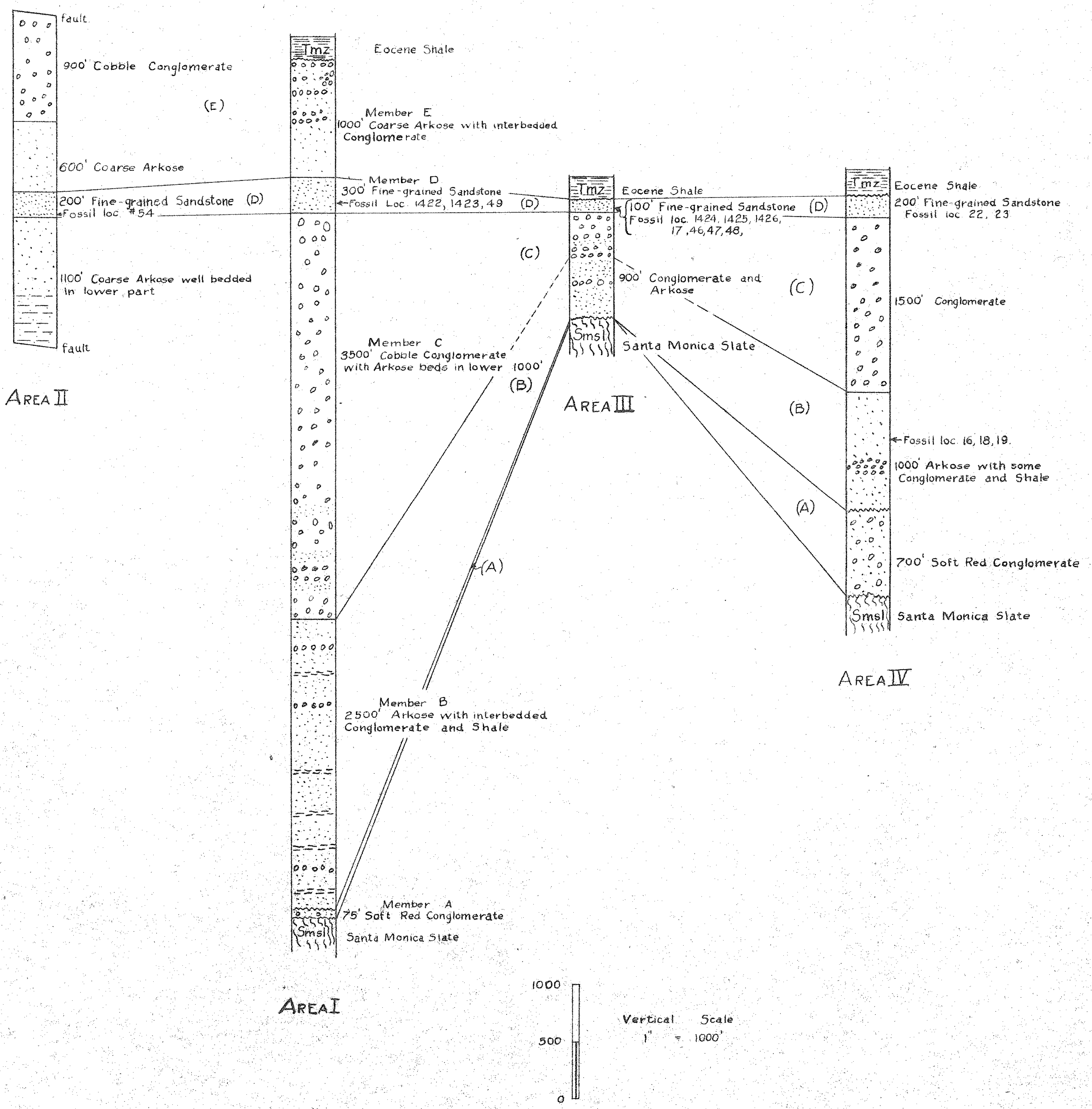
The lithology of the section in Area I is described briefly in Fig. 2, and columnar sections of the four areas are given with the probable correlation of the members (Fig. 3).

Figure 2

UPPER CRETACEOUS SECTION
between Temescal and Mandeville canyons (Area I)

		Maximum thickness	Lithology
MIOCENE			Modelo
			UNCONFORMITY
UPPER CRETACEOUS	E	1000'±	Unfossiliferous arkose and conglomerate similar in appearance to that in member B. Thickness indeterminate due to overlap of Modelo and possible faulting, but probably at least 1000'
	D	300'±	Fine grained, massive, tawny colored fossiliferous sandstone. Fossils occurring in hard grey lenses usually less than one foot thick and ten feet long.
	C	3500'±	Uniform, unfossiliferous conglomerate with rounded cobbles and boulders usually less than 8" and averaging 3" - 5" in diameter, made up principally of granite, dense andesite porphyry, diorite, and occasionally quartzite and basalt. Sandy micaceous matrix occurring in much less amount than the cobbles and boulders. Massive resistant arkose beds as much as 50' thick in lower 1000' of this member.
	B	2500'±	Light brown, coarse grained, massive, well consolidated arkose composed of quartz, feldspar, biotite, hornblende, and many small granitic fragments. Contains shale beds up to 20' thick and conglomerate beds as much as one or two hundred feet thick. Conglomerate more prominent near top of section, boulders well rounded and similar in appearance to those of member C. Fragmentary plant fossils found in arkose.
			UNCONFORMITY
	A	75'±	Soft, red, unsorted, unfossiliferous conglomerate. Boulders average 5" with a few as large as 2' made up principally of granite, diorite, red aplite, and greenish grey feldspar porphyry, and occasionally quartzite, vein quartz, felsite, and frafments of Santa Monica slate.
			UNCONFORMITY
TRIASSIC(?)			Santa Monica slate

COLUMNAR SECTIONS OF A PORTION OF THE EASTERN SANTA MONICA MOUNTAINS SHOWING UPPER CRETACEOUS STRATIGRAPHY



Stratigraphy of Area I

A. Lower Red Conglomerate.

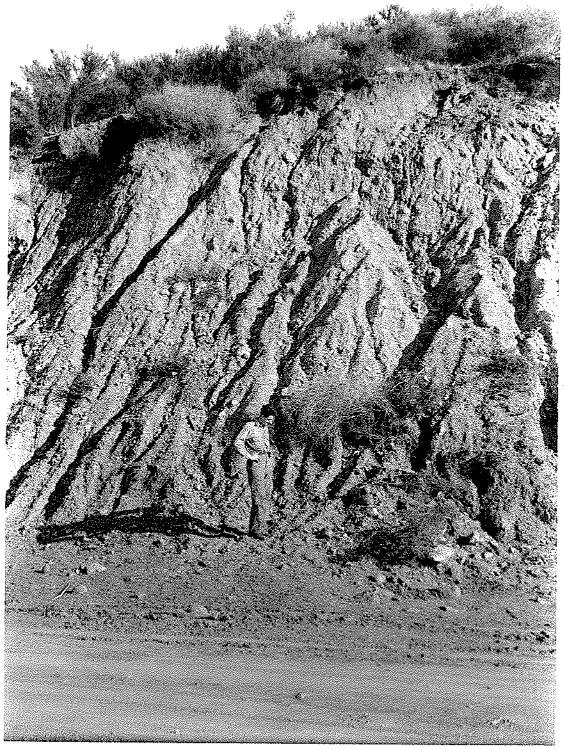
The lower red conglomerate was first described by Hoots. The largest area of outcrop of this member occurs on the north side of the mountains and is best exposed along Mulholland Highway where it reaches a thickness of about 750 feet. It has also been found by the author on the south side of the mountains, but here attains a thickness of only about 75 feet.

The formation is a deep red, almost purple unsorted conglomerate with thin sandstone beds developed in one or two places. The most common boulders of the conglomerate are granite, diorite, red aplite, and a greenish grey feldspar porphyry. The member contains lesser quantities of quartzite, vein quartz, and felsite boulders and a few fragments of Santa Monica slate. The rock is very soft and highly weathered and even the boulders are soft and easily cracked. The matrix is usually present in larger amounts than the boulders. The boulders are poorly sorted, but well rounded and highly polished. Some are as much as two feet in diameter, but most are much smaller.

The relation of the lower red conglomerate to the Triassic slate and the Upper Cretaceous lower arkose (member B) is best shown on the south slope of the mountains in area I, the best exposures being on the first ridge west of Mandeville canyon, where four road cuts cross the contact. In the road cut on top of this ridge the red conglomerate which here is about 75 feet thick, lies on the Santa Monica slate with a profound unconformity. The slate is highly metamorphosed and contorted, but has been

PLATE I

1. Lower red conglomerate on Mulholland Highway, Area IV.



eroded to a smooth surface on which the lower red conglomerate lies. The contact with the slate dips about 35° to the south.

The depositional contact between the red conglomerate and the overlying arkose (member B) is similarly sharp. The dip of this contact approximates that at the base of the conglomerate. On the east side of the ridge the red conglomerate is apparently overlapped by the arkose which is in depositional contact with the slate along the first and second road cuts above the bottom of the canyon. Between these two lower road cuts however, a thin wedge of red conglomerate appears between the slate and arkose.

The red conglomerate is found likewise on the ridge east of Mandeville canyon and also on the ridge east of Rustic canyon. The lensing character of the conglomerate and the sharp contact between it and the lower arkose suggest an unconformity between the two members with the overlying arkose overlapping the conglomerate.

The area of lower red conglomerate on the north side of the range in area IV is much larger and thicker, but the relationships are poorly exposed. However the red conglomerate may be seen lying on the slate with a depositional contact in one small road cut on the Avenida Oriente fire road about 1200' north of Mulholland Highway. No good exposure of the upper contact was found, but the change from red conglomerate to brown conglomerate or arkose seems fairly sharp.

This area of red conglomerate extends in a northeasterly direction with a width of about 2000' for almost three miles. To the northeast it is overlapped by Modelo shale and sandstone. To the southeast the conglomerate pinches out either by thinning or faulting or overlap by the overlying arkose.

No fossils have ever been found in this lower red conglomerate, hence its exact age is not known. A very similar unfossiliferous soft red conglomerate, the Trabuco formation, lies at the base of the Upper Cretaceous section of the Santa Ana mountains. From the appearance of the two rock types and their location in the section, it is thought that they are probably the same age. The Trabuco formation has generally been assigned a late Lower Cretaceous or early Upper Cretaceous age from its relations to the underlying and overlying rock.

B. Coarse arkose with interbedded shale and conglomerate.

The lower arkose is best developed in Area I where it reaches a maximum thickness of 2500', the thickness increasing slightly towards Mandeville canyon on the east. This member in this area forms a strip over two miles in length dipping off the south side of the range at angles ranging from 15° to 50°. It is best exposed on the ridges between Mandeville and Rustic canyons.

The arkose, which makes up about 80% of this member, is characteristically light brown, coarse, massive, and well consolidated. The principal mineral constituents are quartz, feldspar, and biotite with many small granitic fragments. Shale beds, usually of a dark grey color and ranging from paper thin laminae to as much as 20' in thickness, are found interbedded with the arkose. The conglomerate beds may be as much as one or two hundred feet thick, but are very variable and rapidly lense out along the strike. The conglomerate consists of the thick member above the arkose.

This lower arkose member is usually found lying upon the lower red conglomerate with a sharp break in lithology, but with no marked angular unconformity.

Where the arkose lies directly on the slate, slate fragments are sometimes found mixed with the lower five or ten feet of arkose while in other localities no slate fragments can be found at the base of this member. These slate fragments in the lower few feet of the arkose suggest that the arkose was laid down directly on the slate thus offering additional proof of an unconformity between the arkose and lower red conglomerate. The erosion surface on the Santa Monica slate seems to have been generally flat with occasional small gullies. About two thirds of the way up Temescal canyon a small slate monadnock protrudes through the Cretaceous rocks.

A complete gradation exists between the lower arkose and the thick conglomerate section (member C) above, so that the contact between the two members is arbitrary. Conglomerate beds become thicker and more numerous and arkose beds thinner and less numerous at progressively higher levels in member C, so that the upper part of the member is almost entirely made up of conglomerate.

With the exception of a few plant fragments on the ridge west of Mandeville canyon, no fossils have been found in this great thickness of clastic material, hence no direct correlation can be made with other sections of southern California

C. Cobble conglomerate.

Perhaps the most remarkable feature of the Cretaceous rocks of this area is the great thickness of cobble conglomerate. This conglomerate is best exposed in Temescal canyon, but may be traced as far east as Mandeville canyon, where it is completely overlapped by

Modelo and Quaternary terrace deposits.

Near Temescal canyon these conglomerates reach a thickness of between 3000 and 4000 feet. The conglomerate section is duplicated to some extent by several small, probably normal faults which dip steeply to the north.

Massive resistant arkose beds as much as 50 feet thick are found in the lower 1000 feet of the cobble conglomerate member. These are best exposed on the west side of the upper part of the small canyon east of Temescal canyon. The upper two or three thousand feet of the cobble conglomerate is almost entirely composed of a uniform conglomerate with very abundant, strikingly rounded cobbles and boulders usually not over 8" and averaging 3" to 5" in diameter. The cobbles include granite, dense andesite porphyry, diorite, and occasionally quartzite and basalt. The matrix is sandy and micaceous and much less prominent than the cobbles and boulders. Thin lenses of sandstone occur in a few places in the conglomerate too, but on the whole bedding is very indistinct or absent.

The unfossiliferous conglomerate (member C) is overlain by fossiliferous, fine grained, sandstone (member D). The contact between these two emembers is very sharp, but no marked angular unconformity exists between them. The nature of the contact between the conglomerate and upper sandstone on the west side of the lower part of Temescal canyon suggests an overlap, but evidence for this is as yet not conclusive. To the east of Temescal canyon this Cretaceous conglomerate and sanstone is progressively overlapped by the Modelo shale and sandstone and Quaternary terrace gravels.

Hoots believed that these conglomerates were marine, but direct evidence of their origin is lacking.

PLATE II

1. Quarry in <u>Metaplacenticeras</u> beds (Area II), Santa Ynez Canyon, Locality 54.

2. Opposite side of same quarry.

D. Fine grained fossiliferous sandstone.

The sandstone overlying the cobble conglomerate near the bottom of Temescal canyon is fine grained, massive, and tawny colored often stained reddish on the weathered surface. The member may be as much as 300 feet thick, but the contact with the coarser unfossiliferous arkose above the sandstone is not well exposed.

Fossils occur within 100 feet of the base of the sandstone in hard grey lenses which are usually less than one foot thick and five or ten feet long. The fossils are fairly well preserved, but the sandstone in which they occur is so hard that few good specimens can be obtained as the shells tend to break away leaving only the internal casts. Much of the fossil material is fragmentary, so it is probable that the fossils have been transported and deposited in these lenses.

The same sandstone probably occurs about one mile east of Temescal canyon in the vicinity of Hoots' locality 49. This locality is now on privaite property and not accessible, but the fauna is similar and the matrix in which the fossils are found appears to be the same as that at localities 1422 and 1423.

The fauna from localities 1422 and 1423 on the west side of Temescal canyon include:

Glycymeris veatchii (Gabb), Trigonia sp., Meekia navis Gabb, Flaventia lens (Gabb), Cymbophora ashburnerii (Gabb), Perissytis brevirostris ? (Gabb), Conchothyra rotunda (Waring), Margarites ornatissimus (Gabb), Gyrodes expansa Gabb, Turritella chicoensis perrini Merriam, Turritella chicoensis perrini Merriam flat whorled variety, Oligoptycha obliqua (Gabb), Metaplacenticeras californicum (Anderson), Metaplacenticeras pacificum ? (Smith).

Metaplacenticeras is the most characterisitic fossil of this assemblage. Three species of this genus *M. pacificum* (Smith), *M. Californicum* (Anderson) and *M. santaemonica*(Waring), have been described from the Upper Cretaceous beds of the Pacific Coast.

M. pacificum and *M. californicum* have generally been found associated and appear to have a narrow stratigraphic range. The type locality for these two species is Henley, California and they have been reported from Arroyo del Valle, southeast of Livermore, Alameda County; in Siskiyou County; in southern Oregon; in the Santa Ana mountains, and in the Simi Hills (4).

Smith states that *Metaplacenticeras* has a wide range in northern central, and southern California, but is always found in the same horizon. Unfortunately very little is known of the stratigraphic position of this horizon in the local sections in northern and central California.

The position of the genus *Metaplacenticeras* in the Upper Cretaceous sections of the Santa Ana mountains and Simi Hills, however, has been determined by Popenoe (3) who found that it is confined to a very narrow horizon and may be considered to yield a basis for correlation of considerable importance. Popenoe believed *M. sanctaemonica* to be a synonym for *M. pacificum.*

Since *Metaplacenticeras* has been found within narrow limits in all four areas of Cretaceous rocks described in this paper, it has been used as a marker in the probable correlation of the four areas.

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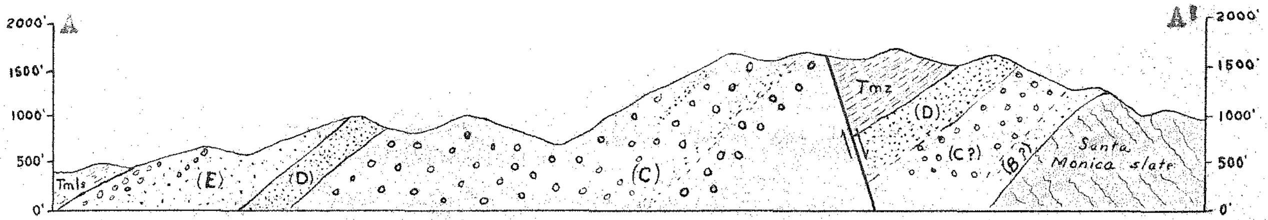
(4) Smith, J. P., The Development and Phylogeny of Placenticeras. Proc. Cal. Acad. Sci., Third Ser., Vol. 1, pp. 181-240,1900.

E. Upper arkose and conglomerate.

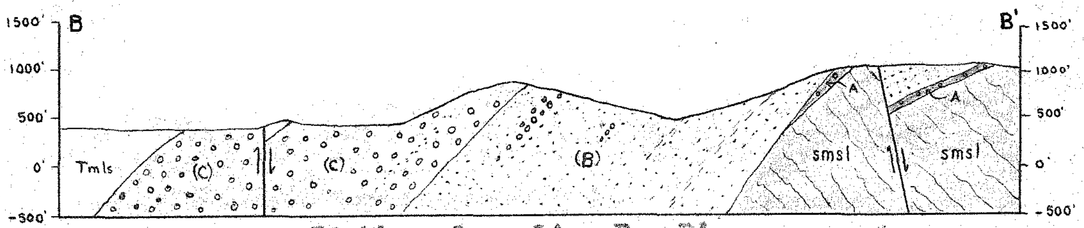
The unfossiliferous arkose and conglomerate overlying the fine grained fossiliferous sandstone west of Temescal canyon is similar in appearance to the lower arkose and conglomerate. The thickness of this upper member is indeterminate due to overlap by the Modelo and complication by faulting, but it is probably at least 1000 feet thick.

Fig. 4

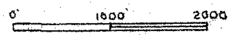
GEOLOGIC SECTIONS ON SOUTH FLANK OF THE EASTERN PART OF THE SANTA MONICA MOUNTAINS



Section along line A-A'



Section along line B - B'



Horizontal and vertical scale
1" 2000'

DESCRIPTION AND SUGGESTED CORRELATION OF THE LESSER CRETACEOUS AREAS.

II. Santa Ynez canyon block. (Area II)

This block in the lower part of Santa Ynez canyon is bounded on all sides by faults, with the possible exception of the southeast corner where the structural relations are not well exposed.

The lower part of the section consists of fairly coarse grained, hard, grey, arkosic sandstone. The lower part of this arkose is well bedded with massive beds ranging from a few inches to ten or twenty feet thick. The upper part is massive and is quarried for use as rip rap. A few small unidentifiable mollusks were found near Hoots' locality 41. Hoots reports Parallelodon brewerianus from this locality.

A fine grained fossiliferous sandstone overlies the arkose. The sandstone is very similar in appearance to that in Area I, and the fossils occur in small, extremely hard lenses. The fauna as listed by Hoots is very similar to that of the sandstones of lower Temescal canyon. It contains Metaplacenticeras and some of the fossiliferous lenses are made up almost entirely of the giant variety of Turritella chicoensis perrini Merriam. It is believed therefore, that since both the lithology and fauna are so similar, that these beds are probably correlatives of the fossiliferous beds of lower Temescal Canyon.

South of these fossiliferous beds the dip steepens rapidly. Several hundred feet of sandstone and arkose overlie the fossiliferous beds. This sandstone and arkose is in turn overlain by a thousand feet of almost vertically dipping cobble conglomerate. The contact between arkose and conglomerate is well exposed on the east side of

Temescal canyon and is a normal sedimentary contact. To the east these conglomerates rapidly grade into arkose, so that at the top of the ridge east of the canyon the conglomerate has largely been replaced by coarse arkose.

The upper part of these conglomerates in Santa Ynez canyon has been faulted against Topanga sandstone.

The age of the block on the ridge on the west side of the lower part of Santa Ynez canyon is not known. No fossils have been found in it so that it may be either Cretaceous or Eocene.

III a. Cretaceous of Upper Temescal canyon. (Area III)

A strip of Cretaceous rocks about half a mile wide extends from about half a mile north of the lookout tower on the Santa Ynez canyon fire road in a south easterly direction for about two and a half miles. This Cretaceous section is not over 1000' thick.

For the most part this strip of Cretaceous rocks is composed of arkose and conglomerate, but in many places near the top of the section lenses of fine grained fossiliferous sandstone are found. The lithology of this sandstone is very similar to that of member D in Area I.

Just east of the lookout tower on the Santa Ynez fire road the Cretaceous section consists of basal member of about 200' of coarse arkose lying on the Santa Monica slate, an intermediate member consisting of 200' of cobble conglomerate lying on the arkose, and an upper member composed of about 100' of the fine fossiliferous sandstone on the top of the conglomerate. The contact between the conglomerate and upper sandstone is very sharp suggesting a possible unconformity between the two.

This succession is similar to that of the thick section of Area I (members B, C and D) but is very much thinner and to the southeast of the locality just mentioned no sharp distinction between the conglomerate and lower arkose can be found so that the lower two members cannot be directly correlated.

Fossils found in the upper sandstone in Area III at localities 1424, 1425 and 1426 are very similar to those found in member D in Area I. The fauna contains Metaplacenticeras californicum (Anderson) and giant specimens of Turritella chicoensis perrini Merriam. The giant variety of Glycymeris veatchii (Gabb) is the most abundant species in the above localities and is also found in Hoots' locality 49 in member D in Area I. Because of the similar lithology and fauna this sandstone is believed to be correlative with member D in Area I.

These Cretaceous rocks at least for the greater part, lie unconformably on the Santa Monica slates and not in fault contact as believed by Hoots. The contact may be followed around the canyon walls and appears to be almost flat or dipping gently to the southwest parallel to the overlying beds. In one locality an excellent exposure may be seen along a cliff between Temescal and Rustic canyons, and may be reached by the fire trails about half way up Temescal canyon. The cliff where the contact is best exposed is about 300 feet north of the fire trail on the east side of the ridge. The contact between the slate and arkose is very sharp and no trace of the lower red conglomerate has been found at this exposure or elsewhere along the contact in this area.

This strip of Cretaceous rocks is cut off at both ends by faults. There seems to be some unexposed structural complication at the south end of the strip as the large easterly trending fault between the Eocene and main Cretaceous section in Area I can be traced only as far as Pulga canyon, but must separate the two areas. It cannot be traced directly across the Cretaceous - Santa Monica slate contact however.

The relation between the Cretaceous and overlying Eocene is apparently one of overlap. At some places along the contact the Eocene shales lie upon the upper fossiliferous sandstone, while at the other places the Eocene shales lie directly on the conglomerate with the sandstone missing. At the point where the contact crosses Temescal canyon some of the upper conglomerate and arkose is exposed between the Eocene shale and the fossiliferous Cretaceous sandstone. No great angular unconformity has been found between the Upper Cretaceous and Martinez rocks, although an erosional unconformity is apparently present.

The Upper Cretaceous section in this strip just described is apparently very much thinner than the section in Area I. It is probable that the nature of the deposition accounts for much of the thinning, but it might be partly due to an overlap by the upper fossiliferous sandstone (D). The lenticular nature and the great thicknesses of coarse arkose and conglomerate suggest very rapid deposition in deep basins so that perhaps great variations in the thickness of the section are to be expected.

IV. The Cretaceous of the Reseda Quadrangle (Area IV).

The lower red conglomerate of this area which has already been described on page (12), is the probable equivalent of member A in Area I, but is here much thicker.

The Cretaceous rocks overlying the red conglomerate in the Reseda Quadrangle were estimated by Hoots to be 2500 feet thick. The basal 1000 feet of this section is composed largely of coarse, light brown arkose, with some thin beds of shale and conglomerate and resembles the rocks of member B in Area I.

The author found no fossils in these beds. Hoots, however, found specifically indeterminate Scaphites and Inoceramus in the lower arkose, and a fauna containg Metaplacenticeras in beds apparently overlying the conglomerate, and just below the Eocene contact.

These facts suggest that the upper 2500 feet of arkose, conglomerate and sandstone developed here probably correspond to the 7000 feet of members B, C, D, and E in Area I.

V. Fossils of the genus Inoceramus have been reported on the ridge east of Stone Canyon reservoir in rocks called Topanga(?) by Hoots, indicating that these rocks are Upper Cretaceous rather than Miocene.

Fossils from the <u>Metaplacenticeras</u> beds of the eastern part of the Santa Monica mountains

(Member D)

						Hoots' localities							
	1422	1423	1424	1425	1426	17	22	23	46	47	48	49	54
PELECYPODS													
Cucullaea youngi Waring				X								X	
Parallelodon brewerianus (Gabb)													X
Glycymeris veatchii (Gabb)		X	X	X	X	X	X	X	X		X	X	X
Meekia navis Gabb	X												X
Crassatella sp. A							X						
Crassatella sp. B												X	
Protocardia sp.								X					
Cymbophora gabbiana (Anderson)			X	X			X	X			X	X	X
Cymbophora ashburnerii (Gabb)		X	X										
Corbula sp.												X	
Flaventia lens (Gabb)		X											
Trigonocallista bowersiana (Cooper)				X		?		X		X	?	X	
Trigonia evansana Meek	X	X	X	X	X	X	X	X	X	X	X	X	X
Trigonia leana Gabb													X
Pholadyma sp.												X	
GASTROPODS													
Gyrodes expansa Gabb		X											X
"Gyrodes compressa Waring"								X		?			
Gyrodes sp.												X	
Margarites ornatissimus (Gabb)		X											X
Turritella chicoensis perrini (Merriam) round whorled variety	X	X		X							X		X
Turritella chicoensis perrini (Merriam) flat whorled variety		X											
Conchothyra rotunda (Waring)		X										X	
Volutoderma averillii (Gabb)				X									X
Oligoptycha obliqua (Gabb)	X	X								X			X
Perissytis brevirostris ? (Gabb)		X											
CEPHALOPODS													
Eutrophoceras sp.													X
Baculites sp.													X
"Pachydiscus" sp. A (giant species)													
"Pachydiscus" sp. B and sp. C													X
Metaplacenticeras pacificum (Smith)		X				X	?	X		?	X	X	X
Metaplacenticeras californicum (Anderson)	X	X	X	X	X								X

Upper Cretaceous fossils from below the <u>Metaplacenticeras</u> beds of the eastern part of the Santa Monica mountains

	Hoots' localities			
	41	16	18	19
Parallelodon brewerianus (Gabb)	X			
Inoceramus sp.		X	X	X
Baculites sp.			X	
Scaphites cf. S. gillisi Anderson		X	X	

CORRELATION OF THE UPPER CRETACEOUS OF THE SANTA MONICA MOUNTAINS

(a) Local correlation.

Although several new Upper Cretaceous fossil localities were found in the eastern part of the Santa Monica mountains, only three species, *Flaventia lens* (Gabb), *Cymbophora ashburnerii* (Gabb), and *Perissytis brevirostris* (Gabb), were added to the previously known fauna. With the exception of Hoots' localities 16, 18, 19, and 41, the fauna appears to be from the same lithologic member and is characterized by *Metaplacenticeras californicum* (Anderson), *Turritella chicoensis perrini* Merriam, and *Glycymeris veatchii* (Gabb). Several other species are found in only a few of the localities. The local correlation is shown in the columnar sections (Fig. 3).

(b) Correlation with the Santa Ana mountains.

Popenoe (3) made the following remarks on the correlation of the *Metaplacenticeras* beds of the Santa Monica mountains. "All the fossils determined from these beds in the Santa Monica mountains have been found in the Williams formation of the Santa Ana mountains with the exception of *Parallelodon brewerianus* and *Conchothyra rotunda*. The Williams formation then, is probably correlative with the *Metaplacenticeras* beds of the Santa Monica mountains."

The present work has tended to confirm this correlation of the *Metaplacenticeras* beds (member D) in the Santa Monica mountains with the Williams formation of the Santa Ana mountains as the additional species found in the Santa Monica mountains are also characteristic of the Williams formation. *Metaplacenticeras* and the flat whorled variety of *Turritella chicoensis perrini* Merriam which occur in member D are found only in the Williams formation of the Santa Ana mountains. Likewise the giant variety of *Glycymeris veatchii* and large specimens of *Oligoptycha obliqua* (Gabb) are characteristic of the uppermost beds of the Santa Ana mountains, and as Popenoe mentioned most of the other species in member D are found in the Williams formation. This correlation therefore is believed to rest on a firm faunal basis.

The lower red conglomerate member (member A) in the Santa Monica mountains is very probably correlative with the Trabuco formation of the Santa Ana mountains. Both formations are unfossiliferous, but their lithology is similar and they have the same relative stratigraphic position. They may well represent the same formation.

If the *Metaplacenticeras* beds (member D) and the lower red conglomerate (member A) of the Santa Monica mountains are correlated with the Williams and Trabuco formations respectively of the Santa Ana mountains, perhaps much of the Cretaceous stratigraphic column, as represented by the Ladd formation in the Santa Ana mountains, is represented by the thick clastic members B, and C, of Area I of the Santa Monica mountains. The lithology of the two sections, however, is much different since shale is predominant in the Santa Ana mountains, while in the Santa Monica mountains the section is much thicker and more irregular and the sediments are predominantly conglomerate and coarse arkose.

(c) Correlation with Simi Hills.

Popenoe (3) has determined that the "calcareous sandstones at the base of the exposed Upper Cretaceous section of the Simi Hills are in part equivalent to the subzone of *Turritella chicoensis* (giant form) at the top of the Holz shale of the Santa Ana mountains, and in part (the *Metaplacenticeras californicum* beds) may be equivalent to the Williams formation.

The *Metaplacenticeras* beds near the top of the calcareous sandstones at the base of the exposed Upper Cretaceous section of the Simi Hills are then probably the equivalent of the *Metaplacenticeras* beds of the Santa Monica mountains. Sixteen of the nineteen determinable species from the *Metaplacenticeras* beds of the Santa Monica mountains are found in the *Metaplacenticeras* beds of Dayton canyon in the Simi Hills. One of the nineteen species, *Conchothyra rotunda* (Waring), has not been found elsewhere in California.

If this correlation is correct the 1500 feet of coarse arkose and conglomerate exposed above the *Metaplacenticeras* beds in areas--I and II on the Santa Monica mountains may represent part of the 5500 feet of massive sandstone above the *Metaplacenticeras* beds of the Simi Hills.

Unfortunately no attempt can be made to correlate the *Metaplacenticeras* beds with northern and central California as although *Metaplacenticeras* is known to occur in several places, no detailed work has been done on the stratigraphy of those areas.

J. P. Smith (4) has suggested that *Metaplacenticeras* was probably of Cenomanian age but F. M. Anderson (5) in his latest remarks on the subject has placed *Metaplacenticeras* about lower Senonian. This latter determination seems to accord better with known Stratigraphic facts than the early correlation of Smith.

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(5) Anderson, F. M., Subdivisions of the Chico Series. Abstract, G. S. A., Cordilleran Section, April 1941.

STRATIGRAPHY OF THE MARTINEZ

The Martinez formation of the Reseda quadrangle has been described by Hoots as a thin unit of shale, sandstone, and limestone with an approximate thickness of 250 to 350 feet.

The largest area of Martinez sediments in the Santa Monica mountains is mainly between Temescal and Santa Ynez canyons in the Topanga canyon quadrangle to the south of the Reseda quadrangle. This area extends in a north-south direction for about three miles and averages about one mile in width. In the southern two-thirds of this area the Martinez rocks dip 20° to 45° to the southwest. The north end of the Eocene block is on the nose of the main anticlinal fold of the mountain range, so that there the dip swings around to the northwest.

The Martinez section is between three and four thousand feet thick. The lower 2000' consists predominantly of shales, with some siltstone and very fine grained sandstone, and interbedded reefs of algal limestone. The shale is micaceous and usually a light brown color, showing little evidence of bedding and containing very hard, fine grained concretions. The siltstone and fine grained sandstone is finely bedded and very often shows excellent cross-bedding.

The algal limestone occurs in prominent discontinuous white reefs varying in thickness from a few inches to about 400' in the case of the largest reef. Usually these reefs terminate very abruptly although one large reef has been traced for about a mile and a half and is approximately 400' thick in its thickest part.

The upper 1000' to 2000' of the Martinez consists of arkose and conglomerate with some shale and many smaller reefs of algal limestone. No unconformity has been found anywhere in the Martinez and the shale and limestone in both the upper and lower parts are similar in appearance. The arkose is usually light colored and the conglomerate is whiter, has more matrix, is poorly sorted, and the pebbles more angular than the cobble conglomerates of the Cretaceous. Many of the arkose beds stand out as bare ridges in the upper part of Pulga Canyon.

The Eocene rocks in the north eastern part of this area lie unconformably on the Cretaceous sandstones and conglomerates. The other contacts are fault contacts with the possible exception of a locality about half a mile north of locality 1435 where the Vaqueros (?) beds may lie unconformably on the Eocene. The exact location of the easterly trending fault which forms the south boundary of this Eocene area is not known as both the Martinez and Upper Cretaceous rocks consist of similar appearing arkose, but it is believed to be approximately as indicated on the map.

A distinct angular unconformity is present between the Martinez and overlying Vaqueros(?) - Sespe (?) as the Middle and Upper Eocene are missing and there is a difference of 20° to 30° in the strike and dip of the two formations.

The small rectangular fault block about one half mile north west of the lookout station is composed of arkoses and conglomerates dipping to the northwest and intruded by gabbro plugs. No fossils have been found in this small block. It contains two small reefs of algal limestone, white, poorly sorted conglomerate, and ridge-forming arkose beds. For these reasons these rocks are believed equivalent to those in the upper part of the Eocene area to the south.

Martinez fossils have been collected at several localities. The fossils are poorly preserved and usually only the casts of the original shells are found. The material was collected mainly to determine whether the rocks were Upper Cretaceous or Martinez, so that only a few of the diagnostic species were identified.

Fossils from the Martinez formation of the eastern part of the Santa Monica mountains

	1427	1428	1429	1430	1431	1432	1433	1434	1435
Turritella pachecoensis Stanton			X	X	X				X
Mesalia martinezensis (Gabb)	X	X	X				X		
Schizaster martinezensis Kew			X			X	X	X	