METHODS OF PREPARATION OF MATERIALS USED IN THE STUDY OF THE OLIGOCENE SEDIMENTS OF RESTORATION POINT, WASHINGTON

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I. INTRODUCTION

To become familiar with the rapidly growing use of petrography for attacking the problems of sedimentation, both in consolidated and unconsolidated formations, the writer has attempted to apply the most modern and approved methods to a particular formation of the Tertiary period. It is not the purpose of the paper to deal with or discuss any change in formational structure or paleontology but rather to give the results of a more or less cursory and wholly preliminary examination of the microscopic lithology and mineral content of the sediments which make up part of the section of the Blakeley Formation as exposed at Restoration Point. Some attempt will be made to roughly locate the places of derivation of the sediments which go to make up this formation.

The area involved in this report is located on Bainbridge Island, across the bay from Seattle and is easily reached by boat. As the time for field and laboratory work was very limited the total Blakely formation, consisting of some nine thousand feet of sediments, could not be examined and accordingly only those sediments exposed along the beach between the Country Club dock and the South Beach dock were used. As this section includes parts of nearly the topmost and lowermost portions of the formations it was thought to be the most representative and most likely to show any mineral change

that was likely to occur, whereas a section from either the top or the bottom would only show that type of sediment which was collecting at the particular period embraced.

The studies on this area previously done have been limited to a discussion of the megascopic lithology and to the fauna, neither of which have been a great aid. The literature regarding this area has been briefly outlined and summarized in a Washington State Geological Bulletin (1).

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(1)"Tertiary Formations of Western Washington." Washington Geological Survey Bulletin #13, 1916.

Miss N. M. Tegland, of the University of California, has in preparation a paper on the fauna of the Blakely series in which she also hopes to bring out some notes on the lithology, both microscopic and megascopic.

In view of the scarceness of the literature dealing with this area and the small extent with which sedimentary petrography is used in the United States it has been found that the problem is much larger than it should be and that many interesting studies cannot be made as the literature pertaining to them is mainly foreign and usually unobtainable. Then again, the geology of the western part of the United States has not received the attention that other parts of the nation have and accordingly one does not know the nature or extent of the rock bodies which can contribute sediments to any particular formations. To be positive of the derivation of the sediment would require a detailed petrographic study of the rocks making up and bordering the Olympic and Cascade Mountains. This

detailed information is not available as yet and, although the writer has received much helpful and useful information as to rock composition of different regions from colleagues, the problem of placing the region of derivation will be more or less inexact and can be only regarded as a foundation for further research.

II. STRATIGRAPHY

The formations as exposed at Restoration Point are part of the northern limb of a large anticlinal fold which has a general trend east and west, extending from the New Castle Hills through South Seattle and then onto the side of the Olympic Peninsula bordering Puget Sound. Before the folding of the sediments they were deposited in an embayment, one of many, which constituted the Oligocene seas or bays of Western Washington. Apparently these embayments were separated by barriers which affected both the type of sedimentation and the marine life of the period.

The period of deposition in the Blakeley Basin evidently was not one of quiescence but must have been one of much disturbance, very small disturbances to be true, but large enough to affect the type of materials being deposited. The lowermost sediments exposed are predominantly grits and medium grained conglomerates, intersperced with shales and sandstones of a gritty nature. Toward the top of the lowermost section or near the middle of the formation a very coarse conglomerate is encountered. This coarse conglomerate is preceded by

several hundred feet of fine shale. Immediately following this coarse conglomerate is a fine shale, which is characteristic of the rest of the section. Using the coarse conglomerate already mentioned, it is possible to divide the section and the whole formation into two parts, the topmost, consisting of shales and fine sandstones and exposed typically at Restoration Point, and the lowermost, which consists of grits and conglomerates, and is exposed best nearer to the South Beach dock.

In the lower section shore or very near shore conditions prevailed. Interbedded with the grits are small seams of a lignitic coal and in some instances the outcrop will be so filled with carbonaceous matter that it appears black. In certain spots ripple marks may be noticed but as a general rule they are very rare and easily escape detection. Associated with the ripple marks can be noticed what H. C. Sorby called "the breaking up structure," which is due to sudden waves disturbing the newly deposited silty material of a near shore deposit. Such a structure would usually be associated with ripple marks and would undoubtedly be among the best criteria for near shore deposition.

The ripple marks noticed were of a fairly large size, much larger, in fact, than those that can be noticed on the beaches today. They average between fourteen and eighteen inches between crests and are about six to eight inches between crest and trough. It would seem that the currents were much stronger during Oligocene time than they are today

in Puget Sound and that they must have corresponded more closely to the conditions which prevail at the mouths of some of the larger rivers of the present time.

In the topmost section, however, these conditions have changed to a more or less deep water type of deposition, although it is doubtful if the shore line was situated at any great distance. In this section nothing like ripple marks or coal seams are found or can be noticed and the shale bodies are very thick and massive with almost negligible amount os sandstone intercalated. However, in a great many places and particularly close to Restoration Point a great deal of carbonized wood is found. I believe that such markers would be more typical of a close shore condition than even one or two miles off shore. Even though the Oligocene embayment was no larger than Puget Sound it must have been rather deep on the very borders. Even in Puget Sound it is a strange sight to see wood floating in the center, and it is a rather common experience to encounter wood near the shores. It is unlikely that the seas of the Oligocene embayment were quiet enough to allow the floating of the wood particles to the center and then the leaving of them there long enough so that they could become waterlogged and in a sinkable condition.

Following the deposition of the sediments came the period of folding which developed the anticlinal structure and tipped the sediments so that in a general way they are nearly vertical. The average dip in this section is about 75° to the

northeast. In several places there has been an overturning of the strata resulting in local dips to the southwest. Minor faulting has also been active, as small displacements of a very few feet are noticeable in nearly every portion of the area.

A recent or late Pleistocene uplift is noticeable in this section, as it is everywhere else on the Sound, by means of the abrupt cliff of ten to fifteen feet which separates the present beach from an older beach which surrounds the highlands which go to make up the interior of the Island. At one locality this upraised portion is strikingly shown by a large deposit of Pleistocene fauna, well preserved in very unconsolidated material.

III. PETROGRAPHY

In making a study of this area petrographically the question of taking representative and worth while samples became a larger one than first surmised. In the first place the area is very large and although made up of two distinct megascopic divisions, the number of microscopic divisions was totally unknown. This fact alone brought up the question as to the number of samples that should and would have to be taken to give the best results. The problem of time and materials also came forward with the question of sampling.

In these formations the sediments are entirely consolidated and the methods of sampling worked out and usually used for unconsolidated material are of no use. On the other hand, if

one is to use the methods of sampling advocated for coal or ore, the samples become bulky and the time consumed is by far too long. To get the best method that fitted all requirements the writer spent some time in experimenting with the different methods and by comparison of results selected the simplest and one which can be used for such a large and unknown area while doing preliminary work.

To get some material for standardization, samples were taken from a bed of sandstone about two feet thick and one hundred feet in length. Tje samples, small chips, were taken three feet apart along the strike and one near the bottom, one at the center and one near the top of the bed. These samples were crushed, thoroughly mixed, coned and quartered until a usable amount was obtained and slides prepared.

The next method was to collect samples at different spaced intervals and scraping the surface of the bed. This gave an easier handled sample and less bulky. When examined petrographically the mineral content was the same as the other sample.

The third method was to simply take samples at intervals along the strike of about twenty-five feet, all the samples taken haphazardly across the bed. This method gave results agreeing with the other two types of sampling, and being very easy it was the method adopted. In using this "grab" method the sampler should be careful to note lithologic changes and differences and to sample each change successively. The sampler should realize that this"grab" method is also only good for a

preliminary and reconnaissance work in which a large area must be covered in a short time. For detailed work the first method mentioned is recommended, for, although the results were approximately identical over a space of one hundred feet, the writer does not believe they would check as accurately over a space of five hundred feet and consequently the results so obtained would be subject to discussion.

To any one making a cursory and very general examination of the sediments, the megascopic methods generally used for sediments are entirely appropriate and can often yield very valuable information, but if one desires to make a careful examination of the sediments with reference to derivation, tidal influence, climatic conditions and distance traveled, the thin section more commonly used in the study of igneous rocks is advocated. In most cases one thinks of a finer argillaceous material as being too dense to yield grains large enough to afford any means of study and consequently the idea of sludging sediments by thin section is repellent. Sandstones and grits are also very hard to grind satisfactorily, and the results in most cases are discouraging. In most cases, however, a little careful preparation before grinding will put any sediment in such condition that it will stand the hardest type of usage.

There are many different methods advocated, some simple and inefficient, others elaborate and very efficient from the standpoint of time and general adaptability. The writer has tried many methods listed, but with the cooperation of Mr.

Aaron Waters, has modified the existing methods to meet the exacting needs of sedimentary petrography and some types of igneous rock section work. In some cases it is advisable to soak the specimen in Canada balsam which has been dissolved in xylol or some other solvent of a like nature. After this soaking has been carried on the soecimen can be gently heated and the excess solvent driven off. The viscosity of the Canada balsam solution is optional and should depend upon the porosity of the material used. With large pored, unconsolidated material a very thick, nearly unadulterated mass of Canada balsam may be used. On the other hand if the specimen is consolidated to such a degree that the pore space is not noticeable to the naked eye, the solution of Canada balsam should have a viscosity similar to thin maple syrup so that by capillary action the solution will penetrate to the interior and not form a cemented rim, penetrating the specimen not over an eighth of an inch. In connection with this cementing of unconsolidated material by immersion, C. S. Ross has listed a method by which the specimen is immersed in liquid bakelite

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"Preparation of Sedimentary Materials for Study," C. S. Ross, Economic Geology, Vol.21, No.5, 1926, p.454.

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for several days and then dried by gentle heating at low temperature until a rock-like hardness is obtained. To help the penetration of the bakelite, the Bakelite Company of America designs and sells a vacuum jar which insures penetration. When using the bakelite as a cementing substance, unconsolidated specimens such as sands, clays and soils may be prepared

and molded into such shapes as lend themselves readily to thin section grinding. The one disadvantage of bakelite, which is not so disadvantageous as it is annoying, is the rather high index of refraction (1.63) which it has.

If the time is not available for the for the immersion process of cementation a rapid and faily efficient method may be substituted. The material to be cemented is placed on the hot plate and allowed to heat until Canada balsam will melt when placed upon it. Any amount of Canada balsam is used until the piece will not appear to soak up any more. A low temperature should be maintained during this process as the Canada balsam darkens when subjected to even a medium heat and the section can easily be spoiled. So far this method has yielded just as good results as the longer method and should be recommended for all but the most delicate kind of work.

After the material has been firmly consolidated, the specimen should have one side smoothed by first grinding on a rotating lap using coarse carborundum or emery dust. The coarseness of the abrasive is optional, but that which has given satisfactory results is of about 90 mesh. After this smoothing with the coarse abrasive the surface should be polished by further grinding on a second lap and using a fine abrasive of about 150 or 200 mesh. Before using the fine abrasive the specimen should be thoroughly washed to remove any of the coarse material which will scratch and groove the prepared surface.

After the specimen has been smoothed as well as possible

it is cemented to a glass slide. If the material has not been consolidated with Canada balsam it is advisable to heat the specimen slightly and to melt Canada balsam upon the prepared surface. The glass slide to be used is them heated and Canada balsam is spread upon the upper surface. Ths specimen is then put upon the slide and the two together are left upon the plate long enough so that the balsam becomes liquid. During this process the heat should be low and the slide removed before the turpentinæ in the balsam start to boil. This boiling of the turpentines produces a great number of bubbles which cannot always be removed.

When the balsam has reached the proper liquid stage and the heat has been removed, the slide is placed upon a flat and even surface, and an even pressure is applied to the material upon it. It is by this pressure that the bubbles and the excess balsam are removed from between the slide and the specimen. If the pressure is too great or the surface of the article upon which the slide is resting is uneven there is danger of cracking the slide. If the pressure is removed too soon from the specimen or if it is uneven bubbles are formed and the material must be recemented.

After cementing the specimen upon the slide it should be allowed to cool until the balsam has become hard enough to stand the strain of further grinding. This final grinding is carried on the same as the first grinding except that the cemented fragment is ground down until it is thin enough for light to show through the more transparent grains, or if the

whole mass is made up of fine material, until the specimen is translucent, with the coarse abrasive, and then the final grinding is completed with the fine abrasive until the quartz or felspar or any other known material shows the proper birefringence to be of a thickness of 0.03 mm. This final grinding with the fine abrasive must be carried on very carefully so that the specimen is not ground wedge-shaped. It is also advisable to wash the specimen frequently, especially if the material is arenaceous. This washing will remove any quartz, as hard grains which should become loosened and gouge the thin section. It has been found to be the best practice to keep the section near the center of the lap, and to hold it lightly against the wheel without moving. This is done by cementing a small cork on the side of the slide opposite to that on which the section is placed and to have one cork at each end of the slide. The slide should be warmed slightly at the ends before the corks are cemented so as to allow a better cohesion of the cementing material, which usually is Canada balsam. Other materials may be used besides corks, such as wood, rubber or metal, but it has been found that the cork will cohere to the glass much better than any other substance.

After the section has been ground to the required thickness care should be taken in washing off of any fragments of carborumdum which may be adhering to the surface. Specks of carborumdum are often noticed imbedded in the Canada balsam, and in some cases may lead to peculiar mineral determinations, as the carborundum is crystalline, blue and in nearly

every respect similar to Anatase. The difference is in the optical sign, Anatase being negative and Carborundum positive.

It has been found that the most troublesome process is is putting the cover glass on the finished section. If one attempts to use melted Canada balsam it is found that the sections of sediments rapidly disintegrate and float out under the edges of the cover glass. To overcome this obstacle Canada balsam dissolved in xylol in the ratio of four parts of balsam to one part of xylol is applied to the section. The cover glass which has been heated is then placed on the section and gently pressed down with two matches or splinters. Any bubbles present may be worked toward the outside and gradually from under the cover glass. If one is careful the excess Canada balsam may be removed with a knife or spatula. If time is no factor it is best to leave the section to stand for several days before touching the balsam. In any case, however, the section may be used for examination immediately after placing the cover glass.

It has been noticed that in the American literature the use of the heavier mineral constituents, those having a specific gravity higher than 2.88, is not encouraged for sedimentary work, but if one remembers that these heavy minerals, though very rare in even their primary source, are usually the most resistant constituent, and will most likely be the ones which survive the process of sedimentation, and give a clue as to the exact origin of the sediment.

To extract and concentrate these heavy minerals is a relatively simple task. If the material to be examined is

unconsolidated it should be screen sized and the finest size separated. The other sizes, the larger, may be separated if it is thought necessary, but as the heavy minerals are usually in very small grains and fragments they will usually be found in the smallest sized screenings. If the material to be examined is consolidated one must crush or otherwise

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"Comparative Losses in Crushing and Lifting Rock Minerals." Journal of Geology, Vol. 34, No.3, 1926, p. 275. Albert Johannsen and C. A. Merritt.

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loosen the binding material so that the grains are free. There are several methods which can be used to do this. If the material is calcareous usually a dilute solution of hydrochloric acid will remove the binding material. This same acid will do equally well on feruginous cements. If the cementing material is simply argillaceous, often just soaking in water is sufficient to cause disintegration. If a silicious cement is encountered it is usually best to simply crush the material. As a whole it is perhaps advisable to crush all material and when the proper size is reached to remove objectionable binders with acid. In this way the relative amounts of calcitic or ferrous cementing materials can be calculated and used for some types of determinative purposes. It is well to note that in crushing a rock sample for petrographic purposes it is possible in a great many cases to obtain grains having their crystal outline. For this the specimen should be crushed by hand in an iron mortar and the resulting products constantly screened to let none of the material suffer

greater abrasion than it should. This scheme of crushing should be carried out especially by the beginner as it is often very difficult to determine some of the minerals and the crystal outline is an important aid. After the crushing has been completed it is best to screen the material. The common practice is to screen the material so that it passes through a 35 mesh screen, and the desired quantity is then removed and weighed. One hundred grams should be the minimum amount used, as the losses from the procedure following are usually large. The sample is then placed in a large beaker, preferably pyrex, with a solution of hydrochloric acid. It has been found that the commercial muriatic acid will dissolve any of the soluble cements and remove the iron stainings without attacking any of the minerals present. In some cases it is necessary and even advisable to boil the sediment with this commercial acid. Such boiling may be carried on for variable lengths of time, up to one-half hour, without evidence of attack being shown by the minerals. With a longer period of time it is problematical if such minerals as biotite will stand the hot acid. When using the acid the material should be watched to note the amount of effervescence and to see if the presence of sulphide can be detected by the odor. Iron pyrites, although somewhat expected in the shore phases of a marine embayment, is often a characteristic marker of certain horizons, and its presence should be noted, and as it is readily attacked by hot acid it is never seen in slides of treated crushed fragments and can only be detected by the odor,

given off during the process of boiling. After the acid treatment has been completed the acid and the silt can be washed away. The silt is that material which remains in suspension for several minutes after the water has been agitated. To remove this silt it is possible to allow a slow stream of water to constantly run in the beaker from one side and out the other, but where time is a factor this method is too slow and it is much more rapid to place the sediments in a large milk pan or some similar receptacle and then to shake with water, renewing the water after the shaking. Care must be taken so as to not pour off more of the sediment than the silt, as often it is of value to know the losses that incur in such a manner. When the sediment can be shaken and the water remains clear it can be dried over a steam plate or radiator. This drying should not be carried on over the gas flame or on a hot plate as the steam generated so rapidly drives a good deal of the lighter grains out of the dish. After the sediment is absolutely dry it is weighed and screened again. The sediment is this time screened through k00 mesh and the screenings caught on a 200 mesh screen. The material which eventually remains upon the 200 mesh is used for the separation with the heavy solutions.

There are many different types of solutions which have a specific gravity greater than 2.88, but for convenient use bromoform is perhaps the best. The other well known and often used solutions are, Sonstadst's, Clerici and Methylene iodide. It has been shown that the Sonstadst solutions

replace the bases very actively and consequently they are losing their popularity. The Clerici solutions are mainly used where a specific gravity of more than 4.0 is needed. The same is true for methylene iodide, which has a psecific gravity of 3.33. Methylene iodid is very useful for the detailed research worker, as it is easily diluted with ether to any specific gravity below 3.33, but for the average student the separation to such a fine point is not necessary. Bromoform, the other "heavy" solution, as it comes commercially has a specific gravity of less than 2.66, and as it is valueless for separation purposes it must be concentrated by distillation, freezing or by washing. The washing is perhaps the easiest but as bromoform may be recovered after using by distilling,it is handier to use the distillation method, leaving the apparatus set up for future use.

In using the bromoform for separation purposes the type of receptacle used is quite important. When an unlimited supply of bromoform is obtainable and time is not short, it often has been recommended that a large porcelain dish be used and the top closed by cardboard or a glass plate. Using such a dish gives a large surface for the material to float upon and in the long run the separation is undoubtedly complete. On the other hand it has been noted that the loss of bromoform is excessive, due to evaporation and handling, and that convection currents are set up very easily and consequently the materials which have a specific gravity closely approximating that of the bromoform are not allowed to settle as

rapidly as they should. For the average student the bromoform necessary and the time used in this procedure make it an impossibility and must therefore be rejected. The other apparatus recommended and commonly employed is a separation funnel. There are many different types of funnels obtainable, but it has been found that one about 20 centimeters tall, 7 centimeters at the widest part, and tapering down to 1 centimeter just above the stopper, is preferable. These dimensions are on the outside and are not inside dimensions of the funnel. The inside should taper so that the hole in the stopcock is not smaller than the smallest inside dimension of the funnel. If this is not true some of the grains repose on the area left around the stopcock hole and are not carried through when they should be. The funnel should also have some means of being tightly corked. In most of the funnels a glass stopper is provided. Other funnels which are made especially for this type of separation are provided with a wide open top, such as is common in ordinary funnels, and which may be sealed with a glass plate that has been coated with vaseline. This last type of funnel is perhaps better for all around work, as the contents may be easily stirred, and the funnel is easier to clean.

When introducing the materials into the first mentioned separation funnel it is best that they be poured in through a paper funnel or some such apparatus, so that the material does not cling to the sides of the separation funnel and is not subject to the action of separation fluids. In the wide-mouth type of flask such precautions are not necessary.

While the separation process is going on the material should be shaken or stirred thoroughly every little while. It can be seen that the longer the material is left standing the better the separation will be, but, in most instances, the time is short and fifteen or twenty minutes is all that can be devoted to each sample. Some sediments are very adaptable to this quick separation, as the minerals do not have a specific gravity nearly approximating that of the bromoform, and consequently a longer period of time than fifteen minutes would be unnecessary. In other sediments it is conjectural if the separation can be completed within this time. However, if the material is shaken or stirred often, the heavier minerals will settle rapidly and give a representative selection which can be used for preliminary work and for some types of practical work.

After the separation of the sediment is complete the heavy minerals can be collected in a filter paper and the bromoform saved. The light residue can also be saved in the same manner. It is advisable to wash both groups of minerals with benzol, as this substance absorbs the retained bromoform from the sediment and the filter papers and may be recovered by distillation at some later time. A rather porous and rapid filter paper should be used so as to make the work more rapid and prevent the evaporation of the bromoform. The apparatus used can then be dried with acetone and used immediately. The separated materials can be dried by placing upon a radiator or steam bath.

"An Introduction to Sedimentary Petrography." H.B.Milner, 1922. D. Van Nostrand Co., New York.

It is often found that a study of the heavy minerals is desired without attention being given to the lighter minerals. Usually when this is done chemical or spectroscopic analyses are wanted and the materials must be obtained in large quantities. To do this economically most men have resorted to the crushing of a large amount of material and using the common miner's pan to concentrate the heavy constituents. One should not attempt this until practice has been given to the methods of panning as it is very easy to allow some of the smaller grains to escape. Then again, in some fine shales and clays the heavy minerals are found to be in definite horizons and by elutriation they may be concentrated. As the writer is unfamiliar with the methods of elutriation reference is made to the English authority, A. Holmes.

"Petrographic Methods and Calculations." A. Holmes, 1921. Thomas Murby and Co., London.

After the minerals have been separated with bromoform it is found that the light sediments will contain chiefly grains of quartz and felspar, and unless further detailed work is required further separation si unnecessary. For further separation the methylene iodide preparation is recommended. This may be diluted to any specific gravity with benzol or ether. A very close separation can be carried on with these diluted solutions, results close enough so that the plagioclase

felspars can be differentiated. For further separation of the "heavy" minerals the Clerici solution would be more advisable. As a means of separating the heavy minerals the writer does not favor the use of heavy solutions, as the method is too slow and cumbersome, but instead advocates the use of the electromagnet. Many writers do not recommend the use of this instrument, but for the separation done for this paper it has been very successful and with more precise instruments for measuring and regulating the current a clean-cut and exact separation should result.

As the electromagnets offered for sale at most instrument houses do not have the required lifting power, or are too large to use for separatory purposes, it was thought best to construct one. It was decided that a "U" shaped magnet would be more advisable than the straight pole piece as a more closely closed circuit would result for the lines of magnetism, and that a higher degree of magnetism would be obtained for the power used. The core used was of wrought iron with a diameter of one inch, the two legs of the "U" six inches long and the curvature at the base with a diameter if four inches. The legs are four inches apart between centers. It was thought that to have other variables besides the current would insure greater efficiency so the legs were equipped with movable pole pieces, constructed of wrought iron and fastened to the bottom of the legs with thumb screws and washers. The wire used was size No.18, single cotton covered, copper magnet wire. As the magnetism is dependent upon the number

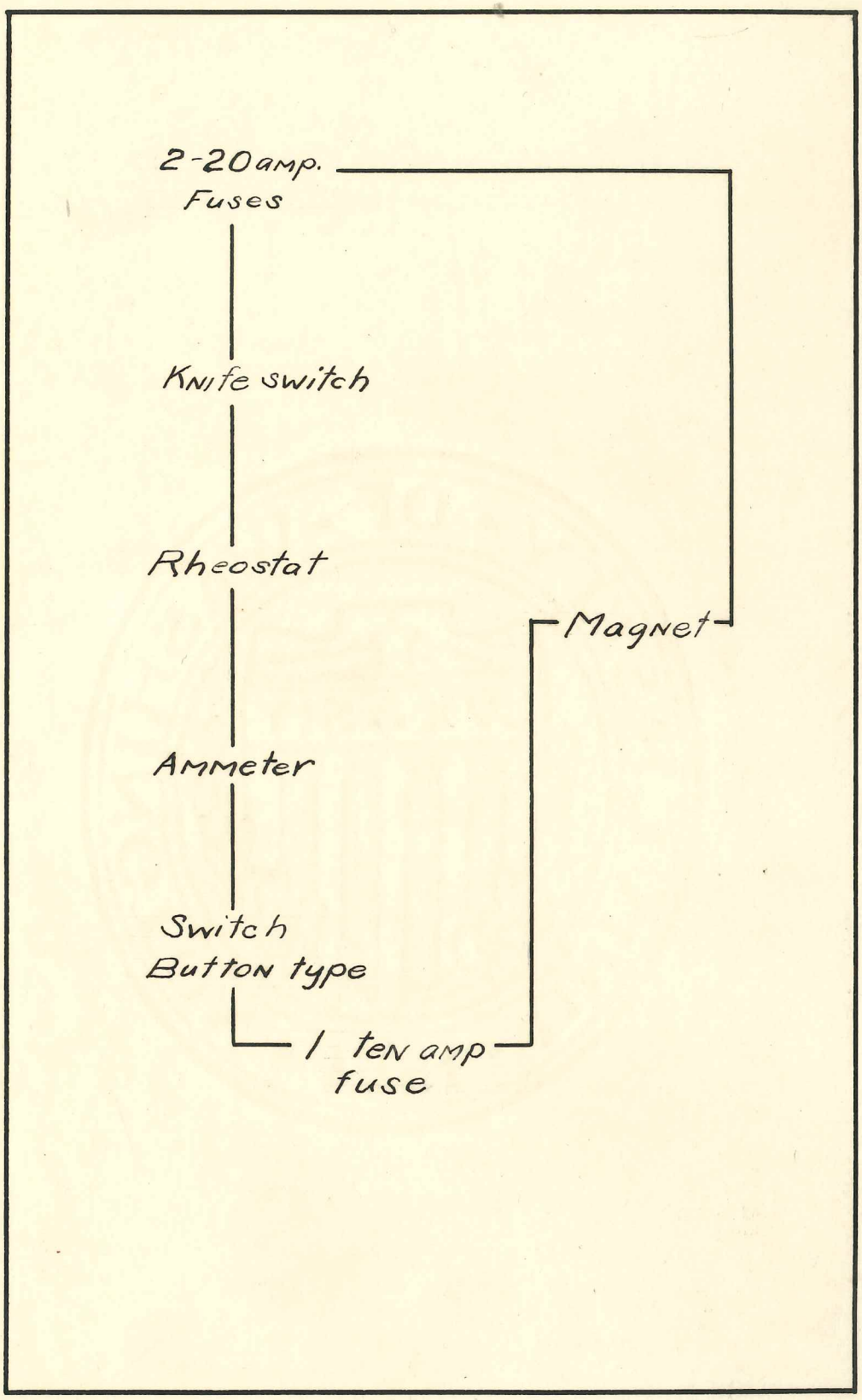
2-20amp.
Fuses
Knife switch
Rheostat
Magnet
Ammeter
Switch
Button type
1 ten amp
fuse

Figure 1

of ampere turns of wire surrounding the core it was found upon calculation that approximately 3000 turns upon each leg would give the maximum efficiency for a current of 10 amperes at a voltage of 110. This number of turns of wire can hardly be wound by hand so a lathe running at very slow speed was used and the wire wound upon wood cores wrapped with cardboard so that the coiled wire could be removed easily. As each coil was wound on the spool it was given a heavy coating of shellac. No other insulating material was used between coils or turns. About 18 pounds of wire was used to wind the magnet. When the coiled wire had been placed upon the iron cores the magnet was permanently mounted upon the wall by means of wall brackets. An ammeter and rheostat were hooked up in series with the magnet and a double bladed knife switch used to control the current. (See figure 1.)

As the writer did not have the time to carry on an elaborate series of experiments it was thought best to take some well known and commonly accepted results obtained by other workers and to check against some of their results. In an article by Thomas Crook the careful and painstaking work of

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"The Use of the Electro-magnet in Petrography." Science Progress, number 5, 1907. Thomas Crook.

Delesse is summarized. Delesse expresses the magnet's power as the ratio of the maximum weight of adhering grains of some standard substance, the magnetic power of which may be taken as unity. Using this idea he listed the magnetic power of some of the commoner minerals with steel as the bases, for

a unit. Steel was given the magnetic power of 100,000.

Steel	100,000		
Magnetite	64,121	Pleonaste	73
Titaniferous magnetite	48,405	Pistacite	49
Ilmenite	5,764	Allanite	47
Pyrrhotite	4,718	Jasper	33
Hematite	2,352	Biotite	20
Hypersthene	687	Idocrase	18
Augite	559	Axinite	17
Garnet (hyacinth)	294	Sahlite	14
Olivine	250	Kyanite	12
Hornblende	237	Salt	12
Chromite	136	Adventurine	7
Siderite	120	Andesine	5
Piedmontite	80	Tourmaline (black)	4
Staurolite	77	Oligoclase (sunston)	4

When the results of Delesse's work were used by the writer it was found that the magnetic power was decreased in the proportion listed above or very nearly so. With the home-made magnet the last mineral which was picked up was the black tourmaline; however, andesine was not affected. To extract the magnetite and titaniferous magnetite a hand magnet only is required. The ilmenite can just be moved with the hand magnet.

For very detailed work it would undoubtedly be best to separate the "heavies" as closely as possible, but for preliminary work the separation into magnetic and non-magnetic minerals will be sufficient. There are only a few minerals which are likely to be confused so where great accuracy is not required the simple separation is sufficient. To do this approximately the maximum magnetic power should be used. The samples should be tested at least three times, as it is possinle that

a group of magnetic minerals will carry a group of non-magnetic minerals with them and dirty up and often destroy the results of a slide. One should not be discouraged if some of the minerals are in the wrong group, as it is surprising how small an inclusion it takes to change the mineral from one typically non-magnetic to one that is magnetic.

When using the magnet at a maximum power great care should be taken in keeping the surroundings clean and free from dust which may get into the material being determined. It has been found that fragments of carborundum are easily picked up which escape notice, and show up in the slides of the heavy magnetic minerals. Whenever possible it is best to have the magnet placed where such contaminations would be impossible.

When the sediment has been separated it is advisable to permanently mount the different materials in Canada balsam, although some people prefer using them mounted in oils. When mounting the fragments in the Canada balsam it has been found that the best method is to first put several drops of the balsam on the slide so that a small lump is formed. An indention can be made in the top of this so as to receive the fragments. When the required amount of fragments, which should be rather small, is place in this indention, the slide is heated with a low heat so that the balsam does not become filled with bubbles and then the cover glass is laid on. The cover glass is gently pressed down with matches or splinters and the bubbles worked out. It is often impossible to remove all of the bubbles from a slide of this kind, due to the usual unevenness

and size of the grains. If the number of bubbles is not excessive they do not harm the slide and may be disregarded.

In the examination of both the thin sections and crushed fragment slides the results have been tabulated wherever possible and no attempt is made to give lengthy descriptions. In this paper it is thought that it is best not to attempt anything more than a listing of the mineral content and allow time for the further detailed work.

In examining the thin sections of the sediments it is strikingly seen that the lower section is largely made up of tiny basaltic pebbles and derived basaltic materials. Felspar is apparently the outstanding mineral, and it is largely of the andesine-labradorite type. In most cases it is remarkably fresh and is very angular.

One of the peculiar features noted in these fresh felspars is that the centers are sometimes corroded and often completely gone, while it is only the outside borders which are fresh. Such alternation could not be attributed to atmospheric weathering but should be attributed to the action of the volatile constituents of the original magma and can, therefore, be classed as primary or endomorphic alteration.

On the other hand the component parts of the grits and conglomerates are well rounded tending to show rapid carrying and deposition at times and other times of slower deposition. In some strata quartz grains, very angular, are found. These are most likely due to the laying down of tuffs in and along the shores of the shallow sea which formed the basin at this time. Some of the beds in this region have a high ash content

Plate 2

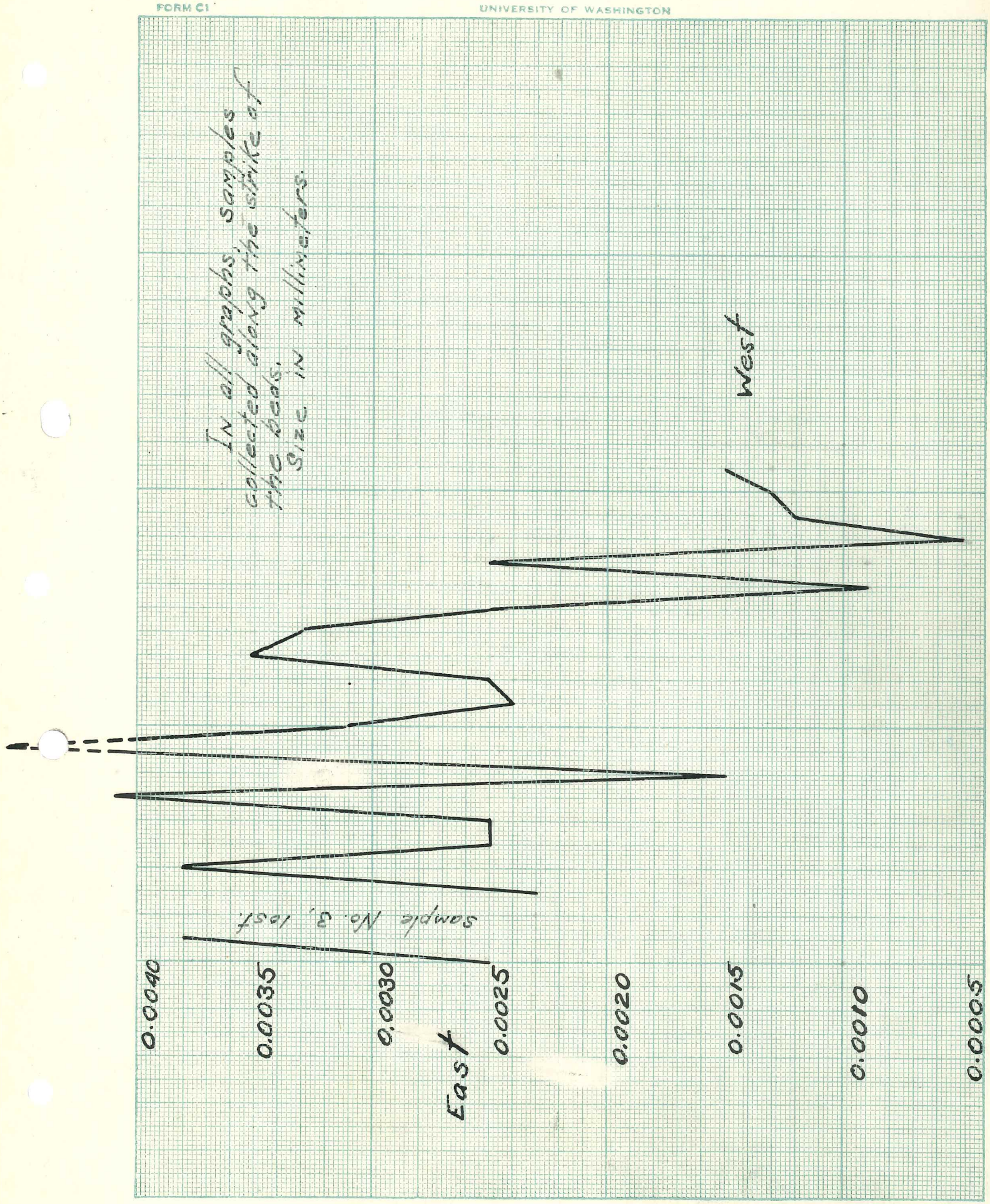


Plate 3

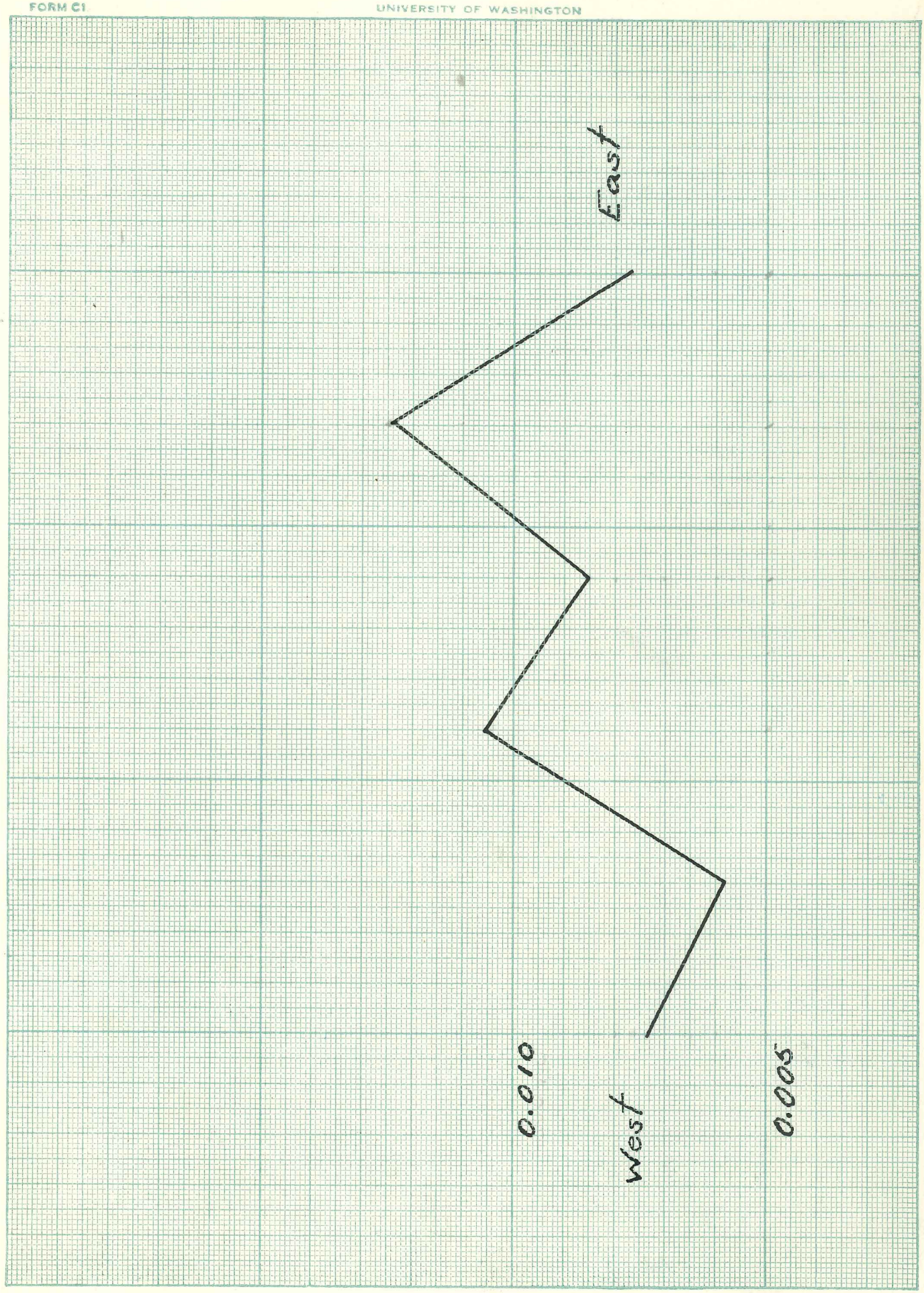
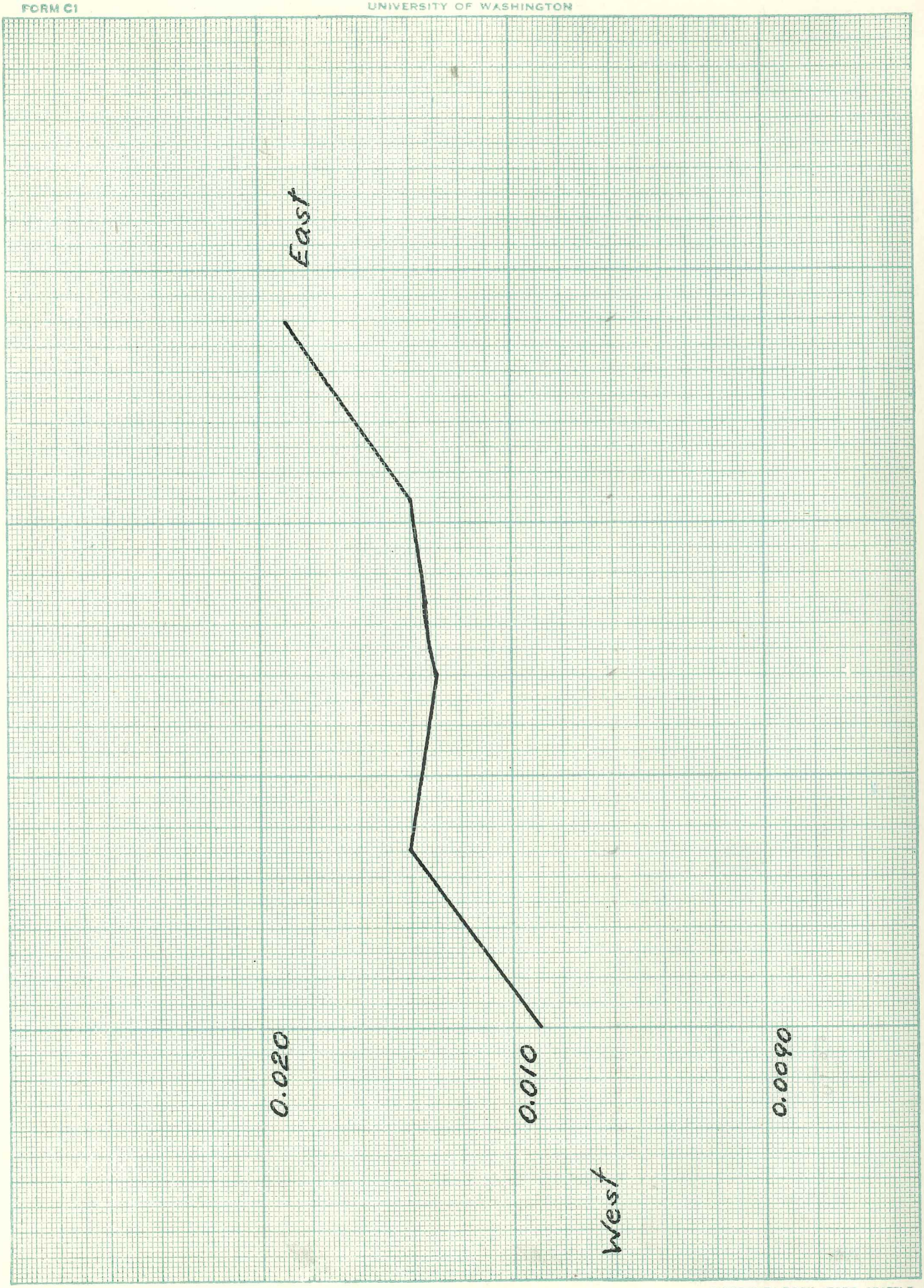


Plate 4



which is quite noticeable under the microscope and simetimes even noticeable megascopically. As one gets into the top section the sediments become finer and the basaltic types of material are not noticeable. Quartz often is plentiful as is orthoclase. In some places the sediments approach anarkose.

In attempting to trace the derivation of the sediments the size of the grains was used to see if there was a lateral variation. The sediments in the top section were only sampled as it was only in this section that a bed could be traced for any distance. In doing this work the grains were measured in the thin section with a micrometer ocular. In all cases the grains were totally quartz or felspar so that the rate of wear would be as equal as possible. The results are tabulated by using two measurements on the grains at right angles to each other and then taking the ~~algebraic sum~~ area and plotting, with the abscissa, giving the grain size and the ordinate the number of the slide. (See plates 2, 3 and 4 for results).

In examining the sections of the crushed fragments it was found that the mineral content was fairly constant. In these slides the sediments close to the coarse conglomerate at the top of the lower section and those of the upper section were only used, as the thin sections did not show anything. It is surprising how the heavy minerals are masked and never show in the thin section.

The heavy minerals in the upper sections are, strangely enough, in direct contrast to the rock materials shown in lower section. As a whole, the minerals are those derived

Plate 5

	ARP-1 >2.88	ARP-1 Non-Mag	ARP-1 Mag	ARP-6 >2.88	ARP-6 Non-Mag	ARP-6 Mag	ARP-12 >2.88	ARP-12 Non-Mag	ARP-12 Mag	BRP-1 >2.88	BRP-1 Non-Mag	BRP-1 Mag	BRP-2 >2.88	BRP-2 Non-Mag	BRP-2 Mag	BRP-3 >2.88	BRP-3 Non-Mag	BRP-3 Mag	BRP-4 >2.88	BRP-4 Non-Mag	BRP-4 Mag	BRP-5 >2.88	BRP-5 Non-Mag	BRP-5 Mag
Anatase		X			X			X			X						X			X	X		X	
Andalusite			X			X						X			X			X			X			
Augite								X	X															
Biotite									X			X						X			X			
Chlorite			X			X			X			X		X	X						X			
Enstatite																								
Epidote						X		X							X			X			X		X	
Felspar	X			X			X			X			X			X			X			X		
Fluorite														X			X							
Garnet						X			X									X					X	
Hematite											X									X	X			
Hornblende			X			X			X			X						X						X
Hypersthene																								
Ilmenite		X			X			X			X	X		X	X		X	X		X	X		X	
Kyanite						X												X						
Leucoxene		X			X			X			X	X		X	X		X	X		X	X		X	
Magnetite			X						X												X			X
Monazite			X		X	X						X		X	X		X	X						
Muscovite		X			X	X			X		X	X		X			X	X		X	X		X	
Opal										X			X			X								
Quartz	X			X			X	X		X			X			X			X			X		
Rutile																								
Sanadine	X			X			X			X			X			X			X			X		
Sillimanite																								
Staurolite																		X						
Topaz		X			X																			
Tourmaline						X					X	X						X			X			X
Xenotime			X																		X			X
Zircon		X	X		X						X	X					X						X	

Plate 6

	BRP-6 >2.88	BRP-6 Non-Mag	BRP-6 Mag	RPX-1 >2.88	RPX-1 Non-Mag	RPX-1 Mag	RPX-11 >2.88	RPX-11 Non-Mag	RPX-11 Mag	RPX-22 >2.88	RPX-22 Non-Mag	RPX-22 Mag	RP2-1 >2.88	RP2-1 Non-Mag	RP2-1 Mag	RP2-2 >2.88	RP2-2 Non-Mag	RP2-2 Mag	RP2-3 >2.88	RP2-3 Non-Mag	RP2-3 Mag	W-1 >2.88	W-1 Non-Mag	W-1 Mag
Anatase					X	X		X	X		X	X		X	X		X	X		X				
Andalusite		X	X						X									X		X	X			
Augite			X												X			X			X			X
Biotite						X												X			X		X	X
Chlorite		X				X			X			X												X
Enstatite																								
Epidote												X		X										
Felspar	X			X			X			X			X			X			X			X		
Fluorite						X					X									X				
Garnet			X		X	X		X	X			X		X	X						X		X	X
Hematite																								
Hornblende		X	X			X					X										X			
Hypersthene																					X			
Ilmenite		X	X		X	X		X	X		X	X		X	X			X		X			X	X
Kyanite								X												X				
Leucoxene		X	X		X	X		X	X		X	X		X	X			X		X			X	X
Magnetite																								
Monazite			X			X			X			X						X			X			
Muscovite		X	X		X	X		X			X	X		X	X	X	X		X	X	X		X	X
Opal													X						X			X		
Quartz	X			X			X			X			X			X			X			X		
Rutile																							X	
Sanidine	X			X			X			X														
Sillimanite																							X	
Staurolite																								X
Topaz																								
Tourmaline												X									X			X
Xenotime						X						X												X
Zircon								X									X			X			X	

Plate 7

	W-2 >2.88	W-2 Non-Mag	W-2 Mag	W-3 >2.88	W-3 Non-Mag	W-3 Mag.	W-4 >2.88	W-4 Non-Mag	W-4 Mag	W-5 >2.88	W-5 Non-Mag	W-5 Mag	GSP-1 >2.88	GSP-1 Non-Mag	GSP-1 Mag	GSP-2 >2.88	GSP-2 Non-Mag	GSP-2 Mag	GSP-3 >2.88	GSP-3 Non-Mag	GSP-3 Mag			
Anatase		X	X		X						X	X		X	X		X			X	X			
Andalusite			X						X			X			X									
Augite						X									X									
Biotite			X					X	X			X			X					X	X			
Chlorite											X						X							
Enstatite		X	X																					
Epidote					X							X					X	X			X			
Felspar	X			X			X			X						X			X					
Fluorite																								
Garnet			X						X			X								X	X			
Hematite																								
Hornblende			X			X			X			X						X			X			
Hypersthene											X									X				
Ilmenite		X	X		X	X		X	X		X	X		X	X		X	X		X	X			
Kyanite								X												X				
Leucoxene		X	X		X	X		X	X		X	X		X	X		X	X		X	X			
Magnetite																								
Monazite			X															X		X	X			
Muscovite		X		X	X			X		X	X		X	X	X	X	X	X	X	X	X			
Opal													X											
Quartz	X			X			X			X			X			X			X					
Rutile																								
Sanidine																X								
Sillimanite																				X				
Staurolite												X												
Topaz																								
Tourmaline									X			X												
Xenotime												X						X						
Zircon								X												X				

from granitic and the contact zones of granitic intrusions. In one slide microcline was noticed. There are also minerals found which may be derived from basalts. One of the particular features of the upper section material is the scarcity of magnetite. If the sediments had been wholly derived from basaltic rocks this mineral should be noticeable if not plentiful, as it is very resistant and would be a surviving member of any mineral aggregate. Muscovite is another mineral found plentifully. It is found in both the light and heavey residues and this property seems to depend upon the inclusions. It is common in all sediments and is not particularly useful in correlation purposes. The greater part of it is most likely secondary.

In determining some of the minerals it was noticed that the anatase was very prevalent but upon closer examination the carborundum described before was found being taken for anatase. In rechecking the slide it was found that anatase was present in nearly every case noted but in not as large quantities as first thought. With this experience it is perhaps wise to again recommend extreme care in keeping all instruments used clean and away from any possible source of contamination.

No attempt has been made to differentiate zircon and xenotine, except that those grains which are magnetic are termed xenotine, and those non-magnetic, zircon. There is a great deal of opaque material which no attempt was made to separate. (See plates 5, 6 and 7).

From a preliminary standpoint it can be seen that most likely there is a microscopic division of the sediments as

well as a megascopical division. In the lower division the material is basaltic while in the top section the minerals are more granitic and metamorphic. This fact would tend to show that there was either a rejuvenation of stream action and an intrenching into basal material, or that the drainage was changed from one position to another. In tracing the materials it was noted that the Eocene basalts are very consistent and retain a composition approximately the same over widespread areas. From a hasty examination it was thought that the basaltic material was brought from the eastern part of the area over an area extending form Olympia to Port Townsend. The ripple markings show that the currents were probably from the northward. From the measurement of grains in the thin section it was noted that the sediments were probably derived from the eastward, possibly in the Jurassic batholithic area. There is the possibility of two different periods being present, separated by a slight unconformity, or even a hiatus.

It was also interesting to note the climatic conditions as shown by the felspars. Nothing definite is attempted.

"Felspars in Sedimentary Rocks as Indices of Climate." Edinburgh Geological Society, #7, 1893, Article #IV, page 443. W. Mackie.

In the lower section the felspar, as has been said before, is clear and shows no signs of weathering outside of the endomorphic alteration. It may be said that the felspars are of the sanidine type, but as the felspars chiefly noted are not a component series of grains in a sandstone, but are found

as phenocrysts and the matrix of pebbles in the conglomerate, it is thought they would be readily attacked by weathering agencies. As the weathered condition is not present it is best to assign the conditions of disintegration to an arid climate, subject to such torrentials as prevail in like areas today. On the other hand, as one goes up into the top section the felspars become corroded and badly clouded. The centers, endomorphically altered, do not seem to be present. In some cases felspar has been noted with a perfectly clear center and an altered ring around the outer edges. The material found is not kaolinite but rather a gelatinous mass. With such conditions the climate may be interpreted as being humid and similar to that of the west coast of today.

The climatic conditions can be brought out much clearer by a cooperative study of paleontology but due to a shortened period of time the fauna was not investigated.

In the study of sediments it has been found that although paleontology is not essential, it is a great help and that the two should be used together. The fauna supplement the study of the conditions of deposition and the climatic conditions, and in the long run and for detailed work all such helps are of the utmost importance. No paleontology is attempted in this paper, but should the reader desire information along this line he is referred to several papers by Dr. C. E. Weaver.

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