BRIGHAM YOUNG UNIVERSITY RESEARCH STUDIES

GEOLOGY SERIES VOL. 7 NO. 6 JUNE, 1960

HEAVY MINERALS STUDY OF THE INTRUSIVE BODIES OF THE CENTRAL WASATCH RANGE, UTAH

by

Charles W. Berge

BRIGHAM YOUNG UNIVERSITY
DEPARTMENT OF GEOLOGY
PROVO, UTAH

HEAVY MINERALS STUDY OF THE INTRUSIVE BODIES

OF

THE CENTRAL WASATCH RANGE, UTAH

A Thesis

Submitted to the

Faculty of the Department of Geology

Brigham Young University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Charles W. Berge

June, 1960

CONTENTS

LIST OF ILLUSTRATIONS

ABSTRACT

The Little Cottonwood, Alta, Clayton Peak and Park City stocks occur generally in a line from west to east within the north-trending central Wasatch Range at its intersection with the east-west structures of the Uinta uplift, and represent the only large intrusions in either range. A heavy mineral petrographic study of these four stocks showed these intrusions to become progressively more acidic to the west; and a statistical comparison, using Pearson's Product-Moment Correlation Coefficient and Contingency Coefficient, confirmed the presence of greater quantities of early-forming minerals in the eastern intrusions. The Park City stock (quartz diorite porphyry), easternmost of the four stocks, and the Little Cottonwood stock (Adamellite), on the west, show the greatest contrast in general mineral content and rock texture and in the amount and type of heavy constituents. The Clayton Peak and Alta stocks (granodiorites) appear intermediate in essentially all respects. From west to east, the stocks become more basic showing less quartz, potash feldspar, biotite and sphene, and more plagioclase (more calcic to the east), hornblende, pyroxene, opaques and zircon. The stocks become smaller, more highly altered (hydrothermal) and have solidified at shallower depths.

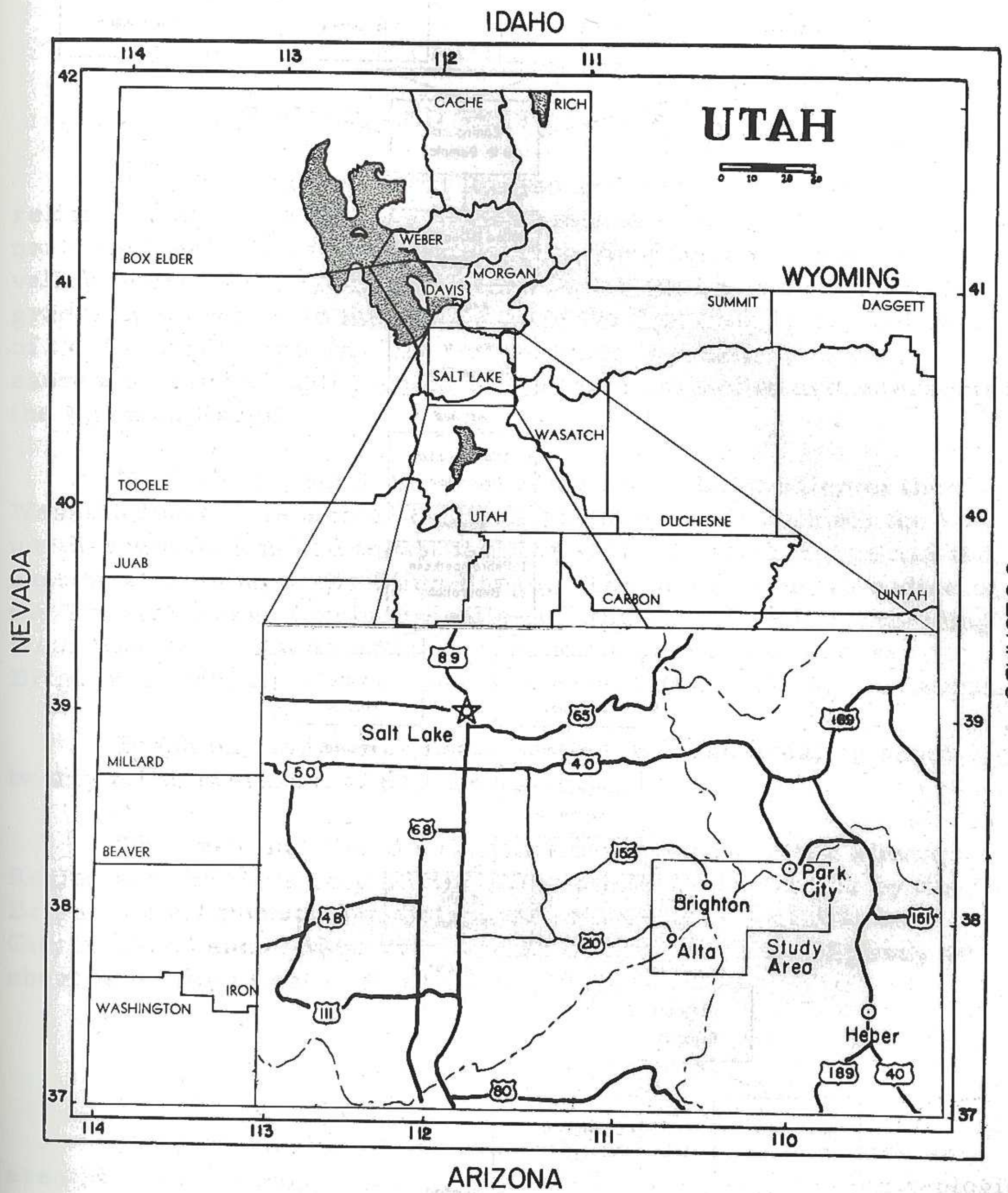


Fig. 1. Index Map

LABORATORY FLOW CHART

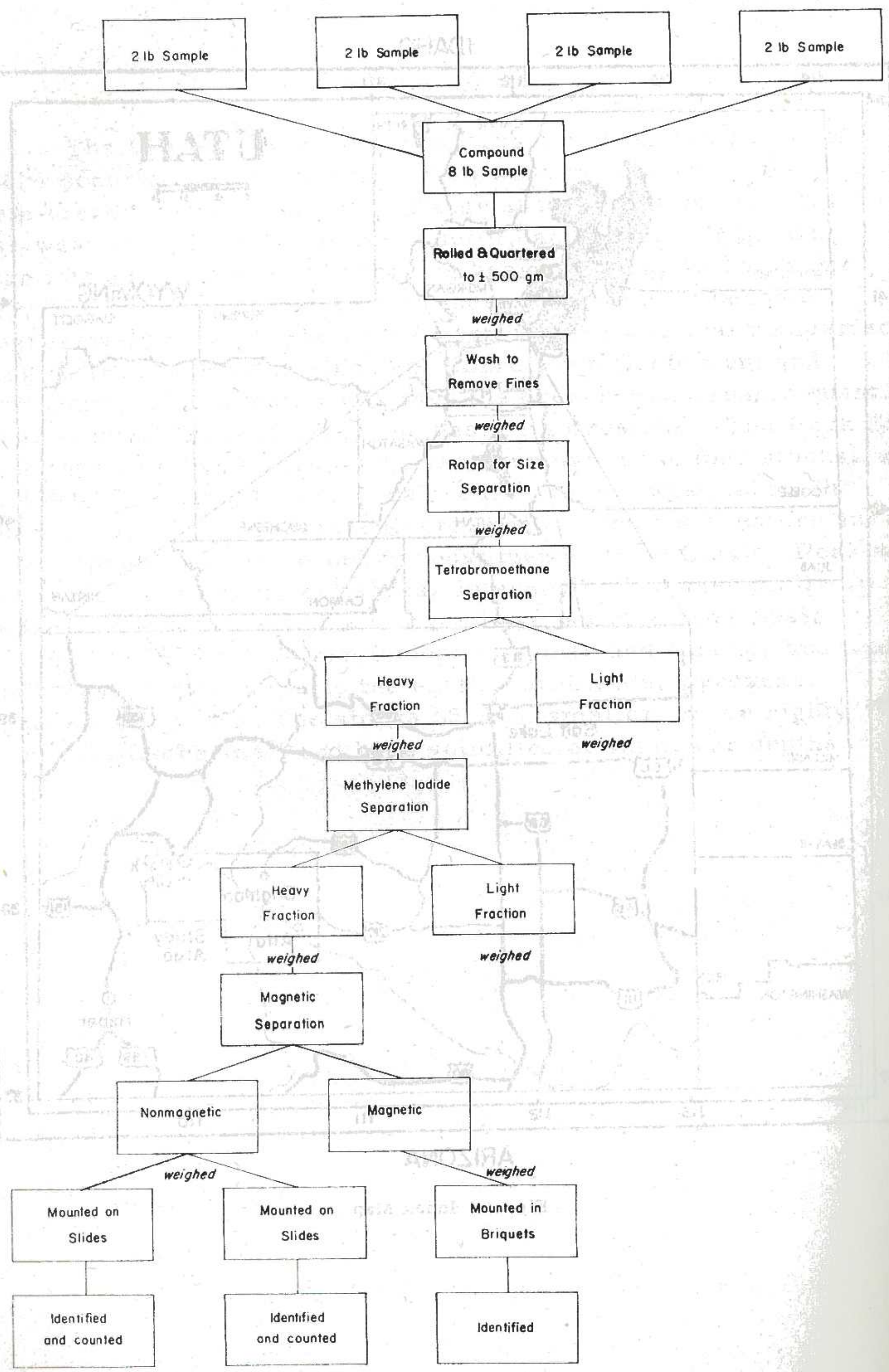


Fig. 2

INTRODUCTION

LOCATION AND SETTING OF THE AREA

The Wasatch and Uinta Ranges are the two main features of relief in Utah. The Wasatch Range extends from Nephi, Utah, northward into Idaho. Its western face rises abruptly from the valley floors of the Basin and Range Province; but the eastern side gradually merges into the highlands of the Wyoming Basin and part of the Colorado Plateau. The Uinta Range is a broad, linear, eastward-trending uplift which runs nearly normal to and intersects the Wasatch Range.

The area in which the intrusives lie is that portion of the Wasatch Range intersected by Uinta structures. It reflects the north-south folding and thrust faulting of the Wasatch Range and the east-west arching of the Uinta Range. The main intrusive bodies of the Wasatch Range (excluding sills and dikes) lie in a line extending from Bald Mountain near Heber City to Clayton Peak, across Brighton to Mount Millicent and then down Little Cottonwood Canyon.

Brighton, which lies near the center of the area, is about twenty miles southeast of Salt Lake City.

The area includes the Cottonwood-American Fork Mining Region and the Park City Mining District and is accessible by the Brighton road through Big Cottonwood Canyon south of Salt Lake City or the Glencoe Mine road, which intersects U. S. Highway 40 about five miles west of Heber City, Utah.

GEOLOGIC SETTING

The intersection of the Wasatch and Uinta axes creates an area of unique geology. The area contains the most complex geologic structures, the only large intrusions, and the only major ore deposits of either range. A wide variety of sedimentary, igneous, and metamorphic rocks are represented and the stratigraphic section ranges from Precambrian to Jurassic. The most complete stratigraphic section is near the mouths of Little and Big Cottonwood Canyons. It includes all the formation of the Park City district plus a thick section of older beds. The section discussed will be that of the Cottonwood region because the geologic detail has been more recently completed (Calkins and Butler, 1943).

The general region has been subjected to compressional forces resulting in the east-pitching anticline called by Boutwell (1912) the "Park City Anticline." The Precambrian, Paleozoic, and Mesozoic strata have been subjected to thrust-faulting, folding, and then to complex normal faulting. The faults vary considerably in attitude, direction, and displacement. The igneous intrusives are later than the major thrusting and folding, but younger than some of the faults according to Calkins and Butler (1943) who worked out the detailed geology in this area.

The stratified rocks in the Cottonwood area have an aggregate thickness of approximately twelve thousand feet. About fifteen hundred feet of Precambrian, which is mostly quartzites and argillites, is exposed. A tillite bed lies unconformably upon the Precambrian which Calkins and Butler (1943) questionably assign to the Cambrian. The Tintic quartzite is the lowest formation that is certainly Cambrian and it lies unconformably upon the tillite. The Paleozoic is represented by approximately six thousand feet of section which is primarily marine limestone with considerable shale (Ophir shale and Humbug formation) and two thick sections of quartzite (Tintic quartzite and Weber quartzite). The Mesozoic is characterized by about three thousand five hundred feet of shale (Woodside shale, Ankareh shale) containing some limestones (Thaynes formation) and sandstones (Nugget) which may be fresh water or even terrestrial (Butler and Calkins, 1916, p. 229).

TOPOGRAPHY

The four stocks to be considered lie in the high rugged topography of the central Wasatch Range and form some of the higher peaks. The area rises abruptly from the Salt Lake Valley on the west, at five thousand feet, to peaks whose summits range above ten thousand feet. The eastern side slopes rather gently into high rolling hills and high valleys between the Wasatch and Uinta Ranges. The highest point on this divide is Clayton Peak at 10, 738 feet. The major streams show the typical dendritic drainage patterns of crystalline rock areas and radiate generally from Clayton Peak.

The U-shaped valleys, hanging tributaries, drift deposits, and broad cirques reflect Quaternary glaciation of the area.

CLIMATE

The climate of the region is typical of high altitude mountains and valleys; cool in the summer and severely cold in the winter. The winters have considerable snow which makes the area practically inaccessible except for the roads kept open to the resort areas of Alta and Brighton.

In the early mining days much of the timber was removed from the slopes, and landslides are now quite common. These slides, plus time and the elements, have practically obliterated the signs of the once booming mining communities and operations.

STATEMENT AND PURPOSE OF PROBLEM

The primary purpose of this study is to determine if there is a relationship between the heavy mineral content of four intrusive bodies in the Park City-American Fork-Little Cottonwood area, namely the Park City, Clayton Peak, Alta, and Little Cottonwood stocks. If some correlation or relationship exists, it may be indicative of a common origin; and a marked straight line association may indicate the relative sequence of origin.

The secondary purpose of the study is to note any differences in the heavy mineral content of the stream beds in areas of commercial mineralization (Park City area) and the heavy mineral content of the relatively non-mineralized areas (Little Cottonwood). If differences exist, it may be feasible to prospect using the heavy mineral content of stream beds.

PREVIOUS WORK

In the early 1860's the start of the mining industry preceded the first geological study of the Wasatch Mountains by Clarence King and S. F. Emmons, of the Fortieth Parallel Survy in 1869.

Boutwell, in 1902, published his progress report on the Park City mining district, followed by the stratigraphy and structure of the Park City mining district in 1907 and finally, in 1912, by Professional Paper 77, Geology and Ore Deposits of the Park City District, Utah.

Several notable geologic and economic studies of the area have been published, among them are works by Geikie (1880, 1881), Hintze (1913), Butler and Loughlin (1915), Atwood (1909), and Calkins and Butler (1943). A study of the Central Wasatch Range by Arthur A. Baker and Max W. Crittenden of the U. S. Geological Survey will be published in the near future.

ACKNOWLEDGEMENTS

This study was carried out under the supervision of Dr. William Revell Phillips who suggested the problem, helped with the laboratory techniques, and criticized the manuscript.

Dr. Robert L. Egbert of the Education Research and Services Department of the Brigham Young University suggested the statistical methods of analysis.

Mr. John S. Berge assisted in the collection of samples.

PROCEDURES

FIELD SAMPLING

The four, two-pound samples of detritus taken from each of the major streams of the four intrusive bodies, were combined to form a compound sample. Topographic and geologic maps of the area were studied to select the sampling sites which were chosen with regard to the size and location of the stream, after ascertaining that the stream had not traversed any outcrop other than the igneous body, thus lessening the possibility of contamination.

Compound sampling has the advantage of reducing the probable error of the sample (Krumbein and Pettijohn, 1938, p. 18), thus giving a more representative sample of the sediments. However, reducing the number of samples, by combining them, prevents calculating the probable error between the samples and the actual mineral content of the sediments.

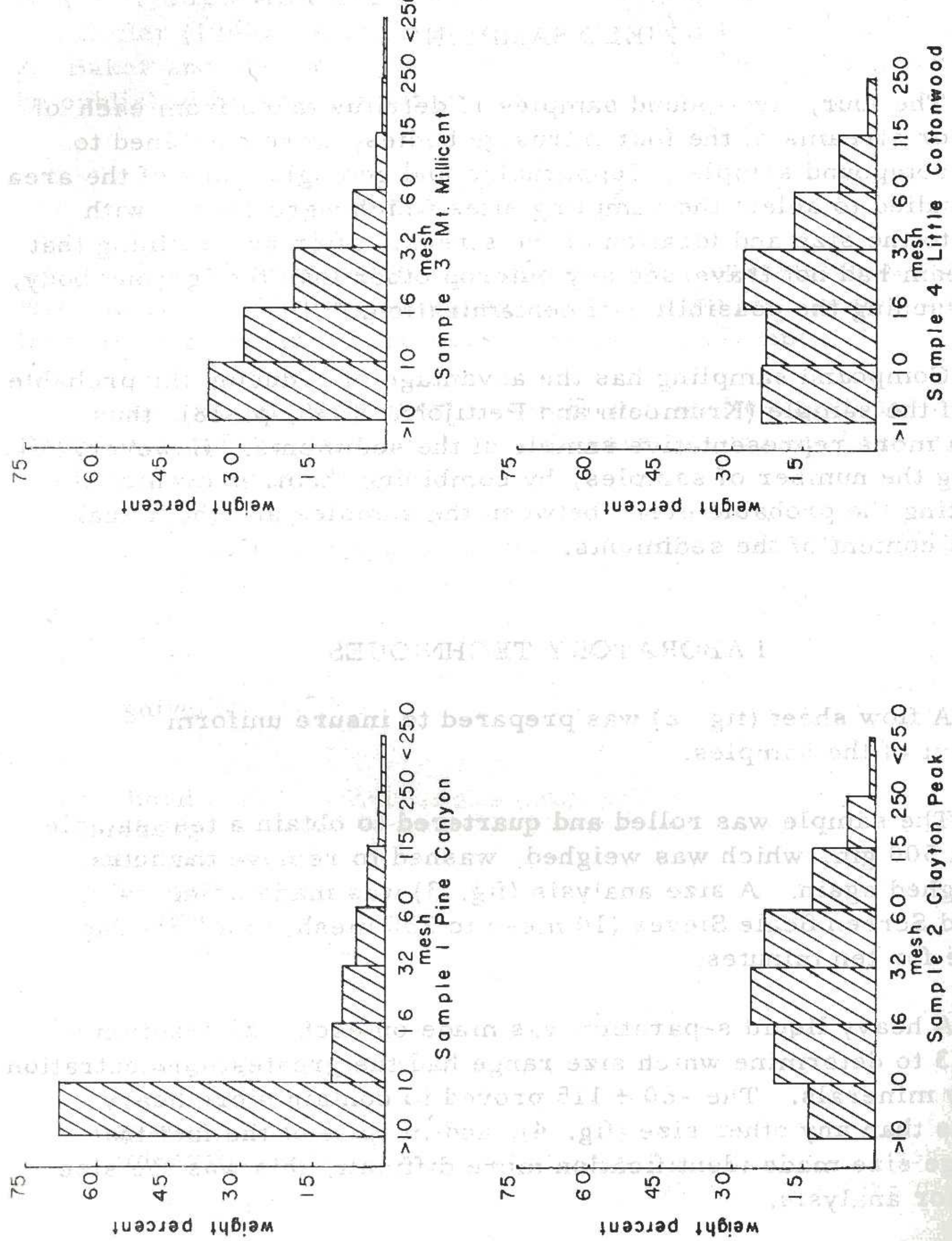
LABORATORY TECHNIQUES

A flow sheet (fig. 2) was prepared to insure uniform treatment of the samples.

The sample was rolled and quartered to obtain a test sample of about 500 gm, which was weighed, washed to remove the fines, and weighed again. A size analysis (fig. 3) was made using Tyler Standard Screen Scale Sieves (10 mesh to 250 mesh) in a "Ro-Tap" machine for ten minutes.

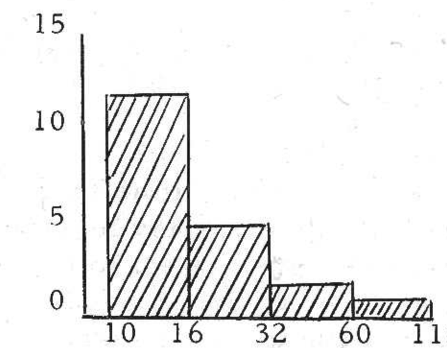
A heavy liquid separation was made on each size fraction of sample 3 to determine which size range had the greatest concentration of heavy minerals. The -60 + 115 proved to contain more heavy minerals than any other size (fig. 4), and in spite of the fact that this large size made identification more difficult, this was the size chosen for analysis.

Tetrabromo-ethane (sp gr 2.89) was the liquid used in the separation; however a large amount of the common ferromagnesian minerals still remained in the heavy fraction; this was further divided by using methylene iodide--diiodomethane--(sp gr 3.3).



Size Distribution in Stream Samples

Fig. 3.



Per Cent Heavy Minerals by Grain Size

Sample 3 Mt. Millicent

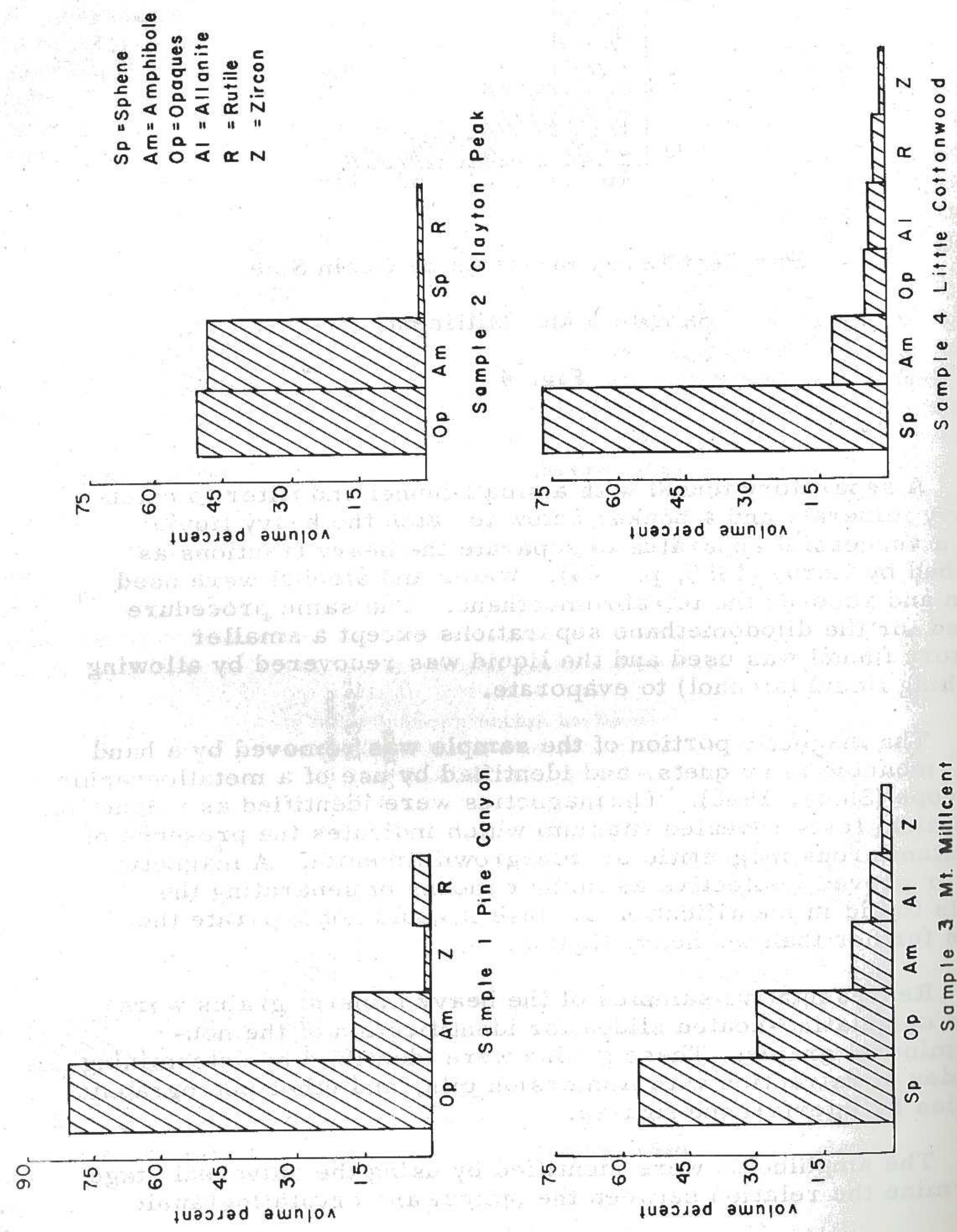
Fig. 4

A separatory funnel with a small funnel and filter to catch the heavy minerals and a beaker below to catch the heavy liquid proved a successful apparatus to separate the heavy fractions as prescribed by Leroy (1959, p. 104). Water and alcohol were used to clean and recover the tetrabromoethane. The same procedure was used for the diiodomethane separations except a smaller separatory funnel was used and the liquid was recovered by allowing the washing liquid (alcohol) to evaporate.

The magnetic portion of the sample was removed by a hand magnet, mounted in briquets, and identified by use of a metallographic microscope (Short, 1940). The magnetics were identified as magnetite, and chemical tests revealed titanium which indicates the presence of either titaniferous magnetitie or intergrown ilmenite. A magnetic separator proved ineffective as further means of separating the minerals to aid in identification because it could not separate the samples further than the heavy liquids.

Representative samples of the heavy mineral grains were mounted on gelatine-coated slides for identification of the non-opaque mineral grains. These grains were identified by determining their index of refraction with immersion oils, and other petrographic properties by interference figures.

The amphiboles were identified by using the universal stage to determine the relation between the optical and crystallographic



Percent Heavy Mineral Content of Samples of -60+115 Mesh

Fig. 5.

orientations. The plagioclase was identified by the same procedure. The universal stage was used to identify minerals both in grains and thin sections.

The heavy fraction in some cases was quite small and to determine the indices of refraction in the conventional manner would have wasted too much of the sample, therefore the gelatine-coated slides were used. These slides proved better than either Lakeside cement or Canada balsam as a mounting material; cover glasses were mounted on some slides to preserve a representative slide. The samples which were used to study and identify the minerals were not used in counting the grains because the washing of the various liquids from the gelatine slides could loosen some of the grains, thus invalidating the sample. A second sample was mounted on a slide and a mechanical stage employed to select random fields of view in which to count between 200 and 250 grains. The binocular microscope was used to count about 100 grains as a check on mineral identification, sampling and counting. No difference was discovered, so the counts were considered valid. The non-magnetic opaque minerals were identified with the binocular microscope and by chemical tests.

Hand samples were taken from each of the four bodies under study, and a thin section, petrographic study of these samples gave the author a knowledge of the mineral composition of the stocks, thus facilitating identification and counting of the mineral grains.

PRESENTATION OF DATA

DISCUSSION

The difference in the petrographic description of the rocks from the four areas indicated the possibility of considerable variation in the heavy fractions of the samples, which proved to be the case. However, the variation seemed to be fairly constant in that certain minerals increased or decreased directly either to the east or west. There are several features which vary from east to west besides the mineralogy and this, too, may have a bearing on the problem. Calkins and Butler (1943, p. 34) state: "These masses are aligned in a nearly east-west direction, roughly with the Uinta Crest and the intrusive masses in the Oquirrh Mountains. They decrease in size, in coarseness of grain, and in percentage of silica from west to east." The percentage of sphene, quartz, orthoclase, decreases from west to east; the percentage of zircon, opaques, amphiboles, plagioclase, and hydrothermal alteration minerals increases from west to east as shown by the heavy mineral count and by the petrographic descriptions of the slides.

The grains of heavy minerals counted in the sample from the Pine Canyon (Park City stock) region exhibited mostly opaque minerals, hematite and limonite, many of which appeared as pseudomorphs of pyrite. The Little Cottonwood sample (#4) was a very "clean" sample showing no alteration, and the heavy fraction consisted almost entirely of sphene and amphibole. The Brighton and Clayton Peak areas seemed to range in almost every respect, between these two extremes.

In the past it had been generally considered that the relative ages of the intrusives were in order from east to west, but recent lead-alpha dating (Jaffe, 1959, p. 75) indicates that although the Little Cottonwood stock is probably the youngest, the Clayton Peak stock may be younger than the Alta stock (Mt. Millicent).

PETROGRAPHIC DESCRIPTIONS

SLIDE 1, Quartz Diorite Porphyry (Johannsen no. 228 P), Pine Canyon (Park City stock)

Megascopic Description

The rock is dark gray with a slight green cast suggesting chloritic alteration. Abundant phenocrysts of white plagioclase and clear quartz are apparent. The texture is porphyritic with a dark, fine-grained groundmass and phenocrysts ranging from 1.2 mm to 14 mm. A few hornblende crystals are visible.

Microscopic Description

The sample shows a dark groundmass of mostly plagioclase with phenocrysts of quartz and plagioclase. The phenocrysts in section average about 2.0 mm, and the groundmass grain size is less than .1 mm. It is highly altered, and, at first glance, this appears to be surface weathering; however, a slide made from drill core cuttings shows the same alteration to be present at considerable depth (eighty-nine feet), indicating the alteration to be hydrothermal. The fine texture suggests a shallower intrusive than the other stocks examined.

Mineral Description

Essential minerals.--The plagioclase is Andesine (An31) and comprises about seventy-five per cent of the rock, being present as both groundmass and phenocrysts. In many cases the plagioclase is considerably altered to sericite. Albite twinning occurs occasionally in the phenocrysts, but the crystals in the groundmass are too small for twinning to be discernible. The plagioclase crystals are less than 1 mm in the groundmass with phenocrysts from .3 mm to 14 mm.

Quartz occurs mostly as phenocrysts which range up to 1.5 mm and comprise about ten per cent of the mass. Most phenocrysts are rounded and embayed by resorption indicating free silica to be unstable at the time of cooling.

Accessory minerals.--Accessory minerals occur as minute crystals in the plagioclase groundmass and range from less than .1 mm to .5 mm with the average being toward the smaller size. The most common accessory mineral is hornblende (4%), followed by augite (3%), biotite (6%), and sphene (less than 1%).

The alteration minerals are magnetite ($\pm$ 3%), epidote ($\pm$1%) and chlorite ($\pm$ 1%). Biotite has altered to about equal amounts of chlorite and epidote.

SLIDE 2, Granodiorite (Johannsen no. 227 P), Clayton Peak

Megascopic Description

This light gray, holocrystalline, medium-grained ($\pm$ 1 mm), equigranular rock contains about twenty-five per cent dark minerals. The light minerals are orthoclase and plagioclase, the latter predominating, and the dark constituents are biotite and hornblende. The plagioclase commonly shows albite twinning in this plutonic, over-saturated rock.

Microscopic Description

The sample has a granitic interrelationship of grains which vary from .1 mm to 2.0 mm with a mean of approximately 1.0 mm. The rock is essentially plagioclase with minor amounts of orthoclase and quartz. Biotite and pyroxene are abundant in the groundmass; the pyroxene usually shows reaction rims of hornblende, and occasionally a second rim of biotite. There are graphic intergrowths of pyroxene and magnetite, and the pyroxene minerals were generally unstable during the later stages of crystallization.

Mineral Description

Essential minerals.--Plagioclase crystals, ranging from .2 mm to 1 mm and about An35 in composition (andesine), constitute about sixty per cent of the rock. Considerable albite twinning is present, but these subhedral, unoriented crystals exhibit little zoning.

Anhedral quartz occurs in small amounts and seems to be the last mineral to have formed, occupying what little space remained.

It forms about ten per cent of the rock, occurring as crystals smaller than .5 mm.

Anhedral orthoclase crystals comprise only nine per cent and the average size is 1 mm.

Accessory minerals.--This slide has many pyroxene crystals which proved to be augite, that vary considerably in size due to reaction rims about them. Originally they were probably all about 1 mm to 1.5 mm; now, however, many of them are as small as .1 mm and some of them have been completely replaced. The pyroxene crystals are generally anhedral, and show reaction rims of hornblende, commonly with a rim of biotite about the hornblende.

Hornblende is the most common dark mineral and usually occurs as a reaction rim about augite. These anhedral crystals are about 1.5 mm, and constitute about ten per cent of the specimen.

Biotite occurs as a primary mineral, but occasionally it forms the outer reaction rim in the pyroxene, hornblende, biotite sequence. Six per cent of the rock is formed of biotite crystals varying from .5 mm to 1.5 mm.

Apatite occurs as very small, less than .1 mm, subhedral to euhedral crystals within the ferrogmagnesian minerals. Both primary and secondary magnetite are present in this slide.

SLIDE 3, Granodiorite (Johannsen no. 227 P), Mt. Millicent (Alta Stock)

Megascopic Description

The hand sample is light-gray with crystals of dark minerals randomly dispersed. Plagioclase, quartz, and orthoclase are the essential minerals; biotite, hornblende, and magnetite comprise the patches of dark accessory minerals. The texture is equigranular and granitic with a mean grain size of 2.0 mm. The specimen exhibits none of the large orthoclase phenocrysts of sample no. 4, and its dark minerals are more evenly interspersed.

Microscopic Description

This slide has an equigranular granitic texture in which most of the crystals are anhedral. Crystal sizes average .8 mm, varying from .2 mm to 1.0 mm, and about ten per cent of the slide is dark minerals.

Mineral Description

Essential minerals.--The plagioclase, which comprises about forty per cent of the rock, is andesine (An30-35); albite and carlsbad twinning are common and zoning occasionally occurs. The crystals are generally anhedral, .4 mm to 2.0 mm grain size and about one-half altered to sericite.

The potash feldspar is orthoclase, not perthite or microcline as in slide no. 4, and is slightly altered to sericite. The grain size ranges from .3 mm to 2.0 mm with a mean of .7 mm, and these grains form twenty-five per cent of the slide.

The quartz crystals, which form twenty per cent of the rock, exhibit undulatory extinction, and grain size is from .3 mm to .9 mm with a mean of .7 mm.

Accessory minerals.--Dark colored minerals, mostly biotite and hornblende, comprise about fifteen per cent of the rock. Biotite occurs as anhedral, crystals ranging from .3 mm to 3.2 mm with an average of 1.0 mm, and makes up about seven per cent of the rock.

Hornblende is more common than in the quartz monzonite of the Little Cottonwood stock, but still not as prevalent as biotite. These crystals are anhedral, form about three per cent of the rock, and range from .2 mm to .8 mm.

Although not as common as in slide no. 4, subhedral crystals of sphene with a grain size of .3 mm occasionally are present, forming less than one per cent of the rock.

Apatite occurs as small euhedral crystals, usually within the ferro-magnesian minerals. The grain size is .1 mm, and these small grains constitute less than one per cent of the rock.

The magnetite occurs both as a primary mineral and as a secondary mineral within the ferro-magnesian minerals. The former is more common and occurs in crystals up to .5 mm in size constituting about two per cent, making it more prevalent than in slide no. 4.

Alteration.--Sixty per cent of the feldspars is partially altered to sericite. Plagioclase is more altered than orthoclase.

Both biotite and hornblende show considerable alteration to chlorite and small amounts of clinozosite.

SLIDE 4, Quartz Monzonite (Adamellite), (Johannsen no. 226 P)
Little Cottonwood Canyon

Megascopic Description

The sample is a light-gray, medium-grained phanerite, with clusters or patches of dark minerals which give it a speckled appearance. The grain size of the light minerals is predominantly 1 mm to 10 mm with several large orthoclase crystals ranging up to 4 cm. The essential minerals are plagioclase, quartz, and potash feldspars, with accessory biotite, hornblende, and magnetite constituting the dark patches. There is no apparent orientation of the crystals. Plagioclase commonly exhibits albite twinning. The general texture is equigranular granitic. The dark minerals make up ten to fifteen per cent. This rock is from an oversaturated, plutonic intrusive body which is commonly referred to as the Little Cottonwood Stock (Butler and others, 1943, p. 38; Boutwell, 1912, p. 67).

Microscopic Description

This specimen has a granitic texture; most minerals are poorly shaped and have an average grain size of about 2 mm. The large potash feldspar phenocrysts give the rock a porphyritic appearance.

Mineral Description

Essential minerals. --Plagioclase (An32, Andesine), constitutes about twenty-five per cent of the rock, occurring as anhedral crystals ranging from 2 mm to 15 mm. Plagioclase exhibits poor crystal shape, and both albite and carlsbad twinning are present.

Potash feldspar, the predominant mineral in the sample, comprises about forty per cent of the rock, occurring as perthite intergrowths or microcline. There are several large crystals ranging up to 10 mm which make up the potash feldspar component. Graphic intergrowths (micropegmatite) and lattice intergrowths (perthite) are frequently found in the potash feldspar crystals, and weak zoning occasionally occurs. Random thin sections may give a great deal of variation in the percentage of this mineral. The microcline is anhedral and shows the usual percline and albite twinning.

Quartz crystals, randomly distributed, ranging from .3 mm to 1.0 mm and showing no apparent crystal shape, comprise about twenty-five per cent of the rock.

Accessory minerals. --The clusters of ferro-magnesian minerals constitute about ten per cent of this rock. Seven per cent is biotite, which occurs as anhedral crystals ranging from .3 mm to 2.0 mm with a mean size of 1.0 mm. Cleavage planes are readily discernible and a few euhedral crystals are present.

The predominant heavy mineral is sphene which occurs in acute rhombic, euhedral crystals ranging from .15 mm to .1 mm. These crystals are grayish brown and exhibit slight pleochroism.

Hornblende is olive-green in color and occurs in the ferro-magnesian clusters as anhedral crystals of .15 mm to 1.5 mm.

Numerous euhedral to subhedral crystals of apatite appear in the ferro-magnesian clusters; they form less than one per cent of the rock and range in size up to .15 mm.

Both primary and secondary magnetite occur in the dark patches as crystals of about .2 mm.

Euhedral crystals, about .8 mm in size, of allanite, show definite extinction angles and are very pleochroic.

A few zircon crystals appear in this slide.

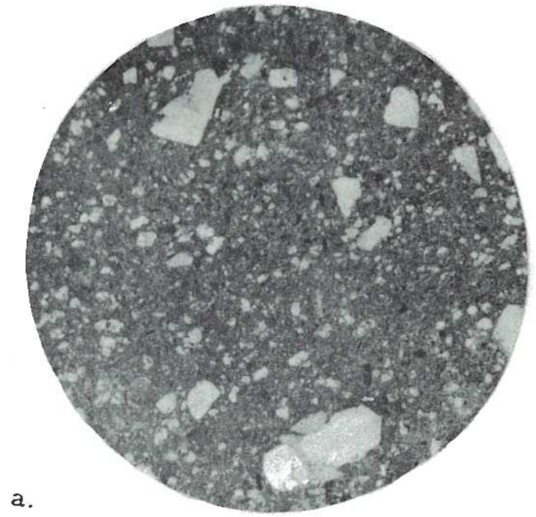
Alteration. --In many cases the biotite is altered along its cleavage planes to chlorite; perthite and microcline are commonly slightly altered to sericite and epidote occurs in the dark clusters of ferro-magnesians, however, it is neither abundant nor common. Although epidote is assumed to be secondary, it exhibits none of the apparent signs of secondary alteration.

COUNTED DATA

Heavy Minerals, Sp Gr 3.3

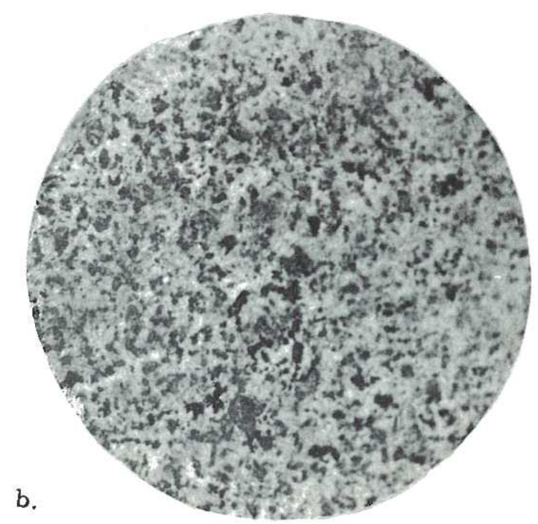
	Stock #1		Stock #2		Stock #3		Stock #4	
	grains	Vol. %	grains	Vol. %	grains	Vol. %	grains	Vol. %
Opaques	178	80.9	105	50.7	60	27.2	10	4.8
Amphiboles	32	14.6	100	48.3	20	9.0	25	12.0
Sphene			1	.5	125	56.6	160	76.9
Rutile	8	3.6	1	.5			5	2.4
Allanite					11	4.9	7	3.4
Zircon	2	.9			5	2.3	1	.5
	200	100.0	207	100.0	221	100.0	208	100.0

Plate I



a.

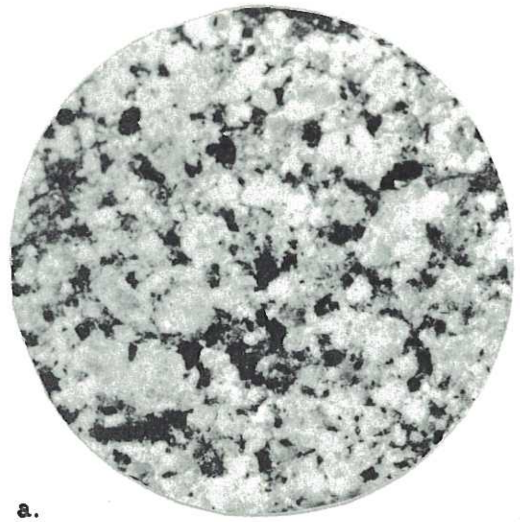
Hand sample of quartz diorite porphyry, Park City stock. Sample collected at Pine Canyon. X 2.



b.

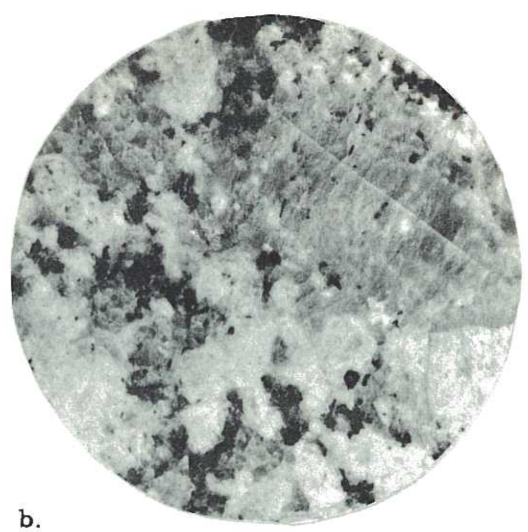
Hand sample of granodiorite, Clayton Peak stock. Sample collected at Clayton Peak, X 2.

Plate II



a.

Hand sample of granodiorite, Alta stock. Sample collected at Mt. Millicent. X 2.



b.

Hand sample of quartz monzonite, Little Cottonwood stock. Sample collected at Little Cottonwood Canyon. X 2.

STATISTICAL ANALYSIS OF DATA

The purpose of the statistical analysis is to determine whether or not there is a definite relationship between the four stocks and, if so, can it be measured, thus suggesting a common origin. Certain trends are discernible by inspection and, if validated by analysis, would be significant when coupled with the geologic evidence in the field. Combined, this data could show age, origin, correlation, and inferences as to what might lie to the east and to the west.

The first step was to determine the number of grains to be counted and the probable error involved. To count the whole heavy mineral residue would have been too time-consuming and yet a large enough portion needed to be counted to be statistically sound.

The probable error (P. E.) of a frequency (Peatman, 1947, p. 395) is given by the formula:

$$P.E. = 0.6745\sqrt{Npq}$$

Applying this to a heavy residue, N is the total number of grains counted, p is the relative frequency of any given mineral in all possible events (the given mineral plus all the other minerals), and is the probability of any grain not being the particular mineral (or 1-p). For example the heavy residue of the Little Cottonwood stock contains 206 grains of which 160 are sphene. By substituting in the formula:

P. E. (in grains) = 6745 208 x 160/208 x (1-160/208)
= 6745 297 x . 77 x . 23
= 6745 56. 86
= 6745 x 7. 54
= 5. 09

To change this to per cent probable error:

P. E. (in per cent) = 5. 09/160 x 100 = 3. 0%

In undertaking a statistical analysis the study should start before the sampling to determine what kind of sampling will best lend itself to the statistics. In this case it would have been better if compound sampling had not been used so that the sampling error, or the error between the sample population and the actual population, might have been given a better analysis.

It is obvious that the larger the number of grains counted, the smaller the probable error; to determine the probable error for any of the mineral grain counts in this study consult fig. 6. It is readily observed that any mineral comprising less than five per cent in 200-250 grains will have a considerable error (fig. 5).

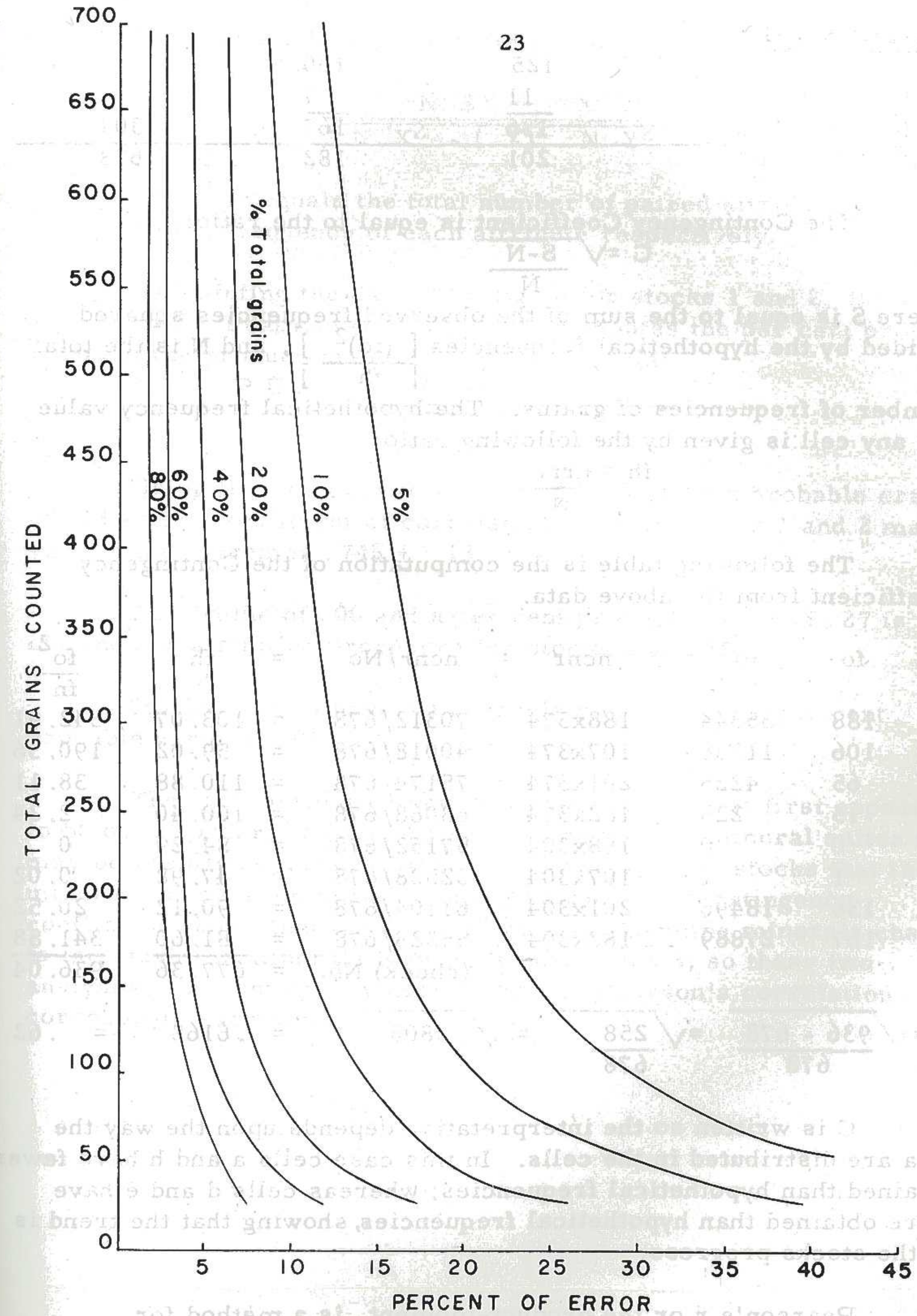
The statistical analysis was computed on counted data, and since the magnetics were drawn off the sample prior to counting, they had to be converted back to frequencies. The grains were all about the same size, so this conversion was done on the basis of specific gravities and per cent weight composition. The specific gravities of the various samples were determined by use of a pyncnometer. However, the counted magnetics were not used in the analysis; because of the small amounts of some of the sample, the reconversion to counted data was considered invalid.

The statistical analysis was approached in several methods; analysis of variance, which was rejected due to the small number of total samples; chi square, which would have established whether or not there was a difference in the samples but would not show the trend; contingency coefficient; and the product-moment correlation coefficient (Pearson's "r"). The two latter methods were used to compute a correlation between the stocks by the minerals. Pearson's product-moment proved the more satisfactory method and was used in the analysis.

A chi square analysis was computed on the heavy residues of the stocks by using samples 1 and 2; then samples 2 and 3; and finally samples 3 and 4. The results showed that the samples were different and significant to the 1 per cent level.

The Coefficient of Mean Square Contingency, or the Contingency Coefficient (C), has been developed for computing an index of correlation for cross-tabulated data of attributes divided into more than two broad classes. The heavy fraction of each sample was dichotomized into early-forming non-magnetic minerals (opaques, zircon, rutile) and late-forming minerals (sphene, allanite). The samples had been arranged in the same numerical order which had been used throughout the study, which gives the following cell arrangement:

	Stock #1	Stock #2	Stock #3	Stock #4	nr
EARLY-FORMING					
op	178	105	60	10	
z	2	0	5	5	
r	8	1	0	0	
	188	106	65	15	374



Curves for estimation of probable error (after Dryden)

Fig. 6.

LATE-FORMING

s	0	1	125	160	
a	0	0	11	7	
	0	1	136	167	304
	188	107	201	182	N = 678

The Contingency Coefficient is equal to the ratio:

$$C = \sqrt{\frac{S-N}{N}}$$

where S is equal to the sum of the observed frequencies squared divided by the hypothetical frequencies $\left[\frac{(fo)^2}{fh}\right]$, and N is the total number of frequencies of grains. The hypothetical frequency value for any cell is given by the following ratio:

$$fh = \frac{nrnc}{N}$$

The following table is the computation of the Contingency Coefficient from the above data.

Cell	fo	fo^2	ncnr	=	ncnr/No	=	fh	$\frac{fo^2}{fn}$
a	188	35344	188x374		70312/678	=	103.07	342.91
b	106	11236	107x374		40018/678	=	59.02	190.36
c	65	4225	201x374		75174/678	=	110.88	38.11
d	15	225	182x374		68068/678	=	100.40	2.24
e	0	0	188x304		57152/678	=	84.29	0
f	1	1	107x304		32528/678	=	47.98	0.02
g	136	18496	201x304		61104/678	=	90.12	20.52
h	167	27889	182x304		55328/678	=	81.60	341.88
					(check) Nh	=	677.36	936.04 = S

$$C = \sqrt{\frac{936 - 678}{678}} = \sqrt{\frac{258}{678}} = \sqrt{.3805} = .6168 = .62$$

C is written so the interpretation depends upon the way the data are distributed in the cells. In this case cells a and h have fewer obtained than hypothetical frequencies; whereas cells d and e have more obtained than hypothetical frequencies, showing that the trend is as the stocks progress.

Pearson's r or the product-moment, is a method for determining the relationship or correlationship between two populations which have a similar group of characteristics which may be paired. Two identical populations would give an r of + 1; whereas two inverse populations would give an r equal to - 1; an r of zero would indicate no correlation whatsoever.

Pearson's r is derived from the formula:

$$r = \frac{N\ XY - X\ Y}{\sqrt{N\ X^2 - (X)^2\ \ N\ Y^2 - (Y)^2}}$$

Where N equals the total number of paired attributes; and X and Y are the frequency of each attribute respectively.

Substituting the data from fig. 6 for stocks 1 and 2, the r equals .745. Peatman (1947, p. 395) computes the per cent probable error of the product-moment r by the formula:

$$P\ E\ r = \frac{(.6745)\ (1 - r)}{\sqrt{Ns}}$$

Using this formula with the r of 3745 gives a probable error of .13 so the coefficient of correlation between stocks 1 and 2 may vary to the extremes .745 ± .13.

An r value of .06 and a per cent probable error of .27 is obtained by a similar procedure for stocks 2 and 3.

Stocks 3 and 4 have a Pearson's r of .90 and a per cent probable error of .01.

The low correlation between stocks 2 and 3 at first appears to be out of order; however by comparing the two mineral suites it may be readily ascertained that it is between these stocks that the mineral composition of the suites changes. The contingency coefficient shows that the trend from early-forming minerals changes to late-forming minerals between stocks 2 and 3; so these two analyses, the contingency coefficient and Pearson's correlation corroborate each other.

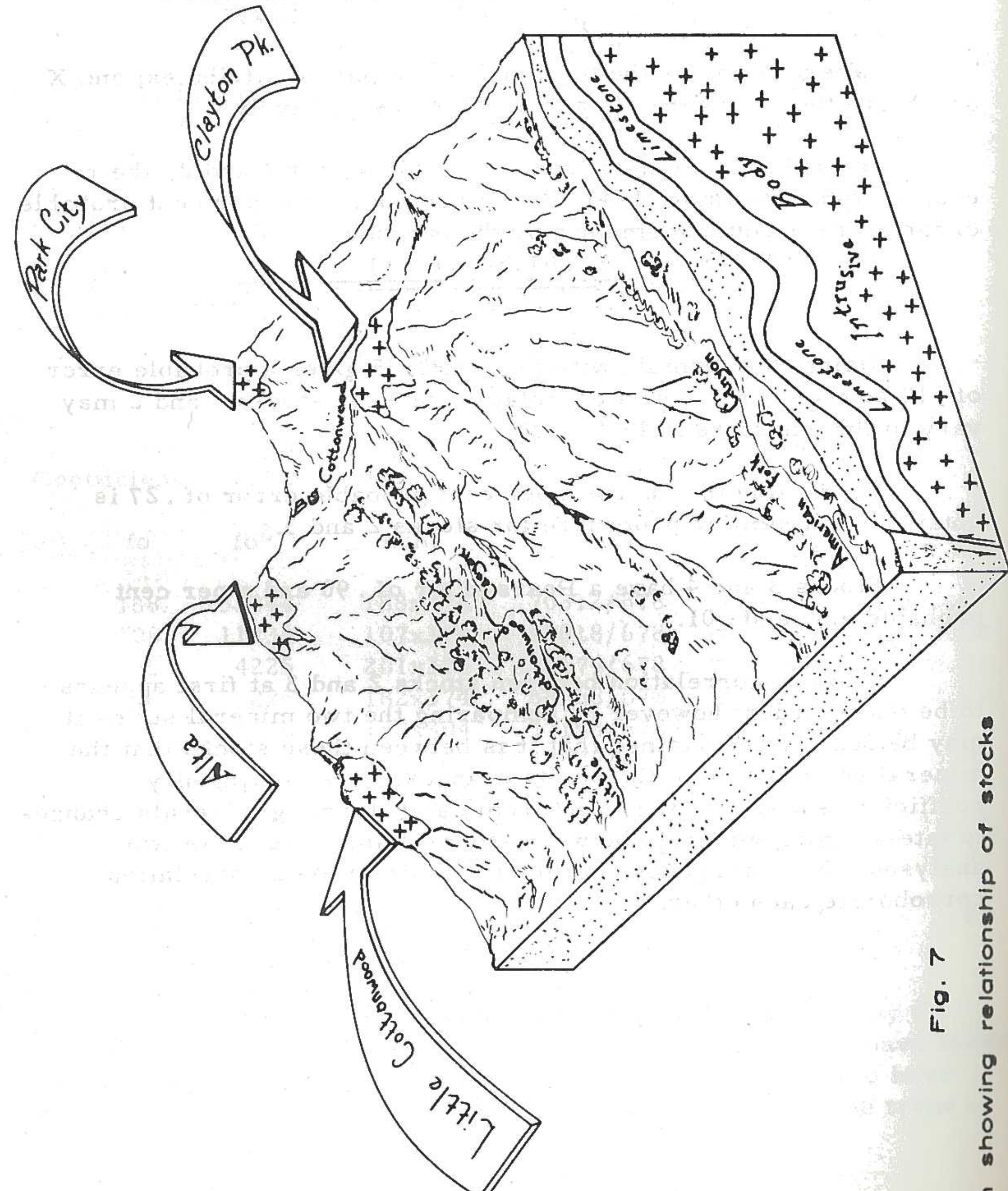


Fig. 7

Sketch showing relationship of stocks

<u>CONCLUSIONS</u>

Previous work in the area has left some question as to the relationship of the ages and origins between the four intrusive bodies.

The author has approached this problem on the basis that, if the stocks had a common origin, there should be some obvious relationships between them.

The initial petrographic descriptions have shown that the relationship between the minerals of the various stocks is one of increase in one direction among certain minerals and decrease in the same direction among other minerals. This holds true for light minerals, but is not readily apparent for heavy minerals in the petrographic descriptions, so a heavy mineral analysis was performed on stream samples of the stocks.

The minerals which indicated the trend could be roughly classified in relation to comparatively early or comparatively late-forming minerals, and perhaps also on an acidic-basic relationship assuming that the more basic rocks form earlier. Although the heavy mineral study is more analytical, because actual counts are easier to perform and evaluate, the petrographic analyses show a similar trend; for example, the general increase of biotite, potash feldspar and quartz toward the west as compared with the increase of hornblende and plagioclase toward the east, show a tendency toward and perhaps reflect the relative origins. The plagioclase composition indicates a slight trend toward a more calcic composition to the east; and a ratio of plagioclase over potash feldspar also shows a trend of increasing basicity to the east.

The heavy mineral separations indicated a discernible difference in composition of the stocks which was confirmed by Chi Square statistical analysis.

The assumption was made that there was a correlation between the stocks on the basis of early-forming versus late-forming minerals, and a Contingency Coefficient was computed which showed a correlation of .62. The Product-Moment-Correlation showed the relative correlations between stocks and that the greatest change in the composition occurred between stocks 2 and 3. The author concluded that it is very probable that the stocks have originated from the same source and were formed in the following order: Park City, Clayton Peak, Alta, Little Cottonwood.

This study has indicated that there is a relationship between the heavy minerals that occur in an altered body (Pine Canyon) and a relatively unaltered body (Little Cottonwood Canyon). In the Pine Canyon area, the heavy minerals are ore minerals (ilmenite and magnetite), oxides (limonite and hematite), and amphiboles. In the Little Cottonwood area the heavy minerals contain magnetite and ilmenite, but the bulk is sphene plus a small portion of amphibole and practically no opaques or oxides or evidence of alteration.

The trend established in this study may reflect the fact that the Park City stock is the outer portion of a large igneous mass which has moved up with the Wasatch Fault. If this is the case the Little Cottonwood extremity is the deeper portion of the same igneous body which is exposed because it was uplifted further and therefore eroded deeper (see Fig. 8). To the west of the Wasatch Fault, under the valley alluvium, there may be a remnant, also mineralized, of the igneous body. This remnant was contiguous with the rest of the igneous body prior to the uplift along the Wasatch Fault. The trend of mineralization would suggest that east of the Park City stock there may be an area of mineralization which has not been eroded away.

The trends established in this study would indicate more ore bodies to be to the east and, if they are exposed near the surface, it might be feasible to prospect for these ore bodies by sampling the streams and conducting a survey of the heavy mineral content.

BIBLIOGRAPHY

Amin, S. R., 1950, A heavy mineral study of the intrusive rocks of the Antelope Range, Piute County, Utah: Thesis, University of Utah.

Bayley, R. W., 1950, A heavy mineral study of the Morrison Formation of South Central Utah: Thesis, Ohio State University.

Blake, W. P., 1876, Notes on some points in the mineralogy and geology of Utah: Am. Jour. Sci., v. 102, p. 216.

Blood, Goerge D., 1912, The Park City Mining District: Salt Lake Min. Rev., v. 14, p. 9-12.

Boutwell, John M., 1933, Park City Mining District: 16th Inter. Geol. Cong. Guidebook, v. 14, p. 69-82, 98.

Boutwell, John M., 1933, Cottonwood region: 16th Inter. Geol. Cong. Guidebook, v. 17, p. 82-94, 98.

Bramlette, M. N., 1934, Heavy mineral studies on correlation of sands at Kettleman Hills, California: Am. Assoc. Pet. Geologists Bull., v. 18, no. 12, p. 1559-1576.

Butler, B. S., 1916, A reconnaissance of the Cottonwood-American Fork Mining Region, Utah: U. S. Geol. Survey Bull. v. 620, p. 165-226.

Butler, B. S., and Calkins, F. C., 1920, Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 229.

Chayes, Felix, 1956, Petrographic modal analysis: New York, John Wiley and Sons Inc.

Clarke, F. W., 1915, Rock analysis: U. S. Geol. Survey Bull. 591, p. 144-148.

Dreimanis, A., 1957, Heavy mineral studies of Ontario and adjacent areas: Jour. Sed. Pet. v. 27, no. 2, p. 148.

Dryden, A. L., 1935, A statistical method for the comparison of heavy mineral suites: Am. Jour. Sci. 5th Ser. v. 19, no. 173, p. 393-408.

Eisenhart, Churchill, 1935, A note on "A Statistical Method for the Comparison of Heavy Mineral Suites.": Am. Jour. Sci. v. 30, p. 549-553.

Emmon, S. F., 1903, The Little Cottonwood granite body of the Wasatch Mountains: Am. Jour. Sci., 166 (4s, 16) p. 139-147.

Fairbairn, H. W., 1935, Concentration of heavy accessories from large rock samples: Am. Mineralogist, v. 40, no. 36, p. 458-468.

Feo-codecido, 1956, Heavy mineral techniques, Venezuela: Am. Assoc. Petroleum Geologists, v. 40, no. 5, p. 484.

Gilbert, C. M., and Turner, F. J., 1949, Use of the Universal Stage in sedimentary petrography: Am. Jour. Sci, v. 247, p. 1-26.

Helson, Harry, 1935, On statistical methods of comparing heavy mineral suites: Am. Jour. Sci. v. 32, p. 392-395.

Ives, Ronald L., 1946, The Little Cottonwood Area, Utah: Rocks and Minerals, p. 67-74.

Krumbein, W. C., and Pettijohn, F. J., 1938, Manual of Sedimentary Petrography: New York, Appleton-Century-Crofts, Inc.

Larsen, E. S., and Berman, H., The Microscopic determination of the non-opaque minerals: U. S. Geol. Survey Bull. 848.

Lee, K., 1950, Petrography of the Price River formation in the Sanpete Valley, Utah: Thesis, Ohio State University.

McAdams, R. E., 1936, Accessory minerals of the Wolf Mountain granite: Am. Min. v. 21, p. 128-135.

Morris, H. T., 1950, Supergene and hydrothermal dispersion of heavy metals in wall rocks near ore bodies, Tintic District, Utah: Geol. Soc. Am. Bull. 61, p. 1488-1489.

Nickel, E. H., 1955, A new centrifuge tube for mineral separation: Am. Mineralogist, v. 40, no. 7, 8, p. 697-699.

Peatman, John Gray, 1947, Descriptive and Sampling Statistics: New York and London, Harper and Brothers Publishers.

Pettijohn, F. J., 1949, Sedimentary Rocks: New York, Harper and Brothers.

Reed, R. D., 1924, Some methods of heavy mineral investigating: Econ. Geol., v. 19, no. 4, p. 320-337.

Rittenhouse, Gordon, 1950, Detrital Mineralogy: LeRoy, L. W., Subsurface Geologic Methods, Colorado School of Mines, Golden, Colo., p. 116-140.

Rogers, A. F., and Kerr, P. F., 1942, Optical mineralogy: New York, McGraw-Hill Book Co., Inc. p. 390.

Ruby, William W., 1933, The size distribution of heavy minerals within a water-laid sandstone: Jour. Sed. Pet. v. 3, p. 3-29.

Short, M. N., 1948, Microscopic determination of ore minerals: U. S. Geol. Survey Bull. 914.

Sidwell, R. J., 1939, Types and sources of sediments deposited by the South Canadian River in New Mexico and Texas: Jour. Sed. Pet., v. 9, p. 36-41.

Spiroff, K., 1952, Residual minerals in Keweenawan conglomerate: Rocks and Minerals, v. 27, no. 5-6, p. 243-246.

Stillman, F. B., 1928, A reconnaissance of the Wasatch front between Alpine and American Fork Canyons, Utah: Jour. Geology 36, p. 44-55.

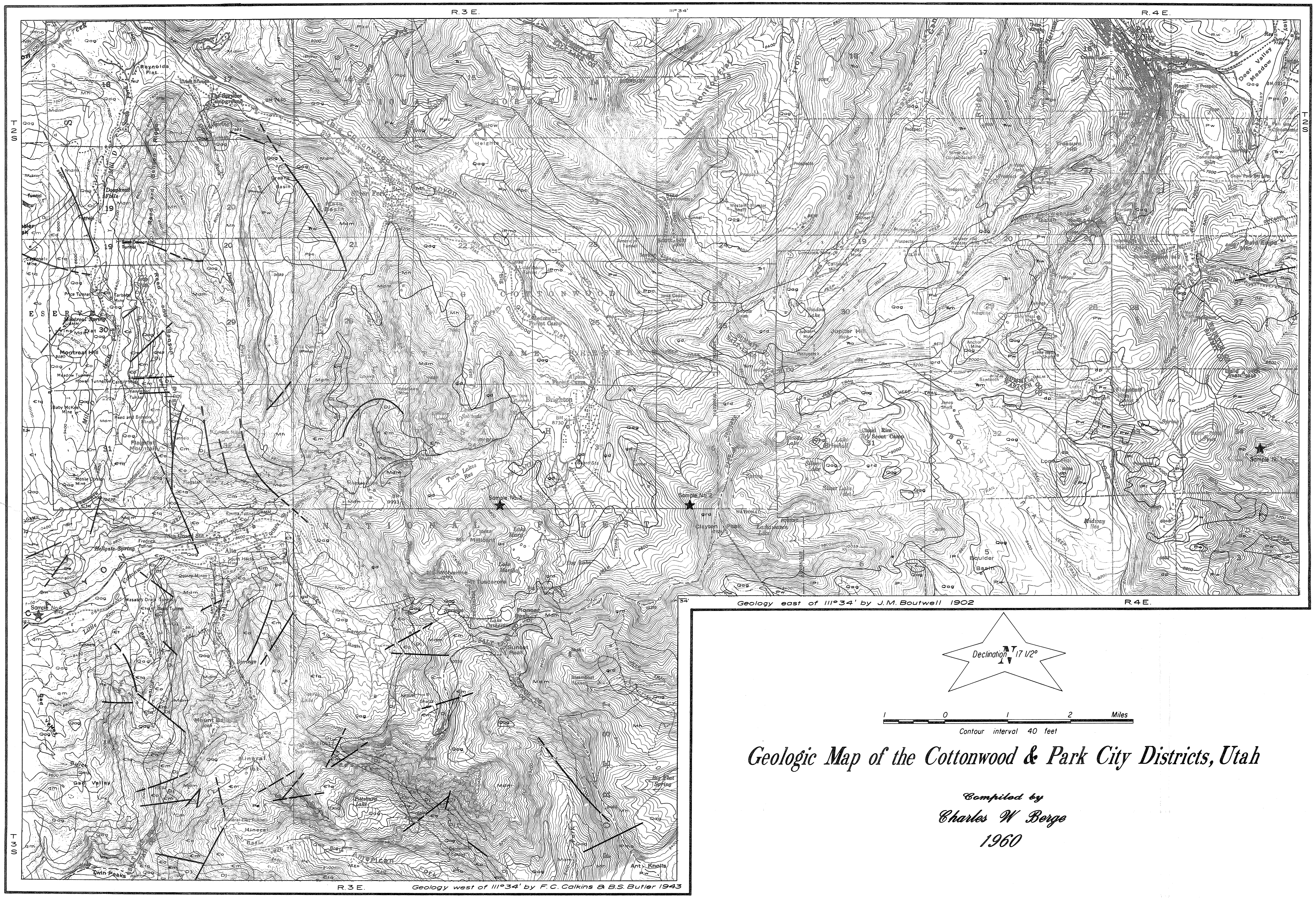
Twenhofel, W. H., and Tyler, S. A., 1941, Methods of Study of Sediments: New York, McGraw-Hill Book Co.

Von Huene, Rudolf, 1949, Notes on Lakeside no. 70 transparent cement: Am. Mineralogist, v. 34, p. 125-127.

Wahlstron, E. E., 1943, Optical Crystallography: New York, John Wiley and Sons, Inc.

Wahlstron, Ernest E., 1955, Petrographic Mineralogy: New York, John Wiley and Sons, Inc.

Williams, Havel, Turner, F. J., and Gilbert, C. M., 1954, Petrography: San Francisco, W. H. Freeman and Co.



Declination 17 1/2°

1 0 1 2 Miles

Contour interval 40 feet

Geologic Map of the Cottonwood & Park City Districts, Utah

Compiled by

Charles W Berge

1960

Legend

— Sedimentary Rocks —

Qag	Alluvium & glacial deposits	Quat.
Jn	Nugget sandstone	Jur.
Ŧa	Ankareh shale	Triassic
Ŧt	Thaynes formation	Triassic
Ŧw	Woodside shale	Triassic
Ŧm	Metamorphosed sediments	Triassic
Ppc	Park City formation	Permian
Pw	Weber quartzite	Permian
IPmo	Morgan (?) formation	Penn.
IPl	Undifferentiated limestones in Park City district	Penn.
Mh	Humbug formation	Miss.
Mdm	Deseret and Madison limestones	Miss.
Dj	Jefferson (?) dolomite	Dev.
Єm	Maxfield limestone	Cambrian
Єo	Ophir shale	Cambrian
Єtq	Tintic quartzite	Cambrian
Єt	Tillite	Cambrian
Pє	Quartzites, sandstones and shales	Prec.

— Igneous Rocks —

qm	Quartz monzonite (Little Cottonwood)	Cretaceous or Tertiary
gd	Granodiorite (Alta)	Cretaceous or Tertiary
grd	Granodiorite (Clayton Peak)	Cretaceous or Tertiary
dp	Quartz diorite porphyry (Park City)	Cretaceous or Tertiary
d	Dikes	Cretaceous or Tertiary

★ Sample No. 1 — Sample location