A STUDY IN SEDIMENT TRANSPORTATION BY THE ARKANSAS RIVER IN COLORADO AND KANSAS

by

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ABSTRACT

Sediment along the Arkansas River and major tributaries was sampled from Royal Gorge, Colorado to Dodge City, Kansas to study the effects of fluvial transportation of the sediment. In addition, the two terraces along the Arkansas River, from the Colorado-Kansas border to Dodge City, were bored and sampled to a maximum depth of 70 feet in an attempt to differentiate them sedimentologically.

Very little overall decrease in sediment size is noted downstream. An increase in median grain-size is seen in the sediment of the main stream below the mouth of each tributary. This is attributed to an increase in competence caused by the added volume of water from each tributary.

The sediment becomes enriched in quartz and impoverished in feldspar downstream. This is the result of both mechanical wear of the feldspar and progressive dilution by quartz-rich sediment from the tributaries.

The total number of different heavy minerals increases downstream, but there is little change in the proportions of the ones found consistently at each locality. Diagnostic minerals from each source are evident in the sediment of the main stream.

With no change in mineral proportions vertically on either of the two terraces, or from one terrace to the other,

no sedimentary criteria were found to distinguish the terraces. The author believes that the terraces formed on unconsolidated material of the same age and origin by means of the alternation of stream incision and valley widening controlled by changes in climate.

INTRODUCTION

Location and Description of Area

Geography

The area discussed includes the floodplains and terraces of the Arkansas River valley and its major tributaries from the head of Royal Gorge in Fremont County, Colorado, to Dodge City in Ford County, Kansas (Pl. I). These tributaries are Huerfano River and Cucharas River in Huerfano and Pueblo counties, Colorado; Fountain Creek in Pueblo County, Colorado; Apishapa River in Las Animas, Otero, and Bent counties, Colorado; Chacuaco Creek in Las Animas County, Colorado; and Two Butte Creek in Las Animas, Baca, and Prowers counties, Colorado.

The climate in the area ranges from humid in the extreme western part to semiarid in the eastern part. Rainfall in the west averages 25 inches per year and in the east about 18, with a low of 14 inches per year being found in the central part of the area. The Arkansas River and all of the before mentioned tributaries are subject to occasional flood, which greatly affects the distribution of sediment.

Physiography

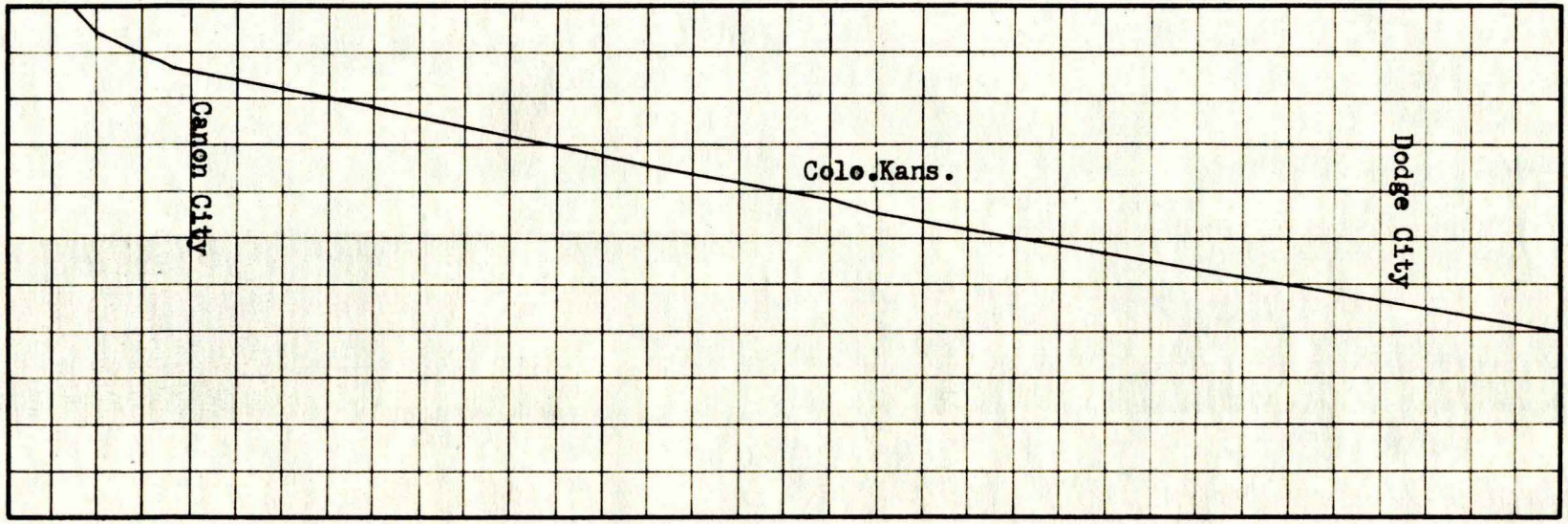
The extreme western border of the area of study is located in the Southern Rocky Mountain Province; the remainder is in the Great Plains Province. The highest elevation is about 7,500 feet above sea level along the Huerfano River in Huerfano County, Colorado, and the lowest about 2,500 feet at Dodge City, Kansas. The Huerfano River is the only major tributary in the area that rises in the Rocky Mountains. Although the Cucharas, Apishapa, and the Purgatoire rivers rise at great elevations in the Spanish Peaks area, they are classified as Great Plains rivers, because the peaks are not related to the Rocky Mountains.

The Arkansas River drops in elevation from about 5,400 feet above sea level at the head of Royal Gorge to about 2,500 feet at Dodge City. A longitudinal profile of this reach of the stream is shown in text figure 1.

Purpose of Study

This report deals with the effects of fluvial transportation of sediment and the reflection of varied sources on the sediment downstream. It also contains a discussion on differentiation of terraces developed along the Arkansas River in western Kansas by means of sedimentology.

It is hoped that this paper will throw additional light



Scales

Horizontal: 1 inch = 50 miles

Vertical: 1 inch = 2,000 feet

Text Fig. 1. Profile of Arkansas River in area of study (modified from Gannett).

on the sedimentation of river terraces, and on the prevalent concept that there is great downstream change in sediment size.

Previous Studies in the Area

There has been no specific sedimentological study on fluvial deposits in this area, but the terraces along the Arkansas River in western Kansas have been mentioned in publications by Frye and Leonard (1952), Latta (1944), Smith (1940), Waite (1942), and others.

Many studies have been made on sizing and mineral distribution along rivers in other areas, but only one other investigation was found in which an attempt was made to correlate terraces at various points along a stream by criteria other than profiles. This study was made by Mathis (1942) on the Colorado River of Texas.

Acknowledgements

Without the advice and criticism of Dr. H. A. Ireland of the Department of Geology, University of Kansas, the successful completion of this paper would have been difficult. Appreciation is also extended to Dr. Elliot Gillerman and Dr. W. Kenneth Hamblin of the Department of Geology, University of Kansas, who served on the advisory committee and assisted in making final corrections.

The author wishes to thank Mr. V. C. Fishel of the United States Geological Survey for serving as adviser for the Survey, and Mr. C. K. Bayne of the State Geological Survey of Kansas and Mr. C. W. Lane of the United States Geological Survey for their advice and criticism.

Last, but by no means least, my wife deserves much credit for inspiration and drive during this thesis study. Were it not for her working unselfishly for our support, graduate school would never have been attained.

This study was subsidized in part by the State Geological Survey of Kansas. They furnished topographic maps, a power auger, and automobile expenses within the state of Kansas.

SEDIMENTOLOGY

Field Work

Publications and maps dealing with the area were studied thoroughly in order to select significant localities for study more intelligently. The article by Smith (1940) was especially helpful in giving localities of well-preserved remnants of the terraces in western Kansas. Field work was done during the summer of 1958.

Sampling was done by means of both hand and power auger. Use of the power auger was confined to Kansas. It was used to take deep samples (up to 70 feet) in an attempt to determine whether one terrace lapped over another. The samples taken with the power auger were used only in the attempt to differentiate the terraces. They were not used in the overall sediment sizing and mineral distribution study.

A total of 43 holes were bored with the power auger in eight profiles across the terraces south of the Arkansas River. These profiles were located south of the following towns: Dodge City, Cimarron, Pierceville, Garden City, Lakin, Kendall, Syracuse, and Coolidge.

Several hundred grams of sample were collected as a composite for each 5 feet of hole bored. An attempt was made to bore each hole to the maximum depth of the auger (70 feet), but in many cases this could not be done because

the auger became stuck in the hole, or reached the water table. If boring was continued below the water table the sample became contaminated by caving caused by the water, and further sampling was considered useless. A total of 2,095 feet of hole was bored and sampled.

The hand auger was used for all other sampling and was valuable as a means of getting below the soil zone and/or dune sand into the river deposited sand. Sampling localities were 10 to 20 miles apart along the Arkansas River. Three to five localities were selected along each tributary, with the exception of Fountain Creek.

Sampling localities were picked on the lower terrace, rather than on the floodplain, to reduce the possibility of error which might be caused by man-made sedimentation associated with irrigation and dams. Several samples were taken at each locality in order to get a representative mineral and size distribution for that area. A total of 192 samples of several hundred grams each was taken at 46 localities.

Laboratory Work

The several samples taken at each locality by hand auger were mixed in the laboratory to obtain as nearly as possible an average of the sediment at each locality. No disaggregation was necessary because of the unconsolidated nature of the sands. Clay particles were removed by

decantation and the composite sample was then dried and split down to 100 grams. This 100-gram sample was sieved by means of standard screens on a Ro-tap machine into standard Wentworth grade-sizes of 2 mm. and larger, 2-1 mm., 1-.5 mm., .5-.25 mm., .25-.125 mm., .125-.062 mm., and less than .062 mm. A histogram and cumulative curve was constructed for each of the composite samples.

The samples taken by power auger were handled somewhat differently. Each of the 5-foot samples from a given hole were examined under a binocular microscope and adjacent similar samples were mixed for sizing. Clay particles were removed by decantation and the samples were then handled in the same manner as those taken with the hand auger.

The particle size .250-.125 mm. was used for the heavy mineral determination from both the hand and power auger samples. This fraction of the sample was reduced to 0.5 gram by means of a microsplit. The heavy minerals were separated with tetrabromethane and thus all those having a specific gravity greater than 2.96 were included. The heavy minerals were mounted in Canada balsam and 300 grains were identified and counted on each slide. Dryden (Twenhofel and Tyler, 1941, p. 99) has shown that counts of large numbers of particles are not essential for accurate results, and he suggested 300 from a representative slide. Table 1 shows the terminology used in the discussion of heavy mineral percentages.

Table 1. Terminology used in discussion of heavy mineral percentages (Modified from Evans, Hayman, and Majeed)

Percent	Term
60 to 100	Dominant
28 to 59	Abundant
13 to 27	Fairly abundant
7 to 13	Very common
4 to 6	Common
2 to 3	Fairly common
1 to 2	Scarce
½ to 1	Rare

All the composite samples collected by both hand and power auger were examined under a binocular microscope to determine the quartz-feldspar ratio.

Sizing and Heavy Mineral Analyses

Huerfano River

The sediment found near the head of Huerfano Valley (Pl. I, loc. 1) has a median size, or 50 percentile, of about 1.3 mm. and the ratio of quartz to feldspar is about 1:20. The dominant heavy minerals are black-opaques, mostly magnetite with some ilmenite. Hornblende is fairly abundant. Monazite is very common, which makes the Huerfano River unique in this study. Appendix figure A-1 illustrates the characteristics of this sample graphically.

The Cucharas River is a tributary of the Huerfano River and is here included with it. The headwater sediment of the Cucharas (loc. 2) has a median size of about 1.3 mm., with a quartz-feldspar ratio of 1:10. The dominant heavy minerals are black-opaques, mainly magnetite and ilmenite. Other heavy minerals are present in minor amounts; garnet is fairly common and all others are scarce to rare (App. Fig. A-2).

Downstream from the mouth of the Cucharas (loc. 3) the median size of the sediment along the Huerfano River is about 1.7 mm., an increase over that at the heads of both the Cucharas and Huerfano valleys. The ratio of quartz to feldspar is about 1:5 (App. Fig. A-3). The dominant heavy minerals are black-opaques, chiefly magnetite and ilmenite. Hornblende is very common, garnet common, monazite fairly common, and others scarce to rare.

At the mouth of the Huerfano River near Boone, Colorado (loc. 4), the median size of the sediment is only 0.875 mm. and the quartz-feldspar ratio is 1:3. The dominant heavy minerals continue to be black-opaques, with garnet and hornblende being very common, and monazite and apatite fairly common. Other heavy minerals from this locality occur in very minor amounts (App. Fig. A-4).

Fountain Creek

Samples from Fountain Creek were taken at locality 5, just north of Pueblo, Colorado. The sediment along this tributary has a median size of about 1.3 mm., with the quartz-feldspar ratio being 1.5 :1 (App. Fig. A-5). Among the heavy minerals, augite and black-opaques were found to be abundant, and hornblende fairly abundant. Zircon is fairly common and all others found are in minor amounts.

Apishapa River

In the headwaters of the Apishapa River (loc. 6) the sediment has a median size of about 1.2 mm. and a quartz-feldspar ratio of 1.5 :1. The dominant heavy minerals are the black-opaques; garnet is very common; apatite, zircon, and monazite fairly common; and hornblende absent. The absence of hornblende makes this locality very unique (App. Fig. A-6).

Downstream about 60 miles (loc. 7) the sediment is very similar in many respects to that found near the head. The sorting and median size of 1.2 are about the same, but the quartz-feldspar ratio has changed to 1:1. The heavy mineral frequencies are also considerably changed. Black-opaque minerals are abundant and hornblende is fairly abundant. Garnet remains common, with sphene and apatite being fairly common (App. Fig. A-7).

At the mouth of the Apishapa River near Olney Springs, Colorado (loc. 8), the median size has decreased to about 0.9 mm. and the quartz-feldspar ratio is 1: 1.5. The sediment is somewhat better sorted, as can be seen in appendix figure A-8. Black-opaque minerals remain abundant, with hornblende being fairly abundant and sphene common. Garnet and apatite are fairly common and epidote and staurolite are scarce.

Purgatoire River

Near the head of the north fork of the Purgatoire River (loc. 9), sampling revealed a sediment with a median size of 1.5 mm. and a quartz-feldspar ratio of 1:1 (App. Fig. A-9). Black-opaques are the dominant heavy minerals; hornblende is very common, and epidote, garnet, and sphene common.

Sediment at the head of the south fork (loc. 10) is quite different from that of the north fork. The quartz-feldspar ratio is 1:1, as on the north fork, but over half the sample is greater than 2 mm., resulting in a mean of about 4 mm. The heavy mineral content is in even greater contrast. Hematite and limonite, collectively, are the abundant heavy minerals; hornblende and black-opaques are fairly abundant, and garnet and sphene fairly common. Leucoxene, anatase, and brookite are scarce in this locality. Appendix figure A-10 is a graphical representation.

Near Trinidad, Colorado (loc. 11), downstream from the union of the north and south forks of the Purgatoire River, the sediment has a median size of about 0.75 mm. and a quartz-feldspar ratio of 1: 2.5. The sediment of the south fork has the greatest influence on the sediment of the Purgatoire River as shown by the heavy mineral contents: hematite-limonite are abundant, black-opaques fairly abundant, and hornblende very common. The other heavy minerals present reflect the lesser influence of the north fork (App. Fig. A-11).

Localities between Trinidad and the mouth of the Purgatoire, near Las Animas, Colorado, show a steady decrease in hematite and limonite, with an increase in the percentage of black-opaques. At locality 12, upstream from the mouth of the Chacuaco Creek, the hematite-limonite content still slightly exceeds the black-opaques (App. Fig. A-12), but at locality 14, downstream, the black-opaques slightly outnumber the hematite-limonite (App. Fig. A-14).

Sediment along Chacuaco Creek (loc. 13) shows a median size of about 0.75 mm., with a quartz-feldspar ratio of 9:1. The dominant heavy minerals are the black-opaques; hematite-limonite are very common. Zoisite constitutes only one percent of the heavy minerals at this locality, but increases considerably downstream. The total heavy mineral content and other analyses of this locality are shown on appendix figure A-13.

At the mouth of the Purgatoire River (loc. 15) the median size of the sediment is about 0.38 mm. and the quartz-feldspar ratio is about 4:1 (App. Fig. 15). Black-opaque minerals are the abundant heavy minerals; hematite-limonite are fairly abundant, and zoisite very common.

Two Butte Creek

The grain-size of the sediment along Two Butte Creek is the only characteristic that changed to any degree. The median size decreases from 1.35 mm. near the head (loc. 16) to 0.48 mm. at the mouth (loc. 18). The quartz-feldspar ratio remains about 9:1 throughout the length of this tributary and the heavy mineral content changes very little. The dominant heavy minerals are the black-opaques, but hematite-limonite and garnet are very common. Graphical representations of the sampling locations at head, intermediate, and mouth are shown respectively in appendix figures A-16, A-17, and A-18.

Arkansas River

The Arkansas River was sampled at 25 localities from the head of Royal Gorge, west of Canon City, Colorado, to Dodge City, Kansas. The sediment collected at these various localities differed in response to the tributaries bringing

in new material. In spite of the fact that several samples were taken in a given locality and were mixed in the laboratory in an attempt to get a more representative sample, some of these are considered erratic because of wide variation in size from one locality to another. The heavy mineral content remained fairly regular and predictable.

At the head of Royal Gorge (loc. 19) the median size is about 0.8 mm. and the quartz-feldspar ratio is 1.5 :1. The black-opaque minerals are the abundant heavy minerals; hornblende is fairly abundant and garnet common. Appendix figure A-19 illustrates this sample graphically.

Samples taken at the mouth of the Royal Gorge (loc. 20) show some changes from those at the head of the gorge. The median size has increased to about 0.9 mm., the sample is better sorted, and the quartz-feldspar ratio is 1:8. Among the heavy minerals, black-opaques and hornblende are abundant, garnet has decreased, but is still common, and the others remain about the same (App. Fig. A-20).

A locality near Portland, Colorado (loc. 21) shows a reduction in the median size to about 0.75 mm. and a quartz-feldspar ratio of 1:9. Hornblende outnumbers the black-opaques, but both are still abundant (App. Fig. 21). Garnet has decreased further and is common in this sediment.

Sampling just downstream from the mouth of the Fountain Creek (loc. 22), near Pueblo, Colorado, shows the influence

of this tributary. The median size is greater than sand-size and the quartz-feldspar ratio is 1:4. This ratio is a reflection of the 1.5 :1 ratio of the Fountain. In the heavy minerals, the black-opaques considerably outnumber the hornblende, both still being abundant, and augite is common (App. Fig. A-22).

Less than 10 miles downstream from the mouth of the Fountain (loc. 23) the quartz-feldspar ratio is back to 1:9 and the median size is 1.4 mm. Black-opaques are dominant, hornblende fairly abundant, and augite fairly common. Appendix figure A-23 shows a graph of the heavy mineral content and cumulative curve of the sediment from this locality.

Just below the mouth of the Huerfano River (loc. 24), near Boone, Colorado, the median size is about 0.8 mm., and the quartz-feldspar ratio is 1:1 (App. Fig. A-24). Black-opaques are the dominant heavy minerals; hornblende and garnet are very common, and sphene common. Monazite is rare, and is a reflection of the sediment from the Huerfano River.

At location 25, upstream from the mouth of the Apishapa River, the median size diminishes to 0.4 mm., the quartz-feldspar ratio is 1:4, and the heavy mineral percentages remain about the same (App. Fig. A-25). Below the mouth of the Apishapa (loc. 26), near Olney Springs, Colorado, the median size increases to greater than sand-size and the quartz-feldspar ratio changes to 1.5 :1. The heavy minerals

show very little change, except for an increase in monazite (App. Fig. A-26).

No great change was noted in the sediment for about 65 miles east of locality 26. The median size decreases steadily below the mouth of the Apishapa River and at locality 29, near Las Animas, Colorado and below the mouth of the Purgatoire River, it is 0.4 mm. The only influence of this tributary on the main channel deposits at this locality is the increase of quartz over feldspar to 4:1 (App. Fig. A-29).

The main effects of the sediment brought in by the Purgatoire River were noted at location 30, about 20 miles below the mouth. Here the hematite-limonite and zoisite were noted in the heavy minerals and the median grain-size increased to 1.5 mm. (App. Fig. A-30).

For about the next 60 miles the median size fluctuated considerably, and also the percentages of black-opaques and hornblende. At locality 31 the median size was 0.375 mm. (App. Fig. A-31), and locality 32 was 1.7 mm. (App. Fig. A-32). At locality 33 the hornblende percentage was greater than that of the black-opaques, but both were still abundant (App. Fig. A-33).

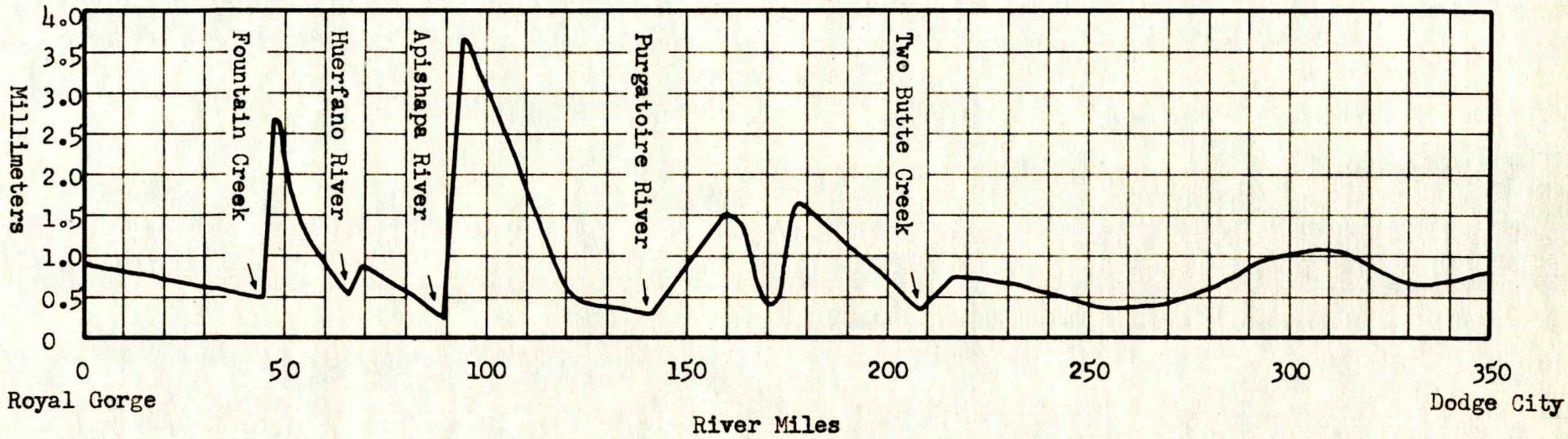
No significant effect of Two Butte Creek was noted in sediment directly below the mouth, but at locality 35, near Coolidge, Kansas, the black opaque minerals had increased considerably because of the sediment from this tributary.

From Coolidge to Dodge City no major tributaries enter the Arkansas River and there was no great change in the character of the sediment. It was noted, though, that between Lakin (loc. 38) and Pierceville (loc. 40) there was a steady increase in the median grain-size, accompanied by an increase in hornblende. Whether or not this relationship would hold true elsewhere or over a greater distance is not known because of the entry of tributaries with sediment having different percentages of minerals. It might warrent additional study downstream in areas without tributaries. The quartz-feldspar ratio ranged from 3:1 to 4:1 in this area.

Effects of Transportation

Sizing

Some downstream decrease in size was noted, though very slight. By plotting median grain-size of the composite samples versus the distance of travel (Text Fig. 2), a small decrease may be seen. Below the mouth of each tributary an increase occurs in the median size, regardless of the size of the tributary sediment. This is believed to be the result of an increase in the velocity and competence of the main stream because of the added volume of water from each tributary.



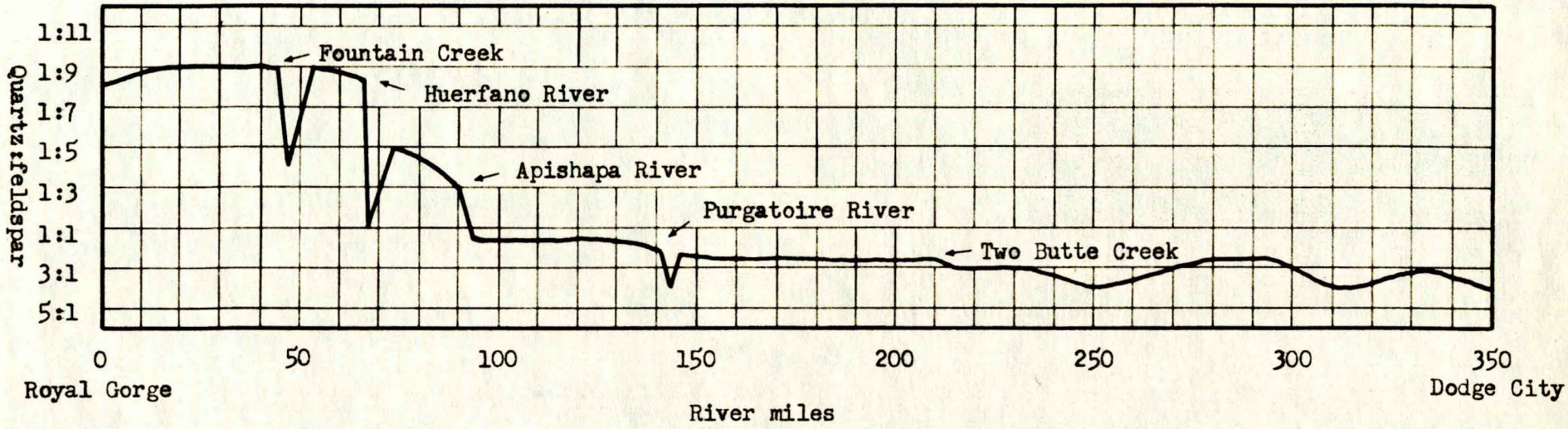
Text Fig. 2. Median grain-size of sediment along Arkansas River from Royal Gorge to Dodge City, showing entry of each major tributary.

Mineral Distribution

The most pronounced effect of transportation on mineral distribution is in the quartz-feldspar ratio. Text figure 3 is a graph of the quartz-feldspar ratio along the Arkansas River from Royal Gorge to Dodge City, showing the point of entry of each tributary. On the upstream end of the area of study the feldspar outnumbers the quartz significantly, but there is a very rapid decline in feldspar downstream, and quartz becomes the most abundant. Pettijohn (1957, p. 125) states that feldspar is supposed to be more susceptible to mechanical wear than quartz; hence sands during transport would be enriched in quartz and impoverished in feldspar. Results of this study are in accord with the above statement of Pettijohn.

There is little change in the proportions of the heavy minerals from one locality to another. Variation between localities is caused by sediment from tributaries, and probably from local sources.

An increase in the total number of different minerals was noted downstream. This slightly reduced the proportions of the minerals found consistently at each locality. This is not evidence for a downstream change in mineral proportions caused by selective sorting or abrasion, but is a progressive dilution of the consistent minerals. Pettijohn (1957, p. 565) states that "sediment from a given source



Text Fig. 3. Quartz:feldspar ratio of sediment along Arkansas River from Royal Gorge to Dodge City, showing entry of each major tributary.

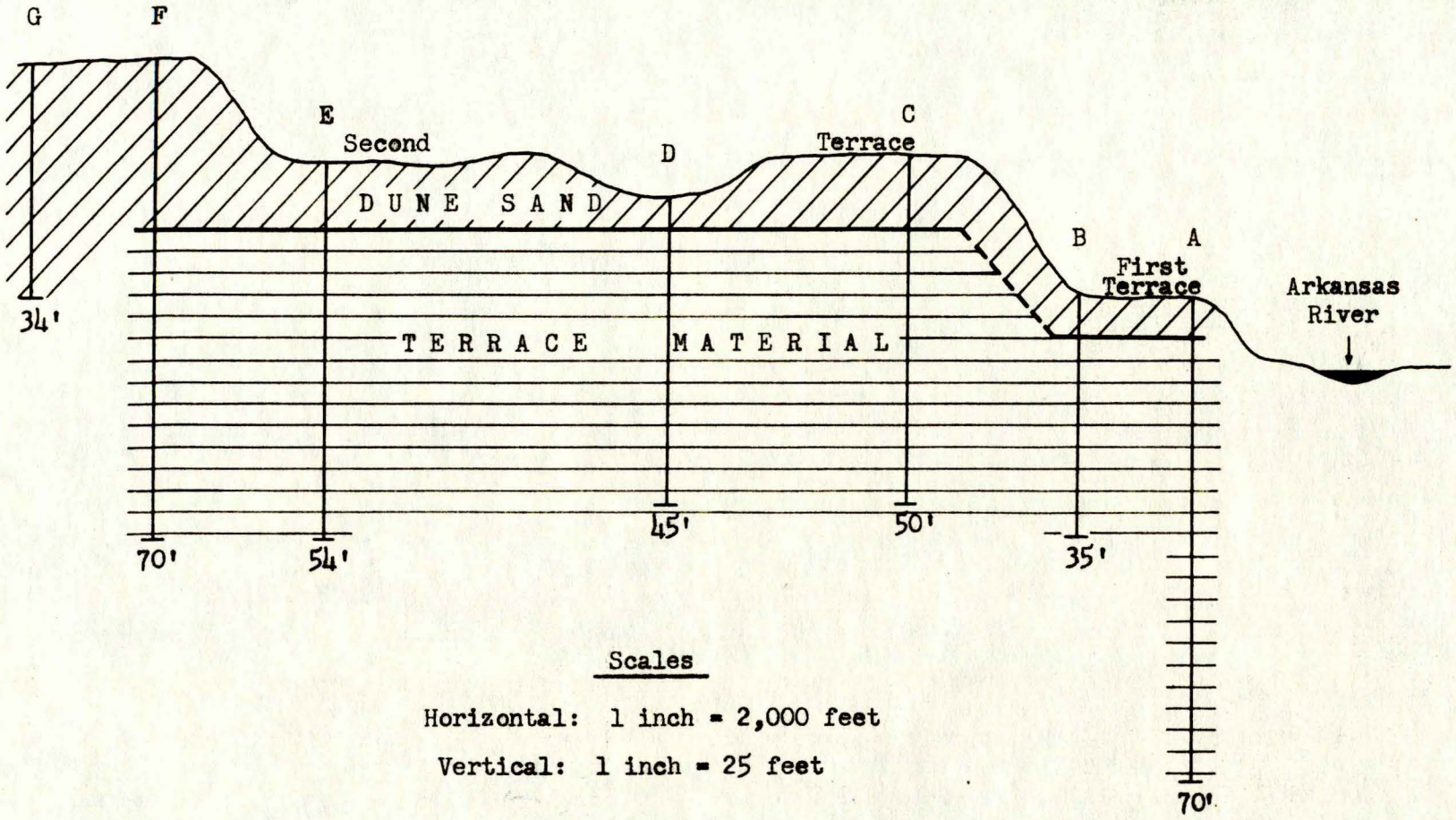
area, as it moves out and away from such area, mingles with and becomes diluted by materials from other areas or places. The constituents of such a sediment, if they be distinctive or different from those with which they mingle, are progressively diluted as they move out from the source area. The progressive dilution of a given constituent results in a decrease in said constituent."

Arkansas River Terraces in Western Kansas

Two recognizable terraces occur along the Arkansas River from the Colorado-Kansas border to Dodge City. The lower terrace lies about 5 to 8 feet above floodplain level and remnants of the higher terrace lie about 15 to 25 feet above the floodplain (Smith, 1940, pp. 150-151).

The terraces were sampled by power auger in eight localities south of the river (Pl. I) to determine if they could be distinguished by any means other than profiles, and if so, was there overlap. Holes were bored along a profile, perpendicular to the river, beginning at the edge of the lower terrace nearest the river and continued south until the thickness of the dune sand prohibited boring (Text Fig. 4). Bedrock was not encountered in any of the borings.

Grade-sizes of the terrace material varied considerably both horizontally and vertically, but there was almost no change in proportions of heavy minerals in a given profile.



Text Fig. 4. Section of Arkansas River terraces and distribution of auger holes at Garden City, Kansas

The quartz-feldspar ratio also remained about the same in a given profile. Appendix figures A-43 through A-54 show the analyses of the sediment from the Garden City profile. This profile is typical of all the profiles bored and is seen in section in text figure 4.

With no change in mineral proportions vertically on either of the two terraces, or from one terrace to the other, the author found no sedimentary criteria to distinguish the terraces. The lack of differentiating minerals in the bore holes indicates that the terraced material is probably of the same age and origin. Thus history of downcutting, geomorphic features, and differences in elevation are the only criteria for distinguishing the two terraces. There is no evidence that one terrace laps over the other.

CONCLUSIONS

The most apparent effect of fluvial transportation noted in this study was the reduction in the proportion of feldspar downstream. The author considers this the result of mechanical wear due to the good cleavage of feldspar and, possibly more important, the progressive dilution of the feldspar by addition of materials brought in by tributaries.

Results showed that there was very little overall reduction in the median size in the downstream direction. The slight decrease in the median size was probably due to the breaking up of rock fragments into their component minerals, and the breakage of easily cleavable minerals such as feldspar. The size decrease might also be the result of the stream losing competence downstream during times of greater aridity. As the stream lost volume, it would also lose velocity, and larger particles would be deposited. This effect could be determined better by sampling over a greater length of the river.

The reflection of different sources was very apparent in the sediment within reasonable distances below the mouths of the tributaries. Because of progressive dilution, the diagnostic minerals lost much of their significance after great distances of travel. In the sediment of the Arkansas River, downstream from the mouth of the last tributary studied, diagnostic minerals could be picked from each source,

but it would be difficult to ascertain amounts of sediment coming from each source. If such a study were to be undertaken it would be necessary to make a preliminary study to determine minerals common to all areas and not specifically diagnostic. These common minerals should then be disregarded and 300 grains of other minerals counted.

The results of deep sampling of the terraces in western Kansas indicate that they were formed by the alternation of stream incision and valley widening in a valley filled with unconsolidated material. The control for this incision and widening is believed to be climatic, and not rejuvenation or meandering of the stream. Tectonic rejuvenation does not satisfactorily explain the widespread occurrence and uniformity of the terraces. To explain them by eustatic lowering of sea level would require headward migration of a knickpoint more than 1,000 miles from the sea for each terrace. The terraces are much too continuous to be the result of sideward cutting by random meandering of the stream.

The valley had probably been filled with sediment during a long period of extreme aridity by deposition due to the intermittency of the stream. The stream would begin to downcut when it became through-flowing and more competent because of increased humidity. The incision, made by the stream, would become widened by mass-wasting and slope retreat when the stream was neither degrading nor aggrading.

Another cycle of increased humidity would cause the stream to incise again and to leave terraces in the widened valley. This process could be repeated and the retreat of the scarps would form terraces at different levels.

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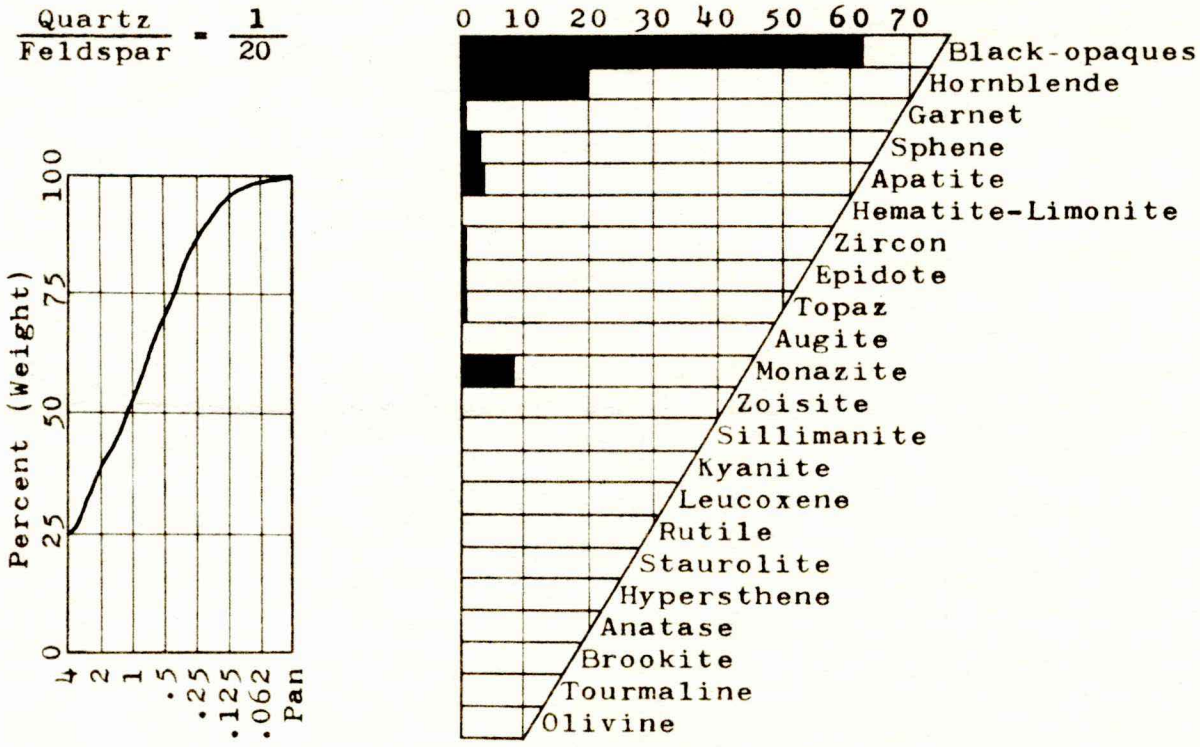
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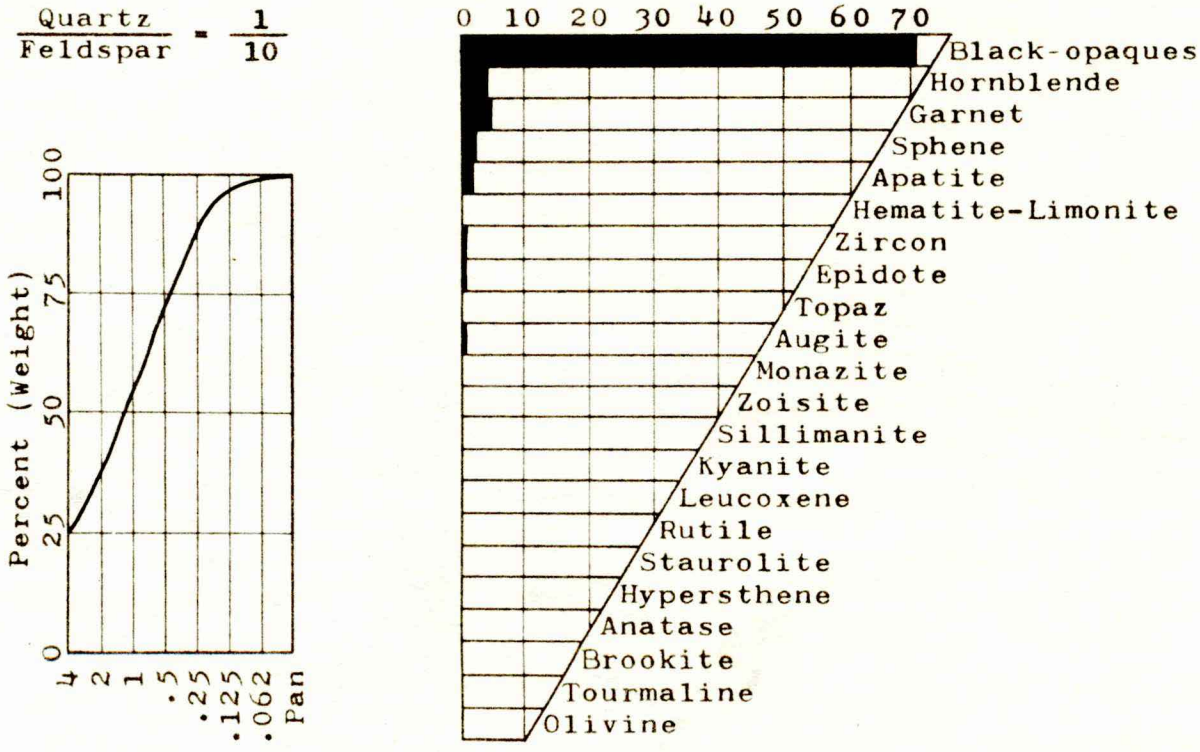
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APPENDIX

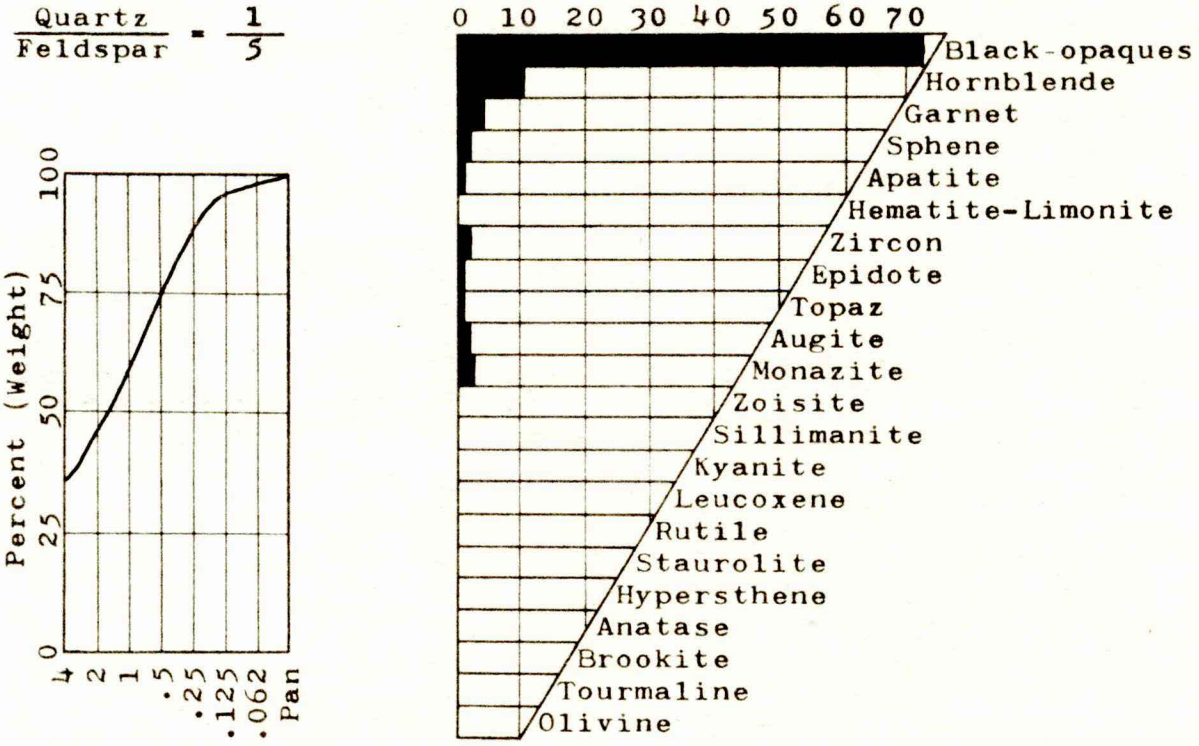
The following pages are graphical illustrations of sediment analyses of the composite samples discussed in this paper.



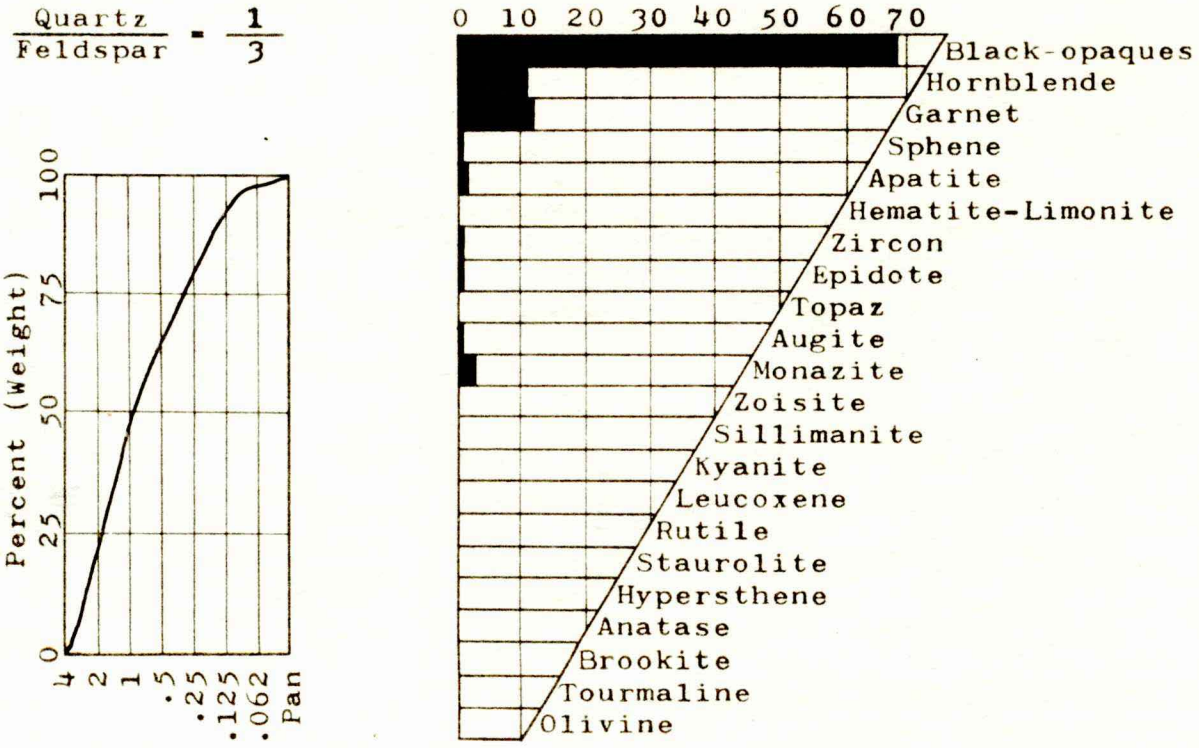
App. Fig. A-1. Analyses of sediment from locality 1 along Huerfano River near head.



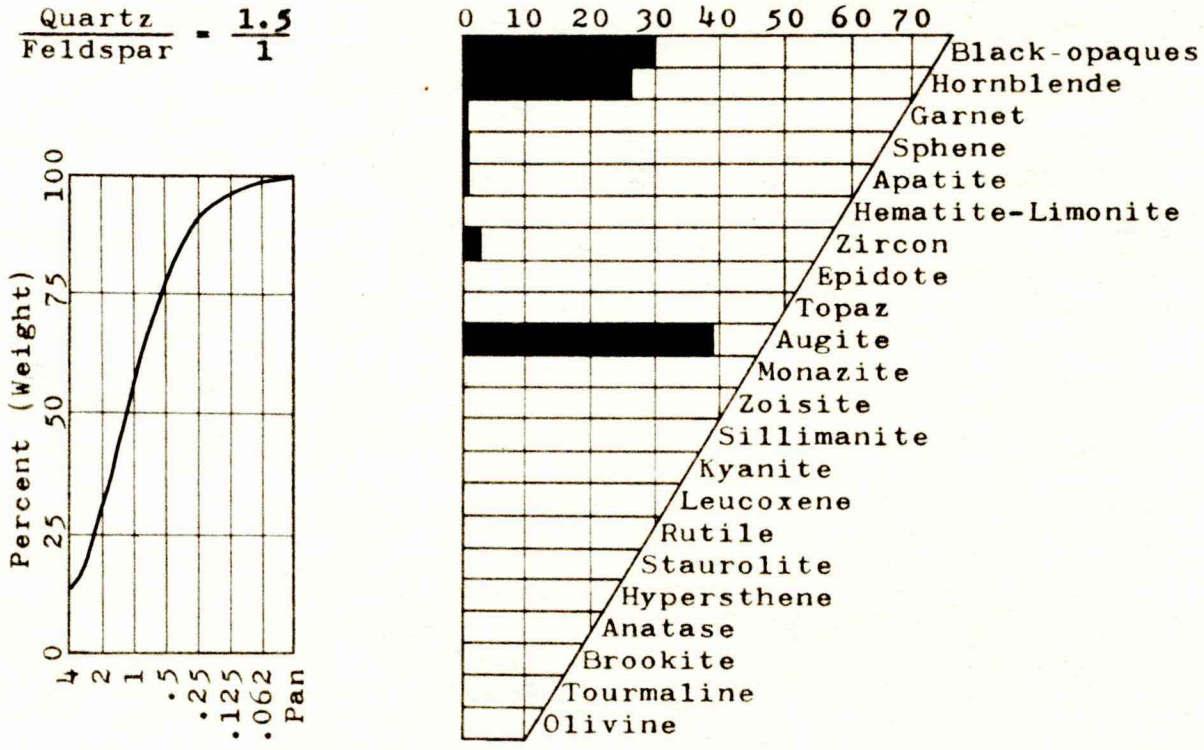
App. Fig. A-2. Analyses of sediment from locality 2 along Cucharas River near head.



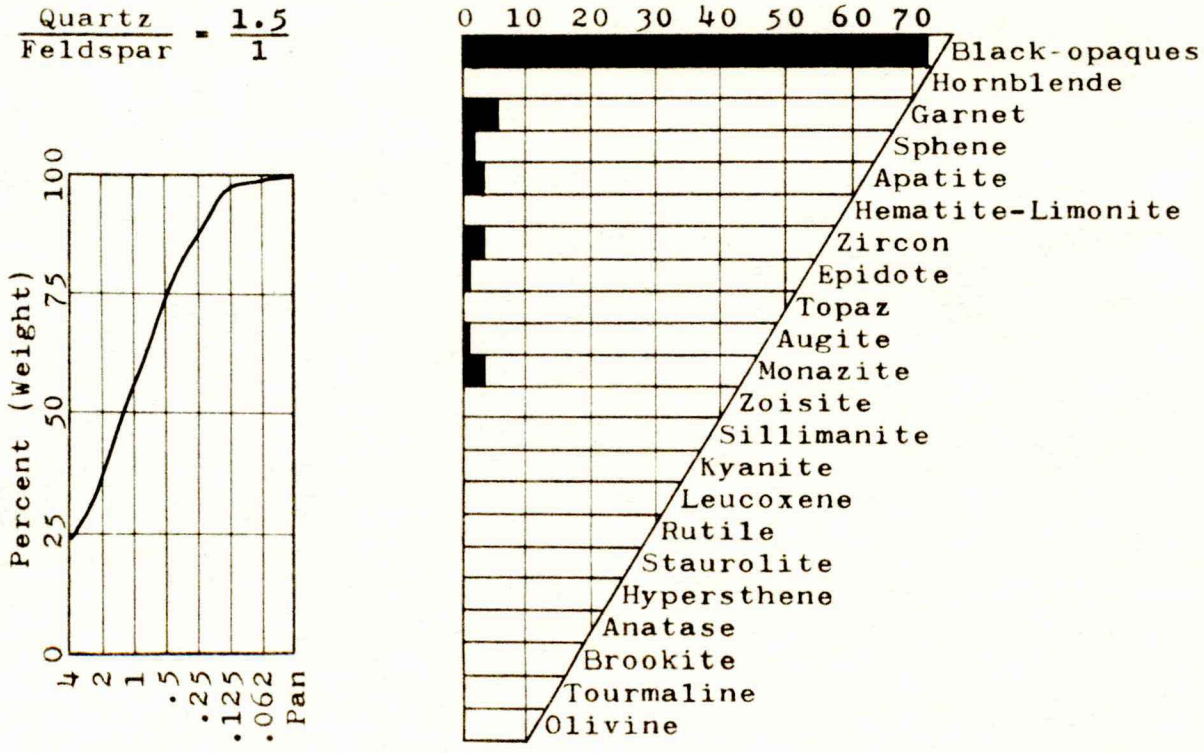
App. Fig. A-3. Analyses of sediment from locality 3 along Huerfano River below mouth of Cucharas River.



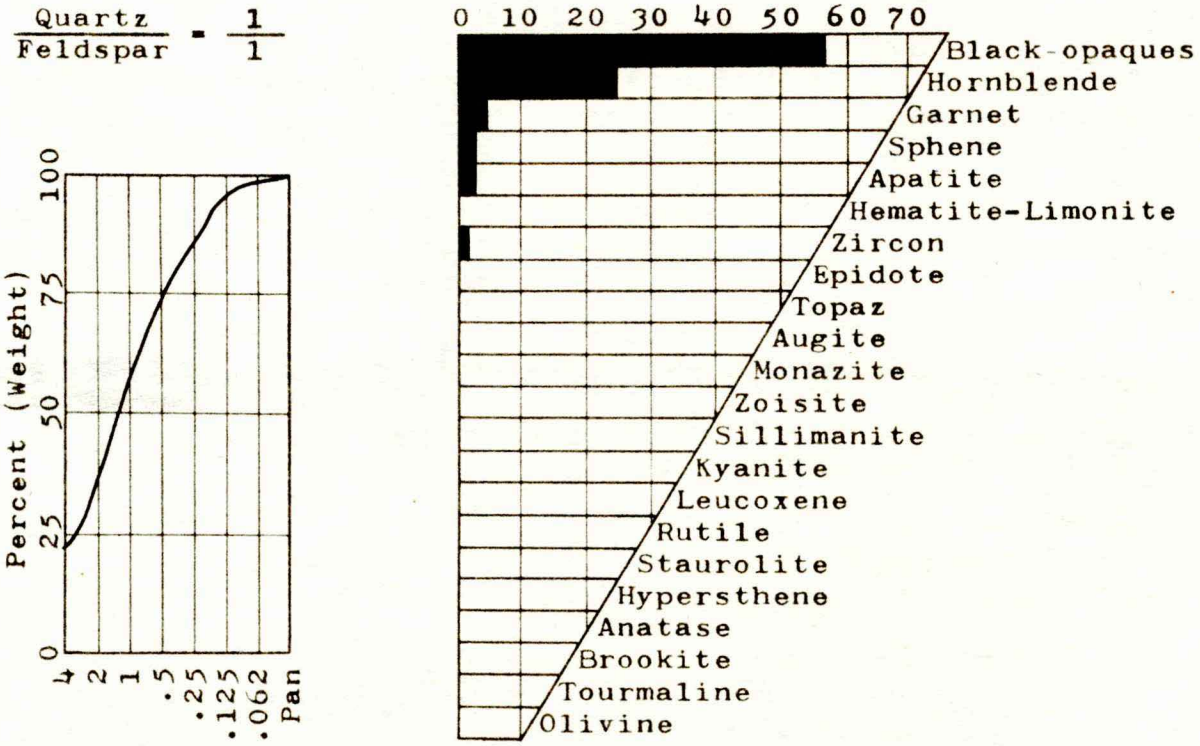
App. Fig. A-4. Analyses of sediment from locality 4 along Huerfano River near mouth.



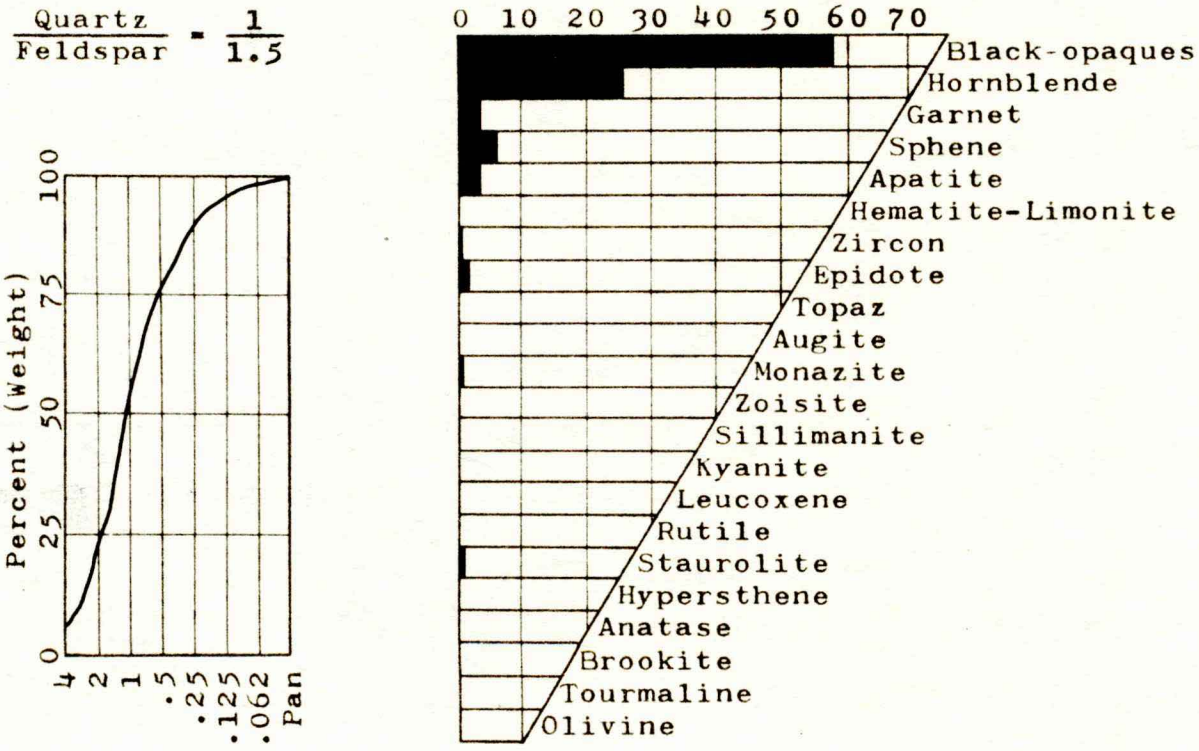
App. Fig. A-5. Analyses of sediment from locality 5 along Fountain Creek near mouth.



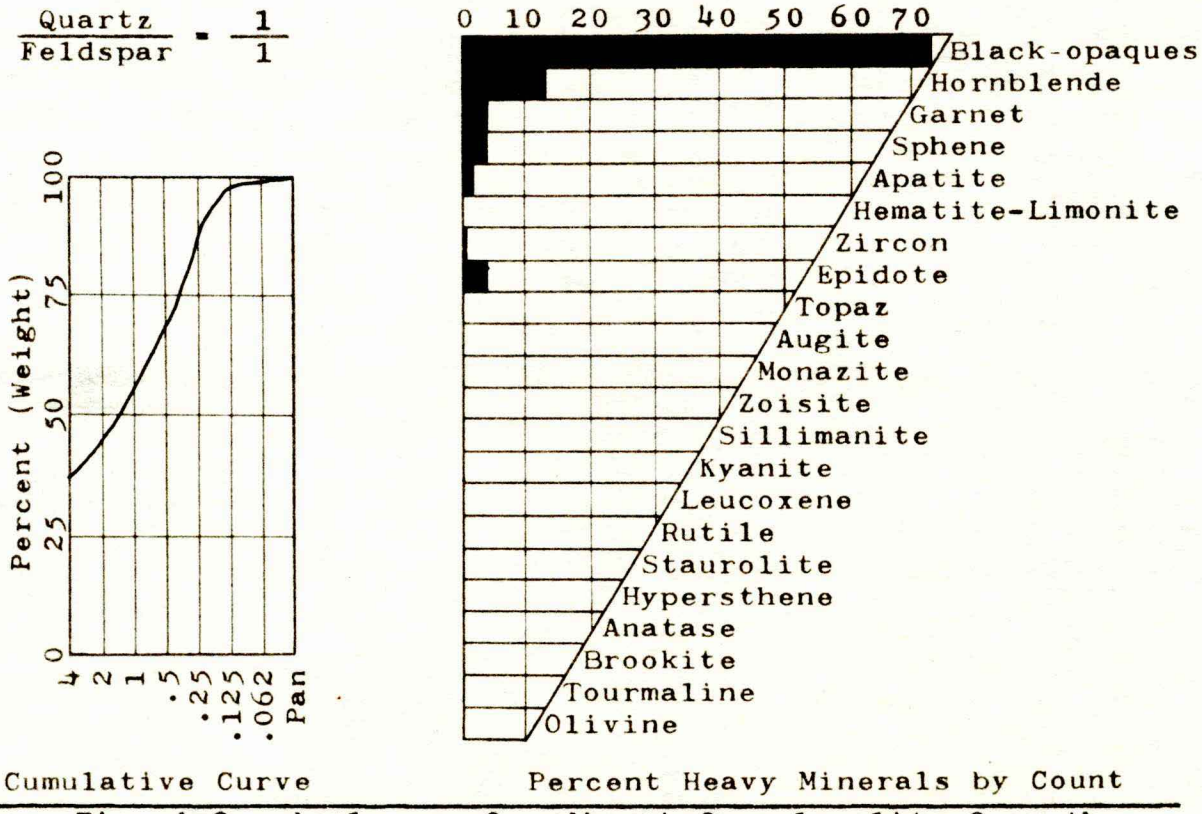
App. Fig. A- 6. Analyses of sediment from locality 6 along Apishapa River near head.



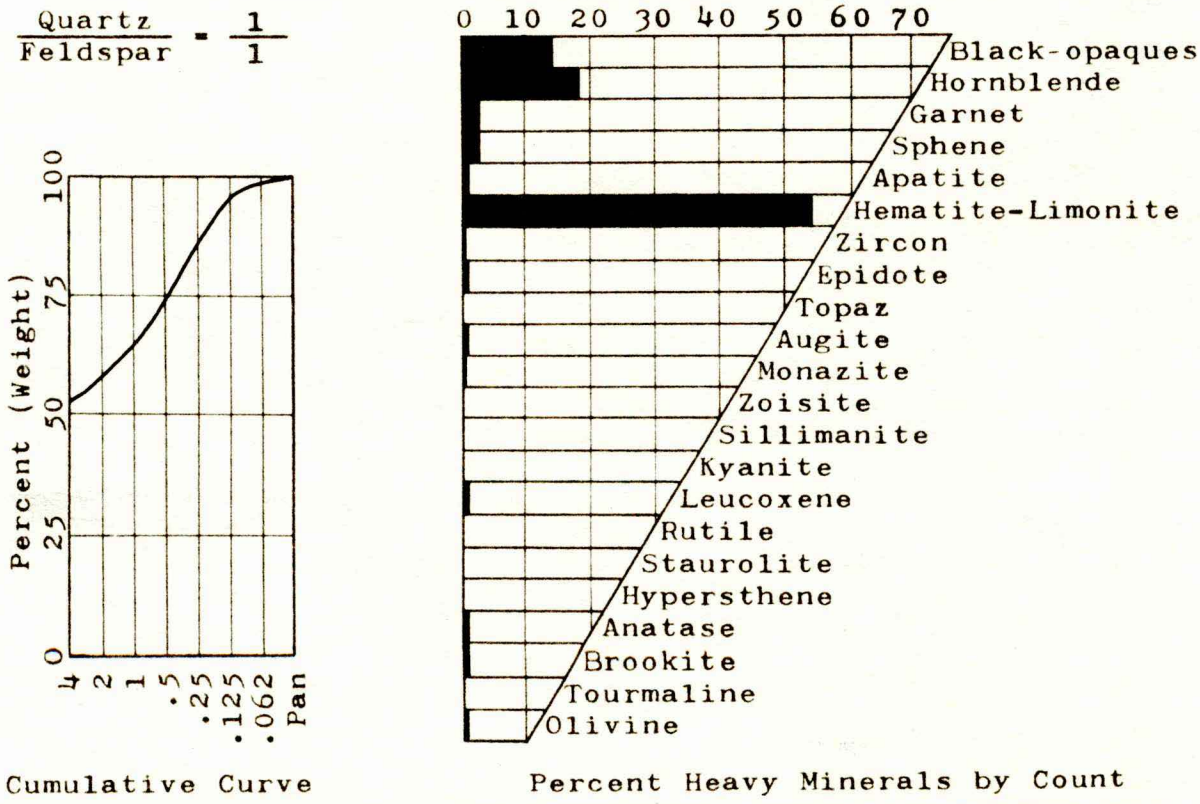
App. Fig. A-7. Analyses of sediment from locality 7 along Apishapa River in Pueblo County.



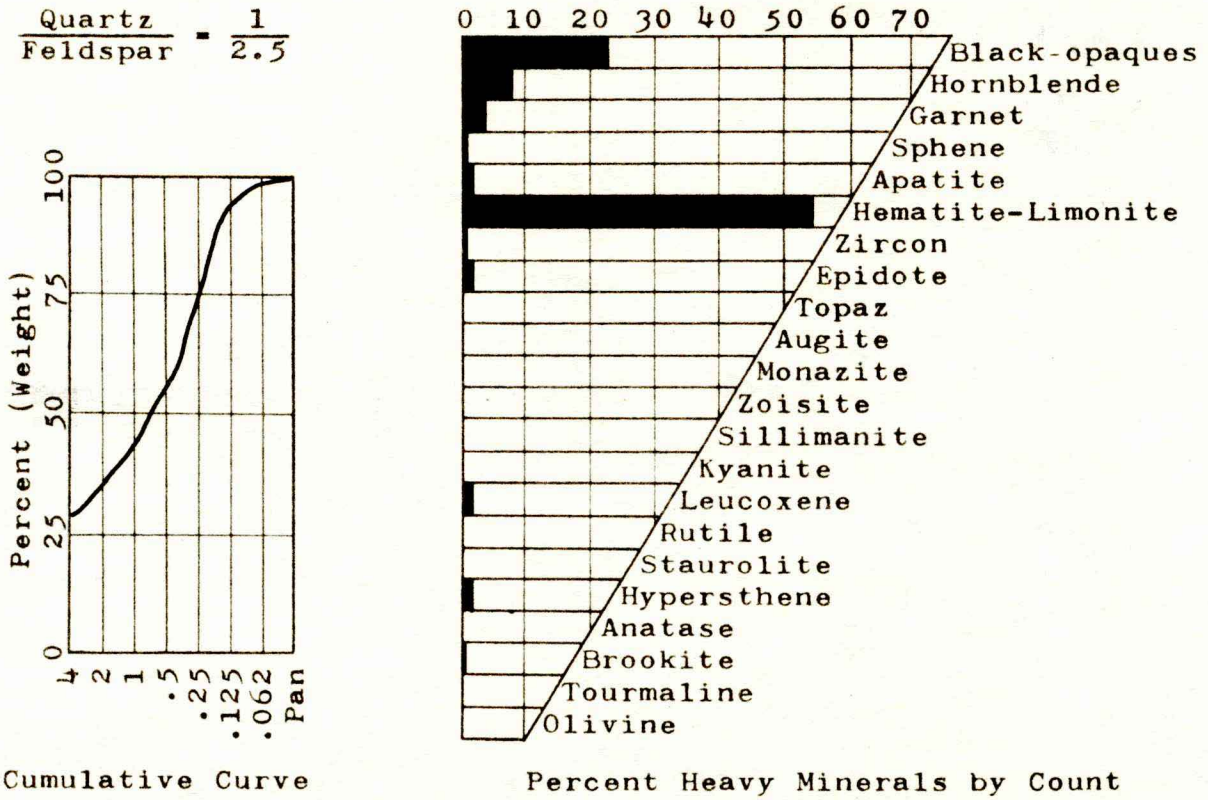
App. Fig. A-8. Analyses of sediment from locality 8 along Apishapa River near mouth.



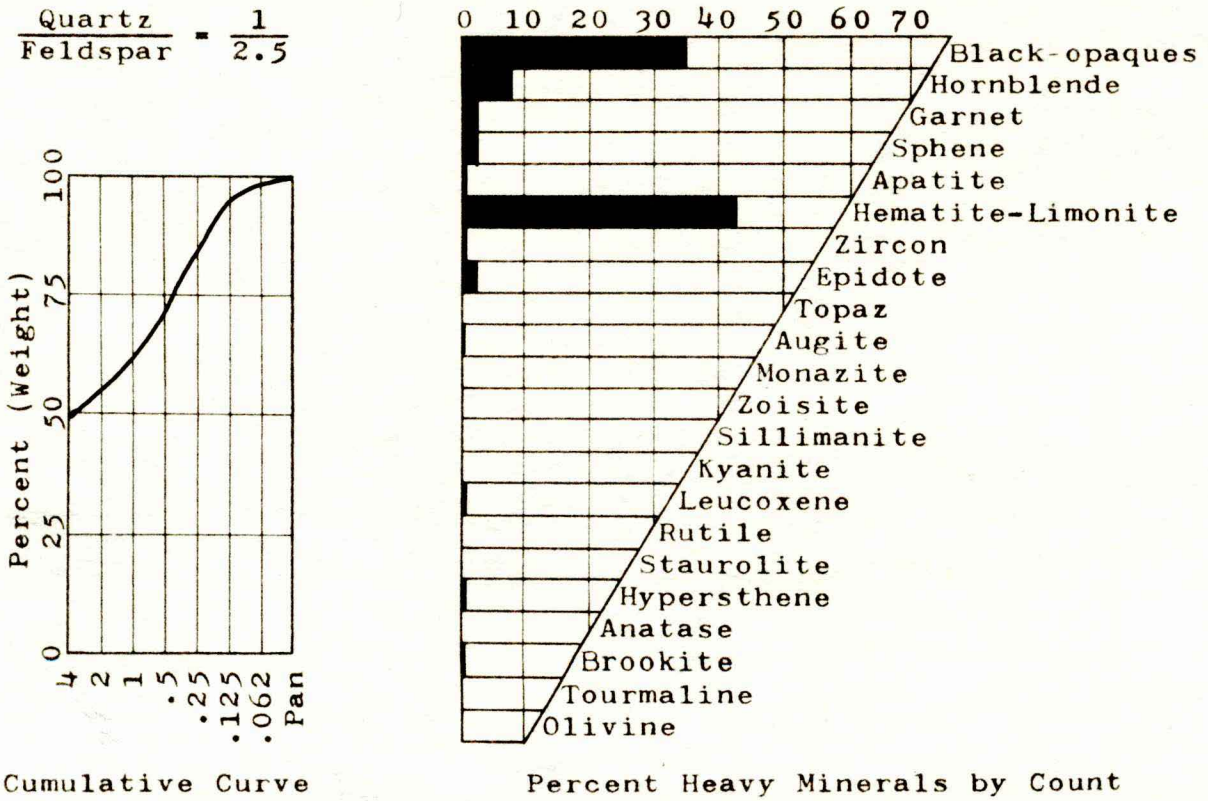
App. Fig. A-9. Analyses of sediment from locality 9 on the north fork of Purgatoire River.



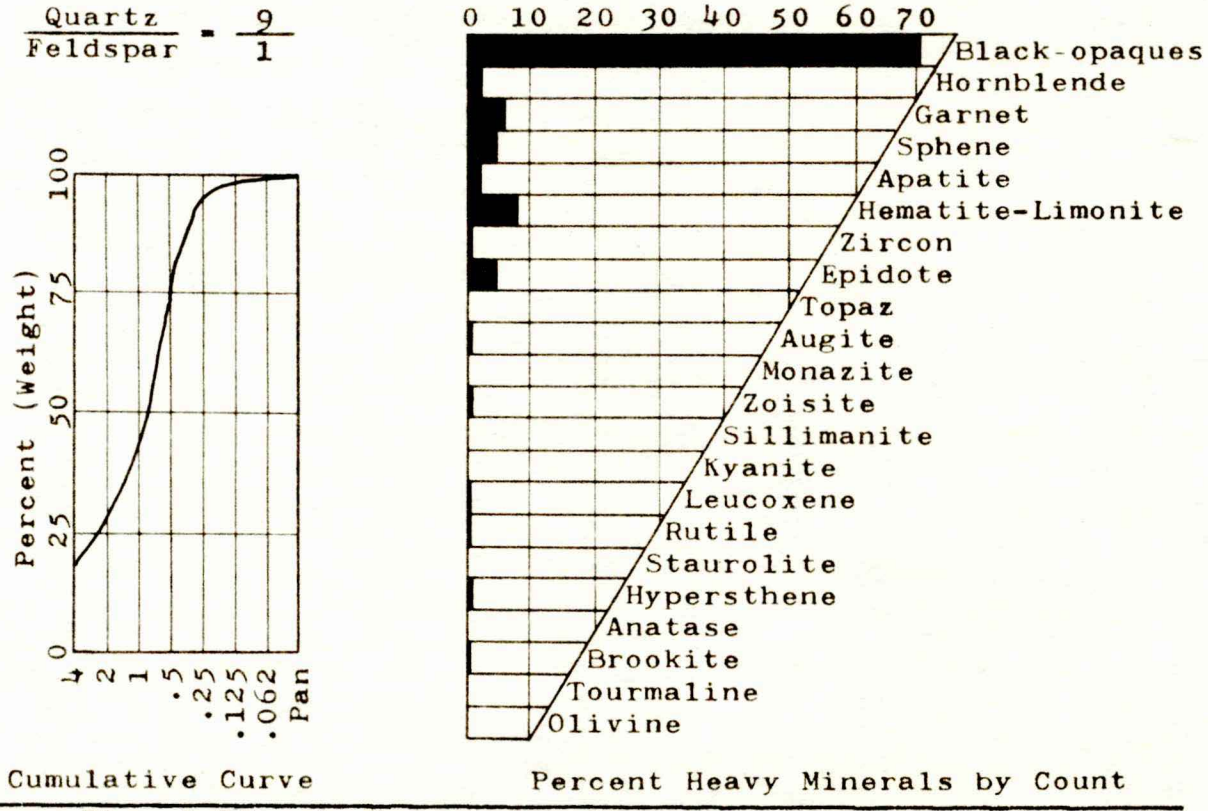
App. Fig. A-10. Analyses of sediment from locality 10 on the south fork of Purgatoire River.



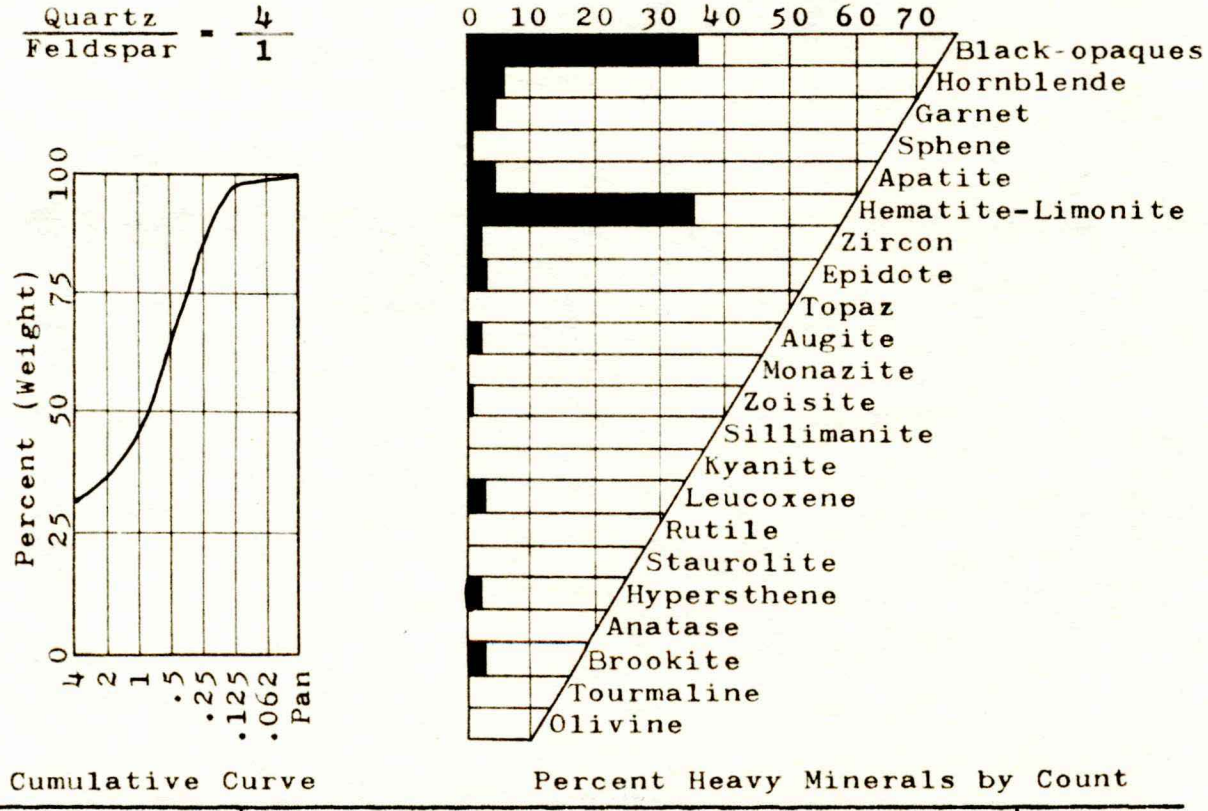
App. Fig. A-11. Analyses of sediment from locality 11 along Purgatoire River near Trinidad, Colorado.



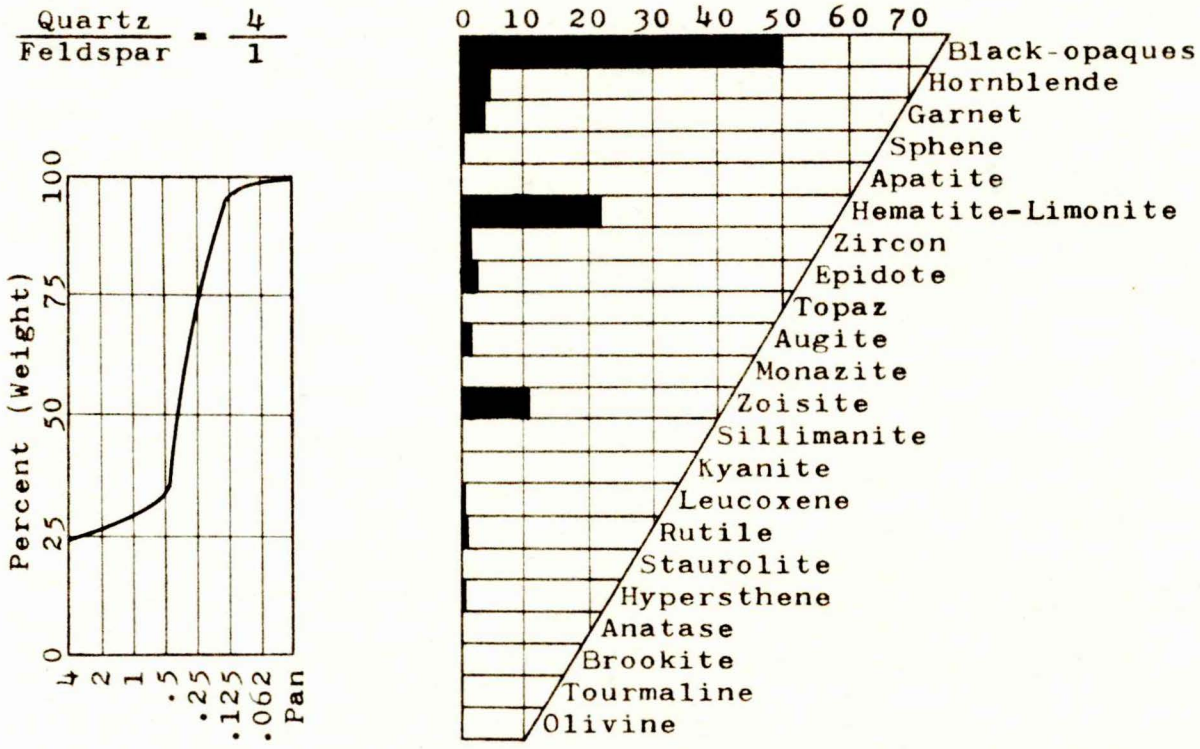
App. Fig. A-12. Analyses of sediment from locality 12 along Purgatoire River, upstream from mouth of Chacuaco.



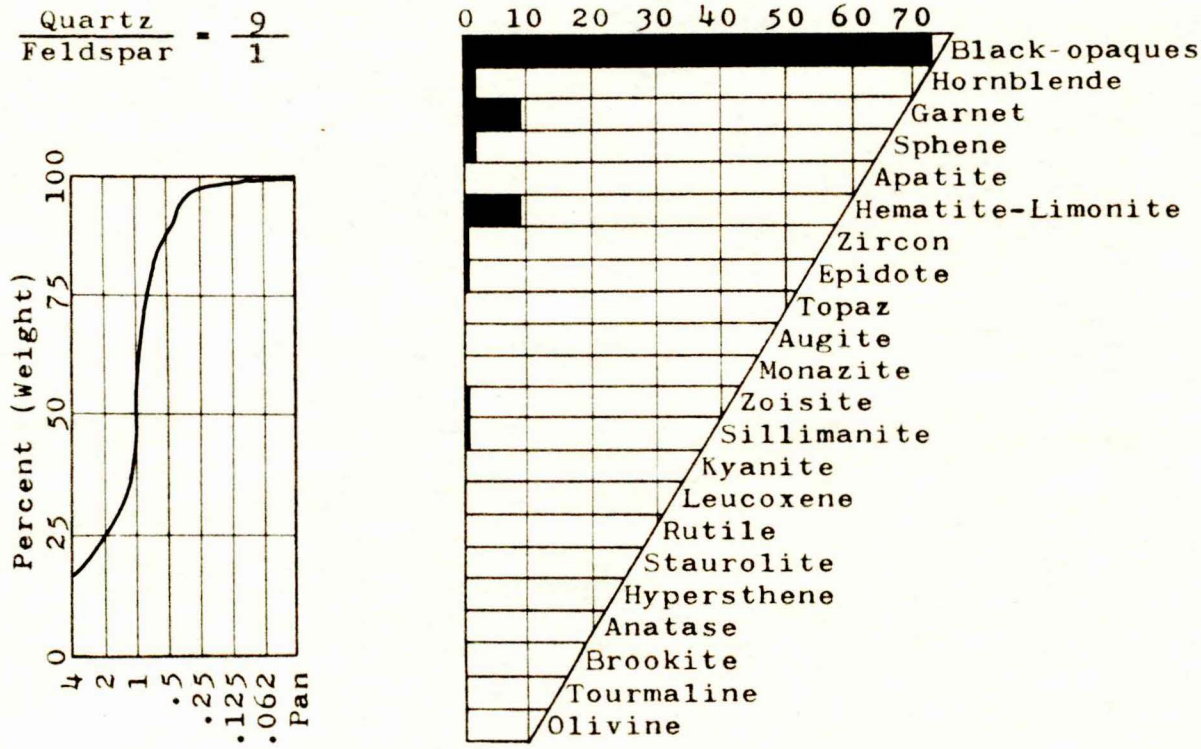
App. Fig. A-13. Analyses of sediment from locality 13 along Chacuaco Creek near head.



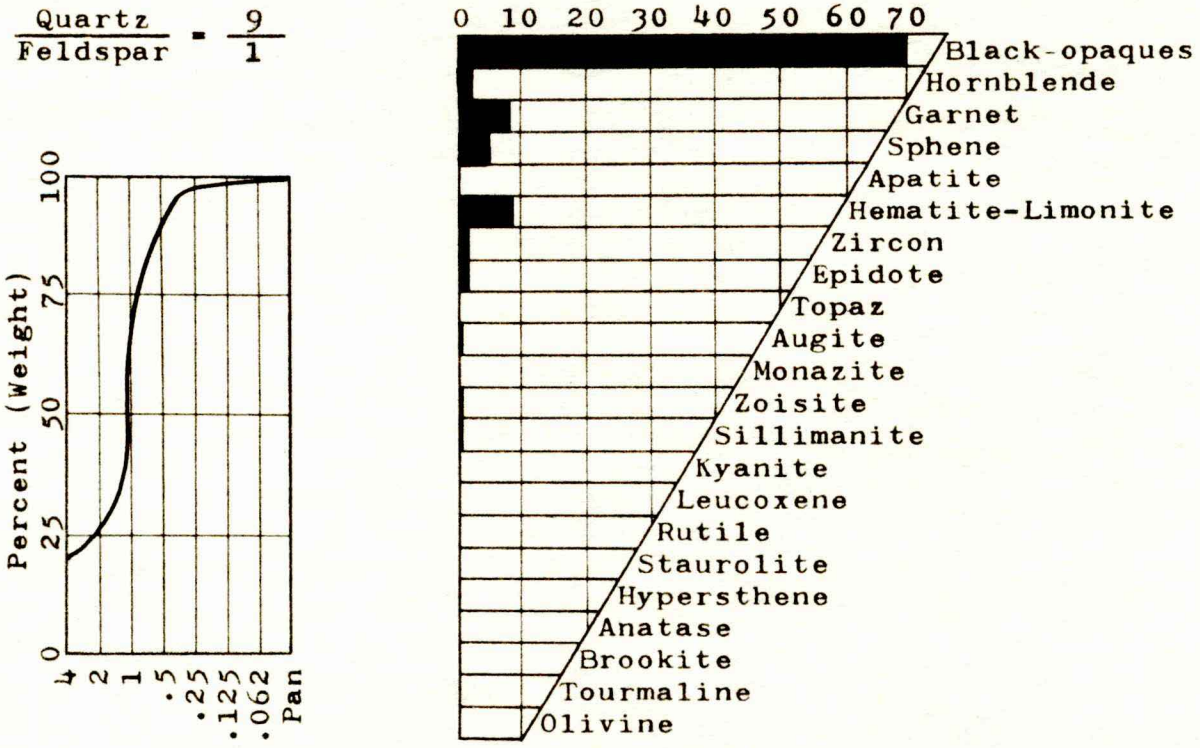
App. Fig. A-14. Analyses of sediment from locality 14 along Purgatoire River, below mouth of Chacuaco Creek.



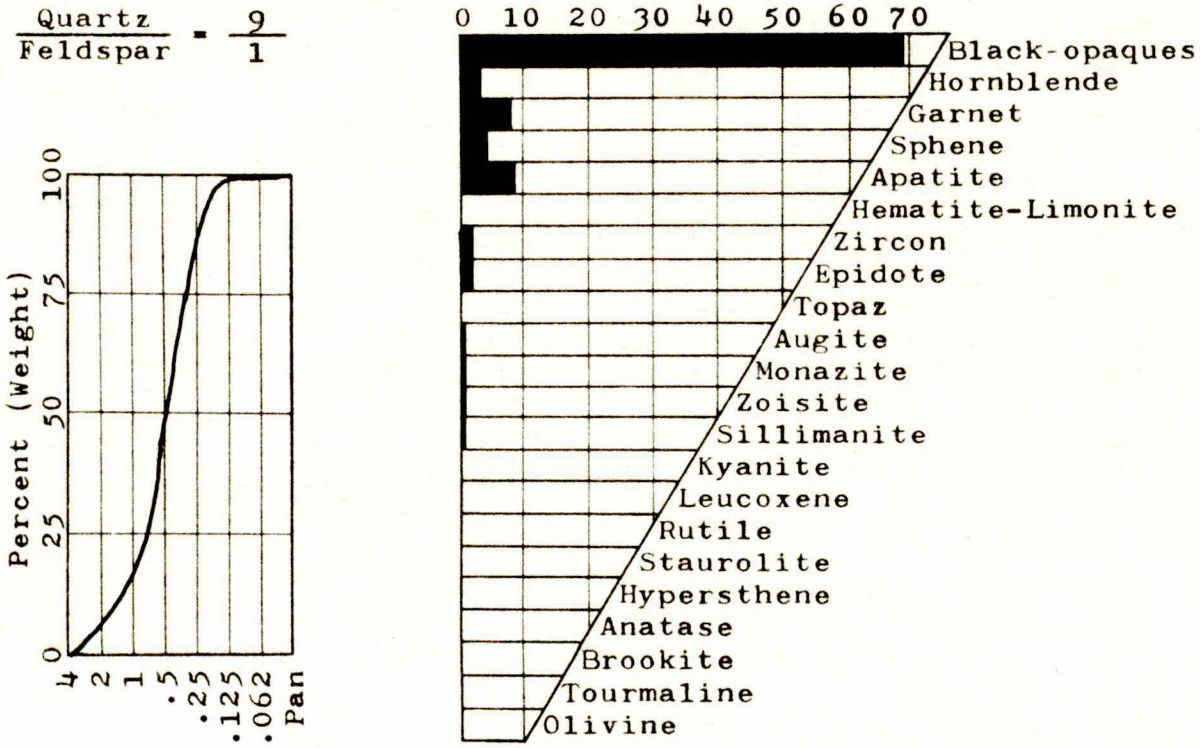
App. Fig. A-15. Analyses of sediment from locality 15 along Purgatoire River near mouth.



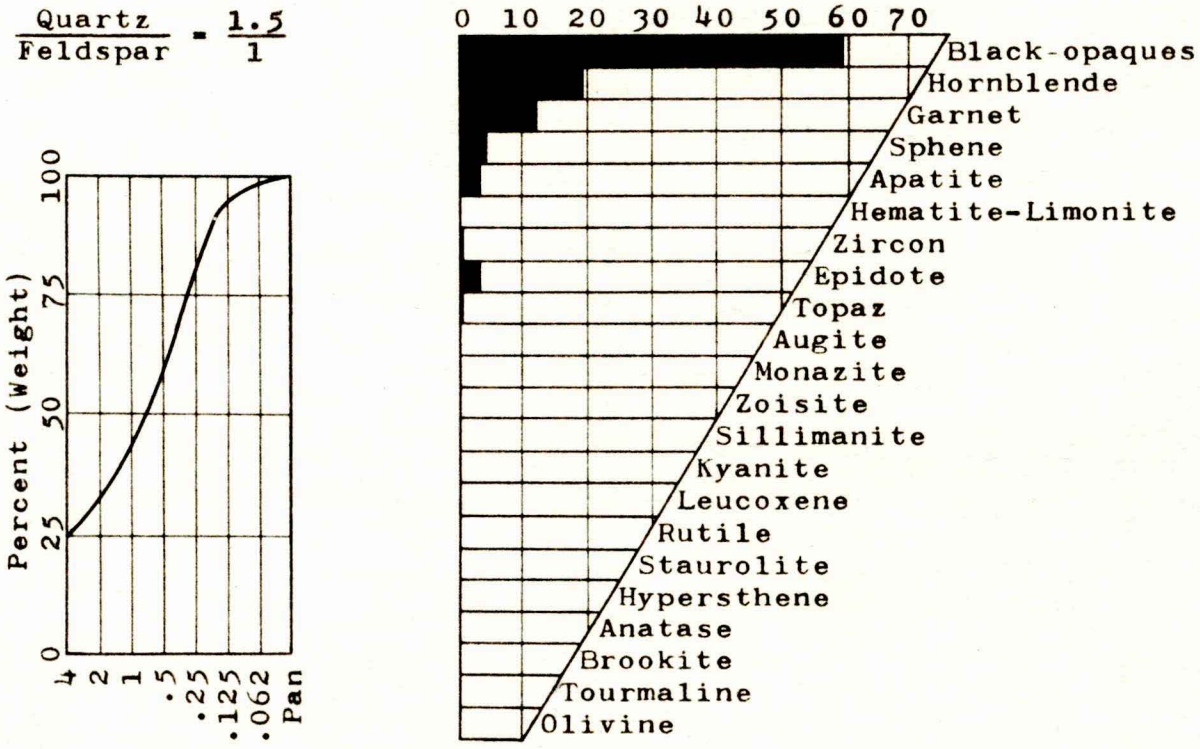
App. Fig. A-16. Analyses of sediment from locality 16 along Two Butte Creek near head.



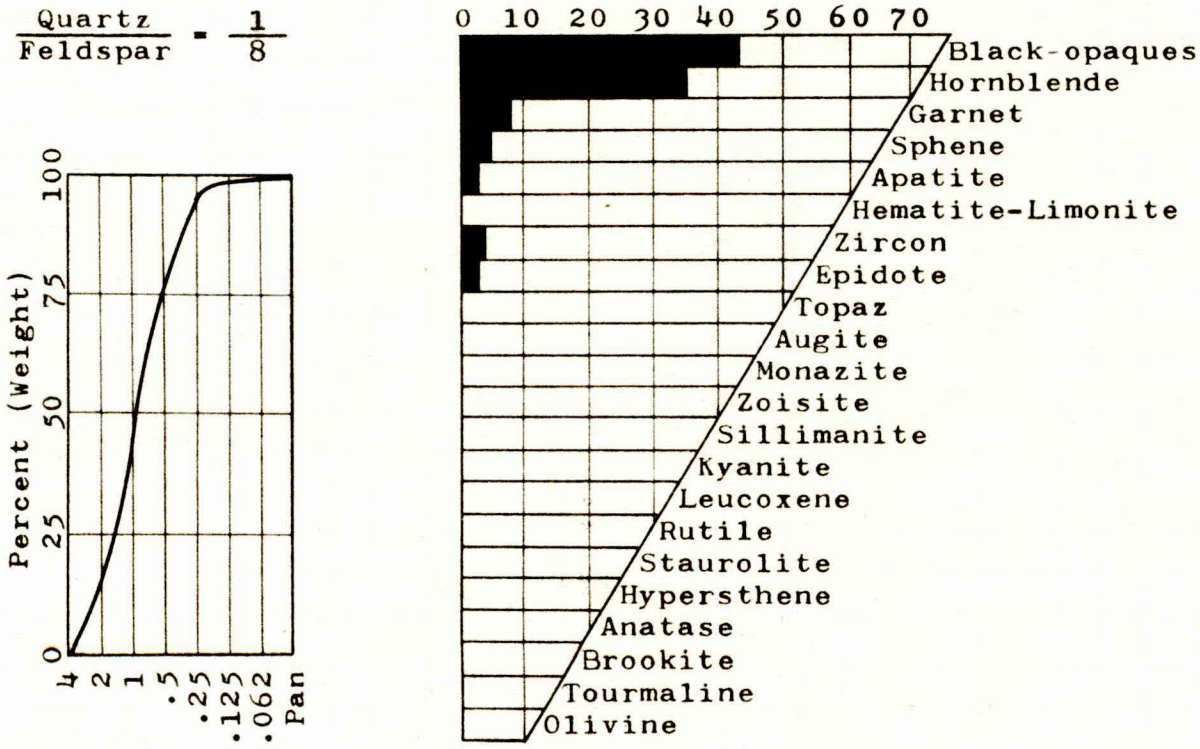
App. Fig. A-17. Analyses of sediment from locality 17 along Two Butte Creek near Two Butte Reservoir.



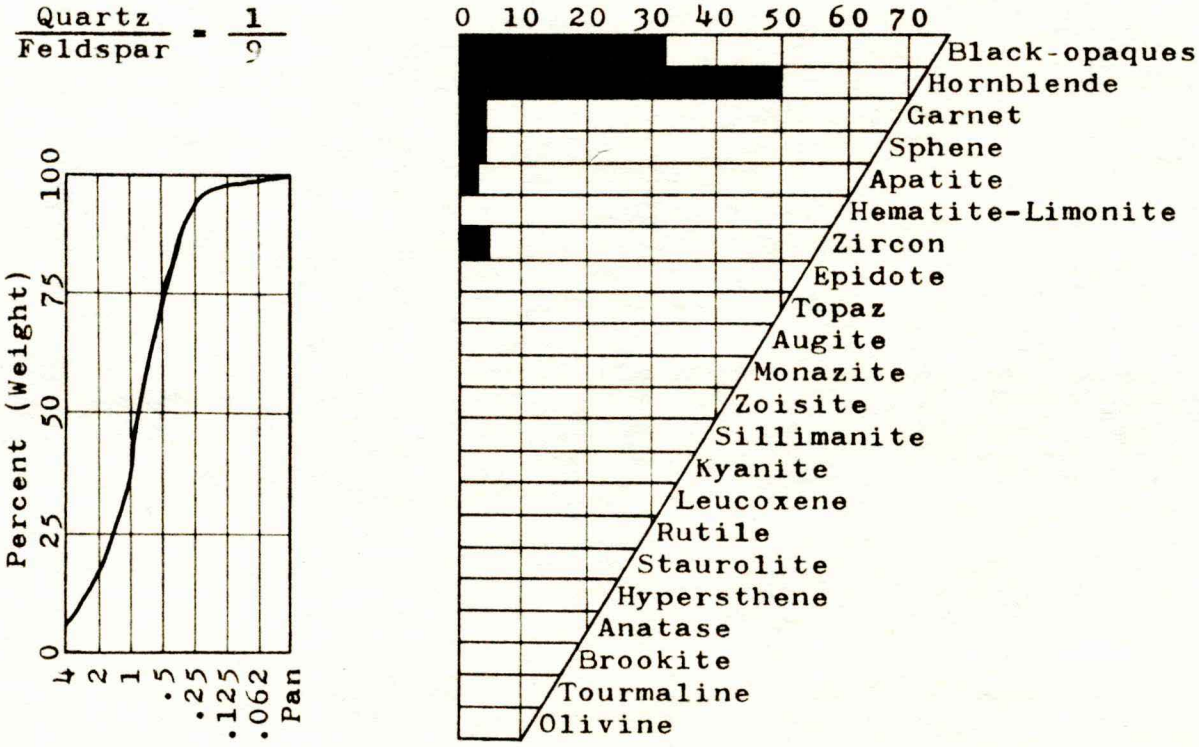
App. Fig. A-18. Analyses of sediment from locality 18 along Two Butte Creek near mouth.



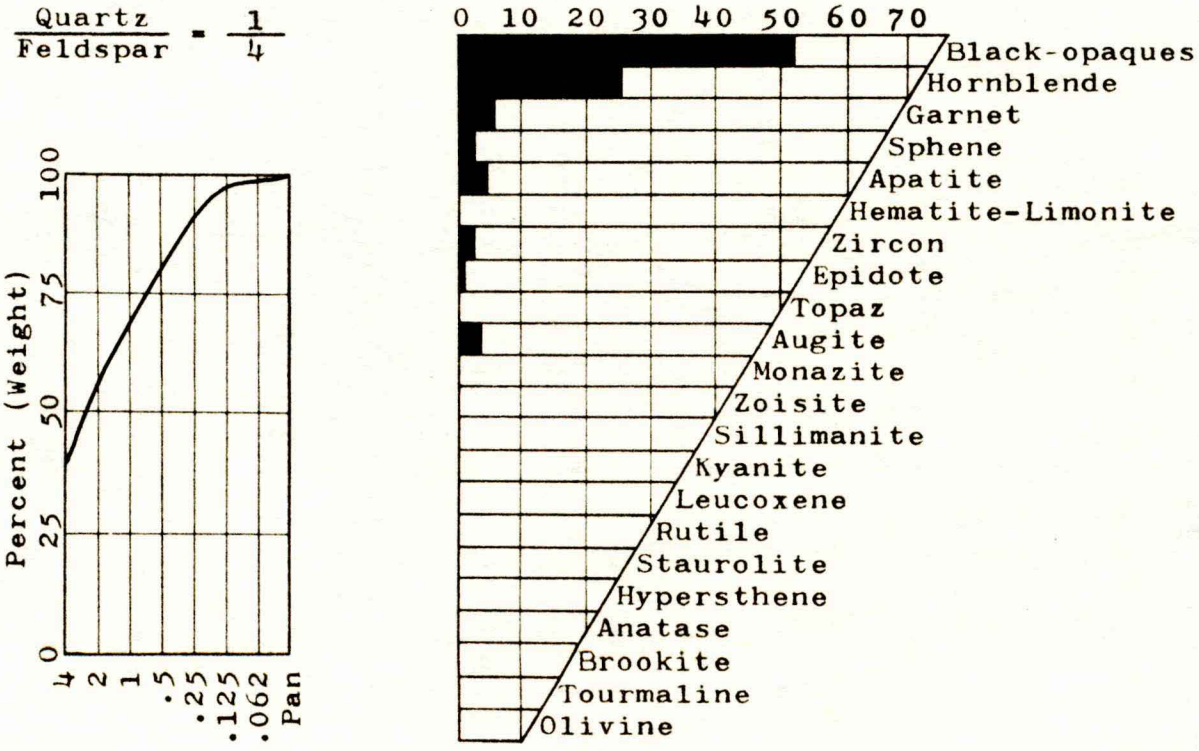
App. Fig. A-19. Analyses of sediment from locality 19 along Arkansas River at head of Royal Gorge.



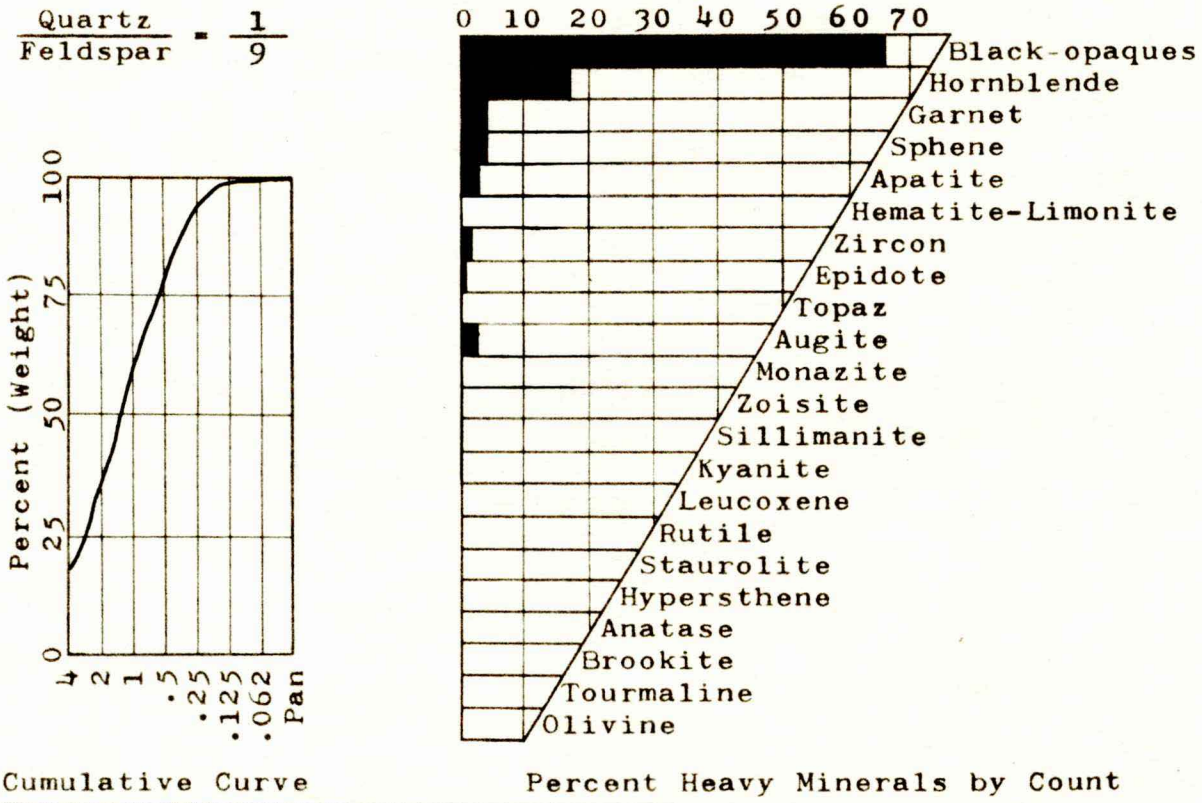
App. Fig. A-20. Analyses of sediment from locality 20 along Arkansas River at mouth of Royal Gorge.



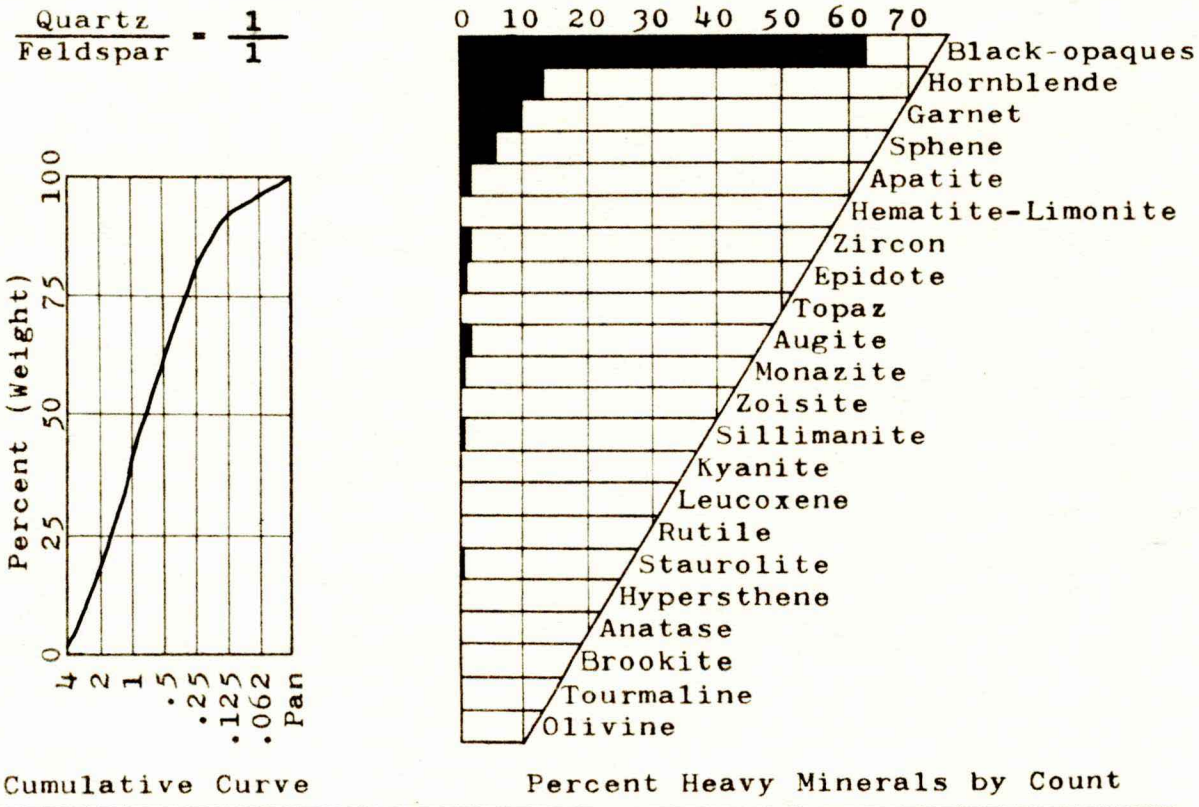
App. Fig. A-21. Analyses of sediment from locality 21 along Arkansas River near Portland, Colorado.



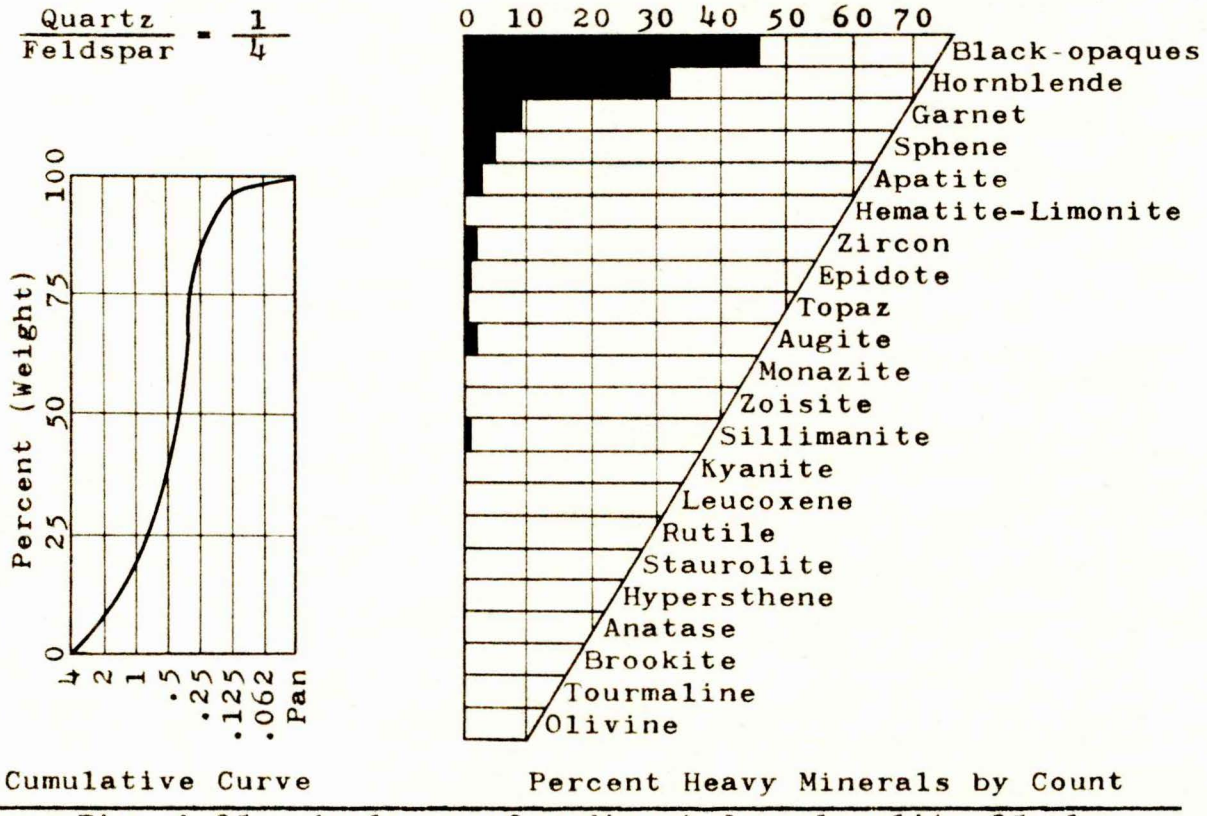
App. Fig. A-22. Analyses of sediment from locality 22 along Arkansas River below mouth of Fountain Creek.



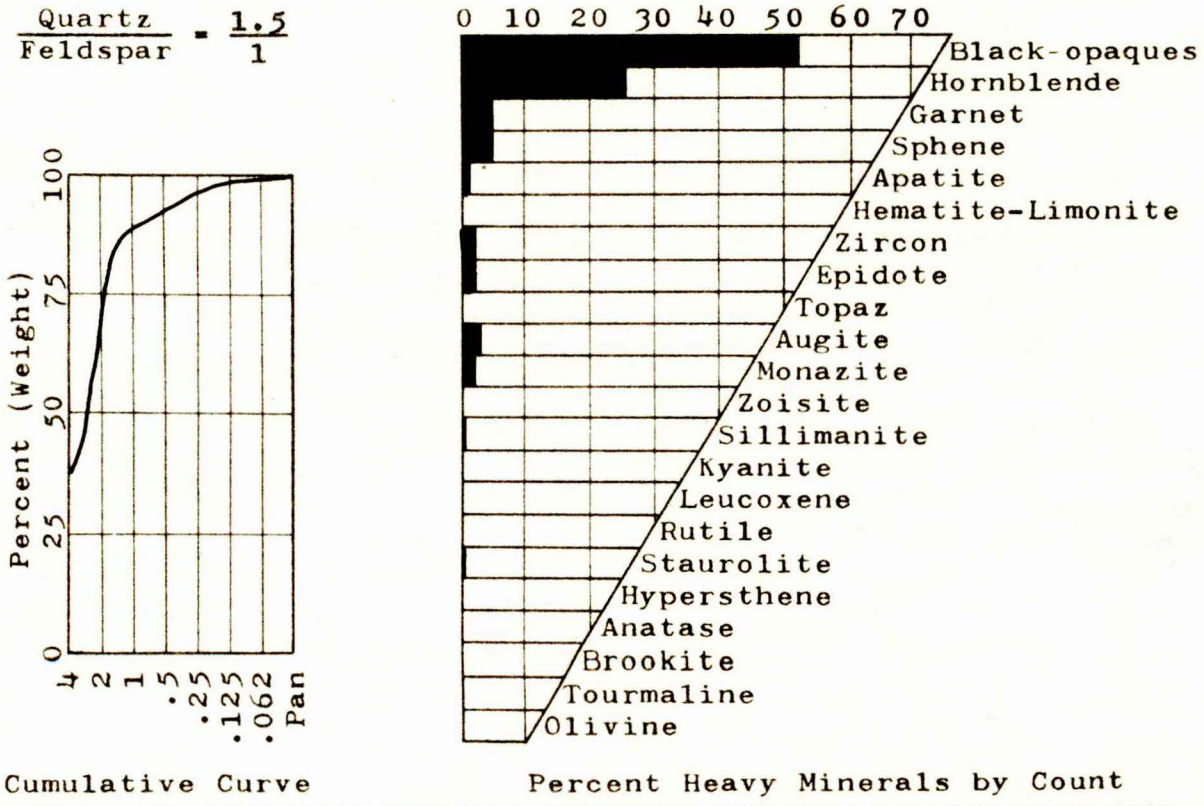
App. Fig. A-23. Analyses of sediment from locality 23 along Arkansas River near Devine, Colorado.



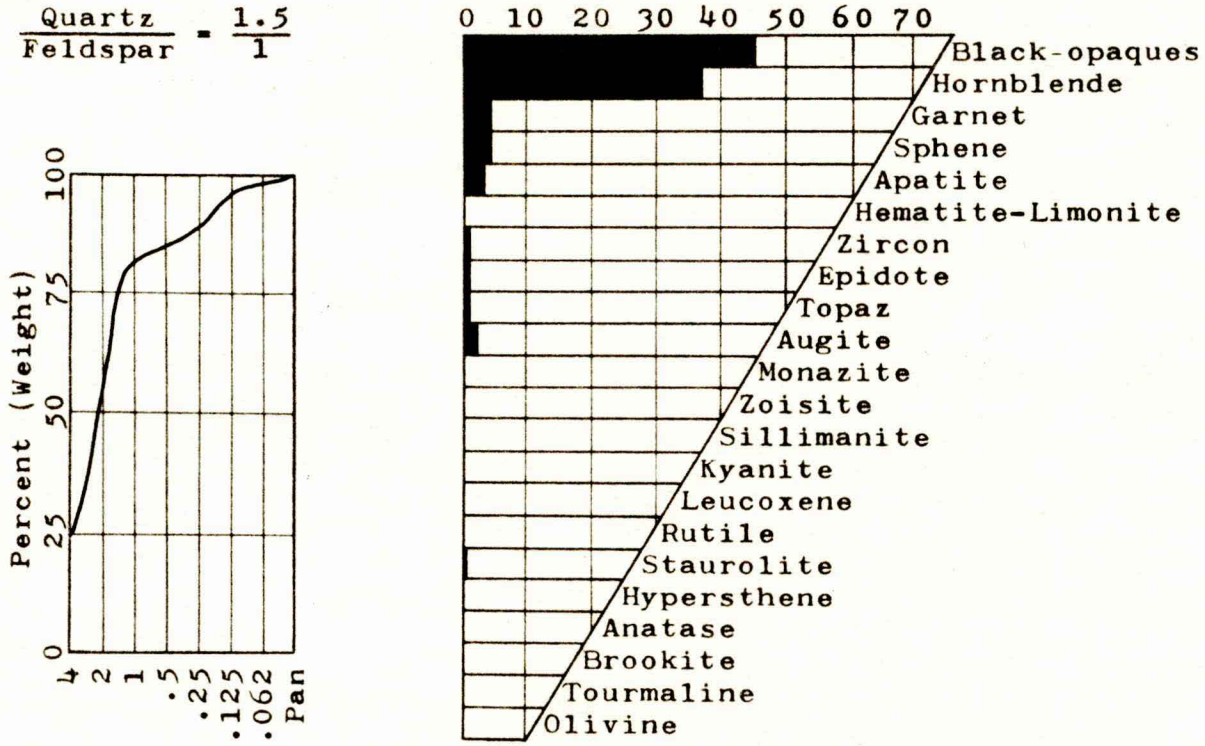
App. Fig. A-24. Analyses of sediment from locality 24 along Arkansas River below mouth of Huerfano River.



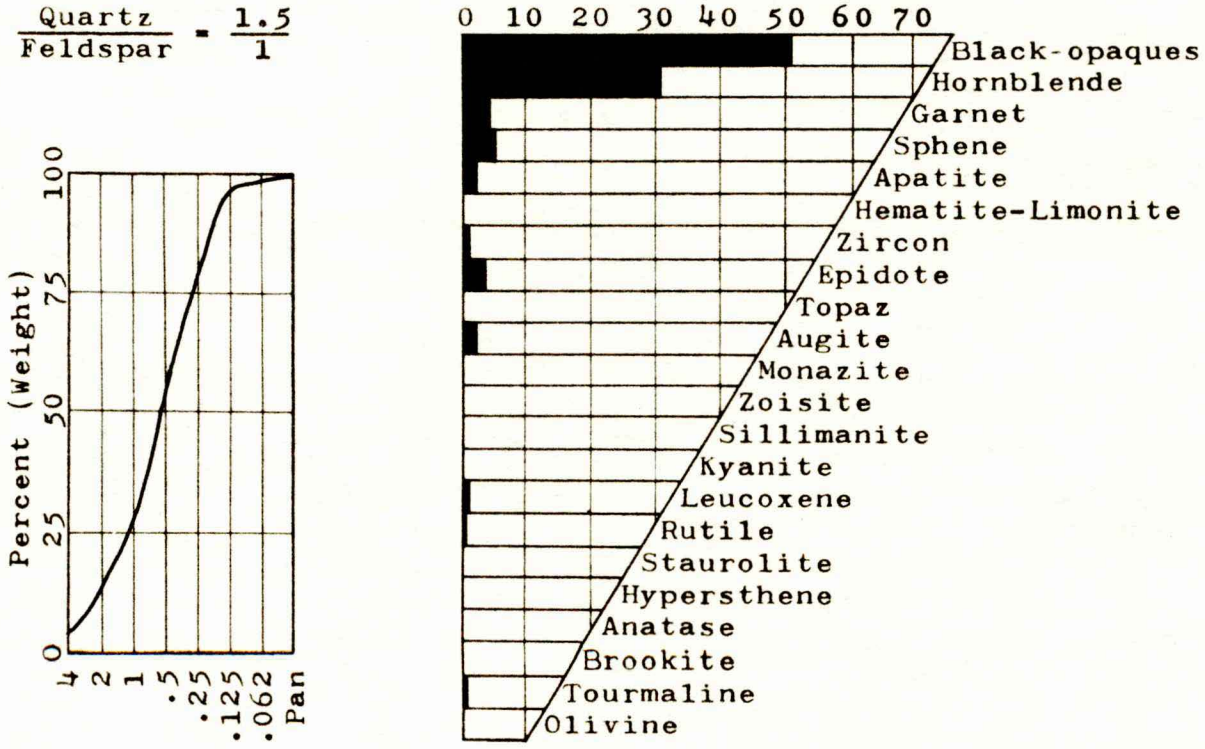
App. Fig. A-25. Analyses of sediment from locality 25 along Arkansas River near Fowler, Colorado.



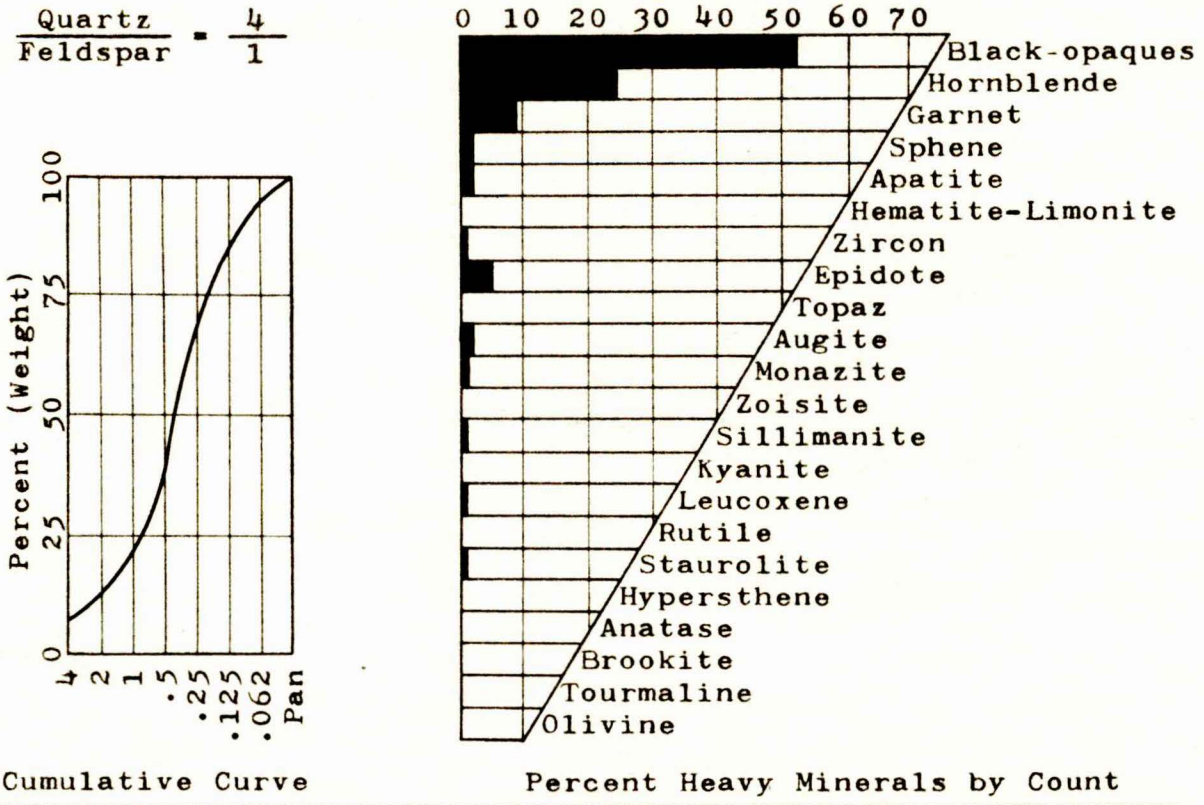
App. Fig. A-26. Analyses of sediment from locality 26 along Arkansas River below mouth of Apishapa River.



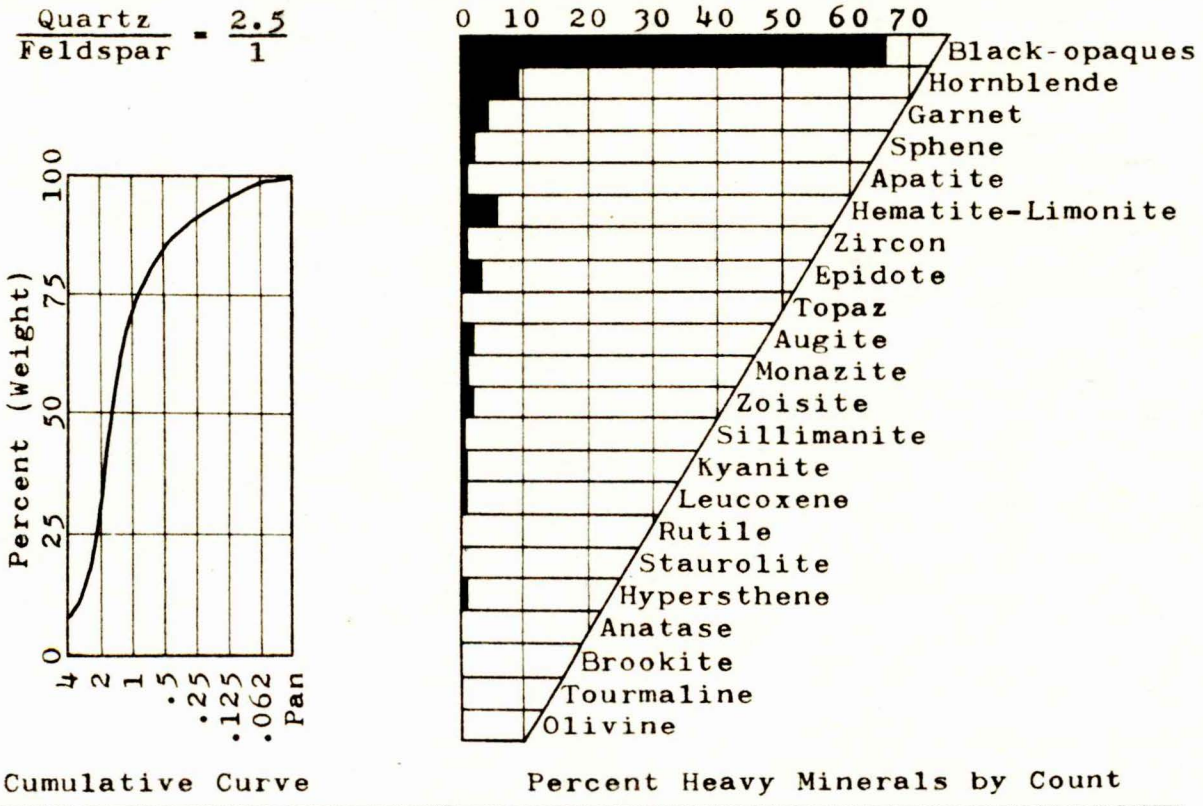
App. Fig. A-27. Analyses of sediment from locality 27 along Arkansas River near Rocky Ford, Colorado.



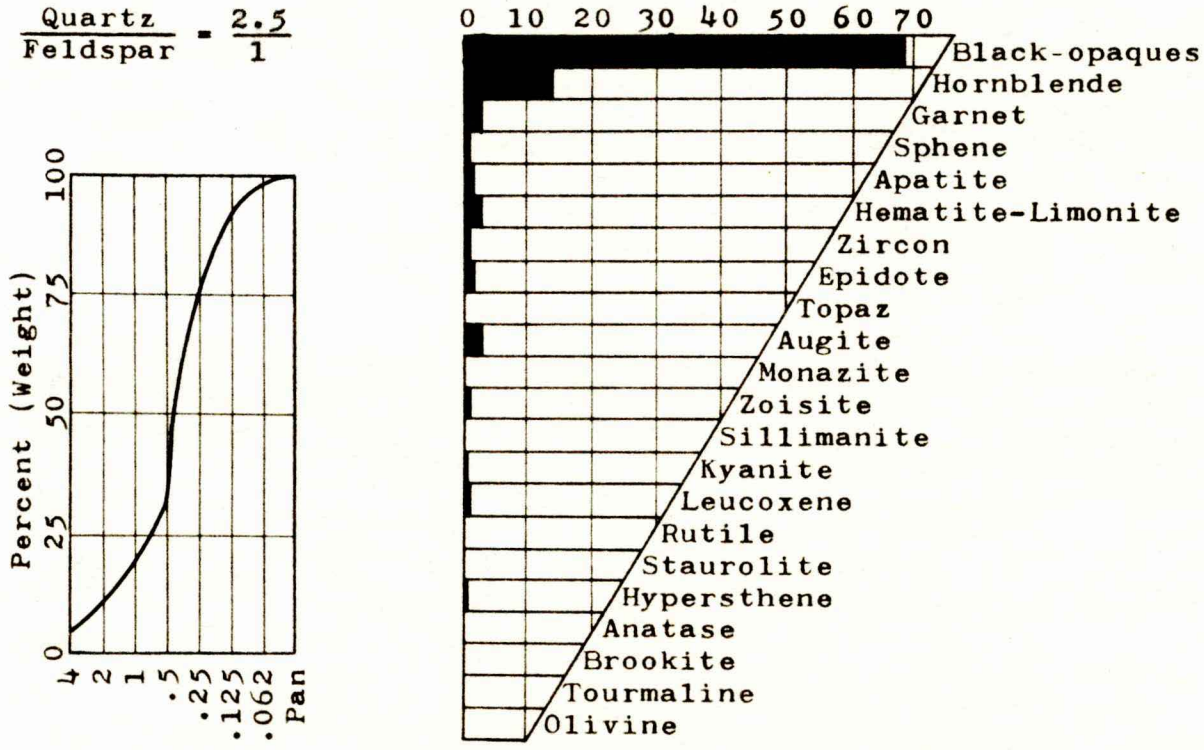
App. Fig. A-28. Analyses of sediment from locality 28 along Arkansas River near La Junta, Colorado.



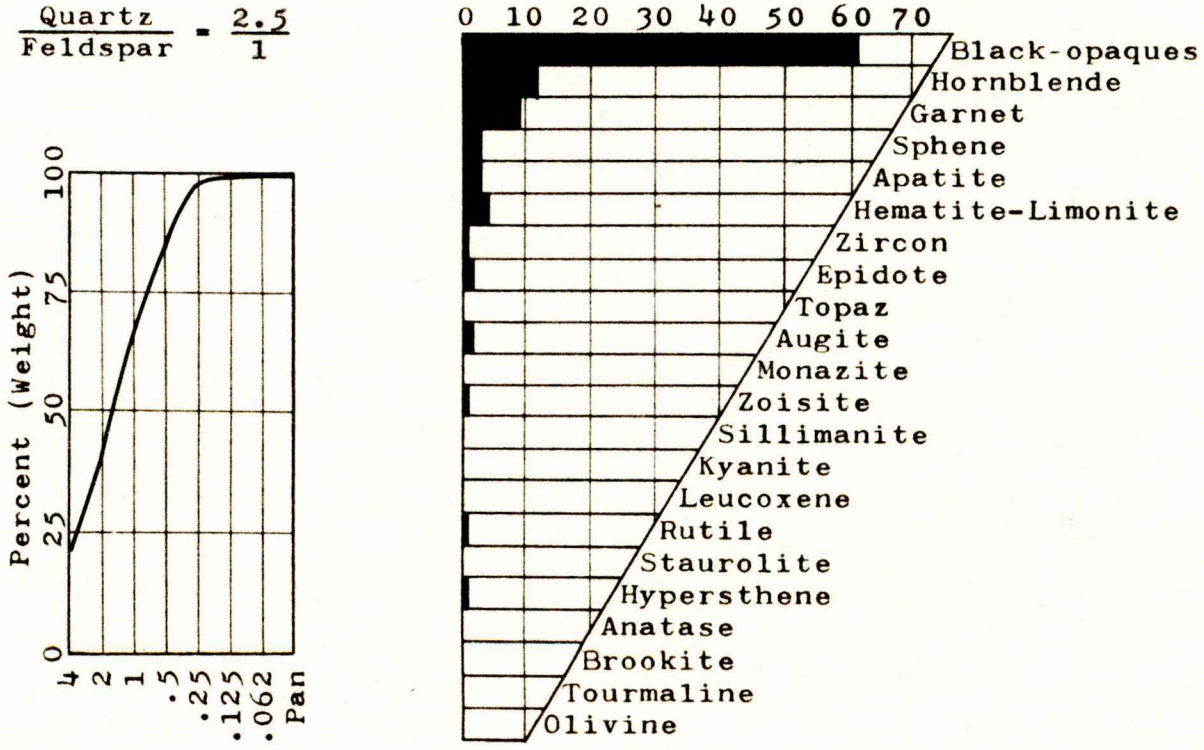
App. Fig. A-29. Analyses of sediment from locality 29 along Arkansas River below mouth of Purgatoire River.



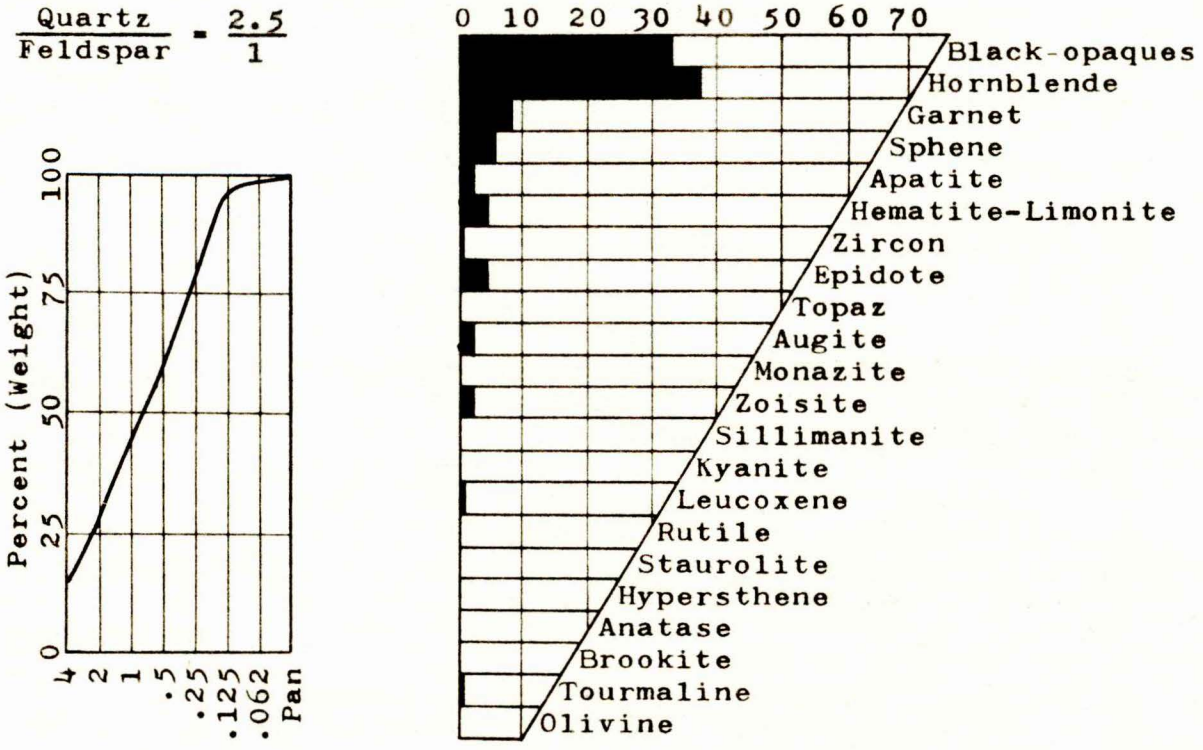
App. Fig. A-30. Analyses of sediment from locality 30 along Arkansas River east of John Martin Dam.



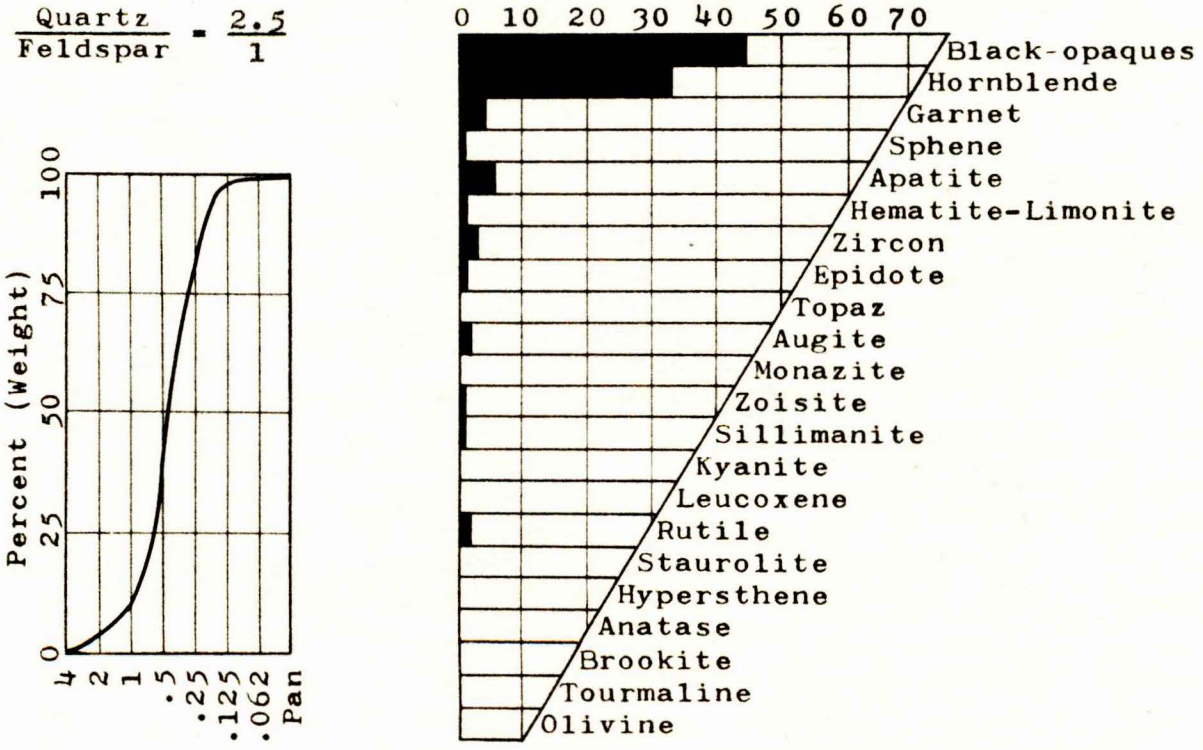
App. Fig. A-31. Analyses of sediment from locality 31 along Arkansas River near Prowers, Colorado.



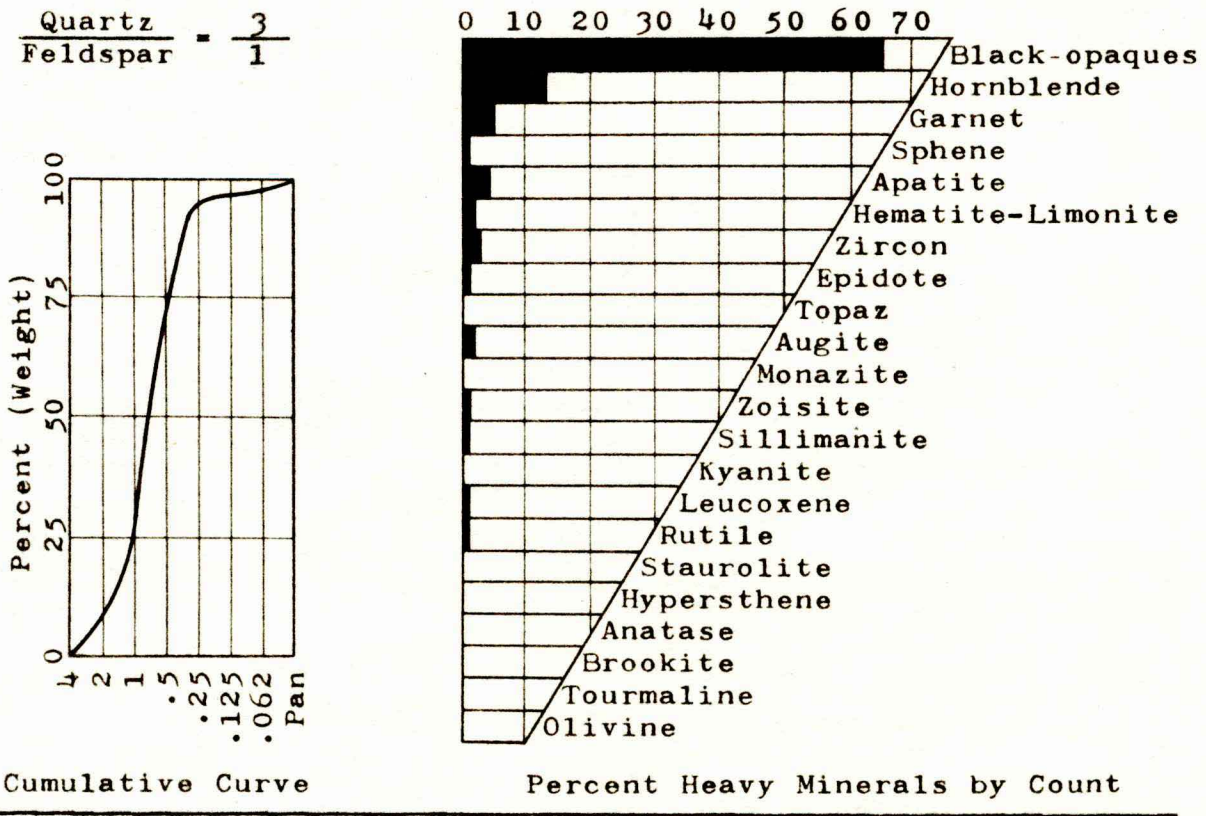
App. Fig. A-32. Analyses of sediment from locality 32 along Arkansas River near Lamar, Colorado.



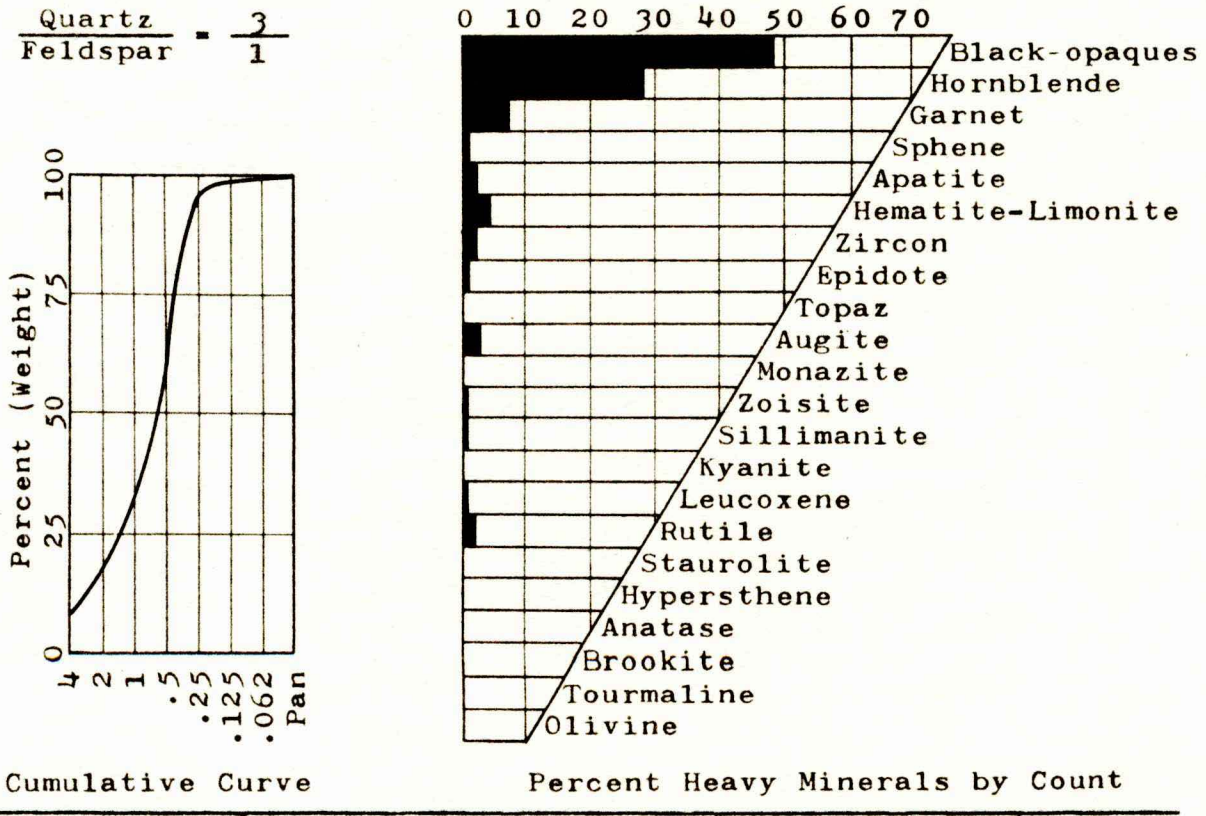
App. Fig. A-33. Analyses of sediment from locality 33 along Arkansas River near Granada, Colorado.



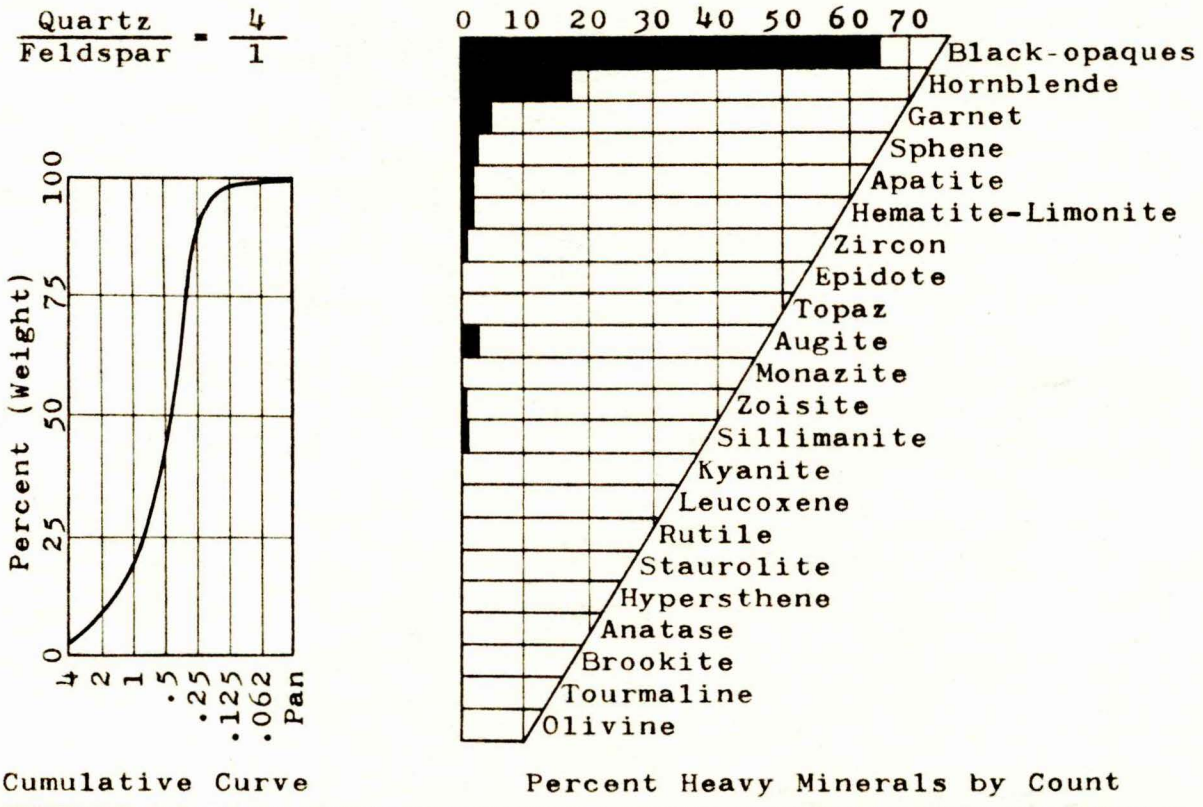
App. Fig. A-34. Analyses of sediment from locality 34 along Arkansas River below mouth of Two Butte Creek.



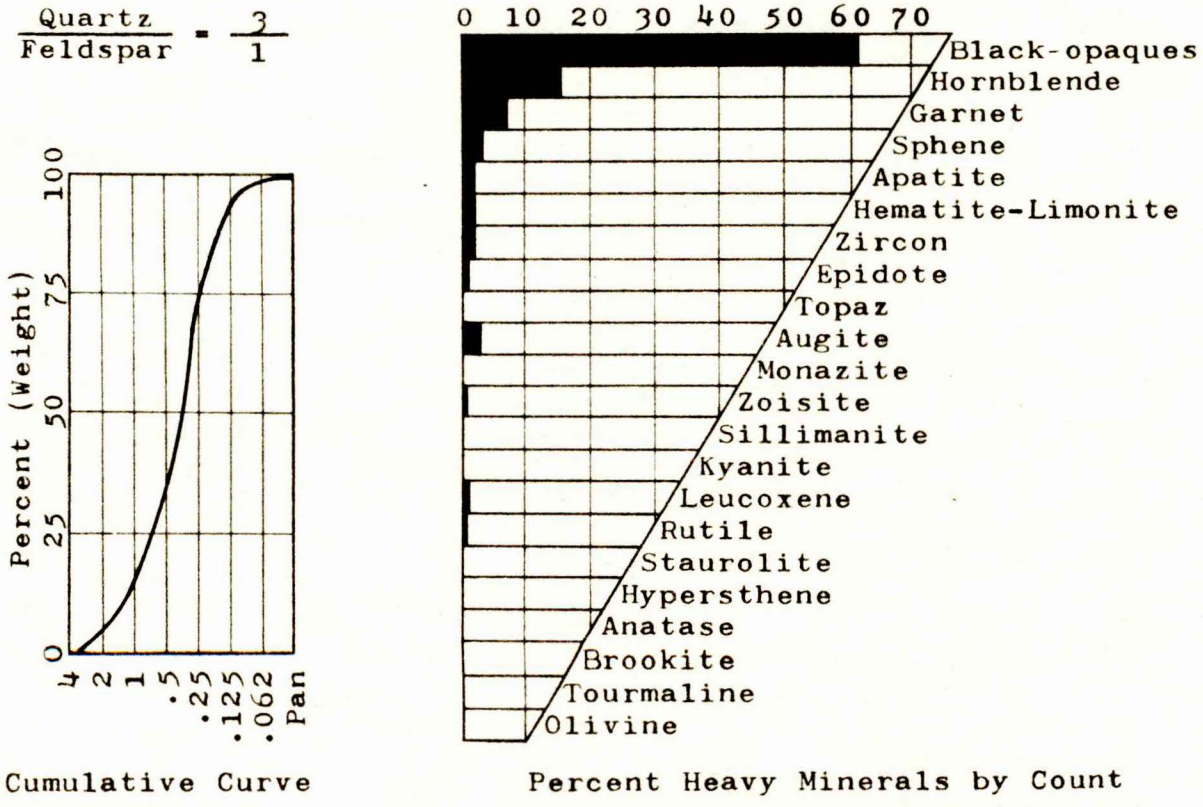
App. Fig. A-35. Analyses of sediment from locality 35 along Arkansas River near Coolidge, Kansas.



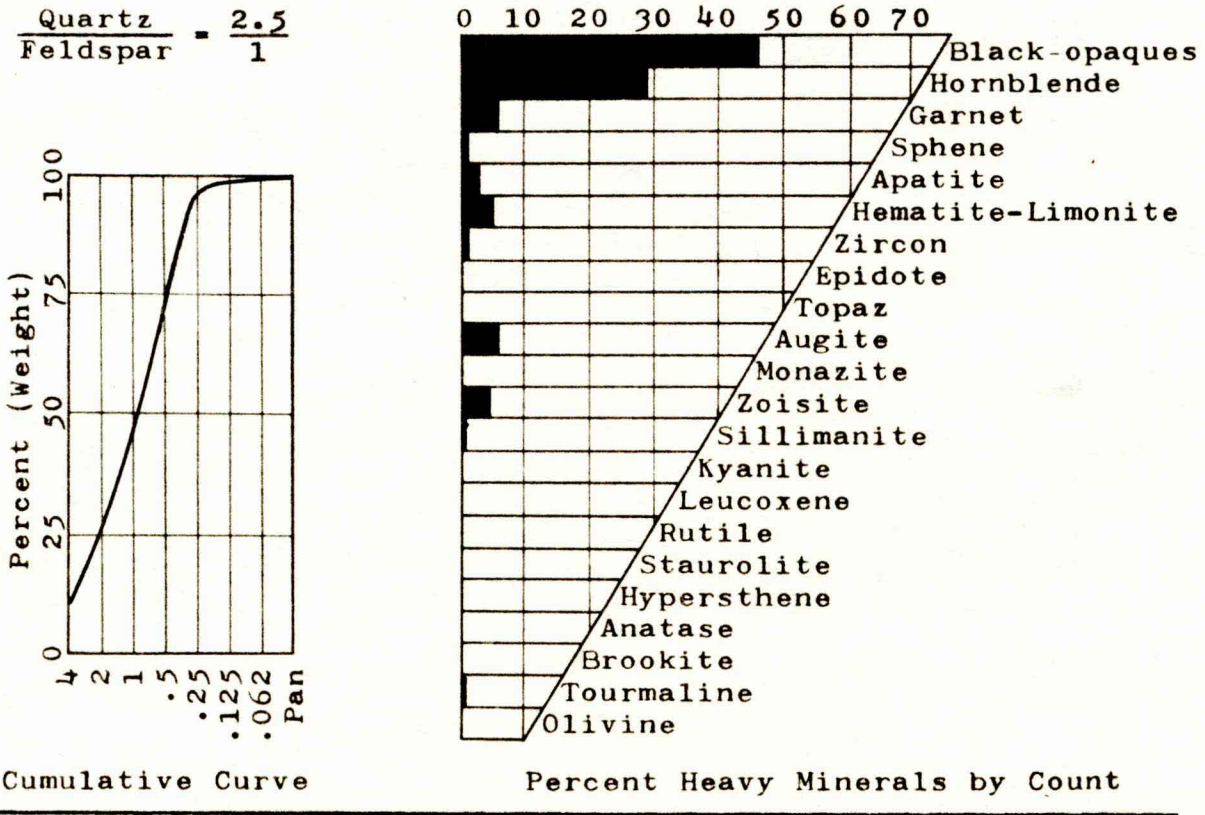
App. Fig. A-36. Analyses of sediment from locality 36 along Arkansas River near Syracuse, Kansas.



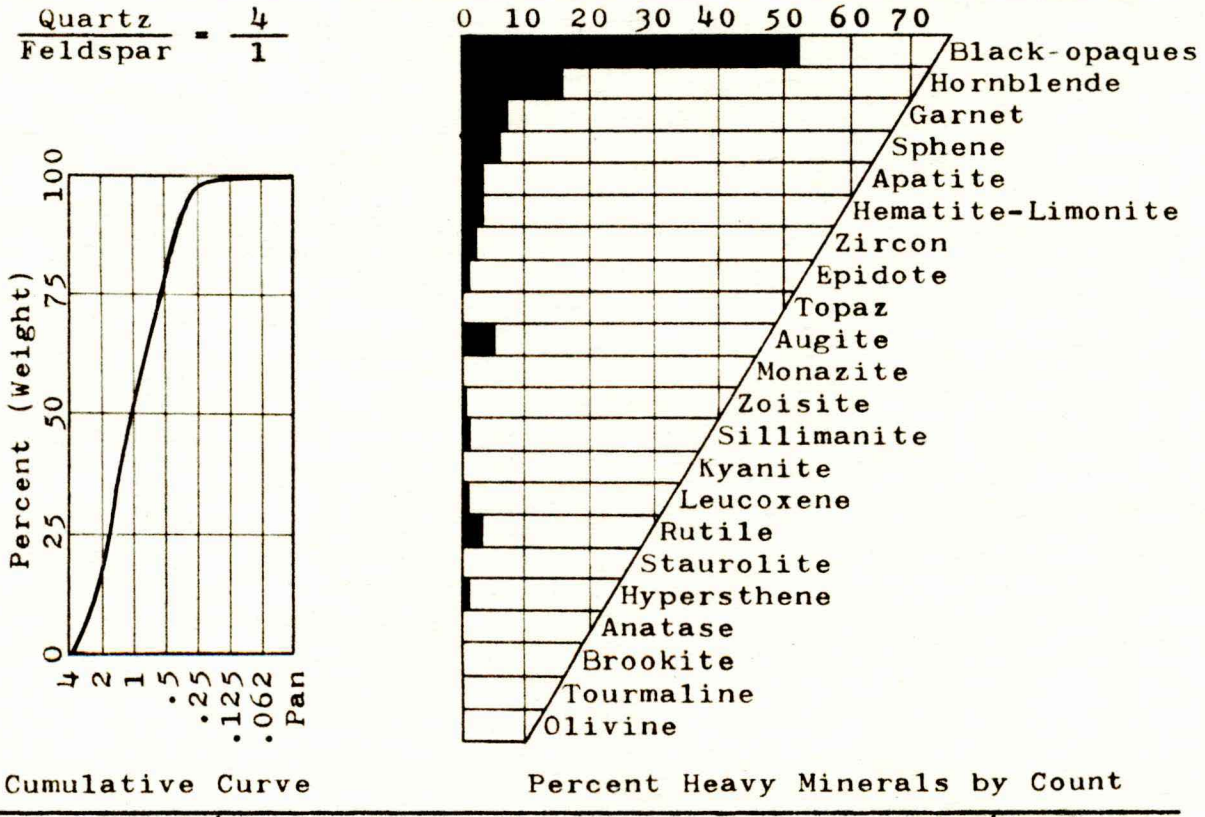
App. Fig. A-37. Analyses of sediment from locality 37 along Arkansas River near Kendall, Kansas.



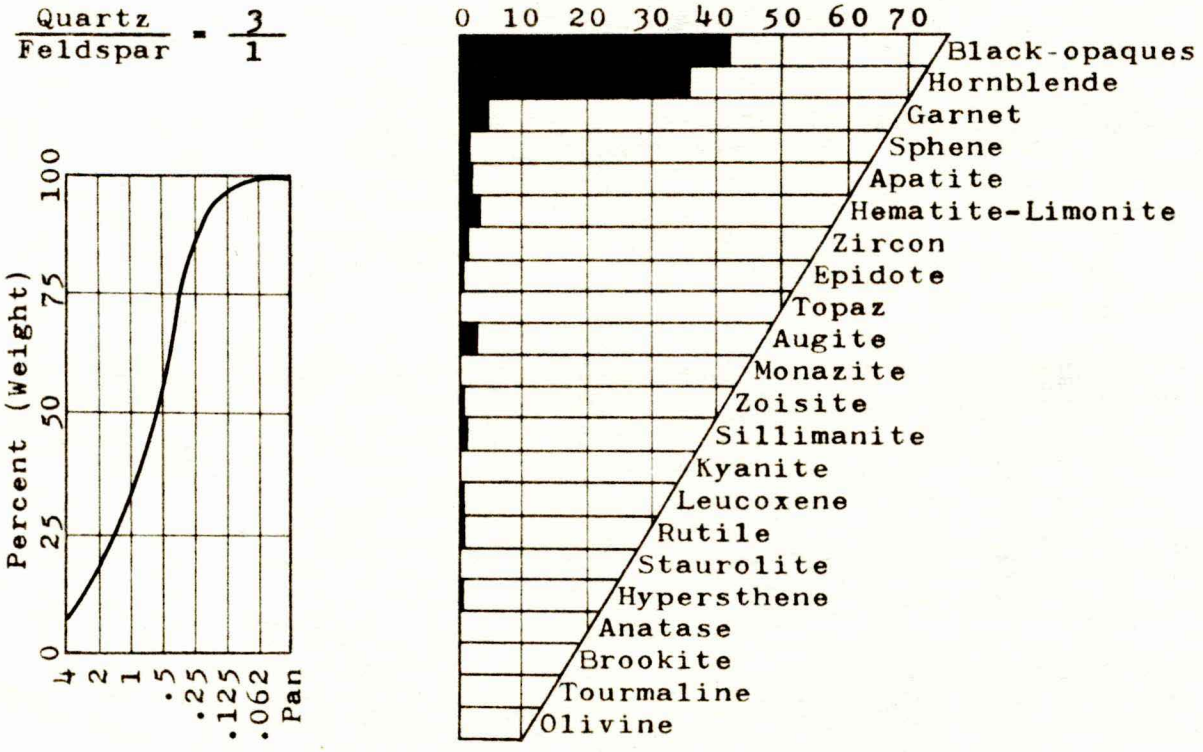
App. Fig. A-38. Analyses of sediment from locality 38 along Arkansas River near Lakin, Kansas.



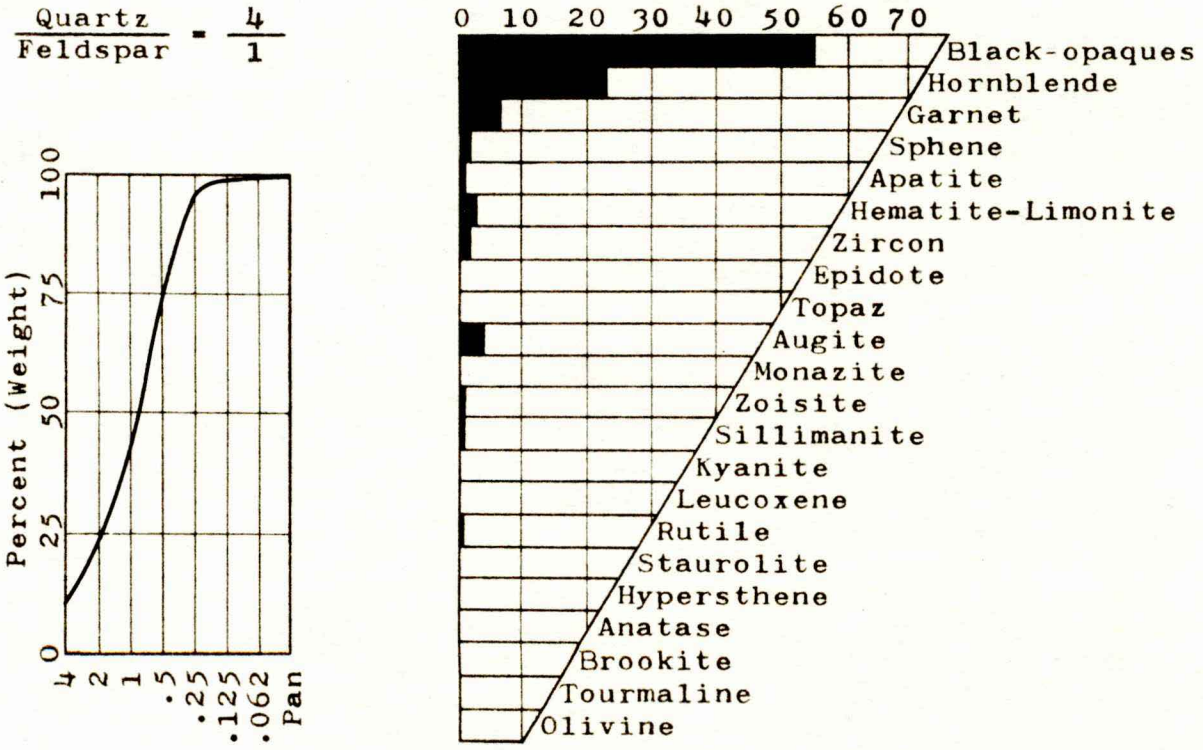
App. Fig. A-39. Analyses of sediment from locality 39 along Arkansas River near Garden City, Kansas.



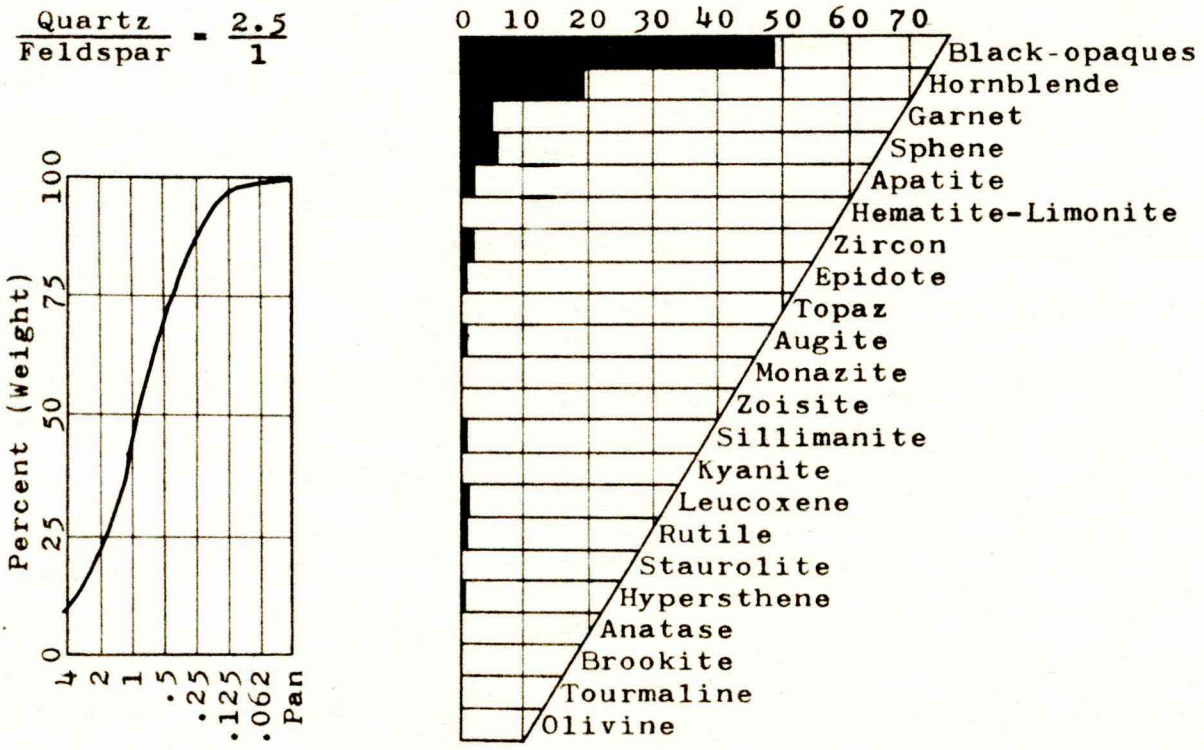
App. Fig. A-40. Analyses of sediment from locality 40 along Arkansas River near Pierceville, Kansas.



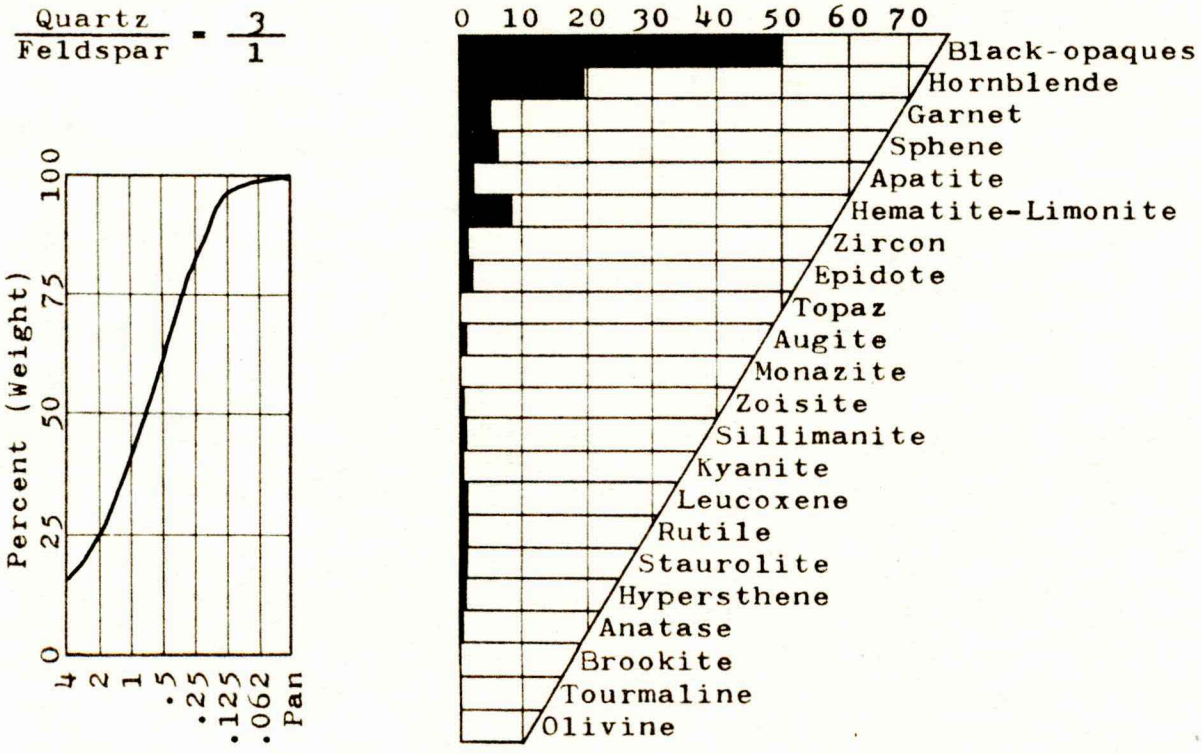
App. Fig. A-41. Analyses of sediment from locality 41 along Arkansas River near Cimarron, Kansas.



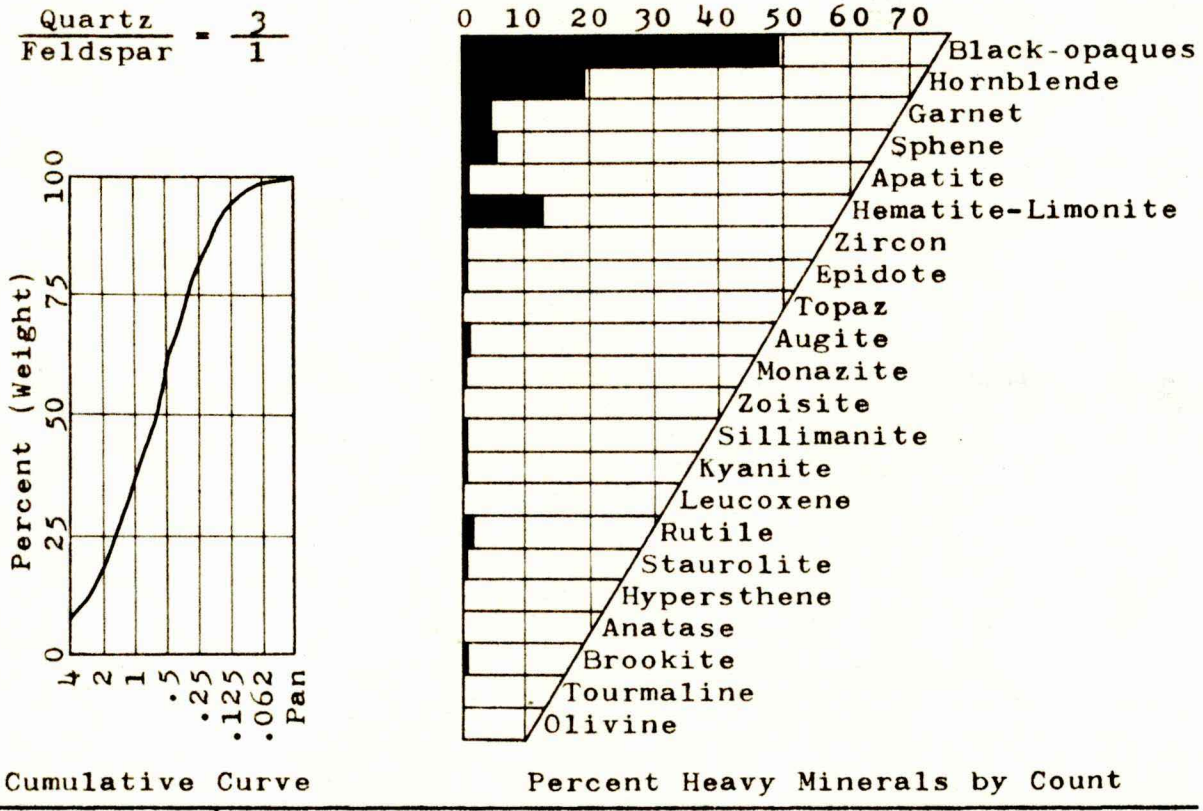
App. Fig. A-42. Analyses of sediment from locality 42 along Arkansas River near Dodge City, Kansas.



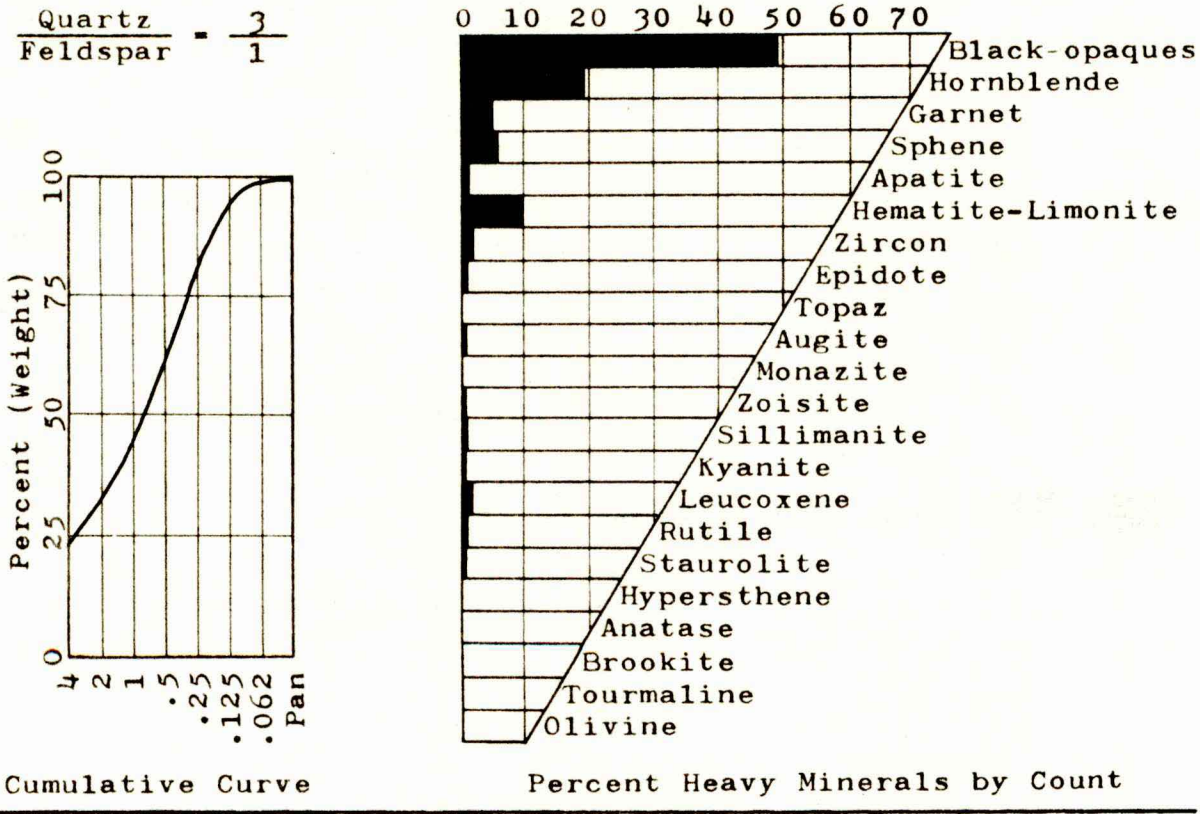
App. Fig. A-43. Analyses of lower terrace sediment from depth of 4-19 feet (Hole A, Text Fig. 4) near Garden City, Kans.



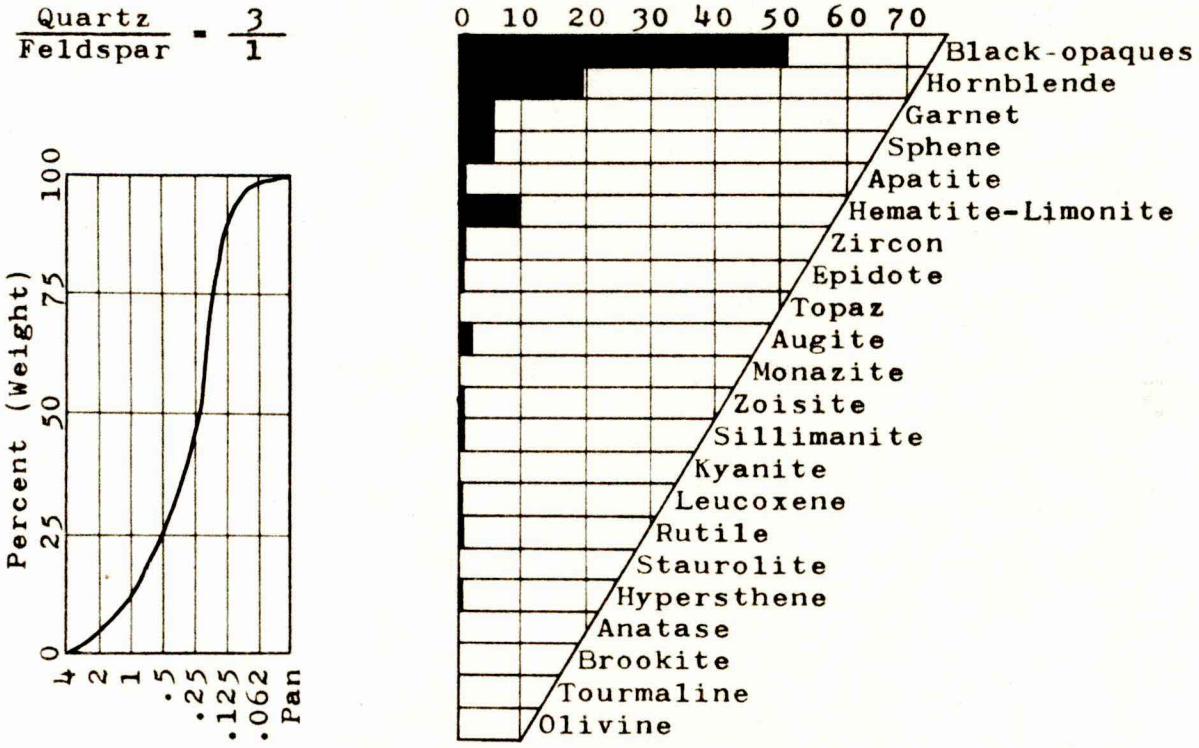
App. Fig. A-44. Analyses of lower terrace sediment from depth of 19-36 feet (Hole A, Text Fig. 4) near Garden City, Kans.



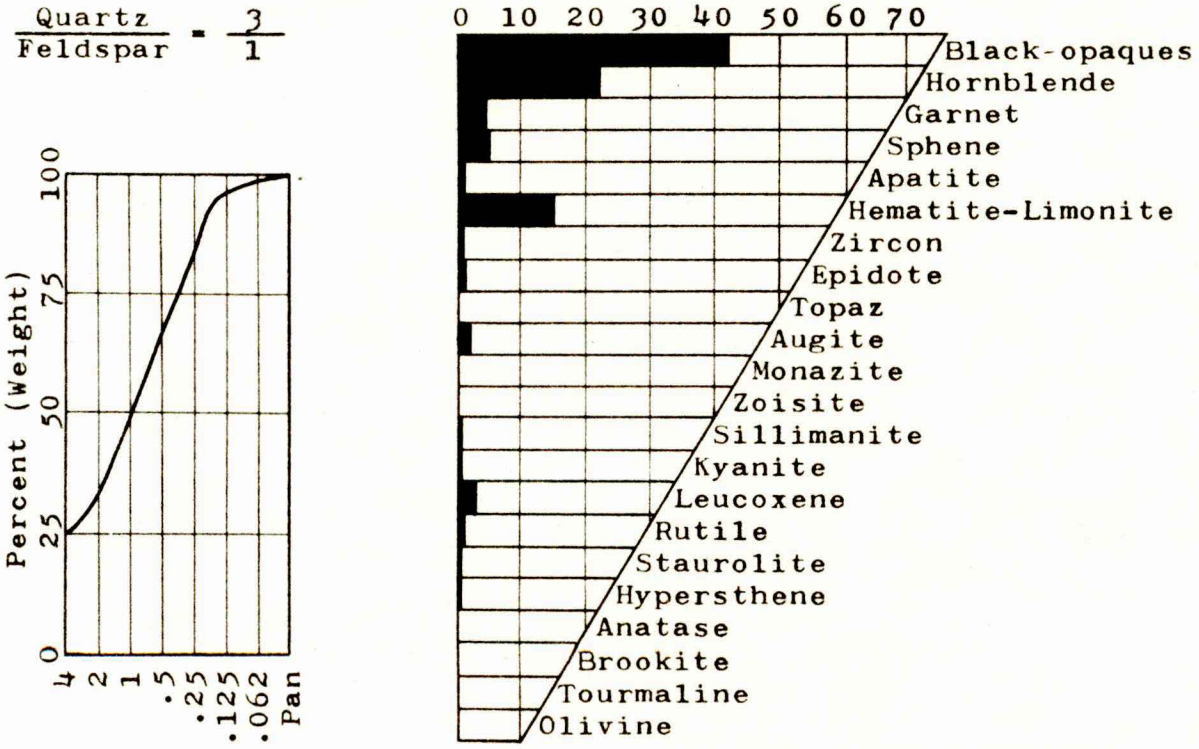
App. Fig. A-45. Analyses of lower terrace sediment from depth of 4-14 feet (Hole B, Text Fig. 4) near Garden City, Kans.



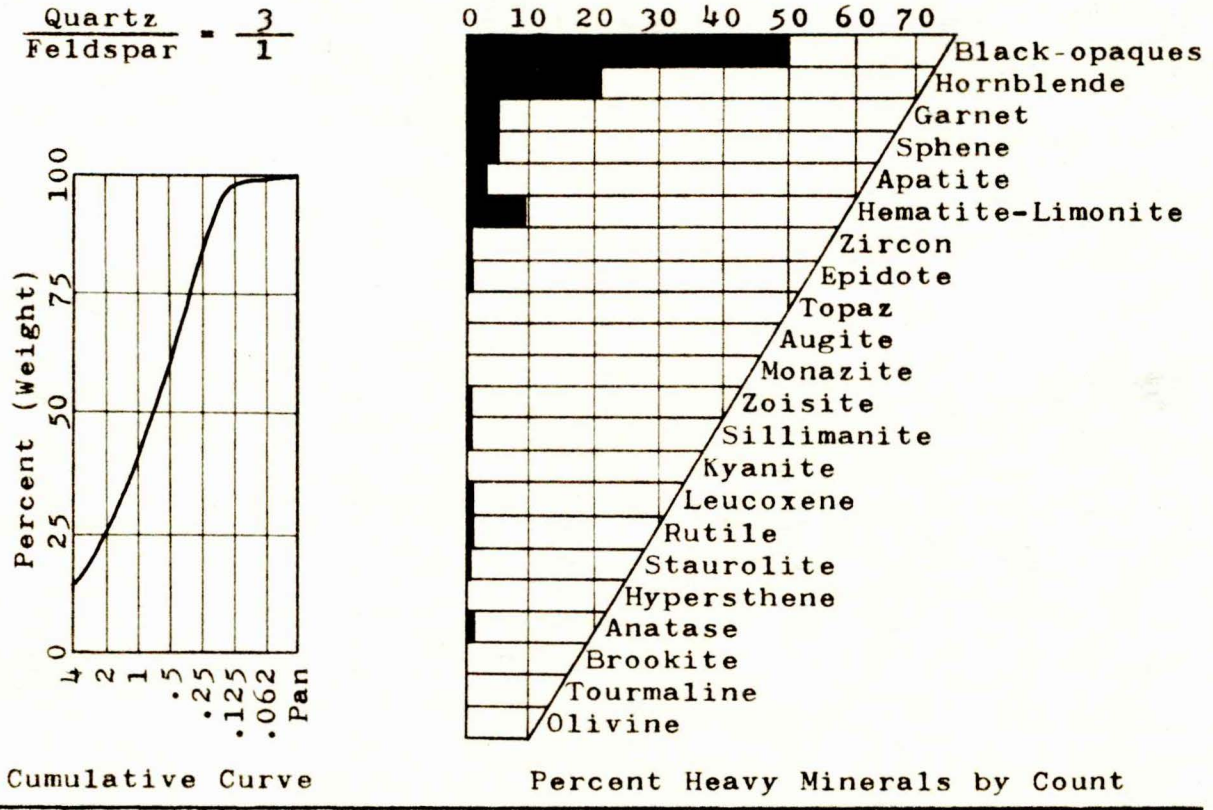
App. Fig. A-46. Analyses of lower terrace sediment from depth of 14-24 feet (Hole B, Text Fig. 4) near Garden City, Kans.



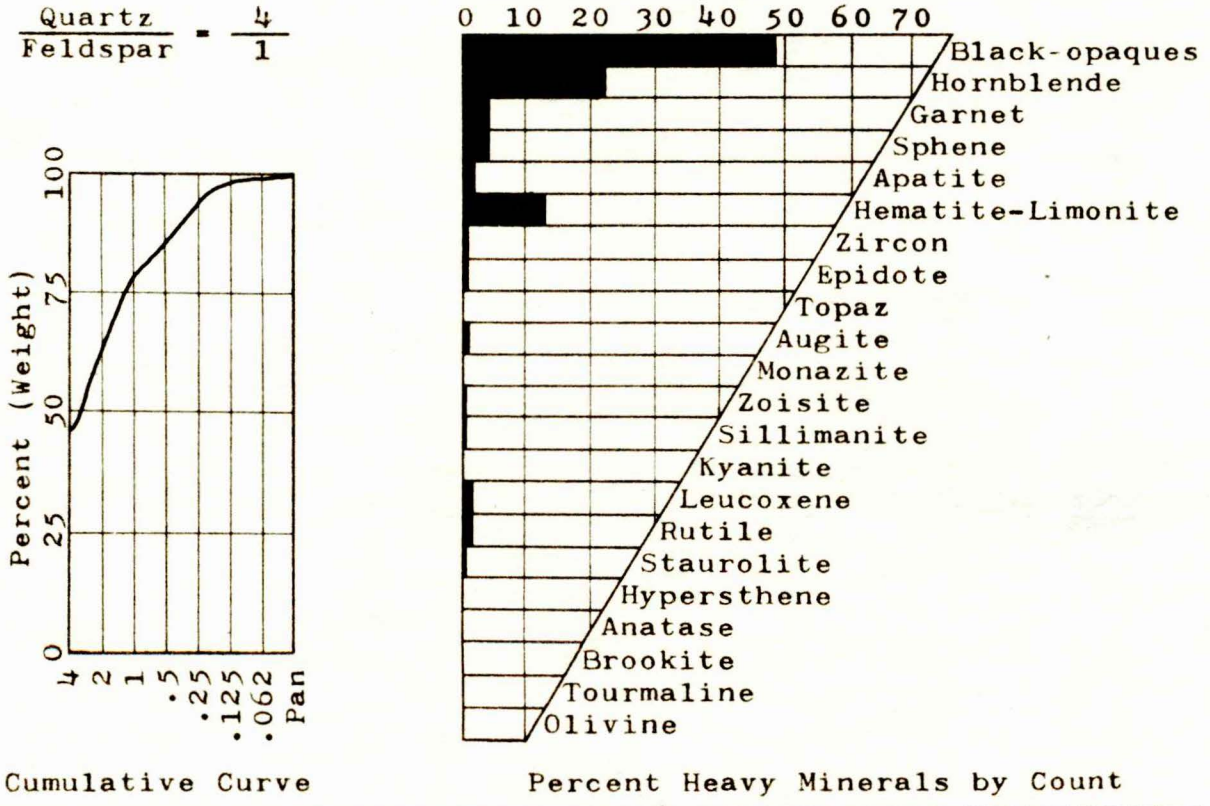
App. Fig. A-47. Analyses of upper terrace sediment from depth of 9-14 feet (Hole C, Text Fig. 4) near Garden City, Kans.



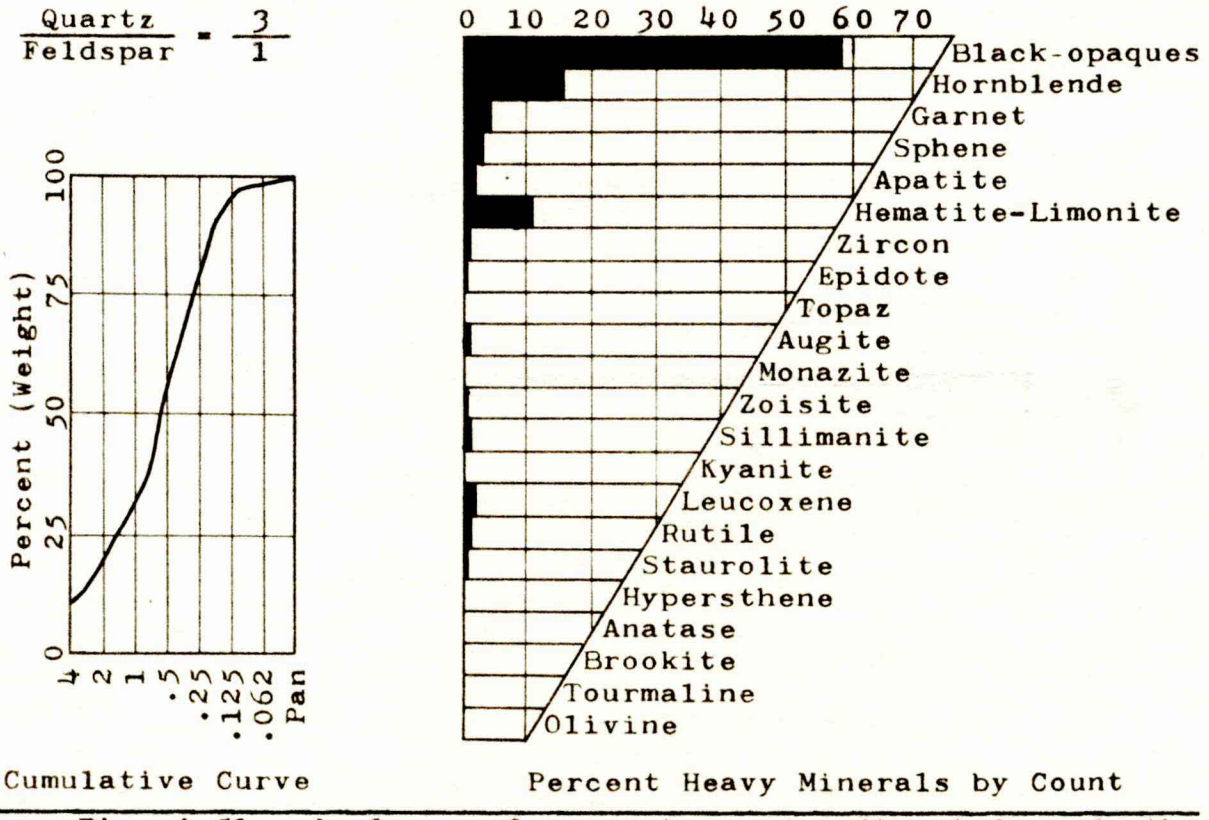
App. Fig. A-48. Analyses of upper terrace sediment from depth of 14-24 feet (Hole C, Text Fig. 4) near Garden City, Kans.



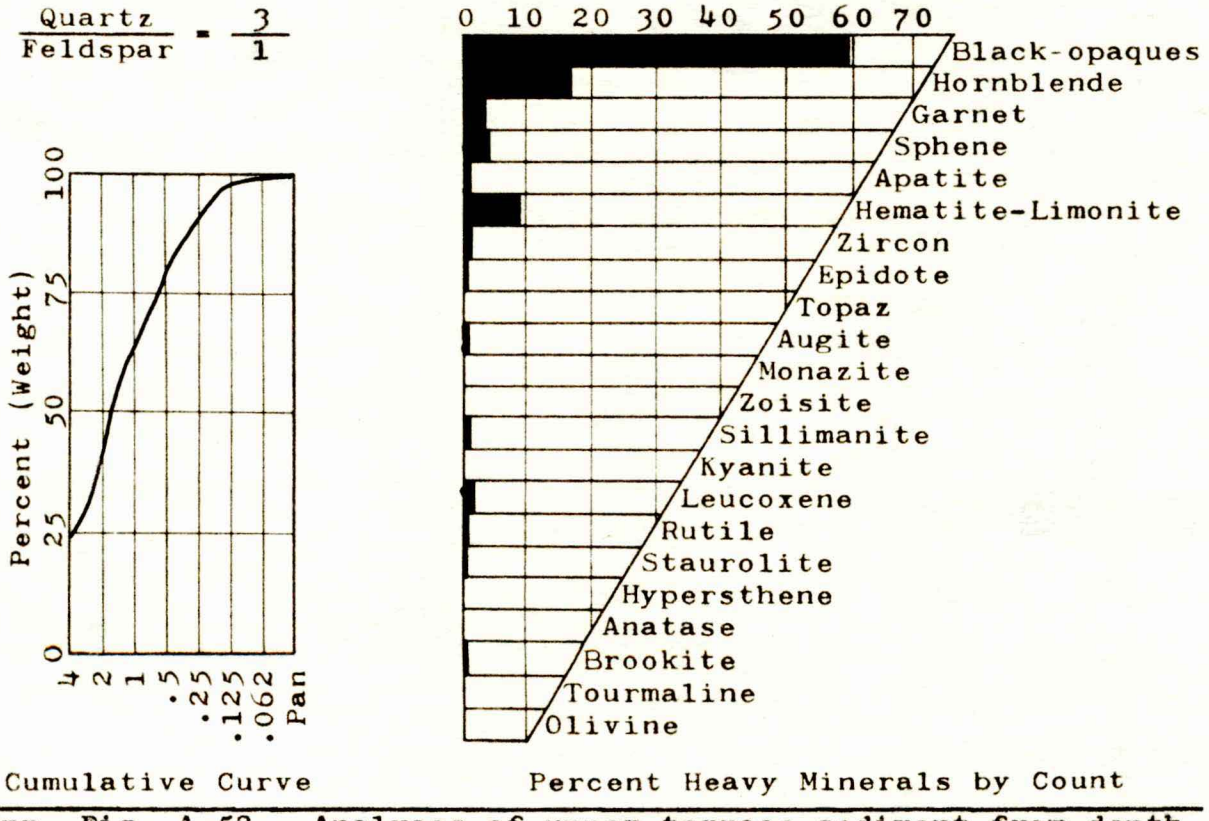
App. Fig. A-49. Analyses of upper terrace sediment from depth of 4-19 feet (Hole D, Text Fig. 4) near Garden City, Kans.



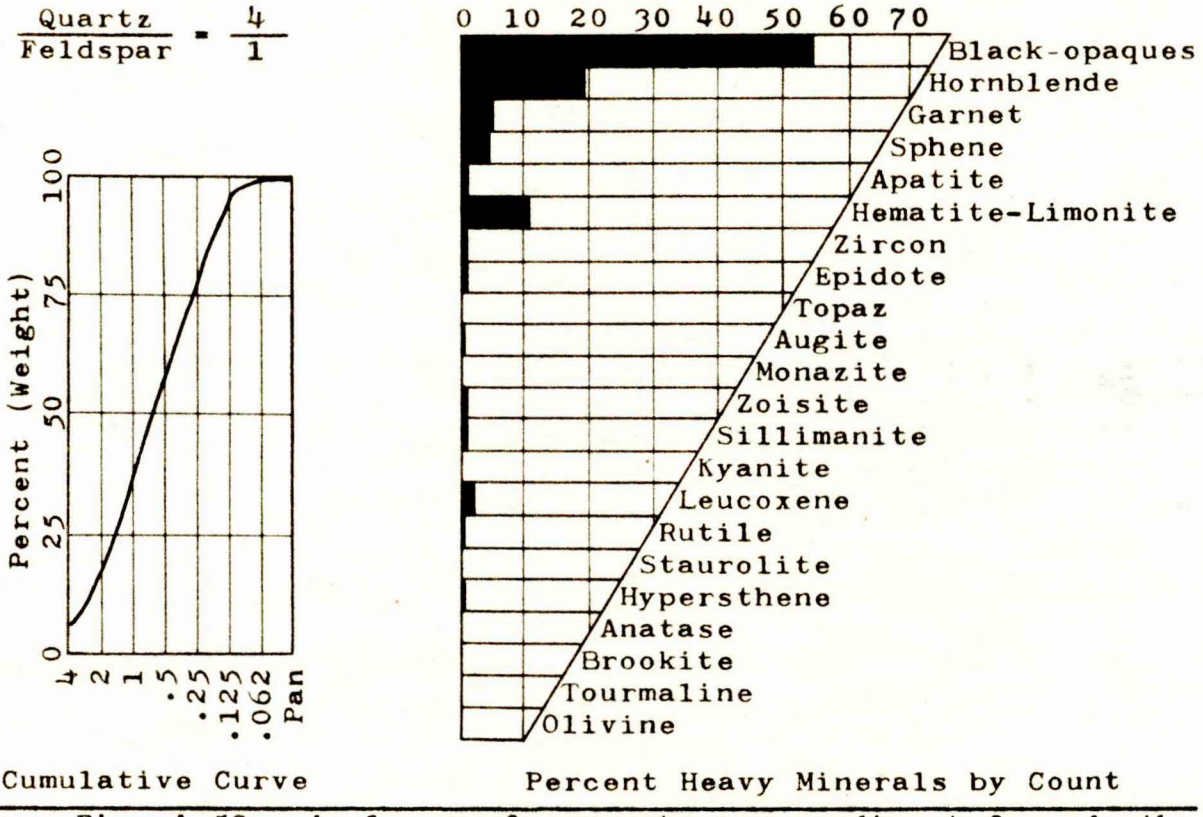
App. Fig. A-50. Analyses of upper terrace sediment from depth of 19-24 feet (Hole D, Text Fig. 4) near Garden City, Kans.



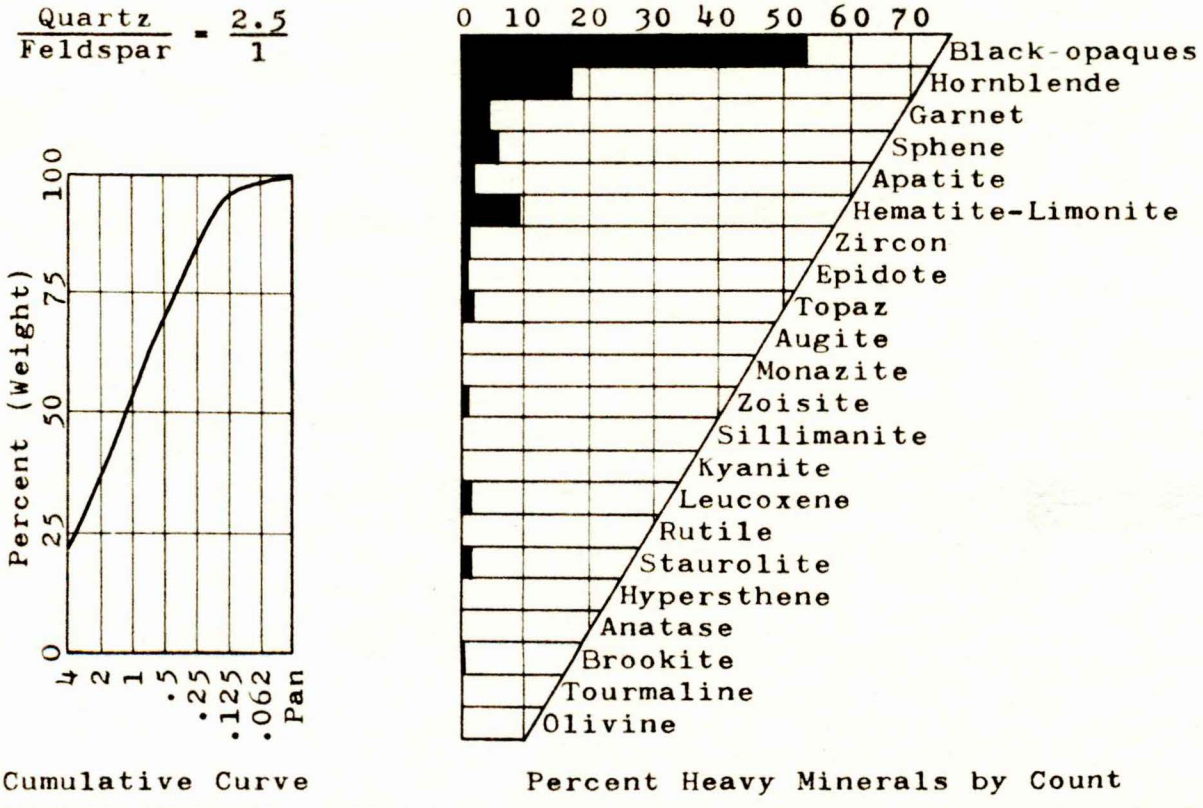
App. Fig. A-51. Analyses of upper terrace sediment from depth of 9-24 feet (Hole E, Text Fig. 4) near Garden City, Kans.



App. Fig. A-52. Analyses of upper terrace sediment from depth of 24-54 feet (Hole E, Text Fig. 4) near Garden City, Kans.



App. Fig. A-53. Analyses of upper terrace sediment from depth of 19-34 feet (Hole F, Text Fig. 4) near Garden City, Kans.



App. Fig. A-54. Analyses of upper terrace sediment from depth of 34-49 feet (Hole F, Text Fig. 4) near Garden City, Kans.