STRATIGRAPHIC RELATIONSHIPS OF THE FLORISSANT LAKE BEDS TO THE THIRTYNINE MILE VOLCANIC FIELD OF CENTRAL COLORADO

A Thesis

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Master of Science

by

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ABSTRACT

The Florissant Lake Beds of Tertiary age are situated in the northeastern corner of the Thirtynine Mile volcanic field of Central Colorado. They are a complex series of lacustrine and fluvial sediments. They were deposited in a basin, which was formed in part by faulting along the Florissant-Oil Creek lineament and in part by obstruction of the drainage system by andesitic breccias of the lower andesite. Andesitic clasts and tuffs in the lower portion of the Florissant Lake Bed sequence and the gradation of the youngest mud flows of the sequence into epiclastic lahars of the lower andesite suggests that the Florissant Lake Beds are a fluvial and lacustrine facies of the lower andesite. Age of the Florissant Lake Beds can be bracketed at less than the 35.4 ±1.1 m.y. (million years) and 37.3 ±1.9 m.y. K/Ar ages for the ash flow -1 cooling unit and greater than the 34.1 ±1.1 m.y. K/Ar age for an andesite flow in the upper member of the lower andesite.

The oldest volcanic unit in the study area is the tuff of Fish Creek, a volcani-clastic sediment, which underlies the ash flow -1 cooling unit, previously thought to be the first eruptive event. Ash flow -4 (Agate Creek Formation of DeVoto, 1964, p. 119, 121) was found to be a member of

the ash flow -1 cooling unit as indicated by petrographic correlation of ash-flow samples from an outcrop in NW/4, NW/4, sec. 11, T. 13 S., R. 71 W.

The Florissant basin is a shallow graben within a structural and topographic lineament, which extends from the Oil Creek graben of the Canon City embayment northward through the High Park and Alnwick basins to Florissant. Observed offset of the ash flow -1 sheet totals about 500 feet in the Florissant area with the east or Front Range side up. Alignment of basins along the fault zone suggests mid-Tertiary deformation; faults, which offset the Florissant Lake Beds 25 to 75 feet, indicate a later period of movement.

Location and Accessibility

The Florissant Lake Beds are located about 35 miles west of Colorado Springs in Central Colorado (Figure 1). They occupy an irregular, sickle-shaped valley about 10 miles long and 2 miles wide that extends from Lake George to Florissant along U. S. Highway 24 and then south along State Highway 143. Accessibility throughout the valley is excellent and no part of the area is more than a mile from a ranch or subdivision road.

Methods of Investigation

Geologic mapping was conducted in the field on topographic maps at a scale of 1:24,000. The base map for the final geologic compilation was prepared by joining copies of the following U. S. Geological Survey quadrangles: Florissant 15-minute (enlarged to 1:24,000), Divide 7 1/2 minute, Lake George 7 1/2 minute and Cripple Creek North 7 1/2 minute. Aerial photographs (U. S. Forest Service) at a scale of 1:20,000 were used as a guide to the location and configuration of outcrops.

Petrographic classification of the rock units is based on mineralogical compositions and follows the terminology of Wentworth and Williams (1932) and Williams,

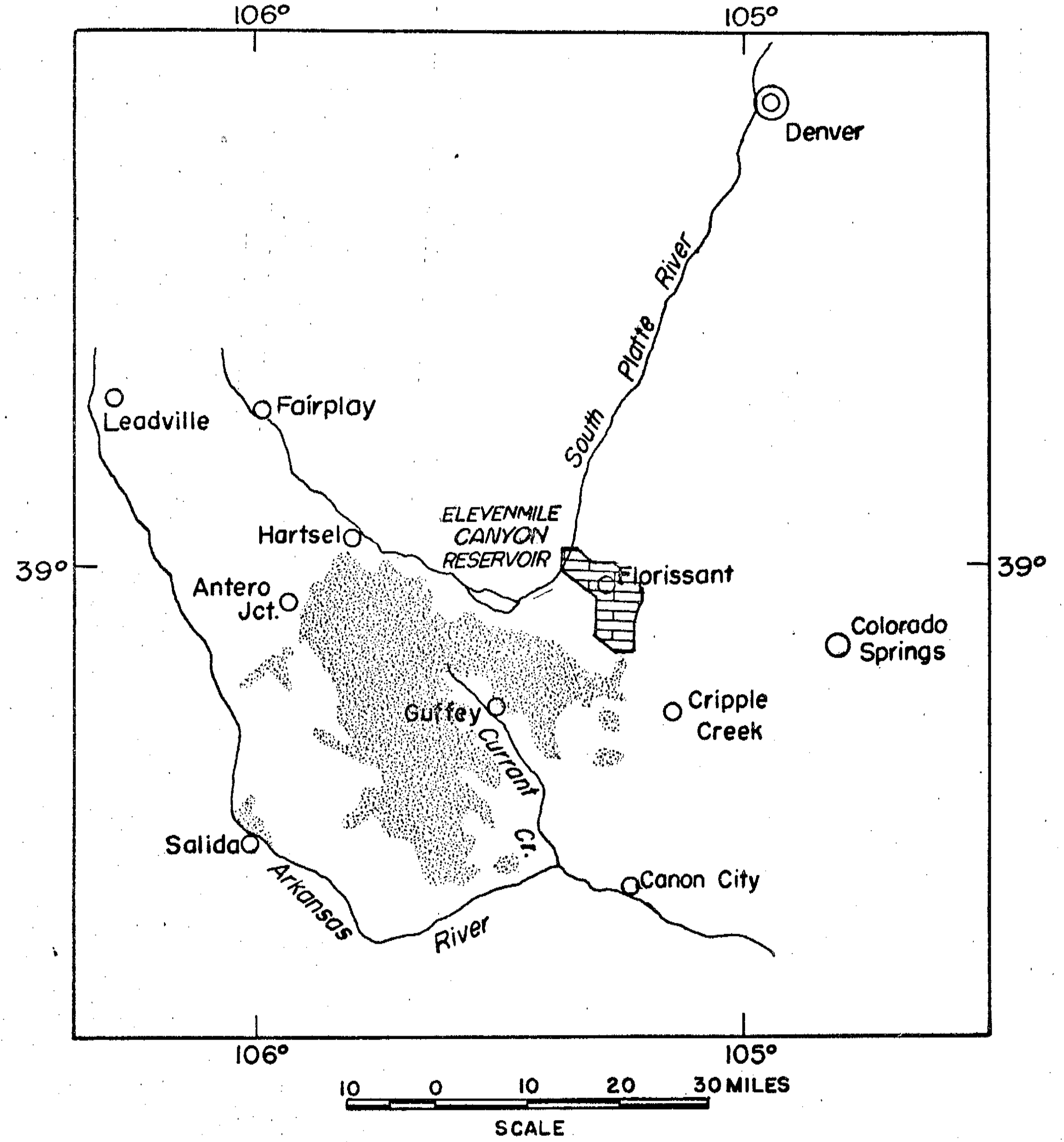
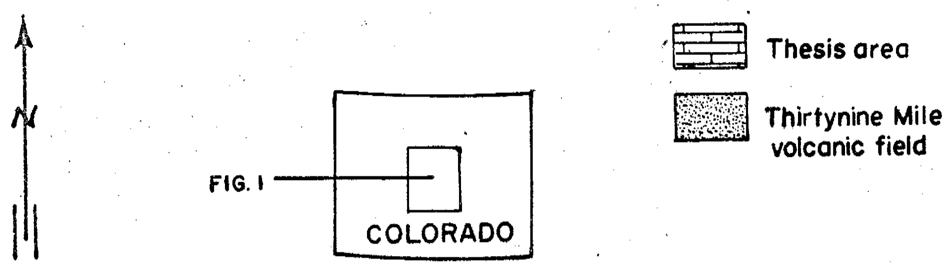


Figure 1

LOCATION OF THIRTYNINE MILE VOLCANIC FIELD, CENTRAL, COLORADO



Turner and Gilbert (1954). Plagioclase compositions were determined using the Fouque method and the high-temperature curves of Troger (1956, p. 133). Optic axial angles of alkali feldspar crystals were measured orthoscopically on a 5 -axis universal stage. Correlation of ash-flow tuffs was by the method of Chapin and Epis (1965).

Previous Investigations

The first geologic and physiographic investigations of the Florissant area were carried on by the Hayden Survey of 1873. In the survey report (Hayden, 1874), A.C. Peale reported finding fossils in the Florissant area. Endlich (1878), also of the Hayden Survey, published a review of the erupted rocks of Colorado, which included references to the rocks of the Thirtynine Mile volcanic field. S. H. Scudder (1883) published a short report describing the Florissant basin with its lithology and fossil fauna and flora. More comprehensive geologic accounts of the lake shales were also made available in 1883 by Wadsworth.

Whitman Cross (1894) prepared the earliest and most comprehensive geologic map of the Florissant region in the Pikes Peak Folio. The author feels compelled to include a word of praise for the accuracy of Cross's map as he found it of great value to the present study. During the next 70 years numerous papers dealing with the Florissant fossils and strata were published. Most significant amongst these were Gazin (1935), who reported on a marsupial found in the Florissant Lake Beds, James (1937) who reviewed the known fossil assemblages, and MacGinitie (1953) who published an excellent monograph of the Florissant flora.

In recent years, Weilbacher (1963) and McLeroy and Anderson (1966) have studied seasonal laminations in the shale sequence of the Florissant Lake Beds. The stratigraphy and structure of the Thirtynine Mile volcanic field was compiled by Chapin and Epis (1964); since then graduate students under their direction have conducted detailed mapping throughout the field. A progress report containing much new information was published by Epis and Chapin in 1968.

ROCK UNITS

Prevolcanic Rocks

Precambrian Rocks

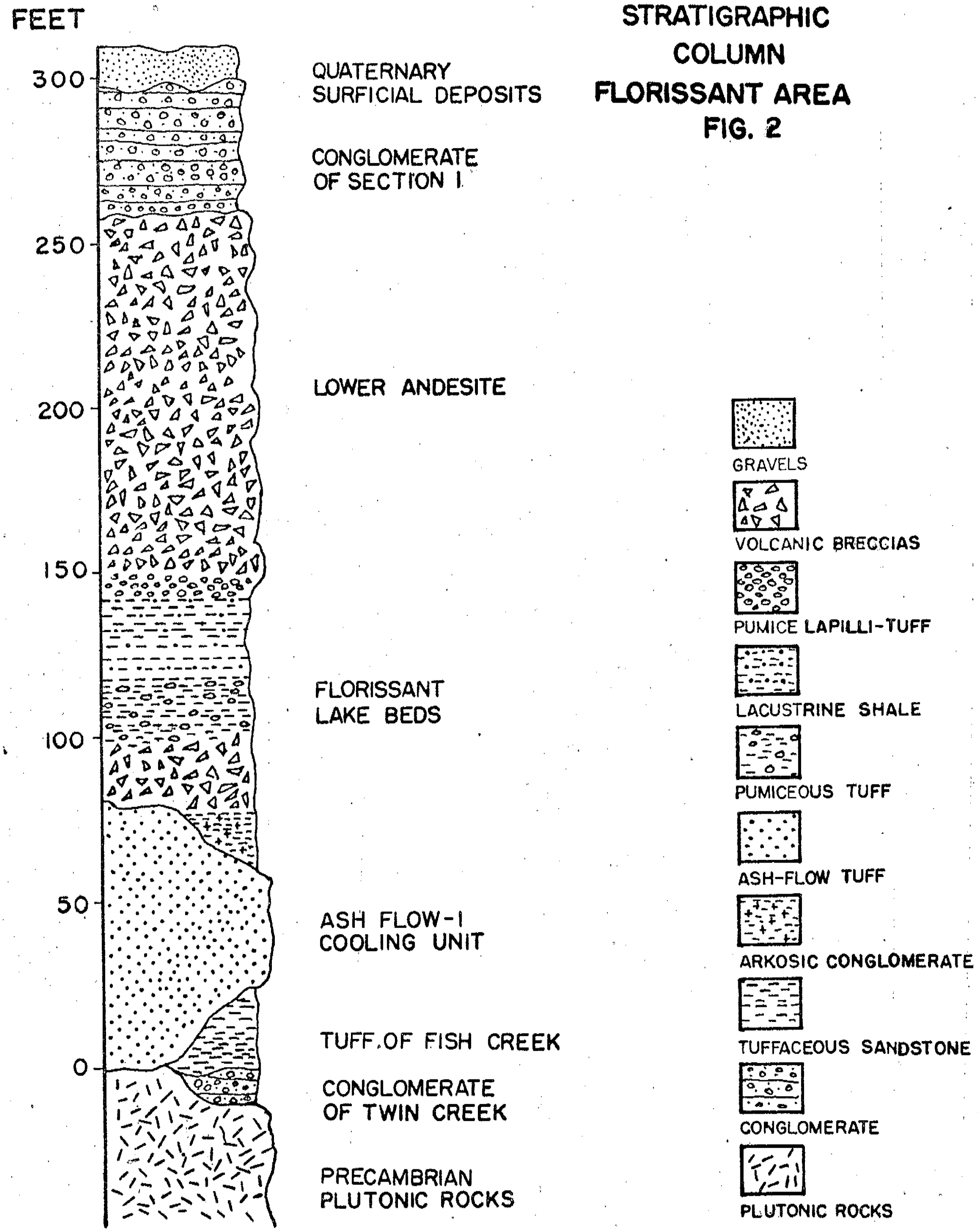
Precambrian igneous and metamorphic rocks crop out over much of the thesis area; only their gross characteristics were noted, however, and they were mapped as one unit (Plate 1 and Figure 2). For detailed accounts of the Precambrian rocks see Cross (1894), Hutchinson (1960), Kraus (1960), Stewart (1964), Hutchinson and Hedge (1967), Peterman and others (1968) and Wobus (1966, 1969).

In the Florissant area, the oldest rocks are metasedimentary rocks that occur as detached masses in the Pikes Peak granite. These rocks form elongate ridges south and west of Florissant and Lake George. They are intruded by the Pikes Peak granite with sharp contacts.

The Pikes Peak granite is a medium-to coarse-grained, equigranular rock that is generally massive in outcrop but sometimes has a planar flow structure developed by alignment of microcline crystals. Fresh exposures are light pink in color but the granite is usually deeply weathered to an orange-red color and covered by a mineral gruss. Perthitic microcline, quartz and biotite are the dominant minerals but minor amounts of plagioclase and hornblende are also present.

COMPOSITE STRATIGRAPHIC COLUMN FLORISSANT AREA

FIG. 2



Wobus (1969) reported a Rb/Sr age of 1.05 billion years (b.y.) for Pikes Peak granite from the Florissant area which is in good agreement with a Rb/Sr date of 1.04 b.y. reported by Hutchinson and Hedge (1967).

Tertiary Rocks

Conglomerate of Twin Creek: Following the strongest pulses of Laramide diastrophism, and probably during middle or late Eocene time, an erosion surface with moderate, local relief was carved across a large area of Central Colorado (Epis and Chapin, 1968, p. 56). In the Florissant area arkosic conglomerates were deposited in topographic lows on this surface prior to the beginning of Thirtynine Mile volcanism. Six small outcrops of conglomerate were observed where younger units have protected them from erosion; they are informally referred to in this report as the conglomerate of Twin Creek (Plate 1 and Figure 3). The unit rests unconformably on Precambrian rocks and was extensively eroded prior to deposition of the tuff of Fish Creek and the ash flow -1 cooling unit. The thickness is variable but averages about 10 feet. Geomorphically, the unit forms boulder-strewn slopes on which the matrix has washed away leaving a lag gravel and an illusion of greater coarseness.

Figure 3. View showing the Conglomerate of Twin Creek (Tctc) overlain by the Ash Flow -1 Cooling Unit, (Tat) 1 1/2 miles west of the town of Florissant 1/8 mile north of Highway 24 (SW/4, NE/4, sec. 3, T. 13 S., R. 71 W.)

Boulders, ranging in size from 6 inches to 3 feet, make up 65 per cent of the unit and are contained in a matrix of red-brown sandy silt and clay; the whole unit is poorly sorted and unindurated. The boulders are composed of three principal rock types: (1) fine-grained pink and gray granites; (2) medium-grained, gneissic metasedimentary rocks; and (3) medium-grained, dark-colored, basic igneous rocks. Volcanic fragments are distinctly absent.

This unit is similar in lithology to the prevolcanic arkose of the Thirtynine Mile volcanic field (Epis and Chapin, 1968, p. 56-60) and to the Farisita Conglomerate of Huerfano Park (Johnson and Wood, 1956, Johnson, 1959, 1961). The conglomerate of Twin Creek may represent the same period of prevolcanic erosion and alluviation in middle or late Eocene time as suggested by Epis and Chapin (1968, p. 60) for their prevolcanic arkose.

Extrusive Volcanic Rocks and Volcani-clastic Sedimentary Rocks

Tertiary Rocks

Tuff of Fish Creek: A tuffaceous deposit, here referred to as the tuff of Fish Creek, crops out in two locations in the Florissant Valley (NW/4, sec. 3, T. 13 S., R. 71 W.

and NW/4, sec. 13, T. 13 S., R. 71 W.) (Plate 1). At both of these localities the unit has been preserved by the overlying ash flow -1 cooling unit (Figure 4). However, exposures are very poor due to slumping of the resistant welded tuffs over the poorly-consolidated tuffaceous strata. The unit rests unconformably on the conglomerate of Twin Creek; its thickness is uncertain but approximates 25 feet.

The tuff of Fish Creek consists of tuffaceous, gray-green, volcani-clastic sandstones. Most of the unit is poorly cemented, extremely friable, porous, and moderately thick-bedded with slight graded bedding in the outcrop. Grain size varies from silt to medium-grained sand; grains are generally angular to sub-rounded and poorly sorted. Compositionally, the tuff contains 75 per cent volcanic glass and pumice, 12 per cent sanidine, 10 per cent clay, 1 per cent plagioclase, 1.5 per cent biotite, and less than one per cent microcline.

Tuffaceous deposits of similar stratigraphic position have not been found in the Thirtynine Mile volcanic field. The ash flow -1 cooling unit was previously believed to be the oldest volcanic deposit belonging to this field (Epis and Chapin, 1968, p. 60). The tuff of Fish Creek probably represents reworked material from an older ash fall.

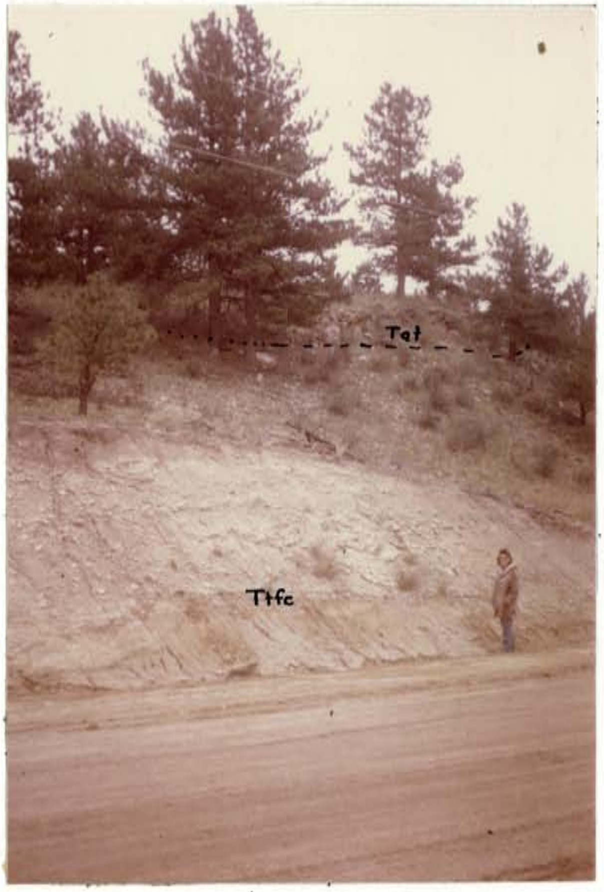


Figure 4. View showing the Tuff of Fish Creek (Ttfc) overlain by the Ash flow -1 Cooling Unit (Tat), 2 miles west of the Town of Florissant and 1/8 mile south of Highway 24 (SW/4, NW/4, sec. 3, T. 13 S., R. 71 W.)

The Ash Flow -1 Cooling Unit: The ash flow -1 cooling unit (Epis and Chapin, 1968, p. 60-62) is a widespread, multiple--flow, simple cooling unit of latitic to trachytic composition. In the Florissant area, the unit is made up of at least three megascopically similar ash flows, informally designated ash flows -1, -2 and -4 (page 15)(Plate 1). These individual ash flows are differentiated by their modal mineralogic compositions and by the optic axial angles (2V's) of sanidine phenocrysts. The unit rests unconformably on prevolcanic rocks or on the tuff of Fish Creek and was extensively eroded prior to deposition of the Florissant Lake Beds and the lower andesite. Erosion has nearly removed the unit from intervalley areas and only scattered remnants remain; outcrops typically occur as thin, irregular masses draped on rocks of Precambrian age. Thickness in outcrop varies widely due to irregularities in the underlying topography and to subsequent erosion of the top. West of Lake George a remnant of this unit forms a prominent cliff about 80 feet high (Figure 5). In the area between Guffey and Tallahassee Creek, Chapin and Epis (1964) found that the ash flow -1 unit ranges from 10 to 80 feet in thickness.

Flint (1969) concluded from statistical analysis of the optic angles of alkali feldspar crystals in thirteen samples that ash flows -1 and -4 are present in the Florissant area.

Figure 5. View of the Ash flow -1 Cooling Unit (Tat) west of the Town of Lake George (Plate 1). Ash flow -1 west on Precambrian Rocks (p€) and is about 80 feet thick. (SE/4, NW/4, sec. 19, T. 12 S., R. 71 W.)

By correlating the elevations of outcrops from which these samples were collected with the mean optic angles of the contained sanidine crystals, Flint concluded that ash flow -4 occurred at elevations higher than ash flow -1 and that deviations from this trend could be explained by variations in the prevolcanic topography.

In the present investigation, statistical analysis of the optic axial angles of sanidine phenocrysts in thirteen samples (different from those studied by Flint) revealed the presence of three ash flows (1, 2 and 4) rather than two flows as Flint suggested. Flint (1969, p. 44) also recognized the possibility that 3 ash flows might be present. In ash flow -1 the sanidine crystals have a median optic axial angle of 38° to 39°; in ash flow -2 the median ranges from 34° to 37.5°; in ash flow -4 the median for the one sample measured is 31.5° (see Table 1). Optic axial angles when measured orthoscopically on a universal stage using only crystals with both axes accessible for a direct measurement are determined with a precision of ±1°. Thus, the difference in median 2V listed in Table 1 are believed to be significant and a useful correlation tool in distinguishing the various ash flows, especially when used in conjunction with modal analyses.

Table 1. Optic Axial Angles of Sanidine Phenocrysts in the Ash Flow -1 Cooling Unit

Based on data in Appendix I.

	Sample Number	Median	Range	Number of Crystals Measured
Ash Flow -1	F-30	38.5	13.0	18
	F-34	39.0 *	11.5	20
	F-53	38.0 *	20.0	20
Ash Flow -2	D-1	36.0	18.0	24
	F-19	35.5 *	20.5	20
	F-31	37.5 *	20.5	20
	F-32	34.0 *	22.0	20
	F-41	36.5	37.0	19
	F-46	36.0	25.0	19
	F-52	36.5	18.5	21
	F-55	36.0	17.5	19
	F-93	36.0	31.0	17
Ash Flow -4	F-51	31.5 *	15.0	17

* Samples with optic axial angles averaged from two duplicate runs.

A plot of elevations versus median optic axial angles for these samples (Figure 6) failed to show any correlation between elevation and the identity of individual ash flows. Flint's data (1969, Fig. 12, p. 45) (Figure 7) is also amenable to this interpretation. This author feels that the present elevations of ash-flow outcrops are due to post-emplacement faulting as well as to relief on the prevolcanic erosion surface. Ash-flow outcrops, sample numbers, and the identity of ash-flow units are indicated on the paleotopographic map (Plate 2); samples analyzed by Flint from within the study area are also plotted.

DeVoto (1964, p. 119, 121) named ash flow -4 the Agate Creek Formation for exposures in southwestern South Park and concluded that the unit was interbedded with the tuff member of the Antero Formation. Epis and Chapin (1968, p. 68) disagree with this interpretation and have found evidence that ash flow -4 was warped into folds (both tectonically and by compaction) and very extensively eroded before deposition of the Antero Formation (Chapin, 1969, personal communication). Known outcrops of ash flow -4 lie exclusively on prevolcanic rocks or on minor tuffaceous strata such as the tuff of Fish Creek; this relationship is difficult to explain if ash flow -4 is as high in the volcanic sequence as DeVoto's interpretation required (Chapin, 1969, personal communication).

Figure 6. Elevations of welded-tuff outcrops compared with Mean Optic Axial Angles and identity of ash-flow units.

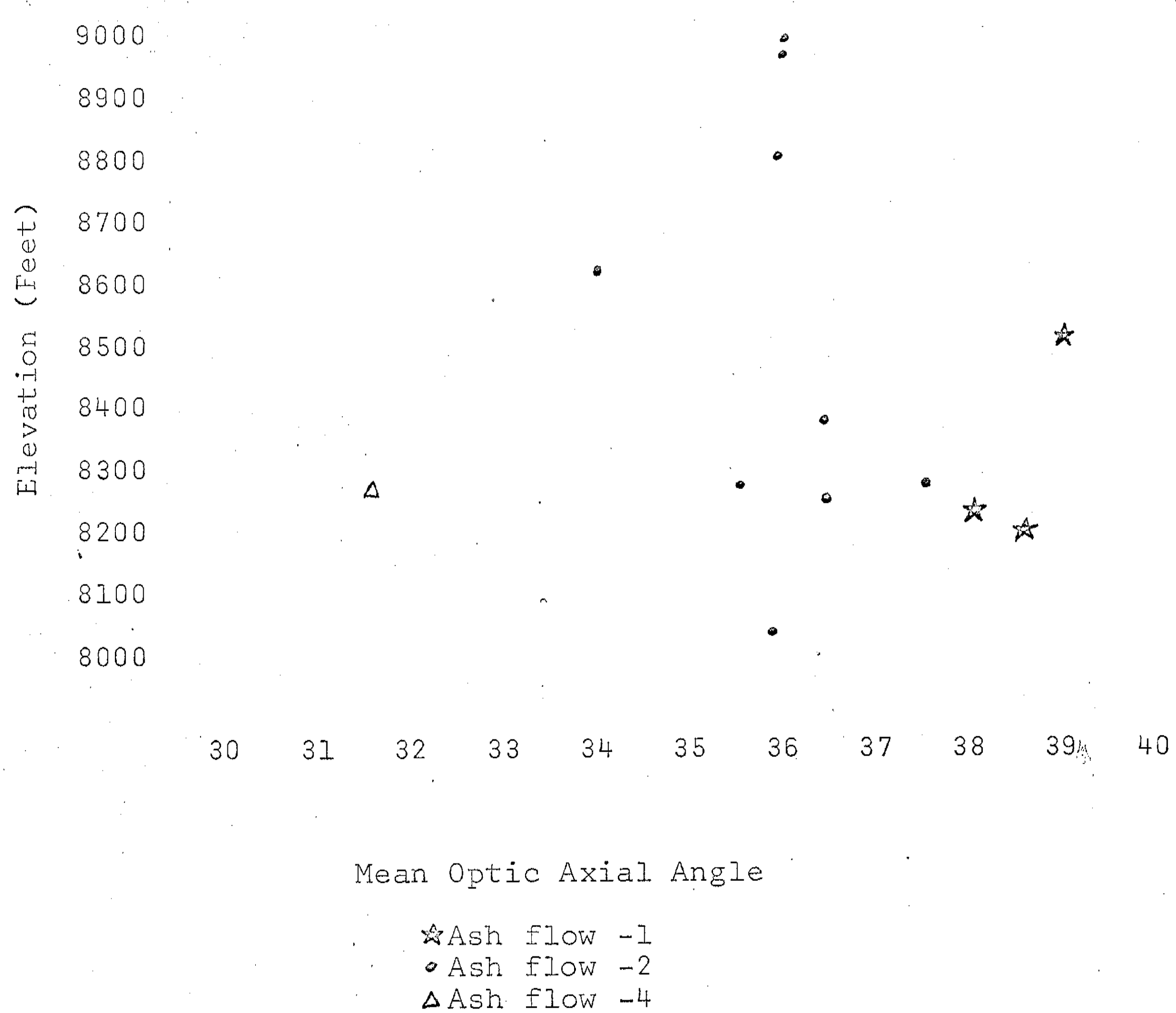
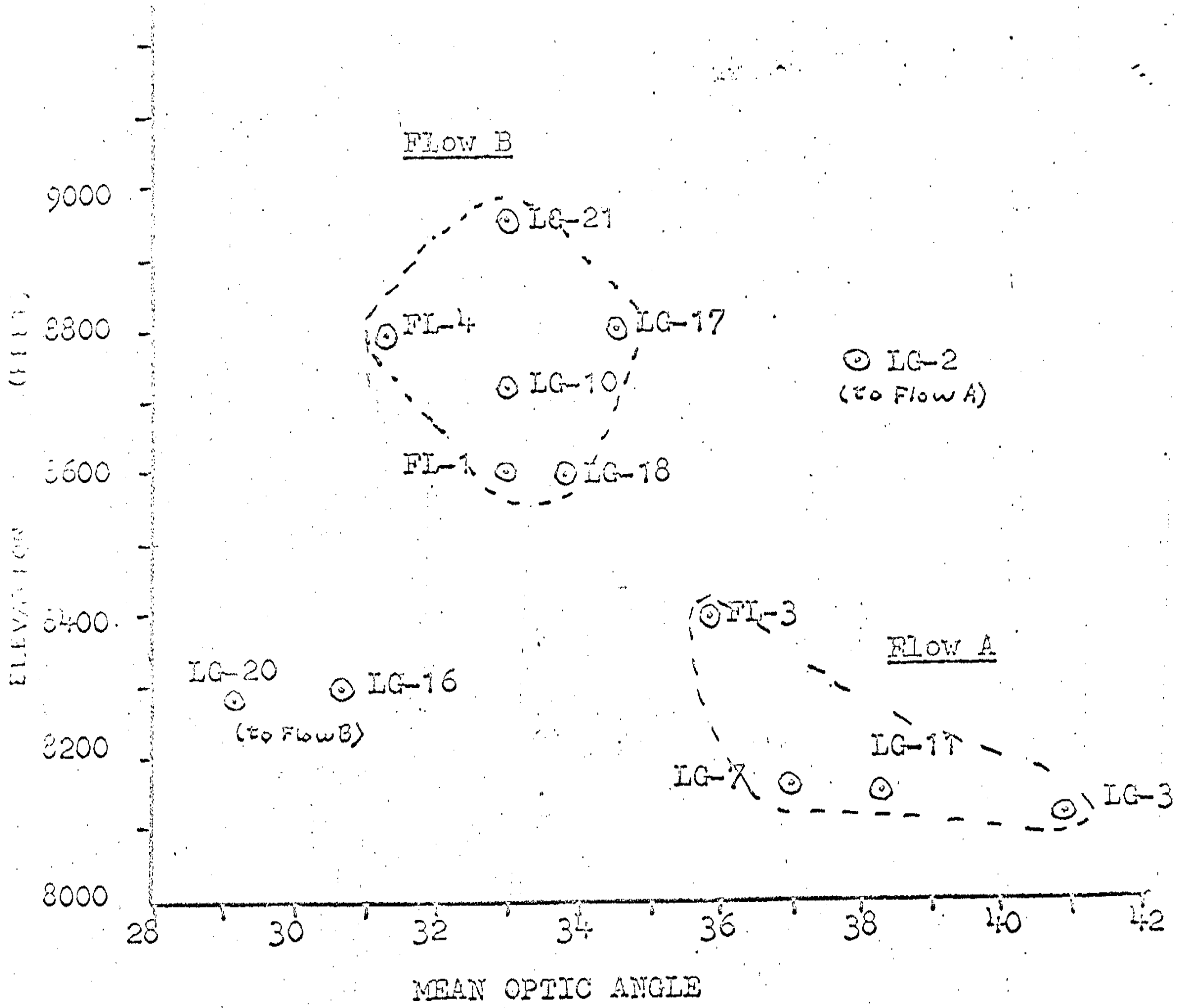


Figure 7. Separation of Flint's Ash Flows A and B on the basis of Mean Optic Axial Angle and Elevation (1969, Fig. 12, p. 45).



One possible exception occurs northwest of Hartsel where Lozano (1965, 1967) mapped a welded tuff similar in appearance to ash flows -1, -2, -3, or -4 which lies on laharic breccias similar to the lower andesite and is unconformably overlain by the Antero Formation. These outcrops have not been identified by the sanidine 2V method, however, and may belong to ash flow -3 which is interbedded with the lower andesite farther to the south. Chapin (1969, personal communication) thinks that ash flow -4 may belong to the ash flow -1 multiple flow sheet and cites as additional evidence the striking mineralogical and textural similarities of ash flows 1 through 4 which would be difficult to explain if they were separated widely in time. Some confirming evidence is available from this study in that samples collected from different parts of the same outcrop have been identified by the sanidine 2V method as being ash flow -2 and ash flow -4.

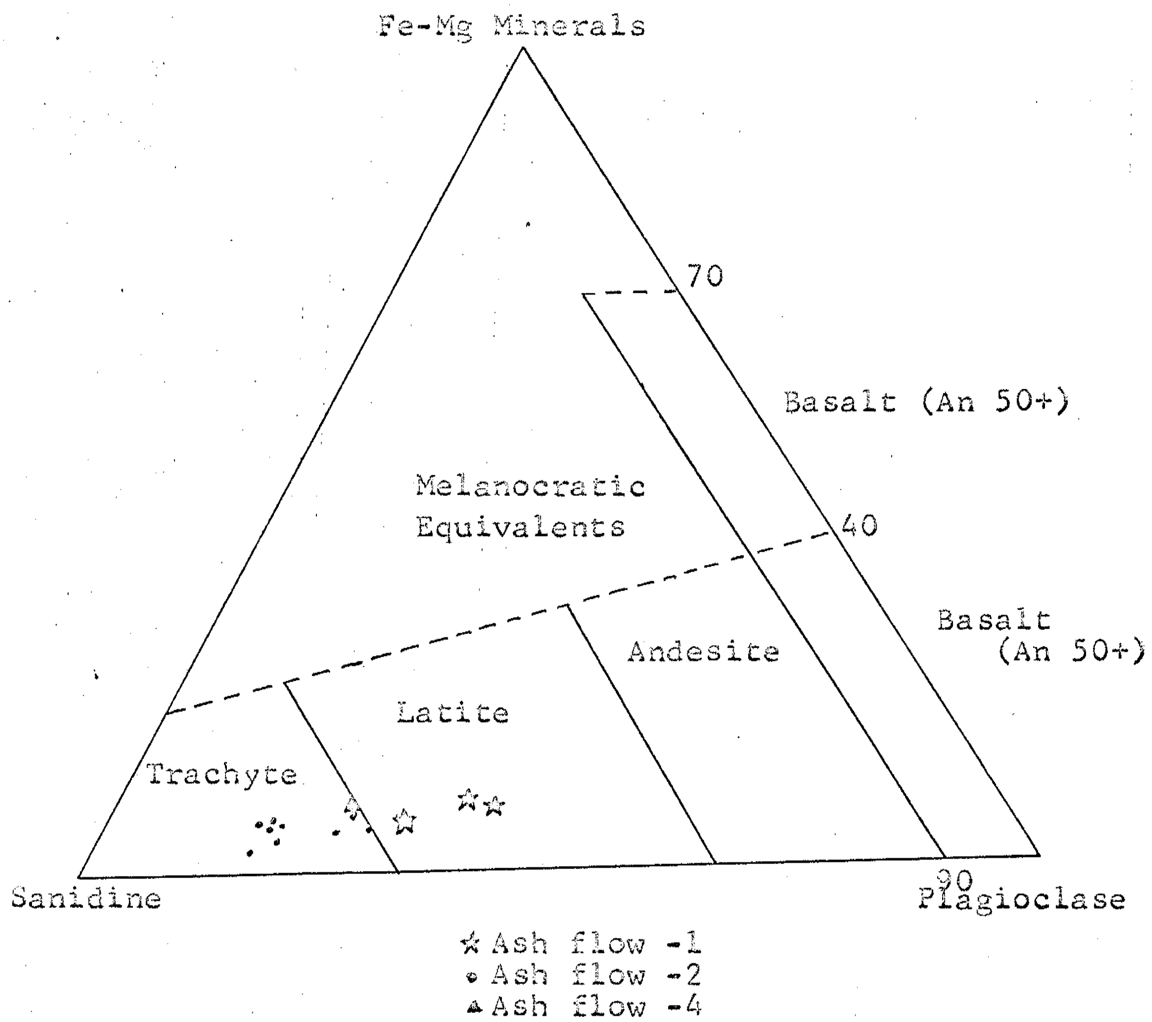
In outcrop, tuffs of the ash flow -1 sheet have a pronounced eutaxitic fabric shown by streaks of lighter colored material, mostly collapsed and elongated pumice lapilli, and a rude alignment of tabular crystals. Much of the matrix in these rocks is obscured by a film of iron oxide which imparts the purplish or brownish color to the rocks. The devitrified matrix of ash flows -1, -2 and -4 consists mainly of altered glass shards and crystallites with low birefringence. Axiolitic intergrowths frequently occur in the interior of the larger relic pumice fragments. Small fragments of plutonic and metamorphic rocks as well as weathered microcline are widespread in the ash flow -1 sheet; most fragments are less than 1.5 cm. in diameter.

Phenocrysts, in rocks of the ash flow -1 sheet constitute 6.9 to 28.6 per cent by volume and consist mostly of sanidine and plagioclase with minor accessory biotite and magnetite. Table 2 summarizes 13 modal analysis of the ash flow -1 cooling unit as measured in thin section. When plotted on a sanidine-plagioclase-ferromagnesian triangular diagram (Figure 8), the modes show ash flow -1 to be latitic in composition while ash flow -2 is trachytic. The one sample of ash flow -4 plots on the latite-trachyte boundary. Sanidine phenocrysts occur as broken fragments of Carlsbad twins with some resorbtion along the edges. They are generally clear glassy crystals with little evidence of microperthitic unmixing. Plagioclase phenocrysts are partly to completely altered to chalky-white pseudomorphs of clay. The composition of fresher plagioclase phenocrysts ranges from An_{13} to An_{42} and averages An_{33} (andesine) in ash flow -1; in ash flow -2 plagioclase compositions range from An_{15} to An_{52} and averages An_{36} (andesine); in ash flow -4 the range is An_{15} to An_{52} and

Table 2. Modal Analyses of the Ash Flow -1 Cooling Unit

	Sample Number	Percentage of Phenocrysts in Rock	Phenocryst Proportions: Sanidine	Plagioclase	Biotite	Phenocryst Points Counted
Ash Flow -1	F-30	24.5	59	36	5	730
	F-34	25.2	54	40	6	655
	F-53	18.3	64	31	5	526
Ash Flow -2	D-1	15.6	73	18	9	484
	F-19	8.8	71	22	7	414
	F-31	20.7	80	17	3	557
	F-32	27.3	77	18	7	781
	F-41	25.2	67	24	9	650
	F-46	22.8	75	18	7	818
	F-52	15.2	75	19	6	376
	F-55	14.9	76	17	7	419
	F-93	28.6	66	27	7	848
Ash Flow -4	F-51	6.9	68	28	4	460

Figure 8. Petrographic Classification of tuffs in the ash flow -1 Cooling Unit.



Three component classification of quartz and feldspathoid deficient volcanic rocks (based on AGI mineral ratios from data sheet 23a).

the average is An_{33} (andesine) (see Table 3). Oxidized biotite is the only mafic phenocrystic mineral of appreciable abundance. Magnetite crystals are generally subhedral and fractured like the other phenocrystic minerals.

Sanidine separates from tuffs of the ash flow -1 sheet have yielded a K/Ar date of 40.0 ±1.2 million years (m.y.) (Epis and Chapin, 1968, p. 52). More recently, outcrops in the Browns Canyon area north of Salida have been identified as the ash flow -1 sheet by G. R. Lowell (1969, personal communication) and Van Alstine (1967, personal communication) has obtained K/Ar dates of 35.4 ±1.1 m.y. (sanidine) and 37.3 ±1.9 m.y. (biotite) for these rocks.

<u>Florissant Lake Beds</u>: MacGinitie (1953, p. 5) established the following sequence from top to bottom for the Florissant Lake Beds which are the most extensive unit in the study area (Plate 1):

5. Pumiceous andesite tuff, shales, agglomerates and volcanic river gravels
4. Rhyolitic tuff
3. Lake shale and associated volcanic sediments
2. Bedded andesite tuffs
1. Basal water-laid pebbly arkose

Table 3. Compositions of Plagioclase Phenocrysts in the Ash Flow -1 Cooling Unit

Sample Number	Number of Crystals Measured	Number of Zones Measured	Average Composition	Range in Composition
F-30	3	8	An_{33}	An_{13} -An_{42}
F-32	3	7	An_{42}	An_{15} -An_{48}
F-41	5	15	An_{36}	An_{20} -An_{58}
F-46	2	8	An_{21}	An_{16} -An_{35}
F-51	2	4	An_{34}	An_{15} -An_{52}

Compositions determined from high temperature curves of Troger (1952, p. 133) using angles measured by the Fougue method, 1 to x or 1 to z.

The Florissant Lake Beds lie unconformably on the prevolcanic surface and on the ash flow -1 cooling unit. In sec. 11, T. 13 S., R. 71 W., the lake beds can be seen draped on an erosional remnant of the ash flow -1 cooling unit (Figure 9). At other locations in the study area the ash flow -1 sheet dips under the lake beds. Due to irregularities in the underlying topography, the thickness of the Florissant Lake Beds varies widely, but averages 75 feet.

Because the present study is concerned with regional aspects of the geology of the Florissant area, no attempt is made to present a detailed account of the Florissant Lake Beds. Rather, the following information is intended to provide a frame of reference for interpretation of the relationships of the Lake Beds to the Thirtynine Mile volcanic field. The author would like to re-emphasize, however, two points made by MacGinitie (1953, p. 4) concerning the Florissant beds:

(1) "The beds, instead of forming a single unit, comprise a complex and varied series of sediments and volcanics,"...

(2) "The plant-bearing member makes up less than a third of the total thickness and it alone is of lacustrine origin. The remaining beds are mudflows and reworked river-deposited tuffs."

Figure 9. View showing Florissant Lake Beds (Tflb) draped over the Ash flow -1 Cooling Unit (Tat) in the NW/4, NW/4, sec. 11, T. 13 S., R. 71 W.

I observed MacGinitie's basal unit, an indurated arkosic conglomerate, exposed in the SE/4, sec. 12, T. 13 S., R. 71 W. (Figure 10). It lies unconformably on the eroded Pikes Peak granite and averages about 10 feet in thickness with a maximum observed thickness of 25 feet. Grains are angular to subangular and generally less than 1 inch in greatest dimension. The unit is poorly sorted with the majority of fragments in the sand to gravel size. Pink microcline and quartz from the underlying Pikes Peak granite constitute the bulk of the fragments. The matrix, on the other hand, is a fine-grained greenish tuff which cements the sand and gravel. MacGinitie (op. cit., p. 6) suggests that these basal beds of the Florissant Formation are fluviatile deposits which had been transported only a short distance. They are readily differentiated from the conglomerate of Twin Creek (p. 8) which contains larger clasts with greater rounding and more diverse lithology.

Lying unconformably above the arkosic congomerate are 30 to 40 feet of epiclastic laharic breccias and slightly indurated pumiceous tuffs (which MacGinitie (op. cit., p. 7) referred to as the lower tuffs (unit 2, p. 25)). The lower member of this unit is a heterogeneous series of mudflows which range from 3 to 20 feet in thickness. These laharic breccias are heterolithic and contain many different types

Figure 10. View of the basal pebbly arkose unit of the Florissant Lake Bed sequence, exposed in the SE/4, sec. 12, T. 13 S., R. 71 W.

of clasts of volcanic and non-volcanic origin. Subangular andesitic to basaltic lithic fragments and large subrounded pumice fragments occur in a matrix of light-colored, finely-comminutated rock material and clay. Lesser amounts of non-volcanic clasts, chiefly Pikes Peak granite, are also present.

The upper member of unit 2 is a fine-to coarse-grained, moderately-sorted, pumiceous tuff which averages 20 feet in thickness and appears reddish-purple in outcrop. Thin-section study of a sample from the Princeton fossil locality (NE/4, SE/4, sec. 20, T. 13 S., R. 71 W.) shows the tuff to be predominantly glass with lesser amounts of plagioclase, pyroxene, and magnetite. The most distinctive feature of the pumiceous tuff member is the numerous fossil stumps buried in its middle and upper parts. Large Sequoias up to 10 feet in diameter, standing erect and in place, are found in the middle part while in the upper part fossil tree trunks averaging less than 5 feet in diameter are found lying at low angles with their tops pointing north and northeast. Both members of unit 2 are well-exposed in the Petrified Forest area (Plate 1).

Perhaps the most interesting unit within the Florissant Lake Beds sequence is the lake shales unit of MacGinitie (unit 3, p. 25) (Figure 11). These beds have received considerable attention by MacGinitie (1953), Weilbacher

Figure 11. View of the "lake shales" unit of the Florissant Lake Bed sequence exposed in the SE/4, NW/4, sec. 30, T. 13 S., R. 71 W.

(1963) and McLeroy and Anderson (1966). They are extremely complex series of lacustrine "paper shales" and pumiceous tuffs with a maximum thickness of 25 feet at the Princeton locality. Weilbacher (1963) found three fundamental groups of laminations: (1) couplets of diatomite and sapropel laminae which average 1 mm in thickness, (2) graded-tuff laminae coupled with one or more overlying diatomite-sapropel couplets and averaging about 8 mm in aggregate thickness, and (3) inversely-graded, yellow pumice layers sporadically interbedded with diatomite-sapropel couplets and averaging 1.5 cm in thickness.

Associated with the sapropel laminae are numerous fossil insects and leaf impressions. Lateral variations due to stream channeling and changes in the ponded areas make correlations of any particular stratum of this series between outcrops almost impossible. Above the youngest "paper shale" is a layer of sandy-tuff shale. This stratum consists mainly of pumice and glass shards but also contains angular, fractured grains of feldspar with minor amounts of augite, hornblende, volcanic rock fragments and microcline.

Overlying the lake shale unit is a rhyolitic pumice-lapilli tuff (unit 4, p. 25) that has a measured thickness of 10 feet in the W/2, SE/4, sec. 14, T. 13 S., R. 71 W. (one mile west of the Petrified Forest) (Figure 12). The

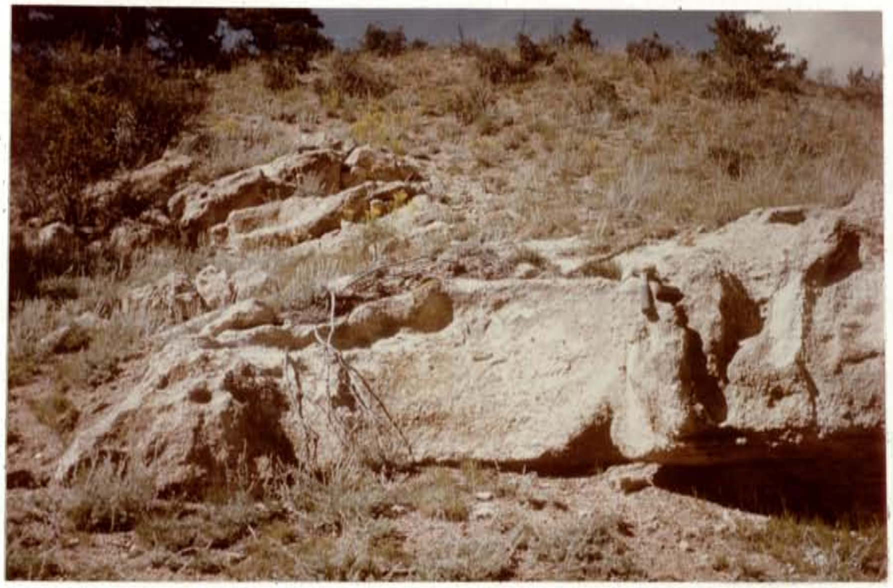


Figure 12. View of the rhyolitic pumice-lapilli tuff unit of the Florissant Lake Bed sequence exposed one mile west of the Petrified Forest (NW/4, SE/4, sec. 14, T. 13 S., R. 71 W.).

tuff is white to gray in color on the weathered surface and contains numerous bands of partially altered, pink microcline. The tuffaceous constituents are relatively homogeneous, undeformed pumice lapilli and glass shards; however, many of the pumice fragments have been partly altered to clay. Two very distinctive features of this unit are cross-bedding and lenses of altered, pink microcline.

The uppermost unit of MacGinitie (unit 5, p. 25) is a series of laharic breccias that stand out prominently at the Princeton locality. The breccias cap the ridge and are 7 to 15 feet thick. The lowest 3 or 4 feet of this unit consists of laharic breccia firmly cemented by clay and partly altered plagioclase laths. Clasts in this lowest portion are predominantly andesitic and basaltic scoria with lesser amounts of ash-flow tuffs, pink microcline, granitic lithic fragments and mineral grains. About midway through the unit, the laharic breccias contain inclusions of the underlying lacustrine beds as well as andesitic and basaltic scoria. In the upper portion, the unit takes on the appearance of the overlying lower andesite.

Abundant plant and insect remains found in the lacustrine beds indicate a geologic age intermediate between Bridge Creek time and Green River time, most probably in the upper part of the Lower Oligocene (MacGinitie, 1953, p. 77).

This age is further substantiated by mammalian fossils; Gazin (1935) described a small primitive type of oppossum from the Florissant beds and MacGinitie (1953, p. 74) reports an oreodont jaw from the lake shales.

In summary, the Florissant Lake Beds are the erosional remnants of early Tertiary fluvial and lacustrine sediments (op. cit., p. 77). These sediments vary from epiclastic laharic breccias to delicate water-laid tuffs whose composition ranges from rhyolitic to andesitic. The lacustrine tuff beds contain abundant plant remains and insect fauna, while some of the older laharic breccias contain petrified trees.

Lower Andesite: The lower andesite (Epis and Chapin, 1968, p. 62-64) is a heterogeneous assemblage of andesitic breccias and flow rocks. Wyckoff (1969, p. 23) divided the lower andesite into lower and upper members which correspond to the lower and upper halves, respectively, of the Thirtynine Mile volcanic series of Stark and others (1949, p. 101). The upper member is a well-stratified sequence of flows, flow breccias and laharic breccias that represent remnants of a large composite volcano formed over the Guffey area in Oligocene time. A whole rock K/Ar date of 34.1 ±1.1 m.y. has been obtained from the upper member near the top of Thirtynine Mile Mountain (Epis and Chapin, 1968, p. 65). The upper member, however, is not present in the Florissant area.

The lower member of the lower andesite varies greatly in thickness from tongues a few feet thick along the margins of the field to a possible maximum thickness of 1,000 feet along the south flank of Thirtynine Mile Mountain (Wyckoff, 1969). It is a series of irregularly overlapping epiclastic and erupted laharic breccias with minor flow breccias. It constitutes the most voluminous and areally extensive formation in the Thirtynine Mile Field (Chapin and Wyckoff, 1968). Cross (1894, p. 3) mapped the lower member in the Pikes Peak Sheet as "basic breccia and agglomerate".

The relationship of the Florissant Lake Beds to the lower andesite is as yet uncertain. Just north of Balanced Rock (sec. 8, T. 13 S., R. 71 W.) (Plate 1) a mudflow exposed in road cuts of Highway 103 contains clasts of lake bed sediments and cobbles of older laharic breccias in a matrix of clay and fine-grained silt derived from the lake bed sequence; this relationship suggests that the lower andesite is younger than the lake beds. On the Snare Ranch, in the S/2, sec. 25, T. 13 S., R. 21 W., the Florissant Lake Beds grade upward into the lower andesite which also indicates an age younger than the Florissant Lake Beds (Figure 13). However, the bedded andesite tuffs (unit 2, p. 25) within the Florissant Lake Beds sequence is a series of mudflow deposits and andesitic tuffs with large quantities of

Figure 13. View showing the lower andesite (Tal) overlying the Florissant Lake Beds (Tflb) on the Snare Ranch in S/2, sec. 25, T. 13 S., R. 71 W.

andesitic and basaltic clasts. These mudflows may be the same age as the lower andesite and the Florissant Lake Beds may be a fluvial and lacustrine facies of the lower andesite.

Post-volcanic Rocks

Tertiary Rocks

Conglomerate of Section 1: A fluvial deposit exposed just north of Highway 24 and about 1/4 mile east of Florissant in the W/2, sec. 1, T. 12 S., R. 71 W. is informally termed the conglomerate of Section 1 (Plate 1). It rests unconformably on a shale member of the Florissant Lake Beds and on the conglomerate of Twin Creek and is unconformably overlain by surficial deposits. A complete section of the unit could not be measured, but the formation is estimated to attain a maximum thickness of 40 feet. The unit consists of poorly cemented gravel whose clasts represent practically all older rocks of the region. Metasedimentary rocks and granites are minor constituents while quartzites, andesites, and ash-flow tuffs are common. The matrix is composed of arkosic silt and clay. In general, the pebbles are well-rounded and oblate; sorting and stratification are not apparent but outcrops are poorly exposed. In appearance and character it is distinctly different from other conglomeratic formations and younger surficial deposits. However, the age of the unit cannot yet be determined more accurately than Oligocene to early Quaternary.

Quaternary Deposits

Surficial Deposits: Surficial deposits of varying types cover much of the Florissant area and have been mapped in places where they obscure the bedrock geology. Thus, the geologic map (Plate 1) shows large areas covered by gravels, alluvium, and one landslide. The character of the deposits themselves has been accorded scant attention except where they provide clues to the bedrock distribution and major events in the geologic history of the area.

Thin pediment gravels veneer the older units beneath slopes of Pikes Peak granite. These gravels are predominantly granite gruss with occasional pebbles of lower andesite and ash-flow tuffs (Figure 14). Their thickness ranges from less than 1 foot in the intervalley areas to as much as 10 feet in the valleys. Grain size in the poorly-sorted deposits ranges from coarse sand to pebbles. The occurrence of these gravels makes mapping of contacts between granitic basement rocks and the Florissant Lake Beds very difficult since the granite weathers to a gruss which is nearly indistinguishable from the gravels.

Figure 14. View of pediment gravels consisting of transported gruss derived from the Pikes Peak granite exposed along Highway 134 south of the Town of Florissant (SE/4, SW/4, sec. 12, T. 13 S., R. 71 W.)

Alluvium related to present stream levels is generally confined to the major tributaries of the South Platte River and to the valley of the South Platte. The alluvium ranges in general from silt to pebble size and is lithologically characteristic of its drainage area.

One landslide was observed in the NW/4, sec. 3, T. 13 S., R. 71 W. where ash-flow tuffs overlie the unconsolidated tuff of Fish Creek. It consists of a small, jumbled aggregate of loose debris which has slumped irregularly downhill into the valley of Twin Creek.

STRUCTURE

Regional Structure

The Thirtynine Mile volcanic field occupies a structural plateau between South Park and the Wet Mountain Valley with the Florissant Basin situated in the northeastern corner (Figure 15). The volcanic field is within a belt of north-northwest trending intermontane basins extending from North Park to the Raton Basin. Approaching the volcanic field from the north and bounding the west side of the Front Range are the east dipping Williams Range thrust, Elkhorn thrust and South Park reverse fault (Boos and Boos, 1957, p. 2639). Impinging on the volcanic field from the south are the Parkdale, McIntyre and Wet Mountain thrusts (op. cit., Lovering and Goddard, 1950, p. 58, 59). Faults along Current Creek in the central part of the Thirtynine Mile field are believed to connect these structural lineaments (Epis and Chapin, 1968, p. 82). These authors also suggest that post-volcanic faulting is most prevalent in the peripheral portions of the field such as the Florissant Basin.

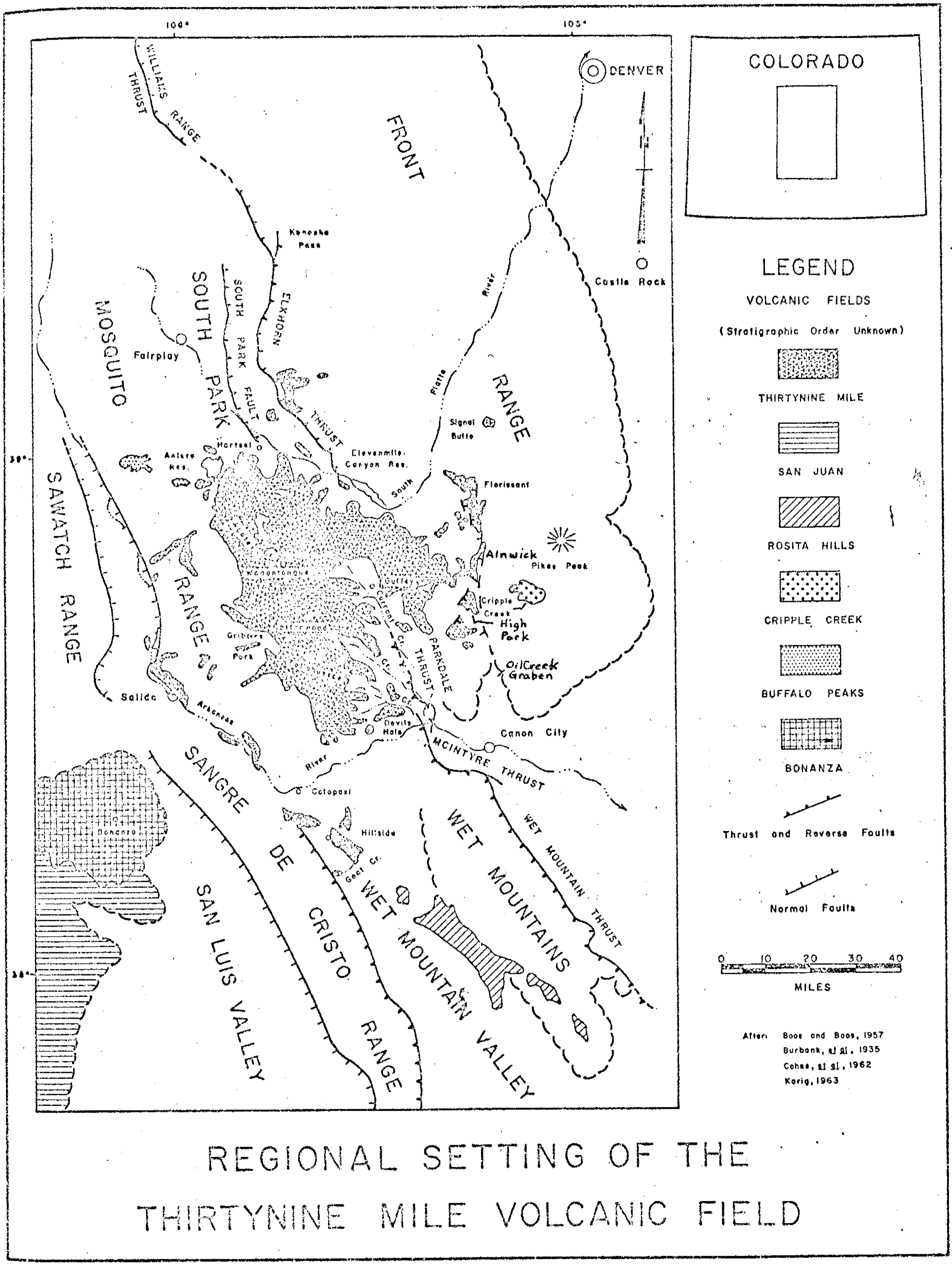


Figure 15. After Chapin and Epis, 1964.

Local Structure

Volcanic rocks and associated sedimentary rocks in the Florissant area generally dip to the northwest from 90 to 100 feet per mile. Superimposed upon this regional dip are north and northwest-trending post-volcanic faults that form a shallow graben in which the Florissant valley is situated. Faulting is postulated in three areas on the basis of lineaments on aerial photographs and displacements of the pre-volcanic erosion surface (Plate 2). Offset of the ash flow -1 sheet can also be seen in the cross sections (Plate 1). The paleotopographic map (Plate 2) is contoured on the base of the volcanic rocks where possible; otherwise, the contours are based on topographic highs on the present erosion surface which represent minimum elevations for the pre-volcanic surface.

Along the eastern side of the thesis area, fault F-1 strikes generally north-northeast and extends for at least 6 miles from sec. 31, T. 12 S., R. 71 W. southward to sec. 35, T. 13 S., R. 71 W., where it joins fault F-2. The west side is downthrown with a throw of about 25 feet and the dip appears to be nearly vertical. Fault F-2 has a sinuous pattern trending north-northwest beginning in sec. 17, T. 14 S., R. 71 W. This fault is also downthrown to the west with a displacement of approximately 75 feet. Faults F-1, F-2 may extend south of the mapped area along a prominent topographic escarpment which parallels Hay and Four Mile Creeks. Fault F-3 trends northwesterly along a series of topographic escarpments and ridges beginning in sec. 27, T. 13 S., R. 71 W. The northeast side is downthrown with an approximate displacement of 200 feet as measured between outcrops one mile apart in sec. 26 and sec. 27, T. 13 S., R. 71 W.

A result of faulting in the Florissant area has been the displacement and tilting of the Florissant Lake Beds and associated volcanic rocks into a graben-like structure. This structure may follow Four Mile Creek and the F-1, F-2 fault southward from the present study area through the Alnwick and High Park areas (Chapin and Tobey, 1969, personal communication) to the Oil Creek graben northeast of Canon City. Alignment of the High Park, Alnwick and Florissant sedimentary basins along this structural zone further suggests that aggradation of these basins may have occurred in response to an earlier period of faulting which followed emplacement of the ash flow -1 sheet but preceded deposition of the Florissant Lake Beds.

Total offset along the Florissant-Oil Creek fault zone is considerably greater than was observed on the faults mapped in the study area. Other faults undoubtedly exist, but their presence is difficult to document because of poor exposures and the scattered distribution of volcanic outcrops. The lower andesite has been offset approximately 1600 feet between the Alnwick basin and Mount Pisgah (Chapin, 1969, personal communication) and about 1400 feet between the High Park basin and Little Pisgah Peak near Victor (Tobey, 1969, personal communication). About 500 feet of elevation separates outcrops of the ash flow -1 sheet near the Town of Florissant and the highest ash-flow outcrop along the eastern edge of the map area (sec. 16, T. 13 S., R. 70 W.). These offsets may represent middle and late Tertiary uplift of the southern Front Range; further mapping east of the Florissant area may help to evaluate this possibility.

GEOLOGIC HISTORY

Prevolcanic History

The recorded geologic history of the Florissant region begins with deposition of sedimentary rocks during Precambrian time followed by their metamorphism and the subsequent intrusion of the Pikes Peak batholith. Age determinations by the Rb/Sr method indicate that emplacement of the Pikes Peak granite occurred some 1.05 billion years (b.y.) ago (Wobus, 1969, Hutchinson and Hedge, 1967). During the late Precambrian and early Cambrian, erosion exposed this batholith providing the earliest appearance of the ancestrial Front Range.

No Paleozoic or Mesozoic sedimentary rocks are preserved in the Florissant area although they are present only a few miles away at Woodland Park, in South Park, and in the Oil Creek graben. The reader is referred to excellent summaries in Weimer and Haun (1960) for this portion of the geologic history. Inliers of Paleozoic formations in the Woodland Park area northeast of Florissant and in the Oil Creek graben south of Florissant probably owe their existence to down faulting during the late Paleozoic uplift.

The end of the Mesozoic era was marked by the early pulses of the Laramide orogeny which resulted in uplift of the Front Range as well as other highlands in Colorado. During and following these early Laramide orogenic movements, many thousands of feet of Mesozoic sedimentary rocks were eroded from the study area until by late Eocene time an erosion surface with local relief of 600 to 800 feet was developed on the Precambrian basement rocks (Plate 2). North and east of Florissant the erosion surface correlates with the Cheyenne Mountain surface (Van Tuyl and Lovering, 1935, p. 1307-1309). Epis and Chapin (1968, p. 59) suggest that the surface probably formed in middle or late Eocene time. Volcanic materials of the Thirtynine Mile field were deposited on this surface of moderate relief.

Topographic lows on the erosion surface were filled with arkosic debris in the Cottonwood Creek area (Epis and Chapin, 1968, p. 59) and in the High Park area (Tobey, 1969, personal communication). The arkosic debris was derived from erosion of the Precambrian basement rocks, and the conglomerate of Twin Creek corresponds to these arkoses.

Volcanic History

The earliest unit of volcanic derivation in the Florissant area is the tuff of Fish Creek. It is a sedimentary deposit filling topographic lows on the erosion surface and appears to represent fluvial reworking of an ash-fall older than the ash flow -1 cooling unit. At least four ash flows (0.5, 1, 2 and 4) were then rapidly erupted from an unknown source and welded together to form the ash flow -1 cooling unit. These flows filled meandering valleys on the prevolcanic surface throughout the Thirtynine Mile field (Epis and Chapin, 1968, p. 1, Lowell, 1969, personal communication and Tobey, 1969, personal communication). Preliminary dating of the ash flow -1 sheet by Epis and Chapin (1968, p. 52) and Van Alstine (1967, personal communication) (see p. 25) has resulted in dates of 40.0 ±1.2 m.y., 35.4 ±1.1 m.y. and 37.3 ±1.9 m.y. for the unit.

A period of uplift of the southern Front Range and faulting along the Florissant-Oil Creek lineament probably occurred after emplacement of the ash flow -1 sheet and prior to deposition of the younger units. Alignment of the Florissant, Alnwick and High Park sedimentary basins along the fault zone, the existence of ash flow-1 outcrops at appreciably higher elevations on the Front Range block, and a greater total offset of the ash flow -1 sheet than can be observed on faults cutting the Florissant Lake Beds are the lines of evidence for this period of movement.

The ash flow -1 sheet was largely removed by erosion from the intervalley areas and only small remnants were left in the valleys. Erosional products of this period did not accumulate in the Florissant area but are present to the south in the Alnwick and High Park basins (Tobey, 1969, personal communication) and in the Tallahassee Creek area (lower volcanic conglomerate of Epis and Chapin, 1968, p. 62).

Renewal of volcanism in the Thirtynine Mile field resulted in deposition of a widespread sheet of andesitic breccias, dominantly of mudflow origin and termed the lower andesite. Aggradation of the Florissant basin during emplacement of the breccia sheet formed a series of lacustrine and fluviatile sediments which have been called the Florissant Lake Beds. The oldest member of the Florissant formation is an indurated arkosic conglomerate consisting of fragments of the Pikes Peak granite. Following deposition of the basal member, a series of light colored epiclastic laharic breccias and pumiceous tuffs were deposited. Northward orientation of downed fossil Sequoias suggest that these mudflows came from the southwest (see p. 30). Drainages blocked by these mudflows formed shallow ponds in which fine-grained shales and tuffs of the "lake shale" member were deposited. The "lake shale" member is a complex series of finely laminated shales and pumiceous tuffs that contain many types of fossil fauna and flora to which MacGinitie (1953, p. 77) has assigned a Lower Oligocene age. Following these lacustrine sediments, a thin layer of cross-bedded, sandy tuff-shale was deposited. Pumice lapilli tuffs and light-colored laharic breccias marked the close of the Florissant Lake Bed sequence.

The laharic breccias of the lake beds grade upward into dark colored epiclastic laharic breccias of the lower andesite. Numerous small vents scattered throughout the volcanic field erupted fragmental andesite to form the breccia sheet (Chapin and Wyckoff, 1968). An andesitic flow on Thirtynine Mile Mountain southwest of Florissant and belonging to the upper member of the lower andesite has been dated by the K/Ar method at 34.1 ±1.1 m.y. (Epis and Chapin, 1968, p. 65).

Post-volcanic History

Movement along the Florissant-Oil Creek fault zone occurred again after deposition of the Florissant Lake Beds and the lower andesite. The age of this faulting is uncertain, but Steven and Epis (1968, p. 246) have suggested a late Cenozoic age for widespread block-faulting in Central Colorado. The Florissant area presently occupies a shallow graben along the Florissant-Oil Creek lineament.

The conglomerate of section 1 was deposited east of the Town of Florissant where it rests unconformably on a shale member of the Florissant Lake Beds and on the conglomerate of Twin Creek. It contains clasts of the lower andesite as well as all older units of the study area which together with its low elevation and unconformable relationships with the underlying formations suggests a late Cenozoic age.

The geologic history of the area since the deposition of the conglomerate of section 1 has been dominated by the formation of pediments veneered with thin gravels derived from Pikes Peak gruss. Quaternary alluvium deposited along the present streams is now being dissected by erosion.

CONCLUSIONS

Several important conclusions concerning the volcanic stratigraphy and structural history of the Florissant area and the Thirtynine Mile field may be drawn from evidence accumulated during the thesis investigation.

Pre-ash Flow -1 Volcanism

Prior to the present study, the ash flow -1 cooling unit was thought to be the oldest volcanic event in the Thirtynine Mile field. However, the tuff of Fish Creek, a volcani-clastic sediment, underlies the ash flow -1 sheet and records an earlier eruption. Because this sediment has been found at only two locations in the present study area and nowhere else in the Thirtynine Mile field, its vent area and other details of its stratigraphy and age are yet to be determined.

Age and Stratigraphic Position of the Florissant Lake Beds

The Florissant Lake Beds are a series of fluvial and lacustrine deposits along the northeastern margin of the Thirtynine Mile volcanic field. They were deposited after an extensive period of erosion, which thoroughly dissected the ash flow -1 cooling unit. The basin in which they were deposited was probably formed in part by faulting along the Florissant-Oil Creek lineament and in part by obstruction of the drainage system by andesitic breccias of the lower andesite. Stratigraphic relationships between the lower andesite and the Florissant Lake Beds have been established. The presence of andesitic clasts and tuffs in the lower portion of the Florissant Lake Bed sequence and the gradation of the youngest mudflows of the sequence into epiclastic lahars of the lower andesite indicate that the Florissant Lake Beds are a fluvial and lacustrine facies of the lower andesite. From this record, the age of the Florissant Lake Beds can be bracketed at less than the 35.4 ±1.1 m.y. and 37.3 ±1.9 m.y. K/Ar ages obtained by Val Alstine (1967, personal communication) for the ash flow -1 cooling unit and greater than the 34.1 ±1.1 m.y. K/Ar age obtained by Epis and Chapin (1968, p. 65) for an andesitic flow in the upper portion of the lower andesite. This stratigraphic and radiometric dating agrees well with the Lower Oligocene age assigned to the Florissant formation by Gazin (1935) and MacGinitie (1953) on paleontologic grounds.

Structure of the Florissant Basin

The Florissant basin lies at the north end of a structural and topographic lineament that extends from the Oil Creek graben of the Canon City embayment northward through the High Park and Alnwick basins to Florissant. The ash flow -1 sheet has been uplifted 500 to 1500 feet along the east or Front Range side of the fault zone with the amount of displacement decreasing northward. Alignment of the Florissant, Alnwick and High Park sedimentary deposits along the foot of the escarpment suggest that some of the movement occurred after emplacement of the ash flow -1 sheet but before aggradation of the basins. A later period of movement is recorded by faults that cut the Florissant Lake Beds; however, the 25 to 200 feet of offset along these later faults does not account for the total displacement of the ash flows, which is about 300 feet in the Florissant area. Thus, the Florissant basin is a shallow graben along a major structural lineament.

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APPENDIX I

Optic Axial Angles Used in Correlation of Ash Flows -1, -2 and -4

Ash Flow -1

Sample F-30 S/2, NE/4, sec. 3, T. 13 S., R. 71 W. 18 Crystals 21 measurements	Sample F-34 S/2, NW/4, sec. 1, T. 13 S., R. 71 W. 20 Crystals 23 measurements	Sample F-53 NW/4, SW/4, sec. 1 T. 13 S., R. 71 W. 20 Crystals 20 measurements
39.0	45.0	43.0
45.0	41.0	40.5
44.0, 36.5	37.5, 43.5	45.0
36.0	36.0	39.5
41.0	38.5	37.5
46.0	40.0	34.5
39.0, 30.5	46.5, 40.5	40.5
40.5	36.5	37.0
34.0, 39.5	38.0	37.0
33.0	42.5	38.5
37.5	38.5	40.5
34.5	38.0	34.0
36.5	36.5	43.0
36.5	40.5	35.0
40.0	37.0	37.0
38.0	35.5	32.0
39.5	37.0, 38.5	40.0
40.5	38.0	31.5
	43.0	27.0
	46.0	37.0

	Repeat 20 Crystals 23 measurements		Repeat 19 Crystals 19 measurements	
	38.0	41.0	30.0	37.5
	42.5	46.0	36.5	44.0
	40.5	42.0	44.0	39.0
	41.0	36.0	36.5	41.5
	39.5	38.0	34.5	39.0
	35.0	39.5	37.0	30.0
	38.5	38.5	44.0	47.0
	40.5	40.0	38.5	42.5
	40.0	46.5	41.5	
	39.5		39.5	
	38.5		33.0	

Ash Flow -2

Sample D-1
NW/4, NW/4, sec. 16
T. 13 S., R. 70 W.
24 Crystals
28 measurements

35.5
48.5, 42.0
38.0
33.5
32.0, 41.5
32.0
35.0
40.5
35.0
36.0
35.0
38.5, 41.5
34.5
38.0
30.5
41.0
30.5
40.0
33.0, 41.0
39.0
38.5
32.0
36.5
35.5

Sample F-19
NW/4, NW/4, sec. 11,
T. 13 S., R. 71 W.
19 Crystals
21 measurements

34.5
32.5
30.5
39.5, 34.5
40.0
35.5
26.0
44.5
38.0
31.5
48.0, 36.5
37.5
37.0
31.5
36.5
32.0
32.5
38.0
30.0

Repeat
20 Crystals
22 measurements

45.5
35.5
40.5
33.0
37.0
35.0
36.0
34.0
49.0, 35.0
37.0, 34.0
34.0
40.5
37.5
32.0
28.5
37.5
31.5
42.5
28.5
38.0

Sample F-31
NW/4, NW/4, sec. 11,
T. 13 S., R. 71 W.
20 Crystals
25 measurements

39.0, 38.0
45.5, 37.5
42.5, 36.0
33.0
36.0, 41.0
40.5, 31.5
35.0
38.0
45.0
37.5
34.0
34.5
38.0
35.0
34.5
42.0
39.0
33.0
32.0
34.6

Repeat
20 Crystals
23 measurements

39.5, 40.5
42.0, 35.0, 28.0
37.0
38.0
40.5
36.0
39.0
35.5
33.0
34.5
38.0
33.0
33.5
38.0
43.5
38.5
29.0
50.5, 39.5
47.5, 44.5
32.0

Ash Flow -2

Sample F-32
SW/4, NE/4, sec. 30,
T. 13 S., R. 71 W.
19 Crystals
23 measurements

38.0
34.5
24.5
33.5
46.5, 40.5
36.0, 43.0
30.5
36.0
35.0, 39.0
29.0
42.0, 36.5
34.0
29.5
33.0
30.0
32.0
32.0
33.0
31.5

Sample F-41
SW/4, NW/4, sec. 3,
T. 13 S., R. 71 W.
19 Crystals
21 measurements

35.0
36.5
39.5
37.0
40.0
38.0, 34.0
35.0
39.5
37.0
35.5
66.5, 37.0
35.5
35.0
41.0
36.5
29.5
36.0
35.5
37.0

Sample F-46
SE/4, SW/4, sec. 27,
T. 13 S., R. 71 W.
19 Crystals
21 measurements

39.5
36.0
35.0
34.5
27.0
52.0, 40.5
36.0
38.0
36.5
42.0
36.5
43.5
35.5
33.0, 37.0
36.0
37.5
38.0
47.5
31.5

Repeat
20 Crystals
23 measurements

41.0, 35.0
34.5
31.5
32.5
40.0
35.0
38.0, 29.5
31.5
41.5
31.5
34.5
36.5
31.0
32.0
36.5
46.0, 34.5
38.5
34.5
36.5
34.0

Ash Flow -2

Sample F-52 S/2, NE/4, sec. 10, T. 13 S., R. 71 W. 21 Crystals 22 measurements	Sample F-55 NE/4, SW/4, sec. 31, T. 12 S., R. 70 W. 19 Crystals 22 measurements	Sampe F-93 SE/4, NW/4, sec. 19, T. 12 S., R. 71 W. 17 Crystals 18 measurements
37.5	36.0	34.5
34.5	34.0	38.0
47.0	36.5	33.5
35.5	35.0	39.0
33.5	37.0	36.0
44.0	36.0, 42.0	34.5
33.5	33.5	36.5
32.5	41.0	44.0
37.5	37.0	34.0
37.5	34.0, 45.0	31.5
36.5	38.0	63.5, 41.0
37.5	33.5, 50.0	41.5
38.0	36.5	34.0
37.0	38.0	32.5
37.0, 31.0	32.5	36.0
33.0	36.0	41.0
37.5	36.0	34.0
33.0	38.5	
28.5	33.0	
37.5		
30.0		

Ash Flow -4

Sample F-51
NW/4, NW/4, sec. 11,
T. 13 S., R. 71 W.
17 Crystals
20 measurements

31.0
31.5
27.5, 33.5
33.5
33.0
29.0
37.0
39.5
31.0
40.0, 31.0
31.0
34.0
35.5
30.5, 39.0
31.5
40.0
28.5

Repeat
15 Crystals
17 measurements

36.5
30.5
30.5
30.0, 33.0
31.0
35.0
39.0, 30.0
31.5
39.0
36.5
31.0
32.5
31.0
29.0
25.0

This thesis is accepted on behalf of the faculty of the Institute by the following committee:

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Date: September 28, 1969