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Stratigraphy, tephrochronology, and structural setting of Miocene sedimentary rocks in the Middlegate area, west-central Nevada

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Abstract

Miocene strata in the Middlegate area, Churchill County, Nevada, consist of the Middlegate Formation unconformably overlain by the Monarch Mill Formation. The Middlegate Formation is about 110 m thick and consists of a lower member of fluvial and lacustrine tuffaceous sandstone and conglomerate and an upper member of lacustrine diatomaceous siltstone. Megabreccia landslide deposits are common in the Middlegate Formation. Tephrochronologic studies indicate that the Middlegate Formation is about 15.2 Ma. The Monarch Mill Formation consists of lacustrine, fluvial, and alluvial-fan deposits that are at least 700 m thick in the central part of the Middlegate basin. Coarse, near-source, alluvial-fan deposits of the Monarch Mill Formation interfinger with finer-grained fluvial and lacustrine deposits from source areas to the north and east and southeast of the Middlegate basin. Local megabreccia deposits are present in the Monarch Mill Formation in the southern and eastern parts of the basin. Tephrochronologic studies indicate that the Monarch Mill Formation ranges from about 14.7 to 9.8 Ma.

The Middlegate Formation is mostly a quiet-water lake deposit that appears to have been deposited in an environment distinctly different from the present-day environment that is dominated by alluvial-fan deposits. It does, however, contain megabreccia deposits, indicative of nearby escarpments that produced far-traveled landslide deposits. The Monarch Mills Formation represents a distinct change in the paleogeographic setting in the Middlegate area. It contains coarse near-source deposits that indicate local high-relief, probably related to the development of faults and topographic relief that led to the present-day structural setting of the Middlegate area. This change occurred at about 14 Ma.

Introduction

The Middlegate area lies in western Nevada about 170 km east of Reno, Nevada (Fig. 1). The area contains extensive exposures of Miocene sedimentary rocks that were studied by Axelrod (1956, 1985) as a part of his description of the abundant Miocene flora in the area. Willden and Speed (1974) published a map and a report on Churchill County, which contains the Middlegate area, and described the general geology of the region. Barrows (1971) studied the geology, Axelrod (1991) the flora, and Perkins and others (1998) the tephrochronology of the Buffalo Canyon area centered about 10 km east of the area described here. The present study was undertaken to reevaluate the stratigraphic and structural interpretations of Axelrod (1956, 1985) and to extend mapping into areas not covered by him. Some preliminary results of the study were reported by Stewart (1992). The field study was done during parts of 1993 and 1994 and included geologic mapping, measurements of stratigraphic sections, studies of paleocurrent directions, and collection of tephra samples for major element analysis. Analysis of the tephra samples and preparation of the report were from 1995 until 1998. Companion studies have been made of Miocene strata in the Cobble Cuesta area, Gabbs Valley, 40 km south southwest of the Middlegate area (Stewart and others, 1999) and in the Trinity Range-Hot Springs Mountains area, 110 km west northwest (Stewart and Perkins, 1999).

Stratigraphy and structure of rocks older than Middlegate Formation

In most of the Middlegate area, Tertiary rocks older than those of the Middlegate Formation were not mapped, or were mapped showing only a few major rock types (Fig. 2). However, in the Clan Alpine Mountains, two major ash-flow tuff units are recognized (informally named the tuff of Bench Creek Well and tuff of Clan Alpine Mountains). In addition, from sec. 7, T. 17 N., R. 36 E. southward in the Clan Alpine Mountains, several other volcanic units are recognized in a structurally complex setting that may be a caldera.

The tuff of Bench Creek Well and tuff of Clan Alpine Mountains are thick ash-flow tuff units that comprise most of the Clan Alpine Mountains. The tuff of Bench Creek Well

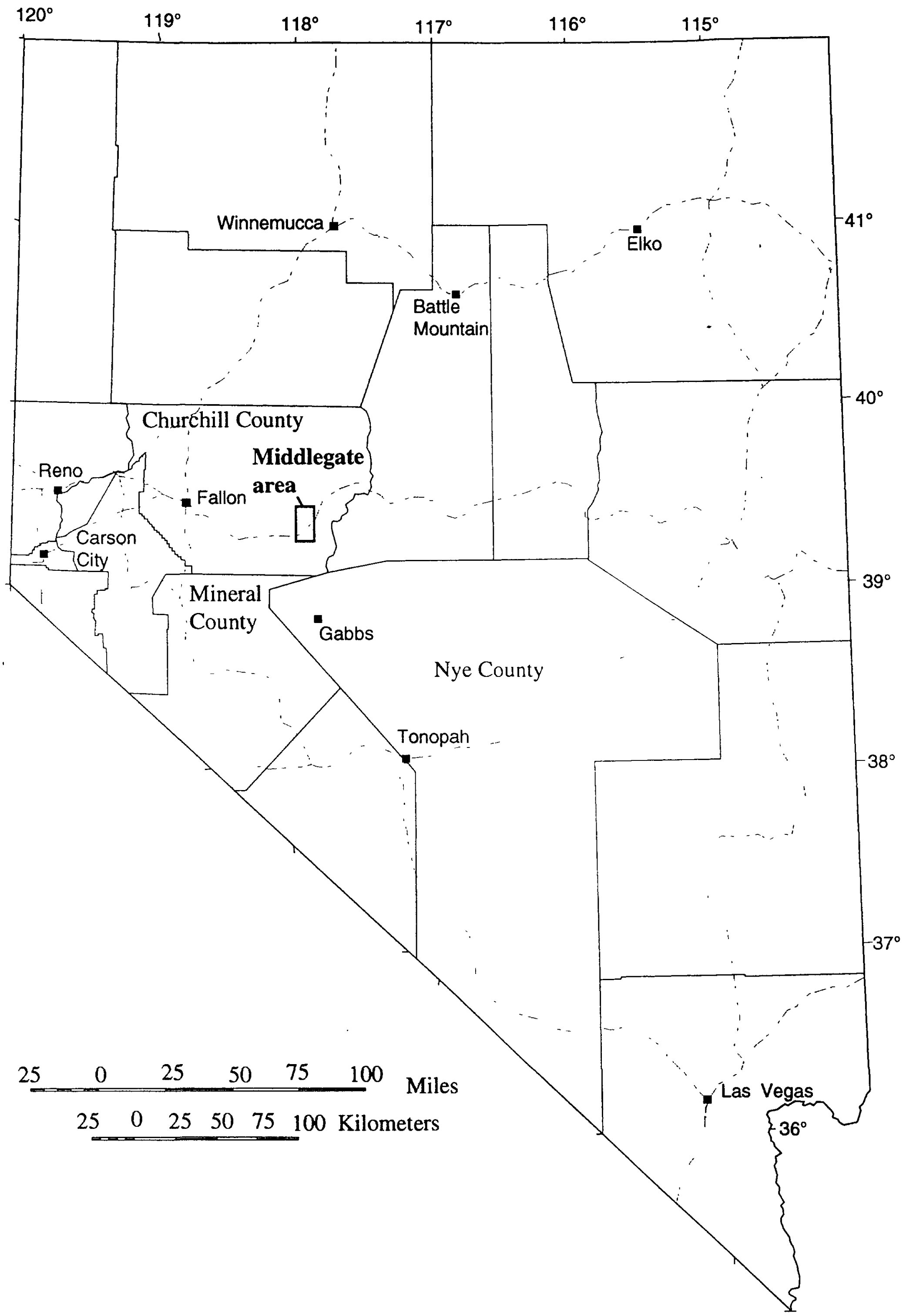

Figure 1. Index map showing location of Middlegate area

is distinguished by the abundance of flattened pumice. Internal cooling units are not evident in it, although unit Tbct is a relatively unwelded part of the unit that appears to indicate a cooling break. The tuff of Clan Alpine Mountains, on the other hand, is complex and contains many individual cooling units.

From section 7 southward, the stratigraphic and structural complexity of the Clan Alpine Mountains increases greatly. Two major units (Tmb and Tbt) are present in this area lying between the tuff of Bench Creek Well and the tuff of Clan Alpine Mountains. Unit Tmb is a megabreccia that pinches out to the north, and appears to have only limited distribution to the south. Some uncertainty concerns the distribution of Tmb, because it resembles, and may not consistently be distinguished from, unit Tcab. Unit Tbt is an ash-flow tuff containing abundant vitrophyre that is present only in a relatively small part of the Clan Alpine Mountains. Unit Tcat is a major unit from section 7 southward. It is several hundred meters thick and consists of ash-flow tuff with abundant coarse volcanic fragments. Megabreccia layers are present within it. Units Tcr and Tv, both ash-flow tuffs, also are present in the area south of section 7.

The area of the Clan Alpine Mountains south of section 7 is considered to be the northern part of a major caldera. The thick tuff unit (Tcat) and associated megabreccia (Tcab) are considered to be caldera-fill deposits, and the lithologically similar Tca to be outflow sheets from the caldera. Two major down-to-the-south normal faults in sec. 13, T. 17 N., R. 35 E., and in sec. 18, T. 17 N., R. 36 E. may be near the caldera boundary although the lack of extensive alteration and intrusions along these faults is perhaps inconsistent with the idea of caldera-bounding faults. However, a few small outcrops of fine-grained intrusive rock and porphyry are present near the presumed boundary of the caldera in sec. 13 and 24, T. 17 N., R. 35 E. Some outcrops of pre-caldera tuff and breccia units (Tmb, Tbt, Tv, Tcr) may be slide blocks into the caldera, although field evidence of this is uncertain. Units Tmb and Tbt are present only near the presumed caldera boundary, and may indicate precursor eruptions along structures that would later form the caldera wall.

Middlegate Formation

The Middlegate Formation was named by Axelrod (1956) for outcrops directly east, north, and south of Middlegate (mostly secs. 19, 20, 29, 30, and 31, T. 17 N., R. 36 E., sec. 6, T. 16 N., R. 36 E., and sec. 1, T. 16 N., R. 35 E.). The formation also is exposed in areas (1) extending for about 7 km north of Middlegate, (2) 4 to 6 km south of Middlegate, (3) 8 km south southeast of Middlegate, (4) west of the Eastgate Mine, and (5) 8 to 9 km east southeast of Middlegate (Fig. 2).

The Middlegate Formation is divided into a lower member and an upper member. The lower member (unit M_1 of Axelrod, 1956) is composed mostly of tuffaceous sandstone, and minor amounts of conglomerate and sedimentary breccia. The largest clasts in the lower member are about 1 m, but most of the conglomerate contains clasts no larger than pebbles. The lower member is generally about 10 to 20 m thick, but locally it is thicker. The lower member rests unconformably on Tertiary volcanic rocks.

The upper member of the Middlegate Formation consists of white, yellow-gray, and light-brownish-gray, laminated, diatomaceous siltstone containing plant detritus and carbonaceous material. The dominant diatom taxa (Table 1) are *Aulacoseira* spp. which were probably planktonic forms, preferring an alkaline, freshwater (<5‰) nutrient-rich lake environment (S. W. Starrett, written commun., 1997). In some places, the diatomaceous siltstone is somewhat silicified and porcelaneous. The upper member also contains carbonaceous shale, a few very thin to thin beds of medium- to coarse-grained tuffaceous sandstone, and local opalized masses. A 5-m-thick deltaic sandstone is present in the upper member in central part of sec. 11, T. 16 N., R. 16 E. This deltaic unit contains several separate layers with foreset beds as much as 3 m high. The upper member is about 92 m thick in a measured stratigraphic section in the southwesternmost part of sec.

Table 1. Diatoms from the Middlegate Formation identified by Scott W. Starratt

Localities:

JS-94-2: SW1/4 sec. 31, T.17N., R.36E.
1-36-66J: NW1/4 sec. 21, T.16N., R.36E.
1-10-22J: SW1/4 sec. 17, T.17N., R.36E.

JS-94-2

Aulacoseira granulata
A. islandica
A. islandica f. *curvata*
Cymbella mexicana
Fragilaria brevistriata
Tetracyclus ellipticus var. *lancea* f. *subrostrata*
T. javanicus

Sponge spicules
Crysophyte cysts

1-36-66J

Achnanthes conspicua
A. miocenica
Aulacoseira granulata
Caloneis sp.
Cocconeis placentula
Cymbella cistula
C. mexicana
Fragilaria brevistriata
F. construens
Gomphonema intricatum
G. lanceolatum
Navicula oboensis
N. scutelloides
Opephora martyi
Tetracyclus celatom
T. rupestris

Sponge spicules

1-10-22J

Aulacoseira granulata
A. islandica
A. islandica f. *curvata*
Cymbella cistula
Navicula densa

Sponge spicules

7, T. 17 N., R. 36 E. The upper member of the Middlegate Formation contains a large Miocene flora (Axelrod, 1956; 1985) at two localities, one about 3.5 km northeast of Middlegate (southeasternmost part of sec. 19, T.17N., T.36E. and the other about 4.6 km south-southwest of Eastgate (northeast part sec. 11, T.16N., R.36E. The Middlegate Formation also contains large megabreccia deposits (apparently Miocene far-traveled landslide deposits) at the boundary between the lower and upper members of the Middlegate Formation as well as within the upper member. These megabreccia deposits contain blocks as large as 100 m composed of Tertiary welded tuff, rhyolite, and locally andesite and dacite. Axelrod (1985) mapped "marginal tectonic breccia" along the margin of outcrops of the Middlegate Formation in the Eastgate Mine area. These breccias appear to be late Pliocene or Quaternary landslide deposits covering the Middlegate Formation, rather than coarse detritus within the Middlegate Formation. The lower and upper members of the Middlegate Formation apparently intertongue judging by the presence of the same tephra layer in the lower member in one area and in the upper member in another area (Table 2, 3).

Member 2 of Barrows (1971) in the Buffalo Canyon area about 10 km east of the southern part of the Middlegate area is similar lithologically to the Middlegate Formation and may correlate with it. Member 2 is composed of diatomite, and minor amounts of siltstone, sandstone, and vitric tuff. Unit 2 apparently is within the "Lower Buffalo Canyon" section of Perkins and other (1998) that has an age of 15.84 to 15.17 Ma, agreeing well with the age of the Middlegate Formation established by tephrochronolgy in this report.

The age of the Middlegate Formation in the Middlegate area based on study of 10 tephra samples (Fig. 3; Tables 2, 3) is 15.41 to 15.18? Ma. Axelrod (1985) published a K-Ar age of 18.5 Ma for the Middlegate Formation, but this seems too old based on the younger ages of the tephra mentioned above and because the rhyolite and dacite tuff that underlie the Middlegate Formation has a K-Ar age of 16.3 Ma (recalculated using new age constants) according to Evernden and James (1964).

Monarch Mill Formation

The Monarch Mill Formation was named by Axelrod (1956) for Monarch Mill which is designed only as "ruins " (section 32, T. 17 N., R. 36 E) on the U.S. Geological Survey Eastgate 7 1/2' topographic map published in 1969. The Monarch Mills Formation is widely exposed in the north-south trending valley between Middlegate and Eastgate. At least locally, it rests unconformably on the Middlegate Formation. A 10 degree angular unconformity between the Middlegate and Monarch Mill Formations was noted in the southwestern part of sec. 11, T. 16 N., R. 36 E. The formation is laterally variable in lithologic facies and is here divided into 10 units, many of which are apparently laterally equivalent units (Fig. 2).

Unit Tmmc is a widespread unit in the northern part of the map area. It is at least 300 m thick and grades from cobble and boulder (as large as 1.5 m) conglomerate in its lower part to finer conglomerate, sandstone and siltstone in its upper part. It also grades laterally from cobble and boulder conglomerate in the northern part of the area to sandstone and siltstone in the central part of the area, where it appears to grade laterally into units Tmmsc, Tmmtr, Tmmts, Tmmz, and Tmmss. The conglomerate in Tmmc contains clasts of welded tuff, and minor amounts of andesite and dacite.

Units Tmmsc, Tmmtr, Tmmts, Tmmz, and Tmmss are exposed in the central part of the area (Fig. 2). They are composed primarily of siltstone, sandstone, conglomerate and minor amounts of tuffaceous sandstone and reworked tuff. The conglomerate consists of granules and small pebbles composed mainly of welded tuff and rhyolite. No coarse conglomerate is known from these units. Unit Tmmz is a conspicuous tuff that has been extensively prospected for zeolites. Unit Tmmtr contains a Hemphillian vertebrate fauna in the south-central part of sec. 33, T. 17 N., R. 36 E. (Axelrod, 1956). Unit Tmmss is

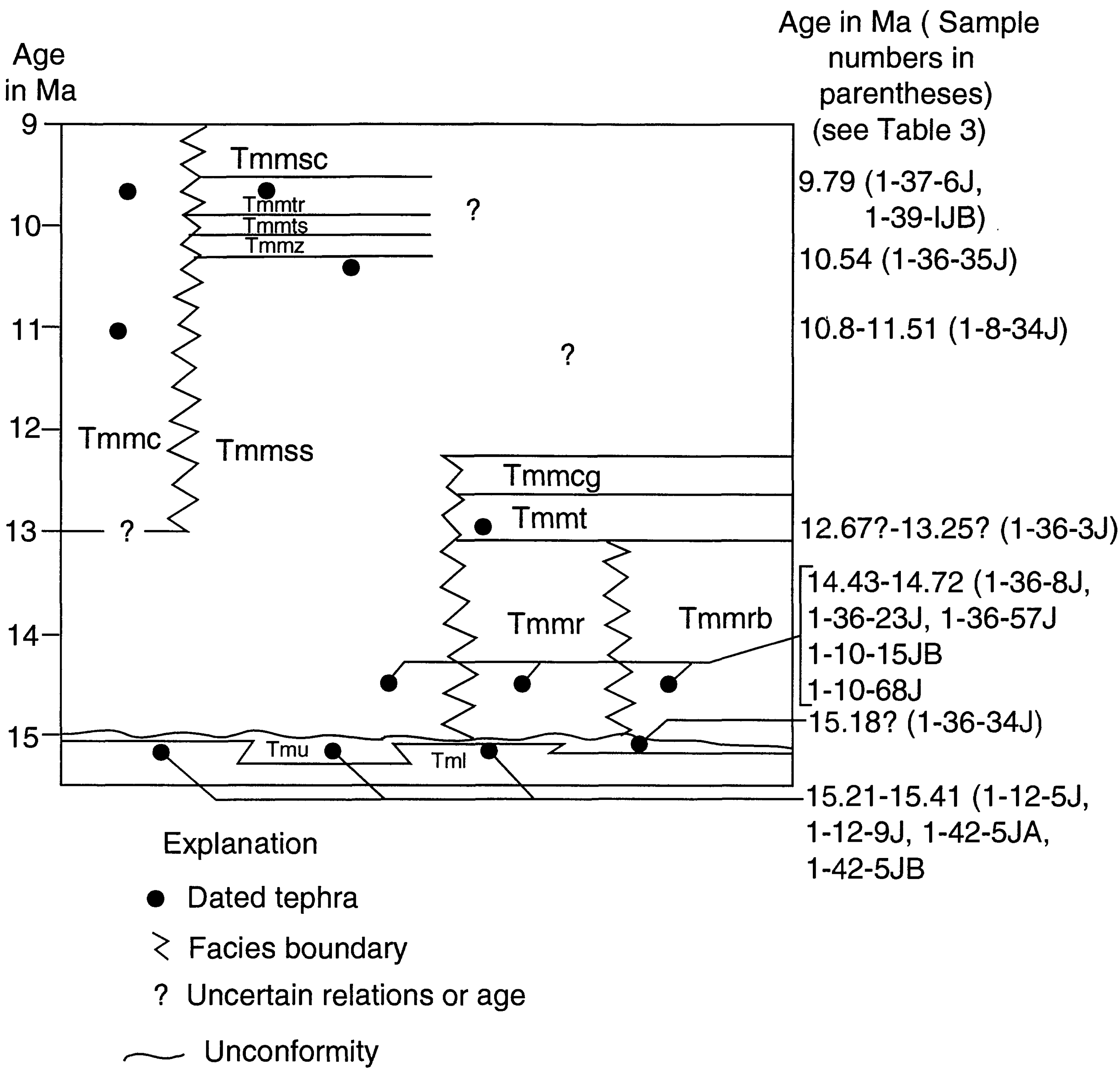

Figure 3. Diagram showing ages of stratigraphic units based on tephrochronology

Table 2. Chemical composition of volcanic glass shards in tephra layers of the Middlegate Basin, Nevada, as determined by electron-microprobe analysis. Values shown below represent the average of between about 15 and 20 analyzed shards for each sample. Some samples have more than one compositional mode. The modes are: ma - major mode; mi - minor mode. 1 sh, one shard analyzed. Results of replicate analysis of a homogenous internal glass standard, RLS132, is given below to provide an approximation of analytical precision. Analyses by Charles E. Meyer, U.S. Geological Survey, Menlo Park, Calif., using the JEOL 8900 instrument.

Sample No.	SiO2	Al2O3	Fe2O3	MgO	MnO	CaO	TiO2	Na2O	K2O	Total,R
1-8-30J	76.19	10.77	3.17	0.06	0.17	0.09	0.19	2.93	6.43	100.00
1-8-34J	76.87	12.79	0.59	0.07	0.05	0.61	0.10	1.84	7.08	100.00
1-8-135JA (ma)	76.20	11.57	2.07	0.09	0.12	0.11	0.26	2.52	7.06	100.00
1-8-135JB (mi)	75.96	10.60	3.25	0.06	0.18	0.10	0.21	2.61	7.04	100.01
1-8-156JA (ma)	77.18	12.73	0.66	0.05	0.06	0.41	0.11	3.67	5.13	100.00
1-8-156JB (mi)	75.39	12.22	2.40	0.12	0.04	0.82	0.32	2.87	5.83	100.01
1-10-15JB	75.54	12.22	1.89	0.04	0.02	0.57	0.18	2.06	7.14	99.66
1-10-65J (ma)	72.25	15.03	1.15	0.15	0.20	0.48	0.12	3.27	7.34	99.99
1-10-65J (mi)	72.81	15.29	0.72	0.10	0.07	0.50	0.19	2.86	7.47	100.01
1-10-68J	75.81	12.12	1.89	0.04	0.03	0.57	0.19	2.21	7.14	100.00
1-10-77J (ma)	74.49	12.17	3.04	0.02	0.06	0.82	0.27	2.47	6.66	100.00
1-10-77J (mi)	75.91	12.33	2.94	0.02	0.08	0.78	0.28	1.64	6.01	99.99
1-12-5J	75.11	12.61	2.67	0.08	0.05	0.77	0.26	1.88	6.57	100.00
1-12-9J	74.50	12.52	2.61	0.08	0.04	0.72	0.25	2.54	6.74	100.00
1-36-3J	76.35	12.29	1.49	0.06	0.03	0.53	0.16	2.49	6.59	99.99
1-36-8J	76.27	12.22	1.92	0.04	0.04	0.58	0.16	1.81	6.96	100.00
1-36-9J	73.17	14.68	2.06	0.12	0.08	0.52	0.20	2.20	6.96	99.99
1-36-23J (ma)	76.66	12.27	1.95	0.04	0.05	0.58	0.19	1.70	6.56	100.00
1-36-23J (mi)	75.83	12.15	1.83	0.04	0.03	0.56	0.16	2.32	7.08	100.00
1-36-26J	73.26	14.97	2.13	0.13	0.11	0.51	0.21	2.50	6.18	100.00
1-36-35J	75.51	12.03	2.49	0.08	0.04	0.73	0.28	2.70	6.14	100.00
1-36-39J	75.89	12.82	2.12	0.08	0.04	0.64	0.25	1.75	6.40	99.99
1-36-57J	75.87	12.35	1.93	0.03	0.02	0.58	0.18	1.96	7.08	100.00
1-37-6J	75.40	12.39	2.46	0.13	0.04	0.90	0.34	3.20	5.14	100.00
1-37-26J	72.94	14.40	1.92	0.28	0.08	0.75	0.45	5.27	3.91	100.00
1-37-39JA (ma)	76.22	12.24	1.99	0.08	0.03	0.60	0.27	3.26	5.32	100.01
1-37-39JB (mi)	74.31	12.62	2.62	0.19	0.04	0.98	0.44	3.01	5.78	99.99
1-39-1JB	74.85	12.53	2.59	0.12	0.04	0.89	0.34	3.06	5.58	100.00
1-42-5JA (ma)	74.53	12.20	3.19	0.03	0.07	0.84	0.28	3.26	5.62	100.02
1-42-5JB (mi)	74.99	12.13	2.84	0.03	0.06	0.75	0.26	3.15	5.77	99.98
Homogenous glass standard, analyzed by the SEMQ (S) and JEOL (J) electron-microprobes										
RLS132(S)	75.37	11.26	2.12	0.06	0.16	0.11	0.19	4.88	4.42	100.00
±1 σ (n=18)	0.57	0.16	0.04	0.01	0.01	0.01	0.01	0.13	0.06	0.78
RLS132(J)	74.40	11.51	2.13	0.05	0.16	0.10	0.19	5.23	4.41	100.00
±1 σ (n=28)	0.34	0.10	0.06	0.004	0.01	0.01	0.01	0.13	0.04	0.48

Table 3. Summary of correlation and age of tephra in Middlegate area, based on major element analysis. Sample numbers in **bold** type are from this report. Unless otherwise indicated, the tephra are from eruptions in the Snake River Plain.

Unit Tml: Samples **1-8-30J**, **1-8-135JA**, and **1-8-135JB** (**1-8-135JA** is 3 m stratigaphically below **1-8-135JB**) are from Tml and have high alkali content (commenditic). Generically (but not specifically) related to Grouse Canyon Tuff and related tuffs of the Nevada Test Site in southern Nevada. These commenditic tuffs in the Nevada Test Site have ages of 13.95 and 14.2 Ma. These ages are younger than other ages for samples in unit Tml (see below) and may not indicate age of unit Tml.

Sample **1-12-9J** is an excellent match for to buf94-617 of Perkins and others, 1998) that has an extrapolation age of 15.21±0.05 Ma.

Sample **1-42-5JA** is 3 m below **1-42-5JB.** These two samples are chemically similar to each other, to **1-12-5J** in unit Tmu (see below), to buf94-617 of Perkins and others (1998) that has an extrapolation age of 15.21±0.25 Ma, and to vvy93-8 of Perkins and others (1998) that has an extrapolation date of 15.41±0.25 (Perkins and others, 1998).

Unit Tmu: Sample **1-36-39J** matches tephra from several units of different age, namely the Boswell datum (about 11.82 Ma), the Tuff of Ibex Hollow (11.93±0.03 Ma, Perkins and others, 1988); and Virgin Valley 12 (15.18, ±0.3 Ma). Other tephra in unit Tmu are about 15 Ma suggesting that the correlation of sample **1-36-39J** with the 15.18 Ma Virgin Valley 12 tuff is the most likely.

Sample **1-12-5J** is a close match to buf94-617 (Perkins and others (1998) that has an extrapolation age of 15.21±0.25 Ma (Perkins and others, 1998). Based on chemistry, may be same tephra as **1-12-9J**, which would indicate that part of unit Tml is the time equivalent of part of unit Tmu.

Sample **1-10-65J** has no close chemical match with other tephra. Sample **1-10-65J** may have had a source in southern Nevada.

Sample **1-10-77J**, chemically similar to 1-42--5JA and 5JB that are correlated with buf94-617 of Perkins and others (1998) that has an extrapolation age of 15.21±0.25 Ma, and with vvy93-8 of Perkins and others (1998) that has an extrapolation date of 15.41±0.25 (Perkins and others, 1998).

Unit Tmmrb: Samples **1-36-8J** and **1-36-23J** from unit Tmmrb, are chemically similar to, and probably the same tephra as samples **1-10-15JB** and **1-10-68J** from unit Tmmss, and **1-36-57J** from unit Tmmr. A single tephra layer is consistent with mapped relations that indicate that units Tmmr, Tmmrb, and Tmmss are in part lateral equivalents of one another. The tephra in Tmmr, Tmmrb, and Tmmss matches well with tephra layers from the Carlin Formation in northern Nevada that have ages of 14.43± 0.08 Ma (96TT129), 14.48±0.05 Ma (96TT132), 14.72 ±0.05 Ma (96TT133) (Fleck, R.J., Theodore, T.G., Sarna-Wojcicki, Andrei, and Meyer, C.E., written commun., 1998).

Samples **1-36-9J** and **1-36-26J** are chemical similar and probably the same tephra layer. They appear to be stratigraphically somewhat higher than the tephra in samples **1-36-8J**, but cannot be correlated with tephra outside of the study area.

Unit Tmmr: Sample **1-36-57J**, probably 14.43 to 14.72 Ma, see unit Tmmrb above.

Unit Tmmt: Sample **1-36-3J**, Very good matches with several samples collected by D.M. Miller from Toyano Mountains in northeastern Nevada (M90TM-140 and others) but with no direct, secure age contral. Closest match to a dated layer is to tc90-30 (13.25±0.50 Ma) and tc89-12 (24) 12.67 ±0.03 Ma) (Perkins and others, 1998).

Unit Tmmss: Samples **1-10-15JB** and **1-10-68J** are 15.21 to 15.41 Ma (see Tmmrb). Sample **1-36-35J** correlates with **2-96-38J** in the Cobble Cuesta area, which is correlated with tephra dated as 10.54 Ma (see table 1). This relatively young age of 10.54 Ma compared with the 15.21-15.41 Ma age of samples **1-10-15JB** and **1-10-68J** from the same map unit indicates that Tmmss has a large age range. Tmmss is relatively homogeneous lithologically and difficult to subdivide. It probably intertongues extensively with other strata ranging in age from about 10 to 15 Ma (Fig. 3).

Unit Tmmz: Sample **1-37-39JA** from middle of unit Tmmz and **1-37-39JB** from top part of unit Tmmz, or perhaps in basal part of unit Tmmts. Chemically similar to tephra layers in Carlin Formation in northern Nevada dated as 15.09±0.11 Ma (96TT153) (Fleck, R.J., Theodore, T.G., Sarna-Wojcicki, Andrei, and Meyer, C.E., written commun., 1998), but also similar to tephra layers associated with qe-6 from the Hazen area, western Nevada that have an age of about 9.79 Ma (Perkins and others, 1998). The 9.79 Ma age seems more likely because unit Tmmz appears to be relatively high in the stratigraphic section in the Middlegate area.

Unit **Tmmtr:** Sample **1-37-6J** is correlated with QA-9 (DK) at Hazen, Nevada which as conventional K-Ar age of about 9.79 Ma (Perkins and others, 1998).

Sample **1-37-26J** has a close match to vvy93-05 from Virgin Valley, northwest Nevada, but this tephra has an extrapolation age of 15.41±0.25 Ma to 15.54±0.25 Ma that does not match with the high position of **1-37-26J** in the stratigraphic section in the Middlegate area. We presume that sample **1-37-26J** is about 10 Ma.

Unit Tmmc: Sample **1-39-1JB** has a very good match with **1-37-6J** in unit Tmmtr in the Middlegate map area (this report), and **JS-92-66** and **2-96-46J** in the Cobble Questa map area (Stewart and Sarna-Wojcicki, 1998). **2-96-46J** in the Cobble Cuesta area is considered to be about 9.79 Ma. Similar to tuff of Mullin Creek in the Trapper Creek area, Idaho, that has an age of 8.84±0.03 Ma (Perkins and others, 1998), but this age seems too young compared with the 7.79 Ma date stated above.

Sample **1-8-34J** is similar to BE-249 and BE-25 (Eastwood, 1969) from the Aldrich Station Formation in western Nevada and dated about 11.4 to 10.8 or slightly younger. Also similar to **2379-5JB** in the Cobble Cuesta area which has a probable age of age of 11.51 Ma (Figure 5).

Sample **1-8-156JA** (about 6 m below **1-8-156JB**) has no correlatives within possible age range of unit. Source in southern Nevada.

Sample **1-8-156JB** is similar to several tuff units outside of the Middlegate area including TC-90-20 (47) in the Trapper Creek area, Idaho, that has an age of 10.02±0.03 Ma (Perkins and others, 1995) and to BE95 in the uppermost part of the Coal Valley Formation (about 10 to 12 Ma) in western Nevada, and qe-6 in the the Hazen area (9.79±0.13 Ma) (Perkins and others, 1998).

crudely estimated to be about 430 m thick in the central part of the area, but could be thicker in areas where it contains strata laterally equivalent to units Tmmcg, Tmmt, and Tmmr. Unit Tmmz is about 12 m thick, unit Tmmts is about 45 m thick, unit Tmmtr about 127 m thick, and unit Tmmsc is estimated to be at least 120 m thick. The depth to bedrock in the Middlegate area is about 4 km (Jachens and others, 1996), and a significant part of this thickness could be Miocene sedimentary rocks. If so, the total estimated thickness of units Tmmss, Tmmz, Tmmts, Tmmtr, and Tmmsc (534 m, from thickness listed above) is only a minor part of the total Miocene section. Units Tmmcg, Tmmt, Tmmr, Tmmrb, and Tmmcs crop out in the southern and eastern parts of the area. They are composed of conglomerate, sandstone, siltstone, and minor amounts of tuff and tuffaceous sandstone. Except for Tmmrb, clasts in the conglomerate from these units are of granule to pebble size (as large as 4 cm). Unit Tmmrb contains distinctly coarser conglomerate than other units in the southern or eastern part of the Middlegate area. About 20 percent of this unit is conglomerate which consists of subangular to subround clasts, mostly 10 to 30 cm in size, but locally as large as 1 m. The clasts are composed of rhyolite, welded tuff, and minor andesitic or dacitic rocks. A few megabreccia layers are present. They are composed of 10 cm to 10 m blocks of poorly consolidated sandstone and siltstone, and locally of rhyolite, welded tuff, and andesite or dacite. Unit Tmmcs is mapped only in the area west of the Eastgate Mine where it lies between the upper member of the Middlegate Formation, and below unit Tmmrb. It is composed mostly of sandstone and minor amounts of granule- and small-pebble conglomerate.

The Monarch Mill Formation, based on analysis of 17 tephra samples (Table 2, 3) ranges in age from 14.7 to 9.8 Ma., although some of the correlations on which this age span is based are uncertain (Table 3).

Paleocurrent directions

Strata suitable for paleocurrent studies are generally sparse in the Middlegate area, and only 10 studies of cross-strata and imbrication, and one study of soft sediment folds were made (Fig. 4). Two paleocurrent studies were made in the upper member of the Middlegate Formation. One of these is on fluvial cross-strata in a sandstone in the western part of the area (Fig. 4) and indicates flow toward the northwest. The other is on deltaic cross-strata in sandstone in the eastern part of the area and indicates a westerly flow. Soft sediment folds in the upper member of the Middlegate Formation in the southern part of the area (Fig. 4) indicate slumping toward the west northwest. Paleocurrent studies in unit Tmmc give a considerable spread of paleocurrent direction from east, southeast, southwest, and northwest (Fig. 4). The average direction of these studies is southerly which is consistent with the southward fining and interfingering of units Tmmc into Tmmsc, Tmmtr, Tmmts, Tmmz, and Tmmss. A paleocurrent study of imbrication in conglomerate of unit Tmmcs in the eastern part of the area did not produce a dominant paleocurrent direction (Fig. 4). Cross-strata in sandstone of unit Tmmr gives a bimodal result, but with the majority of measurements indicating a southwest flow. Studies of imbrication and channel trends in unit Tmmrb in the southern part of the area indicate a northwest flow.

Environments of deposition

The Miocene sedimentary rocks in the Middlegate area are composed of lacustrine, deltaic, fluvial, and landslide deposits. Fluvial deposits include fine-grained sandstone deposited far from source areas as well as coarse near-source alluvial-fan deposits.

The lower member of the Middlegate Formation contains mainly fluvial sedimentary deposts, perhaps derived mainly from local sources in the unconformably underlying Oligocene and Miocene volcanic rocks. The upper member, on the other hand, is of lacustrine origin. This environment is indicated by the abundance of diatoms and by the laminated character of the strata. Sparse cross-stratified sandstones in the upper member

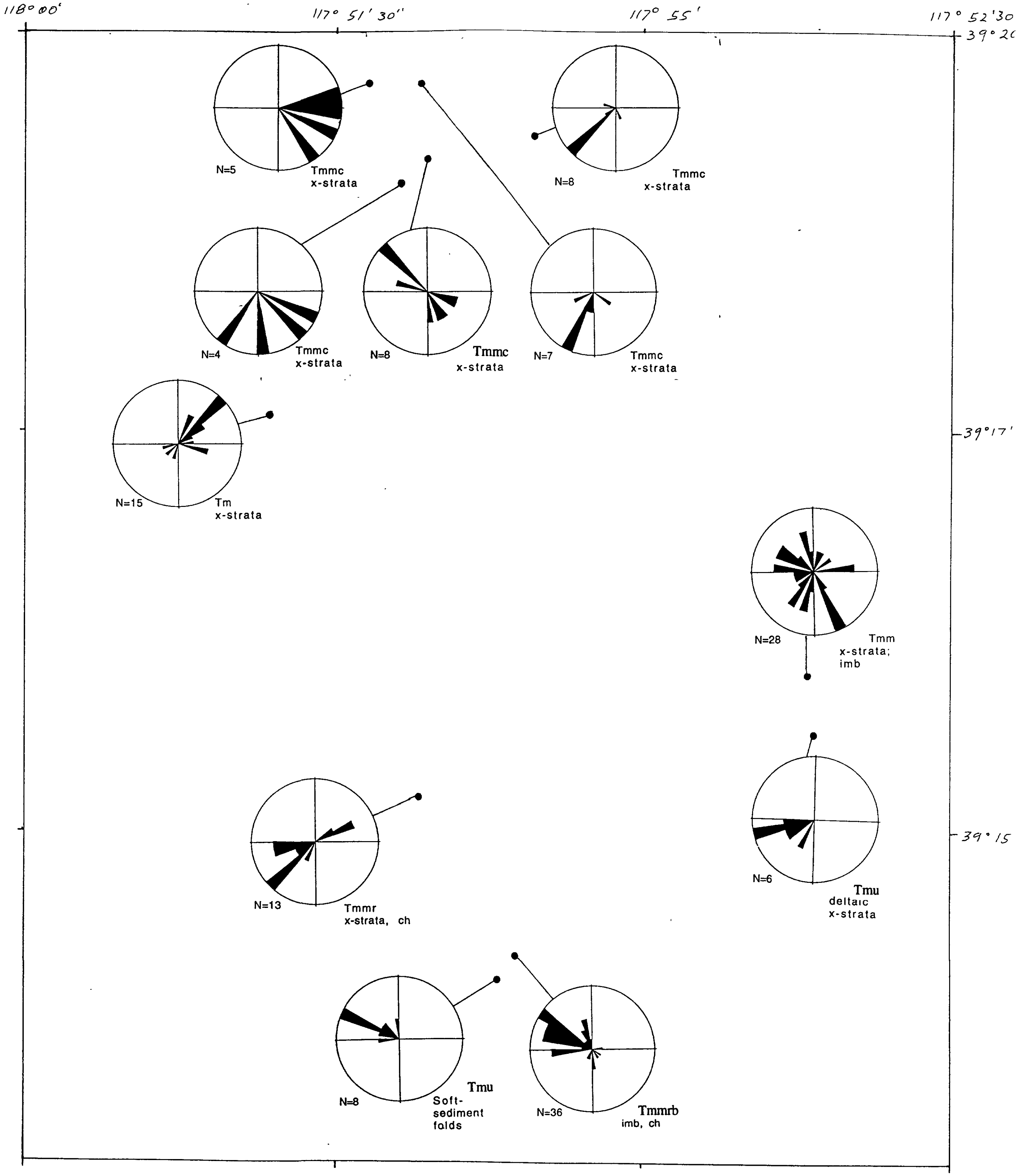

Figure 4. Rose diagrams showing paleocurrent information at localities in Middlegate area. Symbols: N, number of readings at locality; x-strata, paleocurrent data from cross-strata or trend of trough sets of cross-strata; imb, paleocurrent data from imbrication, downcurrent direction shown; soft-sediment folds, downslope direction shown (90 degrees from fold axis)

are probably of fluvial origin. Well defined foreset strata in the central part of sec. 11, T. 16 N., R. 16 E. indicate local deltaic systems. Megabreccia deposits in the Middlegate Formation are considered to be landslide deposits.

The Monarch Mill Formation is primarily a fluvial unit, although lacustrine strata are probably also present. Much of the formation is fine grained sandstone and probably deposited relatively far from source areas, but coarse near-source deposits comprise much of unit Tmmc in the northern part of the area and unit Tmmbr in the southern part of the area (Fig. 5). Unit Tmmc contains coarse cobble and boulder conglomerate and is considered to represent alluvial fan deposits entering the Miocene basin from the north. Unit Tmmrb is also a near-source alluvial-fan deposits that includes megabreccias presumed to have formed by landslides from nearby sources.

Ash-layers in both the Middlegate Formation and the Monarch Mill Formation indicate air-fall from distant sources, mostly from the Snake River Plain (Table 3).

Paleogeography and structural setting

The detrital material in the lower member of the Middlegate Formation is probably mostly fluvial in origin and derived from local sources. Sediment in the upper member was deposited in a lake with little fluvial input. This interpretation is based on the near absence of fluvial sandstone, and lack of coarse conglomerate in the upper member. On the other hand, the presence of megabreccia in the Middlegate Formation, interpreted to be landslide deposits, indicates significant local topographic relief. These megabreccia deposits are on the south and west side of outcrops of the Middlegate Formation indicating an area of relatively high relief to the west or southwest of these outcrops. The Miocene paleogeographic setting of the Middlegate Formation could be analogous to that of a caldera lake in which local landslide from the caldera walls produce coarse megabreccia deposits, but deposition in the lake took place in generally quiet water. However, the possible caldera described above for the Oligocene and Miocene tuffs in the southern part of the Clan Alpine Mountains appears to be too old to account for the lake in which the Middlegate Formation was deposited. In closeby regions, such tuffs generally range from 30 to 20 Ma (Barrows, 1971; McKee and Stewart, 1971) whereas the Middlegate Formation is approximately 15 Ma old. Conceivably, the 16.3 Ma rhyolite and dacite tuff and associated rhyolite and breccia near Middlegate could represent the margin of a caldera that was associated with the Middlegate Formation, although we think this is an unlikely possibility. More likely, the Middlegate Formation represents a part of a much larger lake deposit (including similar diatomaceous lake deposits in "Lower Buffalo Valley" 10 km east of the Middlegate area [Barrows, 1971; Perkins and other, 1998]) that locally received landslide detritus, perhaps mostly from fault-produced escarpments.

The Monarch Mill Formation represents a distinct change in the paleogeographic setting in the Middlegate area. It contains coarse near-source deposits that indicate local high relief, perhaps related to the development of faults and topographic relief that led to the present-day structural and topographic setting of the Middlegate area. This change occurred at about 14 Ma, based on ages obtained by tephrochronologic correlation (Table 3). Both units Tmmc and Tmmrb indicate local major source areas. Unit Tmmc, as described previously, is a major alluvial-fan system entering the Middlegate area from the north. This system apparently had a source in the Clan Alpine Mountains north of the map area and died out to the south in the Middlegate area. This alluvial-fan system is similar in some respects to present-day alluvial deposits that are being spread southward into the Middlegate area. Unit Tmmc, however, is faulted, dips as much as 20 degrees, and extends to the crest of the Clan Alpine Mountains within the map area. Thus, although it may be analogous to present-day drainage patterns it clearly has been tilted and faulted more than present-day deposits. Unit Tmmrb also indicates a local source area. This unit contains abundant coarse conglomerate with clasts as large as 1 m, and local megabreccia

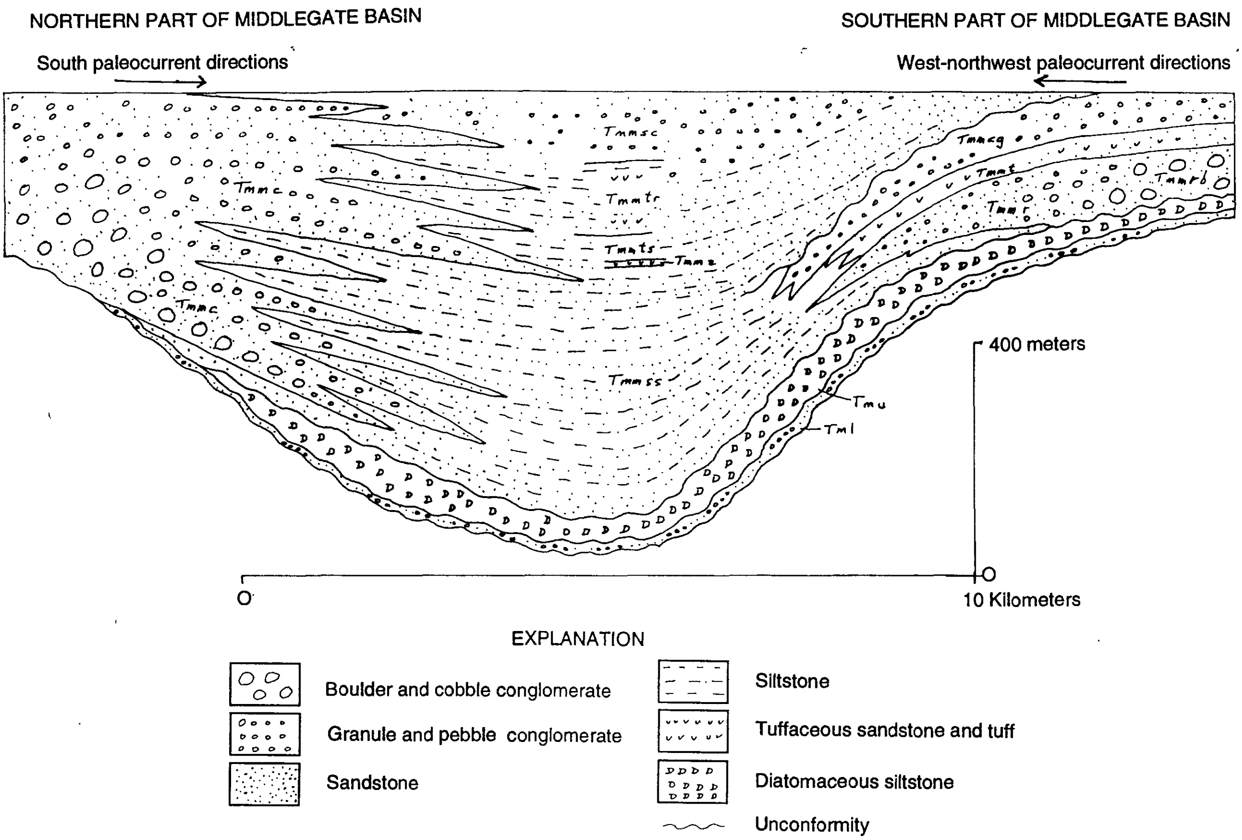

Figure 5. Interpretative diagram of stratigraphy of Middlegate basin

units. Paleocurrent directions in Tmmrb are to the northwest indicating a source area to the southeast. Conceivably, these near-source deposits indicate that the major south-southwest-trending fault in sec. 21, 22, and 23, T. 16 N., R. 36 E. was active and led to the high topographic relief and the alluvial-fan deposits of Tmmrb. Alternately, these coarse deposits were derived from the Buffalo Canyon area, 10 km east of outcrops of Tmmrb. Miocene(?) near-source, coarse, alluvial-fan deposits (member 5 of the Buffalo Canyon Formation of [Barrows (1971] in the Buffalo Canyon area lie along the west side of the present-day Desatoya Mountains. Imbrication studies in member 5 indicate west northwest paleocurrent directions, consistent with an interpretation that alluvial-fan deposits may have spread westward from the Desatoya Mountains into the Middlegate area.

Two major north to northeast-trending basin-and-range faults are present in the map area. One passes through Eastgate on the eastern side of the map area, and one passes through Middlegate in the western part of the map area. As discussed above, part of one of these faults (in sec. 21, 22, and 23, T. 16 N., R. 36 E.), may have been active and related to coarse detritus in unit Tmmrb, but elsewhere these major basin-and-range faults apparently have no relation to depositional patterns in the Middlegate and Monarch Mills Formations. In particular, the major fault that passes through Middlegate cuts parts of these formation. We interprete these major basin-and-range faults as young features that have overprinted the basin in which the Middlegate and Monarch Mill Formations were deposited.

REFERENCES CITED

Axelrod, D.I., 1956, Mio-Pliocene floras from west-central Nevada: Publications in Geological Sciences, University of California, v. 33, 321 p.

Axelrod, D.I., 1985, Miocene floras from the Middlegate basin, west-central Nevada: University of California Publications in Geological Sciences, v. 129, 279 p.

Axelrod, D.I., 1991, The early Miocene Buffalo Canyon flora of western Nevada: University of California Publications in Geological Sciences, v. 135, 76 p.

Barrows, K.J., 1971, Geology of the southern Desatoya Mountains, Churchill and Lander Counties, Nevada: Los Angeles, University of California, Ph.D. dissertation, 349 p.

Eastwood, W.C., 1969, Trace element correlation of Tertiary volcanic ashes from western Nevada: Berkeley, University of California, M.A. thesis, 89 p.

Evernden, J.F., and James, G.T., 1964, Potassium-argon dates and the Tertiary floras of North America: America Journal of Science, v. 262, p. 945-974.

Jachens, R.C., Moring, B.C., and Schruben, P.G., 1996, Thickness of Cenozoic deposits and the isostatic residual gravity over basement, in D.A. Singer, ed., An analysis of Nevada's metal-bearing mineral resources: Nevada Bureau of Mines and Geology, NBMG Open File Report 96-2, p. 2-1 to 2-10.

Perkins, M.E., Nash, W.P., Brown, F.H., and Fleck, R.J., 1995, Fallout tuffs of Trapper Creek, Idaho—A record of Miocene explosive volcanism in the Snake River Plain volcanic province: Geological Society of America Bulletin, v. 107, p. 1485-1506.

Perkins, M.E., Brown, F.H., Nash, W.P., McIntosh, William, and Williams, S.K., 1998, Sequence, age, and source of silicic fallout tuffs in middle to late Miocene basins of the northern Basin and Range province: Geological Society of America Bulletin v. 110, no. 3, p. 344-360.

McKee, Edwin H., and Stewart, J.H., 1971, Stratigraphy and Potassium-Argon ages of some Tertiary tuffs from Lander and Churchill Counties, central Nevada: U.S. Geological Survey Bulletin 1311-B, p.B1-B28.

Stewart, J.H., 1992, Paleogeography and tectonic setting of Miocene continental strata in the northern part of the Walker Lane Belt, *in* Craig, S.D., ed., Structure, tectonics, and mineralization of the Walker Lane, Walker Lane Symposium, Proceedings Volume: Reno, Nevada, Geological Society of Nevada, p. 1-16.

Stewart, J.H.and Perkins, M.E., 1999, Stratigraphy, tephrochronology, and structure of part of the Miocene Truckee Formation in the Trinity Range-Hot Springs Mountains area, Churchill County, west-central: U.S. Geological Survey Open File Report 99-330, 17 p.

Stewart, J.H., Sarna-Wojcicki, A.M., Meyer, C.A., and Wan, Elmira, 1999, Stratigraphy, tephrochronology, and structural setting of Miocene sedimentary rocks in the Cobble Cuesta area, west-central Nevada: U.S. Geological Survey Open File Report 99-352, 17 p.

Willden, Ronald, and Speed, R.C., 1974, Geology and mineral deposits of Churchill County Nevada: Nevada Bureau of Mines and Geology Bulletin 83, 95 p.