Text to accompany Nevada Bureau of Mines and Geology Map 163

GEOLOGIC MAP OF THE HUNTSMAN RANCH 7.5' QUADRANGLE, ELKO COUNTY, NEVADA

by

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INTRODUCTION

The Huntsman Ranch quadrangle is 3 kilometers northeast of the town of Carlin in western Elko County (Fig. 1). The quadrangle is in the middle of a topographic lowland that is flanked by the Adobe Range to the east, Swales Mountain to the north, Marys Mountain to the west, and the Piñon Range to the south. Perennial Susie Creek and ephemeral Dry Susie Creek and Dry Gulch flow southward through the quadrangle, and all drainages feed into the Humboldt River just south of the quadrangle border; perennial Maggie Creek flows southeast to the river through the southwest corner of the quadrangle.

The Overland Trail, used by tens of thousands of pioneers in the mid 1800s, followed the Humboldt River. A spur of the trail over the southern Adobe Range—the Greenhorn Cutoff—was used by some wagon trains to avoid the narrow Carlin Canyon along the river just southeast of the quadrangle. This spur traversed the southeastern part of the quadrangle, passed the hot springs shown in section 8 between Susie and Dry Susie Creeks, and descended along Susie Creek back to the river.

The quadrangle also lies along the eastern edge of the northwest-trending Carlin gold trend, from which more than 50 million ounces of gold have been produced (Thompson and others, 2002). The Gold Quarry mine, which exploits one of the largest gold deposits along the trend, is 8 km west of the quadrangle (Fig. 1).

The middle Miocene sedimentary rocks that are exposed throughout much of the quadrangle are the remnants of a broader Neogene sedimentary basin—here called the Carlin basin—that once covered the Gold Quarry deposit and other parts of the Carlin trend. Miocene sediments deposited in adjacent Miocene basins also host significant Miocene epithermal gold-mercury deposits in northern Nevada, the closest of which are in the Ivanhoe district, 50 km northwest of the quadrangle (Wallace, 2003).

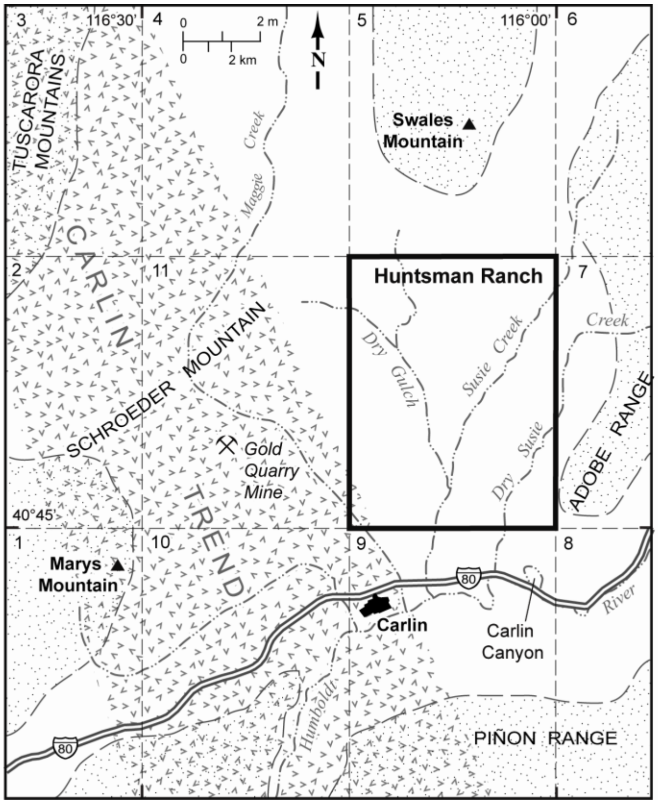

Figure 1. Location of the Huntsman Ranch 7.5-minute quadrangle (solid rectangle), surrounding 7.5-minute quadrangles, and geographic features mentioned in the text. Stippled areas are the approximate outlines of interpreted middle Miocene highlands that shed debris into the Carlin basin, which is shown as white across much of the map. Schroeder Mountain is a topographic high, cored by Paleozoic sedimentary rocks, that formed after Miocene sedimentation. V pattern shows the approximate location of the Carlin gold trend through the Carlin basin area. Geologic maps of the surrounding quadrangles: 1, Emigrant Pass (Henry and Faulds, 1999); 2, Welches Canyon and 3, Rodeo Creek NE (Evans, 1980); 4, Swales Mountain SW (unmapped); 5, Swales Mountain and 6, Adobe Summit (Evans and Ketner, 1971); 7, Hunter (Ketner, 1973); 8, Grindstone Mtn., 9, Carlin East, and 10, Carlin West (Smith and Ketner, 1978); 11, Schroeder Mtn. (Evans and Cress, 1972).

Studies of the Carlin basin and the Huntsman Ranch quadrangle were initiated to expand regional studies of the late Cenozoic paleogeographic evolution of the region (Wallace and others, 2004, 2008; Wallace, 2005), including the roles of the basins in the formation of epithermal Au-Ag-Hg deposits and the processes that took place after the formation of the late Eocene gold deposits along the Carlin trend. In addition, the Miocene sedimentary rocks form one of the aquifers affected by dewatering at the Gold Quarry open-pit mine, and evaluation of the effects of the sedimentary facies and faults on ground-water compartmentalization in that aquifer became an outgrowth of the basin studies (Wallace, 2005).

The Huntsman Ranch quadrangle and the Miocene sedimentary rocks of the Carlin basin have received little attention. This was due in part to the general absence of exposures of the Eocene and Paleozoic rocks that were related to or host major gold deposits in adjacent areas, and in part to the generally non-economic nature of the Miocene units. Regnier (1960) provided the first geologic descriptions of the area in his study of the Cenozoic geology of the Carlin area. Subsequent to Regnier's studies, the geology of the surrounding quadrangles was published in a series of 7.5-minute quadrangle maps; these included, clockwise from the southwest: Emigrant Pass (Henry and Faulds, 1999), Schroeder Mtn. (Evans and Cress, 1972), Swales Mountain and part of the Adobe Summit quadrangle (Evans and Ketner, 1971), and Hunter (Ketner, 1973) (Fig. 1). In addition, Smith and Ketner (1976, 1978) mapped the geology of the Piñon Range area, the northern part of which includes the south end of the Carlin basin. These mapping efforts focused principally on the Eocene and older geologic units and features, and stratigraphic and structural details of the post-Eocene units generally were not provided. Plume (1995) studied the hydrology of the Carlin basin as it related to dewatering at the Gold Quarry mine, and Harlan and others (2002) provided some local detail on the late Cenozoic geology in the vicinity of the Gold Quarry deposit. Overall, however, little was known about the Miocene and younger geologic history of the Carlin basin before the present study.

As a supplement to the map-unit descriptions, this text insert discusses the Miocene sedimentology in the Huntsman Ranch quadrangle and adjacent areas, as well as the paleogeographic evolution of the basin. All data and observations from this and adjacent quadrangles are based on this study except as cited otherwise.

PRE-MIOCENE GEOLOGY

The extensive exposures of Miocene rocks conceal most of the pre-Miocene geology of the quadrangle. On the basis of exposures in this and surrounding quadrangles, Paleozoic sedimentary rocks, with a discontinuous cover of late Eocene rocks, underlie the Miocene sedimentary rocks. Paleozoic units exposed in this quadrangle include the Ordovician Vinini Formation (Ov), which is part of the upper plate of the Roberts Mountains allochthon (Roberts and others, 1958), and the Mississippian Webb Formation (Mw) and undivided Permian and Pennsylvanian carbonate and clastic sedimentary rocks (PPsu), which depositionally overlie the allochthon ("overlap" rocks). Additional post-allochthon units, including the Mississippian Tonka and Melandco Formations and the Pennsylvanian Moleen and Strathearn Formations, are exposed a few kilometers southeast of the quadrangle (Ketner, 1973; Smith and Ketner, 1976; Trexler and others, 2003), and they may be present beneath the southeastern part of the quadrangle. In the Gold Quarry area 8 km west of the quadrangle, rocks of the Roberts Mountains allochthon structurally overlie lower Paleozoic carbonate rocks of the lower plate (Evans and Cress, 1972; Evans, 1980). These lower-plate rocks likely are present beneath the upper-plate and overlap rocks in the quadrangle, although at an unknown depth.

Very limited exposures of early Tertiary rocks in the quadrangle include late Eocene rhyodacite to rhyolite flows and tuffs. These units are similar to and locally continuous with units exposed in the Swales Mountain area to the north (Evans and Ketner, 1971) and the southern Adobe Range to the east (Ketner, 1973; this study). However, they are absent in several locations both within and near the quadrangle where Miocene sediments were deposited directly on Paleozoic rocks. In the northeastern part of the quadrangle, a feldspathic sandstone underlies Eocene tuffs in a small area. The sandstone contains sparse, small, altered pumice or ash grains and thus is not a pre-Tertiary unit, such as the Silurian Elder Formation. The unit may be in part related to the Eocene Elko Formation, a largely pre-volcanic clastic sedimentary unit that is exposed in nearby areas. Haynes (2003) described very sparse (less than 1 percent) volcanic material in the Elko Formation, similar to this unit.

The Elko County geologic map (Coats, 1987) shows middle Tertiary andesite rocks exposed in a small area west of Susie Creek and north of the Huntsman Ranch site in this quadrangle and in extensive areas to the northeast and east. The state geologic map (Stewart and Carlson, 1978) shows the same units but designates them as Miocene. The present study shows that those areas previously mapped as andesite in this quadrangle actually are gravel deposits (QTg) that cap a terrace surface. The Eocene rhyodacite flow units that *are* exposed in the northeastern corner of the quadrangle are not shown on the other geologic maps, and they are continuous with the Eocene "andesite" flows in the Adobe Summit quadrangle (Coats, 1987).

The area of the Carlin basin was part of a V-shaped (plan view), late Eocene paleotopographic high that extended northwest from the northern Piñon Range through the southern Tuscarora Mountains and bifurcated to the northeast along the Adobe Range (Haynes, 2003). Although Haynes' paleogeographic reconstructions are generalized at a small scale, it appears that the area of this quadrangle was topographically high in the late Eocene. This would explain the apparent absence of the Elko Formation, which was deposited on the flanks of and in basins between the Eocene highlands (Haynes, 2003).

In the few areas where early Tertiary rocks are exposed beneath the Miocene sedimentary rocks in and near the Huntsman Ranch quadrangle, the early Tertiary rocks dip more steeply than the Miocene sedimentary rocks. In the northeastern part of the quadrangle, the difference in dip ranges from 5º to 17º, and similar to slightly greater differences were measured in the southern Swales Mountain and western Hunter quadrangles. To the west in the Emigrant Pass quadrangle (Henry and Faulds, 1999), dip differences average about 18º. There, pre-Miocene north-striking normal faults tilted the Eocene rocks and one overlying 25-Ma tuff to the east prior to Miocene sedimentation, with some post-sedimentation fault reactivation. Similar pre-Miocene faults have not been found in or near the Huntsman Ranch quadrangle. However, the extensive Miocene rocks could conceal any older faults, and some of the many faults that cut Miocene sediments could be reactivated older faults.

Additional data indicate that at least some of the tilting appears to have occurred in the late Oligocene to early Miocene. Thermochronologic data along the Carlin trend (Fig. 1) suggest Oligocene to early Miocene uplift and denudation (Tosdal and others, 2003), and alunite dates from the trend indicate supergene weathering during the same period of time (summarized in Wallace and others, 2008). Local red-colored regoliths in Paleozoic rocks beneath Miocene sedimentary rocks in this quadrangle may have formed then as well. Some clasts in the basal Humboldt Formation sediments were derived from late Eocene plutons in the Swales Mountain and southern Tuscarora Mountains areas. Although the depth of emplacement of these plutons is unknown, they had been uplifted and exposed by the beginning of sedimentation in the Carlin basin shortly before 16.3 Ma.

MIOCENE GEOLOGY

Miocene sedimentary units are exposed throughout most of the quadrangle. Epiclastic sediments and ash were deposited in fluvial and lacustrine environments from before 16.3 Ma until after 15.1 Ma, and minor andesite and rhyolite flows were erupted during sedimentation. Post-sedimentation normal faults have cut and gently tilted all of the sedimentary and volcanic units. The following text provides detailed descriptions of the units and interpretations of the sedimentary environments. Nearly complete stratigraphic sections are exposed just east of Susie Creek southeast of the Huntsman Ranch site and in section 11, and in areas to the north and west in the northwestern part of the quadrangle.

Nomenclature of Miocene Sedimentary Units

Sharp (1939) assigned the name Humboldt Formation to many of the Cenozoic rocks in the region, especially those west of the Ruby Mountains and East Humboldt Range near Elko. Subsequent work by others removed some units, such as the Eocene Elko Formation, from that formation (Van Houten, 1956), but the name Humboldt Formation was retained for the Miocene units.

Regnier (1960), in his study of the sedimentary rocks in the Carlin area, informally divided the sedimentary rocks in the Carlin basin into the near-source pyroclastic and volcaniclastic Raine Ranch formation and overlying fluvial and ash-rich Carlin formation. As the major Eocene gold deposits of the Carlin trend were discovered and mined since the early 1960s, numerous authors informally used the name Carlin formation to describe post-mineralization sedimentary rocks that were laterally continuous with or similar to Regnier’s Carlin formation. However, Smith and Ketner (1976), in their study of Cenozoic sedimentary rocks on the east and west sides of the Piñon Range south of Carlin, determined that the Regnier’s Carlin formation was equivalent to the Miocene Humboldt Formation in the type area east of the Piñon Range, and that the Raine Ranch formation was late Eocene to early Oligocene in age and thus unrelated to the Humboldt Formation.

Mapping for the present study within and beyond the Carlin basin (Wallace and others, 2004, 2008; Wallace, 2005) shows that the Miocene Carlin depositional basin extended beyond the limits of the modern basin and connected with the depositional system that produced the Humboldt Formation in its type area (Smith and Ketner, 1976). Therefore, the name Humboldt Formation is applied to the middle Miocene sedimentary rocks in this quadrangle, in keeping with the rationale described by Smith and Ketner (1976) and, in part, Sharp (1939).

Geochronology

Tephra correlations were obtained from ash-rich samples of the Humboldt Formation in the quadrangle and nearby areas, and ^{40}Ar/^{39}Ar dates were obtained on some of those samples. Two additional tephra samples were dated using ^{40}Ar/^{39}Ar methods but do not have tephra correlations. Dating of the andesite (Ta) and rhyolite (Trf) flow units in this quadrangle was attempted but not successful. The Palisade Canyon rhyolite, which is widely exposed in the western and southern parts of the basin and is exposed in a small area in this quadrangle, was dated by Armstrong (1970) and Henry and Faulds (1999). The very limited Eocene volcanic rocks in the quadrangle were not dated because of their direct correlations with dated units in the Swales Mountain area to the north (Henry and Ressel, 2000).

Samples for tephrochronology and isotopic dating were collected from three general areas in and immediately adjacent to the quadrangle: (1) the tephra-bearing upper two thirds of the Humboldt Formation north of Dry Gulch in the north-northwest part of the quadrangle (sections 1 and 2, Fig. 2); (2) along Susie Creek in the northeastern part of the quadrangle (section 3); and (3) from the Great White Hope diatomite mine a few hundred meters south of the quadrangle (section 4). The samples in the first area were collected from outcrops at the base of the epiclastic and ash-rich member (Thm) up through the top of the ash-rich member (Tha). Samples for the second area were collected from outcrops of the epiclastic and ash-rich member on both sides of Susie Creek near the Huntsman Ranch site, as well as from road cuts in the ash-rich member at the north edge of the quadrangle just north of Susie Creek. The third suite of samples was collected from the ash-rich member in open cuts and outcrops at and near the diatomite mines in the Carlin East quadrangle. The units sampled extend into the Huntsman Ranch quadrangle. M. Perkins collected several samples at the third area prior to this study, and those tephra correlations are shown in Figure 2 and Table 1 along with the new data.

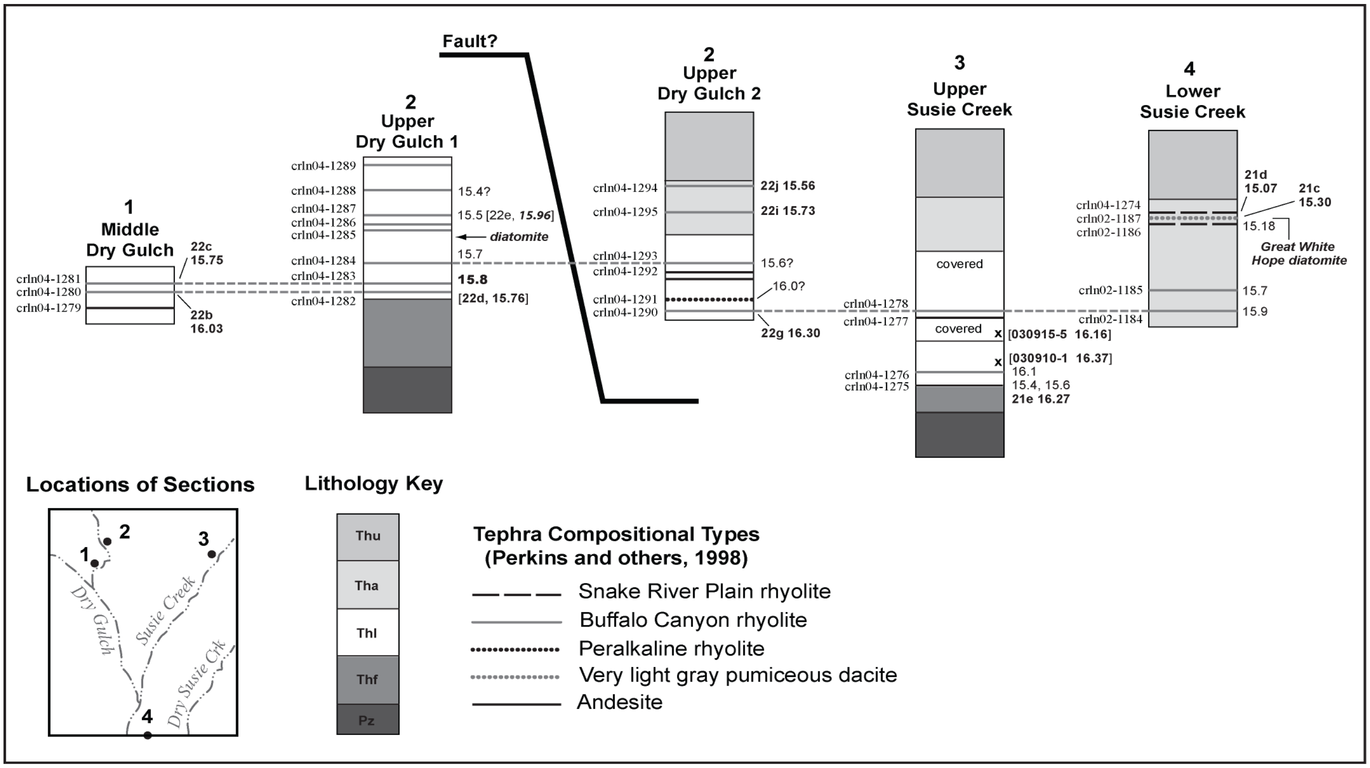

Figure 2. Schematic diagram showing tephra correlations and ^{40}Ar/^{39}Ar dates in the Carlin basin. Inset map of quadrangle shows general locations of sampling areas; those areas and specific locations are cited in Table 1 and shown on the geologic map. Tephra composition types are based on regional tephra sources and types discussed in Perkins and others (1998) and Perkins and Nash (2002). Stratigraphic symbols are those used on the geologic map. Thicknesses of units are schematic only.

Table 1. Tephra correlations and ^{40}Ar/^{39}Ar dates, Huntsman Ranch quadrangle.
[--, no sample or not determined; all ^{40}Ar/^{39}Ar dates calculated using 28.02 Ma FCT sanidine standard (Renne and others, 1998).]

Area (fig. 2)	Map site	^{40}Ar/^{39}Ar sample	Tephra sample	Map unit	Latitude	Longitude	^{40}Ar/^{39}Ar* date (Ma)	Tephra age (Ma)	Reference
3	1	049-21E	CLN04-1275	Thm	40°50.778	-116°1.096	16.28±0.04	~16.0	This study
3	1	--	CLN04-1276	Thm	40°50.778	-116°1.096	--	~16.0	This study
1	2	049-22C	CLN04-1281	Thm	40°50.616	-116°5.713	15.75±0.03	~15.9	This study
1	3	049-22B	CLN04-1280	Thm	40°50.604	-116°5.724	16.03±0.05	--	This study
1	4	--	CLN04-1279	Thm	40°50.572	-116°5.767	--	--	This study
2	5	049-22D	CLN04-1282	Thm	40°51.808	-116°5.657	15.76±0.02	~15.9	This study
2	5	--	CLN04-1283	Thm	40°51.808	-116°5.657	--	~15.9	This study
2	6	--	CLN04-1284	Thm	40°51.706	-116°5.679	--	15.94	This study
2	7	049-22E	CLN04-1287	Thm	40°51.612	-116°5.66	15.92±0.08	15.7	This study
2	7	--	CLN04-1288, 89	Thm	40°51.612	-116°5.66	--	--	This study
2	8	--	CLN04-1291	Thm	40°51.392	-116°5.329	--	16.0	This study
2	9	049-22G	CLN04-1290	Thm	40°51.392	-116°5.309	16.31±0.25	15.92	This study
2	10	--	CLN04-1293	Thm	40°51.353	-116°5.236	--	15.94	This study
4	11	049-21D	CLN04-1274	Thu	40°44.887	-116°3.548	15.17±0.03	~15.3	This study
4	11	049-21C	CRLN02-1187	Thu	40°44.888	-116°3.547	15.2±0.03	--	This study
4	11	--	CRLN02-1186	Thu	40°44.895	-116°03.475	--	15.28	Perkins, unpubl. data, 2002
4	12	--	CRLN02-1184	Thu	40°44.978	-116°03.659	--	~16.0	Perkins, unpubl. data, 2002
4	12	--	CRLN02-1185	Thu	40°44.978	-116°03.659	--	~15.8	Perkins, unpubl. data, 2002
3	13	--	CLN04-1277	Tha	40°52.382	-116°0.52	--	~15.5	This study
3	13	--	CLN04-1278	Tha	40°52.382	-116°0.52	--	~15.5	This study
2	14	049-22I	CLN04-1295	Tha	40°51.278	-116°5.135	15.73±0.06	16.1-15.5	This study
2	15	049-22J	CLN04-1294	Tha	40°51.33	-116°5.127	15.56±0.05	--	This study
3	16	030910-1	--	Thm	40°49.824	-116°02.439	16.38±0.1	--	This study
3	17	030915-5	--	Tha	40°49.857	-116°00.926	16.16±0.03	--	This study
--	--	--	--	(Trf)**	40°37.34	-116°11.20	15.26±0.03	--	Wallace and others (2008)
--	--	--	--	(Trf)**	40°42.7	-116°16.1	15.32±0.04	--	Henry and Faulds (1999)
--	--	--	--	(Trf)**	40°36.92	-116°11.83	15.4±1.0***	--	Armstrong (1970)

* Sample 049-21E dated using incremental step heating on plagioclase. All other ^{40}Ar/^{39}Ar dates were single-crystal analyses of multiple sanidine crystals.

** Palisade Canyon rhyolite (rhyolite of Marys Mountain in Henry and Faulds, 1999).

*** K/Ar whole-rock date; recalculated from published 15.0±1.0 Ma date.

Sample locations within the quadrangle are shown on the geologic map and in Figure 2. Table 1 provides sample location and geochronologic data. ^{40}Ar/^{39}Ar dates were obtained on single-crystal analyses of multiple sanidine crystals from the same sample, and dates and uncertainties are the weighted mean of multiple analyses. Sample 049-21E was dated using incremental step heating on plagioclase. Tephra correlations were determined using the chemical and petrologic methods described in Perkins and others (1998). All published and new ^{40}Ar/^{39}Ar dates reported here were calculated using the 28.02 Ma standard for Fish Canyon Tuff sanidine (Renne and others, 1998).

Miocene Sedimentology

The two principal middle Miocene depositional environments in the Huntsman Ranch quadrangle were fluvial and lacustrine. During mapping of the quadrangle, the sedimentary units that formed in these environments were divided into four members on the basis of the dominant depositional facies. These members include: a lower epiclastic member (Thl) that was deposited predominantly in a fluvial to alluvial environment; an ash-rich member (Tha) that was deposited in a lacustrine environment; a member that contains a mixture of epiclastic and ash-rich units (Thm) and was deposited in a mixed fluvial and lacustrine environment; and an upper epiclastic unit (Thu) that was deposited in a fluvial to alluvial environment. The thickness of each member varies considerably with location, and not all members are present in all places. The general stratigraphic relations of the four members are shown in the figure on the geologic map.

The two principal components of the sediments are ash and pumice that were derived from far-distant to, less commonly, relatively more local eruptions, and materials that were eroded from pre-Miocene bedrock exposures in uplands that surrounded the Carlin basin. The bedrock-derived materials generically are referred to as epiclastic sediments to highlight their more local, bedrock derivation in comparison to the air-fall materials. Air-fall deposits that landed on the uplands were redistributed during erosion and stream transport and intermixed with epiclastic materials at the depositional sites. Both sediment components were deposited in the fluvial and lacustrine environments, and the distinctions between air-fall and bedrock-derived sediments in the strata are described in the text.

Lower epiclastic member (Thl)

The lower epiclastic member is exposed in the northwestern and northeastern parts of the quadrangle and along the upper parts of Susie Creek south of the Huntsman Ranch site. The absence of beds composed entirely of fine-grained silver ash was used in the field to distinguish this member from the overlying mixed epiclastic and ash member (Thm). Dates from the overlying mixed epiclastic and ash-rich member (Thm) indicate that deposition of the sediments in the northwestern area began before about 16.3 Ma, but the age of initial sedimentation is unknown due to the lack of datable material.

In the northwestern part of the quadrangle, the member is composed of pebble conglomerate, pebble- to cobble-bearing sandstones, and sandstone; boulders up to a meter in diameter are abundant in some beds. Lithologies of the clasts are identical to various Paleozoic sedimentary and Tertiary volcanic rocks exposed in the southern Tuscarora Mountains to the west and Swales Mountain to the north. The sand component is dominantly epiclastic but contains variable amounts of reworked ash and small pumice.

The beds and sedimentary structures in this area are not well exposed. As exposed, the dominant bedform is structureless sand with minor to abundant amounts of matrix-supported (“floating”) small pebbles, cobbles, and, to a lesser extent, boulders up to a meter in diameter. The sandy matrix weathers readily, resulting in a residual surface lag of clasts that commonly gives the impression that the source rocks had more clasts than they originally contained. Most of the clasts, regardless of size, are subangular to subrounded; some beds contain small, angular pieces of Paleozoic siltstone. Where structures can be seen, they include pebble- and cobble-filled channels cut into the clast-bearing sandstone, clast-supported gravel lenses and layers within sandstone, and normal graded bedding. Beds that contain these features closely resemble channel and overbank deposits exposed along the incised banks of modern Susie Creek. Some beds are composed entirely of clast-supported pebble to cobble conglomerate. Beds vary from less than a meter to several meters in thickness, and contacts between beds are poorly to rarely exposed. Other exposures show multiple, 5–10-cm-thick beds of small, well-sorted, platy pebbles of Paleozoic siltstone; imbrication is strong in these beds and indicates a southeasterly transport direction. Imbrications in other clast-supported conglomerate beds are less common, but, where present, indicate a similar transport direction.

Dark, medium-grained, reworked pumice is abundant in some beds and locally comprises the entire bed. Some coarse sand bodies in both this member and the overlying mixed epiclastic and ash member (Thm) are composed of a basal tan, coarse sand that grades up into an upper black, reworked pumice. Multiple, stacked beds of these bicolored sedimentary rocks are exposed in some areas. The gradational contact between tan and black materials suggests that both epiclastic sand and pumice were transported in the same flow regime, and that the relatively more buoyant pumice was deposited after the denser epiclastic components. Faint cross-bedding is evident in some of these exposures. Microprobe analyses indicate that the pumice composition is basalt to basaltic andesite (M. Perkins, unpubl. data, 2005). The coarseness of the pumice, compared with the fine-grained, far-source ash that is common in the ash-rich member (Perkins and Nash, 2002), suggests a relatively more proximal source for this pumice. The general ages of these pumiceous beds range from about >16.3 to 15.7 Ma, on the basis of ages of enclosing ash beds. These ages are the same as those of early mafic eruptions along the northern Nevada rift, 60 km to the west (John and others, 2000), suggesting that the mafic pumice in the Carlin basin may have been derived from those eruptions.

The lower epiclastic member in the northeasternmost part of the quadrangle overlies Paleozoic sedimentary and

Eocene volcanic rocks, and it is very poorly exposed. Areas underlain by these beds typically have weak outcrops of brown sand with variable amounts of matrix-supported clasts. The pebble- to cobble-sized clasts are subangular to subrounded, and their lithologies indicate a provenance to the north in the Swales Mountain area. These beds extend discontinuously to the north-northeast into the southern Independence Valley.

The conglomerate along Susie Creek is best exposed in two areas: a thick sequence that is exposed east of Susie Creek just east of the center of the quadrangle, and a thin, laterally restricted package that is exposed farther north on both sides of Susie Creek near the Huntsman Ranch site.

The southern sequence is more than 200 m thick and composed of alternating beds of thick packages of 0.5–3-m-thick, sheet-like and laterally continuous beds of coarse conglomerate zones and poorly exposed, ash- and cobble-rich sandstone that form thick intervals between the conglomerate packages. At a distance, broad, shallow cross-bedding and channels are evident in the conglomerate sequence. At the outcrop scale, individual conglomerate beds show normal graded bedding from clast-supported conglomerate upward into pebble-bearing sandstone. Cut-and-fill and channel structures are common at that scale. The matrix in the conglomerate beds is tan, epiclastic sand with little ash, whereas the matrix in the poorly exposed intervening zones contains considerable amounts of white ash. The top of the combined section grades upward into fine-grained beds of the ash-rich member (Tha).

Clasts in the conglomerate are subangular to subrounded, 5–100 cm in diameter, and clast- to matrix-supported with relatively smaller amounts of matrix. They are composed of Eocene rhyolite porphyry and monzonite and Paleozoic sandstone, argillite, limestone, and chert identical to units exposed in the Swales Mountain area to the north. The absence of clasts derived from the Mississippian Melandco Formation exposed only in the Adobe Range to the east (Ketner, 1973; Trexler and others, 2003) indicates that area was not a source for these conglomerate beds. Strong clast imbrications indicate a general southwesterly flow direction, with variations to the northwest and south.

The conglomerate-rich zone thins to the northeast into a kilometer-wide, 20-m-thick conglomerate horizon that is exposed on the hillsides on both the eastern and western sides of Susie Creek. Tephra beds that overlie these beds were dated at 16.0 to 16.2 Ma (Fig. 2, Table 1). The zone is within finer-grained, ash-rich and epiclastic beds of member Thm, and the beds pinch out laterally, away from Susie Creek, into these units. Distinctive strata directly overlie the conglomerate beds in both areas, indicating that the conglomerate zone was continuous across the Susie Creek drainage prior to incision of the creek.

The conglomerate beds in this zone are similar to those exposed to the south, although they contain more sand-rich beds than clast-rich beds. Individual beds are a few to more than 10 cm thick. Pebble- and cobble-rich conglomerate grades up into sandstone, and, although most beds are planar overall, cut-and-fill structures are common. Clast lithologies and imbrications, like those to the south, indicate a provenance to the north and a general southerly to southwesterly flow direction, similar to modern Susie Creek. If the original, uneroded beds represented a stream channel with an axis along Susie Creek, then the presently exposed beds would have been the margins of that channel, perhaps explaining the greater abundance of sand.

The coarse conglomerates along Susie Creek were included in the lower epiclastic member for the sake of field differentiation and due to their similarity to conglomerates in the lower member (Thl) to the northwest. The beds exposed near the Huntsman Ranch site are within the mixed member (Thm) and stratigraphically somewhat higher than Thl beds exposed to the north, as decribed above. The northern end of the southern, much thicker exposures contains alternating zones of conglomerate and finer-grained, ash-and-sand Thm-like materials. Farther south, within the main mapped body of the conglomerate (such as the NE1/4 of sec. 32), the ash-rich conglomerates, which were not mapped separately, may be lateral equivalents of the finer-grained zones but with greater amounts of coarse clasts. The base of the southern conglomerate sequence is not exposed. The overall field relations suggest that the conglomerate thickens to the south, that the combined conglomerate and Thm section to the north is time transgressive with the thick conglomerate sequence to the south, and that the base of the southern sequence may be time equivalent to Thl exposed to the north. These overall relations appear to indicate that the sediments were deposited in a south-flowing stream that sourced in the Swales Mountain area and flowed into a paleovalley or perhaps a submerged slope environment that permitted the accumulation of the thicker sequence of sediments.

The sedimentary features in the lower epiclastic member suggest deposition largely in an alluvial fan to fluvial environment. The structureless sandstones with variable amounts of matrix-supported pebbles to boulders resemble sediment-supported debris or density flows (Gani, 2004). The temperate climate (Axelrod, 1956), coupled with deposition of ash in the source areas, may have triggered some of these flows. The interbedded pebble to cobble conglomerates with imbricate clasts, along with gravel-rich interbeds and lenses in the sandstones, are similar to sediments deposited in and adjacent to stream channels, including modern streams in this quadrangle. Some of the debris flows may have been deposited as subaqueous debrites and densites (Gani, 2004), although the complexly interbedded fluvial-like conglomerate beds in some locations would argue against that interpretation. In nearby areas west and northwest of the quadrangle, cobbles and boulders entrained in an ash- and pumice-rich matrix suggest that sudden deposition of abundant air-fall materials on source highlands may have triggered some density flows. The conglomerates along Susie Creek appear to have been deposited in a broad stream system that carried coarse sediments through a lower-energy setting typified by flanking marsh and overbank environments. The sedimentation rate for the member as a whole likely was episodic.

The distribution of the lower epiclastic member, as well as clast provenance and imbrications, show that early alluvial and fluvial systems flowed into the northwestern part of the quadrangle from the southern Tuscarora Mountains to the northwest and Swales Mountain to the north, and into the northeastern part of the quadrangle from the Swales Mountain area. These two regimes may have merged in the central part of the quadrangle and flowed to the south.

Mixed epiclastic and ash-rich member *(Thm)*

Fluvial and lacustrine environments shifted in both space and time to produce a sedimentary sequence—the mixed epiclastic and ash-rich member (Thm)—that is composed of alternating beds of each facies. This member is stratigraphically between the lower epiclastic and ash-rich members (see figure on correlation of map units on map) and accumulated between about 16.3 and 15.7 Ma. The percentage of each facies varies with location, and some sections are largely fluvial and others are largely lacustrine. A few outcrops of foreset beds in epiclastic units suggest some epiclastic sedimentation in deltaic environments, but the generally poor exposures obscure most sedimentary structures. Sand is the dominant clastic grain size, and conglomerates are uncommon and finer-grained relative to the underlying fluvial member, indicating a lower-energy depositional environment for these epiclastic sediments than those in the lower epiclastic member. The sedimentary environment at any point in time likely was laterally extremely variable, and those environments changed through time as the depositional setting responded to varying lacustrine and fluvial conditions. Eventually, though, the lake expanded over the fluvial environment to form the ash-rich member. The sedimentation rate for this member at any one place must have varied considerably depending upon the dominant depositional environment.

Ash-rich member *(Tha)*

The ash-rich member is composed largely of abundant thin- and evenly bedded ash beds, with minor beds of limestone, sandstone, and small-pebble conglomerate. The ash was derived from distant eruptions, largely to the northwest and north along the track of the Yellowstone mantle plume (Perkins and Nash, 2002). A meter of section commonly contains multiple, in places a dozen or more, air-fall units interbedded with more locally derived sediments. Ash grains in these units are oriented with their long axis parallel to bedding, a likely product of settling through water, which imparts a bedding-parallel fabric to the rocks. These primary fabrics commonly are undisturbed and imply little or no reworking after deposition. However, many ash beds are more than a meter thick and structureless, and they likely are reworked to some degree. Wind ripple marks, eolian cross bedding, mud cracks, and thin clastic beds composed of quartz and feldspar phenocrysts attest to periodic exposure of the sediments with local fluvial reworking. Diatomite, described in more detail in the “Economic Geology” section, is abundant near the top of the member. The sedimentation rate for this member likely varied widely, with low rates of lacustrine sedimentation, periodic subaerial exposure, and instantaneous but episodic deposition of centimeters to a meter or more of air-fall ash. The lateral continuity of individual beds over the distance of a kilometer, and of sequences of strata over several kilometers, point to a widespread, low-relief sedimentary environment.

The ash-rich member was deposited between about 15.7 and 15.2 Ma and is conformably overlain by the upper epiclastic member (Thu). The contact with the underlying mixed epiclastic and ash-rich member (Thm) is gradational and somewhat arbitrarily defined by the general paucity of epiclastic sediments above that horizon. In the Dry Gulch area (section 2 on figure 2), the youngest tephra beneath the upper epiclastic member was deposited at about 15.6 Ma, and the diatomite zone, which typically is at the top of the member, is absent. In that area, either the transition into a fluvial environment began earlier than in other parts of the quadrangle, or a period of post-15.6 Ma erosion preceded deposition of the upper epiclastic member.

The ash-rich member is the basal unit of the Humboldt Formation in the southeastern part of the quadrangle and adjoining parts of the Hunter and Carlin East quadrangles, roughly east of a southwest-trending line extending between and beyond the 15–22 section border at the eastern edge of the quadrangle, to the middle of section 13 at the southern edge. Lacustrine sediments in this area were deposited directly on Eocene and Paleozoic rocks. Underlying and interbedded epiclastic sediments are not present or are fine grained, volumetrically insignificant, and, on the basis of their lateral continuity, deposited subaqueously. Beds near the top of this southeastern section were deposited at about 15.2 Ma (Table 1, Fig. 2). The ash-rich member continues laterally west of that line, where it overlies the lower epiclastic and mixed epiclastic and ash-rich members. The coarse conglomerate beds along Susie Creek, described above, were deposited just west of and parallel to this line. As such, this southeastern area likely was a topographic bench that blocked early southeast- and south-flowing streams and directed streamflow to the southwest. The bench was not a site of sedimentation until later in the basin history, indicating that the base level of the lake shore rose during the basin’s history.

Upper epiclastic member *(Thu)*

The upper epiclastic member of the Humboldt Formation was deposited in an alluvial fan environment beginning at about 15.2 Ma in the southeastern part of the quadrangle and sometime after 15.6 Ma in the Dry Gulch area. Clast lithologies are similar to those in the lower epiclastic member and indicate similar source areas and transport directions. However, the Adobe Range, which did not shed sediments into the lower epiclastic member, did contribute significant amounts of sediments to the upper member in the eastern part of the quadrangle. This provenance indicates streamflow to the west from the Adobe Range during this late stage of basin sedimentation. All sediments become finer grained towards the southwestern part of the quadrangle.

The member is composed of alternating sandstone and conglomerate beds, and many sandstone beds contain matrix-supported (“floating”) subangular pebbles. The sand is massive and contains abundant rhyzoliths and some burrows that indicate bioturbation. The beds resemble overbank deposits along modern streams, such as those in this quadrangle. Weak soil horizons, identified by their lighter color, increased carbonate cement, and upward termination of burrows and rhyzoliths, are common in some exposures, and desiccation cracks in thin mud zones at the tops of some beds indicate periods of subaerial exposure prior to the deposition of additional sediments.

The upper member typically is reddish and commonly calcareous. Thin sections show an early hematitic coating on sand grains, with later calcite cement in the remaining pore spaces. One bed in section 18 at the southeastern edge of the quadrangle, just west of the diatomite mines, is composed of clasts of the Webb Formation, has a deep maroon color, and resembles the Eocene Elko Formation (see Smith and Ketner, 1976). However, this bed is conformably within the upper member and possibly derived its intense color from source-area rocks, such as the red regolith found locally at the top of the Webb Formation. Similar red conglomerate beds in the Humboldt Formation that were derived from red-colored Melandco Formation source rocks are exposed west and southwest of Elko on the east side of the Adobe Range. Some beds in the southeastern part of the quadrangle are almost monomict conglomerates composed of limestone clasts. These beds are beige to off-white and are very calcareous due to *in situ* weathering of the limestone clasts during lithification.

The contact between the upper epiclastic member and the ash-rich member (Tha) is conformable. Throughout the quadrangle, the contact is consistently just above the laterally persistent diatomite zone in the upper part of the lacustrine member. In the center of the quadrangle, the contact zone is a few centimeters thick, with some reworked ash in the basal sediments of the upper member. The absence of fluvial interbeds in the lacustrine member and lacustrine beds in the upper member, as well as the lack of a soil horizon or evidence of erosion of the ash-rich strata, indicates a relatively short time interval between when the lake dried up and the time that streams carried epiclastic sediments into these areas. In the southeastern part of the quadrangle, however, the contact zone spans several tens of meters, with alternating ash-rich beds and beds of coarse conglomerate and debris flows derived from (on the basis of clast lithologies) the southernmost Adobe Range. Regnier (1960) collected fossils of several mammal species (*Protolabis, Aphelops, Merychippus,* and camelid) from epiclastic beds in this interval. In addition, 50−150-cm-wide boulders derived from the Mississippian Melandco Formation in the Adobe Range occur near the base of the member just east of the nearby hot springs in section 8. This high-energy fluvial environment was restricted to this part of the Carlin basin and the age-equivalent part of the Elko basin on the immediate east side of the Adobe Range (Wallace and others, 2008). It must have resulted from events, such as a series of storms and flash floods, that were centered on and affected only the southernmost Adobe Range.

Miocene Volcanic Rocks

Miocene andesitic and rhyolitic volcanic rocks are exposed in the Huntsman Ranch quadrangle. The andesite was erupted in the eastern and southwestern parts of the quadrangle. The eastern flows are exposed in a narrow zone that extends east into the Hunter Quadrangle, where they are exposed at the top of and on the eastern flank of the Adobe Range. The western flows are more restricted in their exposures, but aeromagnetic data indicate a larger subsurface extent (Plume, 1995). The andesite flows have distinctive, coarse-grained, bladed plagioclase phenocrysts. In both areas, the flows were erupted onto the ash-rich member, the top of which was deposited at about 15.1 Ma. The absence of hyaloclastic breccias or water-quenching textures, as well as the presence of local bake zones in the underlying sediments at the contact, indicates that the flows were erupted subaerially onto the top of the ash-rich member. The upper member (Thu) overlies the flow units, and cobbles of subangular andesite are present in nearby basal sediments of the upper member.

The presence of the flows at the lacustrine-fluvial contact, combined with the conformable nature of the contact throughout the study area, provides a time-stratigraphic link between the western and eastern areas. In addition, the lack of evidence for eruption into water indicates that the flows were erupted during a period after the lake had dried up and before fluvial systems began to carry epiclastic sediments into these areas, similar to the contact zones between the ash-rich and upper epiclastic members elsewhere in the quadrangle.

The rhyolite flows are present only in the southwestern part of the quadrangle beneath the andesite flow units, with a thin intervening section of diatomaceous lacustrine sediments. The chemistry, mineralogy, and flow textures are identical to those in the Palisade Canyon rhyolite, which is extensively exposed southwest of the quadrangle and was dated at about 15.3 Ma on Marys Mountain to the west and near Palisade, south of Carlin (Henry and Faulds, 1999; Wallace and others, 2008).

The base of the rhyolite is not exposed in this quadrangle. Near Palisade, 15 km to the southwest, the rhyolite was erupted onto late Eocene and Paleozoic rocks; to the west along Interstate 80, the flows overlie a few meters of ash-rich sediments. Those nearby relations might suggest that the rhyolite flows were erupted before or during early Humboldt Formation deposition and that the underlying Miocene section is thin. However, the early, south-flowing fluvial system that deposited the lower epiclastic member was active before 16.3 Ma, and considerable amounts of fluvial and lacustrine sediments were deposited between then and 15.3 Ma. As such, the rhyolite may have been erupted in topographically higher areas to the west and southwest and flowed down and northeastward into the middle of the basin. Thus, the thickness of the Humboldt Formation beneath the rhyolite in this quadrangle may be thicker than in the exposures to the west. Unfortunately, water-related drilling in the area of the rhyolite exposures was shallow and did not penetrate rocks beneath the flow units.

Miocene Structural Geology

Differentiation and mapping of the four members of the Humboldt Formation has revealed abundant normal faults in the Huntsman Ranch quadrangle. The faults are rarely exposed and most were identified where faulting juxtaposed two members or identifiable parts of a single member. Additional faults may be present in areas underlain by a single member or in the many areas of extremely poor exposure. For example, tephras collected from a stratigraphic profile north of Dry Gulch indicate the presence of a small, west-dipping normal fault in the middle of the section, although poor exposures obscure the fault trace (Fig. 2). The faults cut all members of the Humboldt Formation and thus largely formed after deposition of the upper epiclastic member. Decreased dips upsection, which usually indicate syn-sedimentary faulting, are not strongly apparent, and concealed faults such as the one noted above could just as easily have produced any differences in dip.

Most of the mapped faults strike north-northeast to northeast, and some small cross faults strike northwest. West of Dry Susie Creek, the hanging walls of most faults were downdropped to the west, and beds dip gently to moderately to the east. Displacements commonly are on the order of a few tens of meters, although much greater offsets, described below, are evident along a few faults.

In the Hunter quadrangle to the east, as well as in the eastern part of this quadrangle, Humboldt Formation units are depositional on the pre-Miocene basement on the west side of the Adobe Range and dip gently to the west. The boundary between east- and west-dipping domains is an arcuate, generally north-striking, west-dipping normal fault. The fault has little displacement at its southern end, and the opposing dips on either side define a syncline; to the north, offset increases to about 50 m. The conglomerate beds east of Susie Creek are in the immediate hanging wall of the fault, suggesting that the fault may have been active earlier and produced the topographic bench that controlled the distribution of the conglomerate and the ash-rich member to the east, as described earlier.

In the southeastern part of this quadrangle and the southwestern part of the Hunter quadrangle, a west-facing, parabola-shaped normal fault system encloses an area of abundant north-striking, east-dipping normal faults (Fig. 3). Displacement along the parabolic fault system was down to the “inside” of the parabola, with minimal offset along the northern half and up to 100 m along the southern half. Strike-slip offset may have occurred but is not apparent. The internal normal faults have only a few tens of meters of offset, and they do not extend beyond the parabolic fault system. These internal faults displace Paleozoic and Eocene units, Miocene andesite flows, and the ash-rich and upper epiclastic members of the Miocene Humboldt Formation, all of which dip less than 20° to the west. Miocene units north and east of the parabolic fault system are nearly flat lying, whereas those to the south dip moderately to the west.

A broadly arcuate, east-dipping normal fault terminates the western limbs of the parabolic fault system (Fig. 3). This fault strikes north-northeast and has less than 50 m of offset in this quadrangle. It extends north-northeast into the Hunter quadrangle, where it has minimal offset and eventually dies out, and south into the Carlin East quadrangle, where it curves slightly to the south-southeast and the displacement increases to 200 m before it continues south-southeast into Paleozoic rocks (Smith and Ketner, 1978). As such, both this and the parabolic fault system have greater amounts of offset in their southern segments.

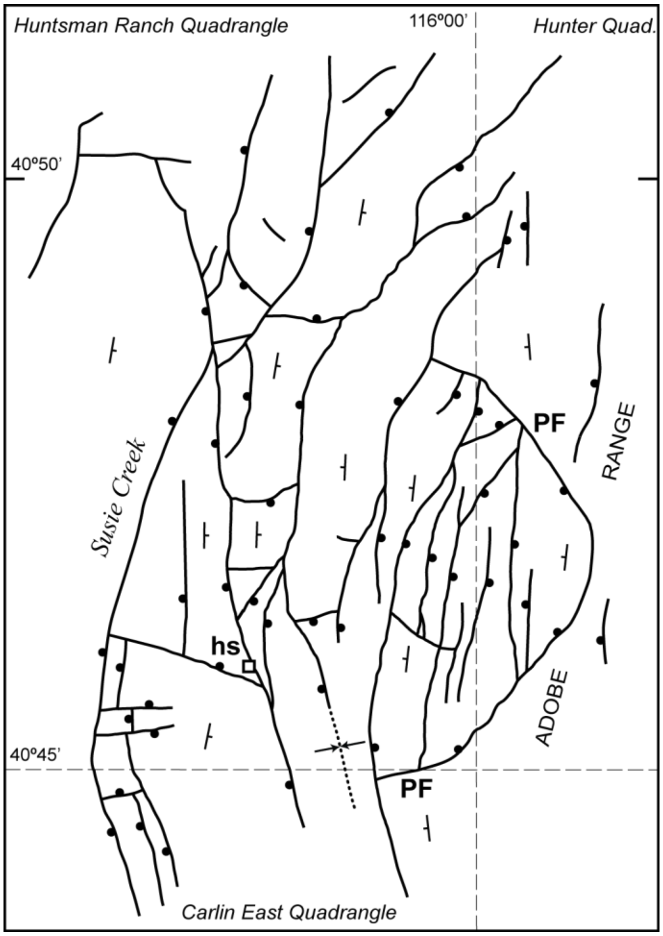

Figure 3. Map showing faults in the southeastern part of the Huntsman Ranch quadrangle (this report) and adjacent parts of the Hunter and Carlin East quadrangles (A.R. Wallace, unpubl. mapping). All faults shown as solid lines, regardless of degree of exposure. Dip symbols show general stratigraphic dips of Miocene sedimentary and volcanic units. PF, parabolic fault system; hs, hot springs.

Just to the west of this fault, down-to-the west normal faults have a similar arcuate pattern. The westernmost of these faults extends from just east of the “Hot Springs” near the southern edge of the quadrangle northward past Susie Creek, and then dies out in sections 18 and 19. Displacement at the southern end of the fault is less than 30 m, and displacement increases to the north, reaching at least 760 m just south of where it extends beneath Susie Creek. In that area, two parallel north-northeast-striking faults bifurcate from the north-striking fault and extend beyond the northern boundary of the quadrangle. The western of these two down-to-the-west faults has more than 400 m of offset, and the eastern fault has approximately 250 m. The combined offset on these two faults equals that along the north-striking fault just to the south, and, although the latter apparently cuts the former, all three faults may have formed at about the same time.

The overall fault pattern in the eastern part of the quadrangle, and extending into adjacent quadrangles to the east and south, suggests mild, very local extension along the west side of the Adobe Range, east of the major normal fault along Susie Creek. Based on the modest stratigraphic dips and generally small amounts of fault offset, extension was not significant. Some domains, such as those within the parabolic fault system, responded with more faulting than did other areas, and synclines and anticlines in the easternmost part of the quadrangle may have been products of this structural event. Reconnaissance mapping along the west side of the Adobe Range in the Adobe Summit quadrangle, 10 km to the north-northeast, has identified similar faulting and modest extension in Eocene and Miocene units.

Two normal faults in the northwestern part of the quadrangle and one along lower Susie Creek have 150 m or less of offset. The north-striking fault exposed in the northwestern corner of the quadrangle offset the contact between the Vinini Formation and the lower epiclastic member of the Humboldt Formation (Thl) by approximately 500 m. A parallel fault about 2 km to the east has approximately 150 m of displacement. The fault along Susie Creek is inferred from the apparent down-to-the-west offset of the contact between the upper epiclastic member and underlying ash-rich member. The amount of offset is uncertain but exceeds 100 m, on the basis of projections of the contact into that area. This fault extends several kilometers south to the Humboldt River floodplain in the Carlin East quadrangle, but its continuation southward into the northern Piñon Range is not apparent from the geologic map by Smith and Ketner (1978).

Several minor folds are present in the quadrangle. In the vicinity of the Huntsman Ranch site, beds of the epiclastic and ash-rich member on the west and east sides of upper Susie Creek dip to the west and east, respectively. Projection of these units and dips over Susie Creek defines a gentle, northeast-trending anticline, the axis of which is along the creek. At the northeastern end of the anticline, near the quadrangle boundary, Eocene volcanic rocks dip in opposite directions; at the southwest end, gravel beds in the lower epiclastic member dip gently in opposite directions directly above the Paleozoic basement. Faults truncate both ends of the anticline. A small west-northwest-trending anticline and a northeast-trending syncline also are present in the Humboldt Formation and underlying Eocene rocks in the northeastern corner of the quadrangle.

Late Cenozoic Erosion

More than a dozen strath terraces are present above streams and rivers in the Humboldt River drainage basin, including the Carlin basin (Wallace, 2005). The highest, oldest terraces, which are preserved in the northern part of the quadrangle, are more than 200 m above the youngest terraces (Fig. 4A, B). Erosion has dissected the older terraces, but remnants of these terraces can be traced along the sides of hillslopes on both sides of drainages, indicating the original locations and elevations of the terraces. This relation is very evident along both sides of Susie Creek upstream from the Huntsman Ranch site, where gravel deposits are preserved on small to larger remnants of at least four terrace surfaces

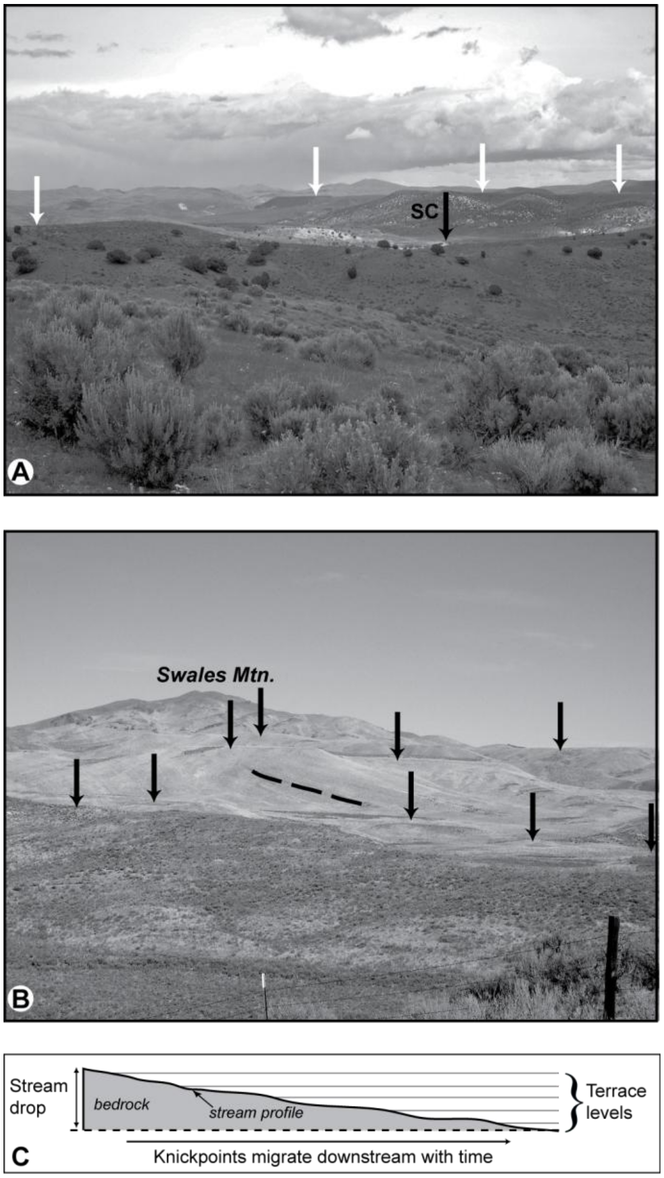

Figure 4. Strath terraces in the Huntsman Ranch quadrangle. A) Photo looking northeast from the ridge between Susie Creek and Dry Gulch. Distant peaks are in the Adobe Range north of Adobe Summit. White arrows delineate the uppermost (oldest) terrace; black arrow points to Susie Creek (SC) in the middle of section 20, where it is incising into the terrace formed at that elevation. The difference in elevation between Susie Creek at that location and the upper terrace above it to the east is approximately 210 m. Three additional, younger strath terraces are present downstream from and at lower elevations than this level of Susie Creek; the youngest terrace is 40 m lower than Susie Creek at this location. B) Photo taken in the northwestern part of the quadrangle looking north-northeast from Dry Gulch towards Swales Mountain. Arrows point to multiple strath terraces cut into the tilted Humboldt Formation (dashed line shows dip of bedding in 5,555-foot-elevation hill in section 11). The youngest terrace is the low terrace at the lower right part of the photo; the oldest terrace is the highest terrace slightly left of center of the photo. The difference in elevation between these terraces is approximately 180 m. Correlation of terraces throughout the quadrangle indicates that the lowest terrace is about 60 m higher, and thus older, than the Susie Creek terrace level shown in photo A. C) Sketch showing the relation of strath terrace elevations, downstream knickpoint migration, and modern stream gradients. In areas where Miocene sedimentary units comprise the bedrock, the blank area above the stream profile line represents strata that were eroded. See photo B for examples.

above the modern floodplain. Within the quadrangle, the younger terraces are moderately well preserved and closer to the axis of the modern stream. The terraces are paired across and stacked above all modern streams, and they reflect pediments that extended across the drainage. Knickpoints for the terraces become progressively younger downstream towards the Humboldt River, south of the quadrangle (Fig. 4C). Terraces in this quadrangle merge with those that formed above and along the river. As such, an incremental regional drop in the base level of the Humboldt River drainage system as a whole, including the Carlin basin, has produced the terraces (Wallace, 2005). The age of the oldest terraces is unclear. Erosion began before about 3 Ma near Elko, on the east side of the Adobe Range, and supergene alunite dates from the west side of the Carlin basin indicate erosion and weathering as early as about 7 Ma (Wallace and others, 2008). However, erosion apparently did not start until after about 1 Ma in Pine Valley, south of Carlin (Smith and Ketner, 1976).

The strath terraces are wider and more strongly developed in the Humboldt Formation than in underlying Eocene and Paleozoic bedrock. The Humboldt Formation units were less resistant to erosion due to their poorly consolidated nature, and the progressive incision of streams preferentially eroded areas underlain by the Miocene units. Because most of the Huntsman Ranch quadrangle is underlain by the Humboldt Formation, immense volumes of that unit have been removed as a result of the 200 m of downcutting. The modern drainage pattern in the Huntsman Ranch quadrangle reflects the combination of sediment removal and increased segmentation of the drainages during progressive downcutting. In places, such as along upper Susie Creek, it is readily apparent that the modern stream follows the same approximate course as the middle Miocene streams, such as the one that produced unit Thl near the Huntsman Ranch site.

Gravel deposits form 1–3-m-thick veneers above the highest terraces, but most terraces were primarily erosional and have only minor to no capping gravel deposits. In most of the latter cases, including isolated remnants of the higher terraces, rounded cobbles are scattered on the surface but do not form a continuous deposit. Some of the lowest terraces, such as those that formed low benches on either side of Susie Creek in the southern part of the quadrangle, also have thick gravel deposits, as does the creek's floodplain. Some of these gravel deposits have been mined (see next section). Local thick covers of gravel above the higher terraces may have increased resistance to further erosion, such as the steep-sided, gravel-capped bluff north of the Huntsman Ranch site.

Economic Geology

Mining in the quadrangle has exploited gravel deposits (QTg), andesite flow units (Ta), and diatomite in the Humboldt Formation. Zeolites are present in ash-rich strata in parts of the quadrangle, as shown on the geologic map; although they constitute a possible resource, they have not been mined. Abundant lode claim posts in many parts of the quadrangle indicate interest in possible metallic resources, although the prospective targets are unknown. In addition, the stratigraphy and structure of both the Humboldt Formation and older units influence the ground water in the area, including geothermal resources.

Aggregate

Mining in the early 2000s was limited to sporadic sand and gravel operations in the extreme southern part of the quadrangle west of Susie Creek, which are continuous with larger operations in the adjacent Carlin East quadrangle. This mining has exploited coarse gravel that was deposited on one of the lowest terrace surfaces in the area. The gravel deposits are several meters thick, although mining and some reclamation have obscured most textural and contact information. No mining was apparent during the course of this study, although mixing of stockpiled gravel with asphalt for highway construction took place sporadically.

The andesite (Ta) exposed in the southwestern part of the quadrangle was quarried in the early 1990s. Meter- or greater-sized andesite blocks were hauled 5 km northwest to a reservoir site northeast of the Gold Quarry mine. The blocks were used to line the upstream face of the dam and to stabilize potential overflow areas along the southeast margin of the reservoir. Abundant large blocks of quarried andesite remained at the quarry site in 2006.

Diatomite

Diatomite was mined in 1921 and 1922 in the south-central part of the quadrangle and adjacent Carlin East quadrangle. A mill was constructed in 1919 at the Vivian siding along the railroad several kilometers south of the deposits, but mining and processing did not start until 1921 (Lincoln, 1923). The two producing mines were the Tri-O-Lite mine in this quadrangle ("prospect" in the northwestern part of section 18) and the Great White Hope mine a kilometer to the south in the adjacent Carlin East quadrangle (LaPointe and others, 1991). The Tri-O-Lite mine was primarily an open cut into the diatomite beds; the Great White Hope mine included a ~50-m-long adit, a short vertical shaft to the tunnel, and several open cuts along the diatomite bed. All the underground workings were less than 20 m deep. Other areas along the diatomite zone throughout the quadrangle have been disturbed by prospecting and other mining-related activities, mostly bulldozer scrapes, but no production was reported from those areas.

The mined diatomite beds are in the ash-rich member (Tha) of the Humboldt Formation just below the contact with the upper epiclastic member (Thu). Several gray ash beds are interbedded with the diatomite, and the diatomite-rich zone is over- and underlain by beds of ash-rich siltstone. Tephras at the Great White Hope mine, along strike with diatomite beds in this quadrangle, were deposited at about 15.2 Ma (Table 1). The total thickness of the mined beds is less than 10 m, and individual beds are 1 to 2 m thick. The diatomite beds are planar and thinly bedded, in places varve-like. Abundant small faults cut the diatomite beds in the mines, each producing a few centimeters to several meters of offset. At the north end of the mined diatomite exposures, two eaststriking normal faults offset the section by several tens of meters, and the diatomite horizon is present at a shallow depth north of this area.

The diatomite beds are white and composed largely of *Aulocoseira granulata* and lesser *A. distans*. Minor genera (less than 2–3 percent of total diatoms) include Tetracyclus (common), Pinnularia, Nitzschia, Cymbella, Fragileria, Cocconeis, and Cyclostephanus. Using modern analogs, all these diatoms commonly bloom in freshwater lakes with neutral to slightly alkaline pH (6–8.5), total phosphorus of 10–1000 ppm, and low alkalinity (based on data compiled on the European Diatom Database website, http://craticula.ncl.ac.uk/Eddi/jsp/index.jsp). Aulocoseira species, which dominate the diatom-rich beds, are planktonic; a few of the diatoms in these strata, such as Cocconeis, are benthic and live on the substrate; and others are common in benthic to shallow, open-water environments (Houseman, 2004; also European Diatom Database). In the thicker diatomite beds, the benthic diatoms, although proportionately minor, are more common at the base of the section. On the basis of the diatom assemblages and their preferred environments, the late stage of the lake in the Carlin basin was composed of fresh water; it was deep enough to support a thriving planktonic community but shallow enough to allow light to reach a modest benthic community. The barrel shape of Aulocoseira diatoms requires turbulence for the diatoms to remain suspended, and proximity to an inflow source, such as streams from the nearby Adobe Range, favors these diatoms (Houseman, 2004).

Phosphorus is the limiting nutrient for diatom growth, and, in most cases, it is washed into lakes from surrounding highlands (Wallace, 2004). In the case of the Carlin basin, especially the eastern side where the diatomite deposits are the largest and most common, weathering and erosion of phosphatic Permo-Pennsylvanian limestones in the southern Adobe Range (Ketner, 1973) could have provided ample phosphorus for diatom growth.

Thinner (<1 m thick, commonly 5–20 cm thick) diatom-rich beds occur near the top of the ash-rich member in the northern, central, and southwestern parts of the basin, where they alternate with sediments composed only of ash. In addition, a thin, diatomaceous section of the ash-rich member is present between the rhyolite flow units (Trf) and overlying upper epiclastic member in the southwestern part of the quadrangle. Thin (2–20 cm thick), discontinuous, diatom-rich beds are present in the lacustrine parts of the mixed epiclastic and ash-rich member, especially in the northwestern part of the basin. Given the likely fluctuating environments during deposition of this member, the duration of quiet lacustrine conditions likely was much shorter than that during the later deposition of the ash-rich member, thereby producing thinner diatomite beds.

The diatomite deposits at the Tri-O-Lite and Great White Hope mines contain an average of 85 weight percent SiO_2 (recalculated to volatile free; Table 2), with variable amounts of other elements. Diatomite beds in other areas contain 75 to 89 weight percent SiO_2. One thin diatomite bed in the mixed epiclastic and ash-rich member in the northern part of the quadrangle contains substantial secondary calcite and thus has 16 weight percent CaO and only 60 weight percent SiO_2.

Hydrothermal Alteration and Sinters

Lacustrine and fluvial sediments of the fluvial (Thl) and epiclastic and ash-rich (Thm) members of the Humboldt Formation are bleached and contain secondary silica in two areas: the upper Dry Gulch area (sections 10 and 15) and on both sides of Susie Creek downstream from the Huntsman Ranch site (primarily sec. 20, also sections 16, 17, 29, and 21). The areas of hydrothermal alteration are indicated by the overlay pattern on the geologic map.

The silica phases include clear to light-cream chalcedony and opal that partly to completely replaced ash-rich strata, generally parallel to bedding. Silica phases also partially to completely filled pores in sand- and pebble-rich beds; in some locations, calcite filled the remaining pore space. Some coarser clastic beds are silicified and enclosed by unaltered, finer-grained beds, suggesting that higher-permeability clastic rocks focused hydrothermal flow parallel to the bedding. Mineralogical changes related to the bleaching were not determined, although primary textures in the sediments were preserved during alteration.

In the Susie Creek area, the alteration effects are limited to the strata in the epiclastic and ash-rich member (Thm), and beds in the overlying ash-rich member (Tha) are not altered. Altered areas on either side of Susie Creek are in the same stratigraphic interval and were offset by later faulting. Ash beds just above silicified rocks in both locations were deposited at 16 to 16.2 Ma (Table 1). The distribution and intensity of the alteration effects increase towards an area beneath Susie Creek in the northeastern part of section 20, which may have been the locus of upwelling hydrothermal fluids. The upper stratigraphic limit of the zone of alteration roughly coincides with the green chert layer that demarks the top of the epiclastic and ash-rich member. Alteration products are present farther down in the section to about 10 m above the underlying Paleozoic rocks, and the latter are moderately silicified just south of the Huntsman Ranch site. West of Susie Creek, the silicified and bleached zones dissipate northward along strike into unaltered and unsilicified sedimentary rocks. East of Susie Creek, the degree of bleaching and silicification similarly tapers off along strike to the north and south, although a 30-cm-thick zone of massive white to reddish chalcedony persists beyond these limits.

On the west side of Susie Creek, relict silicic algal mats, dessication cracks in the tops of chalcedony beds, and mammary silica textures are present in stratiform, 1-m-thick banded chalcedony beds. Underlying ash-rich sediments were completely replaced by massive chalcedony. These textures resemble sinter deposits in modern hot spring systems. Similar features are present in thinner beds on the east side of Susie Creek, and, in both areas, thin-bedded lacustrine sediments overlie the sinter deposits. These textures and relations indicate episodic subaerial exposure and lacustrine sedimentation. The combined textures and stratiform relations indicate that the hydrothermal alteration

Table 2. Chemical analyses of Miocene volcanic rocks and diatomite, Huntsman Ranch quadrangle. [All major oxide values are reported in weight percent and normalized to 100% on a volatile-free basis. Total is the oxide and LOI total before normalization. Total iron reported as Fe_2O_3. All trace elements are reported in parts per million (ppm). Analytical methods: major oxides by x-ray fluorescence; trace elements by energy-dispersive x-ray fluorescence; As by flow-hydride generation-atomic absorption spectrometry; Hg by cold vapor atomic absorption. Analysts: XRF, J. Taggart; EDXRF, T. Hannah; Hg and As, Z.A. Brown; all U.S. Geological Survey, Denver CO.]

<u>Volcanic rocks:</u>

Sample No.	W040522-1	W040522-2B
Unit	andesite (Ta)	rhyolite (Trf)
Latitude	40°46.145	40°45.898
Longitude	-116°07.214	-116°07.220
SiO_2	58.06	74.22
Al_2O_3	13.76	12.47
Fe_2O_3	11.53	2.97
MgO	2.48	0.10
CaO	6.18	1.17
Na_2O	2.58	2.09
K_2O	2.69	6.59
TiO_2	1.87	0.28
P_2O_5	0.70	0.05
MnO	0.15	0.04
Total	100.20	99.43
LOI	1.34	3.23
Na_2O+K_2O	5.27	8.68
As	3.3	0.39
Ag	<1	<1
Ba	1620	1330
Bi	<5	<5
Br	<1	<1
Cd	<1	<1
Ce	99	149
Cr	18	6
Cs	<5	15
Cu	26	8
Ga	27	21
Ge	<2	<2
Hg	<0.02	<0.02
La	53	82
Mo	4	3
Nb	22	36
Nd	62	73
Ni	41	28
Pb	21	31
Rb	56	227
Sb	<2	<2
Se	<1	<1
Sn	2	6
Sr	364	125
Th	9	24
U	<4	10
V	195	23
W	<5	<5
Y	49	54
Zn	140	86
Zr	365	442

Table 2. (cont.) Chemical analyses of Miocene volcanic rocks and diatomite, Huntsman Ranch quadrangle. [All major oxide values are reported in weight percent and normalized to 100% on a volatile-free basis. Total is the oxide and LOI total before normalization. Total iron reported as Fe_2O_3. All trace elements are reported in parts per million (ppm). Analytical methods: major oxides by x-ray fluorescence; trace elements by energy-dispersive x-ray fluorescence; As by flow-hydride generation-atomic absorption spectrometry; Hg by cold vapor atomic absorption. Analysts: XRF, J. Taggart; EDXRF, T. Hannah; Hg and As, Z.A. Brown; all U.S. Geological Survey, Denver CO.]

Diatomite:

Sample No.	W040521-1	W040616-1[a]	W030627-1A[b]	W030627-1B[b]	W030627-1C[b]
Latitude	40°46.150	40°51.612	40°45.393	40°45.393	40°45.393
Longitude	-116°06.083	-116°05.660	-116°03.703	-116°03.703	-116°03.703
SiO_2	75.74	60.10	86.06	86.31	84.08
Al_2O_3	11.09	9.64	4.91	7.41	8.17
$FeTO_3$	3.80	3.32	1.11	1.05	1.74
MgO	2.69	5.94	1.48	1.95	1.95
CaO	2.27	15.99	2.20	1.56	1.49
Na_2O	2.44	2.21	3.39	0.92	1.47
K_2O	1.19	2.07	0.50	0.44	0.57
TiO_2	0.58	0.42	0.23	0.31	0.43
P_2O_5	0.17	0.21	0.06	0.06	0.06
MnO	0.03	0.12	0.03	0.03	0.04
Total	88.2	80.7	86.0	88.4	89.2
LOI	11.1	18.5	12.5	11.0	10.7
As	5.2	5.6	1.8	1.4	1.4
Ag	<1	<1	<1	<1	<1
Ba	715	973	173	156	210
Bi	<5	<5	<5	<5	<5
Br	25	11	17	5	8
Cd	<1	<1	<1	<1	<1
Ce	50	46	15	30	27
Cr	17	25	6	6	9
Cs	12	6	6	<5	5
Cu	20	20	14	15	14
Ga	14	14	8	12	12
Ge	2	<2	3	<2	3
Hg	0.03	0.03	0.02	0.03	0.05
La	22	26	13	19	15
Mo	<2	<2	3	<2	5
Nb	12	13	6	6	9
Nd	21	24	<10	24	<10
Ni	20	21	6	4	13
Pb	17	11	5	6	10
Rb	44	65	23	24	31
Sb	<2	<2	<2	<2	<2
Se	<1	<1	<1	<1	<1
Sn	3	<2	<2	<2	2
Sr	232	331	116	115	139
Th	7	6	<4	<4	5
U	<4	7	<4	<4	4
V	72	94	35	36	52
W	<5	<5	<5	<5	<5
Y	13	30	7	17	9
Zn	78	86	31	38	49
Zr	197	209	66	107	124

Table 2. (cont.) Chemical analyses of Miocene volcanic rocks and diatomite, Huntsman Ranch quadrangle. [All major oxide values are reported in weight percent and normalized to 100% on a volatile-free basis. Total is the oxide and LOI total before normalization. Total iron reported as Fe_2O_3. All trace elements are reported in parts per million (ppm). Analytical methods: major oxides by x-ray fluorescence; trace elements by energy-dispersive x-ray fluorescence; As by flow-hydride generation-atomic absorption spectrometry; Hg by cold vapor atomic absorption. Analysts: XRF, J. Taggart; EDXRF, T. Hannah; Hg and As, Z.A. Brown; all U.S. Geological Survey, Denver CO.]

Diatomite (cont.):

Sample No.	W030627-1D[b]	W030627-1E[b]	W030917-1	W030917-2
Latitude	40°45.393	40°45.393	40°48.800	40°47.961
Longitude	-116°03.703	-116°03.703	-116°05.69	-116°06.550
SiO_2	81.86	85.00	79.22	89.06
Al_2O_3	8.34	7.27	10.58	4.65
$FeTO_3$	3.61	2.57	1.97	0.95
MgO	1.96	1.70	0.70	0.61
CaO	1.58	1.21	1.19	1.06
Na_2O	1.58	1.27	1.91	2.25
K_2O	0.69	0.52	4.00	1.09
TiO_2	0.32	0.37	0.32	0.25
P_2O_5	0.06	0.06	0.06	0.06
MnO	0.05	0.03	0.05	0.01
Total	88.2	89.9	92.9	90.5
LOI	11.4	9.45	6.40	8.57
As	1.8	2.1	5	3.1
Ag	<1	<1	<1	<1
Ba	179	281	507	237
Bi	<5	<5	<5	<5
Br	13	3	2	30
Cd	<1	<1	<1	<1
Ce	41	33	70	37
Cr	8	9	12	7
Cs	8	8	13	17
Cu	19	20	9	4
Ga	12	12	16	6
Ge	3	4	<2	<2
Hg	0.04	0.03	0.04	<0.02
La	23	20	32	21
Mo	<2	<2	<2	2
Nb	12	7	21	7
Nd	19	27	13	30
Ni	10	12	17	6
Pb	11	8	20	7
Rb	37	31	148	48
Sb	<2	<2	<2	<2
Se	<1	<1	<1	<1
Sn	<2	<2	3	<2
Sr	137	142	181	97
Th	6	<4	13	<4
U	<4	5	5	5
V	47	66	73	26
W	<5	<5	<5	<5
Y	12	9	39	7
Zn	61	63	80	27
Zr	104	101	151	77

[a] Thin section of this sample shows abundant interstitial calcite, explaining the large CaO and LOI values.

[b] W030627-1A through E were collected from a vertical profile through a single 4−m-thick diatomite bed in the south-central part of the quadrangle; A is at the base of the exposure, E is at the top.

and sinter formation took place in a near-surface to surficial environment during continued deposition of the sedimentary units. On this basis, the absence of hydrothermal products in the overlying ash-rich member most likely indicates that hydrothermal activity ceased by the time that those sediments were deposited.

Sediments of the fluvial member (Thl) in the Dry Gulch area are weakly to moderately bleached. The amount of silicified sediments is minor, although small pods of secondary chalcedony locally cut bedding in ash-rich beds and some pebble-rich beds contain a silica cement. Local thin beds of silicified algal mats are present here as well, but no clear sinter deposits were observed. Similar to the Susie Creek area, alteration tapers off along strike. The stratigraphic base of the alteration is approximately 100 m above the basal contact with the Paleozoic basement. The amount and distribution of alteration products increases towards an area just south of Dry Gulch in the southwest part of section 10, which may have been the locus of upwelling hydrothermal fluids. Weak, thin zones of altered and silicified strata also were observed within the same stratigraphic interval in the easternmost part of the Schroeder Mtn. quadrangle to the southwest. On the basis of dated samples just to the northeast, the fluvial member in this area is older than about 16.3 Ma. Based on the weak development of synsedimentary algal mats, at least some of the hydrothermal activity took place during sedimentation.

The two main areas of silicified and altered rocks resemble those associated with syn-sedimentary hot-spring epithermal systems, such as at the Ivanhoe district, 50 km northwest of this quadrangle (Wallace, 2003). There, hydrothermal fluids ascended along faults and migrated laterally along more permeable sedimentary beds, producing local to widespread bleaching and silicification. The Ivanhoe alteration and silicification took place at approximately 15.2 Ma, contemporaneously with rhyolite volcanism and faulting that provided the heat and conduits for the hydrothermal system (Wallace, 2003). Hydrothermal activity in at least the Susie Creek area occurred at or just before 16 Ma, but no volcanic rocks of that age are exposed or known anywhere near this area, nor are any faults demonstrably of this age.

Zeolite minerals

Secondary zeolites and chert are present in ash-rich sedimentary rocks in the lower part of the ash-rich member in the west-central part of the quadrangle (sections 23, 26, 27, and 35), as well as in fine-grained ash- and mud-rich sediments in the mixed epiclastic and ash-rich member near the center of the quadrangle (sections 19 and 30). These deposits may constitute a resource, although their quality was not determined for this study. They have not been mined or prospected. These areas of diagenetic alteration are indicated by an overlay pattern on the geologic map.

Reflectance spectroscopy analyses indicate that erionite and (or) clinoptilolite (spectra are indistinguishable) are the principal zeolites, with lesser chabazite. Chert phases include opaline silica and knobby, Magadi-type chert (Sheppard and Gude, 1983). The zeolites and chert partially or, in places, completely replaced the host sediments, and the zeolites principally replaced ash in the sediments. Primary sedimentary textures generally were preserved, and thin interbeds of tufa were not affected. Neither detrital nor authigenic clay minerals were detected by the spectroscopic analyses. In the west-central area, alteration diminishes to the north and is not present north of Dry Gulch; younger units and faults conceal the extent of the alteration in other directions. The degree of alteration diminishes higher in the section, and lacustrine strata near the top of the section contain unaltered beds of freshwater diatomite. In addition, a persistent green replacement chert bed (ch) in the west-central and entire eastern parts of the quadrangle is present at or near the contact between members Thm and Tha or, in the absence of Thm, within Tha. This bed contains chabazite in addition to chert.

The presence of erionite/clinoptilolite and Magadi-type chert, the interbedded tufa beds, and the absence of detrital or authigenic clay minerals indicate that the secondary minerals formed in an alkaline (pH=7–10), evaporative lake environment (Sheppard and Gude, 1983). The presence of freshwater diatomite higher in the section in the western area, as well as above the green chert bed in the eastern part of the quadrangle, indicates that the lake evolved from an early alkaline setting into a more freshwater environment.

Water resources

Water in the Miocene sedimentary rocks in the Carlin basin has domestic, agricultural, and mining importance. Previous water-related studies (Plume, 1995; Maurer and others, 1996) treated these rocks as hydrologically uniform. However, the complex stratigraphy and diverse compositions of the rocks identified during the present study suggest equally complex hydrologic characteristics. For example, epiclastic sedimentary units composed of epiclastic sediments have greater permeability, whereas ash-rich strata, such as those in the ash-rich member, are less permeable and form impermeable clay-rich zones, both within the sedimentary sequence and at the contact with the underlying pre-Miocene basement (P. Pettitt, Newmont Gold Co., oral communication, 2004). In addition, many of the epiclastic beds contain variable amounts of reworked ash, and parts of the stratigraphic section with mixed facies, such as member Thm with its complexly alternating and interfingering lithologies, may have large variations in their hydrologic properties. Thus, sedimentation produced considerable lithologic compartmentalization of the future aquifers.

In addition, the abundant post-sedimentation faulting strongly compartmentalized the already complex stratigraphy, thereby affecting ground-water flow in the Carlin basin. The faulting isolated stratigraphic packages, juxtaposed units with different hydrogeologic characteristics, and, by tilting the units, exposed different units with different permeabilities to surface recharge. As a result, flow is from north to south (Plume, 1995), down hydrologic gradient and parallel to the major faults, and the faults may restrict flow in an east-west direction. This flow compartmentalization likely has an effect on efforts to dewater the Miocene aquifer at the nearby Gold Quarry mine, and monitoring wells in different fault domains may not be hydrologically connected. Also, interaction between the Miocene and Paleozoic aquifers that are being dewatered may be affected by the lithology, ash content, and hydrologic conductivity of the Miocene strata in any particular location.

Geothermal Resources

Several hot springs are located in the northwestern part of section 8 in the south-central part of the quadrangle. These springs are located along a north-northwest-striking normal fault, and they have deposited a small apron of white calcareous silt above the upper epiclastic member on the southwest side of the fault. During the course of this study (2003–2005), the spring water flowed several hundred meters down a small drainage before sinking into the alluvium, although less flow was observed in late summer and fall. The measured temperature of the springs is 64°C (Garside, 1994). This is one of just three thermal springs in the Carlin basin; the other two are southwest of Carlin and have measured temperatures of 22° and 79°C (Garside, 1994). None of these thermal areas have been drilled or evaluated, likely due to their low temperatures.

DESCRIPTION OF MAP UNITS

[Tephra correlation ages and $^{40}Ar/^{39}Ar$ dates are given in Table 1 and shown in Figure 2. All dates and correlations were calculated using the 28.02 Ma standard for Fish Canyon Tuff sanidine (Renne and others, 1998).]

Qal Alluvium (Quaternary) Unconsolidated, massive to crudely bedded deposits of silt, sand, pebbles, and cobbles along modern streams, related floodplains, and lowest recent terraces. Clasts are subrounded to subangular and are composed of Paleozoic sedimentary and Tertiary volcanic rocks derived from bedrock exposures. Conglomerate beds in the Humboldt Formation and gravel deposits (QTg) also may have contributed clasts. Modern streams along these drainages are incised 1–2 m into older alluvial deposits (Qoa).

Qoa Older alluvial deposits (Quaternary) Unconsolidated silt, sand, and gravel is exposed adjacent to and above Susie Creek, Dry Susie Creek, and Maggie Creek. The deposits are poorly exposed and covered by tall, dense sagebrush except where sagebrush was burned by wildfires. The unit also includes narrow alluvial deposits along many ephemeral streams, including Dry Gulch. Down-slope wash from the Humboldt Formation merges with alluvial deposits (Qal, Qoa) to create indistinct and irregular contacts.

Qls Landslide deposits (Quaternary) Where exposed near Lower Dry Susie Spring, deposits are composed of stratigraphically intact beds of andesite (Ta) and the ash-rich member of Humboldt Formation (Tha). A small, poorly exposed landslide northwest of the Huntsman Ranch site is composed of materials derived from upslope exposures of units Tha, Thm, and QTg.

QTg Gravel deposits (Quaternary and Pliocene) Unconsolidated deposits of subangular to subrounded pebbles, cobbles, and boulders of Paleozoic sedimentary and Eocene volcanic rocks that were deposited on terrace surfaces at multiple elevations above modern streams. The gravel deposits are overlain and obscured by minor to significant amounts of eolian silt and sand. The thickness of gravel deposits ranges from more than 40 m on a high pediment surface north of the Huntsman Ranch site to 1–3 m on other surfaces, such as at the southern edge of the quadrangle west of Susie Creek. Most commonly, the gravel is present as a single, incomplete clast layer on a pediment surface, and many of these discontinuous areas of gravel are not shown on the map. On the basis of lithologies in surrounding highlands (Evans and Ketner, 1971; Ketner, 1973), most clasts were derived from the Swales Mountain area to the north; sparse clasts in some eastern exposures of the gravel deposits were derived from the Adobe Range to the east. Erosion of the underlying Humboldt Formation has caused significant down-slope clast redistribution from this unit. Shiny, dark Fe-Mn-oxide coatings on many clasts distinguish float of this unit from residual, uncoated clasts in the upper epiclastic member of the Humboldt Formation (Thu), although distinguishing between the two can be impossible where the clast size in Thu is similar to that in QTg.

HUMBOLDT FORMATION (MIOCENE)

The Humboldt Formation is composed of weakly to moderately consolidated middle Miocene sedimentary rocks that include the informal Carlin formation of Regnier (1960). The sedimentary units are composed variably of epiclastic materials derived from bedrock exposures in and near the quadrangle, and ash derived from distant eruptions. The complex facies architecture of the formation is here divided into four informal members: an upper member of tan epiclastic sandstone and conglomerate (Thu), an ash-rich member (Tha), a mixed epiclastic and ash-rich member (Thm), and a lower epiclastic member of brown siltstone, sandstone, and conglomerate (Thl). Brief unit descriptions are given here. Depositional environments and unit nomenclature are discussed earlier in the text. On the basis of $^{40}Ar/^{39}Ar$ dates and tephra correlations, deposition of Humboldt Formation sediments in this and adjacent quadrangles began before 16.3 Ma and continued until after about 14.8 Ma.

Thu Upper epiclastic member Tan, brown, to light gray-brown, weakly to moderately consolidated sandstone, siltstone, and conglomerate. The unit generally is poorly exposed and forms a surface float of tan sand and scattered pebbles and cobbles. More lithified beds are 10 cm to 2 m thick, and they are massive to very crudely bedded. Strata are weakly to moderately calcareous and contain faint paleosol horizons, rare mudcracks, locally abundant calcareous rhyzoliths, and rare mammal bone fragments. Clast compositions are identical to Paleozoic and Eocene rock types exposed in the Adobe Range to the east and the Swales Mountain area to the north; relative percentages of clast lithologies vary widely with location in the quadrangle. Sand- to silt-sized matrix is composed of similar materials and minor amounts of reworked ash. Clasts decrease in grain size towards the west-central part of the quadrangle. The contact between Thu and the underlying member Tha generally is conformable and is sharp to gradational over <1 m. At the southern edge of the quadrangle, east of Susie Creek, the contact zone spans several tens of meters and includes alternating conglomerate and ash-rich beds; this sequence grades upward into cobble-rich sandstone of Thu. In the southeastern part of the quadrangle east of Dry Susie Creek, the member is composed of cobble conglomerate and, just south of the quadrangle, directly overlies Paleozoic sedimentary rocks. Between Dry Gulch and Susie Creek, the member becomes coarser near the top of the exposed section; cobble-rich residual lag along some ridge crests resembles QTg. The top of the member is not apparent. The exposed thickness of Thu is 10–30 m in the southeastern part of the quadrangle and at least 400 m between Susie Creek and Dry Gulch. The member overlies 15.2 Ma tephra beds near the southeastern edge of the quadrangle and 14.8 Ma tephras along Interstate 80 between Carlin and Emigrant Pass (Fig. 1), southwest of the quadrangle. The upper age of the member is not known.

Tha Ash-rich member Light-gray to white, less commonly light-green, yellow, and tan, to rarely orange and reddish, fine-grained, thinly bedded to massive ash, locally abundant diatomite, and thin beds of limestone, ash-rich sandstone, and chert. The member mostly is poorly exposed. Ash beds are composed of fine-grained ash with minor feldspar phenocrysts; beds are a few centimeters to more than a meter thick, have uniform thicknesses, and are laterally continuous. Weak to pronounced cross bedding, ripple marks, thinly bedded algal mats, and gypsum- and calcite-cemented concretions locally are common. Diatomite (**dt**) is white and massive to thinly bedded, <1 m to >4 m thick, with 1–20-cm-thick interbeds of light-gray ash. Diatomite is most common near the top of the member, but it also forms 5–30-cm-thick beds throughout the member. Limestone beds are finely to coarsely crystalline, light tan to dark gray, and usually less than 10 cm thick. Massive gray limestone forms small outcrops near Lower Dry Susie Spring; these could be slide blocks derived from similar Paleozoic exposures just out of the map area to the northeast. In sec. 26, T. 34 N., R. 52 E., limestone forms thin tufa-like beds, and enclosing ash beds were replaced by secondary zeolites and chert. In the eastern part of the quadrangle, this member contains thin beds of siltstone to coarse-grained sandstone composed of reworked ash, phenocrysts, subrounded grains of black vitric material, and small, subrounded platy siltstone clasts derived from the Webb and Vinini Formations. The ash-rich member is distinguished from the underlying mixed epiclastic and ash-rich member (Thm) by the dominance of air-fall ash and diatomite and greatly subordinate amounts of epiclastic materials. Just east of Susie Creek, a persistent green chert horizon (ch) generally occurs near the contact between these two members. However, sediments beneath this horizon in the Dry Susie Creek area are composed mostly of ash but are included in Thm on the map. The member is about 80 m thick west of Dry Gulch and near the east-central edge of the quadrangle. The member directly overlies Paleozoic sedimentary rocks in the southeastern part of the quadrangle and rhyolite porphyry (Trp) along the eastern edge of the quadrangle. Near the southeastern edge of the quadrangle, the member ranges in age from about 16 to 15.2 Ma (Fig. 2, section 4). In the northern and northeastern parts of the quadrangle, the top of the member is about 15.6 Ma (Fig. 2, section 2).

Thm Mixed epiclastic and ash-rich member Commonly poorly exposed gray, white, to tan, fine-grained ash; tan, gray, to black siltstone and sandstone; and minor pebble conglomerate. The proportions of each lithology vary widely with location. The percentage of ash-rich sediments increases upsection and to the south and southwest. Ash-rich beds are similar to those in the ash-rich member (Tha) but contain only minor, 5–20-cm-thick diatomite beds. Ash beds are gray to off-white, thin- to thick-bedded, and massive to cross-bedded. Sandstone beds are grayish tan to brown, fine-grained, and several centimeters thick; they increase in thickness, coarseness, and abundance to the north and northwest. Sandstone contains a mixture of quartz and feldspar sand and reworked dark ash. Dark-gray to black tuffaceous to pumiceous sandstone forms distinctive beds that alternate with tan to brown sandstone. The thickness and percentage of the dark pumiceous beds increases to the northwest. Planar-bedded to reworked and cross-bedded black pumice also is present. Local pebble conglomerates lenses are composed of Paleozoic sedimentary and sparse Tertiary volcanic clasts. Poorly exposed beds with 10–50-cm-diameter clasts of Tertiary and Paleozoic rocks are interbedded with sandstones south of Dry Gulch. These beds may be continuous along strike with debris flow deposits in member Thl, indicating the interfingering nature of the member with Thl. Along Susie Creek and upper Dry Gulch, the base of the member contains pistachio-green to tan, planar-bedded shale, siltstone, white ash, and minor chert, with increasing small-pebble to granule-conglomerate beds higher in the section. Conglomerate beds in these areas contain only clasts of Paleozoic rocks and, at Susie Creek, large round quartz grains. Secondary erionite and clinoptilolite are common in these areas. Some strata in both areas also contain abundant secondary chalcedony and quartz and are extensively bleached. The age range in the upper Dry Gulch area is about 16.0 to 15.7 Ma. Three tephra beds near the Huntsman Ranch site were dated at 16.3 to 16.2 Ma (Fig. 2, Table 1).

Thl Lower epiclastic member The lower epiclastic member is composed of epiclastic sandstone and conglomerate, with some boulder-rich beds. In the northwestern part of the quadrangle, the member includes tan to grayish-tan massive sandstone and massive, planar-bedded to channel-filling pebble to cobble conglomerate; planar-bedded beds of fine-grained ash similar to those in units Thm and Tha are rare to absent. The quartz-feldspar sand matrix contains variable amounts of reworked ash. Coarser clasts are subangular to subrounded, 5–100 cm in size, and composed of Eocene rhyodacite, Paleozoic (Vinini) chert and quartzite, and variable amounts of Eocene rhyolite porphyry. Many planar-bedded pebble conglomerates are composed entirely of small, platy clasts of Vinini (Ov) siltstone with clear silica cement and little or no matrix. In the northeastern part of the quadrangle, Thl includes poorly exposed tan sandstone with variable amounts of pebbles and cobbles of Eocene rhyodacite and lesser amounts of Paleozoic chert. The contact with the overlying mixed epiclastic and ash-rich member (Thm) is defined by the first appearance of beds composed only of fine-grained ash. In the southeastern corner of the quadrangle, the basal 10–20 m of the Humboldt Formation is composed of angular to subangular clasts, 1–30 cm in diameter, that were derived from nearby Paleozoic rocks and likely represent a colluvial deposit along the early margin of the basin. In sections 29 and 32, T.34N., R.53E. east of Susie Creek, a >200-m-thick stratigraphic section of conglomerate forms massive, 1–3-m-thick, sheet-like beds with lesser tan, massive, 10-m-thick ash-bearing sandstone interbeds. The top of this thick conglomerate sequence grades upward into member Tha. The conglomerate-rich zone thins to the northeast, towards and into the Hunter quadrangle, into a kilometer-wide, 10-m-thick conglomerate horizon both vertically and laterally contained within finer-grained, ash-rich and epiclastic beds of member Thm. The lower epiclastic member was not dated. Tephra near the base of the overlying mixed epiclastic and ash member (Thm) north of Dry Gulch was dated at 16.03±0.05 Ma. Along Susie Creek near the Huntsman Ranch site, the conglomerate sequence underlies tephras dated at 16.0 to 16.2 Ma (Fig. 2, Table 1).

Ta Andesite (Miocene) Dark-brown to black andesite flow units exposed in the east-central and southwestern parts of the quadrangle. This unit occurs at the horizon between members Tla and Thu of the Humboldt Formation. The andesite contains abundant, tabular, 0.5−2-cm-long plagioclase phenocrysts in a black, fine-grained groundmass; phenocrysts are highly visible on fresh surfaces but indistinct on weathered surfaces. One sample contains 58.1 weight percent SiO_2 and 5.3 weight percent Na_2O+K_2O (Table 2). Flow-unit thickness varies from 1 m to >3 m. These units contain a basal platy, weakly to non-vesicular zone and an upper, massive to vesicular zone. The southwestern exposures include one massive, vesicular to aphyric and glassy flow; a possible feeder vent is exposed in the rock quarry in section 10. Geophysical and drilling data indicate that the southwestern flows extend in the subsurface southwestward beneath Maggie Creek (Plume, 1995). Attempts to date the unit failed. An estimated age of 15.1 Ma is based upon the age of the youngest tephra in underlying Tha (Fig. 2, Table 1) and the apparent depositional continuity between Tha and overlying Thu.

Trf Rhyolite (Miocene) Dark-brown to black, flow-folded, fine-grained to vitric rhyolite flows exposed in the southwestern part of the quadrangle east of Maggie Creek; includes one and possibly two flow units that are several meters thick and laterally extensive. The base is vitric and weathers easily; the upper part of the flows is devitrified and extremely hard and massive. Convoluted flow folds locally are abundant. Rhyolite contains 0.5−1-mm-diameter phenocrysts of sanidine, plagioclase, and quartz in a massive to porous aphanitic groundmass; pores locally contain chalcedony. One analysis of chalcedony-free rhyolite shows 74.3 weight percent SiO_2 and 8.7 weight percent Na_2O+K_2O (Table 2). Flow units pinch out laterally and may have been erupted into a shallow, west- to southwest-trending swale. A 2−3-m interval of ash-rich and fine-grained epiclastic sediments with local diatomite separates the rhyolite and the closely overlying andesite (Ta). The base of the rhyolite is not exposed. Attempts to date the unit failed; the estimated age of 15.2 Ma is based on tephra ages in Tha, but the unit could be older. The rhyolite likely is equivalent to the 15.3 Ma Palisade Canyon rhyolite (Henry and Faulds, 1999; Wallace and others, 2008) exposed in the Carlin West quadrangle 8–10 km to the southwest and south.

Trd Rhyodacite (Eocene) Dark-brown rhyodacite flow units and breccias form minor exposures in the northeastern corner of the quadrangle; the unit is much more extensive in quadrangles to the north, northeast, and east. The rhyodacite is brittle, massive to locally flow foliated or vesicular, glassy to aphyric, and contains small plagioclase, sanidine, biotite, and hornblende phenocrysts. Flow tops, especially the uppermost flow, are brecciated. Where exposed, the rhyodacite overlies Eocene tuff (Twt) and is overlain by the lower epiclastic member of the Humboldt Formation (Thl). The rhyodacite occurs between the Vinini Formation and the Humboldt Formation just north of the northwest corner of this quadrangle but is absent in that interval within this quadrangle. The rhyodacite is equivalent to the latite in the "Volcanic rocks" unit mapped in the Swales Mountain quadrangle, where it overlies the equivalent of unit Trp (Evans and Ketner, 1971). Intrusive equivalents of the latite were dated at ~38.8 Ma in that area (Henry and Ressel, 2000).

Tt Tuff (Eocene) Light-tan to off-white, nonwelded tuff forms small exposures in the northeastern corner of the quadrangle; these are continuous with more widespread exposures in quadrangles to the east and northeast. The tuff is pumice rich and contains moderate amounts of angular lithic fragments, including dark, aphyric, 1−5-cm-diameter volcanic clasts and 1−10-cm-diameter, white to tan pumice clasts. The tuff overlies Paleozoic rocks and is overlain by rhyodacite flow units (Trd). The tuff is equivalent to pyroclastic rocks within the late Eocene “Quartz porphyry” unit mapped in the Swales Mountain quadrangle (Evans and Ketner, 1971), which underlies ~38.8 Ma latite flow units (unit Trd in this quadrangle) (Henry and Ressel, 2000).

Tss Sandstone (Eocene) Strongly cemented, moderately sorted, light-tan sandstone is exposed in a small area in the northeastern corner of the quadrangle. The sandstone has subangular to angular, <0.5- to >1-mm grains of quartz and plagioclase and lesser amounts of sanidine and hornblende; sparse lithics are small and include altered pumice and siltstone of possible Paleozoic age. Nearly vertical, north-striking small fractures cut the rocks and largely obscure the westerly dip of the bedding. The unit is overlain by Eocene tuff (Tt). The base is not exposed. The unit may be related to the Eocene Elko Formation (Haynes, 2003).

Trp Rhyolite porphyry (Eocene) Light-tan to reddish-tan rhyolite flow units of rhyolite porphyry are exposed near the east-central and north-central edges of the quadrangle, extending into adjacent quadrangles. The rhyolite has a fine-grained, light-tan to light-gray groundmass with abundant 1−5-mm quartz, sanidine, and lesser plagioclase, biotite, and hornblende phenocrysts. Clear quartz phenocrysts are distinctive on reddish-tan weathered surfaces. The flows are massive and weather to coarse grus. Internal black, vitric zones suggest contacts between multiple flow units, and isoclinal flow folds are visible in the northern exposures. The phenocryst assemblage in the rhyolite is identical to that in an undated pluton exposed in the Hunter quadrangle to the east (Ketner, 1973) and to late Eocene rhyolite flows in the Swales Mountain area (“Quartz porphyry” unit of Evans and Ketner, 1971), which underlie ~38.8 Ma latite flows.

Pℙsu Sedimentary rocks, undivided of Ketner (1973) (Permian and Pennsylvanian) Tan, platy siltstone and tan to gray, massive to thin-bedded limestone and silty limestone are exposed in the southeastern corner of the quadrangle. Clasts derived from these rocks are abundant in nearby exposures of the lower epiclastic member (Thl) and the upper epiclastic member (Thu) of the overlying Humboldt Formation. On cross sections, the presence of this unit is inferred from exposures just east of the quadrangle; however, its presence and thickness are interpretative.

Mw Webb Formation (Mississippian) Dark-gray to black, thinly bedded, fissile, siliceous shale and siltstone is exposed in small areas near Susie Creek southwest of the Huntsman Ranch site. The rocks weather to form float of small, platy tan chips. Rocks beneath the contact with the overlying Humboldt Formation locally have a weak to strong secondary reddish iron-oxide stain that may indicate a pre-Humboldt regolith. Rocks in exposures along the border between sections 16 and 17 were silicified. Clasts derived from this formation are a significant component of some epiclastic beds in the Humboldt Formation, although specific source locations are not known.

Pzlp Lower Paleozoic carbonate rocks beneath Roberts Mountains allochthon Shown only on cross sections. Includes Devonian and older carbonate and epiclastic rocks that underlie siliceous rocks (unit Ov in this quadrangle) of the Roberts Mountain allochthon exposed 5 km west of the quadrangle (Evans and Cress, 1972). The structural depth of this unit is very uncertain and its presence is inferred from exposures to the west. See the “Pre-Miocene Geology” section for an explanation of the allochthon and its related structural history.

Ov Vinini Formation (Ordovician) Platy to massive, dark-brown to gray siliceous siltstone, bedded chert, and quartzite is exposed in the northwestern corner of the quadrangle. The unit as exposed includes minor beds of tan-gray, thin-bedded limestone along the northwesternmost edge of the quadrangle. Rocks beneath the contact with the overlying Humboldt Formation locally have a weak to strong secondary reddish iron-oxide stain that may indicate a pre-Humboldt Formation regolith. The Vinini Formation was a major source of clasts in the Humboldt Formation, although most sources likely were outside of this quadrangle.

Geology was mapped in 2003–2005 by Alan R. Wallace. Tephra and ^{40}Ar/^{39}Ar samples were collected by Michael E. Perkins and Robert J. Fleck in 2004; additional samples were collected by Wallace in 2003–2005. Tephrochronology analyses were by Perkins. Isotopic dating was by Fleck.

ACKNOWLEDGEMENTS

The Maggie Creek Ranch granted access to the privately owned parts of the quadrangle. Deb McFarlane (U.S. Bureau of Land Management, Elko) made available various public documents containing mining-related drilling data in the western part of the Carlin basin. Michel Houseman (World Minerals) provided advice on the identification of the diatom species. Wendy Calvin (University of Nevada, Reno) gave access to the reflectance spectroscopy equipment and related spectral database at UNR for the identification of the zeolites. Reviews by Keith Howard, Sue Beard, Jim Trexler, Jack Deibert, and Chris Henry helped to clarify the presentation and interpretation of various stratigraphic and structural relations.

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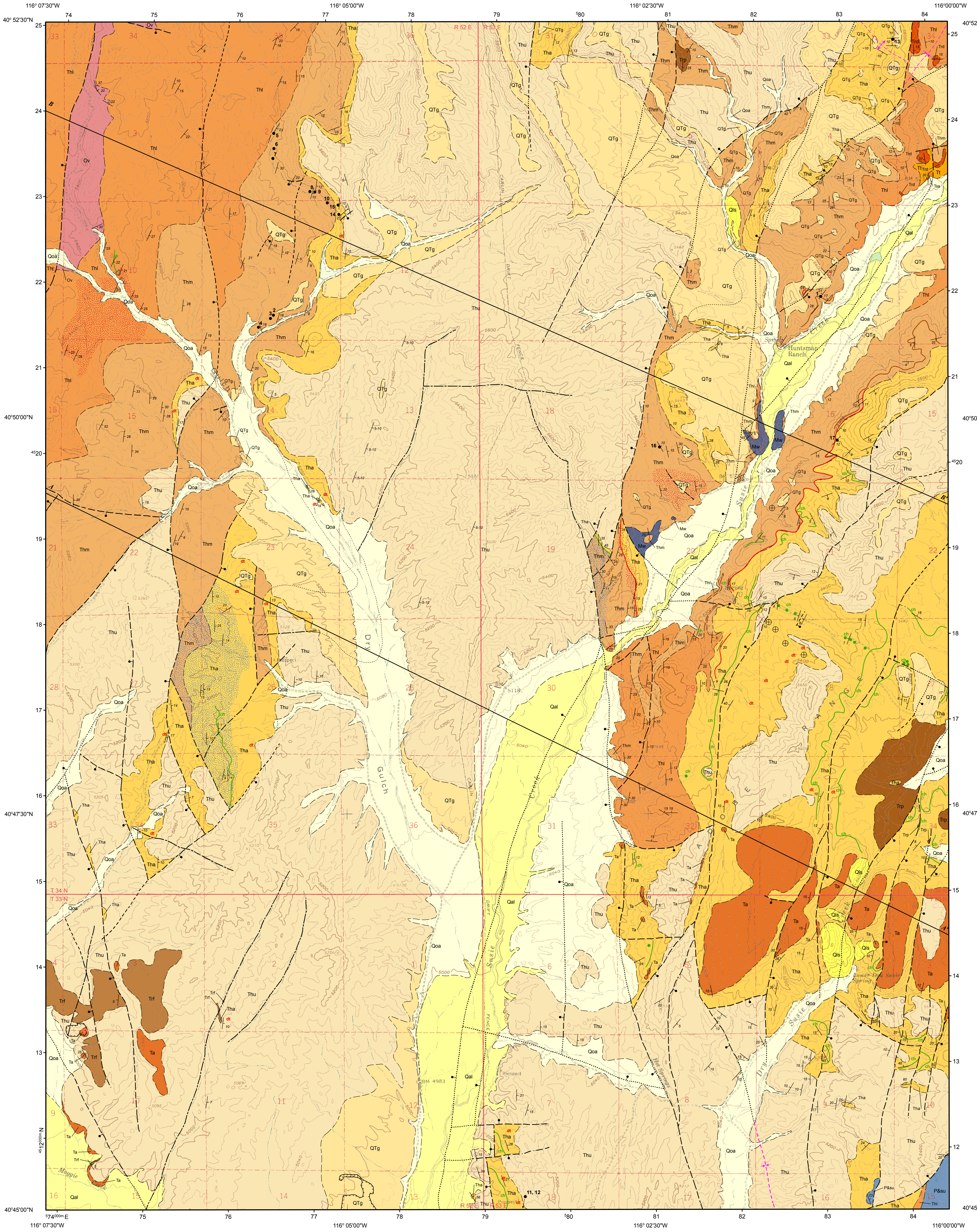
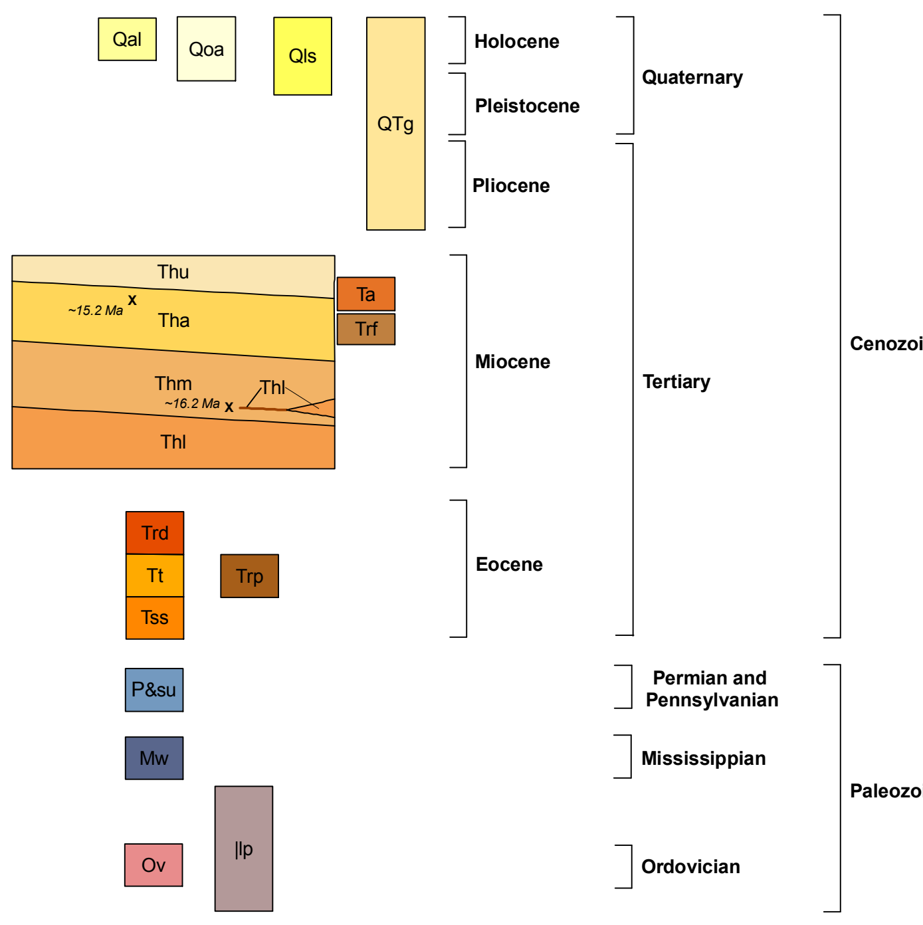
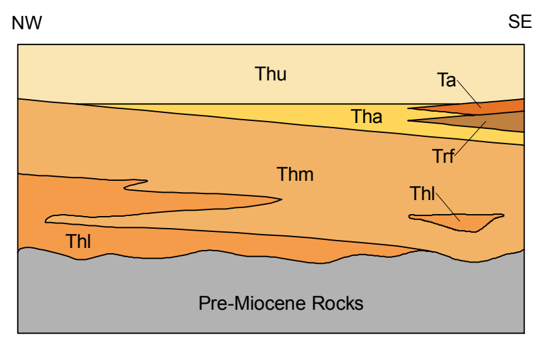






Stratigraphic relations of Miocene units

Qal	Alluvium (Quaternary)
Qoa	Older alluvial deposits (Quaternary)
Qls	Landslide deposits (Quaternary)
QTg	Gravel deposits (Quaternary and Pliocene)

HUMBOLDT FORMATION (MIOCENE)

Thu	Upper epiclastic member
Tha	Ash-rich member
Thm	Mixed epiclastic and ash-rich member
Thl	Lower epiclastic member

Ta	Andesite (Miocene)
Trf	Rhyolite (Miocene)
Trd	Rhyodacite (Eocene)
Tt	Tuff (Eocene)
Tss	Sandstone (Eocene)
Trp	Rhyolite porphyry (Eocene)
P&su	Sedimentary rocks, undivided of Ketner (1973) (Permian and Pennsylvanian)
Mw	Webb Formation (Mississippian)
|lp	Lower Paleozoic carbonate rocks beneath Roberts Mountains allochthon
Ov	Vinini Formation (Ordovician)

See accompanying text for full unit descriptions, notes, and references for this map.

Symbology (per FGDC-STD-013-2006)

Contact Long-dashed where approximate; short-dashed where inferred; dotted where concealed. *All contacts poorly exposed or covered by younger deposits.*

Fault Long-dashed where approximate; short-dashed where inferred; dotted where concealed. Ball on downthrown side. *On cross-sections, arrows show relative motion. All faults poorly exposed or covered by younger deposits.*

Thrust Fault Short-dashed where inferred. Sawteeth on upper plate. *On cross-sections only. Location and depth not known with any certainty.*

Lineament *Visible on aerial photographs but of indeterminate origin; could be produced by preferential weathering along faults or sedimentary bedding.*

Quarry *Andesite was quarried in the southwest corner of quadrangle; sand and gravel were quarried at the southern edge of the quadrangle. See text for details.*

Anticline Dashed where approximate.

Syncline Dashed where approximate. *Locally related to offset along a fault, but offset was minimal where shown as a synform.*

A ——— *A′*
Line of cross section

Strike and dip of bedding

41 Inclined   Vertical   ⊕ Horizontal

*
Feeder vent for andesite flow units
(NW 1/4, NW 1/4, sec. 10, T.33N., R.52E.)

● 9
Location of $^{40}Ar/^{39}Ar$ and (or) Tephra sample site Adjacent number refers to sample sites listed in Table 1.

dt
Exposure of diatomite bed Beds likely are laterally continuous between exposures.

● ch
Green chert bed

Area of diagenetically altered strata Secondary zeolites and chert are present in ash-rich sedimentary rocks in the lower part of member Tha in the west-central part of the quadrangle, as well as in member Thm near the center of the quadrangle. Reflectance spectroscopy (PIMA) analyses indicate that erionite and (or) clinoptilolite (spectra are indistinguishable) are the principal zeolites, with lesser chabazite; neither detrital nor authigenic clay minerals are present. Chert includes opaline silica and knobby, Magadi-type chert. In the Dry Gulch area, the degree of alteration diminishes to the north and is not present north of Dry Gulch; faults and unaltered younger units conceal the extent of the altered rocks in other directions. Alteration products also decrease upsection. In addition, a persistent green replacement chert bed (ch) in the west-central and entire eastern parts of the quadrangle is present at or near the contact between members Thm and Tha or, in the absence of Thm, within Tha. This bed contains chabazite in addition to chert.

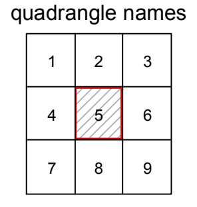
Area of silicified and bleached strata Massive secondary chalcedony and opaline silica are present in some tuffaceous units in member Thm in the upper Susie Creek area south of the Huntsman Ranch site and in members Thm and Tfl along upper Dry Gulch. Red-orange lines are thin zones of stratabound massive secondary chalcedony and quartz that form sinuous outcrop patterns. Opaline chalcedony and later calcite also fill pore spaces in pebble conglomerates in Thm. On the west side of Susie Creek sec. 17 & 20, T.34N., R.53E., textures suggest at least two sinter deposits at different stratigraphic horizons, each of which is <1 m thick and underlain by massive, stratiform silica replacement bodies in tuffaceous sediments. On the east side of Susie Creek, altered sedimentary rocks are present several tens of meters stratigraphically beneath the silicified zone shown on the map. In the Dry Gulch area, most sediments are bleached but do not contain significant amounts of secondary silica; one tuffaceous bed was replaced by white amorphous silica. Bleached beds alternate with unbleached beds, and the amount of bleached rocks diminishes along strike to the south and north of Dry Gulch. On the basis of dates and field relations in both areas, alteration of the strata ended by about 16.1 Ma.

GEOLOGIC MAP OF THE HUNTSMAN RANCH QUADRANGLE, ELKO COUNTY, NEVADA

Alan R. Wallace, Michael E. Perkins, and Robert J. Fleck

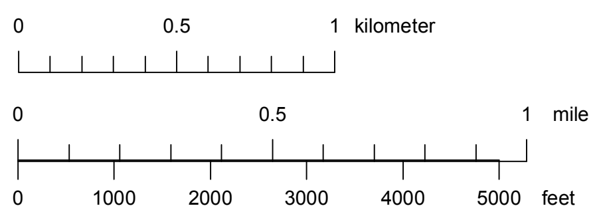
2008

Adjoining 7.5'
quadrangle names



1 Swales Mountain NW
2 Swales Mountain
3 Adobe Summit
4 Schroeder Mtn.
5 Huntsman Ranch
6 Hunter
7 Carlin West
8 Carlin East
9 Grindstone Mtn.

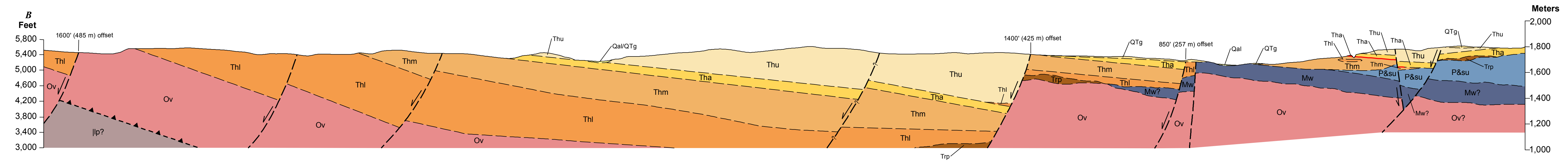
Scale 1:24,000

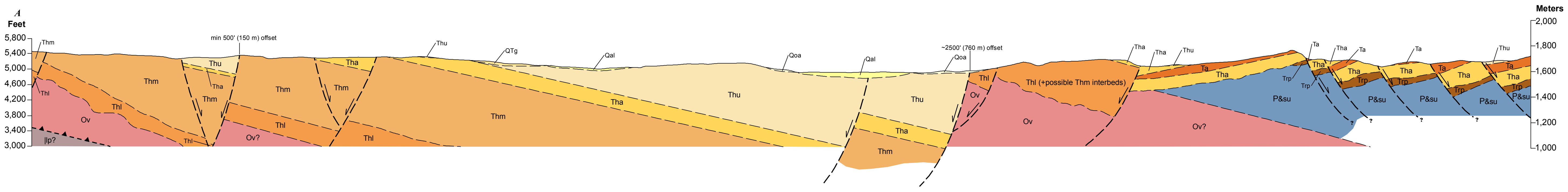


CONTOUR INTERVAL 40 FEET

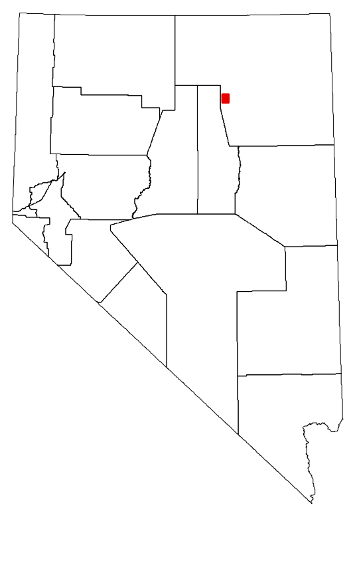
Projection: Universal Transverse Mercator, Zone 11,
North American Datum 1927 (m)

Base map: U.S. Geological Survey Huntsman Ranch 7.5' Quadrangle (1958)





Map location



Nevada Bureau of Mines and Geology
Mackay School of Earth Sciences and Engineering
College of Science
University of Nevada, Reno

Field work done in 2003-2005
Supported by the U.S. Geological Survey

PEER-REVIEWED MAP
Office review by Jim Trexler, Jack Deibert, Chris Henry,
Keith Howard, and Sue Beard
Field review by Chris Henry

Edited by Jack Hursh and Susan Tingley
Compilation by Alan R. Wallace
Cartography and map production in ESRI ArcGIS v9.2 (ArcGeology v1.2)
by Matthew Richardson
First Edition, February 2009
Printed by Nevada Bureau of Mines and Geology

For sale by:
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1969