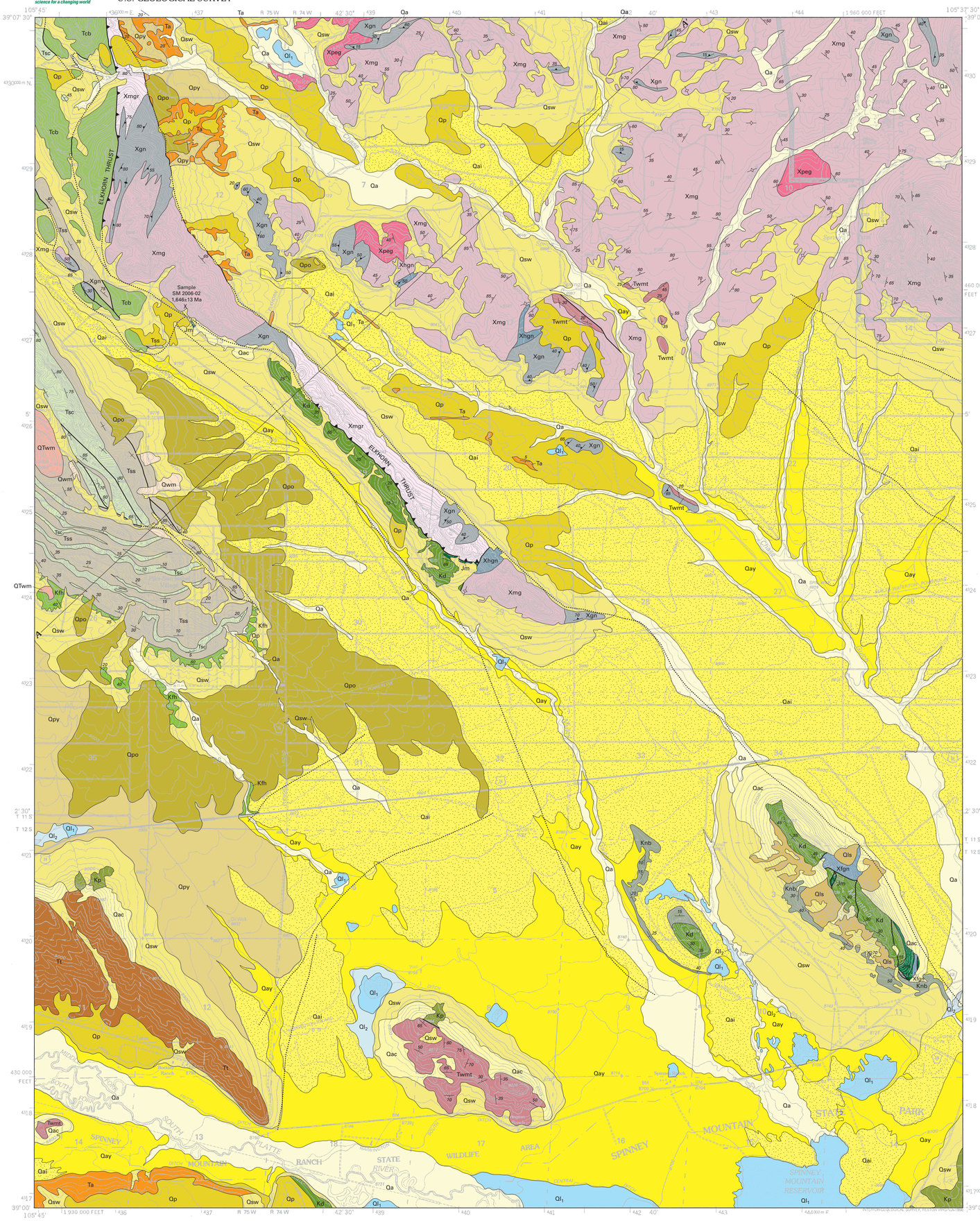

Base from U.S. Geological Survey, 1956
Polyconic projection
10,000-foot grid ticks based on Colorado coordinate system, central zone
1000-meter Universal Transverse Mercator grid, zone 13
1927 North American Datum

APPROXIMATE MEAN DECLINATION, 1956

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

COLORADO
QUADRANGLE LOCATION

Geology mapped by R.G. Bohannon and C.A. Ruleman, 2007–2008

Digital map database prepared by Lyndsay A. Hazan

Editing and digital cartography by
Gayle M. Dumonceaux
Denver Publishing Service Center

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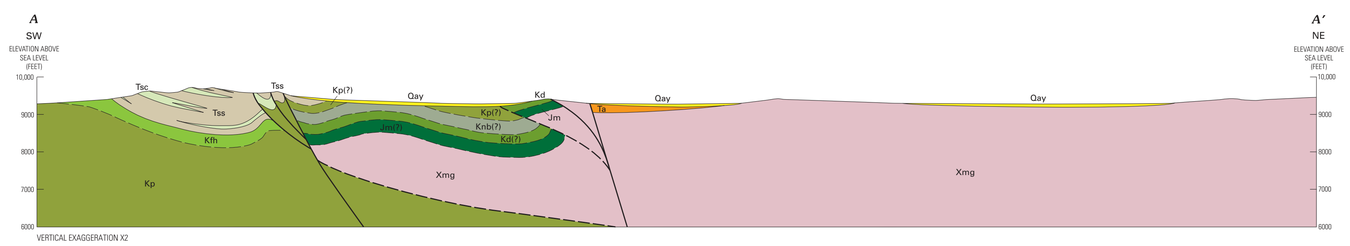

CORRELATION OF MAP UNITS

Qa	Ql_1	Holocene	QUATERNARY
Qac	Ql_2	Holocene	QUATERNARY
Qsw	Qls	Holocene	QUATERNARY
Qay	Qwm	Pleistocene	QUATERNARY
Qai		Pleistocene	QUATERNARY
Qp	Qpy	Pleistocene	QUATERNARY
	Qpo	Pleistocene	QUATERNARY
QTwm		Pliocene	QUATERNARY
Tt		Oligocene	TERTIARY
Ta		Oligocene	TERTIARY
Twmt		Eocene	TERTIARY
Tcb		Eocene	TERTIARY
Tss		Paleocene	TERTIARY
Tsc		Paleocene	TERTIARY
Kfh		Upper Cretaceous	CRETACEOUS
Kp		Upper Cretaceous	CRETACEOUS
Knb		Lower Cretaceous	CRETACEOUS
Kd		Lower Cretaceous	CRETACEOUS
Jm		Upper Jurassic	JURASSIC
Xmgr			EARLY PROTEROZOIC
Xpeg			EARLY PROTEROZOIC
Xmg			EARLY PROTEROZOIC
Xfgn			EARLY PROTEROZOIC
Xgn	Xhgn		EARLY PROTEROZOIC

DESCRIPTION OF MAP UNITS

Qa — **Alluvium (Holocene)**—Light-brown to dark-brown, organic-rich silt interbedded with light-tan to light-gray fine-grained sand and lenticular beds of pebble-size gravel. Gravel contains locally derived clasts of Tertiary to Precambrian rocks. Mapped within and adjacent to active stream channels and dry gulches and deposited within a low-gradient fluvial system as channel and overbank deposits. Unit has very weak soil development. Thickness less than 3 m

Ql_1 — **Lake, pond, and meadow deposits (Holocene)**—Unconsolidated, moderately to well sorted, silt, clay, and peat deposited in small lakes, ponds, or meadows. Medium brown, forms white ground surface when dry. Surrounds Spinney Mountain Reservoir (south map border) in small closed depressions and cattle ponds. Thickness generally less than 3 m

Qac — **Alluvium and colluvium, undivided (Holocene to latest Pleistocene)**—Unconsolidated, poorly to well sorted, interbedded silt, sand, and gravel. Unit locally contains cobble to boulder gravels. On steep slopes of mountains in southern part of quadrangle. Unit is of local extent and derivation. Thickness approximately 1–3 m

Ql_2 — **Lake, pond, and meadow deposits (Holocene and latest Pleistocene)**—Unconsolidated, moderately to well sorted, silt, clay, and peat deposited in small lakes, ponds, or meadows. Medium brown, forms white ground surface when dry. In small closed depressions surrounding several Ql_1 deposits; formed during time when area was wetter. Thickness generally less than 3 m

Qsw — **Slopewash deposits (late Pleistocene)**—Unconsolidated, poorly sorted boulders and gravel. Clasts include boulders of Wall Mountain Tuff (Twmt). Thickness not known, probably less than 2 m

Qls — **Landslide deposits (late Pleistocene)**—Unconsolidated, unsorted boulders, gravel, and sand. Forms thick deposits flanking northeast and southwest sides of Sulphur Mountain. Thickness not known, probably less than 3 m

Qay — **Younger alluvial deposits, undivided (late Pleistocene)**—Interbedded silt, sand, and pebble-size gravel mainly deposited during Pinedale glacial cycle (oxygen isotope stage 2, 14–24 ka) (Lisiecki and Raymo, 2005; Shroba, written commun., 2006). Depositional surface of deposits has well expressed bar-and-swale morphology with less than 1 m of relief. Gravel clasts are subrounded to well rounded and well sorted and comprised of locally derived clasts from Paleocene South Park Formation (Tss and Tsc) and Precambrian igneous and metamorphic rocks. Soils formed on unit have weak and thin (less than 20 cm) Bt horizons. Unit is commonly inset into unit Qai as much as 3 m. Maximum thickness < 5 m

Qwm — **Younger alluvium with Wall Mountain Tuff**—A subset of the younger alluvial deposits in which clasts and boulders are mostly derived from Wall Mountain Tuff (Twmt)

Qai — **Young dissected pediment deposits (middle Pleistocene)**—Poorly to moderately sorted sandy pebble to cobble-size gravel deposited on gently sloping aprons adjacent to strike ridges and bedrock-cored upland surfaces. Clasts are sub-angular to sub-rounded and locally derived from unit Tsc, within an eolian silt matrix (> 20 percent). Clasts show well developed angular facets from ventification processes. Most bedrock units beneath unit are deeply weathered in most places. Soils show strong development of stage 11 to weak stage III Bk horizons. Where unit is mapped adjacent to unit Xmgr, deposits consist of deeply grussified orthogneissic rocks and have weak and discontinuous soil development. Thickness averages 4–6 m

Qp — **Piedmont deposits (middle to early Pleistocene)**—Poor to moderately sorted sandy pebble to cobble-size gravel deposited on gently sloping aprons adjacent to strike ridges and bedrock-cored upland surfaces. Deposits form a thin mantle of alluvium on pediment surfaces. Clasts are sub-angular to sub-rounded and locally derived from unit Tsc, within an eolian-silt matrix (> 20 percent). Clasts show well-developed angular facets from ventification processes. Most bedrock units beneath unit Qp are deeply weathered in most places. Soils commonly have stage II to weak stage III Bk horizons. Unit is subdivided into younger and older deposits where morphostratigraphic relationships permit. Thickness averages 1–2 m

Qpy — **Younger piedmont deposits (middle Pleistocene)**

Qpo — **Older piedmont deposits (early Pleistocene)**

QTwm — **Old alluvium (early Pleistocene to late Pliocene)**—Poorly sorted, nearly unconsolidated boulder-to-pebble conglomerate capping Maria Mountain (VABM 9898) at west-central edge of quadrangle. Poorly exposed, but easily recognized by presence of abundant clasts of Wall Mountain Tuff (Twmt). Clasts are as large as 1–2 m in diameter. Exposure is remnant of a once-widespread alluvial deposit that probably had a source in the volcanic terrain to southwest. Unit was source of similar clasts in nearby younger alluvial deposits (Qwm) in canyons and on slopes beneath Maria Mountain. Thickness about 10 m

Tt — **Tallahasse Creek Formation (Oligocene)**—Very poorly exposed, coarse-grained, and unsorted conglomerate. Clasts as large as several meters are composed primarily of assorted metamorphic and igneous rocks probably derived from exposures of Proterozoic rocks to northeast. Forms a large hill in southwestern corner of quadrangle where it can be identified primarily by abundant large boulders scattered randomly on hillsides. Thickness not known

Ta — **Antero Formation (Oligocene)**—Very poorly exposed, non-resistant yellowish-white, porous limestone, locally silicified. Minor amount of poorly consolidated conglomerate and interbedded sandstone present locally. Sample of tuffaceous rock from Antero has been dated from quadrangle by $^{39}Ar/^{40}Ar$ at 33.8 Ma (Bruce Bryant, written commun., 2008; McIntosh and Chapin, 2004). Thickness not known

Twmt — **Wall Mountain Tuff (Oligocene)**—Ash-flow tuff, weathers reddish-brown to yellowish-brown; resistant and well exposed in most places forming cliffs and ledges. Moderately to densely welded with black vitrophyric lenses common. Flow layering is common, but very irregular in orientation and not parallel or only sub-parallel to base of unit, suggesting post-settling flow. K-Ar ages of 40.0 ± 1.2 and 34.8 ± 1.1 Ma on biotite; 35.4 ± 1.1 and 37.3 ± 1.9 Ma on sanidine and biotite have been reported locally (Marvin and Menhert, 1988). McIntosh and Chapin (2004) similarly obtained a mean age of 36.69 ± 0.09 Ma for this unit based on five sanidine $^{39}Ar/^{40}Ar$ age determinations. About 30 m thick

Tcb — **Conglomerate and breccia (Eocene?)**—Very coarse-grained, very poorly sorted, sub-angular to sub-rounded, boulder- to cobble-size conglomerate with interbedded, coarse grained sandy lenses ranging from 0.5–2.0 m in thickness. Clasts are primarily monzogranite with little or no foliation, derived from unit Xmgr. Unit is interpreted to mostly overlap the Elkhorn thrust fault, but earliest deposits may be cut by the thrust. Probably derived from local escarpment created during thrusting. Exposed in northwest corner of quadrangle where unit unconformably or structurally overlies steeply dipping-to-vertical beds of South Park Formation. Thickness varies but generally < 100 m

South Park Formation (Paleocene)

Tss — **Sandstone and conglomerate**—Brown to brown-olive-drab sandstone and conglomerate. Sandstone is coarse-to-medium grained with poorly sorted, angular to sub-angular grains. Sandstone fines upward in unit with lower one-third being almost entirely coarse grained and the upper one-third being medium grained. Sandstone in lower part of unit probably had a mostly volcanic source to southwest, owing to abundance of volcanic lithic fragments, and upper part is more granitic, with abundant quartz and feldspar grains, probably from northeast. Cross-bedding and discontinuous, lenticular beds are common. Discontinuous conglomerate interbeds are nearly ubiquitous, except in lowest part of unit. Conglomerate is differentiated as a mapped unit only in places where it exists in a unit that is thick enough to show and is the sole lithology. Clasts are typically well rounded and oblate, well sorted, and composed chiefly of a variety of intermediate-to-mafic volcanic types with lesser granitic and gneissic types

Tsc — **Conglomerate**—Brown to brown-olive-drab conglomerate. Conglomerate is differentiated as a mapped unit only in places where it exists in a unit that is thick enough to show and is the sole lithology. Clasts are typically well rounded and oblate, well sorted, and composed chiefly of a variety of intermediate-to-mafic volcanic types with lesser granitic and gneissic types. Clasts are commonly clast-supported, vary in diameter from 1 m to 20 cm (larger clasts are rare), and form in beds and lenses that vary from 2 m to several meters thick. Conglomerate typically is resistant (more so than sandstone) and forms ridges and peaks, although exposures are not common, except along crests of ridges or on peaks. Abundance of volcanic clasts indicates unit was primarily derived from volcanic fields to west or south

Kfh — **Fox Hills Sandstone (Upper Cretaceous)**—Yellowish-brown to grayish-brown, well-sorted, fine- to medium-grained, crossbedded sandstone grading down into a parallel bedded calcareous (marine) sandstone. Within map area, most exposures are deeply weathered and covered with soil. Maximum thickness 110 m (Wyant and Barker, 1976)

Kp — **Pierre Shale (Upper Cretaceous)**—Interbedded, brown, gray, and yellowish marine shale, siltstone, and sandstone that locally contains calcareous nodules. Poorly exposed owing to easy erodibility and surface cover. Elsewhere, complete section of Pierre Shale exceeds 1,800 m

Knb — **Niobrara Formation and Benton Shale, undifferentiated (Upper Cretaceous)**—Poorly exposed and non-resistant gray marly shale and black shale. Probably widespread, but covered by soil and younger units in most places. Exposed in southeastern part of quadrangle west of Sulphur Mountain, but not well enough to reliably differentiate Niobrara Formation from Benton Shale. Combined units are about 200 m thick elsewhere in South Park

Kd — **Dakota Sandstone (Lower Cretaceous)**—Sandstone, gray-brown to light-brown, fine-to-medium grained, well-sorted, quartz-rich. Moderately cemented to friable in most places, except at Sulphur Mountain where it approaches being quartzite. Crossbedded in most areas, ripple-marked in some places. About 60 m thick

Jm — **Morrison Formation (Upper Jurassic)**—Siltstone and mudstone, gray to purple, non-resistant and poorly exposed. Only occurrences in this quadrangle are in a small exposure beneath the southern end of Elkhorn thrust and one near the south end of Sulphur Mountain. Thickness not known

Xmgr — **Monzogranite (Early Proterozoic)**—Pale-orange, brown-orange, and pink, equigranular, garnet-bearing, biotite monzogranite. Unit is deeply weathered to grus in most places; however, eroded clasts locally have weak foliation. Locally contains pegmatite and aplite veins and diffuse xenoliths of biotite gneiss and felsic gneiss. Unit dated at 1,646 ± 13 Ma (see sample SM 2006-02, northwestern corner of map)

Xpeg — **Pegmatite (Early Proterozoic)**—Coarse-grained, pink and white pegmatite primarily composed of orthoclase, plagioclase, biotite, and muscovite

Xmg — **Foliated Monzogranite (Early Proterozoic)**—Pale-orange, brown-orange, and pink, equigranular, garnet-bearing, biotite monzogranite; typically medium-grained. In most place is similar to monzogranite of Middle Proterozoic age (Xmgr), but commonly exhibits a consistent foliation formed by consistent alignment of mafic constituents; some rudimentary flow layering is present locally

Xfgn — **Felsic gneiss (Early Proterozoic)**—Light-gray to white, fine- to medium-grained, leucocratic, moderately to strongly foliated plagioclase-quartz-biotite gneiss of apparent granitic origin

Xgn — **Biotite gneiss (Early Proterozoic)**—Gray, black, and white, layered and well-foliated, fine- to coarse-grained biotite-plagioclase-quartz gneiss. Unit is locally interlayered with hornblende gneiss and sillimanite-biotite-quartz gneiss, and contains garnetiferous zones. Leucocratic, plagioclase-potassium feldspar-quartz-rich layers of gneiss comprise 5 to 50 percent of unit

Xhgn — **Hornblende gneiss (Early Proterozoic)**—Dark-colored, medium- to coarse-grained amphibolite and amphibolitic gneiss, strongly foliated in most places

STRUCTURAL SUMMARY

The main structural element in the Sulphur Mountain quadrangle is the Elkhorn thrust. This northwest-trending fault is the southernmost structure that bounds the west side of the Late Cretaceous and early Tertiary Front Range basement-rock uplift. The Elkhorn thrust and the Williams Range thrust that occurs in the Dillon area north of the quadrangle (Kellogg, 2004) bound the west flank of the Williams Range and the Front Range uplift in the South Park area. Kellogg (2004) described widespread, intense fracturing, landsliding, and deep-rooted scarps in the crystalline rocks that comprise the upper plate of the Williams Range thrust. The latter thrust is also demonstrably a low-angle structure upon which the fractured bedrock of the upper plate was translated west above Cretaceous shales. Westward thrusting along the border of the Front Range uplift is probably best developed in that area. By contrast, the Elkhorn in the Sulphur Mountain quadrangle is poorly exposed and occurs in an area of relatively low relief. The thrust also apparently ends in the central part of the quadrangle, dying out into a broad area of open, upright folds with northwest axes in the Sulphur Mountain area.

The South Park Formation (Tss and Tsc) was deposited during the Paleocene in a fluvial environment that formed over a broad region west and southwest of the Elkhorn thrust that underwent gentle subsidence. The fluvial beds are tightly folded and overturned near the thrust. The overturned beds are overlain by very coarse-grained, unsorted, and unstratified conglomerate and breccia (Tcb) that was derived from granites in the upper plate of the thrust. Some of the bedrock in the upper plate adjacent to the thrust is highly fractured, especially to the north of Sulphur Mountain quadrangle. Bedrock fracturing of the hanging wall, probably owing to thrust activity, is a likely first step in the development of the conglomerate and breccia. Landsliding and thrust 'bulldozing' were probably each important as the thrust broke the surface, over-running the granitic debris shed off the uplifting hanging-wall block. Our mapping suggests that the contact at the base of the conglomerate is a low angle feature, but poor exposures preclude a determination as to whether it is chiefly depositional or tectonic in nature.

The Elkhorn thrust is not well exposed except in the central part of the quadrangle where Middle Proterozoic monzogranite (Xmgr) tectonically overlies Jurassic Morrison Formation (Jm) and Cretaceous Dakota Sandstone (Kd). Here the thrust surface dips about 45° to the east-northeast and the apparent throw is comparatively small.

Neogene and Quaternary normal faulting has dissected this pre-existing Laramide structure in a conjugate pair oriented northwest and northeast. Shaffer (1980) and Shaffer and Williamson (1986) found late middle Pleistocene and late Pleistocene gravels displaced 1.2 to 1.8 m on the East-Side Chase Gulch fault; most likely indicating one seismic event on the fault system within the last 130,000 years. The northwest-trending normal fault system has been assigned a slip rate of < 0.2 mm/yr with the most recent event being between 13–30 ka (Kirkham and Rogers, 1981; Colman, 1985; and Widmann and others, 1998). Based on the orientation of the conjugate pair, these extensional normal faults are probably a product of the Rio Grande rift system with an east-northeast–west-southwest-oriented tensional stress field.

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MAP EXPLANATION

Contact

Normal or oblique-slip fault—Dotted where concealed

Thrust or high-angle reverse fault

Strike and dip of bedding

20 **Inclined**

70 **Overturned**

Vertical

Strike and dip of foliation

80 **Inclined foliation in igneous rock**—Showing strike and dip

Vertical foliation in igneous rock—Showing strike

40 **Inclined foliation in metamorphic rock**—Showing strike and dip

Vertical foliation in metamorphic rock—Showing strike

Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government

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GEOLOGIC MAP OF THE SULPHUR MOUNTAIN QUADRANGLE, PARK COUNTY, COLORADO

By
Robert G. Bohannon and Chester A. Ruleman

2009