Geologic Map of the Hagan Quadrangle, Santa Fe County, New Mexico

By

Cather, Steven M.; Connell, Sean D.; Lucas, Spencer G.; Picha, Mark G.; Black, Bruce A.

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New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 050

Scale 1:24,000

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New Mexico Bureau of Geology and Mineral Resources
801 Leroy Place, Socorro, New Mexico, 87801-4796

GEOLOGIC MAP OF THE HAGAN 7.5-MINUTE QUADRANGLE, SANDOVAL COUNTY, NORTH-CENTRAL NEW MEXICO

by
Steven M. Cather and Sean D. Connell
New Mexico Bureau of Geology and Mineral Resources
801 Leroy Place
Socorro, NM 87801

Spencer G. Lucas
New Mexico Museum of Natural History and Science
1801 Mountain Road NW
Albuquerque, NM 87104

Mark G. Picha
15902 Knolls Lodge Drive
Houston, TX 77095

Bruce A. Black
Black Oil Co.
206 West 38th Street
Farmington, NM 87401

New Mexico Bureau of Geology and Mineral Resources
A Division of the New Mexico Institute of Mining and Technology
801 Leroy Place
Socorro, New Mexico 87801

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INTRODUCTION

The Hagan 7.5-minute quadrangle comprises an area of about 158 km^2 (61 mi^2) just east the Rio Grande Valley in Sandoval County, New Mexico. The study area encompasses lands of the Pueblo of San Felipe and the Diamond Tail Ranch as well as private and public (state and federal) lands. The study area is south of Espinaso Ridge and west of highway NM14. A nearly complete stratigraphic section, ranging in age from Pennsylvanian to Quaternary, is exposed on the quadrangle. Early work in the study area includes regional reconnaissance by Stearns (1953) and Kelley (1977). Detailed mapping by Black (1979) and Picha (1982) is incorporated in this report.

Note to Users

A geologic map displays information on the distribution, nature, orientation and age relationships of rock and deposits and the occurrence of structural features. Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic quadrangle map are based on field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist. Cross sections were constructed based upon the interpretations of the authors made from geologic mapping, and available subsurface (drillhole) data. Cross sections should be used as an aid to understanding the general geologic framework of the map area, and not be the sole source of information for use in locating or designing wells, buildings, roads, or other man-made structures. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. The topographic base for the geologic map is the Hagan 7.5 minute topographic quadrangle, published by the United States Geological Survey at a scale of 1:24,000. Topographic and cultural changes associated with recent development may not be shown.

Mapping of this quadrangle was funded by a matching-funds grant from the 2000-2002 STATEMAP program of the U.S. Geological Survey, National Cooperative Geologic Mapping Program, to the New Mexico Bureau of Geology and Mineral Resources (Dr. Peter A. Scholle, Director; Dr. Paul W. Bauer, P.I. and Geologic Mapping Program Manager). The quadrangle map has been placed on open file in order to make it available to the public as soon as possible. The map has not been reviewed according to New Mexico Bureau of Geology and Mineral Resources standards. Revision of the map is likely because of the on-going nature of work in the region. ***The report and map should not be considered final and complete until published by the New Mexico Bureau of Geology and Mineral Resources.***

DESCRIPTION OF MAP UNITS

CENOZOIC ERATHEM

Neogene and Quaternary System

Colluvium and landslide deposits

Qca **Colluvium and alluvium, undivided (upper to middle Pleistocene) —** Poorly consolidated, poorly sorted and stratified, fine- to coarse-grained, clast- and matrix-supported deposits derived from a variety of mass-movement hillslope processes, including debris flow, shallow slump and creep. Discontinuously preserved along margins of valleys capped by the Tuerto Formation. Locally differentiated where areally extensive or thick. Variable thickness, ranging 0-3 m.

Qls **Landslide debris (middle Pleistocene) —** Blocks of well cemented conglomerate from the basal Tuerto Formation. Locally found as discontinuous boulders just below basal Tuerto Formation contact about 15-25 m above local base level. This high elevation relative to base level suggests deposits formed prior to late Pleistocene time. Variable thickness and grades into thin hillslope colluvium with an estimated thickness ranging from 0-6 m.

Alluvium

Qae **Eolian sand, stream alluvium, and colluvium, undivided (Holocene to upper Pleistocene) —** Very poorly consolidated, moderately to well sorted, light brown to yellow brown (7.5 5/4 to 2.5YR 7/6), fine- to medium-grained sand and silty sand with scattered pebbles that commonly forms a relatively thin, discontinuous mantle over broad upland areas, most notably on interfluves of streams cut into the Tuerto Formation and on ridges underlain by Mesozoic strata. Soil development is generally weak with Bw and Bwk horizons, and Stage I and II carbonate morphology. Surface is commonly stabilized by vegetation where not disturbed by human activity. May locally contain hydrocollapsible soils. Mapped only where areally extensive or thick. Variable thickness, ranging from 0-2 m.

Qa **Modern and historic stream alluvium (Historic to Holocene) —** Unconsolidated deposits of sand and pebbly to cobbly gravel with minor, thin silty to clayey sand lenses. Inset against young stream alluvium of unit **Qvy** and underlies modern arroyos. Alluvium derived from Triassic rocks is reddish-brown, whereas, alluvium derived from Cretaceous rocks are pale-brown to yellow. Differentiated only in deep or wide valleys. Soils are development is minimal and deposit surface exhibit well-developed bouldery and cobbly gravel-bar topography. May locally contain hydrocollapsible soils. Base not exposed, but thickness is estimated to be less than 4-9 m.

Qvy **Young stream alluvium (Holocene to uppermost Pleistocene)** — Poorly consolidated deposits of light-brown to yellow (2.5-10YR) sand and gravel inset against upper and middle Pleistocene deposits of units **Qpm1** and **Qpm2**. Slightly dissected surface contains weakly developed soils exhibiting Stage I to II carbonate morphology. Locally includes alluvium of unit **Qa** within inset narrow arroyos and is commonly veneered with eolian sands and silts similar to unit **Qae**. May locally contain hydrocollapsible soils. Contains at least two terrace deposits that are about 3 and 7 m above active streams (i.e., above local base level). Commonly contains colluvium near valley margin hillslopes. Variable thickness, ranging up to 3 m.

Qpm2 **Middle stream alluvium, lower subunit (upper Pleistocene)** — Poorly to moderately sorted and moderately consolidated deposits of pale-brown to reddish-brown (7.5-10YR) gravel and sand. Soils exhibit Bk horizons and Stage II+ to weak Stage III carbonate morphology. Gravel are predominantly subangular to subrounded pebbles, cobbles and minor boulders of Ortiz porphyry, with subordinate to minor amounts of rounded to subrounded light green to black hornfels, quartzite, and sparse petrified wood. Deposit surface is about 13 m above local base level. Thickness is about 2-3 m.

Qpm1 **Middle stream alluvium, upper subunit (middle Pleistocene)** — Moderately consolidated deposits of pale-brown to reddish-brown (7.5-10YR) subangular to subrounded pebble to boulder gravel and sand. Unit is poorly exposed and soils are commonly stripped, but contain thick carbonate rinds on clasts, indicating the presence of at least Stage III carbonate morphologic development. Gravel in streams along the southern and eastern part of the quadrangle. are predominantly subangular to subrounded pebbles, cobbles and minor boulders of Ortiz porphyry, with subordinate to minor amounts of rounded to subrounded light green to black hornfels, quartzite, and sparse petrified wood. Gravel from the western and southwestern part of the quadrangle contains abundant limestone and sandstone. Deposit surface is about 17 m above local base level. Topographic relationships indicate unit is inset about 30-67 m below base of Tuerto Formation. Unit is about 2-3 m thick.

Qpo **Older alluvium, undivided (middle to lower Pleistocene)** — Poorly to moderately consolidated, sorted and stratified, yellowish-brown (10YR) pebbly to bouldery gravel and sand with minor silty-clay mixtures. Clasts are derived from local upland sources. Soils are commonly stripped or strongly modified. Inset against the Tuerto Formation and recognized as ridge-capping gravel. Gravel composition is dominated by Ortiz porphyry (~75%) and hornfels (~25%) recycled from the Tuerto Formation. Gravel is generally less than 4 cm in diameter and contains subordinate (~5-15%) boulders up to 20 cm in diameter and sparse (<2%) boulders up to 70 cm in diameter. Locally divided into two subunits on the basis of inset and topographic relationships. Variable thickness, about 3-5 m.

Qpo2 **Older alluvium, lower subunit (middle to lower Pleistocene)** — Poorly to moderately sorted and moderately consolidated deposits of pale-brown to reddish-brown (7.5-10YR) gravel and sand. Soils are commonly stripped, but contain thick carbonate rinds on clasts, suggesting the presence of at least Stage II+ to III carbonate morphologic development. Gravel clasts are predominantly subangular to subrounded pebbles, cobbles and minor boulders of Ortiz porphyry, with subordinate to minor amounts of rounded to subrounded light green to black hornfels, quartzite, and rare petrified wood. Ortiz porphyry clasts are generally split and weathered to grus. Topographic relationships indicate unit is inset about 55-67 m below the base of the Tuerto Formation.

Qpo1 **Older alluvium, upper subunit (lower Pleistocene)** — Moderately consolidated deposits of pale-brown to reddish-brown (7.5-10YR) subangular to subrounded pebble to boulder gravel and sand. Unit is poorly exposed and forms a thin and discontinuous gravelly veneer overlying a strath inset against the Tuerto Formation. Soils are poorly exposed but contain thick carbonate rinds on clasts, indicating the presence of at least Stage III carbonate morphologic development. Topographic relationships indicate unit is less than 6-12 m inset below the top of the Tuerto Formation. Unit is generally less than 2 m thick.

Spring deposits

Qpsy **Alluvium and spring deposits, lower subunit (Holocene to upper Pleistocene)** — Poorly to moderately cemented pink (7.5YR) silt and sand with medium bedded, irregular interbeds of white gypsum. Deposit surface commonly covered by grasses. Deposit commonly saturated with water near springs and has a faint to distinct sulfurous odor suggesting emanation of H_2S gas from springs or from decomposition of organic matter. Topographic relationships indicate unit is inset against spring deposits of units **Qpso** and **Qsp**. Estimated thickness is 1-4 m.

Qpso **Alluvium and spring deposits, upper subunit (upper to middle Pleistocene)** — Poorly to moderately cemented pink (7.5YR) silt and sand with medium bedded, irregular interbeds of white gypsum. Deposit surface commonly covered by grasses. White, gypsiferous spring mounds found along N-NW trending alignments just north of the Town of Tejon site at the western portion of the quadrangle. Contains strongly efflorescent, finely crystalline layers composed of gypsum. Underlying Triassic rocks locally contain abundant crystals of selenite gypsum oriented subhorizontally and subvertically, suggesting minor faulting of substrate. Deposit surface is about 9 m above local base level. Thickness is variable, ranging from about 2-4 m.

Qsp **Travertine and spring deposits (Pleistocene)** — Light-gray nodule to massive limestone and calcium-carbonate cemented sandstone interlayered with mudstone. Unit is about 6 m thick.

Santa Fe Group (upper Oligocene-lower Pleistocene)

The Santa Fe Group comprises the syntectonic sedimentary fill and associated volcanic rocks of basins within the Rio Grande rift of southern Colorado, New Mexico and northern Chihuahua (Bryan, 1938; Chapin and Cather, 1994). The Santa Fe Group consists of axial-fluvial and piedmont-slope related to deposition within the Hagan embayment prior to widespread valley incision. The Santa Fe Group is divided into lower and upper parts in the map area. For the purposes of mapping, these units were divided on the basis of textural criteria and dominantly volcaniclastic versus dominantly nonvolcaniclastic nature using the method of Cather (1997).

Upper Santa Fe Group (Pliocene(?)-lower Pleistocene)

Tuerto Formation, volcanic-bearing member (lower Pleistocene to Pliocene) — Yellowish- to reddish-brown and yellowish-red (5-10YR), moderately consolidated and slightly cemented, moderately to well stratified pebble to cobble conglomerate, and pebbly to cobbly sandstone, and sandstone. Matrix in conglomerates is fine- to very coarse-grained, very poorly sorted sandstone, and gravel clasts contain abundant subrounded to subangular, commonly porphyritic, volcanic and hypabyssal igneous rocks from the Ortiz Mountains area (40-50%). Also contains light-green laminated hornfels, yellowish-brown and black massive hornfels (45-50%), and minor (10-15%) rounded quartzite and black and brown chert, subrounded sandstone, subrounded to subangular petrified wood, and rare ironstone. Ortiz porphyry clasts are typically platy in shape and exhibit imbrication that is indicative of west or southwest paleoflow. Unit is typically nondeformed and subhorizontally bedded, except adjacent to fault zones where dips of 5-10° locally occur. Overlies Tanos and Blackshare formations of Connell et al. (in review) and older strata with angular unconformity. The constructional top of the Tuerto Formation forms a broad, west-sloping piedmont associated with the Ortiz Mountains. Three textural lithofacies of volcanic-bearing Tuerto Formation occur in the study area. The most widespread is the conglomeratic lithofacies ($\mathbf{QTtpc_{(v)}}$). The subequal sandstone-conglomerate lithofacies ($\mathbf{QTpcs_{(v)}}$) occurs locally along the east margin of the quadrangle near Arroyo Coyote. The sandstone-dominated lithofacies ($\mathbf{QTtps_{(v)}}$) occurs locally north of Arroyo Cuchillo and may represent a low-gradient area of confluence between the volcanic-bearing and limestone-bearing piedmonts. Variable thickness, ranging from about 12-30 m.

Tuerto Formation, limestone-bearing member (lower Pleistocene to Pliocene) — Pale-brown (10YR), poorly sorted, medium to thick bedded sand and sandstone and pebbly to cobbly sand and conglomeratic sandstone with scattered boulders up to 50 cm in diameter. Ortiz porphyry gravel is sparse to locally abundant near boundaries with porphyry bearing member of the Tuerto Formation.

Derived from eastern slope of Sandia Mountains. Upper surface contains well-developed soil with thick calcium-carbonate rinds on clasts and at least Stage III pedogenic carbonate morphologic development. Gravel is composed of approximately 80% limestone of the Madera Fm, ~9% Proterozoic crystalline rocks, ~8% reddish-brown sandstone of the Abo Formation, and ~3% conglomerate and sandstone of the Sandia Formation and Glorieta Sandstone, respectively. Paleoflow was generally north or north-east. Contact with volcanic-bearing member is gradational over an area several km in width near Arroyo Cuchillo. Variable thickness, ranging from 8-27 m.

Lower Santa Fe Group deposits (upper Oligocene–upper Miocene(?))

Blackshare Formation (Miocene) — Piedmont facies consisting dominantly of light-brown to medium gray volcaniclastic conglomerate and sandstone. Clasts are composed predominantly of volcanic and hypabyssal rocks. Sandstones are volcaniclastic, light-brown in color, and form lenticular beds 0.2 to 1.5 m thick. Unit is moderately to well indurated. Unconformably overlain by Tuerto Formation. More than 700 m in thickness (Connell et al., *in review*). Only one lithofacies of the Blackshare is present on the Hagan quadrangle. This is a piedmont facies (**Tbpcs$_{(v)}$**) consisting of subequal volcaniclastic sandstone and conglomerate. Paleoflow was toward the west or northwest.

Tanos Formation (upper Oligocene-Miocene) — Very pale-brown to reddish-brown (5-10YR) tabular and lenticular sandstone and conglomerate. Concretionary sandstone intervals are present in the lower part of the section. Gravel is composed predominantly of volcanic and hypabyssal rocks from the Ortiz Mountains. Moderately to well indurated and disconformably overlies Espinaso Formation. Unit represents the lower, dominantly fine-grained facies of the lower Santa Fe Group in the Hagan embayment. In the Hagan quadrangle, the Tanos Formation consists of two lithofacies: a thin, local conglomerate-sandstone piedmont unit (**Ttpcs$_{(v)}$**) at the base of the unit and a sandstone-dominated distal piedmont facies (**Ttps$_{(v)}$**). Paleoflow was westerly. The Tanos Formation is 270 m thick at the type section in the adjacent San Felipe Pueblo NE quadrangle (Connell et al., *in review*).

Paleogene System

Tid Intermediate to mafic dikes. Dikes dip steeply, trend east–northeast, and are 1 to 10 m thick.

Tis Intermediate composition sills. Trachytic to porphyritic textures, 2–15 m thick.

Te **Espinaso Formation (upper Eocene-Oligocene)** — Unit comprises the remnants of widespread, coarse-grained, volcaniclastic aprons that accumulated adjacent to volcanic vent complexes of the Ortiz Mountains. Consists of volcaniclastic and volcanic rocks, mostly volcaniclastic sandstone and volcanic cobble conglomerate with minor biotite-latite lava flows. Lower part is bluish-gray tuffaceous sandstone with horizontal bedding and rare planar and trough crossbedding and minor conglomerate. Middle part is mostly gray to yellowish-brown volcanic cobble conglomerate, debris-flow deposits and pyroclastic flow units. Upper part is bluish-gray, pinkish-gray and yellowish-brown, matrix-supported volcanic boulder and cobble conglomerate. Conglomerate clasts throughout are mostly of hornblende-latite, augite-latite or biotite-latite composition. Originally defined by Stearns (1953a). Deposits are dominated by well-bedded sandstone and conglomerate that represent a braid plain that drained the Ortiz Mountains eruptive center to the east (Erskine and Smith, 1993). Erskine and Smith (1993) report that the lower part of the unit is calc-alkaline (hornblende and pyroxene) and the upper part of the unit is alkaline (biotite and pyroxene). Unconformably overlain by lower Santa Fe Group deposits and rests conformably on nonvolcanic Galisteo Formation. Various informal subdivisions were proposed by Kautz et al. (1981) and Smith et al. (1991). K/Ar ages and magnetostratigraphy indicate a late Eocene-Oligocene age (Kautz et al., 1981; Prothero and Lucas, 1996). Paleoflow direction, based on clast imbrication orientations, in the basal part of the unit was generally west. Unit is about 430 m thick.

Tg **Galisteo Formation (Eocene) —** Mostly variegated red, green, purple and gray mudstone with intercalated thin beds of crossbedded arkosic sandstone, except upper 60 m of unit, which are dominantly yellow, trough crossbedded arkosic sandstone with fossil logs and some tuffaceous mudstone. Base of formation picked at laterally continuous conglomerate that has clasts up to 4 cm in diameter of chert, quartzite and Paleozoic limestone and sandstone, and minor pink granite. Unit mostly forms slopes and strike valleys between more resistant Diamond Tail and Espinaso formations. Deposited within fluvial channels and broad floodplains in an early Tertiary basin between Albuquerque and Santa Fe, New Mexico. Basal conglomerates are coarser grained (generally > 2 cm in diameter) and more compositionally diverse (contains quartzite, chert, limestone, granite, and sandstone) than the underlying Diamond Tail Formation. Conformably overlain by Espinaso Formation. Basal contact with the Diamond Tail Formation is a regional angular unconformity but appears disconformable in individual outcrops. Fossil mammals collected near Cerrillos and just north of the Hagan quadrangle indicate an age of Wasatchian-Duchesnean (early to late Eocene) (Lucas and Kues, 1979; Lucas, 1982). Paleoflow was variable but generally south or southwest. 860-979 m thick (Lucas, 1982; Lucas et al., 1997).

Tdt **Diamond Tail Formation (upper(?) Paleocene to lower Eocene) —** Mostly coarse-grained subarkosic to arkosic sandstone and conglomeratic sandstone with lesser amounts of drab, green, gray and maroon mudstone. Informally divided into three members: (1) lower member, 165 m thick, mostly grayish-orange and yellowish-gray, medium to coarse grained, trough crossbedded and conglomeratic sandstone; (2) middle member, 176 m thick, of variegated light olive to maroon mudstone; (3) upper member, 101 m thick, of sandstone similar to lower member, with minor mudstone interbeds. Unit is locally conglomeratic and contains petrified wood; ironstone concretions are locally common.

Conglomeratic beds contain fine (<0.5 cm diameter), well sorted pebbles of white and gray quartzite and chert that are distinguishable from coarser-grained and more lithologically diverse clast assemblages in the overlying basal Galisteo Formation (Tg). Disconformably overlies the Menefee Formation of the Mesaverde Group. Interpreted to have been deposited within fluvial channels and broad floodplains in an early Tertiary basin between Albuquerque and Santa Fe, New Mexico. Middle member contains Wasatchian (early Eocene) mammal fossils (Lucas et al., 1997). Mapped as lower part of Galisteo Formation by Stearns (1953a), Kelley and Northrop (1975), Gorham (1979) and Picha (1982). Paleoflow was generally east or northeast. Thickness is up to 442 m at the type section near Hagan and thins northwest to approximately 20 m just west of the northern tip of Espinaso Ridge (Lucas et al., 1997).

MESOZOIC ERATHEM

Mesaverde Group (Upper Cretaceous)

(Includes Point Lookout and Menefee formations of Late Cretaceous age)

Kme **Menefee Formation (Upper Cretaceous)** — contains interbedded white, light-brown and light-gray quartzose sandstone and siltstone, dark-gray to black, carbonaceous shale and brown to black lignitic coal. Picha (1982) recognized three informal members—lower (**Kmel**) and upper (**Kmeu**) coal-bearing members, each about 100 m thick, divided by a medial sandstone member (**Kmem**). This sandstone member (“Harmon Sandstone Member” of some informal usage, such as Black [1979] and Picha [1982]) is 22 m thick and is medium-grained, quartzose fluvial sandstone that is trough crossbedded and contains numerous ironstone concretions up to 0.5 m in diameter. Unit is 207 to 365 m thick.

Kpl **Point Lookout Sandstone (Upper Cretaceous)** — Thick-bedded light-gray, white and light-brown, fine- to medium-grained quartzose shoreface sandstone that is crossbedded; bedding is thicker in upper part of unit. Forms cliffs, ridges and cuestas. Unit is 30 to 97 m thick.

Mancos Shale (Upper Cretaceous)

(Includes all units from the Graneros Shale through the Satan Tongue with the exception of the Cano Sandstone. Late Cretaceous (Cenomanian, Turonian, Coniacian and Santonian) in age. Nomenclature here is a compromise between High Plains and San Juan Basin usage and largely follows Molenaar (1983). Total thickness about 1000 m in thickness.)

Kmu **Upper Mancos Shale, Satan Tongue (Upper Cretaceous)** — Medium-gray to dark-gray silty marine shale with calcareous concretions and some thin interbeds of sandstone. Unit forms a slope; mostly covered. Unit is 110 m in thickness.

Khd **Cano Sandstone (Upper Cretaceous)** — Light-gray, yellowish-orange and olive-gray, very fine- to fine-grained shoreface sandstone and siltstone, with indurated, rusty brown lenses and concretions of fossiliferous calcareous sandstone. Sandstones are typically ripple-laminated or crossbedded. Named by Stearns (1953b), this unit has been termed the Hosta-Dalton sandstone by previous workers (e.g., Black, 1979; Picha, 1982; Moutoux, 2000). Unit is 8 to 114 m in thickness.

Kni **"Niobrara" formation of the lower Mancos Shale, undivided (Upper Cretaceous) —** Consists of three marine units. **Mulatto Tongue:** 244 to 365 m thick; medium-gray to dark-gray shale with numerous calcareous septarian concretions and some very thin interbeds of sandstone. Unit forms a slope; mostly covered. **El Vado Member:** 76 to 91 m thick, very thinly bedded calcareous siltstone and sandy shale with some lenses and concretions of calcareous sandstone. Most sandstone beds are bioturbated and/or have inoceramid shell debris. Forms a slope. Termed Niobrara Formation by previous workers (e.g., Stearns, 1953b; Black, 1979; Picha, 1982). The **Tocito(?) Sandstone** (**Kt**): 0 to 7 m thick; light-gray to pale-brown, lenticular, fine- to medium-grained quartzose sandstone. Beds are trough crossbedded and bioturbated. Forms a cuesta. This is the probable "basal Niobrara sandstone" of Stearns (1953b), Molenaar (1973), Black (1979) and Picha (1982).

Kml **Lower part of lower Mancos Shale (Upper Cretaceous) —** Consists of seven lithologic units of marine origin, most of which are poorly exposed. **D-Cross Tongue:** 91 m thick; gray and olive gray shale with calcareous concretions. Slope former, mostly covered. **Juana Lopez Member (Kmj)**: 0.3 to 3 m thick; ledge and cuesta-forming, brown to dark yellowish-orange, well indurated calcarenite with thin interbeds of calcareous silty shale. Extremely fossiliferous, yielding numerous specimens of inoceramid bivalves and the ammonite *Prionocyclus novimexicanus* (Marcou). **Carlile Shale, Blue Hill Member:** 49 m thick; dark gray to black shale with calcareous concretions, numerous thin bentonite beds and a few thin (< 0.1 m thick) beds of sandstone. Where present, the Semilla Sandstone Member is in the middle part of this unit. **Semilla Sandstone Member (Kms):** 0 to 12 m thick; lenticular, olive-gray to yellowish-orange bioturbated and ripple laminated, muddy quartzose sandstone and sandy shale with some calcareous concretions. Basal concretions are extremely fossiliferous, containing numerous ammonites (especially *Prionocyclus hyatti* [Stanton]) and inoceramids. Where present, unit is ~28 m below the base of the Juana Lopez Member (Fleming, 1989). **Lower shale member:** 84 m thick; dark gray to black shale with sparse calcareous concretions, and a few thin (<0.1 m thick) beds of sandstone. Unit is a slope former and mostly covered. **Greenhorn Limestone, Bridge Creek Member:** 10 m thick, light-gray to very pale-orange, dense, fossiliferous limestone in thin, cyclical beds separated by very thin interbeds of medium gray calcareous shale. Upper part is extremely fossiliferous and yields inoceramid bivalves. **Graneros Shale:** 34 to 76 m thick; dark-gray to black, bentonitic shale with sparse calcareous concretions, a few thin bentonites and a few thin (< 0.1 m thick) beds of sandstone. Upper 10 m are calcareous and are equivalent to the Hartland Shale Member of the Greenhorn Limestone to the east. An approximately 3 m thick lenticular interval of coarse bioturbated sandstone in the lower part of the Graneros Shale on San Pedro Creek may represent the Two Wells Sandstone.

Kd **Dakota Sandstone (Upper Cretaceous)** — Consists of three members that were locally mapped separately. **Cubero Member (Kdc):** 7 m thick; tan, bioturbated quartzose marine sandstone and sandy gray shale. **Oak Canyon Member:** 42 to 52 m thick; lower part (**Kdol**) is 2 to 10 m thick, trough crossbedded brown quartzose shoreface sandstone with local lenses of siliceous conglomerate. Middle-upper part is bentonitic gray marine shale (**Kdou**), siltstone and thin interbeds of bioturbated sandstone and includes the "A bentonite" bed of Owen and Head (2001). **Encinal Canyon Member:** 0 to 37 m thick; white to pale-orange, fine- to medium-grained quartzose sandstone with thin interbeds of grayish-red and grayish yellow-green mudstone. Sandstone is horizontally laminated and has some planar crossbeds and ironstone concretions.

Jm **Morrison Formation, undivided (Upper Jurassic) —** Consists of three fluvial members that were not mapped separately. **Jackpile Member**: 27 to 63 m thick; very light-gray to very pale-orange, fine- to medium-grained, subarkosic sandstone with argillaceous (commonly kaolinitic) matrix; mostly trough crossbedded; contains lenses and interbeds of pale olive to bluish-green mudstone and siliceous (mostly chert and jasper) pebble conglomerate. **Brushy Basin Member**: 79 to 128 m thick, laterally persistent intervals of mudstone and siltstone that are variegated pale-olive, bluish-green and grayish-brown. Contains thin interbeds of trough-crossbedded, horizontal laminated and ripple laminated yellowish gray and grayish yellow-green subarkosic sandstone. In western part of quadrangle, middle part of member locally contains a bed of reddish chalcedony. **Salt Wash Member:** 59 to 75 m thick; massive to thickly bedded, trough crossbedded or horizontally laminated, grayish-yellow, subarkosic, fine- to coarse-grained sandstone separated by thinner beds of pale-olive and pale-brown mudstone and siltstone.

San Raphael Group (Jurassic)

Js **Summerville Formation (Upper Jurassic)** — Grayish-red, pale-red and yellowish-gray, fine- to medium-grained sublitharenitic sandstone and siltstone in massive or parallel laminated beds; some interbeds of grayish red and greenish gray, variegated mudstone and siltstone; basal bed locally is a limestone with red chalcedony nodules. Forms a poorly exposed slope in most places. The Summerville Formation is mapped with the Morrison Formation (**Jsm**) in the southern part of the quadrangle. Unit is 42 to 67 m thick.

Jt **Todilto Formation (Middle Jurassic)** — Consists of two members that were not mapped separately. **Tonque Arroyo Member**: 0 to 61 m thick; white, massive, brecciated gypsum/anhydrite with some thin clay laminae; locally absent (pinches out) in the southern and eastern parts of quadrangle. **Luciano Mesa Member:** 3.7 to 5.7 m thick; thinly laminated or crinkly-bedded, medium gray kerogenic limestone, locally brecciated at top. Typically forms a prominent ridge.

Je **Entrada Sandstone (Middle Jurassic)** — Consists of two members that were not mapped separately. **Slick Rock Member**: 18 to 29 m thick; yellowish gray, fine-to medium-grained, moderately sorted subarkosic sandstone that is thick bedded and locally has large scale crossbeds. Crossbeds dip generally southward. Forms prominent cliffs and cuestas and thickens eastward, where massive, horizontally laminated sandstone beds are present at top of unit. **Dewey Bridge Member**: 17 to 20 m thick; reddish-brown, very fine-grained, moderately well sorted, subarkosic sandstone and silty sandstone. Massive to thickly bedded and friable.

Chinle Group (Upper Triassic)

TRC **Upper Chinle Group (Upper Triassic)** — Consists of two fluvially dominated formations that were not mapped separately. **Petrified Forest Formation** is grayish-red and reddish-brown smectitic mudstone with relatively thin interbeds of litharenitic sandstone and intraformational (calcrete-clast) conglomerate. Upper part contains the **Correo Member**, a 5- to 37-m thick interval of trough crossbedded litharenitic sandstone and intraformational conglomerate. At most locations, the Correo Member is directly overlain by the Dewey Bridge Member of the Entrada Sandstone, but locally as much as 5 m of reddish-brown mudstone of the Petrified Forest Formation separate the Correo from the Dewey Bridge. **Salitral Formation** is 92 m thick and contains gray and purple bentonitic mudstone and intraformational conglomerate. It typically forms a slope. Total unit thickness is 261 m.

TRS **Agua Zarca Formation of the lower Chinle Group (Upper Triassic)** — gray and yellowish-gray, quartzose and sublitharenitic fluvial sandstone. Typically trough crossbedded, laminated and ripple laminated. Includes fossil logs and beds of conglomerate made up of pebbles of quartzite, Paleozoic limestone and recycled Moenkopi lithics. Unit is 45 to 109 m thick.

TRm **Moenkopi Formation (Middle and Lower Triassic)** — Pale-red and very pale-orange, litharenitic fluvial sandstone and some interbeds of pale red siltstone. May include local beds of Artesia Formation (Permian) in lower part. Unit is 20 to 30 m thick.

PALEOZOIC ERATHEM

Psg **San Andres Formation and Glorieta Sandstone, undivided (Upper Permian) —** San Andres Formation contains 5–65 m thick; grayish orange sandy marine limestone. Glorieta Sandstone contains 11-12 m thick, yellowish gray and orange quartzose shoreface sandstone.

Py **Yeso Formation (Upper Permian)** — Consists of two members (not differentiated). **San Ysidro Member** — 115 m thick; light brown, silty, very fine grained gypsiferous sandstone with a few thin (1-2 m thick) beds of coarsely crystalline gypsiferous limestone; forms a slope. **Meseta Blanca Member** — 60 m thick; light brown, pale red and pinkish gray, trough crossbedded and ripple-laminated mostly eolian sandstone; cuesta former.

Pa **Abo Formation (Upper Permian) —** fluvial deposits consisting of pale red and grayish red mudstone and interbeds of trough crossbedded arkosic sandstone. Sandstone beds contain localized scour fills of pale-brown, limestone pebble conglomerate. Lower part of formation is mudstone dominated, whereas upper part is sandstone dominated. Includes the lower unit of the Yeso Formation of Picha (1982). Unit is 112 to 360 m thick.

Madera Group (Middle and Upper Pennsylvanian)

Pm **Atrasado Formation (Upper Pennsylvanian)** — Light-gray, brownish-gray and yellowish-brown fossiliferous marine limestone beds and interbeds of slope-forming calcareous shale. Upper 7 to 20 m is a mixture of fossiliferous limestone, limestone-pebble conglomerate, sandstone and red-bed mudstone homotaxial to Bursum Formation to south. Termed upper arkosic member or Wild Cow Formation by previous workers. Total thickness about 187–244 m, but only upper part of unit is exposed on Hagan quadrangle.

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MAP SYMBOLS

Line of geologic cross section

Geologic contact—Dashed where approximately located; queried where inferred.

Fault— Dashed where approximately located; dotted where concealed; ball-and-bar on downthrown side of normal fault, barbs on upthrown side of reverse fault, arrow shows dip direction and amount.

Syncline

Marker bed

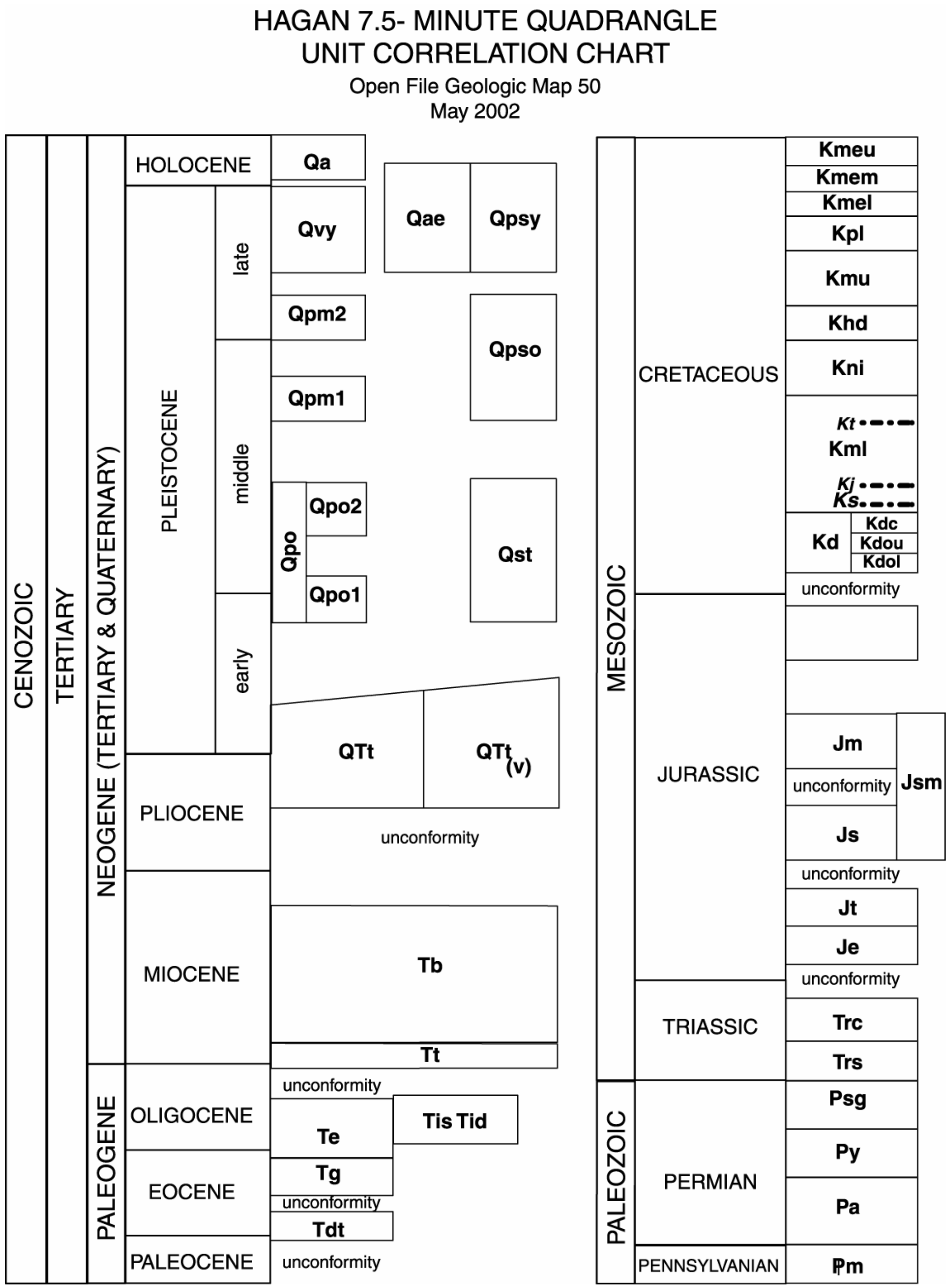
Strike and dip of bedding

Horizontal bedding

Approximate location of wells

Paleocurrent direction

Paleontologic locality



Correlation of map units on the Hagan 7.5-minute quadrangle.

HAGAN QUADRANGLE, FOSSIL SITES

1. NMMNH locality 3029, Salitral Formation, phytosaur fragments, Late Triassic.
2. NMMNH locality 3028, Correo Member, Petrified Forrest Formation, phytosaur fragments, Late Triassic.
3. NMMNH locality 878, Correo Member, Petrified Forrest Formation, phytosaur fragments, Late Triassic.
4. NMMNH locality 876, Correo Member, Petrified Forrest Formation, phytosaur fragments, Late Triassic.
5. NMMNH locality 877, Correo Member, Petrified Forrest Formation, phytosaur fragments, Late Triassic.
6. NMMNH locality 250, Correo Member, Petrified Forrest Formation, phytosaur fragments, Late Triassic.
7. NMMNH locality 875, Correo Member, Petrified Forrest Formation, phytosaur fragments, Late Triassic.
8. NMMNH locality 4673, Cubero Member, Dakota Sandstone, inoceramids, middle Cenomanian.
9. NMMNH locality 5070, Bridge Creek Member, Greenhorn Limestone, *Pycnodonte newberryi*, late Cenomanian.
10. NMMNH locality 5060, Bridge Creek Member, Greenhorn Limestone, *Watinoceras, Mytiloides*, late Cenomanian.
11. NMMNH locality 5064, Blue Hill Member, Carlile Shale, *Prionocyclus hyatti,* Turonian.
12. NMMNH locality 5059, Blue Hill Member, Carlile Shale, *Prionocyclus hyatti,* Turonian.
13. NMMNH locality 5062, Blue Hill Member, Carlile Shale, *Prionocyclus hyatti,* Turonian.
14. NMMNH locality 5058, Blue Hill Member, Carlile Shale, *Prionocyclus hyatti, Ptychodus whipplei,* Turonian.
15. NMMNH locality 5063, Blue Hill Member, Mancos Shale, *Prionocyclus hyatti,* Turonian.
16. NMMNH locality 5065, Blue Hill Member, Mancos Shale, *Prionocyclus hyatti,* Turonian.
17. NMMNH locality 5061, Juana Lopez Member, Mancos Shale, *Prionocyclus novimexicanus,* Turonian.

18. NMMNH locality 4203, Juana Lopez Member, Mancos Shale, *Prionocyclus novimexicanus,* Turonian.
19. NMMNH locality 5069, El Vado Member, Mancos Shale, inoceramids, Coniacian.
20. NMMNH locality 5068, Cano Sandstone, *Placenticeras,* Santonian.
21. NMMNH locality 5071, Cano Sandstone, *Lopha*, Santonian.
22. NMMNH locality 5072, Cano Sandstone, *Lopha,* Santonian.
23. NMMNH locality 5067, Cano Sandstone, *Placenticeras,* Santonian.
24. NMMNH locality 5066, Cano Sandstone, *Lopha,* Santonian.
25. NMMNH locality 3042, Menefee Formation, Trionychidae, Companian?
26. NMMNH locality 3044, Diamond Tail Formation, turtle, Eocene?
27. NMMNH locality 3043, Diamond Tail Formation, *Hyracotherium,* early Eocene.
28. NMMNH locality 253, Galisteo Formation, bones, Eocene?
29. NMMNH locality 254, Galisteo Formation, bones, Eocene?