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### Evolution of the Eocene Galisteo Basin, north-central New Mexico

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# EVOLUTION OF THE EOCENE GALISTEO BASIN NORTH-CENTRAL NEW MEXICO

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#### INTRODUCTION

The Galisteo Formation (Eocene) consists of 261 to 1,295 m of red to white mudstone, sandstone and conglomerate deposited in a continental basin located between Albuquerque and Santa Fe (fig. 1). Terrestrial fossils, coarse-grained sediment, crossbedding, channeling and lateral variation in lithology indicate that the Galisteo was deposited in fluvial channels and broad flood plains feeding sediment into a progressively deepening and enlarging basin (Baltz, 1978; Gorham, 1979; Stearns, 1943). The Galisteo crops out in isolated patches throughout north-central New Mexico, but the Hagan basin contains the most complete and least disturbed section; this is the area in which the present investigation was concentrated, although data from surrounding areas are included in the results.

The most important previous work on the Gal isteo includes the following: Disbrow and Stoll (1957), Galusha and Blick (1971), Harrison (1959), Kelley and Northrop (1975), and Stearns (1943, 1953b). Recent papers discuss in more detail the economic (Chenoweth, this guidebook; Moore, this guidebook) and paleontologic (Lucas and Kues, this guidebook) resources of this formation. Gorham (1979) recently has completed a detailed stratigraphic, sedimentologic, petrologic and paleogeographic study of the Galisteo, and the interested reader is referred to this work for details not contained in the present report.

#### **REGIONAL SETTING**

The Hagan basin or embayment is a structural and topographic basin that has experienced a complex Cenozoic history (Black, this guidebook; Kelley, 1977; Kelley and Northrop, 1975; Stearns, 1943, 1953b; Woodward and Ingersoll, this quidebook). Deposition of the Galisteo was preceded by shallow marine to nonmarine deposition of Cretaceous sediments (Mesaverde Group) in a broad subsiding foreland basin. These sediments are mostly quartzose, fine to medium grained and texturally mature. They were uplifted broadly and eroded at the end of the Cretaceous as the Hagan area began to feel the effects of the Laramide orogeny (McGookey and others, 1972). The Galisteo rests on the Mesaverde with slight angular unconformity (Black, this guidebook). The Galisteo was derived primarily from Laramide uplifts (Sangre de Cristo and Nacimiento mountains) involving Precambrian through Cretaceous rocks. Deposition occurred in a broad subsiding basin bordered on the east, north and west by these uplifts. Following the Eocene, the uniform pattern of sedimentation began to change, and thick sequences of volcanic and volcaniclastic rocks began to form (McDonald, 1972). In the Hagan area, the volcanic-volcaniclastic Espinaso Formation (Oligocene) was derived from the San Pedro-Ortiz-Cerrillos porphyry belt and accumulated conformably on top of the Galisteo (Stearns, 1943, 1953a,b). Following this regional volcanic episode or contemporaneously with it, regional stresses changed from pre-

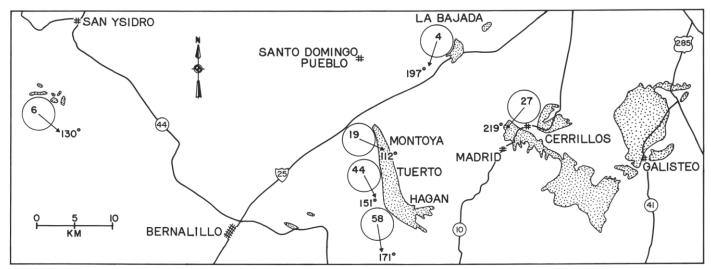


Figure 1. Map showing locations of Galisteo outcrops in north-central New Mexico. Each circle shows mean paleocurrent vector azimuth and number of readings for each location. Hagan basin section is divided into the Montoya, Tuerto and Hagan sections.

dominantly compressional to predominantly tensional as the basins, grabens and tilted fault blocks associated with the Rio Grande rift formed (Kelley, 1977). Contemporaneous with rifting has been the uplift of the Sandia Mountains southwest of the Hagan area (Kelley and Northrop, 1975). The Sandias, as well as other uplifts that bound the rift, probably owe some of their structural height to Laramide deformation (Kelley, 1977).

#### **AGE**

Little fossil evidence has been found in the Galisteo to establish its age. It contains abundant petrified logs, which are preserved beautifully in external form, but the cellular structure of the wood is not retained well and no specific identifications have been made (Stearns, 1943; B. S. Kues, personal commun., 1978). Many vertebrate fossils have been collected in Tuerto Arroyo from a limey mudstone bed 1-to-2 m thick within the transitional zone between the Galisteo and Espinaso. Recent prospecting has turned up additional material, but in general, the Galisteo has few vertebrate fossils (Kues and others, 1978). An attempt was made by the senior author to analyze some of the abundant mudstones of the lower Galisteo for spores and other microfossils, but no identifiable material was found. Lucas and Kues (this guidebook) summarize the paleontologic evidence that indicates that deposition of the Galisteo probably spanned the entire Eocene and may have included the latest part of the Paleocene.

#### STRATIGRAPHY AND SEDIMENTOLOGY

The Galisteo Formation unconformably overlies the Cretaceous Mesaverde Group and Mancos Formation. In the vicinity of San Ysidro (approximately 40 km west of the Hagan area), the steeply dipping Mesaverde is overlain unconformably by the gently dipping Galisteo. However, east of San Ysidro, the angular relation between the two formations becomes less pronounced (Black and Hiss, 1974). In the Hagan basin, the unconformity is illustrated best by tracing a prominent Mesaverde sandstone northward until it becomes truncated by Galisteo (Black, this guidebook; Gorham, 1979). The Mesaverde sandstone maintains a nearly constant thickness and does not appear to be thinning stratigraphically. Locally, the contact between the Galisteo and the Mesaverde appears to be concordant, but when traced over 15 km of exposures in the Hagan basin, the unconformable relation is apparent.

In the Hagan basin, the Galisteo is overlain conformably by and is transitional into the Oligocene Espinaso Formation (Stearns, 1943), but regionally the contact is unconformable (Kelley and Northrop, 1975). Volcanic detritus occurs in the upper Galisteo, which is transitional into the pure volcaniclastics of the Espinaso.

The lower Galisteo is characterized by coarse sandstone and green mudstone, the middle by sandstone, conglomerate and red mudstone, and the upper by mudstone and lenticular pebbly sandstone. Locally, the Galisteo contains colorful, mappable units, but it is not always possible to trace these along strike. Because of the deepening and enlarging of the basin with time, units that are found in the basin center (south within the Hagan basin) are not found on the flanks, and vice versa (fig. 2). The Galisteo has been subdivided into seven coarse-grained members that are the most laterally extensive stratigraphic units within the highly variable lithologies (Gor-

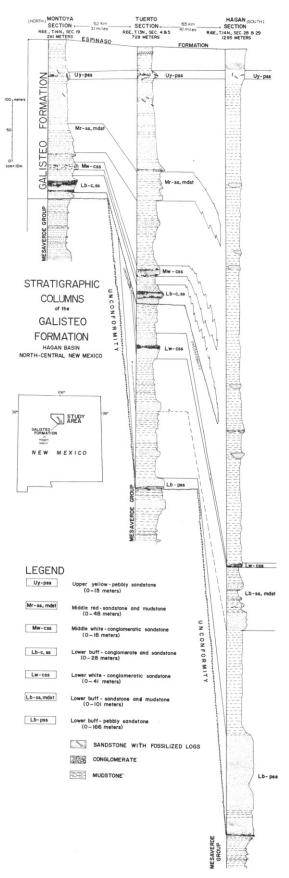


Figure 2. Measured stratigraphic sections of the Galisteo Formation in the Hagan basin. Locations of the sections are indicated at the top and on Figure 1.

ham, 1979). Each member is distinguishable clearly based on its color, lithology, texture and/or stratigraphic position.

Overall, the Galisteo consists of interbedded and intertongued variegated mudstone (approximately 50 percent), subrounded arkosic to quartzose sandstone (approximately 30 percent), conglomerate and conglomeratic sandstone (approximately 15 percent), and siltstone (approximately 5 percent).

Sedimentary structures within the Galisteo are dominantly lenticular and horizontally laminated to thickly bedded strata, with less abundant medium-scale planar, tangential and trough cross-strata (McKee and Weir, 1953). Other sedimentary structures include scour-and-fill structures, pebble and cobble imbrication, soft-sediment deformation structures, graded bedding and concretions. Detailed descriptions of the major rock units, compositions and textures are given by Gorham (1979).

#### **PALEOCURRENTS**

Paleocurrent directions in Galisteo conglomerate and sandstone were determined by computing vector resultants from dip azimuths in crossbeds and imbricated clasts. One hundred and sixty-seven readings were taken, primarily in the Hagan basin. However, several measurements were obtained, including some parting lineations, from other Galisteo exposures. Fossil logs were found to have no preferred orientation with respect to paleocurrent directions. Gorham (1979) describes structures and techniques, and presents most of the original data. Each measurement was rotated on a stereonet to remove the regional dip, data were grouped according to stratigraphic and geographic locations and according to type of structure, vector means and standard deviations were calculated by a computer program, and rose diagrams were plotted, also using a computer program.

Figure 3 compares the mean current vectors for all Galisteo members in the Hagan basin. Variations in dispersal patterns occur through the vertical section. Within this vertical section, there appear to be three major dispersal patterns that suggest changing paleoslopes during Galisteo time. The lower two members (Lb-pss and Lb-ss, mdst) can be grouped into one pattern, the middle four members (Lw-css, Lb-c,ss, Mw-css and Mr-ss,mdst) into another pattern, and the upper member (Uypss), in addition to the uppermost Galisteo, into a third pattern. The paleocurrent data of both of the lower two members have high standard deviations (71° and 1130, respectively), suggesting the possibility of multiple source areas and/or widely meandering or brading channels. The four middle members display uniform southeasterly paleocurrent directions with low standard deviations (53°, 26°, 26° and 50°, respectively), suggesting a fixed paleoslope. The upper Galisteo paleocurrents are directed toward the southwest, west and northwest (fig. 3), indicating a reversal of paleoslope. This eastward derivation corresponds with the beginning of influx of volcaniclastic detritus derived from the San Pedro-Ortiz-Cerrillos porphyry belt; this uppermost Galisteo is transitional into the volcaniclastic Espinaso, as discussed below.

Figure 1 shows the geographic distribution of dispersal patterns averaged for the entire Galisteo in each area. There are significant geographic variations even within the Hagan basin (note the contrast in mean directions for the Montoya, Tuerto and Hagan sections on Figure 1). The geographic variations in paleocurrent data (as well as the stratigraphic thickness variations) in the Galisteo basin suggest that the Hagan-Cerrillos

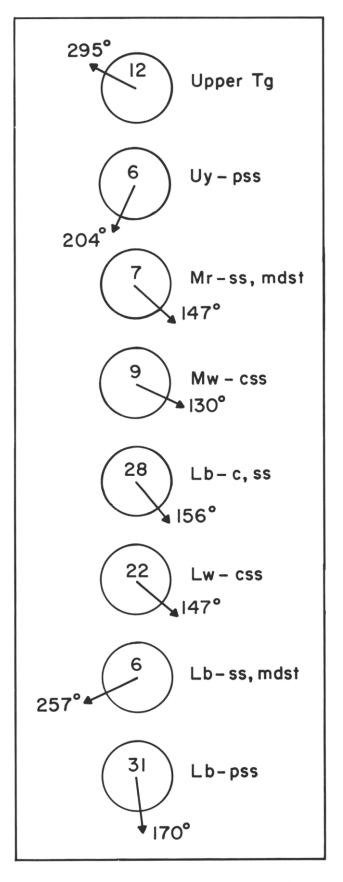


Figure 3. Vector means and numbers of readings for paleocurrent measurements from seven Galisteo members and the uppermost Galisteo, Hagan basin.

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area was near or within the basin axis. Thus, the deepest part of the Galisteo basin likely had a northeast-southwest or north-south trend during deposition, and drainage systems were directed toward this rapidly subsiding area.

#### PETROLOGY AND PROVENANCE

The provenance of the Galisteo Formation can be determined by integrating data for sandstone compositions, pebble-cobble compositions, stratigraphy and paleocurrents. Sandstone petrographic data were obtained using techniques outlined by Dickinson (1970), Gorham (1979), Graham and others (1976) and Ingersoll (1978). Twenty-nine samples were collected from the Galisteo in the Hagan basin, twelve from the Galisteo in other areas, five from the Mesaverde in the Hagan basin, and one from the Espinaso in the Hagan basin. Each sample was impregnated, stained for K-feldspar and plagioclase, sectioned and subjected to a statistical point-count using a petrographic microscope. Techniques and data are presented by Gorham (1979).

Galisteo sandstone tends to be arkosic arenite, with quartz averaging 68 percent, feldspar (primarily microcline and microperthite) 30 percent and lithic fragments 2 percent (figs. 4, 5). The upper Galisteo contains upward-increasing proportions of volcanic lithic fragments in the transition zone into the Espinaso Formation (fig. 6). The Espinaso itself is characterized by the dominance of volcanic lithic fragments and plagioclase. Galisteo and Mesaverde sandstones are similar compositionally, although contrasting texturally; Galisteo detritus is coarsergrained, less well sorted and somewhat less well rounded. The Galisteo and Mesaverde may have had similar ultimate sources, but Mesaverde detritus was transported farther and reworked more.

The coarseness, composition and dominance (volumetrically) of subangular grains in Galisteo sandstone suggest that it is primarily a first-cycle sediment derived from mostly coarsely crystalline source areas. High QFL percentages of quartz and feldspar, and the abundance of microcline, microperthite and granitic rock fragments suggest granitic to granodioritic source

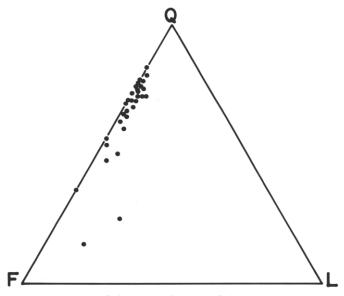


Figure 4. Quartz(Q)-feldspar(F)-lithic(L) triangle for petrographic counts of twenty-nine Galisteo sandstone samples from the Hagan basin. Note quartzofeldspathic nature.



Figure 5. Photomicrograph (crossed nicols) showing typical poorly sorted, arkosic Galisteo sandstone (Lb-pss member) with large unaltered microcline grain, angular quartz and highly altered feldspars (sericite); Hagan basin.

terranes. Abundant strained quartz suggests significant plutonic and/or metamorphic contributions, but low polycrystal-line-to-monocrystalline-quartz ratios and the lack of abundant metamorphic lithic fragments suggest that volumetrically, metamorphic rocks were less significant than plutonic rocks (Dickinson, 1970). The lack of substantial volcanic lithic fragments (except in the uppermost Galisteo) suggests very little or no contribution from volcanic sources. The presence of well rounded quartz, rounded overgrowths of quartz and some chert fragments indicates contributions from sedimentary rocks.

Pebbles and cobbles in Gal isteo conglomerates and conglomeratic sandstones are composed predominantly of sedimentary rocks, mostly limestone and sandstone. The associated sandstones are arkosic with very few sedimentary lithic fragments. Presumably, the limestone clasts are chemically unstable when broken into sand-sized detritus, and the sandstone clasts are

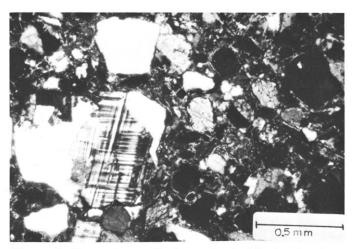


Figure 6. Photomicrograph (crossed nicols) showing large granitic fragment composed of quartz and microcline, with finer-grained volcaniclastic material (pyroxenes, biotite, volcanic lithic grains). Upper Galisteo sandstone; Hagan basin.

disaggregated into quartz sand grains; thus, the sedimentary provenance of the sandstones is expressed less well than is that of the conglomerates.

The Galisteo Formation was derived from variable amounts of granitic, gneissic and sedimentary source terranes. Certain members (e.g., Lb-c,ss and Lw-css) originated from primarily sedimentary sources; other members (Lb-pss, Lb-ss,mdst and Mw-css) had predominantly plutonic and/or metamorphic sources. Thick (10 to 30 m) red mudstone units in the Galisteo could represent erosion of Permo-Triassic red beds (e.g., Abo, Yeso, Sangre de Cristo and Chinle formations). The highly variable colors within the Galisteo present complex problems of provenance interpretations.

#### PALEOGEOGRAPHY AND PALEOTECTONICS

The formation of the Galisteo basin, the uplift of the surrounding areas, and the resulting rapid deposition of Galisteo sediments are direct responses to the Laramide orogeny of Paleocene through Eocene age (Baltz, 1967, 1978; Woodward, 1974, 1976; Woodward and Ingersoll, this guidebook). Pre-Galisteo history of the Hagan area is discussed by Black (this guidebook) and Gorham (1979). Following final regression of the Cretaceous seas, the Hagan basin probably was a mildly positive area off of which the uppermost Cretaceous rocks were eroded (e.g., McGookey and others, 1972).

The Nacimiento uplift appears to have emerged sometime during late Paleocene and/or early Eocene, thus separating the San Juan and Galisteo basins. This is recorded in the San Juan Basin where the Nacimiento Formation is overlain unconformably by the San Jose Formation (Eocene) (Baltz, 1967). However, before the Nacimiento uplift became a significant source area for the Galisteo, sediments were being deposited in the Hagan area. Paleocurrents and petrology of lower Galisteo sandstone suggest that primarily granitic and/or metamorphic source areas were to the north and northeast (fig. 3). The Brazos-Sangre de Cristo geanticline probably was the main source at this time (Baltz, 1978).

Paleocurrents and petrology beginning with the deposition of Galisteo member Lw-css and Lb-c,ss (figs. 2, 3), indicate that source areas changed in middle Galisteo time. The gradual enlarging of the basin is indicated by the onlapping to the north and northwest of these coarse-grained units. Middle Galisteo members are characterized by extremely coarse-grained sandstone and conglomerate that are stratified predominantly horizontally, indicating upper flow-regime deposition. Poor sorting, extremely coarse detritus, lenticular beds and high ratios of horizontal stratification to planar cross-stratification suggest braided-stream deposition (Smith, 1970).

Uplift of the Nacimiento Mountains and eastward tilting of the Galisteo basin is recorded in the slight angular unconformity between members Lw-css and Lb-c,ss (fig. 2). The petrology of pebbles, cobbles and boulders of members Lw-css and Lb-c,ss, and to a lesser extent Mw-css, indicates significant contributions from reworked Paleozoic and Mesozoic sediments, especially Pennsylvanian limestones. Also, red mudstones first were deposited at this time in the Galisteo, thus suggesting erosion of Permo-Triassic red beds (see above). The dominantly granitic and metamorphic composition of Mw-css clasts suggests that sedimentary rock had been stripped off the source area(s) by this time, thus exposing Precambrian crystal-line rocks in the cores of uplifts. Depositing currents generally flowed toward the southeast during this time (fig. 3).

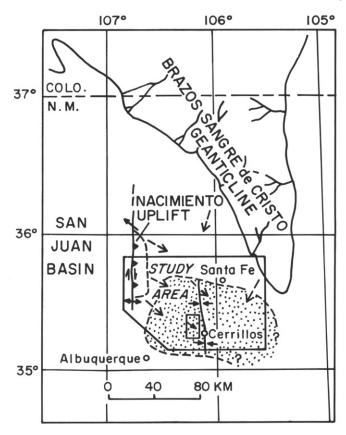


Figure 7. Probable paleogeography of north-central New Mexico during mid-stage deposition of the Galisteo Formation. Stipple pattern indicates approximate extent of the Galisteo basin. See Baltz (1978) and Gorham (1979) for additional paleogeographic maps.

The stratigraphy and composition of the San Jose Formation (Eocene) in the San Juan Basin suggest that the Nacimiento uplift was the principal source for these deposits (Baltz, 1967). Paleocurrent data, petrology and stratigraphy of the Galisteo members suggest that by middle Gal isteo time, the Nacimiento uplift also became a major source for the Galisteo Formation (fig. 7). The Nacimiento uplift is an east-tilted fault block with much of its Paleozoic and Mesozoic sedimentary cover still preserved on the south and east sides. This implies that additional local source areas probably existed somewhere to the north and northwest of the Galisteo basin, possibly presently covered by the Neogene volcanic rocks of the Jemez Mountains.

Following deposition of Mw-css, Galisteo sediments in the Hagan area no longer received significant amounts of coarse-grained detritus. This probably reflects a reduction in tectonic activity as source areas were eroded and the basin widened. Low ratios of horizontal stratification to planar cross-stratification, moderate sorting, fining-upward sequences and laterally continuous bedding suggest deposition of upper Galisteo sediments by meandering rivers (Smith, 1970). Paleocurrent measurements and petrology imply multiple source areas in the northwest and northeast that contributed primarily Precambrian material. Galisteo sediments had on-lapped eroded Precambrian source areas by this time (Baltz, 1978). A red pebbly sandstone containing some volcanic clasts is found at the top of the Galisteo Formation in the La Bajada outcrops

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(fig. 1), as well as in certain parts of the Hagan basin. These upper Galisteo rocks appear to thicken northward and are thickest in the La Bajada outcrops. The distribution of this red pebbly sandstone suggests that deposition in latest Galisteo time occurred in a shallow structural basin extending north to the El Rito basin (late Eocene), as suggested by Baltz (1978).

Arkosic compositions and westward paleocurrents in the Cerrillos area (fig. 1) suggest that the Sangre de Cristo uplift provided granitic and metamorphic detritus to this part of the Galisteo basin. The Cerrillos section contains more sandstone, and less conglomerate and mudstone than does the Hagan section. Because the Cerrillos section is nearly as thick as the Hagan section, it appears that both areas were near the axis of the depositional basin during early Galisteo time. There is no evidence to support derivation of any of the Galisteo from the vicinity of the Sandia Mountains, as suggested by Baltz (1978) and Kelley and Northrop (1975).

Uppermost Galisteo rocks are characterized by abundant volcanic material, and paleocurrent measurements indicate westward transport as volcanic activity began in the San Pedro-Ortiz-Cerrillos area at the end of the Eocene. Deposition of the Espinaso Formation (Oligocene) conformably on the Galisteo in the Hagan area marked the end of Galisteo deposition.

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