GEOLOGY AND VERTEBRATE PALEONTOLOGY OF CRETACEOUS AND TERTIARY STRATA ON THE PITCOCK ROSILLOS MOUNTAIN RANCH, BREWSTER COUNTY, TEXAS

by

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# TABLE OF CONTENTS

Acknowledgements........................................................................................................... ii

List of Figures.................................................................................................................... iv

Introduction...................................................................................................................... 1
  Previous Work............................................................................................................... 4
  Regional Geologic History............................................................................................ 5
  Field Area....................................................................................................................... 8
  Techniques Employed..................................................................................................... 9

Stratigraphy and Sedimentology..................................................................................... 10
  Pen Formation.............................................................................................................. 10
  Aguja Formation.......................................................................................................... 12
  Javelina Formation....................................................................................................... 17
  Black Peaks Formation................................................................................................. 19
  Hannold Hill Formation................................................................................................. 20
  Canoe Formation.......................................................................................................... 21

Mappability within the Tornillo Group.......................................................................... 22

Field Observations......................................................................................................... 25

Vertebrate Paleontology................................................................................................. 44

Conclusions..................................................................................................................... 49

References...................................................................................................................... 52
LIST OF FIGURES

Fig. 1) Location of field area.................................................................2

Fig. 2) Stratigraphic column of Upper Cretaceous and Paleogene units in the Big Bend region.................................3

Fig. 3) Regional geologic map.................................................................7

Fig. 4) Interbedded mudstones and sandstones of the Black Peaks Formation in the Canoe Valley.................................23

Fig. 5) Interbedded mudstones and sandstones of the Javelina Formation in West Tornillo Pasture.................................24

Fig. 6) Geologic map of southeast corner of Pitcock Ranch.................................................................26

Fig. 7) Contacts between Canoe, Hannold Hill and Black Peaks Formations on northeastern flank of Canoe syncline.................................27

Fig. 8) Stratigraphic section of upper Black Peaks Formation, Hannold Hill Formation and Big Yellow Sandstone Member of the Canoe Formation.................................................................28

Fig. 9) Sandstone with trough cross-bedding and conglomeratic horizons containing reworked calcareous nodules near base of section in the Black Peaks Formation shown in Fig. 8.................................30

Fig. 10) Contact between Black Peaks and Hannold Hill Formations shown in Fig. 8.................................................................30

Fig. 11) Conglomeratic base of Hannold Hill Formation shown in Fig. 8.................................................................31

Fig. 12) Contact between Hannold Hill and Canoe Formations shown in Fig. 8.................................................................31

Fig. 13) Planar cross-bedding in Big Yellow Sandstone Member of Canoe Formation shown in Fig. 8.................................................................32

Fig. 14) Canoe syncline, looking downplunge toward the southeast.................................................................32
Fig. 15) Black Peaks Formation in contact with portions of the laccolith northwest of the Canoe Valley .......................................................... 34

Fig. 16) Vertical fault west of the Canoe Valley, with anticline in Aguja Formation west of fault ................................................................. 34

Fig. 17) Stratigraphic section of lower Javelina Formation ................................................. 35

Fig. 18) Javelina sandstone displaying trough cross-bedding at base of section shown in Fig. 17 ........................................................................ 36

Fig. 19) Tabular Javelina sandstones in middle of section shown in Fig. 17 ................................................................. 36

Fig. 20) Faulted Cretaceous volcaniclastic deposits in Aguja Formation ................. 37

Fig. 21) Diagrammatic cross section across Canoe Valley ................................................. 38

Fig. 22) Geologic map of the southwestern portion of Pitcock Ranch ......................... 40

Fig. 23) Aguja/Javelina contact west of Cottonwood Wash ........................................... 41

Fig. 24) Syncline in Javelina Formation exposed in western wall of Cottonwood Wash Canyon ........................................................................... 42

Fig. 25) Aguja/Javelina contact in West Tornillo Pasture ................................................ 43

Fig. 26) Kritosaurus neural arches (side view) ................................................................. 45

Fig. 27) Kritosaurus caudal vertebra (side view) ............................................................. 45

Fig. 28) Proximal portion of humerus from juvenile Torosaurus utahensis (ventral view) ................................................................................. 46

Fig. 29) Portion of frill from Torosaurus utahensis ........................................................ 47

Fig. 30) Bone fragment from Quetzalcoatlus northropi ................................................... 48
The Pitcock Rosillos Mountain Ranch of Brewster County, Texas (Fig. 1), is a privately owned ranch bordered on three sides by Big Bend National Park, with breathtaking panoramas, abundant desert wildlife and a rich geologic history. The ranch covers approximately 25,000 acres, much of which is mountainous terrain.

While Big Bend National Park was mapped extensively by Maxwell et al. (1967), the ranch was not, due to restricted access. The Texas Christian University Department of Geology, however, has been allowed on the property, and over the years, various graduate students have been studying and mapping the geology. This thesis focuses on mapping Upper Cretaceous and Lower Tertiary strata exposed around the Rosillos Mountains laccolith, a quartz syenite laccolith of middle Tertiary age intruded into some of the formations of interest. The units that will be discussed in this thesis are the Cretaceous Pen, Aguja and Javelina Formations and Tertiary Black Peaks, Hannold Hill and Canoe Formations (Fig. 2). These units record the evolution of the region from a marine shelf environment to a terrestrial setting dominated by fluvial deposition. Because very little roof rock remains on the laccolith and Plio-Pleistocene alluvial fan deposits cover the units surrounding the intrusion, the formations are generally only exposed in canyon walls and valleys.

Maxwell et al. (1967) produced a detailed geologic map of Big Bend National Park, which extends onto the southernmost portions of the ranch. The objectives for the present project were to map the unknown areas and to test the validity of the map produced by Maxwell et al. (1967) where it falls on the ranch. Differences between the
Fig. 1) Location of field area, modified from http://www.nps.gov/bibe/BIBEmaps/BIBE_Map1_SR.pdf.
Vertebrate remains are common in the units discussed. *Kritosaurus*, *Alamosaurus* and *Quetzalcoatlus* faunal assemblages are contained within the Cretaceous formations. Mammalian remains are found within the Lower Tertiary formations. Another objective of this project was to collect vertebrate specimens from the mapped units and identify them.
Previous Work

Von Steeruwitz (1892) performed the first geologic investigation on what is now Big Bend National Park, describing what he believed to be Lower Cretaceous strata. Hill (1900) also described and mapped these units. His discussions included a brief description of the Rosillos Mountains. The rocks were first described as Upper Cretaceous by Vaughn (1900) and remapped by Hill and Udden (1904). Udden (1907) described deposits that he termed the Rattlesnake Beds and Tornillo Clays. He also performed the first paleontological investigation, finding remains of dinosaurs, crocodilians, turtles and fish in these beds. The Rattlesnake Beds were renamed the Aguja Formation by Adkins (1933) because a Pliocene unit in Oregon already claimed the former name. The Tornillo Formation was mapped by Bloomer (1949) and Tertiary mammals were recovered from the unit by Wilson et al. (1952). Udden (1907) had thought these units to be Cretaceous marine deposits. Maxwell et al. (1967) further studied the Tornillo Clays, elevating that unit to group status, and naming the three units it contained the Javelina, Black Peaks and Hannold Hill Formations (Fig. 2). The Canoe Formation, stratigraphically above these three, was also named and described.

Further studies have been performed on each of these formations. Schiebout (1970) studied the Black Peaks Formation where it crops out on western Tornillo Flat. Lawson (1972) studied the Tornillo Group with a focus on the Javelina Formation and found the first remains of the giant pterosaur Quetzalcoatlus. Hartnell (1980) studied the sedimentology of the Hannold Hill Formation and Rigsby (1982) described the Canoe Formation. Lehman (1985a) subdivided the Aguja Formation into six members. He also reclassified the former marine shale member of the Aguja Formation as a tongue of the
marine Pen Formation. Murray (1999) produced a geologic map of the southern flank of the Rosillos Mountains laccolith using remote-sensing data. Shepard (1982) also studied the geology of the Rosillos Mountains. Dennie (2001) studied the alluvial fan deposits in the southern portion of my field area. Kenneth Befus, a graduate student at Texas Christian University, is currently studying Cretaceous and Lower Tertiary volcanic and intrusive rocks on the Pitcock Ranch and in Big Bend National Park (Befus et al., 2006a, 2006b). Another graduate student, Jennifer Buford, is working on the structure of the Rosillos Mountains laccolith. Thomas Lehman and students from Texas Tech University are currently mapping portions of Big Bend National Park directly south of my field area.


**Regional Geologic History**

During the Late Cretaceous, a subduction-related volcanic arc was present in western Mexico and served as a major sediment source for deposits in the Trans-Pecos region (Lehman, 1991). Separating the two areas was a Late Triassic rift basin associated with the opening of the Gulf of Mexico and known as the Chihuahua Trough. The Coahuila Platform, a carbonate platform located northeast of the Chihuahua Trough, extended into the Big Bend region (Muehlberger, 1980). At this time, the Western
Interior Seaway covered the interior of North America including the Big Bend region, connecting the Arctic Ocean with the Gulf of Mexico (Ziegler and Rowley, 1998). The marine Boquillas and Pen Formations accumulated on the Coahuila Platform within the seaway (Lehman, 1985b). During the Early Campanian, as the basin filled and subsidence slowed, the strandline moved rapidly across the region toward the northeast, as recorded in lower portions of the Aguja Formation (Kauffman, 1977). The McKinney Springs Tongue of the Pen Formation records a younger, westward transgression of the seaway over the region. During the Late Campanian, the final regression was recorded in upper portions of the Aguja Formation (Lehman, 1985a, 1985b).

With the onset of Laramide tectonism in the Maastrichtian, sediments within the Chihuahua Trough were folded and thrusted, creating the Chihuahua Tectonic Belt west of Big Bend. To the east, the Del Norte-Santiago-Sierra del Carmen thrusted monocline was also created (Muehlberger, 1980; Cobb and Poth, 1980). Sedimentation was restricted to the northwest-trending Tornillo Basin, which developed between the two uplifted regions. The basin is highly asymmetrical and thickest sediment accumulation occurred in the southeastern portion (Lehman, 1991; Atchley et al., 2004). As tectonism progressed through the Cretaceous into the Tertiary, the Upper Aguja, Javelina, Black Peaks and Canoe Formations were deposited in the basin (Fig. 3) (Pause and Spears, 1986). By the middle of the Maastrichtian, the shoreline had regressed to eastern Coahuila, Mexico, and the Rio Grande Embayment of Texas. The upper Aguja and Javelina Formations reflect fluvial deposition in a well-drained floodplain and contain remains of dinosaurs including *Kritosaurus*, *Torosaurus* and *Alamosaurus* (Lehman,
The Maastrichtian to Lower Tertiary Black Peaks and Lower Tertiary Hannold Hill and Canoe Formations record a similar terrestrial environment with overbank...

Fig. 3) Regional geologic map, modified from Barnes (1979).
deposits and channel sandstone bodies containing mammalian faunas (Schiebout et al., 1987).

During middle Tertiary magmatism, the Rosillos Mountains quartz syenite laccolith was intruded into the Upper Cretaceous Aguja Formation in the field area (Fig. 3) (Maxwell and Dietrich, 1965). Parts of the laccolith also intruded into units as young as the Black Peaks Formation in the southeast. Erosion of roof rocks exposed the laccolith, probably in the Late Pliocene or Early Pleistocene. Fluctuating climates and base levels throughout the Miocene, Pliocene and Pleistocene are recorded in alluvial fan and terrace gravel deposits which contain weathered spheroidal syenite clasts derived from the laccolith, as well as clasts of Cretaceous and Tertiary sedimentary rock (Dennie, 2001).

Miocene extensional faulting related to Basin and Range tectonism created what is known as the “Big Bend Sunken Block,” a large graben bordered on the east by the Santiago Mountains and Sierra del Carmen and on the west by Mesa de Anguilla and Sierra Ponce (Udden, 1907). This downdropped region has protected the formations described in this study from erosion, as well as the abundant Tertiary intrusive and volcanic rocks in Big Bend.

Field Area

The Pitcock Rosillos Mountain Ranch is owned by Mr. Roy Pitcock, an alumnus of the Texas Christian University Department of Geology. The ranch is located in southwest Texas in the northern part of the Chihuahua Desert and adjacent to Big Bend National Park (Figs. 1 and 3). The southeastern part of the Rosillos Mountains laccolith,
a large mid-Tertiary intrusion 12 km long and 10 km wide, occurs on the ranch. Surrounding the laccolith is a series of alluvial fans, which lie on a suite of Upper Cretaceous and Lower Tertiary strata, described in this thesis. The majority of these units crop out along the southern border of the ranch, where erosion has exposed them beneath the alluvial fan deposits (Fig. 3). Most localities in the field area were accessible by all-terrain vehicle, but some portions of West Tornillo Pasture in the southwest corner of the ranch could only be reached on foot.

**Techniques Employed**

Field mapping was conducted in the summer and fall of 2005 and the spring of 2006. Mapping was conducted at a 1:24,000 scale. Strike and dip measurements were taken with a Brunton compass at crucial points in the field area and saved in a Magellan Meridian Color GPS receiver with automatic WAAS correction. All data were later transferred to digital topographic maps. Remote sensing data were also used in conjunction with field observations to produce the geologic map. Stratigraphic sections were measured using a five-foot Jacob staff. Graphics were produced on Macintosh G5 computers through Canvas X software with GIS add-on in the Holme geology computer lab at TCU. Fossil bones were also collected as part of the project. They were catalogued and identified through comparison with specimens described in the literature or housed in the University of Texas Vertebrate Paleontology Museum in Austin.
STRATIGRAPHY AND SEDIMENTOLOGY

Although the Pen Formation and lower portions of the Aguja Formation are not exposed on the Pitcock Ranch, they do crop out in Big Bend National Park along Chalk Draw Fault near the northern boundary. Because of their proximity to the field area, they are described below with the units that were mapped on the ranch. Formation descriptions are also vital to understanding the environmental changes taking place during and after deposition of the Pen and Aguja Formations.

Pen Formation

The Upper Cretaceous Pen Formation was named by Maxwell et al. (1967) after the Chisos Pen, a holding pen for cattle located north of the Chisos Mountains. The unit is composed dominantly of calcareous marine shales and claystones weathering to form low gentle slopes of a distinctive golden yellow color. The type section of the Pen Formation is located south of the Chisos Mountains near Hot Springs. Its lower boundary with the San Vicente Member of the Boquillas Formation is gradational. Maxwell et al. (1967) described the upper contact of the Pen Formation with the basal sandstone member of the Aguja Formation as unconformable and placed the contact at the highest “substantial” sandstone in a thickening and coarsening upward series. Lehman (1985a) found this contact to be not only gradational, but intertonguing. The lower part of the Pen Formation consists of bluish-gray shale, composed of mixed layer smectite-illite, interbedded with chalky limestone, and the upper portion is composed of yellow-gray
claystone containing abundant pyrite crystals and interbedded with fine-grained sandstones. The sand bodies thicken and become more abundant upward. The thickness of the Pen Formation ranges from 67 m in northeast Big Bend National Park to 213 m in the southwest (Lehman, 1985a).

The unit records deposition on a marine shelf. A succession of muddy shelf, prodelta/delta-front, lower shoreface sand facies and storm-generated shell-bed facies indicates a northeastward prograding delta during deposition of the Pen Formation. *Exogyra* and *Inoceramus* faunal assemblages indicate a Late Santonian to Early Campanian age for this unit (Lehman, 1985a).

**McKinney Springs Tongue**

The McKinney Springs Tongue of the Pen Formation was named by Lehman (1985a) to include strata first identified as a “fossiliferous marine clay” belonging to the Aguja Formation by Maxwell et al (1967). The unit intertongues with the Aguja Formation and is stratigraphically equivalent to the middle shale member of that formation, truncating the basal sandstone and lower shale members of the Aguja Formation in some places. The type section for the McKinney Springs Tongue is located near a group of springs on the northwest flank of McKinney Hills. The unit is a southwesterly thinning wedge of sediment, well developed in eastern portions of Big Bend National Park, but absent in some places in western areas. It consists of dark gray to black fossiliferous marine shale and claystone interbedded with thin sandstones, which are similar to those in the main body of the Pen Formation and increase in number and
thickness up section. The beds weather to form low hills that are yellow to light gray in color (Lahman, 1985a).

Muddy shelf and prodelta/delta-front facies within the unit suggest deposition during a major transgression of the Western Interior Seaway over the Trans-Pecos area (Kauffman, 1977). Faunal assemblages for the McKinney Springs Tongue suggest a Middle Campanian age (Lehman, 1985a).

**Aguja Formation**

The Aguja Formation was first named the Rattlesnake Beds by Udden (1907), as discussed previously. It was given its present name by Adkins (1933) for Sierra Aguja. The unit was first divided into four parts by Maxwell et al. (1967): a basal sandstone, a fossiliferous marine clay, a section of alternating marine sandstone and clay beds and a unit of alternating nonmarine sandstone and clay beds. Lehman (1985a) revised the subdivisions into six members: the basal sandstone, lower shale, Rattlesnake Mountain Sandstone, middle shale, Terlingua Creek Sandstone and upper shale members. The Aguja Formation thins from 285 m in the west to 135 m in the east. It is composed of drab tan, olive and gray silty claystones interbedded with thin, dark red-brown and thick, white to light gray sandstones with a few freshwater limestones. The Aguja Formation contains more sand bodies and is more resistant than the units above and below it. The gradational contact with the Pen Formation beneath is placed at the highest substantial sandstone above marine shale (Lehman, 1982, 1985a). The contact with the overlying Javelina Formation is also conformable and is placed at the highest sandstone above which the mudstones become variegated (Maxwell et al., 1967). The boundary can vary
greatly stratigraphically due to the fact that much of the upper shale member is equivalent to the lower Javelina Formation (Lehman, 1985a).

Marine, paralic and fluvial sediments are contained in the Aguja Formation (Rowe et al., 1992). Depositional environments inferred from these sediments are coastal swamps and marshes, estuaries, deltas and floodplains (Lehman, 1985a). Emplaced on marine shelf deposits of the Pen Formation, the Aguja Formation records two trangressive/regressive cycles of the Western Interior Seaway including its final retreat from the region (Schiebout et al., 1987). *Flemingostrea*, *Deinosuchus* and *Kritosaurus* faunal assemblages suggest a Middle to Late Campanian age for the majority of the Aguja Formation while uppermost portions are Maastrichtian in age (Lehman, 1985a).

**Basal sandstone member**

The basal sandstone member of the Aguja Formation is not continuous throughout Big Bend National Park. It consists of numerous fine-grained sandstone lenses occurring at the same stratigraphic level and weathering to a dark red-brown. In eastern sections of the park it is better developed and is exposed as one lateral unit. The sandstone is calcite-cemented volcanic arenite and is never more than 8 m thick. The type section is at San Vicente (Lehman, 1985a).

The member consists of prograding deltaic and littoral facies (Lehman and Tomlinson, 2004). Depositional environments range from shallow marine, lower shoreface sand sheets in the west, where the member is not well-developed, to deltaic mouth bars and distributary channels in eastern portions. *Inoceramus* and *Cymbophora* assemblages suggest an Early Campanian age (Lehman, 1985a).
**Lower shale member**

This member is only present in western areas of Big Bend National Park. The lower shale member varies in thickness but is up to 183 m thick in places. It was included in the “fossiliferous marine clay” unit of Maxwell et al. (1967) but is different lithologically. It is composed of interbedded dark gray and black claystone, lignite and thin layers of dark brown siltstone and fine-grained sandstone. The beds are easily eroded and generally weather to form low hills with dark brown, tan and gray colors. The type section is located along the southwest flank of Rattlesnake Mountain.

Most of the unit represents a poorly drained coastal marsh environment landward of the shore, with portions recording deposition in a shallow estuary (Lehman, 1985a). Conifer woods preserved in the unit support this interpretation (Wheeler and Lehman, 2005). *Crassostrea, Flemingostrea, Cymbophora* and *Deinosuchus* faunal assemblages indicate a Middle Campanian age for the lower shale member of the Aguja Formation (Lehman, 1985a).

**Rattlesnake Mountain Sandstone Member**

This member of the Aguja Formation is composed of a marine sand body and is only found in western areas of the park. It is the next continuous sandstone above the basal sandstone member and disconformably overlies the lower shale member. The unit ranges in thickness from 6 to 48 m and consists of thin sand sheets. The generally white to gray, fine-grained sandstone is a calcite-cemented volcanic arenite that weathers to a pale yellow or orange color. The type section for the member is located on the southwest flank of Rattlesnake Mountain (Lehman, 1985a).
This unit contains abundant oyster shells and represents a major transgressive event involving landward retreat of a barrier island system. The presence of trough cross-bedding and *Ophiomorpha* burrows indicates the Rattlesnake Mountain Sandstone Member was deposited in a shallow sublittoral environment. *Flemingostrea*, *Crassostrea* and *Ethmocardium* faunal assemblages suggest a Middle Campanian age for the member (Lehman, 1985a).

**Middle shale member**

This member is stratigraphically equivalent to the McKinney Springs Tongue of the Pen Formation and intertongues with it. It reaches a maximum thickness of 30 m and thins southwesterly. The type section of the middle shale member is located on the southwest flank of Rattlesnake Mountain. The unit is composed of dark gray and black carbonaceous claystone interbedded with lignite, coal and light gray shale that weathers to light yellow. The claystones consist of mixed layer illite-smectite, kaolinite and illite. Deposits rich in organic matter are very similar to those in the lower shale member.

Lower portions of the member were deposited in coastal marshes. These facies grade up to prodelta/delta-front facies at the top of the member. *Deinosuchus* and *Crassostrea* assemblages suggest a Middle to Late Campanian age for the unit (Lehman, 1985a).

**Terlingua Creek Sandstone Member**

This is a widespread marine sandstone unit within the Aguja Formation. The unit is present everywhere in Big Bend National Park. It ranges in thickness from less than 2
m to more than 30 m. While it is usually composed of a single sand body, it has been found, in places, to comprise as many as four sandstone layers, which merge laterally. The type section is on the southwest flank of Rattlesnake Mountain. The sandstones are white to light gray volcanic arenite and plagioclase arkose, and coarsen upward from fine grained to medium grained (Lehman, 1985a).

This member has been interpreted to represent prodelta/delta-front, distributary channel and mouth bar, progradational shoreface and inner shelf sheet sands. It records the final regressive event in the region. *Flemingostrea, Crassostrea* and *Deinosuchus* assemblages indicate a Late Campanian age for the Terlingua Creek Sandstone Member (Lehman, 1985a).

**Upper shale member**

The upper shale member ranges from 80 to 170 m thick and thins eastward across Big Bend National Park. The type section is located on the northwest flank of McKinney Hills. Lower parts of the member contain drab gray, tan and olive mudstones composed of smectite. This section is rich in organic matter and contains in situ tree stumps (Lehman, 1985a). Higher in the unit can be found purple and gray banded mudstones similar to those in the overlying Javelina Formation (Davies, 1983). Interbedded with the mudstones are fine- to medium-grained, red-brown lenticular sandstones consisting of volcanic arenite and plagioclase arkose. The upper boundary of this unit represents the Aguja/Javelina contact (Lehman, 1985a).

The majority of this unit represents the final episode of pre-Laramide tectonic sedimentation (Lehman, 1991). Fossil logs are common in the upper shale member of the
Aguja Formation, whether as stumps in mudstones or as fallen logs in channel deposits (Lehman and Wheeler, 2001). It is inferred from the abundance of conifer woods that the lower part of the upper shale member accumulated in poorly drained marshes and swamps near the shore. Dicotylodonous woods found within the upper part of the member suggest deposition by meandering streams in a well-drained alluvial floodplain farther inland after Laramide tectonism began (Wheeler and Lehman, 2005). The *Kritosaurus* faunal assemblage of the lower portion of the upper shale member indicates a Late Campanian age (Lehman, 1985a). Based on associated vertebrate fauna, the age of the upper part of the member is Early Maastrichtian (Lehman, 1985a; Standhardt, 1986).

**Javelina Formation**

The Javelina Formation was named by Maxwell et al. (1967) after Javelina Creek, a tributary of Tornillo Creek, in the northeast part of Tornillo Flat. The Javelina Formation thickens across Big Bend National Park from 85 m in the west to as much as 200 m at some locations in the east. The unit is composed of color-banded mudstones interbedded with lenticular sandstones (Lehman, 1985a). The Javelina Formation is mudstone-dominated, with approximately 65% mudstone and 35% sandstone (Lehman, 1991). The most diagnostic characteristics of this unit, like the ones stratigraphically above it, are the hue and chroma of its mudstones. Dominant colors are purple, light gray and red, with yellow, orange, olive and bluish gray also common (Lawson, 1972). Mudstone colors of the Javelina Formation are less vibrant than those in the Black Peaks Formation above. The mudstones are unresistant to erosion and form badland topography with low rounded hills. Calcareous concretions are abundant. Interbedded with the
mudstones are thin, lenticular, fine- to medium-grained sandstones containing volcanic and sedimentary rock fragments, quartz, chert, feldspar and carbonate grains and reworked Upper Cretaceous foraminifera (Lehman, 1991). The sandstones weather to tan, pale green and dark brown. Chert and carbonate grains were derived from uplifted Cretaceous chert-bearing marine rocks and volcanic detritus was derived from a volcanic arc in western Mexico (Lehman, 1985a, 1991). The upper boundary with the Black Peaks Formation is placed at the top of the most resistant sandstone in the Javelina Formation (Straight, 1996).

The Javelina Formation was deposited after the onset of Laramide tectonism and the final regression of the Western Interior Seaway. It represents fluvial deposition in an inland floodplain. Mudstones are floodplain overbank deposits with color bands recording periodic episodes of soil formation. Color bands indicate environmental conditions during deposition and differing degrees of pedogenesis. Gray mudstone layers represent eluvial horizons depleted in clay and iron oxides. Purple and red layers represent illuvial horizons (zones of accumulation) for leached clay and iron oxides (Lehman, 1989, 1990). Sandstones are channel fills deposited by meandering streams flowing southeastward toward the Rio Grande embayment of the Gulf Coast (Lehman, 1987). Fallen logs and in situ tree stumps are found in these deposits. Fluctuating semi-arid and humid climates a few thousand years in duration are inferred to have existed during deposition of the Javelina Formation (Lehman, 1989). *Alamosaurus*, *Torosaurus* and *Quetzalcoatlus* faunal assemblages indicate a middle to Late Maastrichtian age for the Javelina Formation (Lawson, 1972; Standhardt, 1986).
Black Peaks Formation

The Black Peaks Formation is the middle unit in the Tornillo Group. It was named by Maxwell et al. (1967) after three basaltic peaks northwest of McKinney Hill on western Tornillo Flat. The Black Peaks Formation is mudstone-dominated with about 80% mudstone and 20% sandstone (Lehman, 1991). Fresh-water limestones are present but rare (Schiebout, 1970). The color-banded mudstones represent paleosol horizons, as in the underlying Javelina Formation. Mudstones are generally dark gray, brown and red with distinctive black horizons and contain calcareous nodules (Schiebout et al., 1987). Colors tend to have a richer chroma than those of the Javelina Formation. Contacts between mudstones are highly irregular (Lehman, 1988). Interbedded with these mudstones are gray to gray-white sandstones which fine upward and are more tabular than in the Javelina Formation but less abundant (Schiebout et al, 1987). Sediment was derived from volcanic rocks further west, and also from older Cretaceous rocks uplifted by Laramide tectonism. The Cretaceous/Tertiary boundary is placed in the lower Black Peaks Formation stratigraphically above the highest occurrence of dinosaur remains (Lehman and Coulson, 2002).

The unit was deposited in a floodplain setting similar to that of the Javelina Formation. Characteristic carbon-rich black mudstones reflect periods of water saturation near or at the surface. These conditions are also suggested by concentrated layers of carbonate nodules. The large number of tabular sandstones is indicative of highly sinuous meandering streams (Schiebout et al., 1987). Paleocene mammals and one specimen of Alamosaurus have constrained this unit to be Late Maastrichtian and Paleocene in age (Schiebout, 1973; Lehman and Coulson, 2002).
Hannold Hill Formation

The Hannold Hill Formation was named after Mrs. L. C. Hannold, who owned a local ranch (Maxwell, 1968). The unit is mudstone-dominated with 81% mudstone and 19% sandstone; sandstones are mostly lenticular (Lehman, 1991). The formation ranges in thickness from 110 meters to 238 meters. The Hannold Hill Formation is the only Tertiary unit that contains lignite (Maxwell et al., 1967). Mudstones are mostly gray and maroon in color with some sections also showing red and pink colors. Sandstones are notably less abundant than in the underlying Black Peaks Formation and are composed of carbonate fragments, chert, quartz, orthoclase and plagioclase. Volcanic material is rare or absent (Lehman, 1991). Coarse pebble to cobble conglomerates are also present and contain chert and Cretaceous limestone not seen in lower strata. This lithologic change marks a pulse in Laramide tectonism with sedimentation rates as high as 45 m/Ma and a decrease in sediment derived from the distant volcanic arc (Lehman, 1991). The lower contact with the Black Peaks Formation is placed at a conglomeratic sandstone containing chert and limestone. The contact with the overlying Canoe Formation is unconformable and marked by the appearance of coarser volcanic clasts suggesting a closer source (Lehman, 1988).

Like the units stratigraphically below it, this formation has been interpreted to represent overbank floodplain deposits, with color bands representing palesol horizons. The absence of black mudstone layers of the type found in the Black Peaks Formation is suggestive of uplift and decreased rainfall. A higher proportion of sand lenses indicates a decrease in sinuosity of meandering streams due to an increased gradient (Schiebout et al,

**Canoe Formation**

**Big Yellow Sandstone Member**

The basal sandstone of the Canoe Formation, known as the Big Yellow Sandstone Member, unconformably overlies the Hannold Hill Formation. In areas south and west of Tornillo Flat, the unit overlies strata as old as the Aguja Formation. The member is sandstone-dominated, with 79% sandstone and 21% mudstone (Lehman, 1991). The sandstones are conglomeratic and contain clasts similar to those in the Hannold Hill, except that volcanic rock fragments are also present. This is important because all lower strata only contain volcanic material of sand size, presumably derived from greater distances (Lehman, 1988). The unit becomes better developed from west to east. Sandstone geometry changes from lenticular to tabular and ranges in thickness from 9 to 50 m in the same direction. The varying thicknesses are due to the incision of channels into underlying units (Lehman, 1991).

The Big Yellow Sandstone Member has been interpreted to be a braided stream deposit with a general flow direction toward the southeast (Rigsby, 1982; Schiebout et al., 1987). The member is of Middle Eocene age (Maxwell et al., 1967).
MAPPABILITY WITHIN THE TORNILLO GROUP

Upper Cretaceous and Lower Tertiary fluvial deposits in the Big Bend region consist primarily of color-banded mudstones. As discussed previously, Udden (1907) first named these strata the Tornillo Clays. Maxwell et al. (1967) subsequently renamed these strata the Tornillo Group, and divided the group into the Javelina, Black Peaks and Hannold Hill Formations. The dinosaur-bearing Javelina Formation was concluded to be the only Cretaceous part of the former Tornillo Clays. While both the Javelina and Black Peaks Formations consist of alternating gray or gray-white sandstones with gray and maroon clays, sandstones are more abundant in the Black Peaks Formation. Like the Black Peaks Formation, the Hannold Hill Formation was characterized by Maxwell et al. (1967) as consisting of mostly gray and maroon clays but containing fewer sandstones. Those workers still questioned whether the two units could be accurately identified without the help of biostratigraphy.

Schiebout et al. (1987) argued for a return of these units to their former member status, arguing that they are not lithostratigraphically distinct. They believed that unconformities at contacts between the units represent episodes of insignificant fluvial erosion present also beneath sandstones within each respective formation. They claimed that while the units are easily distinguished in mapped areas, formation recognition in an unmapped area would be very difficult.

In response, Lehman (1988) maintained that such a change in nomenclature is unnecessary. The units have passed the test of mappability in that they have already been mapped. Lehman (1988) produced additional criteria for discerning between the units,
based on “markedly” different mudstone colors. Distinctive black mudstones occur only in the Black Peaks Formation (Fig. 4). Javelina mudstones are olive and light gray (Fig. 5), while the Hannold Hill Formation contains some pink mudstones. In addition to color, lithologic breaks also allow for determination of formation contacts. For instance, the Aguja/Javelina contact was placed by Maxwell et al. (1967) at the top of the sandstone above which the mudstones become variegated. Lehman (1988) found that this sandstone contained chert gravel, the first indicator of Laramide tectonism. Lehman (1988) also stressed the importance of unconformities as formational boundaries, especially at the top and base of the Hannold Hill Formation. Other formational differences were cited, as well.

Fig. 4) Interbedded mudstones and sandstones of the Black Peaks Formation in the Canoe Valley.
Fig. 5) Interbedded mudstones and sandstones of the Javelina Formation in West Tornillo Pasture.
FIELD OBSERVATIONS

Field research on the Pitcock Ranch focused on mapping the structure and distribution of the Upper Cretaceous and Lower Tertiary stratigraphic units in the region (Plate I). Igneous intrusions and Quaternary deposits are shown in the map, but were not studied in detail; their distribution is taken from previous workers. The accuracy of the geologic map of Maxwell et al. (1967) where it covers part of the ranch was also tested, as is discussed below.

Although the Rosillos Mountains laccolith was intruded into sediments discussed in this thesis, almost all roof rock above the laccolith has eroded away. The majority of field time was spent studying the units south of the laccolith, where they are generally overlain by Quaternary fan deposits and typically exposed in canyon walls and valleys.

The southeast region of the ranch is known as the Canoe Valley (Fig. 6). The three units exposed in this area are the Black Peaks, Hannold Hill and Canoe Formations (Fig. 7). A stratigraphic section of the upper Black Peaks Formation through the Big Yellow Sandstone Member of the Canoe Formation in the Canoe Valley is shown in Fig. 8, and representative outcrop photographs are shown in Figs. 9-13. The “Canoe” (Fig. 14) is a syncline in the Lower Tertiary strata with the fold hinge trending 308° and plunging toward the southeast. The Big Yellow Sandstone Member of the Canoe Formation is exposed in the center of the syncline along the top of the Canoe and unconformably overlies mudstones of the Hannold Hill Formation along an erosional contact (Fig. 12). The placement of this contact, at the base of a ledge-forming, conglomeratic sandstone containing volcanic clasts, was based on criteria set forth by
Fig. 6) Geologic map of southeast corner of Pitcock Ranch. See Plate I for location.
Fig. 7) Contacts between Canoe, Hannold Hill and Black Peaks Formations on northeastern flank of the Canoe syncline. View is to the southwest.
Fig. 8) Stratigraphic section of upper Black Peaks Formation, Hannold Hill Formation, and Big Yellow Sandstone Member of the Canoe Formation in the Canoe Valley. Locations of Figs. 9, 10, 11, 12 and 13 are indicated. Locations of base and top of section are shown as localities 1 and 2 on Fig. 6 and Plate I. The section is continued on the following page.
Fig. 8) Continued
Fig. 9) Sandstone with trough cross-bedding and conglomeratic horizons containing reworked calcareous nodules near base of section in the Black Peaks Formation shown in Fig. 8.

Fig. 10) Contact between Black Peaks and Hannold Hill Formations shown in Fig. 8.
Fig. 11) Conglomeratic base of Hannold Hill Formation shown in Fig. 8.

Fig. 12) Contact between Hannold Hill and Canoe Formations shown in Fig. 8.
Lehman (1988). The Canoe Formation is exposed nowhere else on the Pitcock Ranch. The Hannold Hill Formation also disappears a short distance farther to the northwest, as a result of the southeast plunge of the syncline. A conglomeratic sandstone at the base of the Hannold Hill Formation containing clasts of chert, quartzite and limestone (Fig. 11)
marks the contact with the Black Peaks Formation below, which is the oldest unit of Lower Tertiary age in the area. Selection of this horizon was also based on descriptions by Lehman (1988), and relies partly on the presence of limestone clasts in the conglomerate. In the northwest corner of the Canoe Valley, parts of the Rosillos Mountains laccolith have been intruded into the Black Peaks Formation, baking it in places (Fig. 15).

The Canoe Valley is bordered on the west by a vertical fault (Figs. 6 and 16) trending northwest, roughly parallel to the Canoe syncline. Here, the Tertiary Black Peaks Formation on the eastern side of the fault is in contact with the Upper Cretaceous Aguja and Javelina Formations on the western side. Maxwell et al. (1967) also mapped a fault on the east side of the Canoe syncline; however, no evidence for this second fault was observed in the field (Horton et al., 2006). Instead, a conformable contact is present between the Javelina and Black Peaks Formations directly to the east of the boundary fence. On the western side of the mapped fault, an anticlinal crest is exposed in the upper shale member of the Aguja Formation (Figs. 6 and 16), with lower Javelina Formation surrounding it to the north, west and south. A stratigraphic section of the lower Javelina Formation in this area is shown in Fig. 17, and representative outcrop photographs of that part of the unit are shown in Figs. 18 and 19. The canyon immediately to the west contains Javelina strata gently dipping toward the southwest. Near the western end of the canyon are faulted Cretaceous volcaniclastic rocks assigned to the Aguja Formation (Fig. 20) (Busbey et al., 1998; Breyer et al., 2005). South of this canyon on the southern border of the ranch, the Cretaceous/Tertiary boundary is located within the lower Black Peaks.
Fig. 15) Black Peaks Formation in contact with portions of the laccolith northwest of the Canoe Valley.

Fig. 16) Vertical fault west of the Canoe Valley, with anticline in Aguja Formation west of fault. View is toward the north.
Fig. 17) Stratigraphic section of lower Javelina Formation. Locations of Figs. 18 and 19 are indicated. Locations of base and top of section are shown on Fig. 6 and Plate I as localities 3 and 4.
Fig. 18) Javelina sandstone displaying trough cross-bedding at base of section shown in Fig. 17.

Fig. 19) Tabular Javelina sandstones in middle of section shown in Fig. 17.
Formation. However, the exact horizon is difficult to place without biostratigraphic control. Here, the Black Peaks Formation conformably overlies the Javelina Formation with the contact trending northwest. Straight (1996) placed the contact at the top of the most resistant sandstone in the Javelina Formation. I have found that the change in mudstone color is a more effective marker because of the discontinuous nature of the sandstones within these formations. Black and red paleosols are characteristic of the Black Peaks Formation and are easily distinguished from the drab, light gray and purple mudstones of the Javelina Formation. A cross section through the southeast region of the ranch is provided in Fig. 21.

Another part of the ranch studied in detail is the area within and to the west of Cottonwood Wash Canyon, which is located near the center of the southern part of the
Fig. 21) Diagrammatic cross section across Canoe Valley, along line A-B on Fig. 6 and Plate I.
ranch (Fig. 22). Previously, Maxwell et al. (1967) mapped Hannold Hill Formation in the northernmost areas of the canyon, with the Javelina Formation shown directly below an erosional contact. Stratigraphically lower, the Javelina/Aguja contact was placed directly south of the ranch boundary. The contact immediately west of Cottonwood Wash can be seen in Fig. 23. This study finds no Hannold Hill Formation exposed in Cottonwood Wash Canyon. The Aguja/Javelina contact, as mapped by Maxwell et al. (1967), is correct, but the strata exposed in the portion of the canyon located on the ranch is composed entirely of Javelina Formation. A gentle syncline (Fig. 24) is visible in the Javelina Formation when viewing the western wall of the canyon from the east. The syncline can be traced toward the west, plunging to the southwest beyond the western boundary of the ranch (Fig. 22).

The Aguja/Javelina contact in the West Tornillo Pasture (Figs. 22 and 25) follows a similar path curving toward the southwest. The contact was placed at “the top of a sandstone above which the beds are predominantly varicolored bentonic clay” (Maxwell et al. 1967). Because of the lenticular sand bodies and similar environmental conditions during deposition of the highest portions of the upper shale member of the Aguja Formation and the Javelina Formation, the contact can vary over more than 150 m stratigraphically (Lehman, 1985a). A normal fault in the southwest corner of the ranch displaces the contact approximately 400 m toward the southeast (Figs. 22 and 23). This fault was mapped by Maxwell et al. (1967), as well.
Fig. 22) Geologic map of the southwestern portion of the Pitcock Ranch. Location shown in Plate I.
Fig. 23) Aguja/Javelina contact west of Cottonwood Wash. View is toward the northwest.
Fig. 24) Syncline in Javelina Formation exposed in western wall of Cottonwood Wash Canyon.
Fig. 25) Aguja/Javelina contact in West Tornillo Pasture. View is toward the west.
Fossil localities are shown in Fig. 22 and Plate I. While many fossil specimens were collected during field work, few displayed identifiable characteristics. Most fossil localities yielded only small, weathered fragments of bone. All specimens collected occurred within sandstone bodies, which means they were probably transported and deposited as single bones or fragments. No fossil bones were found in paleosol horizons. All identifications below are tentative. Due to time constraints and lack of articulated specimens, no conclusive findings were achieved.

Order ORNITHOPODA

Family HADROSAURIDAE

*Kritosaurus indeterminate*

Description: Two neural arches with high-angle zygapophyses (Fig. 26) were collected weathering out of a ridge-forming sandstone in the Aguja Formation in “West Tornillo Pasture.” A caudal vertebra (Fig. 27) was also collected at this locality (F.L. 1 on Fig. 22 and Plate I). The site relative to the Aguja/Javelina contact suggests it occurs in the lower part of the upper shale member of the Aguja Formation and is of Late Campanian age.
Fig. 26) *Kritosaurus* neural arches (side view).

Fig. 27) *Kritosaurus* caudal vertebra (side view).
Order ORNITHISCHIA

Family CERATOPSIDAE

*Torosaurus utahensis*

Description: The proximal portion of a humerus from a juvenile *Torosaurus* (Fig. 28) was recovered from the Javelina Formation in “West Tornillo Pasture” (F.L. 2 on Fig. 22 and Plate I). Also found at this locality was a portion of frill (Fig. 29) possibly from the same individual. A middle Maastrichtian age is inferred based on the stratigraphic position of the site locality but identification is tentative.

![Proximal portion of humerus from juvenile *Torosaurus utahensis* (ventral view).](image)
Fig. 29) Portion of frill from *Torosaurus utahensis*.

Order PTEROSAURIA

Family ORNITHOCHEIRIDAE

*Quetzalcoatlus northropi*

Description: One bone fragment (Fig. 30) was recovered at a locality west of Cottonwood Wash Canyon in the Javelina Formation just north of the contact with the Aguja Formation (F.L. 3 on Fig. 22 and Plate I). The sample was identified as belonging to *Quetzalcoatlus northropi*. Identification was based on texture and thickness of the specimen. A middle Maastrichtian age is suggested by the proximity of the site to the Aguja/Javelina contact.
Fig. 30) Bone fragment from *Quetzalcoatlus northropi*. 
CONCLUSIONS

This study produced an improved geologic map of the Pitcock Rosillos Mountain Ranch. Building upon previous work on the ranch and Big Bend National Park, a better understanding of the Cretaceous and Tertiary sedimentary strata has been achieved. Previous stratigraphic studies of formations of interest in the park provided criteria for identification of formational boundaries (e.g., Lehman. 1988).

Placement of the Javelina/Black Peaks contact (Plate I) was based on a change in mudstone color and not on criteria proposed by Straight (1996), who placed the contact at the top of the most resistant sandstone in the Javelina Formation. The sandstones have a lenticular geometry and are not continuous over the region. In the field area, the change in mudstone color is more easily mapped and is a more appropriate distinction between the two formations. Drab, light gray and purple mudstones are characteristic for the Javelina Formation. The Black Peaks Formation contains black, red and purple mudstones that tend to be more vibrant in color than those of the Javelina Formation. Lehman (1988) also noted these differences as appropriate criteria for placement of the contact.

The map produced by Maxwell et al. (1967) served as a starting point for this work and is the most complete and detailed geologic map of the park ever produced. However, due to limited access on the Pitcock Ranch, it is probably more accurate within the park boundaries. Where the Maxwell et al. (1967) map extends into my field area, differences between that map and my observations were noted and corrected. The two maps are generally similar. However, important features were missed in the Maxwell et
al. (1967) map. No evidence for the fault mapped by Maxwell et al. (1967) northeast of the Canoe syncline was found; instead, a gradational contact between the Javelina and Black Peaks Formations were observed. Large exposures of Hannold Hill Formation in the Canoe Valley as mapped by Maxwell et al. (1967) are actually sediments of the Black Peaks Formation. Maxwell et al. (1967) also mapped Hannold Hill Formation in northern portions of Cottonwood Wash Canyon. An east-west trending syncline in the Javelina Formation was observed in that area during the present study, and no Hannold Hill Formation was found.

These differences are noticeable only when detailed field mapping techniques are employed. While remote-sensing data and aerial photos can be useful tools, a map based mostly on these techniques is not likely to be completely accurate in this particular region. Similar depositional environments in the described formations produced similar lithologies that can easily be placed into inappropriate formations. Interpretation of remote-sensing data used as a compliment to field mapping, however, will produce a more reliable geologic map. In the future, the map provided through this study may be tested as new information about these units is brought to light.

Due to limited time and the sheer number of fragments, only preliminary identifications were made on a handful of the bone specimens recovered during field research. All fossil bones were found weathering out of sandstones, which is why no articulated specimens were found. The tentative nature of the identifications did not produce better age constraints on the units from which they were collected. In the future, there is great possibility that many more of the samples collected will be identified. All specimens described will be donated to The University of Texas Vertebrate Paleontology
Museum in Austin, which houses the largest collection of Cretaceous and Tertiary vertebrate remains from the Big Bend region in existence. Much of the Pitcock Ranch is still unprospected and many more discoveries of fossil bones are inevitable.
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Robert Paul Horton was born on February 7, 1982, in Shreveport, Louisiana. He is the son of Glen and Christi Horton. After graduating from Haughton High School in 2000, he attended Louisiana State University in Baton Rouge from 2000 to 2003 and received a Bachelor of Science degree in geology. In 2004, he began graduate work at Texas Christian University in Fort Worth, Texas. While in pursuit of a Master of Science degree in geology, he was a teaching assistant for the geology department. Paul received his Master of Science degree in May 2006. He is married to Susan Maurin Horton of Baton Rouge, Louisiana and they currently live in Fort Worth, Texas.
The Late Cretaceous Pen, Aguja and Javelina Formations and Tertiary Black Peaks, Hannold Hill and Canoe Formations are exposed on and around the Pitcock Rosillos Mountain Ranch, adjacent to Big Bend National Park, Texas. The objectives of my project were to produce a geologic map of these sedimentary strata on and around the Rosillos Mountains laccolith and to collect fossil vertebrates from the units of interest. I worked on unmapped areas of the Pitcock Ranch and tested the validity of the geologic map of the park produced by Maxwell et al. (1967) where it falls on the ranch. Numerous differences were found between the Maxwell et al. (1967) map and my observations, while many features coincide. The geologic map produced is important because it includes previously unmapped areas and revisions to a previously constructed map of the area.