The Roles of Fossil Vertebrates in Interpretation of Late Cretaceous Stratigraphy of the San Juan Basin, New Mexico

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INTRODUCTION

Sedimentary rocks of Late Cretaceous, non-marine origin are well exposed in some of the valleys of the Chaco River drainage system that roughly parallels the southern and western margins of the San Juan Basin. In some areas these rocks contain rich concentrations of vertebrate fossils. Interpretations based upon those collections amassed in the early decades of this century have played a part in the development of a stratigraphic nomenclature for the Late Cretaceous, non-marine deposits of the basin and biostratigraphic interpretations of their ages.

In this paper the history of vertebrate paleontological researches in the San Juan Basin will be summarized to the extent that it played a part in the development of a stratigraphic nomenclature for the Late Cretaceous deposits. This hopefully will serve as a background for the synthesis presented by J. Fassett (1973) elsewhere in this volume. Secondly, collections obtained by field parties from the University of Kansas that concentrated their work in the vicinity of the Bisti Trading Post in Hunter Wash contain the first records of the mammalian fauna living in this area during the deposition of parts of the Fruitland and Kirtland formations. A preliminary study indicated that this, the Hunter Wash local fauna, contains some new genera and species in association with animals also known from the type Lance local fauna (Clemens 1964, 1966, 1973), the fauna of the upper part of the Edmonton Formation (Lillegraven 1969), and those recovered from the Judith River (Sahni 1972) and Milk River formations (Fox 1970). Differences in local faunal composition are probably the results of both biogeographic provinciality and inequality in age.

DISCOVERY OF CRETACEOUS VERTEBRATES

Apparently the first vertebrate fossils of Late Cretaceous age collected in the San Juan Basin and brought to the attention of vertebrate paleontologists were found in the vicinity of the Ojo Alamo Trading Post (fig. 1). Excluding the Quaternary alluvium, the most recent stratigraphic unit exposed in the region of the trading post is the Nacimiento Formation, a series of varicolored siltstones and some sandstones. All fossils so far recovered from the Nacimiento in this area indicate its sediments were deposited in continental environments during the Puercan and Torrejonian (approximately early and middle Paleocene). Beneath the Nacimiento is a series of strata that have produced fossilized remains of faunas of Cretaceous age.

The E.D. Cope collection, now at the American Museum of Natural History, contains a few dinosaurian teeth collected in the last century in the San Juan Basin. Brown (1910, p. 269) thought these were collected in the Ojo Alamo area. If they were, their discovery did not spark a major collecting effort in the Cretaceous deposits of the basin, and between 1881 and 1901 the efforts of paleontologists were focused on recovery of the remains of Paleocene mammals. Mr. George Pepper of the Hyde Exploring Expedition of 1902 was the next person to collect Cretaceous vertebrate fossils in the Ojo Alamo area. Study of his collections, taken to the American Museum of Natural History, resulted in the detailing of Barnum Brown to the San Juan Basin in the summer of 1904.

Brown published a formal account of this field work in 1910. In his description of the stratigraphy he (Brown 1910, p. 267-8) commented,

"The known fossil-bearing Puerco [part of the

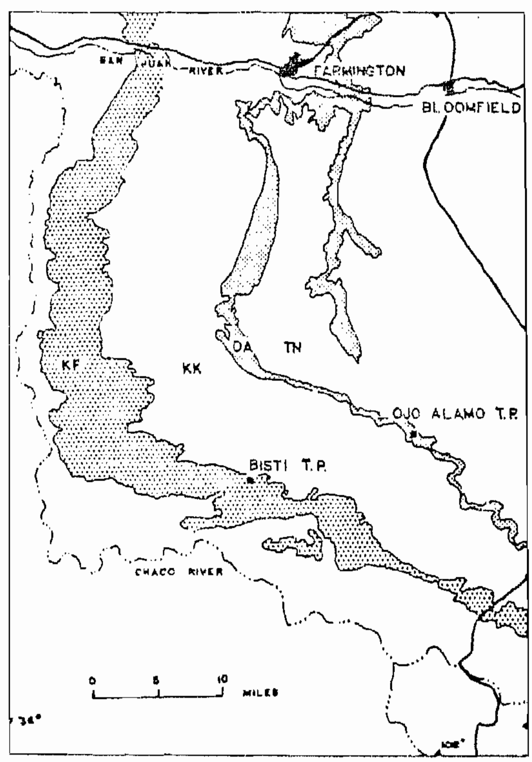

Fig. 1 Index map. The following abbreviations are used to designate outcrops: Fruitland Formation (KF), Kirtland Shale (KK), Ojo Alamo Sandstone (OA), and Nacimiento Formation (TN). Redrawn from Fassett and Hinds (1971).

> Nacimiento Formation of current usage] . . . was traced by the writer southwest from Coal Creek and identified with the unfossiliferous bad lands at the head of Ojo Alamo Creek where the strata are weathered into a great amphitheater of open terraces. A careful search through these upper clays failed to reveal either vertebrate or invertebrate remains . . . Near their base sandstones predominate and are characterized by quantities of petrified wood with large logs . . ."

The directional reference given by Brown does not agree with the other topographic and geological data. Coal Creek (De-na-zin Wash, in part, of current U.S. Geological Survey topographic maps) drains southwestward from the Ojo Alamo area. The information given by Brown suggests his starting point might have been Cope's localities near Chico Springs, which are situated in Gallegos Canyon. Another interpretation is that Brown worked northwestward from Cope's localities in Barrel Springs Arroyo.

Brown goes on to note (*ibid.*, p. 268) that less than a mile South of the store at Ojo Alamo the, "Puerco formation rests *unconformably* [sic] on a conglomerate that is composed of red, gray, yellow and white pebbles". Finally he comments,

> "Below the conglomerate there is a series of shales and sandstones evenly stratified and usually horizontal . . . The shales below the conglomerate that contain numerous dinosaur and turtle remains I shall designate the *Ojo Alamo Beds* [sic]. They were estimated to be about 200 feet thick, but owing to the lack of time I was unable to determine their relation to the underlying formations . . . The vertebrate remains were numerous in several places thirty to one hundred feet below the conglomerate".

In recent years a controversy has developed over the nature of Brown's original concept of the Ojo Alamo Beds, and resulted in a multiplication of formational names and attendant ambiguities. Among the recent revisors of the stratigraphic terminology are Baltz, Ash, and Anderson (1966) who have developed a useful format for discussion of the problem. This format and their numerical unit designations for lithologic units are adopted here (fig. 2). Two papers in this volume deal with the uncertainties surrounding use of the term Ojo Alamo in current stratigraphic literature. Here I will attempt to limit my comments to the history of collection and interpretation of the biostratigraphic record involved in the "Saga of the Ojo Alamo Sandstone".

THE OJO ALAMO BEDS OF BROWN

To place Barnum Brown's work in proper historical perspective it must be remembered that his trip to the San Juan Basin in 1904 was a prospecting venture in response to the discovery of dinosaur bones by a member of the Hyde Exploring Expedition two years earlier. Nothing in the published reports suggests that Brown intended to carry out a thorough stratigraphic study of the area. In fact he described his work as a "preliminary reconnaissance" (Brown 1910, p. 267),. His study of the geology is probably best regarded as a necessary but peripheral adjunct to the collection of vertebrate fossils.

Brown's report (1910) suggests but does not clearly specify that he recognized the following lithologic units (in descending order): a) The Puerco formation consisting of upper clays and lower sandstones characterized by the presence of fossil logs. These were thought to rest unconformably on, b) a conglomerate composed of red, gray, yellow and white pebbles. The stratigraphically lowest unit

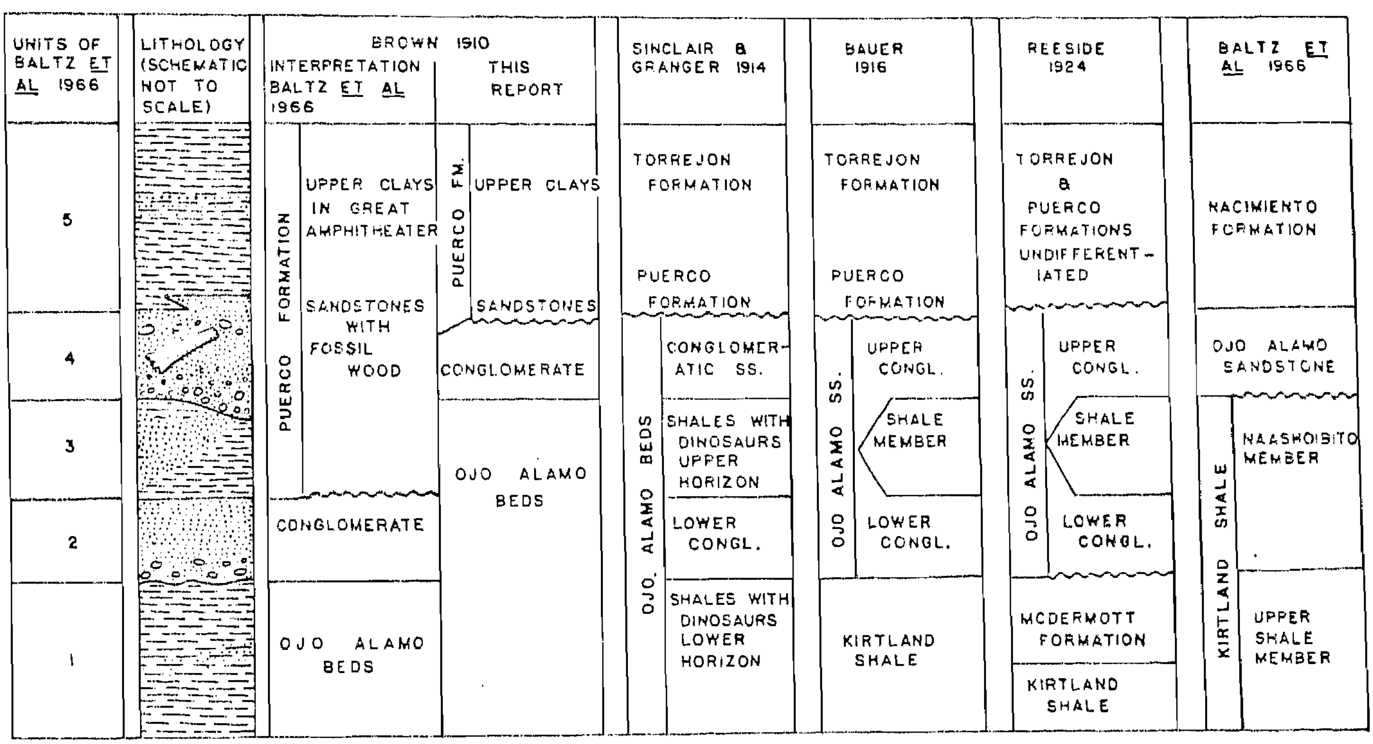

Fig. 2 Interpretations of stratigraphic correlations. Redrawn with modifications and simplifications from Baltz *et al.* 1966, fig. 2. Section attributed to Reeside 1924 is that reported for Ojo Alamo Arroyo.

recognized was the, c) approximately 200 feet of shales below the conglomerate that contains the remains of dinosaurs and turtles. These shales were designated the Ojo Alamo Beds. Brown did not mention the presence of a lower stratum of conglomerate within the shales.

In 1908 J.H. Gardner of the U.S. Geological Survey made a small collection of vertebrate fossils in the vicinity of the Ojo Alamo Trading Post (Knowlton, 1909) and, the following year, returned with J.W. Gidley to enlarge the collection. Two fragmentary turtles collected by them were used by Hay (1910) as types of new species *Basilemys nobilis* and *Adocus vigoratus*. Hay(*ibid.*, p. 307) gave the following description of the stratigraphy of the Ojo Alamo area:

> "In this region they found two distinct formations. In the lower, composed of sandstones, clays, and a bed of conglomerate, there were found fragmentary remains of dinosaurs and turtles below described as *Basilemys nobilis* and *Adocus vigoratus*, together with considerable parts of *Aspideretes vorax?* and unidentifiable fragments of other Trionychidae. These beds are probably the equivalents of the Lance Creek beds. Above these dinosaur-bearing deposits came a deposit of conglomerate, about 12 feet thick at most. Succeeding this are other beds of sandstone and clay, in which were found no remains except those of the turtles described below as *Compsemys vafer* and *Hoplochelys bicarinata*, and probably *Compsemys parva* . . . It is believed that the deposits above the bed of conglomerate belong to either the Puerco or Torrejon".

More detailed information is given when Hay (*ibid.*, p. 316) described the type of *Basilemys nobilis* which was, "found below the upper conglomerate bed, in the dinosaur-bearing deposits and about 50 feet above the lower conglomerate". He states the type of *Adocus vigoratus* was, "secured below the upper bed of conglomerate, in those beds which furnished remains of dinosaurs (*ibid.*, p. 317)".

Although Brown (1910, published July 30) makes reference to the turtle *Thescelus rapiens* Hay 1908, described on the basis of materials collected by him in 1904, he does not cite Hay's paper (1910, published June 29) in either this report (Brown 1910) or the section of the Ojo Alamo fauna that he prepared for Sinclair and Granger (1914). The first synthesis of Hay's contribution of 1910 with other papers on the stratigraphy and paleontology of the Ojo Alamo Beds is found in Gilmore's (1916) report on the vertebrate faunas of the Ojo Alamo, Kirtland, and Fruitland formations.

During the summers of 1912 and 1913, field parties from the American Museum of Natural History worked in the San Juan Basin. The results of their researches were reported by Sinclair and Granger (1914), who studied the sections in both Ojo Alamo and Barrel Springs arroyos and the intervening exposures of the Cretaceous formations around the western half of the mesa just south of Ojo Alamo Trading Post (fig. 3). This mesa, which includes the common corner of sections 7, 8, 17, and 18; T. 24 N.; R. 11 W., is a prominent landmark for this study. It is unnamed on the U.S. Geological Survey topographic map of the area, Alamo Mesa East, 1966 ed. For convenience it shall be informally dubbed South Mesa.

Sinclair and Granger (1914, p. 301) describe a conglomeratic sandstone with fossil logs (unit 4, see fig. 2) on which "the Puerco formation rests, with marked angular unconformity". Although locally extensive, the

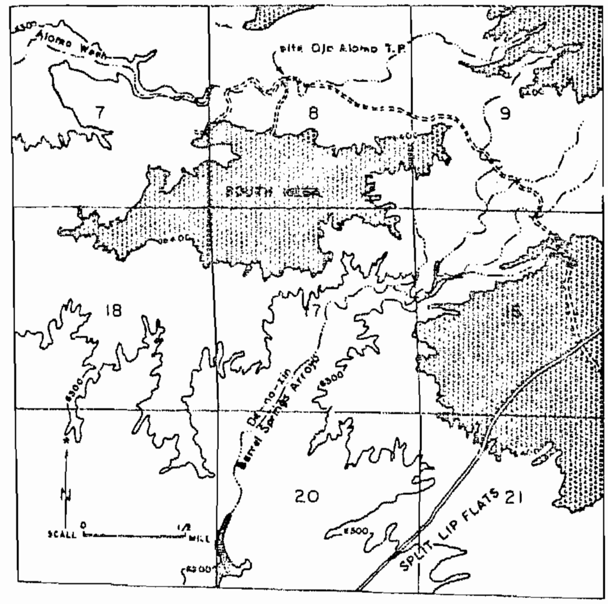

Fig. 3 Index map of the Ojo Alamo Trading Post area, T. 24 N., R. 11W. Shaded regions over 6,400 feet elevation. Redrawn from U.S. Geological Survey, Alamo Mesa East Quadrangle, 1966 ed.

conglomeratic sandstones occur as lenses and pods in an otherwise dominantly sandy unit (note Baltz *et al.* 1966, p. D13-14). Apparently Brown included part of this unit, which lacked conglomerates but contained fossilized logs as a lower part of the Puerco formation and in other areas interpreted its conglomeratic facies as a unit between the Puerco and the Ojo Alamo Beds. One vertebrate fossil, a "centrum of a dinosaurian caudal vertebra (Sinclair and Granger 1914, p. 301)", found as surface float near the edge of Split Lip Flat, was recorded as coming from the "conglomeratic sandstones with logs", unit 4. Fassett (1973, this volume) discusses the significance accorded this fossil.

Although recognized by Gardner and Gidley (Hay 1910), Sinclair and Granger (1914) were the first to clearly describe how the geological section below the "conglomeratic sandstones with fossil logs", unit 4, was interrupted by a "lower conglomerate", unit 2, of 6 to 8 feet in thickness. The superjacent unit, "shales with dinosaurs, upper horizon", unit 3, was described as conformably overlying the "lower conglomerate" and being disconformably overlain by the "conglomeratic sandstones with logs". The varicolored clays and channel sandstones of the "upper horizon", unit 3, attaining a thickness of some 58 feet, were identified without reservation as part of the "Ojo Alamo beds of Brown" (ibid., p. 301).

In a paper that appeared approximately three months later, Brown (1914) published a revision of his initial interpretation of the stratigraphy.

> "On Coal Creek, in the immediate vicinity of Ojo Alamo, the Puerco clays rest on massive sandstones which mark the top of a distinct series of sediments. At the point of contact Messrs. Granger and Sinclair have noted a distinct erosional unconformity, and 30 to 70 feet below this point another discordance appears

> where the sandstones rest on a thick bed of conglomerates. The underlying shales and sandstones, more than 200 feet thick, are lithologically distinct from the clays of the Puerco and the fauna is totally different (*ibid.*, p. 379)".

In a preceding paragraph Brown (*ibid.*) states, "the Puerco is a clay formation". Thus, it is reasonable to assume that in the quotation presented above the "distinct erosional unconformity" referred to in the second sentence is the contact between units 4 and 5. Sinclair and Granger (1914, Fig. 2, Column A, Ojo Alamo section) show unit 4 to be 28 to 66 feet thick. Brown's statement, "and 30 to 70 feet below this point another discordance appears where the sandstones rest on a thick bed of conglomerates", strongly suggests he was referring to the tops of conglomeratic strata that are now regarded as parts of unit 4. If these interpretations are correct, the 200 feet of "underlying shales and sandstones" would encompass units 3, 2, and some part or all of 1. Again Brown made no mention of the "lower conglomerate", unit 2, and it might be assumed that at the time of writing this article he was simplifying the lithologic description and encompassing units 4, 3, and 2 in a unit described as "a thick bed of conglomerates". I think this interpretation is unlikely in view of Brown's subsequent statements to Gilmore (see below).

The "lower conglomerate", unit 2, was described by Sinclair and Granger (1914) as lying disconformably on a series of bluish clays that in some areas contain lignite. Southwest of Barrel Springs dinosaurs and fossil wood were found in banded red and blue-gray clays of this unit. They (*ibid.*,p. 302),

> ". . . did not ascertain how far below this level vertebrate fossils are found in these bluish-gray clays, but a trip down Ojo Alamo Arroyo to a point some eight miles below the store resulted in finding turtle and other reptile bones in shales apparently conformable with those just mentioned, so far as we could judge from rather hastily made observations. The only interruption of the shale deposition seemed to be a prominent stratum of yellow-brown sandstone [Farmington Sandstone Member of the Kirtland Shale?] some three miles below the store, in Ojo Alamo Arroyo . . ."

Sinclair and Granger's interpretation of the formational units is clearly outlined in the stratigraphic column included in their paper (*ibid.*, fig. 2). The Ojo Alamo Beds are shown unconformably underlying the Puerco formation. The concept of Ojo Alamo Beds was expanded to include (in descending stratigraphic order): a) conglomeratic sandstone with logs (unit 4), b) shales with dinosaurs, upper horizon (unit 3), c) lower conglomerate (unit 2), and d) shales with dinosaurs, lower horizon (unit 1). The base of the lowest unit was not specified but from the published comments on their prospecting trip down Ojo Alamo Arroyo, it appears that they saw most of the section of the Kirtland Formation exposed along this arroyo and found no evidence suggesting to them a noteworthy break in the sedimentary regime.

Some recent workers (e.g., Baltz *et al.*, 1966) have contended that Brown's original concept of the Ojo Alamo included only strata that Sinclair and Granger designated "shales with dinosaurs, lower horizon" (unit 1), and that Brown overlooked the fossiliferous upper horizon (unit 3). This is not a new interpretation for Reeside (1924, p. 31 and see fig. 2) commented, "at the time of collecting the specimen [horn core of *Monoclonius* sp.] Brown was applying the name Ojo Alamo to the shale (McDermott and Kirtland [*i.e.*, unit 1]) beneath the conglomerates [units 2, 3, and 4 undifferentiated]." I feel that this is an erroneous interpretation for the following reasons:

First, we have Sinclair and Granger's (1914, p. 301) clear identification of the "upper horizon" (unit 3) as the "Ojo Alamo beds of Brown". Brown knew of Sinclair and Granger's research for in their report he contributed a long section (*ibid.*, pp. 302-3) dealing with the dinosaurian and other reptilian materials they recovered.

Secondly, the topography and occurrence of fossils on the slopes around the western half of South Mesa (fig. 3) would have militated against Brown's overlooking the "upper horizon" (unit 3). Today the strata of this "horizon" and the "lower horizon" (unit 1) are carved into prominent badlands. In recent years, since 1962, field parties from the University of Kansas and other universities have prospected the western parts of South Mesa from time to time and always found reptilian fossils evident in both units 1 and 3. These badlands are not an area formed by quite recent erosion, but one that provided materials to the U.S. Geological Survey field party of 1915 (see Bauer 1916, pl. 69) and, earlier, to Sinclair and Granger in 1913 (note their stratigraphic column A, fig. 2, 1914). On the basis of the recorded distribution of fossils in this area, it is unlikely that Brown, whose goal was to obtain a sample of the vertebrate fauna, would have collected in only what is now designated unit 1, the "lower horizon" and overlooked or avoided units 2 and 3.

This conclusion receives support from the scanty and sometimes contradictory locality descriptions for taxa based on the material Brown collected. Sinclair and Granger (1914, p. 301) note, in the description of the "shales with dinosaurs, upper horizon" (unit 3), "This seems to be the level of Brown's *Kritosaurus navajovius*". Later this stratigraphic reference was amended by Gilmore (1916, p. 283):

> "In his original paper Brown failed to state the geological level where the type specimen was found, but in a letter to me dated February 26, 1916, he says; '*Kritosaurus navajovius* came from the upper part of what is designated by Bauer as the Kirtland Formation[unit 1]'. At the time he wrote the original descriptions of this dinosaur Brown considered the Ojo Alamo formation as extending downward at least 200 feet below the Puerco-Torrejon contact, so that he assigned this specimen to that formation."

Other data concerning the provenience of fossils collected by Brown can be found in Gilmore's paper. He (*ibid.*, p. 295, footnote 1) quotes Brown as stating the type of *Thescelus rapiens* Hay 1908 came from the "lower conglomerate" (unit 2). Also *ibid.*, p. 299, footnote 1):

> "In response to my (C.W. Gilmore) inquiry as to the exact position of the type specimens of *Aspideretes vorax*, *A. fontanus*, and*A. austerus* Barnum Brown in a letter of February 26, 1916, writes as follows: 'The three species of Aspideretes came from clays interbedded in the sandstone of the upper part of the Ojo Alamo formation.' It should be added that this determination is based on Bauer's columnar section, which Brown had before him."

After hearing a presentation of these arguments, Dr. L.S. Russell (pers. commun.) offered the following commentary, "It is a long time since Barnum Brown spoke to me about the Ojo Alamo beds, and my memory could be at fault. As I remember the conversation, Brown held that he had used the name Ojo Alamo for the dinosaur-bearing part of the section, and to restrict it to only a portion of that, and to give another name to that portion where most of the bones occurred, was unjustified. . . . *To him, Ojo Alamo beds meant dinosaur beds* [Italics mine]".

Because of the gaps and discrepancies in the available records, the course of Brown's prospecting and collecting trips around Ojo Alamo cannot be completely documented. Although the data are incomplete and sometimes contradictory, an appreciation of the stratigraphic interval he sampled can be obtained. We know Brown saw and, almost certainly, prospected the badlands along the southern and western flanks of South Mesa. In these badlands unit 1 and unit 3 are separated by the thin "lower conglomerate" (unit 2). During its erosion unit 2 has produced a topographic bench but not a major geomorphological barrier between outcrops of the subjacent and superjacent units. To the eyes of a collector of fossils employed to carry out a reconnaissance, survey, outcrops of units 1, 2, and 3 form a single area that would need to be thoroughly prospected. That Brown did in fact search outcrops of all these units is strongly suggested by the stratigraphic information he provided for inclusion in Gilmore's report on the fauna. Clearly he convinced Gilmore (1916, p. 281) who wrote,

> "These conclusions [on stratigraphic correlations that are contrary to those of Baltz *et al.* 1966] were based by Brown on specimens collected in the upper 200 feet of deposits that immediately underlie the Puerco, and it is quite unlikely that some of these forms came from beds now included in the Kirtland Shale. However that may be, Brown has now established the geological position of the type of *Kritosaurus navajovius* as below the lower conglomerate and therefore in the Kirtland shale, but the discovery of a second specimen of the same species above the lower conglomerate shows that the basis for his original contention *is not altered by this* [Bauer's] *later subdivision* of the deposits, [Italics mine]".

Baltz, Ash and Anderson (1966) recently reviewed the records of Brown's work and came to some conclusions significantly different from those just developed. Major changes in the stratigraphic nomenclature were based on their interpretations. These authors (*ibid.*, p. D3) state,

> "He [Brown] described the lower part of the Puerco as being composed predominantly of sandstones that contain large petrified logs (unit 4 and probably unit 3 which is mostly soft sandstone in the Ojo Alamo Arroyo west of the now-abandoned store)."

They go on to note(*ibid.*),

> "Brown (1910, p. 268) reported that, *less than a mile south (actually, west) of the store at Ojo Alamo,* the rocks that he assigned to the Puerco rest unconformably on a conglomerate composed of red, gray, yellow and white pebbles (unit 2 . . .)". [italics mine].

The change in Brown's designation of direction from the trading post is not justified here or on the following page (*ibid.*, p. D4) where it is repeated in a similar context. This is a critical point on which the differences between Baltz *et al.* and my interpretations hinge.

We appear to be in agreement in the view that Brown's understanding of the rock unit designated unit 4, the "upper conglomerate", was imperfect. I feel that Brown erred in not recognizing that the conglomerates occurred as lenticular units within the sandstone which also contains petrified wood. Instead of being two discrete units separated by an unconformity, they are facies of the same unit.

The disagreement centers on the question, did Brown collect fossils from the rock unit now designated unit 3? The site of the Ojo Alamo store is within the area of outcrop of unit 3 (see Baltz *et al.* 1966, fig. 3), just south of the prominent exposures of unit 4. Remembering that Brown understood the stratigraphic sequence to be (in stratigraphically descending order): a) sandstones with logs, b) conglomerate, and c) siltstones of the Ojo Alamo beds, Baltz *et al.* (*ibid.*) note that proceeding westward down Ojo Alamo Arroyo from the store, the first conglomerate to be encountered would be the conglomerate of unit 2. Therefore, all of Brown's collections must have come from the siltstones beneath it, i.e., unit 1.

However, taking Brown at his word, proceeding southward from the store one must either climb over the top of South Mesa (*the route of the wagon road shown by Bauer* 1916, Pl. 69) or, to minimize the climb, follow a more circuitous route around the eastern end of the mesa and drop into the drainage of Barrel Springs Arroyo. Any route in a generally southerly direction from the store site crosses rocks of unit 4 and, on more easterly routes can cross the lower parts of the Nacimiento Formation before dropping down into outcrops of the subjacent strata. Along the rim of the southern and western flanks of South Mesa unit 4 is well exposed and contains large lenses of conglomerate. Thus, if Brown went less than a mile southward from the Ojo Alamo store site, the first conglomerate he would have encountered would be part of unit 4 that overlies an area of richly fossiliferous strata of unit 3 and unit 1.

The diversity of interpretations has been increased by O'Sullivan *et al.* (1972). After quoting Brown's (1910, p. 268) description of the type area of the Ojo Alamo Beds, without the modification in directional reference presented by Baltz *et al.* (1966), they state, "the store at Ojo Alamo (now in ruins) was built on unit 4 (but see Baltz *et al.*, *ibid.* fig. 3, who place it on unit 3), and the conglomerate 'less than a mile south of the store' would be unit 2" (O'Sullivan et al. 1972, p. E55). Reference to the map of Baltz *et al.* (*ibid.*) shows that south of Ojo Alamo the closest outcrop of unit 2 is just a mile south of the site of the trading post. Any significantly shorter distance would lead to an outcrop of unit 3 or, more likely, areas underlain by unit 4. O'Sullivan *et al.* (*ibid.*) continue,

> "a lower limit was not given to the 'Ojo Alamo Beds', but Brown (1910, p. 268) stated that they 'were estimated to be about 200 feet thick, but owing to lack of time was unable to determine their relation to the underlying formations.' Brown's 'Puerco formation' included units 5, 4, and 3. The lower conglomerate, unit 2, was unnamed by Brown and apparently, was assigned to neither the Puerco nor the Ojo Alamo".

Baltz *et al.* (1966) have not adduced any independent evidence to justify changing Brown's specification of direction from south to west. Evidence to the effect that

Brown saw the outcrops on the southern side of South Mesa, almost certainly collected there, and, in supplying stratigraphic data to Gilmore, indicated that parts of his collections came from units 2 and 3 has already been presented. I must conclude that the fossils making up the Ojo Alamo faunal assemblage were collected from units 1, 2, and 3, and these rock units comprise the Ojo Alamo Beds of Brown.

In summary, Brown's major contribution to our knowledge of the Cretaceous-Tertiary section in the Ojo Alamo-Barrel Springs area was his collection in 1904 of the first significant sample of Cretaceous fossil vertebrates from this region. These fossils were found in units 1, 2, and 3. Four and five years later Gardner and Gidley worked in the vicinity of Ojo Alamo. In addition to obtaining several important specimens of fossil turtles, they developed a much more detailed and accurate stratigraphic interpretation than that arrived at by Brown. Unfortunately Hay's report of their work was largely overlooked by subsequent stratigraphers. As well as collecting additional fossils, Sinclair and Granger provided much more information on the physical stratigraphy. They partially corrected Brown's misinterpretations of the rocks now constituting unit 4, and recognized the sequence of lithologic units employed today. Sinclair and Granger expanded Brown's usage of Ojo Alamo Beds to recognize the discrete units of finer sediments (unit 3 and upper part of unit 1) and include the conglomerates (units 2 and 4).

C.M. BAUER AND THE U.S. GEOLOGICAL SURVEY FIELD PARTY OF 1915

C.M. Bauer, assisted by J. B. Reeside and H.R. Bennett, was charged with the responsibility and ably succeeded in developing a series of reports that provide the major framework of our knowledge of the stratigraphy of a large section of the San Juan Basin. The first of the reports to result from this work was Bauer's (1916) study of the stratigraphy of part of the Chaco River valley. Here the Fruitland Formation and overlying Kirtland Shale are named and described. In defining the top of the Kirtland Shale, Bauer (*ibid.*, p. 275) states, "overlying the Kirtland Shale with apparent conformity is a thin formation of conglomeratic sandstone and shale". Local unconformities are shown in some measured sections (*ibid.*, pl. 70). The result of the choice of this contact between units 1 and 2 was to allocate part of Brown's Ojo Alamo Beds to the Kirtland Shale.

Bauer noted the discrepancies in Brown's and Sinclair and Granger's definitions of the upper limit of the Ojo Alamo beds. Also a series of measured sections suggested to Bauer that the upper shale (unit 3) was lenticular. These observations resulted in the following redefinition, "As he [Bauer] found the formation to be essentially a sandstone including lenses of shale and conglomerate, it seems desirable to call it Ojo Alamo sandstone and to define it as consisting on Ojo Alamo Arroyo of two conglomeratic beds and the shale lenses which they include (*ibid.*, p. 276)". So defined the Ojo Alamo Sandstone includes units 2, 3, and 4.

As parts of the research project which Bauer directed, C.W. Gilmore (1916), T.W. Stanton (1916), and F.K. Knowlton (1916) contributed reports on vertebrate, invertebrate and botanical fossils found in the Fruitland Formation, Kirtland Shale and Ojo Alamo Sandstone. Gilmore (see above, p. 11-12) was able to elicit locality data from Barnum Brown indicating that in 1904 Brown obtained fossils from units 1, 2, and 3.

RESEARCH OF J.B. REESIDE AND OTHERS BETWEEN 1916 AND 1966

In 1916 and in several subsequent years J.B. Reeside returned to the San Juan Basin and continued the research begun with Bauer. Gilmore described fossil vertebrates he collected from the Ojo Alamo Sandstone (1919) and later reported Reeside's discovery in 1921 of the first remains of a sauropod dinosaur, *Alamosaurus*, to be recovered from the Late Cretaceous of North America (1922).

Two years later Reeside (1924) presented a synthesis of his research on the Upper Cretaceous and Tertiary rocks of the San Juan Basin. He (*ibid.*, p. 28-32) reviewed the paleontological and structural evidence concerning the age of the Ojo Alamo Sandstone and then assigned the unit a "Tertiary (?)" age. Anderson (1960, p. 9) has stated, "Reeside (1924, p. 3[*sic*] reviewed the vertebrate fossil evidence and concluded that poor collecting practices and questionable determinations cast doubt on the validity of correlation". From the tenor of these remarks one may, but is not compelled to assume Reeside concluded that all the existing collections of vertebrate fossils were of uncertain stratigraphic provenience and the identifications of the taxa suspect. If this viewpoint has been adopted by the reader, it should be corrected.

Careful reading of Reeside's analysis of the reported vertebrate fauna reveals that he indeed querried the assignment of stratigraphic position and/or identification of many of the fossils collected by Brown, Gardner and Gidley, and Sinclair and Granger. However, he goes on to state,

> "The remaining specimens now known whose stratigraphic position is unquestioned are mostly fragmentary, and though suggesting a varied fauna, are not sufficient for such definite assignment as should be used in correlation. These specimens include teeth of *Deinodon*?; dermal plates and a scapula of an armored dinosaur; part of the frill of a ceratopsian distinct from *Triceratops, Ceratops*, or *Monoclonius;* vertebrae of a very large carnivorous dinosaur of the proportions of *Tyrannosaurus;* and a scapula and ischium of the large sauropod dinosaur *Alamosaurus sanjuanensis* Gilmore (1924, p. 31)".

Reeside was caught up in the Cretaceous-Tertiary boundary problem and had to deal with the conflicting views of various paleontologists.

> "The fauna has been correlated by Brown and by Gilmore with the Judith River and Belly River formations, of middle Montana age . . . The writer believes that of the two most significant forms cited as members of the fauna one probably came from older beds and the other is probably not determinable closely enough to afford a sure correlation. The remainder of the fauna is either entirely new or too fragmentary for precise identification. The known flora suggests Tertiary rather than Montana age, but is, like the fauna, too meager to permit even a comparison. In short, the paleontologic data now available are entirely inconclusive as to the age of the beds (*ibid.*, p. 32)".
> "The writer believes that both of these formations [Ojo

Alamo and Animas] are later than Montana and Laramie and that both are equivalent to some part of the Denver, Raton, and Lance formations, the Animas formation, however, representing a longer time interval than the Ojo Alamo sandstone. In view of the wide differences in opinion expressed by various students as to the correct assignment of this whole group of related formations, the Ojo Alamo sandstone and Animas formation are herein classified as Tertiary (?) (*ibid.*, p. 32)".

Little paleontological work was carried out on the faunas of the Kirtland Shale and Ojo Alamo Sandstone in the years immediately following the publication of Reeside's report. Dane (1936) evaluated the stratigraphic interpretations of previous workers and treated the Ojo Alamo Sandstone as part of the "Upper Cretaceous Series". He (*ibid.*, p. 117) commented, "In Brown's original Ojo Alamo beds they [Sinclair and Granger 1914] also recognized a lower conglomerate which varies from a 'pebbly sandstone to a coarse conglomerate', 6 to 8 feet thick and 58 feet at a maximum below the overlying conglomerate". Thus, contrary to Reeside, Dane included units 2 and 3 in the original construct of the Ojo Alamo Beds of Brown. Colbert's (1950) article is largely a review of information available to Reeside in 1924.

In 1960 Anderson published a study of Cretaceous-Tertiary palynology based primarily on materials from the east side of the San Juan Basin. He did, however, briefly consider the Ojo Alamo area, and raised the question of the possibility of reworking of materials:

"Apparently, articulated parts have not been found. Preservation of the fragments is fair to poor. The Ojo Alamo collections were made in the same local area as those from the Kirtland shale. In view of the wide age discrepancy between the floral and faunal evidence, the possibility that large numbers of bones and fragments have been reworked should be seriously considered (Anderson 1960, p. 9-10)".

Anderson's description of the occurrences of fossils in the Ojo Alamo Sandstone discovered up to 1960 is correct. Most of the fossils are isolated bones, albeit some of them are large or not particularly durable elements to be moved by a high energy stream. Also, we do not know if, "a few fragmentary vertebrae of a very large carnivorous dinosaur . . . collected by J.B. Reeside, Jr. . . . (Gilmore 1919, p. 67)" were articulated. However, even their association in the same area argues against reworking. Subsequent collecting by the author has yielded evidence indicating that at least some of the vertebrate fossils from the Ojo Alamo Sandstone, unit 3, have not been reworked. Though the possibility of reworking of a few vertebrate fossils cannot be fully excluded, the chances of reworking of large numbers of bones are slight.

RECENT STUDIES

As an outgrowth of their investigations Baltz *et al.* proposed far-reaching changes in stratigraphic nomenclature. Because of their assumption, which the author feels is demonstrably suspect if not erroneous, that Brown's Ojo Alamo Beds included only strata of unit 1, they noted that this name was a synonymous name for an upper part of the Kirtland Shale. Although the name Ojo Alamo Beds (Brown 1910) has temporal priority over Kirtland Shale (Bauer 1916), they advanced cogent arguments for maintaining the widely-used and well-understood name Kirtland Shale (Baltz *et al.* 1966, p. D8).

This action left units 2 and 3, "lower conglomerate" and "shales with dinosaurs, upper horizon", without formal stratigraphic names. Baltz *et al.* (*ibid.*, p. D14) dubbed them the Naashoibito Member of the Kirtland Shale. Inclusion of this unit in the Kirtland Shale was justified on its lithologic and faunal similarity to the other members of the Kirtland. Finally Baltz *et al.* (*ibid.*, p. D13-14) redefined the concept of the Ojo Alamo Sandstone and proposed that it be restricted in application to the "upper conglomerate", unit 4. This and the other proposed changes in stratigraphic nomenclature have been adopted in subsequent publications of the U.S. Geological Survey (e.g., O'Sullivan *et al.* 1972).

To the writer and other paleontologists the results of the work of Baltz, Ash, and Anderson have bitter-sweet repercussions. The correction of long-standing errors in understanding of the physical stratigraphy of the Cretaceous and Tertiary units in the Ojo Alamo area is an important contribution. Their clarification of some of the detailed stratigraphic relationships of the contents of the various formations and their members is welcome and already has proved to be a base and stimulus for further research. However, the paleontologist is left with an awkward, to say the least, stratigraphic nomenclature. In relation to the Ojo Alamo area, the Ojo Alamo Sandstone as restricted by these authors refers to a lithologic unit that has not yet yielded vertebrate fossils in certain stratigraphic provenience. Paradoxically the well known, classic Ojo Alamo fauna becomes a paleontological unit based on fossils collected in the Naashoibito Member of the Kirtland Shale. A simple but elegant demonstration of the dangers involved in assigning the same name to lithostratigraphic and faunal units.

As a possible solution for the nomenclatorial problem I would opt for a return to Bauer's definition of the lithostratigraphic unit, Ojo Alamo Sandstone to the extent that this formation would include units 2, 3, and 4. Thanks to the work of Bauer's successors the physical interrelationships of these units and their contacts with super — and subjacent strata are now more clearly understood. Perhaps, following Powell's (this volume) suggestion, it would be useful to recognize two members within the Ojo Alamo Sandstone.

Immediate rationalization of the nomenclature for the paleontological unit or units, is hampered by our clearly incomplete understanding of terrestrial faunal evolution within the San Juan Basin area during the Late Cretaceous. Colbert (1950) and others have argued that the apparent differences in composition of the collections recovered from the Kirtland Shale and the Ojo Alamo Sandstone would be reduced if not eliminated by further collection. I feel a note of caution must be sounded. The appearance of sauropods in the North Horn Formation of Utah and Javelina or Tornillo Formation of Texas (Lawson 1972) as well as their approximately contemporaneous occurrence in the San Juan basin following their extirpation from the western part of this continent in the early Cretaceous, suggests a major change in faunal composition in these areas just prior to the close of the Cretaceous. Much more field work must be undertaken before we can assert with confidence that the stratigraphic range of sauropods in the San Juan Basin is limited within the Ojo Alamo Sandstone, or extends into the upper parts of the Kirtland Shale. In view of these uncertainties, I feel the appropriate course is to continue to treat the fossils collected from the Ojo Alamo Sandstone and upper part of the Kirtland Shale in the vicinity of the old Ojo Alamo trading post as a unit. This paleontological unit can be named the Alamo Wash local fauna — the name being derived from the current designation of Ojo Alamo Arroyo.

VERTEBRATE FAUNAS OF THE FRUITLAND AND KIRTLAND FORMATIONS

Early studies of the fossil vertebrates of the San Juan Basin centered on the Paleocene faunas discovered in strata of the Nacimiento Formation. A little material was collected from Cretaceous strata. Cope (1885, p. 985) noted, "A few fossils sent from time to time by Mr. Baldwin identify the Laramie". These collections include teeth and possibly other skeletal elements of dinosaurs, bones of a "species of Trionyx", and crocodilian remains that served as the type of *Crocodilus stavelianus.* Brown (see above, p. 154) thought that the dinosaurian teeth at least were collected in the Ojo Alamo area, but now the provenience of the small Baldwin-Cope collection cannot be verified. Holmes (1877), Schrader (1906), and Schaler (1907) published descriptions of strata currently included in the Ojo Alamo Sandstone, Kirtland Shale, and Fruitland Formation but do not specifically note the occurrence of vertebrate fossils. Knowlton (1916, p. 327-329) summarized these and other early geological studies of the San Juan Basin.

George Pepper's discovery and the collections of Brown, Gardner, and Gidley focused the attention of paleontologists on the assemblage of fossils here designated the Alamo Wash local fauna. Apparently they did not collect fossil vertebrates from members of the Kirtland Shale below the Upper Shale Member (the stratigraphic nomenclature of Fassett and Hinds 1971 is followed here). Sinclair and Granger (1914, p. 302; see quotation on p. 157) explored the lower parts of Ojo Alamo Arroyo and noted the occurrence of vertebrate fossils in strata possibly including some now recognized as part of the Lower Shale Member of the Kirtland Shale. Certainly the first significant investigation of the paleontology of this unit and the subjacent Fruitland Formation was the work of the U.S. Geological Survey field party of 1915 directed by C.M. Bauer. In his acknowledgments Bauer (1916, p. 271) states, "For these collections and a considerable part of the other data, including mapping, much credit is due to J.B. Reeside, jr., who assisted the writer both in the field and in the office, and to H.R. Bennett, who assisted in the field".

The scope of their paleontological collections can be partially assessed by noting the geographical distribution of the fossil localities. Starting on the bluffs overlooking the south bank of the San Juan River at Fruitland they obtained partial skeletons of a dermatemyid turtle, *Adocus*?, and a hadrosaurian dinosaur in strata of the Fruitland Formation (localities 4 to 6, locality numbers cited here and subsequently are those used by Bauer 1916, pl. 64 and Gilmore 1916). Additional remains of dinosaurs were obtained from the Fruitland Formation exposed in the breaks along Ojo Amarillo Creek (localities 11 to 19). Outcrops of the Farmington Sandstone Member of the Kirtland Shale on the south side of Cottonwood Arroyo yielded a specimen of the turtle *Plastomenus* and hadrosaurian dinosaur remains (localities 33 to 35). Additional hadrosaurian material was found in the Upper Shale Member in the vicinity of Pina Veta China (localities 40 to 43). The density of localities indicates outcrops of the Fruitland Formation and Lower Shale Member of the Kirtland Shale in the vicinity of Hunter's Store in Hunter Wash and those of the Upper Shale Member and the Ojo Alamo Sandstone in the vicinity of the Ojo Alamo Store were areas of intensive collecting.

The original site of Hunter's Store is approximately a mile to the northeast of the site of the former Bisti Trading Post (NW¼, Sec. 32, T. 24 N., R. 13 W.), which was recently destroyed by fire (C. Bond, pers. commun.). Review of the limited locality information now available and the current distribution of fossiliferous strata suggests that the area described by collectors in the early part of this century as being "in the vicinity of" or "to the northeast of" Hunter's Store is included in Secs. 27, 28, 29, 32, 33, and 34 of T. 24 N., R. 13 W. and Secs. 4 and 5 of T. 23 N., R. 13 W. Preliminary review of the older collections and those obtained by University of Kansas' field parties in the 1960's does not indicate the presence of two or more distinct faunal units in the Lower Shale Member of the Kirtland Shale and the upper part of the Fruitland Formation cropping out in this area. As a first step in the analysis, the fossils obtained in Hunter Wash from explosures of these two units that are delimited by an arbitrarily selected contact (see Fassett and Hinds 1971, p. 19) will be treated as representatives of members of a biological unit, the Hunter Wash local fauna.

HUNTER WASH LOCAL FAUNA

The collections amassed by the U.S. Geological Survey field party from the Fruitland and Kirtland formations in Hunter Wash and described by Gilmore (1916), Stanton (1916), and Knowlton (1916) included records of a variety of organisms. I have not been able to find reports of the fossils discovered at all the localities noted on Bauer's map (1916, Pl. 64), but the following are described in the literature.

Stanton (1916) recorded the presence of the freshwater invertebrate *Unio holmensianus* in the Fruitland Formation. Gilmore (1916) identified tooth fragments of carnivorous dinosaurs, remains of crocodilians, and scales of the gar *Lepisosteus* collected from strata of the Fruitland Formation in Hunter Wash. He (*ibid.*) reported a more diverse fauna recovered from the Kirtland Shale in this area. It included the fishes *Lepisosteus* and *Myledaphus* and a variety of reptiles, *Brachychampsa* and another crocodilian, carnivorous and hadrosaurian dinosaurs, and the type specimen of the turtle *Neurankylus baueri.*

Knowlton's (1916) analysis of the floras of the Fruitland and Kirtland formations reports 18 taxa of plants in the strata of the Fruitland Formation cropping out in Hunter Wash. These include the types of *Quercus baueri, Ficus baueri, Ficus praelatifolia,* and *Pterospermites neomexicanus.* The type specimens of *Heterantheria cretacea* and *Carpites baueri* were recovered from strata of the Fruitland Formation in the valley of Coal Creek, the next tributary of the Chaco River immediately south of Hunter Wash.

In the following years Reeside continued his collecting and research in the San Juan Basin. During the 1916 field season he obtained additional material from the Ojo Alamo Sandstone and Kirtland Shale in the vicinities of the Kimbetoh and Ojo Alamo trading posts. In Gilmore's (1919) description of these collections there is no indication that Reeside worked in the Hunter Wash area.

Gilmore (1935) reviewed the materials collected from the Kirtland Shale after the publication of his 1919 report. The major new collections were those made C.H. Sternberg in 1923 and in 1929 by a field party under Gilmore's direction (Gilmore 1930). Fossils collected during these years added the type specimens of *Baena ornata, Boremys grandis,* and *Thescelus hemispherica* to the sample of the Hunter Wash local fauna. Also specimens of the turtles *Basilemys nobilis* and *Adocus bossi,* and a specimen of a squatinid fish were added to the collection. A nearly complete right squamosal recorded the presence of *Pentaceratops sternbergii.* These later collections did not modify Gilmore's (1916, p. 280) statement, "No mammal, bird, or amphibian remains have yet been recorded in these [Ojo Alamo, Kirtland, and Fruitland] formations".

In the summer of 1962 a field party from the Museum of Natural History, University of Kansas started an investigation of the Late Cretaceous, non-marine faunas of the San Juan Basin. Although additional specimens of turtles and dinosaurs were collected, the primary goal of this and field parties in the four following summers was the collection of samples of the smaller vertebrates in the Late Cretaceous faunas. In 1962 the first discovery of a concentration of small vertebrate fossils was made in outcrops of the Kirtland Shale in Escavada Wash. Soon thereafter the field party prospected the more fossiliferous strata of the Fruitland Formation and Kirtland Shale in the vicinity of the Bisti Trading Post. This work resulted in the discovery of a stratigraphic sequence of sites that yielded fossil vertebrates. The stratigraphically lowest is in the Fruitland Formation approximately 40 feet below the thin but wide-spread coal chosen as the top of the formation (Fassett and Hinds 1971, p. 19). Our largest collections of small vertebrates were obtained from the sand and siltstones of a channel filling. On one side of this channel the upper-most coal of the Fruitland conformably feathers out into the sands of the channel deposit. On the other side, the wall of the channel is cut through the coal which is thereby separated from the sediments of the channel filling by an erosional unconformity. The stratigraphically highest concentration of microvertebrate fossils collected in the Bisti area was obtained from a lenticular silty sandstone approximately 55 feet above the base of the Lower Shale Member of the Kirtland Shale.

In the course of prospecting the area members of the field parties searched for both specimens of large vertebrates and concentrations of the remains of smaller animals. Usually the latter type of deposit was found in the lowest sandstones of channel fillings where the fossils are concentrated along with clay balls, sometimes ranging up to gravel size. Fragments of the shells of turtles, scutes of crocodilians, scales of *Lepisosteus*, and fragments of large vertebrate bones are abundant constituents of these concentrations, and the fossils that attracted the prospector's attention. In contrast, well preserved examples of skeletal elements of small, lizard-size reptiles, amphibians and mammals are relatively rare. In order to obtain a large sample of these small vertebrate fossils the paleontologist must employ a collecting technique that involves the processing of a large volume of rock minimizing the possibility of breakage of delicate fossils while maximizing the chance of recovery of vertebrate microfossils, such as the teeth of small mammals whose greatest dimension can be on the order of two or three millimeters.

In similar situations in Late Cretaceous and early Cenozoic deposits of the United States and elsewhere, the underwater screening technique has been employed with great success. This technique involves quarrying the fossiliferous sediment and mechanically breaking it down into lumps that will fit into wooden boxes approximately a foot to a foot and a half in length, width and depth. The bottoms of these boxes are constructed of a fine mesh, wire screen. After loading with fossiliferous sediment, the boxes are placed in a stream or pond where soaking will cause disaggregation of many kinds of silt and sandstones. If this occurs the fine sedimentary clasts can be washed out leaving a concentrate of larger particles and fossils on the screen bottom of the box. This collecting technique has been thoroughly described by McKenna (1962 and 1965).

For a number of reasons attempts to employ the standard screening technique in the San Juan Basin proved unsuccessful. Primarily, clear, moving water is a scarce commodity in the area and usually the water trapped in tanks or ponds is already highly charged with fine particles in suspension or quickly stirred up from their muddy floors. Secondly, the clay minerals in the fossiliferous sediments swell on wetting thus forming a thin but effective seal preventing farther penetration by water and disaggregation of the blocks of rock. To deal with these problems the technique was modified in the following ways: Collecting in the field was limited to hand quarrying of the fossiliferous sediments. As they were manually reduced to small clods, many well-preserved specimens of small limb bones, jaws, and fragments of skulls were recovered. The fragmented rock was then shipped to the laboratory. The late Russell Camp constructed a washing machine that gently agitated the fossiliferous sediments in a strong detergent solution. This combination of detergent and gentle agitation prevented the formation of impervious clay seals on the clods and promoted the disaggregation of the rock. The machine produced a richly fossiliferous concentrate that was subsequently dried and manually sorted under low magnification.

Study of the sample of the Hunter Wash local fauna obtained during the last decade is currently underway and involves several vertebrate paleontologists. Prof. Richard Fox, University of Alberta, and Prof. T.H. Eaton, University of Kansas, are studying the non-mammalian vertebrates of the fauna. The preliminary results of my study of the mammals of the Hunter Wash local fauna are summarized in the following annotated faunal list:

Order Multituberculata
Suborder Ptilodontoidea
Family Ectypodontidae
Mesodma sp. The P_4 resembles that of *M. primaevus* in curvature of the crest of the blade and serration count but is larger.
Cimexomys, cf. *C. judithae*
Family Ptilodontidae
cf. *Kimbetohia campi*
Family Cimolodontidae
Cimlodon sp. At least one species resembling *C. nitidus* and the other including animals of smaller individual size.
Suborder Taeniolabidoidea
Family Eucosmodontidae
A new genus and new species.
Order Marsupialia
Superfamily Didelphoidea
Family Didelphidae
Alphadon cf. *marshi*. Teeth of this species (fig. 4) are approximately intermediate in size and proportions between samples from the type Lance local Fauna (Clemens 1973) and upper part of the Edmonton Formation (Lillegraven 1969) of *A. marshi* and *A. wilsoni*.

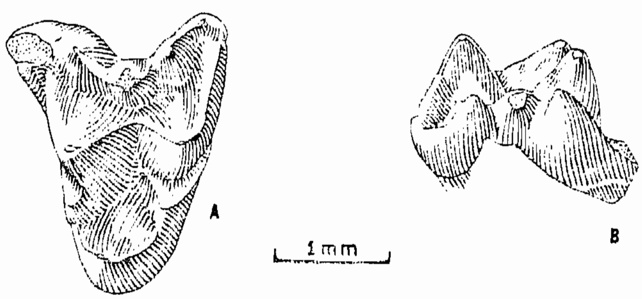

Fig. 4 *Alphadon* cf. *marshi*, left M³, University of Kansas, Museum of Natural History no. 15817. A, occlusal view; B, labial view.

Alphadon?, new species. Represented by isolated teeth of the size of those referred to or compared with *Alphadon rhaister* in studies of the type Lance (Clemens 1966), upper part of the Edmonton (Lillegraven 1969) and Judith River (Sahni 1972) local faunas.
Family Pediomyidae
Pediomys cf. *cooki*. The simplicity of the stylar shelf of the upper molar (fig. 5) indicates this species is not part of the morphologically more primitive *P. elegans* — *P. clemensi* group.
Order Insectivora
Family Leptictidae
Gypsonictops sp. Lillegraven (1969) recognized two species of *Gypsonictops* (*G. hypoconus* and *G. illuminatus*) in the fauna of the upper part of the Edmonton Formation while only one occurs in the type Lance local fauna (*G. hypoconus*). Two species are present in the Hunter Wash local fauna. One is the size of *G. illuminatus* but differs in several morphological features indicating it probably is a new species. The other is *G. hypoconus*.
Family Palaeorcytidae
cf. *Cimolestes* sp. A palaeoryctid smaller than *C. incisus* is represented by a few fragments of teeth.
Eutherian of uncertain ordinal affinities.
Fox (1970) announced the discovery of an isolated molar in the Upper Milk River Formation, southern Alberta. This tooth is of "erinaceomorph appearance" and represents a hitherto unrecognized Late Cretaceous lineage. A member of this lineage is represented by at least one upper molar in the sample of the Hunter Wash local fauna.

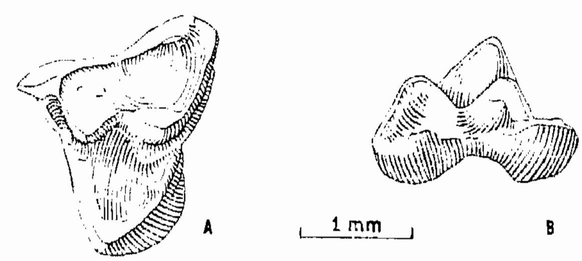

Fig. 5 *Pediomys* cf. *cooki*, left M¹ of M², University of Kansas, Museum of Natural History No. 15979. A, occlusal view; B, labial view.

Although simply a progress report on a study of the mammals of the Hunter Wash local fauna, the preceding listing makes one point that should not be modified when the author's research is completed. The Hunter Wash local faúna clearly is not a southern sample of the type Lance local fauna (Clemens 1964, 1966, 1973) nor the so-called typical Hell Creek fauna (Sloan and Van Valen 1965). Absence of representatives of the *Meniscoessus conquistus* — *M. robustus* — *M. borealis* species group and the rarity of representatives of the species of *Pediomys* distinguish the Hunter Wash local fauna. Also lack of representatives of eutherians such as *Protungulatum* and *Procerberus* differentiate it from the Bug Creek local fauna found in the upper part of the Hell Creek in east central Montana (Sloan and Van Valen 1965). It differs from the fauna recovered from the upper part of the Edmonton Formation of Alberta (Lillegraven 1969) in the absence of the diverse assemblage of palaeoryctids and presence of some new kinds of multituberculates. These, the type Lance, typical Hell Creek, Bug Creek, and upper Edmonton local faunas, are the major, latest Cretaceous local faunas known from the Rocky Mountain-Great Plains regions of Wyoming, Montana, and Alberta. Mammalian local faunas have been recovered from stratigraphically lower formations in Montana and Alberta.

A. Sahni (1972) has recently studied a vertebrate fauna recovered from strata of the Judith River Formation cropping out on the Missouri River in central Montana. R.C. Fox is studying a larger collection of mammalian fossils collected from the Oldman Formation. These strata are a northern extension of the Judith River Formation and yielded the "Belly River fauna" cited in earlier papers. Fox (e.g., 1970, 1971A, and 1971B) has also presented studies of the mammals found in older strata of the Milk River formation of Alberta. Although, as pointed out in the preceding faunal list, some elements of the Hunter Wash local fauna appear identical or closely related to members of the local faunas recovered from the Judith River, Oldman, and Milk River formations there are differences in overall composition. The mammals of the Hunter Wash local fauna do not simply record a southern extension of one of these older, northern mammalian faunal units.

Russell (1964) in his review of Cretaceous non-marine faunas of northwestern North America briefly commented on the Late Cretaceous vertebrate faunas of the San Juan Basin. This work was limited to study of the published records of fishes and reptiles. He concluded,

> ". . . the vertebrates of the Kirtland, Fruitland and Ojo Alamo formations of northeastern New Mexico have resemblances to both the Edmonton and the Oldman fauna (*ibid.*, p. 17)".

In this statement he is distinguishing them from the type Lance and approximately contemporaneous local faunas. In a different type of analysis, Sloan (1969) recognized the same similarities of the vertebrate fauna. Analysis of the microvertebrates of the Hunter Wash local fauna emphasizes its unique composition, and holds open the question: do these dissimilarities in composition reflect temporal or ecologically based, biogeographic differences or some combination of these factors?

CORRELATION OF THE HUNTER WASH LOCAL FAUNA

In his first analysis of the vertebrates recovered from the Kirtland Shale, Gilmore (1916) regarded this formation as being correlative with the Belly River formation of Canada. Earlier Brown (1910) had initially treated the upper part of the Kirtland and overlying Ojo Alamo as correlative with the Edmonton Formation of Canada. Later he (Brown 1914) modified his interpretation to argue they were synchronous with the subjacent Belly River formation. Gilmore (1935, p. 187) maintained, "In light of this more recent study of new vertebrate materials, it is my conclusion that the Kirtland and Belly River are equivalent in age." His conclusion was not accepted by all vertebrate paleontologists, for example Lull (1933) assigned a more recent age to the Kirtland Shale. This interpretation was in agreement with those based upon the invertebrate faunas of the San Juan Basin.

In preparation of their correlation chart for the Cretaceous formations of the Western Interior, Cobban and Reeside (1952) treated the Fruitland Formation and Kirtland Shale as temporal correlatives of the upper part of the Pierre Shale and lower part of the Fox Hills Sandstone of their standard reference sequence for the Western Interior. Thus these formations were regarded as being distinctly younger than the Judith River Formation in Montana. Vertebrate paleontologists had long regarded the faunas of the Judith River Formation and Oldman Formation of Alberta, which yielded the classic Belly River dinosaurian fauna, as being approximately contemporaneous. Cobban and Reeside (*ibid.*, p. 1028) recognized the conflicting correlations of invertebrate and vertebrate paleontologists and noted, "On the basis of the dinosaurian faunas, some vertebrate paleontologists assign the interval from the Ojo Alamo sandstone to the Fruitland formation to horizons older than here shown . . ."

For the purposes of this report it is unnecessary to further recapitulate the history of attempts of correlation of the Kirtland and Fruitland formations and their contained faunas with those from formations of Late Cretaceous age in Wyoming, Montana, and Alberta. In large part the differences in interpretations appear to be traceable to inadequate data or faulty application of biostratigraphic techniques or both. Although far from being ready to attempt precise correlations, I feel enough data has become available recently to permit approximations of relative ages. This is accomplished through employing range zones of various marine invertebrates and assuming that biostratigraphers working with these organisms from the Marine Cretaceous record have been able to recognize and correct for homotaxial inaccuracies. Clearly this is an assumption that some biostratigraphers will be ready to challenge.

In the San Juan Basin rocks of the Fruitland Formation conformably overlie and intertongue with the Pictured Cliffs Sandstone which in turn conformably overlies the Lewis Shale (Fassett and Hinds 1971, p. 8-9). The Lewis Shale is a wedge of sediments of marine origin tapering to a feather edge toward the southwest. Sediments of the Pictured Cliffs were formed in nearshore and beach environments as the Lewis sea made its final retreat to the northeast.

> "The Lewis Shale is entirely of Montana age. According to W.A. Cobban (written commun., 1966), the age span of the Lewis Shale in the Durango, Colo., area (near the type locality) is from the zone of *Baculites mc learni* [*sic*] up into the zone of *Didymoceras cheyennense* (Gill and Cobban, 1965, fig. 3). This age span correlates roughly with the lower half of the Pierre Shale of the Western Interior reference sequence. Where the formation pinches out near Hunter Wash, it is probably middle Pierre in age, although this has not been confirmed by fossils (O'Sullivan *et al.* 1972, p. E50-51)".
>
> "In the Durango agea, the youngest fossils from the underlying Lewis Shale lie in the zone of *Didymoceras cheyennense*, and, therefore, the Pictured Cliffs Sandstone in the same area might be as young as the zone of *Baculites compressus* (Gill and Cobban, 1965, fig. 3). Fauna listed by Reeside (1924, pl. 3) from the middle part of the formation south of Durango (loc. 10502) and along the San Juan River (loc. 9278) contain *Inoceramus barabini* and *Inoceramus sagensis*, and this association also suggests the zone of *Baculites compressus* from the middle of the Pierre Shale of the standard reference secuence (*ibid.*, p. E52)".

Fassett and Hinds (1971, p. 16) have attempted to determine the rate of regression of the Lewis Sea from the San Juan Basin. They suggest that the 500 foot isopach line of their fig. 7 (*ibid.*, p. 14, documenting the interval between the

Huerfanito Bed and top of the Pictured Cliff Sandstone) approximates a time line within the Range Zone of *Didymoceras nebrascense* and the other isopach lines in this figure approximate time lines. If their assumptions are correct, the top of the Pictured Cliff Sandstone in the Hunter Wash area, which is southwest of the 500 foot isopach line, would be older but possibly still within the Range Zone of *Didymoceras nebrascense.*

The collections comprising the sample of the Hunter Wash local fauna have been obtained from the upper 40 feet of the Fruitland Formation and the lower 55 feet of the Lower Shale Member of the Kirtland Shale in Hunter Wash. In the vicinity of Hunter Wash the Fruitland Formation is approximately 300 feet thick. Thus, in terms of the stratigraphic position of the collecting area relative to the top of the Pictured Cliffs Sandstone, the possibility that the age of the Hunter Wash local fauna might be older than or within the span of the Range Zone of *Didymoceras nebrascense* cannot be excluded. However, it appears more likely that it is younger.

A prime collecting area for vertebrate fossils in the Judith River Formation is in the breaks of the valley of the Missouri River and its tributaries in the vicinity of the point where the Judith River debouches into the Missouri. The only extensive sample of the microvertebrate elements of the faunas of the Judith River Formation was recovered approximately 5 to 8 miles northeast of the junction of these two rivers (Sahni 1971). Gill and Cobban (1966, Pl. 3) describe a control section measured at the mouth of the Judith River ("composite section measured by J.R. Gill and L.G. Schultz, Tps. 22-23 N., R. 17 E., Fergus County, and T. 24 N., R. 17 E., Blaine County, Mont."). They note that the top of the Judith River Formation lies within the *Didymoceras nebrascense* Range Zone and the base of the formation within the *Baculites perplexus* Range Zone. Sahni's (1971) two microvertebrate localities, Clambank Hollow and Clayball Hill, are described as being approximately 40 feet below the top of the Judith River Formation (*ibid.*, p. 339-342). Thus, the temporal duration of the vertebrate fauna collected in the Judith River Formation near the junction of the Judith and Missouri rivers appears to fall within the *Didymoceras nebrascense* and *Baculites perplexus* Range Zones. Russel (1970) argues that the top of the Judith River Formation in central Montana and the top of the Oldman Formation of southern Alberta are approximately contemporaneous. Accepting this correlation it follows that the fauna of the Oldman Formation of Alberta, the classic "Belly River vertebrate fauna", are known from deposits contemporaneous with the Range Zone of *Didymoceras nebrascense* and older range zones.

Lacking other methods of correlation, the assumption that the *Didymoceras nebrascense* Range Zone can be used for correlations between stratigraphic sections in Alberta, New Mexico and intervening areas is provisionally accepted. The temporal ranges of the Judith River and Oldman faunas include this and possibly older range zones of the standard stratigraphic sequence of the Western Interior. The temporal range of the Hunter Wash local fauna might include the *Didymoceras nebrascense* Range Zone but probably is slightly younger. Thus the differences in faunal compositions between these vertebrate faunas appear most probably to be the results of both differences in age and biogeographic province.

CONCLUSIONS

Review of the published records of the work of Barnum Brown and others involved in the study of the Cretaceous stratigraphy of the San Juan Basin during the early part of the century, indicates that Brown's concept of the Ojo Alamo Beds included what Baltz *et al.* (1966) designated units 3, 2, and the upper part of 1. The Alamo Wash local fauna is represented by the assemblage of vertebrate fossils obtained from these strata in the region of the old Ojo Alamo Trading Post.

Secondly, there appears to be good reason to retain the definition of the Ojo Alamo Sandstone, which would include units 2, 3, and 4, proposed by Bauer (1916). This action, of course, would take cognizance of the additions made to our knowledge of the physical stratigraphic relationships of these units by geologists and paleontologists subsequently working in the area.

Fossils obtained from the upper part of the Fruitland Formation and lower part of the Lower Shale Member of the Kirtland Shale cropping out in Hunter Wash are taken to represent one paleontological unit, the Hunter Wash local fauna. The stratigraphic relationships of this unit with the underlying Pictured Cliffs Sandstone suggest the Hunter Wash local fauna might have been contemporaneous with but probably is slightly younger than the Range Zone of *Didymoceras nebrascense.* Therefore it is probably slightly more recent than the faunas of the Judith River and Oldman formations of Montana and Alberta.

ACKNOWLEDGEMENTS

This paper reports a small part of the results of a project initiated in 1962. It was begun under the auspices of the Museum of Natural History, The University of Kansas, which provided considerable financial support. Many members of the staff and students helped with the work, in particular I wish to acknowledge the contributions of Prof. T.H. Eaton, Prof. Richard Fox (now at the University of Alberta), and the late Mr. Russell Camp. Support from the National Science Foundation (e.g., Grant GB-5121) contributed greatly to underwriting the research expenses. Since moving to the University of California the author has received financial support for the continuation of the project from the Museum of Paleontology, the Annie M. Alexander Endowment and Faculty Research grants. Many residents of the San Juan Basin have assisted with our work. I especially want to acknowledge the warm hospitality extended by Mr. and Mrs. Clayton Bond. The permission of Dr. L.S. Russell and Mr. Douglas Lawson enabling me to include citations of their unpublished data and interpretations is appreciated. Figures 1-3 were prepared by Mr. David Cook; figs. 4 and 5 are the work of Mr. Merton Bowman. To all who have made contributions to this research project but have been left unnamed, a special vote of thanks.

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