

FOREWORD

ON THE 2005 “REPRINTING” OF DAWN OF THE AGE OF DINOSAURS IN THE AMERICAN SOUTHWEST

More than 15 years ago, the New Mexico Museum of Natural History and Science (NMMNH) began an intensive research and collecting program in the Upper Triassic of the American Southwest. Following the successful *Beginning of the Age of Dinosaurs—Faunal change across the Triassic-Jurassic boundary* (Padian, ed., 1986a), Spencer Lucas and Adrian Hunt edited *Dawn of the Age of Dinosaurs in the American Southwest* (Lucas and Hunt, eds, 1989). This volume sought to pull together a state-of-the-science summary of what was then known about the Upper Triassic geology and paleontology of Arizona, New Mexico, and Texas. Much has changed since then: the once-starving graduate student Hunt is now the NMMNH executive director and Lucas, the youngest curator at NMMNH and the only vertebrate paleontologist on staff at the time, is now the senior of three vertebrate paleontology curators.

Here, from the vantage point of almost 15 more years of scholarship and hugely successful collecting, I review the original volume, now “reprinted” on a CD-ROM. My goal here is, in large part, to showcase the volume itself as a key contribution to our knowledge of the Upper Triassic in the American Southwest. I also try to document how geoscientists have built upon the volume in the fifteen years since its publication. For the sake of brevity, I have excluded those advances that thus far are only published in the form of abstracts, and further restrict this review to the same area covered in the original volume, namely the Upper Triassic of Arizona, New Mexico, and Texas.

Of the 15 contributors to the 22 articles in the original volume, some have all but vanished from the field, including Kirby, Kietzke, McCrea, Davidow-Henry, and Ballew. Others have moved on to other projects, but occasionally return to the Triassic, such as Padian, Good, Dubiel, and Parrish. A relatively small cadre of the original authors, consisting of Ash, Hunt, Long, Lucas, Murry and Small have produced more since 1989 than the other dozen authors put together. Small continues to work on the Triassic both in his native Texas and Colorado, and Ash, while retired, continues to describe Chinle floras. Long and Murry’s (1995) NMMNH Bulletin 4, Late Triassic (Carnian and Norian) Tetrapods from the Southwestern United States on Chinle tetrapods is probably the most cited work on the subject (note also the annotated updates of Angielczyk, 2002). As the following review reveals, the volume was the beginning of a stream of publications by Lucas, Hunt, and their collaborators. Particularly significant leaps forward were recorded with the many articles in NMMNH Bulletins 3, The Nonmarine Triassic, (Lucas and Morales, eds., 1993), 21, Upper Triassic Stratigraphy and Paleontology, (Heckert and Lucas, eds., 2002a), 24, Paleontology and Geology of the Upper Triassic Snyder quarry (Revueltian), north-central New Mexico (Zeigler et al., eds., 2003), and most recently, 27, Late Triassic microvertebrates from the lower Chinle Group (Carnian: Otischalkian-Adamanian), southwestern U.S.A. (Heckert, 2004). Necessarily, each of these volumes, and almost all other papers cited in this review, draw heavily from the 1989 volume.

Dawn of the Age of Dinosaurs in the American Southwest was organized into four sections—“Localities,” “Stratigraphy and Sedimentology,” “Paleontology,” and “Faunal Analysis and Paleoecology.” In the following pages I will step through each of these sections, reviewing each contribution in turn.

Localities

There were six papers in *Dawn of the Age of Dinosaurs in the American Southwest* that covered the stratigraphy, fauna, taphonomy, and history of diverse localities across Arizona, New Mexico, and Texas. In Arizona, Kirby (1989) covered the Owl Rock Formation and

Long and Murry (1989) the Petrified Forest National Park (PFNP; also covered in the paleontology section by Murry, 1989a), while Long et al. (1989) provided an historic account of C.L. Camp’s two decades of collecting vertebrates in the Chinle of Arizona and New Mexico. Hunt and Lucas (1989) indexed New Mexican Chinle localities, with input from Murry (1989b) on the Upper Triassic of eastern New Mexico and West Texas, and Small (1989) discussed the Post quarry in West Texas.

Kirby’s (1989) Owl Rock faunal analysis was the much-distilled preliminary results of his exhaustive master’s thesis (1991). Some of this work was updated by Kirby himself (Kirby, 1993) and later by Lucas and Heckert (1996a), Heckert and Lucas (2000a), Heckert (2001), and Murry and Kirby (2002). The Owl Rock Formation has probably received more attention in the fields of lithostratigraphy and sedimentology (Dubiel, 1993; Lucas and Anderson, 1993a; Luttrell and Morales, 1993; Tanner, 2000, 2003a) than in vertebrate paleontology, but the collections of Kirby and others await detailed description.

Murry and Long’s (1989) summary of paleontology and geology within the PFNP was part of a long-term project that included several earlier publications (Long and Ballew, 1985; Long and Padian, 1986; Padian, 1986b), another in the volume (Murry, 1989a) and culminated by a stratigraphic article by Murry (1990) and Long and Murry’s (1995) monograph. Stratigraphic studies within the PFNP and environs continue to this day, and include the work of Deacon (1990), Ash (1992), Lucas (1992, 1995, 2001), Demko (1995a,b), Heckert and Lucas (1998a,b, 2002b), Dubiel et al. (1999), Therrien et al. (1999), Steiner and Lucas (2000), Woody (2003), and Riggs et al. (2003). It is important to note that much of this work is complimentary, for example Woody (2003) independently reached similar conclusions to Heckert and Lucas (2002b) who themselves arrived at conclusions similar to Deacon’s (1990) regarding the stratigraphic distribution of the Sonsela Member.

The PFNP remains a rich source of vertebrate body fossils as well, and Long and Murry are far from the only parties contributing to that knowledge (e.g., Padian, 1990; Parrish, 1991, 1993; Hunt and Lucas, 1992, 1993a, 1995a; Hunt et al., 1995a,b, 1996, 1998a,b, 2001, 2002a,b; Hunt, 1998, 2001; Hunt and Wright, 1999; Heckert, 2001; Angielczyk, 2002; Murry and Kirby, 2002; Parker, 2002; Parker and Clements, 2004) to name just a few. Parker (2002) has continued and vastly expanded Evanoff’s (1994) attempt to keep this record organized, and more localities, records, and sites are added to the PFNP’s inventory on a near-constant basis. Even a cursory reading of the above cited articles will reveal that the PFNP remains the single best “laboratory” in which to study Adamanian-Revueltian tetrapod evolution in North America, especially when it comes to early dinosaurs (e.g., Lucas, 1992; Hunt et al., 1996, 1998a).

There is more to the Upper Triassic of Arizona than the PFNP, of course. The Placerias quarry continues to receive attention as various parties study its taphonomy (Fiorillo and Padian, 1993; Fiorillo et al., 2000), microvertebrate fauna (Kaye and Padian, 1994; Sues, 1996) and biostratigraphic significance (Lucas and Heckert, 1996a; Heckert and Lucas, 1997; Lucas et al., 1997a). I helped to publish a brief overview of some largely overlooked fossils from the Cameron area (Heckert and Lucas, 2002c) and the NMMNH has revisited the Blue Hills near St. Johns in force (e.g., Heckert and Lucas, 1997; Heckert, 2001; Heckert et al., 2001; Zanno et al., 2002). Polcyn et al. (2002) documented early, but relatively extraordinary, success bridging the gap between the classic PFNP and Blue Hills collecting areas, and I have already reviewed progress on the Owl Rock Formation of northern Arizona in the previous discussion of Kirby’s work.

If there is a field of study in the Triassic of the American Southwest that is lagging, it is the history of the science. Long et al.'s (1989) contribution on C.L. Camp remains one of the few reasonably thorough studies of the storied history of vertebrate collectors in the Chinle. Since 1989, only a few publications have materially added to our understanding of this history. These include Lucas and Hunt's (1992; see also Hunt and Lucas, 1993c) description of Cope and Baldwin's collecting work in northern New Mexico, the first chapter of Long and Murry (1995), Hunt's (1997a) study of E.C. Case and J.T. Gregory's field notes from eastern New Mexico, and Parker's (2002) review of localities in the PFNP. Colbert (1989), Sullivan et al. (1996), Heckert and Lucas (2002e), and Lucas et al. (2002a) also addressed some history in unraveling nomenclatural problems, but other than that, contributions to historical knowledge have been few.

We at the NMMNH are proud to proclaim that Hunt and Lucas' (1989a) compendium of Triassic vertebrate localities in New Mexico is now sadly out-of-date, as is Murry's (1989b) summary of the Triassic paleontology of West Texas and east-central New Mexico. Almost every New Mexico Geological Society Guidebook has included new localities and faunas from New Mexico (and a few from Texas and Arizona as well), new specimens, localities, and even taxa are published yearly now. Particularly stunning, of course, is the Snyder quarry, an extraordinarily rich bonebed in north-central New Mexico (Heckert et al., 2000; Zeigler, 2002; Zeigler et al., eds., 2003a). More thorough reviews of these advances are provided in the section on stratigraphy and with each taxonomic group in the paleontology section.

The most significant Post quarry happenings since Small's (1989a) summary are Chatterjee's publications on *Protoavis* (Chatterjee, 1991, 1995, 1999) and *Shuvosaurus* (1993), along with reinterpretations of those results (e.g., Long and Murry, 1995; Chiappe, 1995; Ostrom, 1996; Rauhut, 1997; Hunt et al., 1998a). Bolt and Chatterjee (2000) named a new temnospondyl, *Rileymillerus cosgriffi* from the Post quarry as well. Recently, Small (2002) updated the aetosaur record from there, and also (Small, 1997), named a new procolophonid, *Libognathus sheddi*, from the same general area.

Stratigraphy and Sedimentology

At first glance, the "Stratigraphy and Sedimentology" section in Dawn of the Age of Dinosaurs in the American Southwest appears a little "light," with a single article on stratigraphy in east-central New Mexico (Lucas and Hunt, 1989b) and another on sedimentology (Dubiel, 1989). These two contributions are but a part of the geological coverage of the volume—in truth most of the other papers, especially the papers on localities, incorporated local stratigraphic, sedimentologic, and even some taphonomic information, so in many ways these two articles are but the proverbial tip of the iceberg.

Still, the biggest advances in our scientific understanding of the Upper Triassic in the American Southwest are doubtless in our understanding of the stratigraphy of the Chinle, covered in the original volume by Lucas and Hunt (1989b) as well as Murry (1989b). Lucas (1993) raised the Chinle from formation to group status, and the Chinle has been the sole focus of one scientific field conference (Lucas and Hunt, 1993a) and a major component of many others, such as the New Mexico Geological Society (NMGS) Fall Field Conferences, especially in 1997, 2001, and 2003. Chinle Group stratigraphy has thus been addressed by Lucas and others in the NMGS Guidebooks (Lucas and Hayden, 1989; Lucas, 1991a; Lucas and Hunt, 1992; Lucas and Anderson, 1993b,c; Lucas et al., 1993, 1997b, 1999a, 2001a; Lucas and Heckert, 1994, 1995, 1996b; Hunt and Lucas, 1995b; Heckert, 1999; Hunt, 2001; Hester and Lucas, 2001; Heckert and Lucas, 2003a,b), in the NMMNH Bulletin series (e.g., Anderson and Lucas, 1993; Hunt and Lucas, 1993b; Lucas and Anderson, 1993a; Lucas and Hunt, 1993a,b,c; Heckert, 1997a; Heckert and Lucas, 2002a,b,e), the New Mexico Bureau of Mines and Mineral Resources publications series (Lucas, 1991b; Lehman et al., 1994; Lucas et al., 1994) as well as other

venues (e.g., Hunt and Lucas, 1990a, 1997; Lehman et al., 1992; Lucas, 1994a,b, 1997; Lucas and Anderson, 1994, 1996; Lucas and Huber, 1994; Heckert and Lucas, 1997). Many of these citations are in addition to the stratigraphic work in Arizona cited earlier.

Dubiel (1989a) presented a more sedimentological approach to Chinle depositional systems, based in part on his dissertation (1987). Dubiel continues to publish on the Chinle of Arizona and New Mexico, but more intermittently than previously (Dubiel, 1989b,c, 1993, 1994; Dubiel et al., 1991, 1993, 1999). Other sedimentological and paleoclimate papers on the Chinle published in the decade after the original volume include Ash and Creber (1992), Newell (1993), Parrish (1993) and Therrien and Fastovsky (2000). More recent papers include those cited previously on the sedimentology of the Owl Rock Formation, Hester and Lucas (2001) and work by Tanner (Tanner, 2003a,b; Tanner et al., 2003).

Paleontology

Half of the 22 contributions in Dawn of the Age of Dinosaurs in the American Southwest were in the section on paleontology. This is also the field with, numerically, the most subsequent work, especially in the field of vertebrate paleontology. Clearly the time is right for another synthesis, something that goes well beyond what I can offer here.

Like Lucas and Hunt, Ash has rendered his own (Ash, 1989a) work obsolete, especially in the last few years as he appears to enjoy "retirement" by publishing new data on Chinle floras at an increasing rate (Ash, 1989b, 1991, 1997, 1998, 1999, 2001a,b; Ash and Litwin, 1996; Ash and Creber, 1992, 2000; Creber and Ash, 2004). Few other workers contribute to our understanding of Chinle plant paleontology, either by working with Ash (e.g., Pigg et al., 1993, 1995; Jones et al., 2002) or not (Demko, 1995a,b; Heckert and Lucas, 1998a; Herrick et al., 1999). A particularly positive step is ongoing work on the petrified wood in the Chinle (e.g., Heckert and Lucas, 1998a; Ash and Creber, 2000; Creber and Ash, 2004) as it is such a prominent portion of the "geoscape" in the Upper Triassic of the American Southwest.

Kietzke (1989) is, unfortunately, one of the last contributions to Chinle microfossils on the books. He was involved in several other Triassic projects, but few of these came to fruition and he is now essentially out of the field, leaving his 1989 paper "state of the art" some 15 years later.

Good's (1989) contribution was a preliminary look at his graduate work on unionid bivalves from the Chinle. He eventually completed his Ph.D. (Good, 1993a) and related works (Good, 1993b; 1998). Otherwise, invertebrate body fossils have received scant attention in the Chinle. For example, Lucas et al. (2003) documented the invertebrate fauna of the Snyder quarry in north-central New Mexico, and Rinehart et al. (2003) named a new decapod, *Rioarribia schrami*, that is part of that fauna. Otherwise invertebrates are occasionally mentioned, usually in faunal lists, but precious little synthetic, or even systematic, work has been published since 1989.

Microvertebrate studies of the Chinle were still in their infancy in 1989, and basically consisted of Murry's dissertation (1982) and related work (e.g., Murry, 1981, 1986, 1987a,b, 1989b,c), Tannenbaum's (1983) M.S. thesis, and a few other preliminary publications (e.g., Johnson, 1980; Lucas et al., 1985; Lucas and Oakes, 1988). Tannenbaum eventually published her thesis as (Tannenbaum-)Kaye and Padian (1994). Other microvertebrate contributions since 1989 include Hunt and Lucas (1993b, 1994), Sues (1996), Lucas et al., (1999b) Heckert and Lucas (2002f) and Polcyn et al., (2002). A few years ago I completed a dissertation on the Carnian microvertebrates of the Chinle (Heckert, 2001) and this has yielded diverse spin-offs (e.g., Heckert, 2002; Heckert and Lucas, 2002g), including another NMMNH Bulletin (Heckert, 2004). Furthermore, we at the NMMNH plan to intensify and complete microvertebrate studies underway in 1989 that have since languished, including projects on the Bull Canyon and Sloan Canyon formations in eastern New Mexico.

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|----------------------|--|--|--|--|--|
| Late Triassic | Carnian | Adamanian | Revueltian | Norian | Apachean |
| | | <i>Paleorhinus/Parasuchus</i> <i>Angistorhinus</i> <i>Longosuchus</i> <i>Trilophosaurus buettneri</i> | <i>Rutiodon</i> <i>Typothorax antiquum</i> <i>Desmatosuchus haplocerus</i> <i>Stagorolpeis wellsi</i> <i>Trilophosaurus jacobsi</i> <i>Revueltosaurus hunti</i> | <i>Pseudopalatus</i> <i>Aetosaurus</i> <i>Typothorax coccinarum</i> <i>Desmatosuchus chamaensis</i> <i>Eucoelophysis</i> <i>Revueltosaurus callenderi</i> | <i>Redondasaurus</i> <i>Redondasuchus</i> <i>Coelophysis</i> |
| | Biostratigraphy and Biochronology | | | | |
| | <p>Upon the publication of Dawn of the Age of Dinosaurs in the American Southwest, Colbert and Gregory (1957), Colbert (1972), Long and Padian (1986) and Chatterjee (1986) all more or less agreed that there were two stratigraphically superposed faunas in the Chinle. The oldest of these was a (more or less) Carnian fauna, and the younger a (more or less) Norian fauna. One consequence of the 1989 volume was that it helped push Lucas and Hunt's understanding of the stratigraphic distribution and taxonomy of Chinle vertebrate fossils forward. The result is the Chinle biochronology proposed by Lucas and Hunt (1993a) and elaborated by Lucas (1997, 1998) and referred to by almost every publication involving a New Mexican author since 1993. This biochronology recognizes four successive, distinctive vertebrate assemblages—the Otischalkian, Adamanian, Revueltian, and Apachean land vertebrate faunachrons (lvf). These were long thought to represent late Carnian, latest Carnian, early-mid Norian, and late Norian-Rhaetian, respectively (see adjacent figure). It is now apparent that tying these faunachrons directly to the marine timescale remains imprecise (for example, the Otischalkian appears to encompass at least some early Carnian time). While we continue to refine this biostratigraphy, most workers have embraced at least part of it. For example, even Long and Murry (1995), who are among its most vocal critics, essentially agree on three of the four faunachrons, even if the names of the index fossils are different (see figure and compare to Long and Murry, fig. 199). For this reason I use the Lucas and Hunt lvfs, as well as a unified Chinle Group, in this foreword.</p> <p>Importantly, the biochronology is based principally on the stratigraphic ranges of index taxa, particularly phytosaurs and aetosaurs. In most publications, the NMMNH group has followed Ballew's taxonomy from the 1989 volume (Ballew, 1989). The sole difference is our recognition of <i>Redondasaurus</i> as a valid genus of phytosaur and the youngest phytosaur known from the Chinle (e.g., Hunt and Lucas, 1993e). As noted in the main text, our knowledge of aetosaurs has advanced greatly since the 1989 volume, and many of the names in the accompanying figure have been coined since then, and others (<i>Aetosaurus</i>) have been found in the Chinle for the first time (Heckert and Lucas, 1998c; Small, 1998). With the recent recognition of distinct species of <i>Desmatosuchus</i> (Zeigler et al., 2002a) and <i>Typothorax</i> (Lucas et al., 2002a), the biochronology has even been revised down to the species-level in some cases.</p> <p>Our knowledge of Chinle vertebrates continues to improve, and it is now possible to use some of the less common taxa as index fossils. Examples include the two species of the archosauromorph <i>Trilophosaurus</i> and the two species of the ornithischian <i>Revueltosaurus</i>. Each of these taxa has some biostratigraphic utility, and their distribution largely reinforces the biochronology developed using phytosaurs and aetosaurs, as does the microvertebrate biostratigraphy I recently published (Heckert, 2004). An under-appreciated and under-utilized paper that ties this record to the non-tetrapod record is Lucas (1997) wherein he integrates the tetrapod biostratigraphy with biostratigraphic frameworks erected using plants, invertebrates, and calcareous microfossils.</p> | | | | |

In the 1989 volume, the only treatment of fish (be they chondrichthyans or osteichthyans) in the Chinle came in faunal syntheses and the various papers on microvertebrates (Murry and Long, 1989; Murry, 1989a,b; Hunt and Lucas, 1989a). Since that time, Huber et al. (1993) reviewed and synthesized Chinle fish faunas, placing them in a litho- and biostratigraphic framework. Later, Hunt (1997b) named a new coelacanth, *Quayia zideki*, from the Bull Canyon Formation in east-central New Mexico, and Murry and Kirby (2002) named a new shark, *Reticulodus synergus*, from Chinle strata of Norian age in Utah, New Mexico, and Arizona. Most recently, I named a new hyodont, *Diplolonchidion murreyi*, for teeth with dual labial pegs from the Tecovas Formation in West Texas. Additionally, Johnson et al. (2002) summarized the osteichthyan fauna of the Redonda Formation in

New Mexico, and I presented work on a fish-dominated microvertebrate fauna from the Ojo Huelos Member of the San Pedro Arroyo Formation in central New Mexico (Heckert, 2001, 2004; Heckert and Lucas, 2002g).

Metoposaurs were heavily emphasized in the 1989 volume, with papers by Davidow-Henry (1989) and Hunt (1989a). Hunt (1993a) supercedes this work, and remains the state-of-the-science revision of the group. A variety of others have documented metoposaurs both within the Chinle (e.g., Morales, 1993; Long and Murry, 1995; Ford, 2000; Heckert and Lucas, 2002c; Zanno et al., 2002) and beyond it, especially recently (e.g., Sengupta, 2002; Sulej, 2002; Steyer et al., 2004; to name just a few). Ongoing work on other temnospondyls (e.g. Schoch and Milner, 2000; Yates and Warren, 2000) indicates that the time is ripe

TABLE 1: Upper Triassic taxon names introduced since 1989

Plants

Pramelreuthia yazzi Ash and Litwin 1996
Pramelreuthia dubieli Ash and Litwin 1996
Alostrobos traversei Ash 1998
Syamaropsis lamyensis Ash 1998
Samaropsis romeri Ash 1998
Samaropsis bigelowi Ash 1998
Samaropsis whitei Ash 1998
Masculostrobos laforii Ash 1998
Brachyphyllum commanchia Ash 1998
Pityoidolepis colberti Ash 1998
Pseudoctenis stewartii Ash 2001
Nilsoonia lewisii Ash 2001
Zamites tidwelli Ash 2001

Invertebrates

Rioarribia schrami Rinehart et al. 2002 (brachyuran decapod)

Chondrichthyes

Reticulodus synergus Murry and Kirby 2002 (hybodont)
Diplolonchidion murryi Heckert 2004

Osteichthyes

Quayia zideki Hunt 1997b (coelacanth)

Amphibia

Apachesaurus gregori Hunt 1993 (metoposaur)
Rileymilleria cosgriffi Bolt and Chatterjee 2000 (laticosipid)

Reptilia (miscellaneous)

Libognathus shedi Small 1997 (procolophonid)
Uatchitodon kroehleri Sues 1996 (microvertebrate, *incertae sedis*)
Otischalkia elderae Hunt and Lucas 1991b (rhynchosaur)
Dolabrosaurus aquitilis Berman and Reisz 1992 (drepanosaur)
Parrishea mccraei Long and Murry 1995 (crocodylomorph)
Vanclavea campi Long and Murry 1995 (archosauromorph?)
Acallosuchus rectori Long and Murry 1995 (archosauromorph?)

for a phylogenetic reanalysis of the Metoposauridae, although Hunt's (1993) taxonomy of the North American forms remains essentially unchallenged (Long and Murry, 1995). A more enigmatic amphibian, *Rileymilleria cosgriffi*, was recently named by Bolt and Chatterjee (2000). Work on these kind of "laticosipids" remains thwarted by the paucity of fossils, although Small (pers. comm.) has another in his possession from the Triassic of Colorado.

Small (1989b) provided only the briefest glimpse into the aetosaurs. Indeed, aetosaurs may be the group of "typical" Chinle tetrapods where we have gained the most understanding since the 1989 volume. Beginning in 1990, Hunt and Lucas would add new names (*Longosuchus*—Hunt and Lucas, 1990b; *Redondasuchus*—Hunt and Lucas, 1991a) and describe new records (Hunt and Lucas, 1992, 1995b; Hunt et al., 1993a), a trend continued into the late 1990s and beyond both by the NMMNH group (Lucas et al., 1995; Heckert et al., 1996; Heckert and Lucas, 1998c, 1999, 2000b) and others (Parrish, 1994; Long and Murry, 1995; Small, 1998, 2002; Martz, 2002). Heckert and Lucas (2000b) is now the state-of-the-science revision of the group. Still, additional records and analysis (Heckert and Lucas, 2002d,e,g,i; Martz, 2002; Heckert et al., 2003a; Parker, 2003; Desojo and Heckert, 2004) as well as new species of previously known genera, such as *Typhothorax antiquum* Lucas et al. (2002) and *Desmatosuchus chamaensis* Zeigler et al., (2002a) happily require additional reevaluation of aetosaur relationships. Aetosaurs remain the best index fossils for correlating the Chinle to other basins (e.g., Lucas and Hunt, 1993a; Lucas and Heckert, 1996a, 2001; Lucas, 1997, 1998a,c 1999, 2000; Heckert and Lucas, 2000b, 2002i). The next obvious course of study is

Sphenodonts

Paleollanosaurus fraseri Heckert 2004
Planocephalosaurus lucasi Heckert 2004

Phytosaurs

Arribasuchus buceros Long and Murry 1995
Smilosuchus gregorii Long and Murry 1995
Redondasaurus bermani Hunt and Lucas 1993e
Redondasaurus gregorii Hunt and Lucas 1993e

Aetosaurs

Longosuchus meadei (Hunt and Lucas) 1990
Redondasuchus reseri Hunt and Lucas 1991c
Lucasuchus hunti Long and Murry 1995
Acaenasuchus geoffreyi Long and Murry 1995
Coahomasuchus kahleorum Heckert and Lucas 1999
Typhothorax antiquum Lucas et al. 2002
Desmatosuchus chamaensis Zeigler et al. 2002

Rauisuchians

Lythrosuchus langstoni Long and Murry 1995
Chatterjeea elegans Long and Murry 1995

Theropod dinosaurs

Protoavis texensis Chatterjee 1991
Shuvosaurus inexpectatus Chatterjee 1993
Chindesaurus bryansmalli Long and Murry 1995
Gojirasaurus quayi Carpenter 1997
Caseosaurus crosbyensis Hunt et al. 1998
Camposaurus arizonensis Hunt et al. 1998
Eucoelophysis baldwini Sullivan and Lucas 1999

Ornithischian dinosaurs

Tecovasaurus murryi Hunt and Lucas 1994
Lucianosaurus wildi Hunt and Lucas 1994
Revueltosaurus hunti Heckert 2002
Prototecovasaurus lucasi Heckert 2004
Crosbysaurus harrisae Heckert 2004

to better incorporate our understanding of relatively complete aetosaur carapaces into aetosaur systematics and biostratigraphy. Promising steps in this direction are underway by Hunt et al. (1993a) and Martz (2002) for *Typhothorax* and Parker (2003) for *Desmatosuchus*.

The only group to receive more attention than the metoposaurs in the original volume was the phytosaurs. Ballew's (1989) phylogenetic analysis, based on her (1986) master's thesis, was the first published for the group, Hunt and Lucas (1989b) provided new genotype descriptions that were necessary for several taxa, and Hunt's (1989b) summary of phytosaur skull morphotypes foreshadowed his (1994) dissertation. Since the 1989 volume, Hunt and Lucas (1991a) remains one of the most-cited articles on phytosaur taxonomy and distribution. Hunt and Lucas (1993e) also identified the new genus *Redondasaurus* which has been denigrated (Long and Murry, 1995), honored (Lucas et al., 1997b,c; Heckert et al. 2001a), and incorporated into cladograms (Hungerbühler, 2002). Long and Murry (1995) provided the first illustrated systematic treatment of North American phytosaurs since the seminal work of Camp (1930), although Gregory (1962a,b) and Westphal (1976) had certainly made strides in the interim. Although many remain at odds over phytosaur taxonomy, Long and Murry (1995) remains the single best compendium of phytosaur specimen photographs in the published literature. More recently Hungerbühler (2002) provided another phylogenetic analysis of the group. Phytosaurs remain among the most common tetrapod fossils recovered from the Chinle, so they routinely dominate faunal analyses (e.g., Hunt, 1994, 2001). They also merit papers on their own (Hunt et al., 1993b, 2002a; Heckert et al., 2001a; Lucas et al., 1997b,c, 2002a; Zeigler et al., 2002b), especially in

cases where a large quarry sample such as that of the Snyder quarry provides insight into their cranial and postcranial anatomy (Zeigler et al., 2002b, 2003c,d).

Here I will review progress in our knowledge of phytosaurs by building on each of the articles in the 1989 volume (Ballew, 1989; Hunt and Lucas, 1989b; Hunt, 1989b). Decades after Camp (1930) and Gregory (1962a,b) we really know little more about phytosaur phylogenetics. The same trend is continually rediscovered: the size and shape of the squamosal, the position of the nares, the presence or absence of a narial crest, and the position and shape of the supratemporal fenestrae define taxa and the extent to which they are primitive or derived (Ballew, 1989; Hunt, 1994; Long and Murry, 1995; Hungerbühler, 2002). With the exception of Hunt (1994), almost no worker seriously considers any aspect of phytosaurs caudal to the occipital condyle. The possibility of sexual dimorphism accounting for differences in the size and shape of the narial crest (Zeigler et al., 2002c, 2003b) brings many of these analyses into doubt, although I hope that it will lead to a simplification of nomenclature.

Phytosaur taxonomy will perennially remain an intellectual minefield from which no one emerges unscathed. Hunt and Lucas (1989b) strove to alleviate some of the difficulties by describing type material of *Mystriosuchus planirostris* (Meyer, 1863) *Clepsysaurus pennsylvanicus* Lea (1851a,b) and *Rutiodon carolinensis* Emmons (1856). This article is a little-cited, underappreciated gem in the volume. Similar treatments of phytosaur taxonomy appear in Hunt (1994) and, to a lesser extent, Long and Murry (1995). New taxa of European phytosaurs alluded to by Hunt and Lucas (1989b) were named *Nicrosaurus meyeri* and *Mystriosuchus westphali* by Hungerbühler and Hunt (2000). Hunt (1994) informally and Long and Murry (1995) formally introduced new names for diverse Chinle taxa, the net result in my opinion resulting in a muddying of already murky taxonomic waters. Hungerbühler (2000, 2001, 2002), Hungerbühler and Hunt (2000), and Lucas et al. (2002a) also each had a significant component of taxonomic history in their contributions to the taxonomic study of phytosaurs.

This leads directly into Hunt's (1989b) description of phytosaur skull morphotypes and possible niche partitioning. These ideas were also explored by Hunt in his (1994) dissertation. The most important phytosaur paleobiological studies since 1989 are those of Zeigler et al. (2002c, 2003b), demonstrating sexual dimorphism in the phytosaur *Pseudopalatus*, which appears to have crested males and uncrested females. These studies were the first results of the discovery of a rich assemblage at the Snyder quarry, which provided well-preserved (Zeigler et al., 2002b) and abundant (Zeigler et al., 2003c, d) phytosaur fossils. As a consequence, it appears likely that sexual dimorphism accounts for at least some of the variation documented by Hunt (1989b, 1994). Specifically, I suspect that Hunt's (1989b) "type 1" are females of a gracile morph; "type 2" skulls are likely a mix of crested males of the gracile morph and uncrested females of the robust morph, the male of which is represented by "type 3" skulls. Much work on phytosaur paleobiology remains, however. For example, Hurlburt et al. (2003) found equations to estimate body mass from isolated phytosaur skulls and limb bones. Obviously, the Snyder and Canjilon quarry samples provide many possibilities for future analysis, especially as phytosaur extinction and subsequent proto-crocodylian diversification remain woefully understudied.

As a ratio of research published relative to number of fossils, dinosaurs probably score the highest since the 1989 volume. The sole dinosaur paper in the original volume was Hunt's (1989c) description of *Revueltosaurus callenderi*. Hunt's interest in Triassic dinosaurs in general and Chinle dinosaurs in particular continues to this day, as seen in his ongoing contributions (Hunt, 1991, 1998; Hunt and Lucas, 1991d, 1994; Lucas et al., 1992; Hunt et al., 1996, 1998; Hunt and Wright, 1999).

Theropod body fossils are the most commonly recovered Chinle dinosaurs, and papers on *Coelophysis* and other ceratosaurs dominate

the recent literature on the topic. This includes Colbert's (1989, 1990) long-awaited studies on *Coelophysis*, the *Coelophysis-Rioarribasaurus* name debate (Hunt and Lucas, 1991d, 1993f; Colbert et al., 1992; Sullivan, 1993, 1995; Huber, 1994), and other papers on the Ghost Ranch sample (Paul, 1993; Downs, 2000). Then there are the other theropods from the Chama basin, including *Eucoelophysis* (Sullivan et al., 1996; Sullivan and Lucas, 1999) and the Snyder quarry theropods (Heckert et al., 2000, 2003b). Other theropods from the Chinle studied since 1989 include the large ceratopsian *Gojirasaurus quayi* Carpenter (1997) and two taxa named by Hunt et al. (1998a): the herrerasaur *Caseosaurus crosbyensis* and the ceratopsian *Camposaurus arizonensis*, the latter first illustrated by Lucas et al. (1992).

If the fragmentary records of dinosaurs receive the most attention of any vertebrates in the Chinle, the extremely fragmentary records of Triassic ornithischians must receive the most, per fossil, of any dinosaur. Immediately after Hunt (1989c) named *Revueltosaurus callenderi*, Padian (1990) reported the same taxon from the PFNP. Shortly thereafter Sereno (1991) revised *Techosaurus smalli* and Hunt and Lucas (1994) named two Chinle taxa, *Tecovasaurus murryi* and *Lucianosaurus wildi*. Hunt and Lucas (1994) also named two taxa from outside the Chinle (*Galtonia gibbidens*, *Pekinosaurus olseni*). My own research has followed the intriguing possibility of identifying ornithischians by their teeth, and thus developing a microvertebrate biostratigraphy of the Chinle (Heckert and Lucas, 1997b; Heckert, 2001). This includes a biostratigraphy of *Revueltosaurus* based on the new species *Revueltosaurus hunti* (Heckert, 2002) and taxa I named in my dissertation (2001) are now properly known as *Crosbysaurus harrisae* and *Protecovasaurus lucasi*. *Crosbysaurus* in particular appears to have great biostratigraphic utility, as it is now known from at least five localities across Texas, New Mexico, and Arizona (Heckert, 2004). Recent discoveries, particularly at the Krzyzanowski bonebed in eastern Arizona (Heckert, 2001; Heckert et al., in prep.) promise to yield still more taxa and perhaps some insight into ornithischian and other dinosaur systematics. Even if some of these fossils turn out not to represent dinosaurs, they continue to have biostratigraphic utility, and doubtless have something to tell us about microvertebrate paleoecology of the Chinle Group.

Sauropodomorphs remain the most enigmatic Chinle taxa, and essentially none were known at the time of the 1989 volume. Sereno (1991) asserted that the type material of *Techosaurus smalli* includes a prosauropod premaxilla, and Long and Murry (1995) described some material questionably assigned to the Prosauropoda. Hunt et al. (1998a) documented these and a few other fragmentary records, and Harris et al. (2002) described a single tooth that likely represents a primitive prosauropod. Similar fossils were also described in my dissertation (Heckert, 2001).

Before continuing onto the final section (Faunal Analysis and Biochronology) of the 1989 volume, it is perhaps instructive to consider the paleontological aspects not covered by the book. Beyond the various vertebrate groups that received relatively short shrift, whole fields of study have emerged separate from the volume, including vertebrate taphonomy, and the study of trace fossils, both vertebrate and invertebrate.

The taxonomic coverage of the 1989 volume is not dissimilar to what initial collectors encountered in the field: some fossil plants, some invertebrates (including microfossils) and a vertebrate fauna dominated by phytosaurs, metoposaurs, and aetosaurs, with rare, fragmentary dinosaurs and problematic microvertebrates (e.g., Cope, 1875, 1877, 1887a,b, 1892). Case (1922) serves as perhaps the best example of this early synthesis, even if he was confused regarding the taxonomic position of aetosaurs. Since 1989, our understanding of Chinle tetrapods has exploded, and the following paragraphs are meant to provide a sweeping overview, not a comprehensive analysis, of that explosion.

Since Camp and Welles' (1956) published their monograph

on the Placerias quarry, no worker has made serious inroads into the study of dicynodont fossils from the Chinle. Still, Lucas and Hunt (1993c) reported the first occurrence of *Ischigualastia* in the Chinle Group and Lucas and Heckert (2002a) described a skull of *Placerias* from the type area near Ward's Terrace in Arizona and outlined the biostratigraphic utility of *Placerias* (see also Lucas, 1998c). Other synapsids remain rare, although the extraordinary discovery of the oldest mammal, *Adelobasileus cromptoni* (Lucas and Hunt, 1990; Lucas and Luo, 1993) was probably the single most important paleontological advance in the Chinle since the 1989 volume. Other cynodonts remain rare, but fragmentary fossils were described by Lucas et al. (1999b) and Heckert (2001, 2004).

The unusual archosauromorph *Trilophosaurus* was, at the time of the 1989 volume, known primarily from the Otis Chalk quarry samples described by Gregory (1945), Parks (1969), and DeMar and Bolt (1981). Murry (1987a) named a second species, *T. jacobsi*, and both species are mentioned in the 1989 volume. Subsequently, Sues and Olsen (1993) hypothesized that *T. jacobsi* was a procolophonid (*Chinleogomphius jacobsi*), but more recent work at a quarry found by Bob Kahle demonstrates that *T. jacobsi* is indeed a valid species of *Trilophosaurus* (Heckert et al., 2001b, 2003, 2004 in prep).

Crurotarsans more derived than aetosaurs are almost ignored in the 1989 volume, largely because of a paucity of diagnostic fossils. Knowledge of Chinle sphenosuchians and related forms has advanced with the work of Parrish (1991), Long and Murry (1995) and Clark et al. (2000) and will leap forward further when analysis of the Krzyzanowski bonebed is completed. Long and Murry (1995) identified *Parrishea mccraei* as a new sphenosuchian, but the material is fragmentary and unconvincing. At least as problematic are the "rauisuchians." Long and Murry (1995) sought to make sense of their extremely fragmentary record, naming the new taxa *Chatterjeea elegans* and *Lythrosuchus langstoni* and dividing Chinle forms into three families: Rauisuchidae (*Postosuchus*), Poposauridae (*Poposaurus*, *Lythrosuchus*) and Chatterjeeidae (*Chatterjeea*). We (Heckert et al. 2002) have tentatively identified the raiisuchid *Saurosuchus* from the Chinle in Arizona, providing a possible Gondwanan-Laurasian correlation to the type area in Argentina. Finally, in his recent masters' thesis, Weinbaum (2002) extensively revised our understanding of *Postosuchus*, and many await publication of this thesis. We are in desperate need of more and better fossils of these taxa. As oversplit as their taxonomy sometimes appears, there are probably several new taxa awaiting discovery, either in the field or in jackets awaiting preparation. It is, after all, somewhat puzzling that individual genera of most other archosaurs, including aetosaurs and phytosaurs, can be used to discriminate three or four discrete intervals of Late Triassic time, but raiisuchians, especially *Postosuchus* and *Poposaurus*, and the sphenosuchian *Hesperosuchus*, appear to persist through multiple intervals when the other taxa have "turned over."

Other problematic archosauromorphs named by Long and Murry (1995) include *Acallosuchus rectori* and *Vancleavea campi*. The latter is now known to occur throughout much of the Chinle geographically and stratigraphically (Hunt et al., 2002b), but the former remains enigmatic. Certainly there are many poorly known archosauromorphs awaiting discovery, if the record of the nearly coeval Newark Supergroup is any indication. Similarly, enigmatic reptiles such as drepanosaurs are now known from the Chinle (Berman and Reisz, 1992; Harris and Downs, 2002), and Lucas et al. (2000) documented a probable turtle fragment akin to *Proganochelys* from the Bull Canyon Formation in eastern New Mexico.

A striking omission from the 1989 volume is a single paper synthesizing the taphonomy of the Chinle. Although many papers on individual faunas, both in that volume and in later papers, would include comments on Chinle Group taphonomy (Hunt and Lucas, 1989a; Murry and Long, 1989; Murry, 1989a,b), very little synthetic work had been done by 1989 (e.g., Elder, 1978, 1987). Happily, Chinle

taphonomy has now matured into a field of study all its own. Contributions since 1989 include papers by Fiorillo and Padian (1993), Hunt et al. (1995b), Fiorillo et al. (2000), Therrien and Fastovsky (2000), Hunt and Downs (2002) and now Zeigler et al. (2002d,e) as well as Zeigler's (2002) master's thesis and related work (Zeigler, 2003).

Even more glaring is the omission, in the 1989 volume, of any real treatment of trace fossils. As part of the general footprint renaissance in the 1990s, Chinle tetrapod tracks received considerable attention, especially in New Mexico (e.g., Hunt et al., 1989b,c, 1993c, 2000; Lockley et al., 1993a,b, 2000, 2001; Lockley and Hunt, 1995; Lucas et al. 2001b). Coprolites, once considered curiosities, have engendered serious scientific study as well (Hunt et al., 1998b; Wahl et al., 1998). Invertebrate traces in the Chinle received additional scrutiny in the decade following the 1989 volume (e.g., Hasiotis and Dubiel, 1993; Hasiotis et al., 1998a,b) although some of these (e.g., Hasiotis et al., 1998b) have been greeted with well-deserved skepticism (Grimaldi, 1999; Engel, 2000, 2001).

Faunal analysis and biochronology

Paleoecology at the level of faunas (as opposed to the paleoecology of specific taxa) was covered in the 1989 volume by Parrish (1989a) and Murry (1989c). Parrish also published an extensive analysis later that year (Parrish, 1989b) and a case study of the Petrified Forest National Park (Parrish, 1993). Since that time few authors have chosen to focus research efforts on paleoecology, although certainly paleoecological hypotheses are advanced in diverse fauna analyses (Long and Murry, 1995; papers in Zeigler et al., eds., 2003) and as part of some studies that are really more taphonomic in nature (see discussion previously on taphonomy). Murry's (1989c) Dockum paleoecology is really a more thorough treatment than that of Parrish (1989a) and based heavily on his previous work (especially Murry, 1982, 1986), albeit with new information from work he conducted later, especially in New Mexico.

Padian (1989) closed the original volume by dealing with the end-Triassic extinctions, or at least the extinction of "thecodonts." Perhaps a testimony to the power of cladistic methods is the extinction of the term "thecodont" (at least as a taxonomic descriptor) in the literature after the 1980s. Padian has published similar articles attempting to bring a phylogenetic perspective to the Triassic (e.g., Padian, 1994), the origin of dinosaurs (Padian and May, 1993) and theropods in general, including of course Triassic theropods (Padian et al., 1999). The end-Triassic extinction event (or the lack thereof) remains a hotly contested arena. Since publication of *Dawn of the Age of Dinosaurs in the American Southwest*, scientific attention briefly focused on a putative Carnian-Norian extinction that has been considered more important than an end-Triassic event (e.g., Benton, 1991, 1993, 1994), less so (Fraser and Sues, 1994; Olsen, 1999), or non-existent (Lucas, 1994b). Now the same arguments are being cast at the end-Triassic again, with Olsen et al. (2002) forcefully arguing for a dramatic event and others (Hallam, 2002; Tanner et al., 2004) refuting those arguments, just to provide a few citations of a wide-ranging debate. Unfortunately, within the area covered in the 1989 volume, few opportunities to explore the record of the Triassic-Jurassic transition exist. The Triassic System is erosionally overlain by Cretaceous or younger strata in Texas and Middle Jurassic or younger strata in much of New Mexico and Arizona. Only the uppermost Triassic formations in eastern New Mexico (Redonda, Sloan Canyon, Sheep Pen, Travesser) and all-but-uncollectable rocks on reservation lands in northern Arizona (Rock Point, Moenave, Wingate) have the potential to yield insight into this issue.

Photography

The nine photographic plates from the original volume were placed at the end of the volume. For purposes of the web/CD-ROM,

version, all 9 were scanned at high (600 dpi) resolution (generally from the original plate) as both large .tif and much smaller .jpg files. Hopefully this will help distribute these important illustrations much more widely. Indeed, the most glaring weakness of the original volume was the poor reproduction of these nine plates. Doubtless some of original owners will covet the high-resolution photographs provided here.

Conclusions

I would be remiss if I did not note that the original dedication to J.T. Gregory rings as true today, 90 years after his birth, as it did in 1989. Gregory laid important ground work both in field studies in West Texas and New Mexico (Gregory, 1972), biostratigraphy (Gregory, 1957, 1969; Gregory and Colbert, 1957; Gregory and Westphal, 1969), phytosaurs (Gregory, 1962a,b), aetosaurs (Gregory, 1953a,b), and of course, *Trilophosaurus* (Gregory, 1945).



So, looking back on fifteen years of extremely productive multidisciplinary work on the Chinle and its faunas, including a decade of my own career, I like to think that the Dawn of the Age of Dinosaurs in the American Southwest marked the commencement of a “golden age” of Triassic studies. With hard work this golden age should continue well into the future.

Andrew B. Heckert, Albuquerque, 2005

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