

AETOSAURUS (ARCHOSAUIROMORPHA) FROM THE UPPER TRIASSIC OF THE NEWARK SUPERGROUP, EASTERN UNITED STATES, AND ITS BIOCHRONOLOGICAL SIGNIFICANCE

by SPENCER G. LUCAS, ANDREW B. HECKERT *and* PHILLIP HUBER

ABSTRACT. Four specimens of the aetosaur *Stegomus* are known from Upper Triassic strata of the Newark Supergroup of the eastern United States. These specimens represent a small aetosaur with a long narrow carapace that is distinctly waisted in front of the hindlimbs, has paramedian scutes much wider than long and lateral scutes that lack spikes. *Stegomus* is thus remarkably similar to *Aetosaurus* Fraas, but has weaker sculpturing on its scutes. This is the principal difference between the two, so we regard *Stegomus* as a junior subjective synonym of *Aetosaurus* and recognize a distinct Newark species, *Aetosaurus arcuatus* (Marsh).

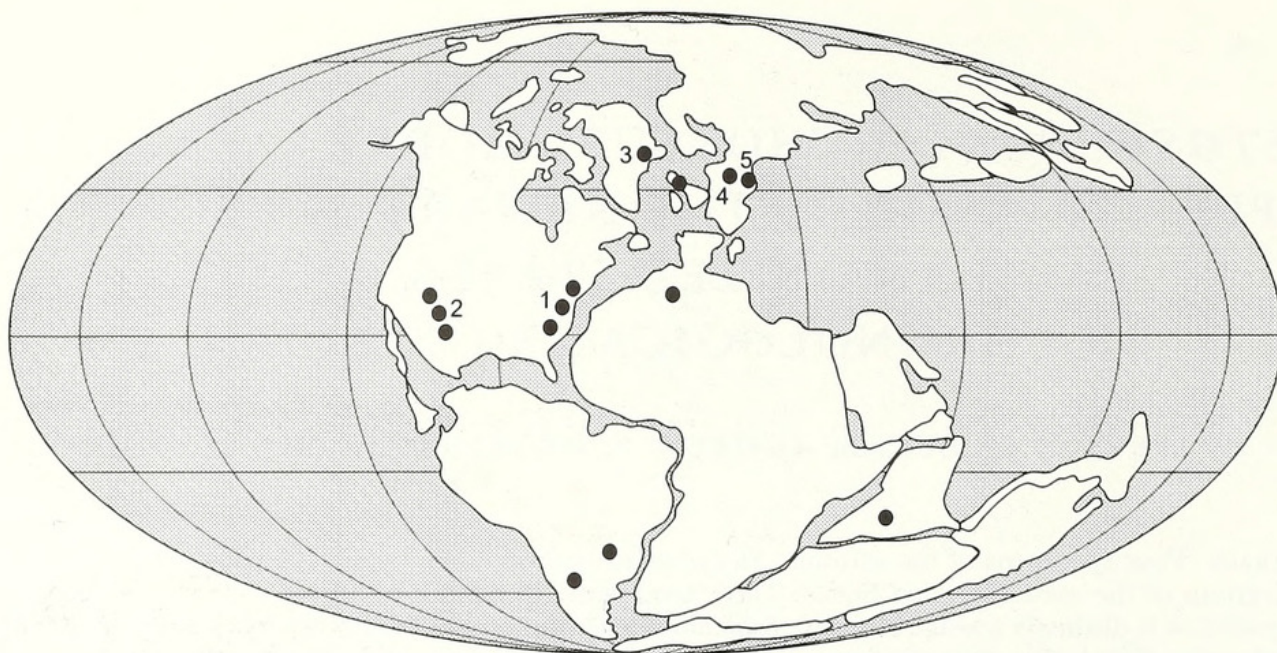
Aetosaurus in the Newark Supergroup is of biochronological significance because the genus has a broad distribution and one of its occurrences can be directly cross-correlated to Triassic marine biochronology. *Aetosaurus* is of early-mid Norian age in the German Lower and Middle Stubensandstein. *Aetosaurus* has been found in mid Norian marine limestones in Italy correlated to the *Himavatites columbianus* ammonite Zone, which directly cross-correlates the genus to the standard global chronostratigraphical scale. *Aetosaurus* is present in the Bull Canyon Formation (Chinle Group) of eastern New Mexico, USA and in the Ørsted Dal Member of the Fleming Fjord Formation in Greenland; both of these units are of early Norian age. *Aetosaurus* localities in the Newark Supergroup are of mid Norian age, a conclusion consistent with Newark palynostratigraphy and magnetostratigraphy. *Aetosaurus* is thus an index fossil of the lower-middle Norian.

AETOSAURS were herbivorous archosaurs of the Late Triassic. Their heads are extremely small relative to their bodies, their rostra lack teeth, and they have small, leaf-shaped maxillary and dentary teeth. The heavily armoured body has quadrangular plates that run from the back of the skull to the tip of the tail and encase much of the abdomen as well as the entire tail. The tarsus is crocodile normal, and the ichnogenus *Brachychirotherium* probably represents aetosaur footprints (Lockley and Hunt 1995).

Aetosaur fossils have a broad geographical distribution (Text-fig. 1) and are among the most common tetrapod fossils in many Late Triassic, non-marine strata. Distribution, abundance, and ease of identification make aetosaurs useful Late Triassic non-marine index fossils (Lucas and Heckert 1996; Hecker *et al.* 1996).

Here, we re-evaluate the taxonomy of one of the first aetosaurs described from North America, *Stegomus arcuatus* Marsh, 1896. We conclude that *Stegomus* is a junior subjective synonym of the European aetosaur genus *Aetosaurus* Fraas, 1877. This enables a robust correlation of *Aetosaurus* localities in the United States, Greenland, Germany and Italy, and thus further develops the biochronological utility of aetosaurs.

Institutional abbreviations. NCSM, North Carolina State Museum, Raleigh, North Carolina, USA; NJSM, New Jersey State Museum, Trenton, New Jersey, USA; NMMNH, New Mexico Museum of Natural History and Science, Albuquerque, New Mexico, USA; PU, Princeton University collection, now at Yale Peabody Museum; SMNS, Staatliches Museum für Naturkunde, Stuttgart, Germany; YPM, Yale Peabody Museum, New Haven, Connecticut, USA.



TEXT-FIG. 1. Map of Late Triassic Pangaea showing aetosaur localities and highlighting *Aetosaurus* records, which are: 1 = Newark Supergroup, eastern North America; 2 = Chinle Group, western United States; 3 = Fleming Fjord Formation, Greenland; 4 = Keuper Triassic, Germany; 5 = Alpine marine Triassic, Lombardian Alps, Italy.

SYSTEMATIC PALAEONTOLOGY

Order CROCODYLOTARSI Benton and Clark, 1988

Suborder AETOSAURIA von Huene, 1908

Family STAGONOLEPIDIDAE Lydekker, 1887

Genus AETOSAURUS Fraas, 1877

Aetosaurus arcuatus (Marsh, 1896)

Plates 1–2; Text-figures 2, 3B, 4; Table 1

- 1896 *Stegomus arcuatus* Marsh, p. 60, pl. 1.
- 1915 *Stegomus arcuatus*; Lull, p. 79, pl. 5
- 1948 *Stegomus arcuatus jerseyensis* Jepsen, p. 9, pls 1–2.
- 1953 *Stegomus arcuatus*; Lull, p. 79, pl. 5.
- 1986 *Stegomus arcuatus*; Baird, p. 142, figs 12–13, 14A.
- 1993a *Stegomus* cf. *Stegomus arcuatus*; Huber *et al.*, p. 179, fig. 5.

Holotype. YPM 1647 (Pl. 1), natural cast of the ventral aspect of part of the dorsal carapace (Marsh 1896, pl. 1; Lull 1915, pl. 5, 1953, pl. 5).

Horizon and locality of holotype. New Haven Formation, Fair Haven, Connecticut (see below).

EXPLANATION OF PLATE 1

Figs 1–3. *Aetosaurus arcuatus* (Marsh, 1896); YPM 1647, holotype; natural mould of ventral surface of part of dorsal carapace; lateral (1) and ventral (2) views and detail (3) of scute impressions showing articulation of paramedian (p) and lateral (l) scutes. 1–2, $\times 0.33$; 3, $\times 0.66$.



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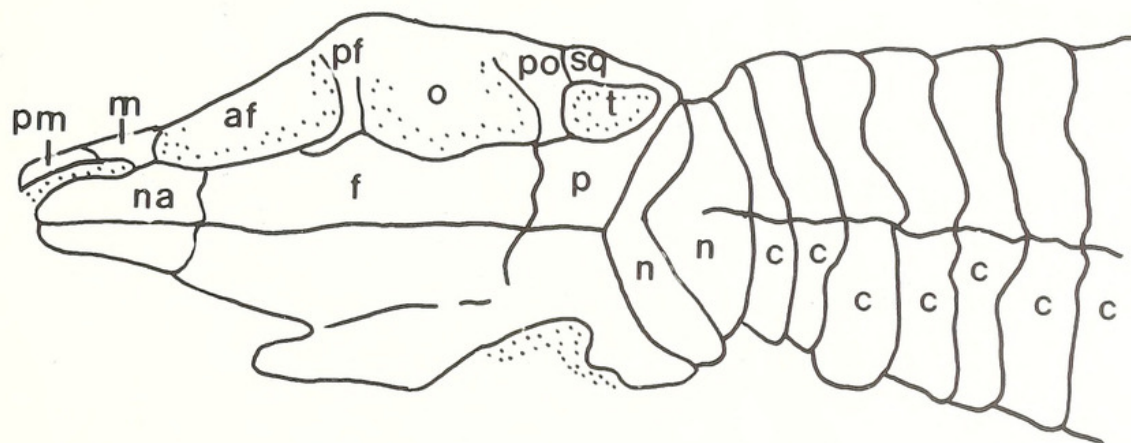


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TABLE 1. Measurements of scutes of specimens YPM 1647, NJSM 10740, NCSM 11756 and YPM [PU] 21750. Note that letter designations (A, B, C, etc.) of scutes of different specimens do not imply homology.

Paramedian scute row	Width (in mm)	Length (in mm)	W:L	Lateral scute row	Width (in mm)	Length (in mm)
YPM 1647						
A	72	21	3.4	A	15	21
B	81	24	3.4	B	15	21
C	81	24	3.4	C	18	21
D	84	24	3.5	D	21	21
E	84	24	3.5	E	18	24
F	84	24	3.5	F	21	24
G	84	27	3.1	G	24	24
H	90	27	3.3	H	24	24
I	84	27	3.1	I	24	24
J	87	27	3.2	J	24	27
K	96	27	3.6	K	27	27
L	90	27	3.3	L	27	24
M	81	24	3.4	M	30	27
N	75	18	4.2	N	33	27
O	72	18	4.0	O	33	27
P	72	15	4.8	P	36	27
NJSM 10740						
A	36	—	—	A	11*	13
B	39	24	1.6	B	13	20
C	31	18*	1.7	C	13	15
D	28	17*	1.6	D	12	16
E	28	16	1.7	E	11	18
F	21*	15	1.4	F	11	16
G	19	16	1.2	G	10	17
H	16	15*	1.1	H	—	—
I	—	14*	—	I	—	—
NCSM 11756						
A	46*	19*	2.4	A	—	—
B	49	18	2.7	B	18	16
C	47	17	2.8	C	19	18
D	41	12	3.4	D	16	17
E	38	12	3.2	E	14	14
F	36	11	3.3	F	9	12
YPM [PU] 21750						
A	19	6	3.2			
B	18	6	3.0			
C	17	6	2.8			
D	16	5	3.2			
E	19	5	3.8			
F	20	6	3.3			
G	19	5	3.8			
H	22	7	3.1			
I	24	5	4.8			
J	24	6	4.0			
K	27	6	4.5			
L	27	6	4.5			
M	28	8	3.5			
N	26	7	3.7			
O	28	7	4.0			
P	27	7	3.9			
Q	27	7	3.9			
R	25	7	3.6			
S	22	9	2.4			
T	16	7	2.3			

* Measurement of incompletely exposed or preserved scute.



TEXT-FIG. 2. *Aetosaurus arcuatus* (Marsh, 1896); YPM [PU] 21759, skull and anterior portion of neck. Abbreviations: af = antorbital fenestra; c = cervical paramedian scutes; f = frontal; m = maxilla; n = nuchal scutes; na = nasals; o = orbit; p = parietal; pf = prefrontal; pm = premaxilla; po = postorbital; sq = squamosal; t = temporal fenestra. Skull drawing modified from Baird (1986); $\times 1.1$.

Material. YPM [PU] 21750, natural cast of ventral aspect of skull and dorsal carapace (Baird 1986, figs 12, 14A; Pl. 2; Text-fig. 2); from the Passaic Formation on the bank of Nishisakawick Creek, Huntendon County, New Jersey.

NJSM 10740, partial tail (Jepsen 1948, pls 1–2; Baird 1986, fig. 13; Text-fig. 3B); from the Passaic Formation near Neshanic Station in Somerset County, New Jersey.

NCSM 11756 partial tail (Huber *et al.* 1993a, fig. 5) (Text-fig. 4A–B); from 'Lithofacies Association II' (= Lower Sanford Formation) at the Triangle Brick Quarry, North Carolina.

Revised diagnosis. A species of *Aetosaurus* distinguished from *A. ferratus* Fraas, 1877 and *A. crassicauda* Fraas, 1907 by the relatively large (3.5:1) width:length ratio of the dorsal paramedian scutes in adult specimens, very faint pitting on the scutes, and a tail that narrows rapidly posteriorly.

Description. Marsh (1896) and Lull (1915, 1953) described the holotype of *Stegomus arcuatus*, and Jepsen (1948) and Baird (1986) described the New Jersey specimens. Parker (1966) described the partial tail from North Carolina, and this specimen was later illustrated by Huber *et al.* (1993a, fig. 5).

The holotype, YPM 1647, consists of the natural mould of the median portion of a carcass that preserves 16 articulated rows of paramedian and lateral scutes and apparently was rolled and contracted dorsally before burial (pl. 1). The specimen is preserved as a natural sandstone mould of the ventral surface of the dorsal armour and also includes seven matrix blocks that include portions of the mould. No original bone is preserved, so YPM 1647 is a steinkern preserved in red, medium- to coarse-grained, arkosic sandstone and pebbly sandstone. The total length of the preserved carapace is about 440 mm.

The so-called 'pitting' of the scutes alleged by Lull (1915, 1953) actually is porosity of the sandstone matrix, not a morphological feature. Thus, this 'pitting' can be seen both on the scute impressions and on the surrounding sandstone matrix. The carapace is composed of two columns of 16 paramedian scutes that are rectangular in shape, much wider than long (width:length *c.* 3.1–4.8; Table 1). Smaller, trapezoidal lateral scutes occur at the margins of all the right paramedian scutes and are attached to six of the left paramedian scutes. There is no evidence that any of the lateral scutes has spikes or protuberances. Fine details of the surface morphology of all scutes are obscured by the coarse-grained fabric of the host matrix.

Baird (1986) provided a brief, but accurate description of YPM [PU] 21750, which is the most complete specimen previously assigned to *Stegomus* (Pl. 2; Text-fig. 2). This is the ventral impression of the skull roof and dorsal carapace from the skull to the pelvis. It represents a small aetosaur with a snout–pelvis length of approximately 210 mm. Skull length is about 69 mm, and width across the orbits is 17 mm. The snout tip is broken, but obviously tapered to a thin beak. The antorbital fenestra is antero-posteriorly long and dorso-ventrally short. The orbit is very large; with an antero-posterior length of 18 mm, it reaches *c.* 25 per cent. of skull length. This suggests that the specimen represents a juvenile (Baird 1986). Sutures for the premaxillary, maxillary, nasals, frontals, prefrontal, frontal, parietal, postorbital and squamosal are present, and are as Baird (1986, fig. 14A) indicated (Text-fig. 2).

A scute covers the occiput and is followed by two columns of 21 pairs of paramedian scutes. These scutes are rectangular – much wider than long (width:length \sim 3.0–4.0; Table 1) – and imbricated. The posterior edge of each scute overlaps (is dorsal to) the anterior edge of the scute behind it. This scute morphology is best illustrated by the natural cast of the scutes that infilled the posterior portion of the mould (Pl. 2, fig. 2). Scute morphology is strikingly similar to that of YPM 1647, although the New Jersey specimen is significantly smaller. The carapace of the New Jersey specimen narrows noticeably toward the pelvis.

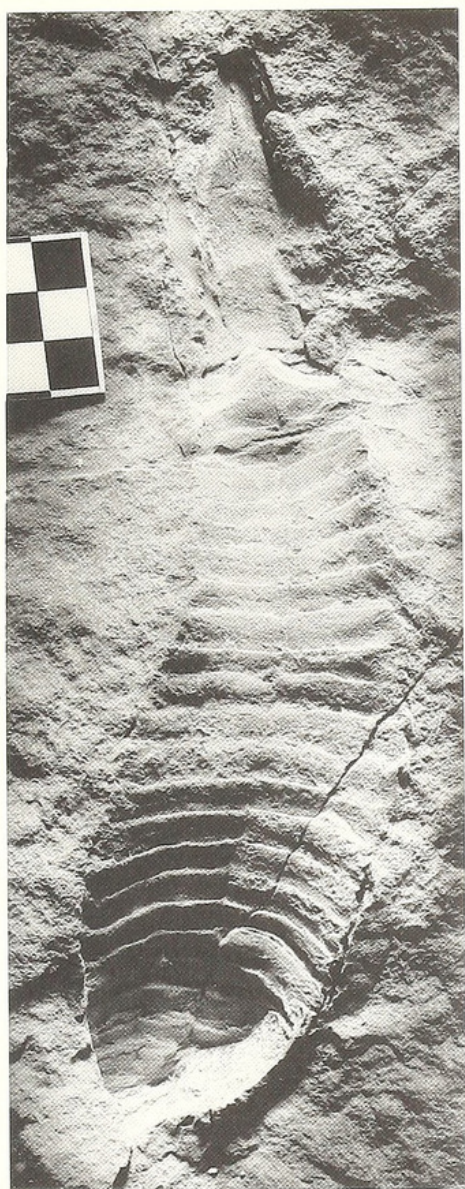
NJSM 10740 is part of the dorsal portion of a tail (Text-fig. 3B). Jepsen (1948) provided an accurate description, and we only draw attention to a few key features. Note that the dorsal paramedian scutes are rectangular and wider than long (width:length \sim 1.6–1.7; Table 1). They are imbricated: the posterior edge of each scute overlaps (is dorsal to) the anterior edge of the scute behind it. The lateral scutes are square to trapezoidal in shape. The tail tapers very rapidly posteriorly.

NCSM 11756 is part of a tail that preserves six rows of scutes (Text-fig. 4). Most of the bone is exfoliated from the scutes, but some preserve the original external surface of the dermal bone. These surfaces have a distinct 'sunburst' pattern of grooves and small pits that radiate away from the scute's antero-posterior axis. As in the other specimens, the paramedian scutes are rectangular and much wider than long (Table 1). The lateral scutes are square to trapezoidal. None of the scutes bear bony spikes or protuberances. The tail tapers very rapidly posteriorly.

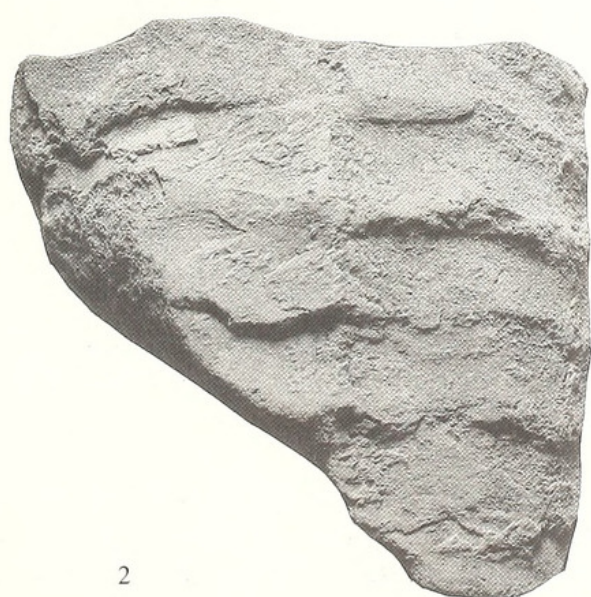
Remarks. The four specimens of *Stegomus* from the Newark Supergroup characterize an aetosaur with the following distinctive features: (1) it is relatively small in comparison to most other aetosaurs; (2) the paramedian scutes are much wider than long, with overlapping anterior bars; (3) the lateral scutes are small, trapezoidal and lack any bony spikes; (4) the paramedian scute surfaces bear a faint 'sunburst' pattern of pits and grooves; and (5) the carapace is 'waisted' (narrows, with a corresponding decrease in width:length ratios of dorsal scutes) immediately anterior to the pelvis.

EXPLANATION OF PLATE 2

Figs 1–2. *Aetosaurus arcuatus* (Marsh, 1896); YPM [PU] 21750. 1, natural mould of ventral aspect of skull and dorsal carapace, stereophotograph; $\times 0.5$. 2, natural cast of infilling of posterior portion of mould, stereophotograph; $\times 1.5$.



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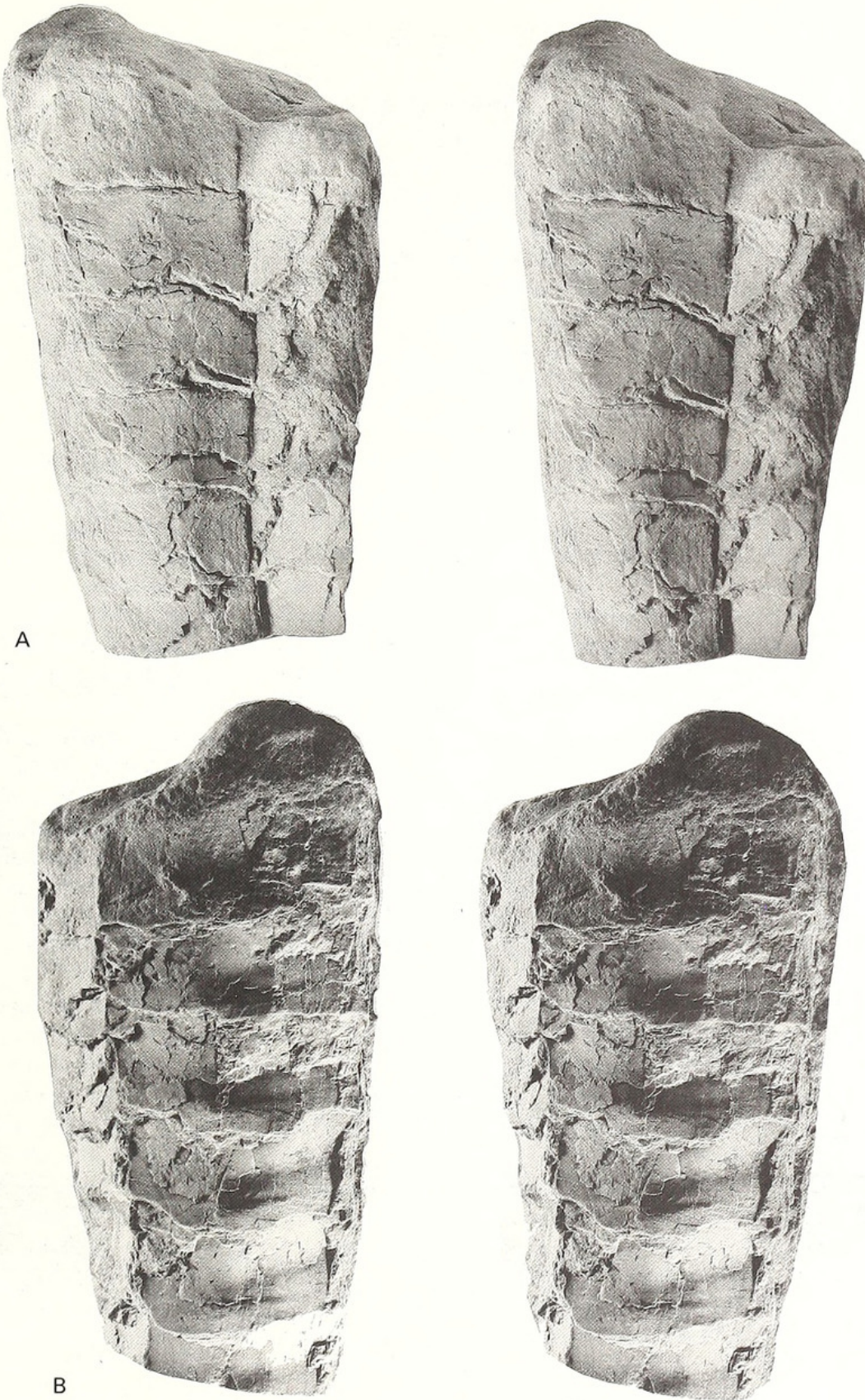
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TEXT-FIG. 3. Selected specimens of *Aetosaurus*. A. SMNS 11837, holotype of *Aetosaurus crassicauda* Fraas, 1907; dorsal view of part of dorsal carapace. B. NJSM 10740; *Aetosaurus arcuatus* (Marsh, 1896); stereophotograph of partial tail. Both $\times 0.55$.

Among the known aetosaurs, all these features are found only in *Aetosaurus* Fraas, 1877 (see Text-fig. 3A). Particularly significant is the pattern of pitting on the scutes and the lack of spikes or bosses. Most of the known aetosaurs have spikes on the scutes (e.g. Long and Murry 1995), but *Aetosaurus* lacks spikes and has a 'sunburst' pattern of pits and grooves on the scutes (e.g. Wild



TEXT-FIG. 4 *Aetosaurus arcuatus* (Marsh, 1896); NCSM 11756; North Carolina; partial tail, stereophotographs of dorsal (A) and ventral (B) aspects; $\times 0.66$.

1989). Indeed, we are unable to distinguish specimens of *Stegomus* from *Aetosaurus* except by minor differences, so we consider the two genera to be synonymous.

On the holotype specimen of *Stegomus arcuatus* Marsh (1896), YPM 1647 (Pl. 1; Table 1), the pattern of sculpture on the scutes cannot be determined, but the specimen still preserves numerous details consistent with its assignment to *Aetosaurus*. The paramedian scutes lack ventral keels and are broadly rectangular, considerably wider than long, and do not appear to have possessed thickened lateral processes for articulation of the lateral scutes, as in some other aetosaurs, such as *Typochothorax*. The lateral scutes are slightly wider than long, flat, and lack any indication of spinescence. In these characters, YPM 1647 clearly pertains to *Aetosaurus* as described originally by Fraas (1877) and subsequently by Fraas (1907), von Huene (1920), Walker (1961) and Wild (1989). We retain, however, a distinct North American species of the genus, *Aetosaurus arcuatus* (Marsh, 1896), based on the following features that distinguish it from *A. ferratus* Fraas, 1877 and *A. crassicauda* Fraas, 1907: the relatively high width: length ratio (3.5:1) of dorsal paramedian scutes in adult specimens, very faint pitting on the scutes, and rapid posterior narrowing of the tail.

DISTRIBUTION OF *AETOSARUS* IN THE NEWARK SUPERGROUP

Four specimens from the Newark Supergroup are referred to *Aetosaurus arcuatus*: (1) the holotype of *Stegomus arcuatus* Marsh from the New Haven Formation in Fair Haven, Connecticut; (2) the holotype of *S. arcuatus jerseyensis* Jepsen, an incomplete tail from the lower Passaic Formation at Neshanic Station, New Jersey; (3) the natural mould of the skull and dorsal armour of a juvenile from the Passaic Formation, Nishisakawick Creek, New Jersey; and (4) a partial tail from the 'Sanford Formation' at Triangle Brick Quarry, North Carolina.

The holotype of *Aetosaurus arcuatus* (Marsh, 1896) was collected by Freeman P. Clark in his brownstone quarry at Fair Haven, located within the city limits of New Haven, Connecticut. This quarry is developed in the New Haven Formation, a red-bed unit that consists mostly of arkosic sandstone and conglomeratic sandstone. The lower part of the New Haven Formation has yielded a Carnian–Norian palynoflora (Cornet 1977), and the upper part the procolophonid *Hypsognathus* and a sphenodontid (cf. *Sigmala*) indicative of a latest Triassic (probably Rhaetian) age (Huber *et al.* 1993b; Lucas and Huber 1993). The *Aetosaurus arcuatus* holotype is from the middle part of the New Haven Formation, which has been assigned a mid Norian age based on correlation with other, better dated Newark Supergroup strata (Lucas and Huber 1993).

The New Jersey specimens of *Aetosaurus* were both obtained from the Passaic Formation. The specimen described by Jepsen (1948) was recovered from a cellar excavation in strata belonging to the Neshanic Member of the Passaic Formation at Neshanic Station, New Jersey. The specimen described by Baird (1986) was obtained as a loose boulder from the bed of Nishisakawick Creek in nearby Frenchtown, New Jersey, from the stratigraphically lower Warford Member of the Passaic Formation. In the Newark basin, the thickness of the stratigraphical interval from the Warford to the Neshanic members of the Passaic Formation is about 600 m (Olsen *et al.* 1996, fig. 8). Based on palynostratigraphy, magnetostratigraphy, and cyclostratigraphy, Kent *et al.* (1995) assigned this interval to the early Norian with an estimated numerical age range of 215–218 Ma. The Newark basin occurrences of *Aetosaurus* in New Jersey thus establish the entire temporal range of *Aetosaurus* in the Newark Supergroup, and were used by Huber *et al.* (1993b) and Lucas and Huber (1993) to help define the Neshanician land-vertebrate faunachron (lvf), of early–mid Norian age.

The North Carolina specimen was described briefly in an abstract by Parker (1966). Its provenance is the Triangle Brick Quarry, near Glenlee, North Carolina, which exposes a 20 m thick section of fine–medium-grained arkosic and quartzose sandstone, siltstone and shale, mapped and informally named by Hoffman and Gallagher (1989) as 'Lithofacies Association II' of the Durham sub-basin of the Deep River basin, a unit that is the stratigraphical equivalent of the lower Sanford Formation in the adjacent Sanford sub-basin (Huber *et al.* 1993a). Other fossils from the Triangle Brick Quarry include megafossil plants (*Equisetum* stem fragments), darwinulid ostracodes,

abundant conchostracans, unionid bivalves, articulated crayfish, insects, bony fishes (*Synornichthys*, *Cionichthys*, *Turseodus*, *Semionotus*, *Osteplurus*), hybodontid elasmobranchs, several types of vertebrate coprolites, indeterminate labyrinthodont and phytosaur teeth and bone scrap, sphe nosuchian and proterosuchian crocodylomorphs, and several, recently collected partial skeletons of a new rauisuchian currently under study by P. E. Olsen (pers. comm. 1995). Based on lithostratigraphical correlation of the Durham and Sanford sub-basin successions (Olsen *et al.* 1990), Lithofacies Association II is stratigraphically higher than the Cumnock Formation, which produced a tetrapod fauna of latest Carnian (late Tuvanian) age (Sanfordian lvf of the Newark Supergroup) (Huber *et al.* 1993a, 1993b). Hence, the Triangle Brick Quarry *Aetosaurus* comes from strata of early Norian age that belong to the early part of the Neshanician lvf, as defined by Huber *et al.* (1993b) and Lucas and Huber (1993).

BIOSTRATIGRAPHY AND BIOCHRONOLOGY

Tetrapod fossils provide one of the principal bases for the correlation of non-marine Triassic strata across Pangaea (Ochev and Shishkin 1989; Lucas 1990). During the Late Triassic, archosauromorph reptiles dominated tetrapod faunas. Two archosauromorph groups – phytosaurs (Parasuchidae) and aetosaurs (Stagonolepidae) – were broadly distributed across Pangaea, and their fossils are abundant in Late Triassic non-marine strata.

Phytosaurs have long been used for correlation of these strata (e.g. Camp 1930; Gregory 1957; Westphal 1976; Ballew 1989). However, they are not ideal index fossils because: (1) nearly an entire phytosaur skull is needed to make a genus- or species-level identification, whereas the vast majority of phytosaur fossils are isolated bones and skull fragments; and (2) phytosaur taxonomy is not well agreed on and generally oversplit, with three different taxonomic schemes (Ballew 1989; Hunt 1994; Long and Murry 1995).

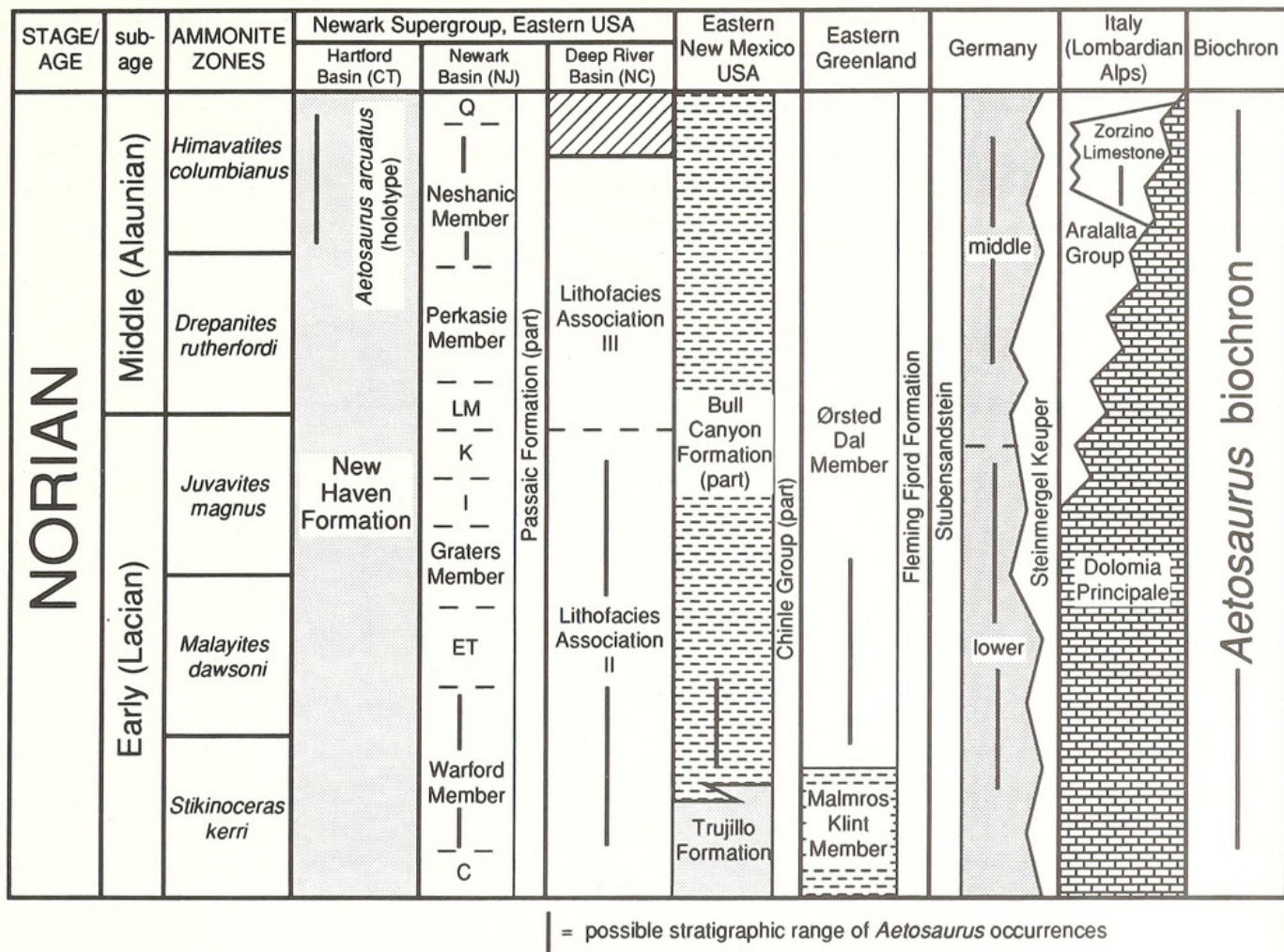
An ideal index fossil should be widely distributed geographically, abundant, have a short temporal range, and be easily identifiable. Aetosaurs meet these four criteria:

1. Aetosaur fossils are found throughout most of Late Triassic Pangaea (Text-fig. 1). Indeed, they have a broader distribution than phytosaurs, most notably being known from Argentina, where phytosaurs have not been found (Lucas and Heckert 1996).
2. Aetosaurs are the most abundant tetrapod fossils in the Chinle Group (western USA) and the Ischigualasto Formation of Argentina (Lucas 1993; Rogers *et al.* 1993). They are common in many other Late Triassic deposits.
3. Stratigraphical/temporal ranges of aetosaur genera are usually relatively short – much less than a stage/age (Lucas and Heckert 1996) (Text-fig. 5).
4. Aetosaurs are easy to identify because their body armour is highly distinctive at the genus level (e.g. Long and Ballew 1985; Long and Murry 1995; Heckert *et al.* 1996; Lucas and Heckert 1996). A single piece or fragment of aetosaur armour, sometimes even as small as a postage stamp, can be precisely identified.

Recognition that *Stegomus* = *Aetosaurus* extends the record of this biostratigraphically significant taxon into the eastern United States. Here, we review the temporal distribution of *Aetosaurus* to establish its status as a non-marine index fossil of early–mid Norian time (Text-fig. 6).

Western United States

Hunt (1994) documented aetosaur scutes from the Bull Canyon Formation of the Chinle Group in east-central New Mexico. The holotype of a new genus he proposed, but did not publish, NMMNH P-17213, is a left dorsal paramedian scute, 75 mm wide and 31 mm long, so it has a low



TEXT-FIG. 6. Correlation of *Aetosaurus*-yielding strata. Vertical bars indicate possible stratigraphical ranges of *Aetosaurus* occurrences. However, actual stratigraphical ranges are probably much shorter, but determination of this requires more precise stratigraphical data than are currently available for most *Aetosaurus* occurrences.

As Jenkins *et al.* (1994) concluded, this assemblage shares many taxa with the German Stubensandstein and clearly is of Norian age. The closest similarity to the Ørsted Dal assemblage is the vertebrate assemblage of the Lower Stubensandstein, especially the co-occurrence in both units of *Aetosaurus ferratus* and *Paratypothorax andressi*, as well as *Cyclotosaurus*, *Gerrothorax* and *Proganochelys*. We thus regard the Ørsted Dal Member vertebrates as of early Norian age (Text-fig. 6). However, we note that Jenkins *et al.* (1994) presented no precise stratigraphical ordering of vertebrate fossil localities in the 150–200-m thick Ørsted Dal Member and that some taxa from the Ørsted Dal Member (*Gerrothorax*, *Plateosaurus*) do not occur in the Lower Stubensandstein, but first appear in the Middle Stubensandstein (Benton 1993, table 1). Therefore, the possibility exists that the Ørsted Dal vertebrate assemblage includes temporal equivalents of both the Lower and Middle Stubensandstein.

Germany

In Germany, *Aetosaurus* is well documented from the Lower Stubensandstein (*A. ferratus*) and the Middle Stubensandstein (*A. crassicauda*) of the German Keuper (O. Fraas 1877; E. Fraas 1907; Wild 1989). Palynostratigraphy, vertebrate biostratigraphy, and sequence stratigraphy suggest that

the Stubensandstein is of early to mid Norian age (Brenner 1973; Brenner and Villinger 1981; Visscher and Brugman 1981; Benton 1986, 1993; Wild 1989; Aigner and Bachman 1992; Kozur 1993; Lucas and Huber 1994). The most precise correlation available suggests that the Lower Stubensandstein is early Norian, whereas the Middle Stubensandstein is mid Norian (e.g. Benton 1993). This suggests that *Aetosaurus* in Germany has an early-mid Norian temporal range comparable to its temporal range in the Newark Supergroup (Text-fig. 6).

Italy

Wild (1989) documented *Aetosaurus ferratus* from the marine Calcare di Zorzino Formation (= Zorzino Limestone) at Cene, near Bergamo in the Lombardian Alps of northern Italy. The Calcare di Zorzino Formation is a carbonate and turbidite facies that immediately overlies and is in part laterally equivalent to the Norian Dolomia Principale (= Hauptdolomit). After the regional progradation of platform carbonates (Dolomia Principale) during the early-mid Norian, extensional tectonism produced intraplatform depressions in which the Zorzino Limestone (Aralalta Group; Jadoul 1985) was deposited as patch reefs, turbiditic debris flows and lagoonal to freshwater facies (Jadoul *et al.* 1994). Palynostratigraphy and conodont biostratigraphy indicate that the fossil vertebrate locality in the Zorzino Limestone near Bergamo is very close to the Alaunian (mid Norian)-Sevastian (late Norian) boundary (Jadoul *et al.* 1994; Roghi *et al.* 1995; Tintori and Lombardo 1996). This indicates that the *Aetosaurus* occurrence documented by Wild (1989) is of late mid Norian age, and correlates with the younger part of the *Himavatites columbianus* Zone of the global Triassic ammonite biochronology (Tozer 1994). This provides a direct cross-correlation of an *Aetosaurus* occurrence to marine Triassic biochronology (Text-fig. 6).

Discussion

The direct cross-correlation of *Aetosaurus* from Italy to the middle Norian accords well with the inferred age of some *Aetosaurus* records in Germany and the United States. However, the German and American records suggest that *Aetosaurus* existed during both the early and mid Norian. Although this is consistent with cross-correlation to the Italian marine occurrence of *Aetosaurus*, the German and Newark Supergroup records obviously encompass a longer temporal range (Text-fig. 6) than the single Italian occurrence.

The total known temporal range of *Aetosaurus* thus equals about four ammonite zones, which is about half of Norian time, approximately 5–7 million years on most numerical time scales (e.g. Kent *et al.* 1995). *Aetosaurus* thus emerges as a tetrapod taxon capable of providing a robust correlation across much of Late Triassic Pangaea and is an index fossil of early-mid Norian time.

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SPENCER G. LUCAS

New Mexico Museum of Natural History and
Science
1801 Mountain Road NW
Albuquerque, NM 87104, USA

ANDREW B. HECKERT

Department of Earth and Planetary Sciences
University of New Mexico
Albuquerque, NM 87131-1116, USA

PHILLIP HUBER

Virginia Museum of Natural History
1001 Douglas Avenue
Martinsville, VA 24112, USA

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