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Reports and Articles that include original research data, theories, or syntheses and are fundamental contributions to basic knowledge or technical achievements of far-reaching consequence are eligible for consideration for the prize. The paper must be a first-time publication of the author's own work. Reference to pertinent earlier work by the author may be included to give perspective.

Throughout the year, readers are invited to nominate papers appearing in the Reports or Articles section. Nominations must be typed, and the following information provided: the title of the paper, issue in which it was published, author's name, and a brief statement of justification for nomination. Nominations should be submitted to AAAS–Newcomb Cleveland Prize, AAAS, 1515 Massachusetts Avenue, NW, Washington, D.C. 20005. Final selection will rest with a panel of distinguished scientists appointed by the Board of Directors.

The award will be presented at a session of the annual meeting at which the winner will be invited to present a paper reviewing the field related to the prizewinning research. The review paper will subsequently be published in *Science*. In cases of multiple authorship, the prize will be divided equally between or among the authors; the senior author will be invited to speak at the annual meeting.

Reports

A Fish from the Upper Cambrian of North America

Abstract. *Phosphatic dermal fragments of* Anatolepis, *interpreted as a heterostracan fish (class Agnatha), have been discovered in the Deadwood Formation of Late Cambrian age in northeastern Wyoming. This discovery extends back the age of the earliest known vertebrate fossils by approximately 40 million years. Other occurrences of* Anatolepis *in North America, Greenland, and Spitzbergen show that these fish had a widespread geographic distribution in Late Cambrian and Early Ordovician marine environments.*

Until recently, vertebrates have been known from rocks no older than the Middle Ordovician (about 450 million years ago) (*1*, *2*). In 1976 and 1977 the known range of the vertebrates was extended back about 20 million years by discoveries of fish fossils in rocks of latest Early Ordovician and earliest Middle Ordovician age in Spitzbergen (*3*, *4*) and Australia (*5*). This report of fish material from Upper Cambrian rocks further extends the record of the vertebrates by approximately another 40 million years.

The oldest known vertebrates, the heterostracan fish (class Agnatha, order Heterostraci), are represented primarily by isolated scales and plates, although very rare partly articulated specimens are known (*1*). Bockelie and Fortey (*3*) reported phosphatic scale-bearing plates from Spitzbergen and proposed the new genus *Anatolepis*. They presented compositional and histological evidence that these fossils are the remains of heterostracans. Ritchie and Gilbert-Tomlinson (*5*) reported the occurrence in Australia of two new genera of fish, which they assigned to the heterostracans. These, *Arandaspis* and *Porophoraspis*, are represented by well-preserved molds of articulated individuals; they bear ornamentation similar to that of *Anatolepis*.

The forms here assigned to *Anatolepis* cf. *A. heintzi* Bockelie and Fortey are from the upper part of the Deadwood Formation in Crook County, northeastern Wyoming. The rock sample containing the fish fragments is a pink bioclastic calcareous siltstone (*6*). Trilobites from the same sample are medial Late Cambrian in age (*7*).

Partial disaggregation of a small amount (210 g) of this siltstone by use of acetic acid and formic acid and separation of the heavy residue with tetrabromoethane (specific gravity ≅ 2.9; specific gravity of apatite group minerals = 3.1 to 3.2) in an attempt to recover conodonts produced four plate fragments and about two dozen individual tubercules of *A.* cf. *A. heintzi*. In size (individual scales are 0.05 to 0.15 mm long), shape, and external morphology, the Deadwood specimens appear similar to *A. heintzi*, but the abraded appearance of most of the scales on the larger fragments prevents a more precise specific identification. Electron microprobe analysis confirmed the apatite composition of these specimens (*8*).

The largest of the Wyoming specimens (Fig. 1a) is approximately 2 mm long and 1.1 mm in maximum preserved width. This fragment shows a partial cylindrical shape, as do the Spitzbergen specimens (*3*, *4*). Most of the rhomboidal scales on the larger plate fragments are broken or show wear due to abrasion, or both (Fig. 1, a and c). Possibly because of this abrasion, the scales show very little surface ornamentation (if any was ever present) and, where broken, they show the punctate lower part of the outer lamellar layer (Fig. 1c). These nodes are matched on the under surface of each scale by a pattern of perforations (Fig. 1, d and e). The perforations may have been the sites of dermal nerves or blood vessels (*3*, p. 37).

Except for the difference in specimen size, the histology of these specimens shows typical heterostracan structure (*9*) consisting of bony outer and inner lamellar layers enclosing a "spongy" aspidin inner layer (Fig. 1, b, f, and g). On several of the fragments, the aspidin layer has torn, exposing the underside of the outer lamellar layer (Fig. 1, d and e). Where the aspidin and lower lamellar layers are preserved intact, the lower surface is relatively smooth and shows a series of

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pits, presumably coinciding with the undersides of the scales. The thickness of each of the bony layers varies with position relative to the location of the surface scales; for instance, the outer lamellar layer is thinnest under the widest part of the scales. The fragmentary nature of these specimens inhibits speculation about the shape of the complete animal and the part of the body surface represented in this small collection. Ritchie and Gilbert-Tomlinson (*5*) illustrated and discussed the shape and morphology of fish presumed to be similar to *Anatolepis*.

Although these specimens constitute the earliest record of *Anatolepis*, the genus has been illustrated now from at least three locations. In addition to the specimens described here and the *Anatolepis* reported by Bockelie and Fortey (*3*) and by Bockelie *et al.* (*4*) from the Lower and possibly the Middle Ordovician of Spitzbergen, I have recovered specimens of *A. heintzi* and *Anatolepis* sp. from both low and high strata in the El Paso Group (Lower Ordovician) of westernmost Texas (*10*). I have also found specimens of *Anatolepis* in the following units: (i) basal Fort Sill Limestone (Upper Cambrian; approximately coeval with the Deadwood Formation locality) in southwestern Oklahoma (*11*); (ii) the type Steves Farm Limestone Member of the Baldwin Corner Formation of R. H. Flower (lowermost Ordovician) in eastern New York (*12*); (iii) the Wahwah Limestone (upper Lower Ordovician) in western Utah (*13*); (iv) the Black Rock

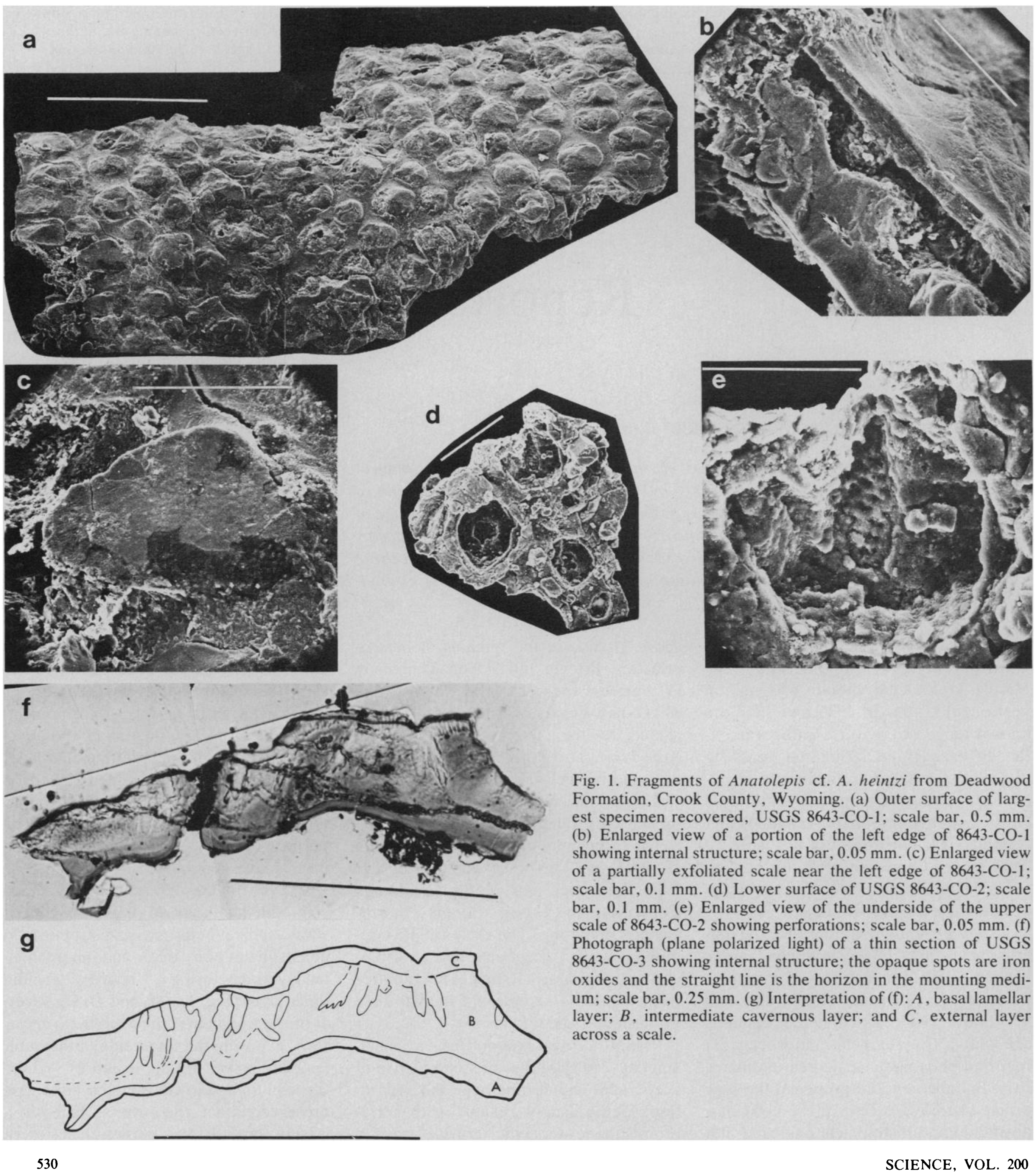

Fig. 1. Fragments of *Anatolepis* cf. *A. heintzi* from Deadwood Formation, Crook County, Wyoming. (a) Outer surface of largest specimen recovered, USGS 8643-CO-1; scale bar, 0.5 mm. (b) Enlarged view of a portion of the left edge of 8643-CO-1 showing internal structure; scale bar, 0.05 mm. (c) Enlarged view of a partially exfoliated scale near the left edge of 8643-CO-1; scale bar, 0.1 mm. (d) Lower surface of USGS 8643-CO-2; scale bar, 0.1 mm. (e) Enlarged view of the underside of the upper scale of 8643-CO-2 showing perforations; scale bar, 0.05 mm. (f) Photograph (plane polarized light) of a thin section of USGS 8643-CO-3 showing internal structure; the opaque spots are iron oxides and the straight line is the horizon in the mounting medium; scale bar, 0.25 mm. (g) Interpretation of (f): *A*, basal lamellar layer; *B*, intermediate cavernous layer; and *C*, external layer across a scale.

Limestone Member of the Smithville Formation (upper Lower Ordovician) in northern Arkansas; and (v) the uppermost part of the Metaline Formation (Middle and ?Upper Cambrian) in northeastern Washington (*14*). *Anatolepis heintzi* also occurs in upper Lower Ordovician strata of eastern Greenland (*15, 16*).

The report (*17*) of "Heterostracoderm fish" of Late Cambrian age from the Gros Ventre Formation of the Bighorn Mountains, Wyoming, must be considered as dubious until further study, including histologic sectioning, confirms the affinities of those objects. The published figures [plate 1, figures 1 and 2 in (*17*)] are inadequate for determination, and Denison (*1*, p. 134) notes that those fragments "have little resemblance to any known vertebrate."

The known occurrences of *Anatolepis* show that vertebrates were extant by the Late Cambrian and that these early fish were widely distributed by Early Ordovician time. These occurrences are restricted to tropical and subtropical localities around the Cambrian-Ordovician North American paleocontinent from approximately 20°N to 25°S (*18*). The presence of these fish in the stratigraphic units listed above, all of which are of undoubted marine origin, is also strong evidence for a marine habitat for the earliest vertebrates (*1, 2, 19*).

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References and Notes

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6. The sample was collected by M. H. Staatz.
7. Trilobites identified from sample by M. E. Taylor include *Ellipsocephaloides* sp., *Ptychaspis striata* Whitfield, and ?*P. tuberosa* Feniak. These taxa indicate the *Ptychaspis-Prosaukia* Zone, Croixian Series, Franconian Stage.
8. Microprobe preparation and analysis were performed by E. Jarosewich and G. Moreland, whose help is appreciated.
9. R. H. Denison, *Fieldiana Geol.* **13**, 309 (1964).
10. *Anatolepis* sp. from high in the El Paso Group is shown as figure 4 in M. H. Nitecki, R. C. Gutschick, and J. E. Repetski [*Fieldiana Geol.* **35**, 1 (1975)].
11. Sample obtained from J. F. Miller.
12. R. H. Flower, *N.M. Bur. Mines Miner. Resour. Mem. 12* (1964); the sample was collected by R. H. Flower.
13. The sample was obtained from R. L. Ethington.
14. The sample was collected by M. E. Taylor and E. Schuster from U.S. Geological Survey (USGS) fossil locality 8667-CO.
15. J. S. Peel (personal communication to E. L. Yochelson) and J. S. Peel and A. K. Higgins (personal communication) interpret *Anatolepis* as a merostome arthropod, based on its resemblance to merostomes portrayed by G. O. Raasch [*Geol. Soc. Am. Spec. Pap. 19* (1939)]. The internal structure and composition of the Deadwood Formation specimens, however, argues for their assignment to the heterostracans.
16. A. R. Palmer recently informed me (personal communication) of the occurrence of *Anatolepis* in USGS fossil collections 2675-CO (Lincoln County, Nevada), 3503-CO (Bonneville County, Idaho), and 4352-CO (eastern Alaska). These collections are from Upper Cambrian strata.
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20. I thank the following for their help in preparation of various aspects of this report: F. C. Whitmore, M. E. Taylor, and E. L. Yochelson critically read the manuscript; D. Dunkle, A. G. Harris, B. Runnegar, N. Hotton III, R. H. Denison, A. R. Palmer, and K. Towe contributed information, criticism, and advice; W. Ross, C. Smith, K. Moore, W. Pinckney, T. DeMoss, S. Braden, H. Mochizuki, and R. Johnson provided excellent technical assistance. After initial submission, this manuscript was improved thanks to critical reviews by Bobb Schaeffer and two anonymous reviewers.

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The Structure of Crystalline Tris: A Plastic Crystal Precursor, Buffer, and Acetylcholine Attenuator

Abstract. *The crystal and molecular structure of the widely used buffer tris(hydroxymethyl)aminomethane (tris) has been determined from single-crystal diffractometer data to a standard agreement factor* (R *value*) *of 0.026 and bond length standard deviations of 0.002 angstrom. Tris crystallizes in the orthorhombic system, space group* $Pn2_1a$, *with four molecules per unit cell;* a = *8.844(1) angstroms,* b = *7.794(1) angstroms, and* c = *8.795(1) angstroms. The center-to-center distances of tris molecules in the ordered phase range from 0.4 to 1.0 angstrom less than they do in the orientationally disordered (plastic) phase of similar molecules.*

The compound tris(hydroxymethyl)-aminomethane, $H_2NC(CH_2OH)_3$ (commonly known as tris or tham), is a widely used buffering agent (*1*) in the *p*H range 7 to 9, important for studies of physiological media and seawater (*2*). However, it was recently reported that tris antagonizes the action of ionophoretically applied acetylcholine on neurons of *Aplysia californica* (*3*). Wilson *et al.* suggested that the mechanism of attenuation might be related to structural similarities between the acetylcholine and tris molecules.

Tris is also of interest for several other reasons. It has been proposed as a standard for solution calorimetry (*4*). The tris molecule is globular and forms an orientationally disordered (plastic) crystal at temperatures between 134°C and its melting point, 173°C (*5*), in a manner similar to the related polyhydric alcohol pentaerythritol $[C(CH_2OH)_4]$ (*6*). Finally, good experimental values of hydrogen bonding in polyhydric molecules are needed in crystal packing computations used to determine the values of the parameters for the potential energy of the $O\text{–}H_4 \cdots O_{18}$ hydrogen bond used in computations of the conformational energy of peptides (*7*).

In view of this current wide-ranging interest in tris, there is a need for a detailed characterization of the properties of this molecule. The results of a crystal structure analysis, presented here, will make it possible to carry out a structural comparison with acetylcholine, to furnish accurate hydrogen bond distances for use

Table 1. Intramolecular interatomic distances (angstroms).

Atoms	Distance (no riding correction)	Distance (riding correction)
A C(C)*–N	1.472(2)	1.479(2)
B C(C)–C(1)	1.522(2)	1.531(2)
C C(C)–C(2)	1.531(2)	1.538(2)
D C(C)–C(3)	1.522(2)	1.528(2)
Average C–C	1.525(2)	1.532(2)
E C(1)–O(1)	1.412(2)	1.435(2)
F C(2)–O(2)	1.426(3)	1.443(3)
G C(3)–O(3)	1.431(2)	1.438(2)
Average C–O	1.423(2)	1.436(2)
N–HN1	0.835(30)	
N–HN2	0.822(36)	
Average N–H	0.828	
C(1)–H11	0.928(31)	
C(1)–H12	0.959(32)	
C(2)–H21	0.998(30)	
C(2)–H22	0.964(35)	
C(3)–H31	1.031(27)	
C(3)–H32	0.966(30)	
Average C–H	0.974	
O(1)–HO1	0.739(49)	
O(2)–HO2	0.878(45)	
O(3)–HO3	0.984(42)	
Average O–H	0.867	

*C(C) is the central carbon atom. Letter designations **A** through **G** identify intramolecular distances in Fig. 1.

Table 2. Average intramolecular angles.

Atom group	Angle (deg)
N–C(C)–C	108.7(0.2)
C–C(C)–C	110.3(0.2)
O–C–C(C)	110.3(0.2)
H–N–H	107.4(2.9)
H–N–C	108.4(2.2)
H–C–H	110.0(2.4)
H–C–O	109.8(1.8)
H–C–C(C)	108.5(1.8)
H–O–C	106.0(2.5)