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Upper Triassic continental margin strata of the central Alaska Range: Implications for paleogeographic reconstruction

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ABSTRACT

Remnants of a Late Triassic continental margin and ocean basin are scattered across central and southern Alaska. Little is known about the fundamental nature of the margin because most remnants have not been studied in detail and a protracted period of terrane accretion and margin-parallel translation has disrupted original stratigraphic and structural relationships.

Three new conodont collections were recovered from a sequence of Upper Triassic calcareous sedimentary rocks in the central Alaska Range. One of the three localities is north of the Denali fault system in an area previously thought to be underlain by an uninterrupted sequence of metamorphic rocks of the parautochthonous Yukon-Tanana terrane. Structural relations in the immediate vicinity of this conodont locality indicate that mid-Cretaceous(?) thrust faulting imbricated Paleozoic metaigneous rocks with the Triassic sedimentary rocks. This may reflect a closer pre-Cretaceous relationship between the Yukon-Tanana terrane and Late Triassic shelf and slope deposits than previously appreciated.

Reexamination of existing conodont collections from the central Alaska Range indicates that Upper Triassic marine slope and basin rocks range in age from at least as old as the late Carnian to the early middle Norian. The conodont assemblages typical of these rocks are generally cosmopolitan and do not define a distinct paleogeographic faunal realm. One collection, however, contains *Epigondolella multidentata* sensu Orchard 1991c, which appears to be restricted to western North American autochthonous rocks. Although paleogeographic relations cannot be determined with specificity, the present distribution of biofaces within the Upper Triassic sequence could not have been the result of simple accordion-style collapse of the Late Triassic margin.

Keywords: Triassic, Alaska, conodonts, continental margin, Yukon-Tanana terrane.

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INTRODUCTION

Scattered elements of a Late Triassic continental margin and ocean basin(s) occur in central and southern Alaska. These elements include rocks exposed north of the Alaska Range (oceanic rocks of the Seventymile terrane), within the Alaska Range (slope and basin deposits of the Pingston terrane, oceanic rocks of the McKinley terrane, and marine rocks of the Chulitna terrane), and south of the Alaska Range (subduction-related volcanic rocks of the Tlikakila complex). For the most part, these rocks have not been studied in detail. All have been involved in post-Triassic deformation related to accretion of major tectonostratigraphic terranes (Wrangellia in particular) and associated basins as well as movement along strike-slip faults. The relationship of the Late Triassic continental margin elements to coeval elements in the Wrangellia terrane is not known.

In the central Alaska Range, recent mapping reveals that Upper Triassic rocks may be more widespread and have a more intimate structural relationship with parautochthonous rocks of the Yukon-Tanana terrane than previously recognized.

The geology of the Alaska Range and its flanks can be separated into three broad zones separated by strands of the Denali fault system (Figs. 1, 2). North of the Hines Creek strand, a vast metamorphic tract, the Yukon-Tanana terrane, extends from the Alaska Range to the Tintina fault and underlies the Yukon-Tanana Upland (Foster et al., 1994). The Yukon-Tanana terrane is composed of several sequences of metamorphic rocks with diverse metamorphic histories; some of these rocks have been interpreted as part of the mid-Paleozoic ancestral margin of North America (Dusel-Bacon et al., 2004). Between the Hines Creek and McKinley strands, along the backbone of the central Alaska Range, is a complex zone of intensely folded and faulted rocks of diverse ages and tectonic affinities (Figs. 1, 2). These rocks include Precambrian(?), Paleozoic, and Mesozoic rocks treated in geologic syntheses as a collage of tectonostratigraphic terranes (Jones et al., 1982; Nokleberg et al., 1994). South of the McKinley strand sits the tectonostratigraphic terrane Wrangellia, which is exotic to North America (Plafker and Berg, 1994), and related basins.

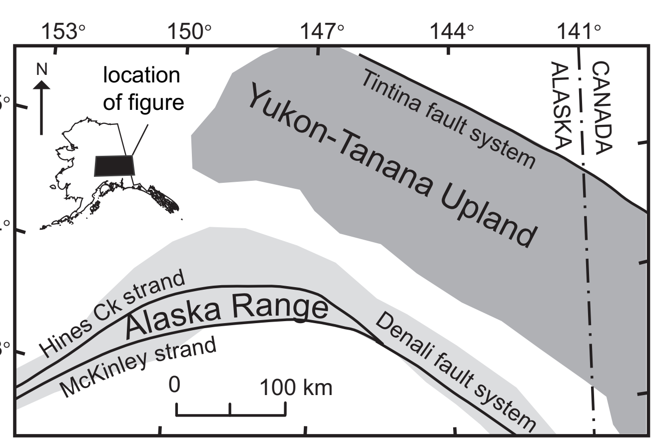

Figure 1. Major geographic features and fault systems of central Alaska.

Conodont-bearing Upper Triassic calcareous continental margin rocks occur in all three of these zones, although the most voluminous and best studied exposures are between the McKinley and Hines Creek strands. Three new Upper Triassic fossil localities from poorly known exposures of these rocks are presented here along with previously unpublished faunal lists and photomicrographs of conodonts. The new data and faunal lists are discussed in relation to geologic history and paleogeography. Upper Triassic host rocks generally correspond to the Pingston tectonostratigraphic terrane of Jones et al. (1982) and Nokleberg et al. (1994) and the calcareous sedimentary rock unit (T̄Rcs) of Csejtey et al. (1992).

UPPER TRIASSIC CALCAREOUS SEDIMENTARY ROCKS

A sequence of dark, generally thin-bedded, carbonaceous and calcareous marine sedimentary rocks is exposed in a series of typically fault-bounded slices distributed at least 300 km along the central Alaska Range (Fig. 2). All of the slices have yielded Carnian and Norian conodont assemblages (Sherwood and Craddock, 1979; Jones et al., 1983; Csejtey et al., 1992) except for the easternmost exposure, which has been tentatively correlated on the basis of lithologic similarity (Fig. 2, queried exposure; Nokleberg et al., 1994). The metamorphic grade and deformational history of the Upper Triassic sequence varies from fault slice to fault slice along the Alaska Range. In most exposures, the metamorphic grade is apparently low greenschist facies but reaches amphibolite facies locally (Csejtey et al., 1992). No detailed sedimentologic studies have been done on these rocks, although the more weakly metamorphosed exposures are amenable to such work. The Upper Triassic sequence commonly contains dikes, plugs, and sills of metagabbro or metadiabase that have a shared deformational and/or metamorphic history with the surrounding Upper Triassic sedimentary or metasedimentary rocks (Sherwood, 1979; Csejtey et al., 1992).

In the central Alaska Range, where these Upper Triassic rocks have been described in the greatest detail, they form a thick (>1000 m), intensely deformed sequence interpreted to have been deposited in environments that range from inner shelf to slope and basin (Csejtey et al., 1992). Deeper water deposits, interpreted as turbidites, include calcareous shale, argillite, sandstone, siltstone, and argillaceous limestone with primary sedimentary structures, such as ripple and parallel laminations, load casts, and evidence of soft-sediment deformation. Rare quartz sandstone beds are up to 30 m thick (Sherwood, 1979). Argillaceous limestone, carbonaceous shale, and calcareous siltstone probably formed in a hemipelagic environment. Fine- to coarse-grained cross-bedded calcareous sandstones that contain fragments of mollusks, brachiopods, echinoderms, foraminifers, peloids, and limestone clasts were interpreted to have been deposited in an inner shelf environment and are less common than the deeper water lithologies (Csejtey et al., 1992).

Sandstones in the turbidite sequence contain detrital microcline, plagioclase, muscovite, and fragments of quartz schist. Calcareous sandstones contain biotite and feldspar as well as fragments of mollusks, brachiopods, echinoderms, and encrust-

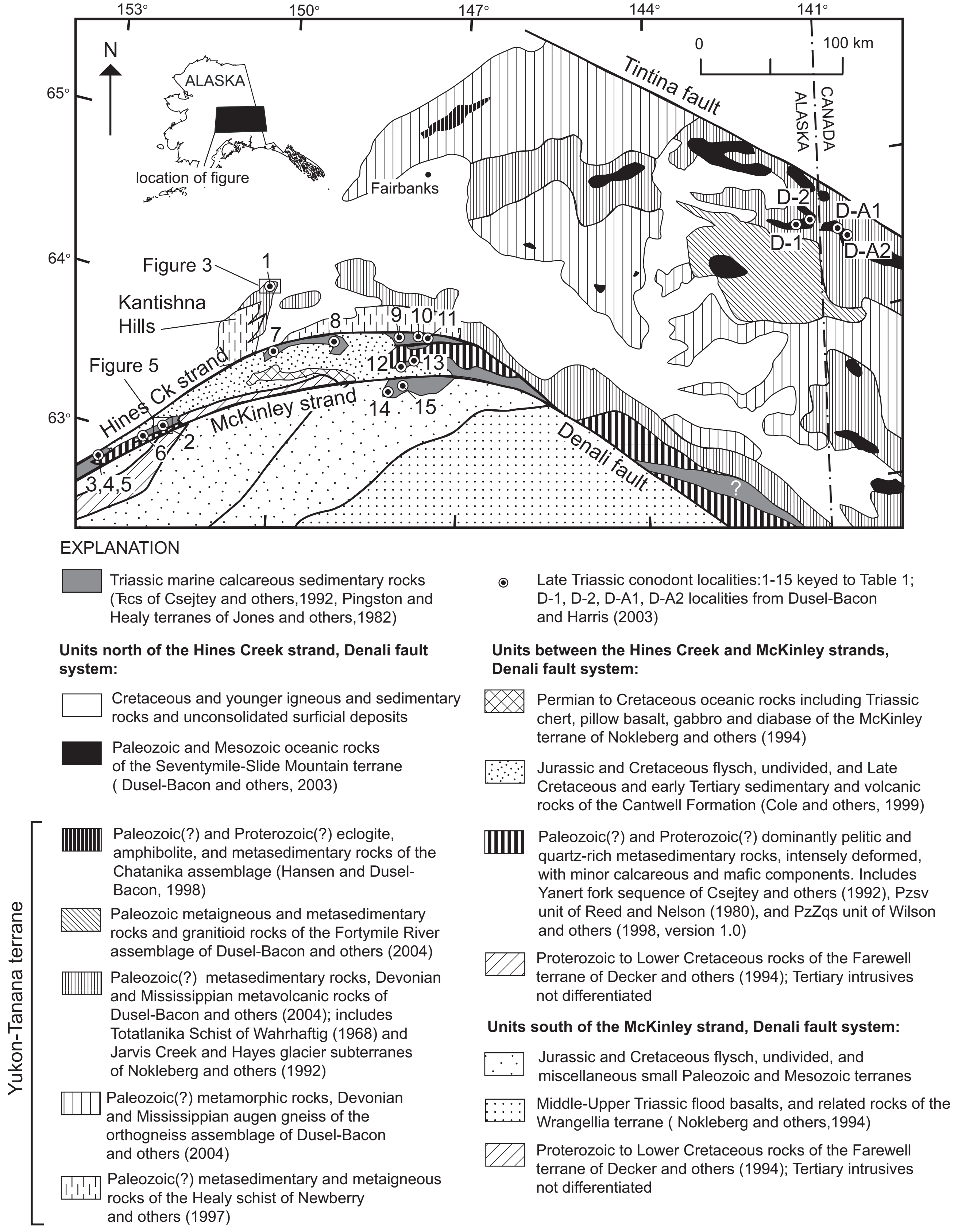

Figure 2. Distribution of Upper Triassic calcareous marine sedimentary rocks in the central Alaska Range and sites of conodont collections discussed in the text. Modified from Jones et al. (1982), Csejtey et al. (1992), and Nokleberg et al. (1994).

ing foraminifers (Sherwood, 1979). These sandstones were deposited adjacent to a carbonate shelf; terrigenous source areas must have included igneous and metamorphic rocks (Sherwood, 1979; Csejtey et al., 1992).

At one locality in the central Alaska Range (near locs. 9–13, Fig. 2), the Triassic calcareous sedimentary rocks unconformably overlie a more intensely deformed group of Paleozoic rocks (Sherwood, 1979). Csejtey et al. (1992) considered the intensely deformed rocks correlative to the parautochthonous Yukon-Tanana terrane. The Upper Triassic rocks are unconformably overlain by Upper Cretaceous and lower Tertiary nonmarine sedimentary and volcanic rocks of the Cantwell Formation (Sherwood, 1979; Ridgway et al., 1997; Cole et al., 1999).

Until recently, these Upper Triassic rocks were known only from areas south of the Hines Creek strand of the Denali fault system. Dusel-Bacon and Harris (2003) recovered Upper Triassic conodonts from metasedimentary rocks of the Seventymile terrane, around 200 km north of the Denali fault near the Canadian border (Fig. 2, localities with D- prefix). One of our new localities is 50 km north of the Hines Creek strand of the Denali system (Fig. 2, loc. 1) in rocks previously mapped as the Yukon-Tanana terrane.

GEOLOGIC RELATIONS AT NEW CONODONT LOCALITIES

During reconnaissance mapping in 1993 and 1994, conodont-bearing samples were collected that extend the known exposures of Upper Triassic marine calcareous rocks north of the Hines Creek strand of the Denali fault system (Fig. 2, loc. 1) and confirm their presence between the Hines Creek and McKinley strands of the fault system (Fig. 2, loc. 2). In descriptions below, we follow the unit designation TRcs of Csejtey et al. (1992) for this unnamed package of Upper Triassic marine calcareous sedimentary rocks.

North of the Denali Fault System—Kantishna Hills

Rocks in the vicinity of the new conodont locality (Fig. 3, location 1) in the northern Kantishna Hills were correlated by Bundtzen (1981) with units now assigned to the Yukon-Tanana terrane. The Yukon-Tanana terrane is a composite of four metamorphic packages with protolith ages ranging from Devonian and possibly Proterozoic(?) to Permian, all intruded by younger granitic rocks (Dusel-Bacon et al., 2004). No Triassic sedimentary or metasedimentary rocks have been previously described from the Yukon-Tanana terrane.

Metasedimentary and metaigneous rocks in the northernmost part of the Kantishna Hills, near Chitsia Mountain, were mapped as Totatlanika Schist, a unit dominated by felsic metaigneous rocks that also includes black carbonaceous schist and chlorite-rich schists, thought to represent metamorphosed basaltic rocks (Fig. 3; Bundtzen, 1981; Wahrhaftig, 1968). Approximately 75 km east of the Kantishna Hills, a single thin limestone lens in the Totatlanika Schist described by Wahrhaftig (1968) yielded Mississippian(?) fossils. In the vicinity of Chitsia Mountain, mafic and felsic metavolcanic rocks, fine-grained metasedimentary rocks, and finely laminated gray marble are the dominant lithologies (Fig. 3). The Totatlanika Schist is considered to be part of the Yukon-Tanana terrane (Dusel-Bacon et al., 2004).

We recovered Late Triassic conodonts from orange-weathering black dolostone in a saddle on the south side of Chitsia Mountain (Table 1, loc. 1; Fig. 2, loc. 1; Fig. 3, Fig. 4; conodont faunas are discussed below). The fine-grained black dolostone occurs as lenses in black-weathering carbonaceous phyllite. Although no similar carbonaceous dolostone-phyllite assemblage has previously been recognized in TRcs and its equivalents (Csejtey et al., 1992), the lithologic association commonly forms in deeper water slope or basin environments and is here considered correlative with the deeper water parts of TRcs. In addition, a thick, platy, yellowish gray marble with abundant lenses of pale green phyllite mapped in the Chitsia area is a lithologic match for calcareous turbidites in TRcs or the equivalent Pingston terrane (B. Csejtey, oral commun., 1995; T. Bundtzen, oral commun., 2003) elsewhere in the Alaska Range and may be Triassic rather than Mississippian in age. Samples collected from the platy marble were barren of conodonts.

Rocks of the Totatlanika Schist unquestionably overlie the Upper Triassic rocks at Chitsia Mountain (Fig. 4). Metarhyolite porphyry from the upper part of the peak yielded a 338 Ma (Mississippian) U-Pb zircon igneous crystallization age (T.K. Bundtzen, written commun., 2004). The lens of metasedimentary rocks that contains the Upper Triassic dolostone dips northwestward beneath the metarhyolite porphyry (Fig. 3). The metarhyolite and underlying metasedimentary rocks are separated by a thin (0.5–2 m) zone with a strong planar tectonite fabric. The Mississippian metarhyolite, therefore, was structurally emplaced above the Triassic metasedimentary rocks, and the tectonite is here interpreted as a ductile shear zone marking a thrust fault.

Outcrops of all units in the northern Kantishna Hills locally show relict igneous and sedimentary features and elsewhere exhibit strong planar fabrics imparted by high ductile strain. This inhomogeneity in strain is consistent with structures observed at Chitsia Mountain itself and suggests that the entire area was structurally imbricated under ductile conditions. Deformation was apparently synchronous with lower greenschist-facies metamorphism in the area. The color alteration index of the conodonts (CAI = 5) and metamorphic minerals in the shear zones (chlorite, white mica, epidote) are consistent with the regional metamorphic grade. A sample of metarhyolite from the Totatlanika Schist near Chitsia Mountain yielded a whole-rock K-Ar age of 108 ± 3.2 Ma (Bundtzen and Turner, 1979), which may approximate the age of metamorphism and deformation. If so, Upper Triassic marine calcareous sedimentary rocks were imbricated with Devonian rocks of the Totatlanika Schist during an Early Cretaceous event.

Evidence for thrust faulting was recognized by Wahrhaftig (1968) in his original work on the Totatlanika Schist, which was done ~75 km east of the Kantishna Hills. Wahrhaftig (1968) described repetitions of section and subunits apparently out of stratigraphic order that he thought might be due to pre- or synmetamorphic thrusting. These unmapped thrusts are parallel to the mineral foliation in

TABLE 1. CARNIAN AND NORIAN CONODONTS FROM CALCAREOUS SEDIMENTARY ROCKS, CENTRAL ALASKA RANGE, SOUTH-CENTRAL ALASKA

Location number*	Field number (USGS Collection number)†	Quadrangle (Latitude N./ Longitude W.)	Conodont fauna§	Color Alteration Index	Remarks
1	93ATi69C (33374-Mesozoic)	Mt. McKinley D-1 (63°57′50″/ 150°17′20″)	*Metapolygnathus* aff. *M. polygnathiformis* (Budurov and Stefanov) (C) *Metapolygnathus?* sp. indet. (R) norigondolellid? fragments (C)	5	Conodonts suggest postmortem transport within or from a metapolygnathid biofacies (outer shelf or deeper water depositional environment). Orange-weathering, black, very fine-grained dolostone lens in black slate to phyllite. Sample weight 8.6 kg.
2	A, 94ATi61C (33376-Mesozoic)	Mt. McKinley A-4 (63°02′20″/ 151°32′25″)	*Norigondolella navicula* (Huckriede), rounded posterior morphotype (A) *Norigondolella navicula* (Huckriede), square posterior morphotype (C) *Norigondolella* sp. indet. (A)	5	Norigondolellid biofacies (basinal depositional environment). Orange-weathering, black, very fine-grained dolostone lenses in black phyllite. Sample weight 6.2 kg.
	B, 94ATi63A (33377-Mesozoic)	Mt. McKinley A-4 (63°03′25″/ 151°32′30″)	*Norigondolella navicula* (Huckriede)? (R)	5	Medium-gray-weathering, black, fine-grained calcite marble layer (~15 cm thick) in isoclinally folded, thinly laminated, black phyllite. Sample weight 10.0 kg.
3	80-S-375 (33378-Mesozoic)	Talkeetna C-6 (62°44.2′/ 152°58′)	*Metapolygnathus primitius* (Mosher) (A) *Norigondolella navicula* (Huckriede) (R)	5, 5.5, 6, 6.5	Locality 45 of Jones et al. (1983). Dark-gray limestone and tan-weathering calcareous siltstone and mudstone associated with poorly exposed black argillite. Metapolygnathid biofacies; postmortem transport(?) from outer shelf or upper slope environment.
4	79-S-132 (33379-Mesozoic)	Talkeetna C-6 (62°44.96′/ 152°51.4′)	*Metapolygnathus polygnathiformis* (Budurov and Stefanov) (C)	5	Locality 42 of Jones et al. (1983).
5	80-S-474 (33380-Mesozoic)	Talkeetna C-6 (62°44.18′/ 152°49.24′)	*Norigondolella navicula* (Huckriede) (R)	5	Locality 49 of Jones et al. (1983).
6	79-S-135 (33381-Mesozoic)	Talkeetna D-4 (62°59.7′/ 151°56.67′)	*Metapolygnathus communisti* Hayashi (R) *Norigondolella navicula* (Huckriede) (R)	5	Locality 44 of Jones et al. (1983).
7	U.W. 1633/ 33, L13A	Healy C-6 (63°40′07″/ 149°36′25″)	*Metapolygnathus communisti* Hayashi (R)	6	Silty limestone, fossil locality 73, T̄Rcs map unit (from Csejtey et al., 1992).
8	A, U.W. 1633/35, R22	Healy C-5 (63°40′12″/ 149°08′12″)	*Metapolygnathus primitius* (Mosher) (R)	5.5–6	Silty limestone, fossil locality 74, T̄Rcs map unit (from Csejtey et al., 1992).
	B, 78-S-413 (33382-Mesozoic)	Healy C-5 (63°37′45″/ 149°06′55″)	*Metapolygnathus communisti* Hayashi? (R)	5	Silty limestone, fossil locality 75, T̄Rcs map unit (modified from Csejtey et al., 1992).
9	83AMM-13	Healy C-2 (63°44′14″/ 147°49′14″)	*Metapolygnathus primitius* (Mosher) (C) *Metapolygnathus polygnathiformis* (Budurov and Stefanov) (C)	5–6	Silty limestone, fossil locality 82, T̄Rcs map unit (from Csejtey et al., 1992).
10	A, U.W. 1633/37, K230	Healy C-2 (63°44′46″/ 147°38′55″)	*Metapolygnathus primitius* (Mosher)? (R) *Norigondolella* sp. (R) *Metapolygnathus polygnathiformis* (Budurov and Stefanov) (R)	6	Silty limestone, fossil locality 83, T̄Rcs map unit (from Csejtey et al., 1992).
	B, 81ACy-18	Healy C-2 (63°44′57″/ 147°37′12″)	*Metapolygnathus primitius* (Mosher)? (R) *Norigondolella* sp. (R)	6	Silty limestone, fossil locality 84, T̄Rcs map unit (from Csejtey et al., 1992).
11	U.W. 1633/36, K285B	Healy C-2 (63°43′47″/ 147°36′05″)	*Metapolygnathus primitius* (Mosher)? (R)	6	Silty limestone, fossil locality 87, T̄Rcs map unit (from Csejtey et al., 1992).

(*continued*)

TABLE 1. CARNIAN AND NORIAN CONODONTS FROM CALCAREOUS SEDIMENTARY ROCKS, CENTRAL ALASKA RANGE, SOUTH-CENTRAL ALASKA (*continued*)

Location number*	Field number (USGS Collection number)†	Quadrangle (Latitude N./ Longitude W.)	Conodont fauna§	Color Alteration Index	Remarks
12	83 AMM-9	Healy C-3 (63°32′58″/ 148°05′05″)	*Metapolygnathus communisti* Hayashi (A) *Metapolygnathus polygnathiformis* (Budurov and Stefanov) (C)	5.5–6	Silty limestone, fossil locality 90, T̄Rcs map unit (from Csejtey et al., 1992).
13	U.W. 1622/23, TC231B	Healy C-2 (63°32′50″/ 147°59′10″)	*Metapolygnathus primitius* (Mosher)? (R)	6	Silty limestone, fossil locality 91, T̄Rcs map unit (from Csejtey et al., 1992).
14	79ACy-8	Healy B-3 (63°23′43″/ 148°21′36″)	*Epigondolella multidentata sensu* Orchard 1991c (A)	5	Silty limestone, fossil locality 96A, T̄Rcs map unit (Csejtey et al., 1992). Conodonts reevaluated.
15	A, 81ACy-82	Healy B-3 (63°25′07″/ 148°06′14″)	*Metapolygnathus primitius* (Mosher) (R) *Metapolygnathus polygnathiformis* (Budurov and Stefanov)? (R)	5	Quartzose packstone to grainstone, fossil locality 93, T̄Rcs map unit (from Csejtey et al., 1992).
	B, 79ASf-3	Healy B-3 (63°25′58″/ 148°05′42″)	*Metapolygnathus communisti* Hayashi (C) *Metapolygnathus polygnathiformis* (Budurov and Stefanov) (C)	5	Quartzose packstone to grainstone containing bioclasts of mollusks, brachiopods, echinoderms, and encrusting foraminifers and peloids and intraclasts, fossil locality 94, T̄Rcs map unit (from Csejtey et al., 1992). Locality represents a barrier-bar shelf depositional setting. Appropriately, conodonts in this collection are relatively well sorted, abraded, and more robust than in other collections from the T̄Rcs map unit.

*Locality number indicates conodont collection site shown on Figure 2.

†Letters in field numbers refer to collector: U.S.G.S. personnel: ATi, A.B. Till; ACy, Béla Csejtey, Jr.; S, N.J. Silberling; AMM, M.W. Mullen; ASf, G.D. Stricker; U.W., personnel of the University of Wisconsin.

§Conodont abundance: R, rare (<5 specimens); C, common (5–19 specimens); A, abundant (>19 specimens). Generic classification chiefly follows Kozur (1990), with modifications.

the Totatlanika Schist, the same relationship we observed in the northern Kantishna Hills, and have been folded by later deformation. The metamorphosed felsic rocks mapped by Wahrhaftig recently yielded Late Devonian to Early Mississippian U-Pb crystallization ages (Dusel-Bacon et al., 2004), some 35–25 Ma older than the metarhyolite porphyry at Chitsia Mountain.

Between the Hines Creek and McKinley Fault Strands—Herron Glacier Area

Triassic slope and basinal deposits were identified just north of the McKinley strand of the Denali fault system by Jones et al. (1983; Figure 2, locs. 3–6). Two of our samples, both from the east side of Herron Glacier, confirm the Triassic age of these rocks (2A and 2B, Fig. 5) and indicate that the Upper Triassic sequence is more extensive than previously mapped. These two conodont samples were collected from exposures with different lithologic characteristics and deformational histories (Fig. 5, units Trcs and PzZqs).

A thick sequence of alternating medium-gray-weathering marble and black phyllite trace cliff-scale tight-isoclinal folds with vertical axial planes above side valleys to Herron Glacier (Fig. 6). Locality 2B is on the opposite side of the ridge depicted in Figure 6. Recrystallization of the marble observed at locality 2B completely obliterated sedimentary features, and the layering in the rock is a tectonic fabric. The folded marble has a structural thickness of greater than 1 km. The conodont collection from locality 2B (Fig. 5, Table 1) is from a single 10-cm-thick fine-grained black marble layer in subcrop along the margin of an unnamed glacier. A biotite granite of unknown age crosscuts the folds in this sequence.

About 2 km south of locality 2B, a second conodont collection was made from a lithologically complex zone mapped as PzZqs (Fig. 5, locality 2A). No Triassic rocks were previously known in this unit (Wilson et al., 1998). Unit PzZqs consists of numerous brown-weathering massive metagabbro bodies several meters thick and weakly metamorphosed black, brown, and orange-weathering fine-grained metasedimentary rocks. The unit has not been mapped in detail. To the east, rocks of PzZqs are in near-vertical fault contact with distinctive black-weathering Jurassic-Cretaceous fine-grained marine sedimentary rocks. In a saddle near this contact, PzZqs consists of orange-brown-weathering, very fine-grained black dolostone lenses interlayered with black slate. The dolostone lenses yielded Late Triassic conodonts (Table 1, loc. 2A). Lithologically, these rocks are similar to the Upper Triassic rocks at Chitsia Mountain, and like them, we correlated these rocks

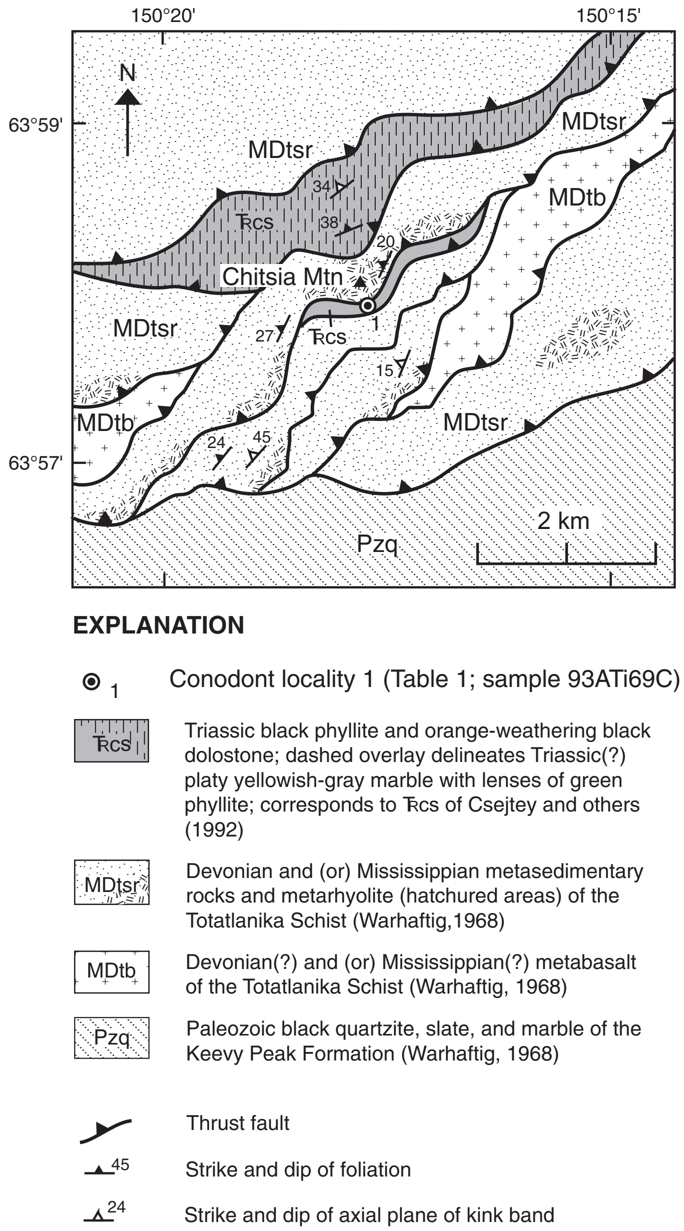

Figure 3. Geology of the Chitsia Mountain vicinity, northern Kantishna Hills. Modified from Bundtzen (1981) based on reconnaissance mapping by A.B. Till and P. Brease in 1993 and 1995 and by B. Csejtey and C.T. Wrucke, Jr., in 1995.

with deeper water parts of TRcs. The conodont assemblage from locality 2A supports this interpretation; the biofacies likely represents the most distal depositional setting documented for TRcs. Unit PzZqs may contain more of these distal Upper Triassic deposits.

West of Herron Glacier is a sequence of thinly bedded slate, calcareous sandstone and argillite, and minor argillaceous limestone (TRcs, Fig. 5). These rocks, despite evidence that they have been folded and faulted, retain primary sedimentary features including graded beds, cross beds, and load casts. This sequence is a lithologic match to typical exposures of Late Triassic slope and basinal deposits elsewhere in the central Alaska Range

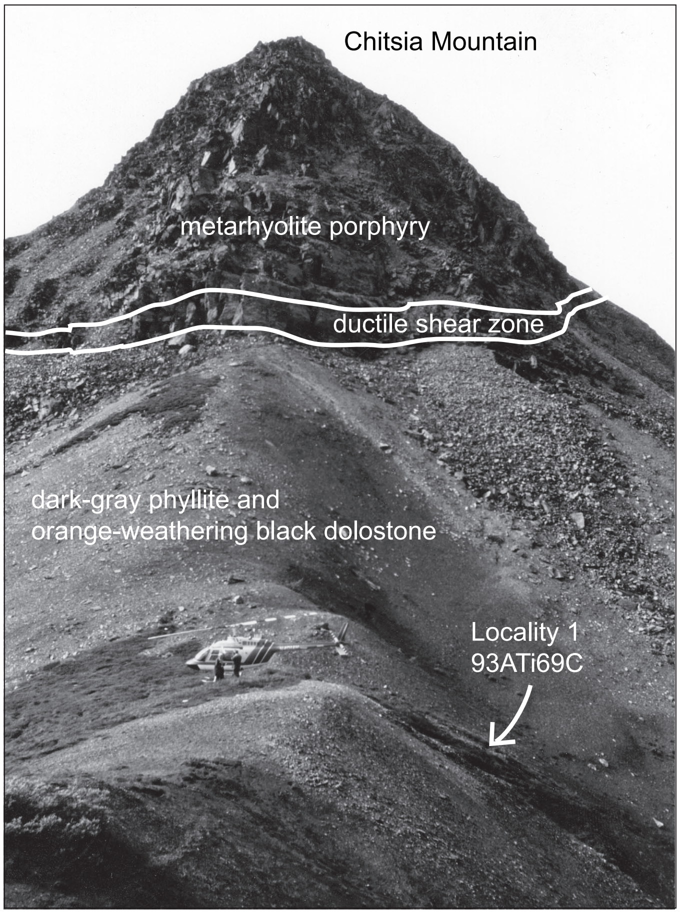

Figure 4. Chitsia Mountain and locality 1 where Late Triassic conodont sample was collected. The ductile shear zone dips northwest away from the viewer.

(B. Csejtey, oral commun., 1994) and was mapped as Triassic sedimentary rocks by Jones et al. (1983). A single sample from this exposure was barren of conodonts.

In summary, in the Herron Glacier area, conodont collections confirm the presence of Upper Triassic rocks at two localities. One locality is in a strongly deformed and metamorphosed layered marble; the other is in a deformed, composite metaigneous and metasedimentary unit not previously known to contain rocks of Triassic age. A third exposure, west of Herron Glacier, is likely of Late Triassic age based on its lithologic characteristics. Additional mapping and paleontologic work will be needed to identify the full extent of the Upper Triassic calcareous sedimentary rocks in this area.

CONODONT COLLECTIONS

Conodonts are the only biostratigraphically diagnostic fossils from the thick sequence (>1,000 m) of marine, calcareous metasedimentary rocks (map unit TRcs of Csejtey et al., 1992) in the central Alaska Range. Collections used to date these rocks are documented in Table 1. Three are new collections (Table 1, locs. 1, 2), and all others, previously analyzed by B.R. Wardlaw (*in* Jones et al., 1983) and M.W. Mullen (Csejtey et al., 1992) have

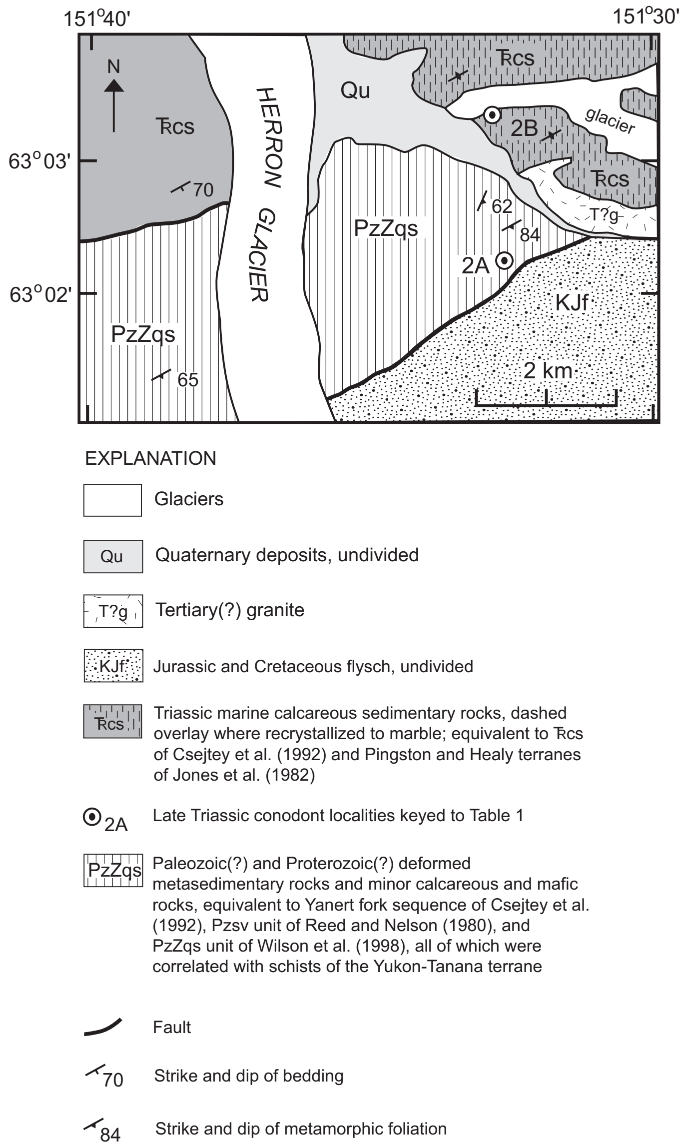

Figure 5. Geology of the Herron Glacier area compiled from mapping by A.B. Till, B. Csejtey, C.T. Wrucke, Jr., P. Brease, and A.B. Ford in 1994.

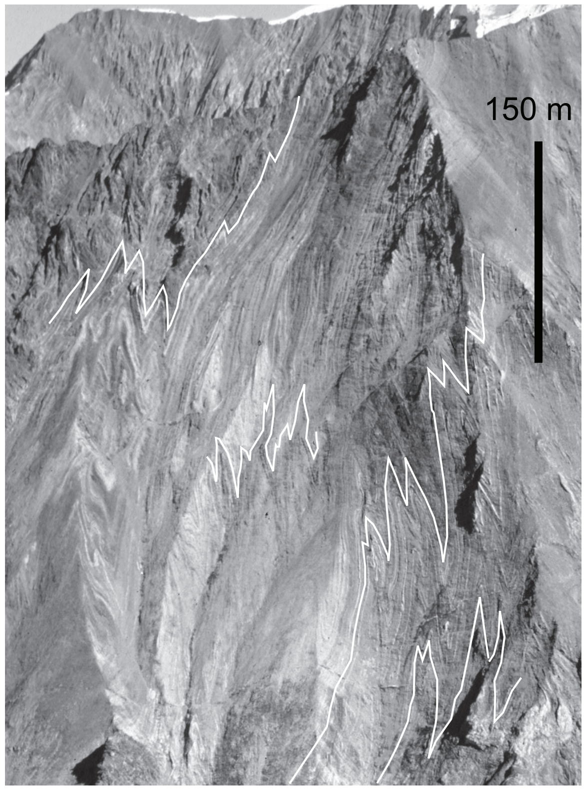

Figure 6. Folded and recrystallized calcareous sedimentary rocks (unit TRcs) ~0.5 km southeast of locality 2B (shown on Fig. 5). Cliff is southwest facing, and locality 2B is on the back side of the ridge.

been reexamined for this report. Csejtey et al. (1992; Table 1) listed 18 conodont collections from their TRcs map unit in the Healy quadrangle. We have used 11 of the 18 collections, those more biostratigraphically diagnostic, in our study (Table 1).

Generally, conodonts from the TRcs map unit are poorly preserved. Most have carbonaceous matter or minerals adhering or annealed to their surface (e.g., Figs. 7Y, 7Z, 7AD), most are corroded to partly recrystallized (Figs. 7E, 7F), and many are deformed. One large specimen is held together by a sericite "vein" (Fig. 7V). Preservation of surface microstructure is variable (compare Figures 7T or 7V to 7AC). All of the above characteristics reflect the degree of deformation and metamorphism of the TRcs map unit. All conodonts have CAI values of at least 5, indicating a regional thermal level of ~300 °C or lower greenschist-facies metamorphism. This metamorphic grade is compatible with the trend of the biotite and garnet isograds of the mid-Cretaceous Maclaren metamorphic belt mapped by Csejtey et al. (1992). The biotite isograd lies just southeast of the southeasternmost conodont collections. Several conodont collections have a range of high CAI values (e.g., Table 1, locs. 3, 9) suggesting proximity to mafic sills, dikes, and plugs that pervade the TRcs unit.

The conodonts are generally small (juveniles to subadult specimens) and few (<20 in a collection), and most were recovered from carbonate to silty carbonate lenses or layers that we interpret as distal calciturbidites and intercalated hemipelagic and pelagic layers. The conodont sorting and species assemblage (predominantly metapolygnathids and "neogondolellids" and absence or scarcity of smooth, full-platform gondolellids) in most collections suggest derivation from shelf environments. One collection (Table 1, loc. 15B) is from cross-bedded, quartzose, skeletal packstone and grainstone containing peloids, intraclasts, and a variety of bioclasts interpreted by Csejtey et al. (1992) to represent a relatively high-energy inner-shelf depositional setting. The metapolygnathids in this collection are the most robust of any from the TRcs map unit, and conodonts characteristic of deeper, quieter water environments are absent. The shelf area and others like it probably sourced the distal calciturbidites that yield low numbers of mainly small (winnowed) conodonts. In contrast, another collection (Table 1, loc. 2A) contains abundant conodonts (>700 specimens) including a range

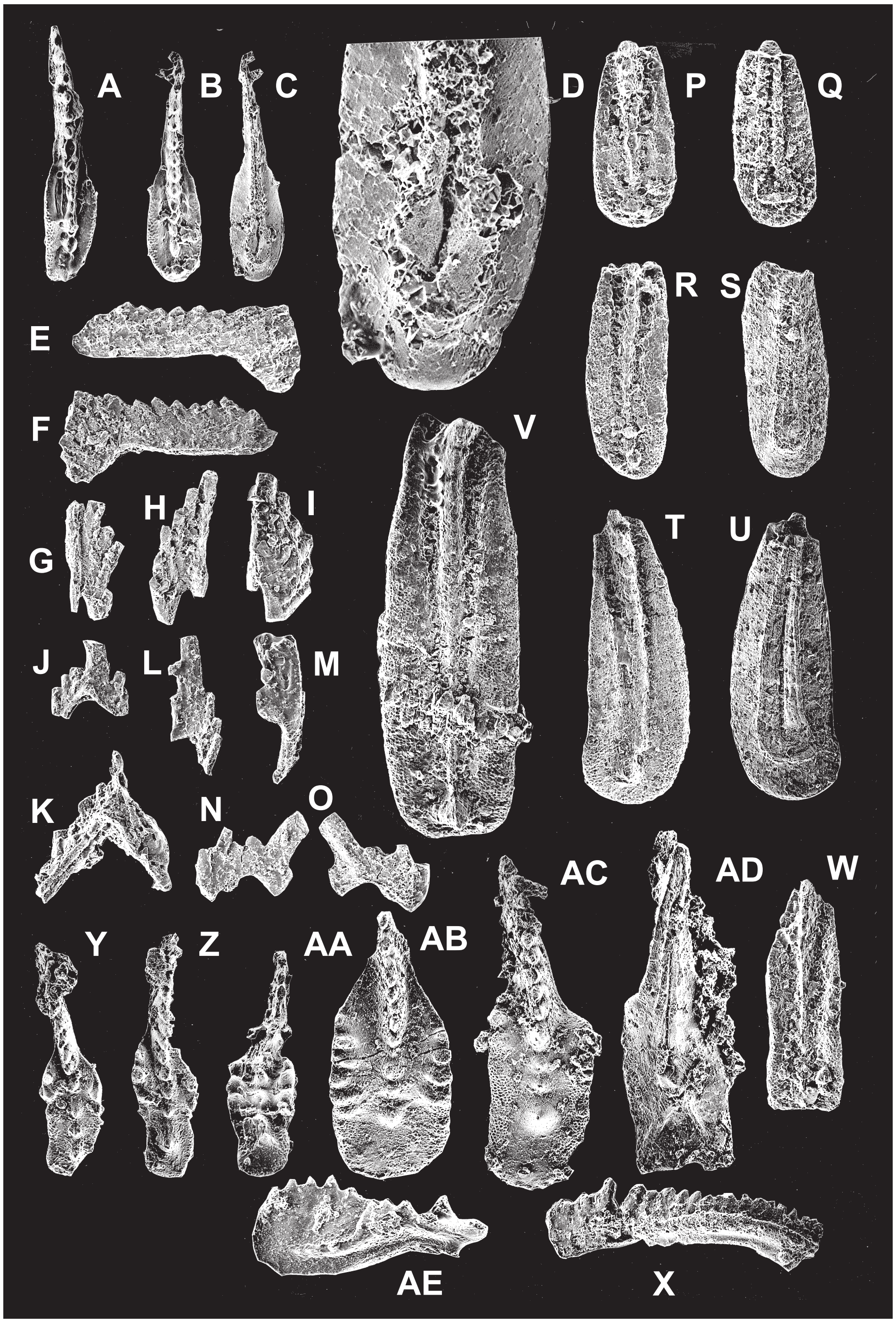

Figure 7. Scanning electron micrographs of Late Triassic (Carnian and early Norian) conodonts from the T̄Rcs map unit of Csejtey et al. (1992), central Alaska Range. All specimens ×65 except Figure7D, which is ×260. Illustrated specimens are reposited in the U.S. National Museum (USNM), Washington, D.C. (A–D) *Metapolygnathus* aff. *M. polygnathiformis* (Budurov and Stefanov), juvenile Pa elements, USGS colln. 33374-Mes. (Table 1, loc. 1). Upper (A, B) and lower (C, D) views of two specimens, USNM 486038 (A), USNM 486039. (B–D). (E–X) *Norigondolella navicula* (Huckriede), Pa elements; from USGS colln. 33376-Mes. (Table 1, loc. 2), except X from USGS colln. 33378-Mes. (Table 1, loc. 3). (E, F) Outer and inner lateral views of Pb element, USNM 486040. (G–I) Anterolateral (G) and opposite lateral views (H, I) of Sb elements, USNM 486041, 486042. (J, K) Lateral views of M elements, USNM 486043, 486044. (L, M) Lateral views of Sa elements, USNM 486045, 486046. (N, O) Inner and outer lateral views of Sc element, USNM 486047. (P–U) Upper and lower views of three increasingly adult specimens having a rounded posterior margin, USNM 486048–50. (V–X) Upper view of an adult Pa and upper and lateral views of juvenile Pa having a square posterior margin, USNM 486051, 486052; anterior blade of juvenile (X) broken and separated during photography so that the upper view of the same specimen (W) lacks the free blade. (Y–AE) *Metapolygnathus primitius* (Mosher); Pa elements, USGS colln. 33378-Mes. (Table 1, loc. 3), Y–AA, Upper views showing typical constriction of posterior half of platform in juvenile specimens, USNM 486054–56-Mes. (AB–AE) Upper, upper and lower, and lateral views of three specimens, USNM 48657–59-Mes.

of growth stages of Pa elements of *Norigondolella navicula* (Huckriede) (Figs. 7P–7X) and relatively complete specimens of other elements of its apparatus (Figs. 7E–7O). The collection represents an in situ norigondolellid biofacies and possibly the most distal depositional setting of all collections in this study.

The most prevalent and biostratigraphically diagnostic species are *Metapolygnathus communisti* Hayashi and *M. primitius* (Mosher). *Metapolygnathus communisti* ranges from the base of its zone in the latest Carnian into the lower part of the Upper *M. primitius* Subzone in the earliest Norian (Orchard, 1991b; Fig. 8). *Metapolygnathus primitius* is restricted to its zone, which straddles the Carnian-Norian boundary (Orchard, 1991b; Fig. 8).

Metapolygnathus polygnathiformis ranges throughout the Carnian (Kozur, 1990, p. 420). Similar forms included in *Metapolygnathus nodosus* by Orchard 1991b may occur as high as the lower part of the Upper *M. primitius* Subzone (lowermost Norian) (M.J. Orchard, oral commun., 1994). Three collections containing both *M. polygnathiformis* and *M. primitius* indicate the Lower

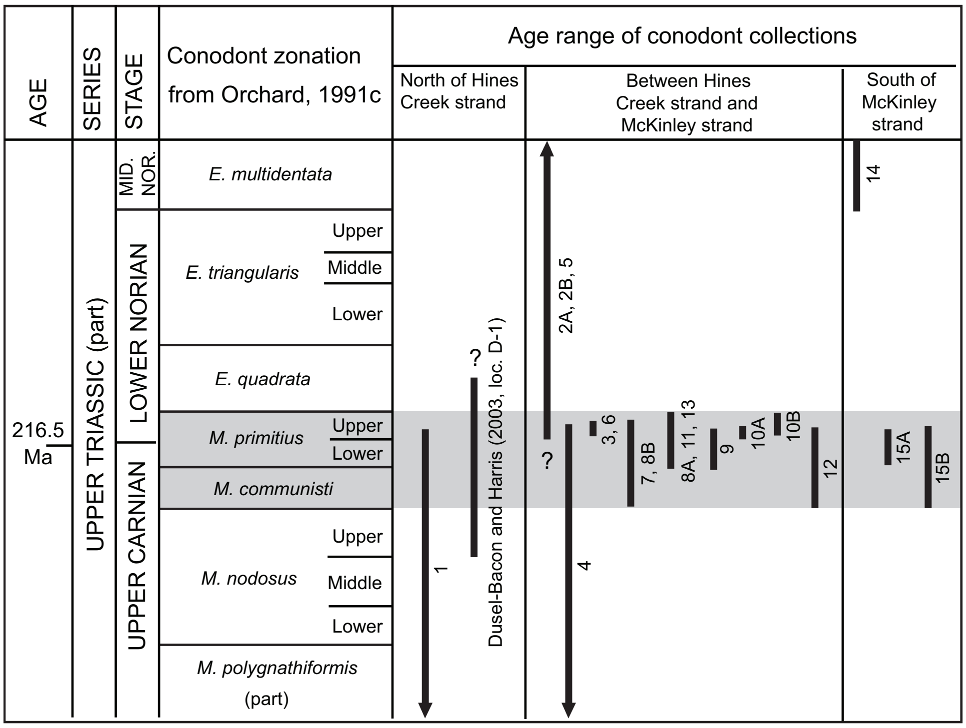

Figure 8. Age range of conodont collections from the Upper Triassic calcareous sedimentary rocks in the central Alaska Range and Yukon-Tanana Upland. Numbers on bars refer to location numbers in Table 1. Nearly all collections overlap in the uppermost Carnian and lowermost Norian (shaded area). The two most prevalent and biostratigraphically diagnostic species are *Metapolygnathus primitius,* which is restricted to its zone, and *M. communisti,* which ranges from its zone into the upper part of the succeeding *M. primitius* Zone. One collection (14) contains *Epigondolella multidentata,* indicating that the thick (>1000 m) TRcs map unit is as young as early middle Norian. It is likely that rocks of older Carnian age are also present in the TRcs unit because some collections produce only long-ranging species such as *Metapolygnathus polygnathiformis* (Table 1, locs. 1, 4). Csejtey et al. (1992) assigned a late Carnian to middle(?) Norian age to their TRcs map unit on the basis of conodonts. This chart includes 12 of their reevaluated collections (Table 1, locs. 7–15). Absolute age for Carnian/Norian boundary is from Gradstein and Ogg (2005).

M. primitius Subzone and lower part of the Upper *M. primitius* Subzone (Fig. 8).

Our most abundant collection contains only *Norigondolella navicula* (Table 1, loc. 2A). Some adult Pa elements of *N. navicula* have a square posterior margin (Figs. 7V, 7W) that could suggest relations to *Metapolygnathus polygnathiformis* and a possible Carnian age for the collection. Sweet (1988) and other workers have suggested that many of the ramiform elements of *Cypriododella* and *Xaniognathus* are indistinguishable from those of other gondolellid genera, such as *Norigondolella* and *Neogondolella.* The above collection tends to confirm this suggestion although others have argued that *Cypriododella* and *Xaniognathus* are always the ramiform elements for non-*Neogondolella* species. P elements of *Cypriododella* are underrepresented in comparison to the large number of other cypriododellan ramiform elements (5 P (Pb?) versus 49 M, 20 Sa, 38 Sb, and 24 Sc elements), implying that many, likely all, of the ramiform elements belong to *Norigondolella navicula* (Huckriede), the only other species in the collection.

Only one collection, containing *Epigondolella multidentata* sensu Orchard (1991c) is younger than earliest Norian (Table 1 and Figure 8, loc. 14). *Epigondolella multidentata* is the nominal species of the lowest middle Norian conodont zone to which it is restricted (Orchard, 1991b).

The conodont faunas are not useful tools for analyzing movement along faults or distance between tectonostratigraphic terranes. The conodont assemblages from the TRcs unit formed chiefly as a result of postmortem hydraulic transport of conodonts from shelf and upper slope environments to deeper water depositional settings. With the possible exception of *Epigondolella multidentata* sensu Orchard 1991c, the species are cosmopolites that have a broad paleogeographic distribution from ~30°S. to at least 40°N. of the Late Triassic equator (Scotese and Golonka, 1993). Orchard (1991a, Fig. 6) shows that the most widely distributed Triassic faunas in the western Canadian Cordillera are those of Carnian and early Norian age, which includes the age range of the conodont faunas from the TRcs unit. The most paleogeographically widespread species in the TRcs unit, *Metapolygnathus polygnathiformis* and *Norigondolella navicula,* are also the longest lived. *Metapolygnathus polygnathiformis* is known from Arctic and western North America, ranging from Ellesmere Island (Mosher, 1973) to British Columbia, western Canada (Mosher, 1973; Orchard, 1991b, 1991c) and central and southeastern Alaska (Csejtey et al., 1992; unpublished U.S. Geological Survey collections) to as far south as western Nevada (Mosher, 1968) and north-central California (Mosher, 1968; Irwin et al., 1983). It is widely distributed in southern and central Europe including Sicily (Martini et al., 1991) Austria (Mosher, 1968), Slovenia (e.g., Ramovs, 1978; Kolar-Jurkovsek, 1994), Bosnia-Herzegovenia (Sudar, 1981), Slovakia (Mello and Mock, 1977), Hungary (Kovács, 1986), Bulgaria (e.g., Budurov and Stefanov, 1965), and Greece (Dürkoop et al., 1986). The species has also been reported from the Middle East and Far East including Turkey (Kristan-Tollmann and Krystyn, 1975), Israel (Eicher and Mosher, 1974), north-central Siberia (Kazakov and Dagys, 1987), Sichuan Province, People's Republic of China (Wang and Dai, 1981), northern India (Chhabra and Kumar, 1984), Japan (Igo, 1989), Malaysia (Metcalfe, 1992), and Sumatra (Metcalfe et al., 1979). *Norigondolella navicula* is even more widespread than *M. polygnathiformis.*

Metapolygnathus primitius is not as widely reported as *M. polygnathiformis.* The species was first described from British Columbia, Canada (Mosher, 1970), and is now known elsewhere in North America in central Alaska (Csejtey et al., 1992) and western Nevada (Mosher, 1970). It has also been reported from Austria (Krystyn, 1980), Hungary (Kovács, 1986), Slovenia (Kolar-Jurkovsek, 1982), Serbia-Montenegro (Sudar, 1981), north-central Siberia (Kazakov and Dagys, 1987), Tibet (Mao and Tian, 1987), Japan (e.g., Igo, 1989), Sumatra (Metcalfe et al., 1979), and off the south coast of Timor (Jones and Nicoll, 1985).

Metapolygnathus communisti, originally described from Japan (Hayashi, 1968), has since been reported from western Canada (Orchard, 1991b, 1991c), Austria (Krystyn, 1980), Bosnia-Herzegovenia and Serbia-Montenegro (Sudar, 1981), Hungary (Kovács, 1986), and Bulgaria (Budurov and Trifonova, 1991).

Epigondolella multidentata sensu Orchard 1991c, may well have the most restricted paleogeographic distribution of the conodont species recovered from the TRcs map unit. It may be limited to western North American autochthonous rocks that include occurrences in northeast British Columbia (Mosher, 1970; Orchard, 1991c), possibly Nevada (Mosher, 1970), and central Alaska (this report).

DISCUSSION

Relationship of Late Triassic Continental Margin Rocks to the Yukon-Tanana and Seventymile Terranes

Conodonts indicate that a thick sequence of Upper Triassic sedimentary rocks (TRcs map unit or Pingston terrane) spans the Hines Creek and McKinley strands of the Denali fault system. Most of these rocks, including the thicker exposures, are associated with rocks of the parautochthonous Yukon-Tanana terrane or rocks thought to be correlative to the Yukon-Tanana terrane.

At the Chitsia Mountain locality, Upper Triassic rocks are imbricated with metafelsic and metabasaltic rocks of the Totatlanika Schist, which is part of the greenschist-facies carbonaceous, siliceous, and volcanic rock assemblage of Dusel-Bacon et al. (2004). This package is one of the assemblages those authors assign to the Yukon-Tanana terrane (the package is equivalent to the Nisutlin assemblage of Hansen and Dusel-Bacon [1998] and Dusel-Bacon et al. [2002]). Correlation of the exposures of this assemblage in the northern Alaska Range with exposures in the Yukon-Tanana Upland has been solidified recently by detailed work on the age, setting, and chemical characteristics of bimodal volcanic rocks from both areas (Dusel-Bacon et al., 2004). The Devonian to Mississippian greenschist facies carbonaceous, siliceous, and volcanic rock assemblage in the western and southern Yukon-Tanana Upland and Alaska Range is proposed by Dusel-Bacon et al. (2004) to represent a marginal basin adjacent to the ancient North American margin. The Upper Triassic rocks at Chitsia Mountain, just north of the Hines Creek strand of the Denali fault system, therefore, are imbricated with rocks thought to have accumulated along the continental margin of North America in mid-Paleozoic time that are now included in the Yukon-Tanana terrane. The Chitsia Mountain locality is the only place north of the Denali fault system where Upper Triassic sedimentary rocks have been recognized amongst exposures of the Yukon-Tanana terrane; the extent to which these rocks were imbricated with the Yukon-Tanana terrane is unknown.

Upper Triassic calcareous sedimentary rocks exposed between the Hines Creek and McKinley strands of the Denali fault system are spatially associated with weakly to strongly metamorphosed and intensely deformed metasedimentary rocks about which relatively little is known. Westernmost exposures of TRcs (near localities 2–6, Fig. 2) are adjacent to a package of schistose, isoclinally folded quartzite, semischist, and metavolcanic rocks (unit Pzsv of Reed and Nelson, 1980). Pzsv was inferred to correlate with schists of the Kantishna Hills, now considered part of the Yukon-Tanana terrane (Foster et al., 1994). One locality in this set of westernmost exposures (locality 2A, Fig. 5) yielded possibly the most distal conodont biofaces yet collected from TRcs. Further work is needed to evaluate the nature of the contact between the Upper Triassic sedimentary rocks and the older metamorphic rocks in those western exposures. Our work shows that the full extent of Upper Triassic sedimentary rocks is not known in this region because we have identified Upper Triassic in units thought to include Paleozoic and older rocks.

Exposures of TRcs in the central Alaska Range (near localities 9–13, Fig. 2) are associated with intensely deformed black carbonaceous shale, sandstone, and siltstone turbidites, metachert, felsic metatuff, phyllitic metabasalt, minor stretched-pebble conglomerate and impure marble with Late Devonian conodonts (Yanert Fork sequence of Csejtey et al., 1992). The sequence is cut by numerous diabase and gabbro intrusions. The Upper Triassic sedimentary rocks are thought to sit on this package in angular unconformity at one locality (Sherwood, 1979). Csejtey et al. (1992) considered this sequence to be correlative to the Yukon-Tanana terrane on the basis of protolith character, metamorphic grade, and structural style. The Yanert Fork sequence sits directly across the Hines Creek fault and due south of exposures of the greenschist-facies carbonaceous and siliceous metasedimentary rock assemblage described by Dusel-Bacon et al. (2004), and based on available literature, it appears to be similar to parts of that assemblage in terms of lithologic association and age. Examination of the depositional relationship of the Upper Triassic rocks with the Yanert Fork sequence and careful geochronologic work on the metavolcanic components of the Yanert Fork sequence are needed to place the Upper Triassic of the central Alaska Range into paleogeographic and tectonic context.

Depositional and structural relationships of Upper Triassic sedimentary rocks mapped as TRcs by Csejtey et al. (1992) south of the Denali fault system are unknown. These exposures of the Upper Triassic rocks include the youngest and most proximal conodont biofacies collected from the unit (loc. 14, Figures 2 and 8). The position of the shelf and slope on which TRcs was deposited during the Late Triassic has not been explored but is key to paleogeographic reconstructions. It is interesting that the one conodont that is typical of autochthonous North America, *Epigondolella multidentata* sensu Orchard 1991c, is from the part of the Upper Triassic sedimentary sequence closest to Wrangellia (Fig. 8). If the present distribution of Upper Triassic calcareous sedimentary rocks is considered to be the result of a relatively simple accordion-like collapse of the Upper Triassic sequence and adjacent continental margin, the most proximal sedimentary facies and biofacies might not be expected in this position.

Upper Triassic rocks are also associated with oceanic rocks that are thought to sit structurally above the Yukon-Tanana terrane. North of the Alaska Range, along the Canadian border, Dusel-Bacon and Harris (2003) describe Upper Triassic sedimentary rocks they consider to be part of the Seventymile terrane, a structural assemblage of oceanic rocks thought to include remnants of a Mississippian to Permian ocean basin that was emplaced above the Yukon-Tanana terrane during the Mesozoic. Models of the paleogeographic relationships of the Seventymile terrane place it adjacent to the North American continental margin and to sequences that ultimately become the Yukon-Tanana terrane (Hansen and Dusel-Bacon, 1998; Dusel-Bacon et al., 2002).

In Canada, the oceanic assemblage equivalent to the Seventymile terrane is the Slide Mountain terrane, which occurs along the length of the Cordillera. In northern British Columbia, Middle(?) to Upper Triassic siliciclastic and carbonate sedimentary rocks are closely associated with oceanic rocks of the Slide Mountain terrane. The Upper Triassic sequence sits structurally atop the oceanic rocks. Nelson (1993) considers this a sheared depositional boundary and relates these sediments to Triassic sequences thought to have an autochthonous relationship with North America. She viewed the Upper Triassic rocks of the Slide Mountain terrane as the distal portion of a clastic wedge that thickens eastward into the Canadian Rocky Mountains, overlapping the remains of a collapsed continental margin and ocean basin. Dusel-Bacon and Harris (2003) considered the lack of a preserved depositional contact between the Upper Triassic sediments and the oceanic rocks in Canada and Alaska to be a critical fact. They prefer a model that places the Upper Triassic rocks adjacent to but not in depositional contact with elements of the North American margin.

Late Triassic Paleogeographic Elements South of the Alaska Range

Within and south of the Alaska Range, several packages of Late Triassic rocks occur as components of accreted terranes. Some of these have largely oceanic affinities, and others have ties to continental rocks.

The Tlikakila complex south of the Alaska Range is thought to be a deformed remnant of a Late Triassic ophiolite with a suprasubduction zone affinity (Amato et al., this volume, chapter 10). Late Triassic conodonts have been recovered from limestone bodies in the complex (Wallace et al., 1989). Detrital zircons collected from a sample of chert pebble conglomerate yielded ages consistent with sediment sources in both North American and the Wrangellia terrane (Amato et al., this volume, chapter 10). The Tlikakila complex may prove to be a critical Late Triassic paleogeographic link between North America and Wrangellia; additional evidence for its paleogeographic position is important to accurate paleogeographic reconstruction.

Portions of more than one ancient continental margin may have been part of the Late Triassic paleogeography. Similarities in Late Triassic gastropod taxa from shallow water marine strata in the Chulitna and Farewell terranes indicates that those packages likely coexisted in a tropical environment during that time along with the Alexander terrane of southeast Alaska (Fig. 2; Frýda and Blodgett, 2001). The Proterozoic to Jurassic Farewell terrane contains Proterozoic and Paleozoic metamorphic and continental margin rocks; it is thought to have an early Paleozoic history different from that of North America (Bradley et al., 2003).

One sliver of oceanic rocks exposed along the backbone of the Alaska Range apparently formed in an ocean basin isolated from continental detritus. In the central Alaska Range, Upper Triassic diabase and pillow basalt depositionally overlie bedded chert that contains Late Triassic radiolarians (Jones et al., 1983), and the Late Triassic pelagic bivalve *Halobia* cf. *H. superba* was found in a clastic interbed in pillow lava (Silberling, cited in Gilbert et al., 1984). These rocks were included in the McKinley terrane of Jones et al. (1982; Fig. 2). Geochemical characteristics of the basalts are inconsistent with an island arc or divergent margin origin but, rather, match characteristics of seamounts (Gilbert et al., 1984). Sedimentary rocks associated with the seamounts lack the detrital components typical of continental source areas (Gilbert et al., 1984). Because the Upper Triassic calcareous sedimentary rocks (T̄Rcs) in the Alaska Range do contain detrital components likely derived from a continent, it is unlikely that the McKinley terrane seamounts sat near the continental slope on which the Upper Triassic sedimentary sequence was deposited. The relationship of the Triassic oceanic rocks of the McKinley terrane to the Mississippian to Triassic oceanic rocks of the Seventymile terrane is not known.

Mesozoic Deformation

The timing of structural juxtaposition of Upper Triassic sediments with elements of the Seventymile-Slide Mountain and Yukon-Tanana terranes is not known. Tectonic models for emplacement of the oceanic packages and collapse of the ancestral North American margin commence in the Permian, with arc volcanism and high-pressure metamorphism interpreted as signs that oceanic crust off North America was being consumed in a subduction zone (e.g., Tempelman-Kluit, 1979; Nelson, 1993; Hansen and Dusel-Bacon, 1998). Once consumption of oceanic crust was complete, arc-continent collision resulted in emplacement of oceanic assemblages and thickening of continentally derived rocks. This episode is thought to have occurred in Late Triassic or Early Jurassic time based on metamorphic ages related to thickening of the continental crust (Hansen and Dusel-Bacon, 1998; Dusel-Bacon et al., 2002). Early Cretaceous Ar-Ar cooling ages obtained from structurally lower assemblages in the Yukon-Tanana Upland are interpreted to document the timing of a subsequent regional extension event (Pavlis et al., 1993; Dusel-Bacon et al., 2002). In other parts of the Upland, however, kinematic indicators of mid-Cretaceous contractional deformation have been documented (Day et al., 2003; Dusel-Bacon et al., 1995).

At Chitsia Mountain, K-Ar ages suggest that the single detectable fabric in the low-grade metamorphic sequence is Early Cretaceous in age (Bundtzen, 1981; Bundtzen and Turner, 1979). That fabric appears to parallel the shear zones that mark thrust contacts within the sequence, a relationship observed by Wahrhaftig (1968), 75 km to the east. Our work shows that the shear zones placed Mississippian metaryholite porphyry directly over Upper Triassic black dolostone and phyllite. At face value, these relationships suggest an Early Cretaceous thrust episode for the Yukon-Tanana terrane in the northern Kantishna Hills—roughly the same time that thrust faulting was documented in the Yukon-Tanana terrane to the northeast. However, none of the detailed fabric analysis, metamorphic petrology, and thermochronology done to document the style and condition of metamorphic events in the Yukon-Tanana Upland has been done along the northern flank of the Alaska Range. An integrated tectonic model for the mid-Cretaceous evolution of the Yukon-Tanana terrane has yet to emerge.

CONCLUSIONS

Although their largely faulted contacts with underlying parautochthonous(?) and oceanic rocks complicate identification of the paleogeographic setting of deposition, the Upper Triassic calcareous sedimentary rocks exposed in the vicinity of the Denali fault system represent part of the Upper Triassic North American continental margin. The present distribution of Upper Triassic biofacies in the Alaska Range disallows models featuring simple accordion-style collapse of that margin during terrane accretion and subsequent deformation.

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