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MIDDLE AND UPPER TRIASSIC BIVALVE BIOSTRATIGRAPHY OF THE SHUBLIK FORMATION FROM THE TENNECO PHOENIX #1 WELL, OFFSHORE CENTRAL NORTH SLOPE, ARCTIC ALASKA

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Abstract—A new biostratigraphic zonation is presented from the Middle and Late Triassic Shublik and Sag River Formations from the Tenneco Phoenix #1 well, offshore central North Slope, Arctic Alaska. The Phoenix #1 well core includes nearly a complete record of the organic-rich and phosphatic Shublik Formation and contains well-preserved and abundant halobiid and monotid bivalves from more than 50 unique depth levels spanning the Ladinian through uppermost Norian time interval. The Shublik Formation of the Phoenix #1 well can be subdivided into five biostratigraphic intervals from oldest to youngest: (1) a narrow Ladinian interval characterized by *Daonella frami*, (2) a Lower Carnian interval with *Halobia zitteli,* (3) an Upper Carnian interval with *H. ornatissima,* (4) a Lower Norian-lower Middle Norian interval with *H.* cf. *H. austriaca*, *H. cordillerana*, *H.* cf. *H. plicosa,* and *H. halorica*, and (5) an upper Middle Norian through Upper Norian interval with *H.* cf. *H. fallax*, *Eomonotis* cf. *E. jakutica*, and *Monotis (Entomonotis) ochotica.* Correlation of these biostratigraphic intervals can be confidently made to both offshore and onshore wells and relatively complete outcrop exposures of Shublik Formation and also with numerous localities of the Otuk Formation in the Brooks Range. Fitted within a depositional sequence stratigraphic framework, the biostratigraphic intervals correspond to transgressive or highstand systems tracts. Apart from the Ladinian-Carnian boundary interval, stratal intervals without identifiable macrofossils correspond to either maximum flooding surfaces (Lower Carnian and Middle Norian) or closely associated with sequence boundaries (Carnian-Norian and Norian-Rhaetian boundary intervals).

INTRODUCTION

The Triassic Shublik Formation is recognized as a significant hydrocarbon source of northern Alaska and its offshore correlatives (Magoon and Claypool, 1985; Bird, 1994; Masterson, 2001; Peters et al., 2006; Yurchenko et al., 2018). The formation is marine, relatively thin but lithologically heterogeneous and contains significant intervals of bioclastic carbonates, sandstones, glauconitic sandstones, organic rich marine mudrocks and phosphorites. It has been interpreted as being deposited underneath an ancient upwelling zone on a gently-dipping ramp/shelf setting during Early through Late Triassic time (Parrish, 2001a, 2001b). Given its potential as a petroleum source, the formation has been extensively studied in the subsurface, especially the Prudhoe oil field (e.g., Kupecz, 1995) and in its outcrop belt along the northern Brooks Range in northeastern Alaska (e.g., Detterman et al., 1975). The Tenneco Phoenix #1 well is especially significant in that it completely cored the Shublik in a proximal location where the formation is relatively thick, and, especially, because it is the only completely cored Shublik where the core is publicly available.

The purpose of this paper is to provide the biostratigraphic framework for the Shublik Formation based primarily on the occurrence of bivalves *Daonella*, *Halobia* and *Monotis* from the Phoenix #1 well core (Fig. 1). The high-resolution biostratigraphy from Phoenix #1 well core provides one of the most complete and continuous records from the Shublik Formation across the North Slope and northeastern Alaska and permits enhanced correlation to coeval faunas elsewhere in the Boreal, North American Cordillera, Panthalassan and Tethyan faunal realms. Furthermore, these macrofossil biostratigraphic data provide a test for sequence stratigraphic and depositional models derived by sedimentology facies analyses.

Materials and Methods

The Phoenix core, donated to the U.S. Geological Survey, was examined and sampled by one of us (RBB) in 2001 at the USGS Core Research Center Facility, Denver Federal Center, Lakewood, Colorado. The observed fossils were represented on surfaces of notable core breaks, and in some cases, additional breakage was induced where prominent shell accumulations were noted on the exterior core surface. Preservation is represented primarily by molds and recrystallized skeletal material. Selected molds were filled with latex rubber and then pulled after hardening. The latex rubber casts were subsequently coated with ammonium chloride and photographed. Taxonomic determinations were made of the better-preserved materials which are represented in the plates. Photographs of the entire Phoenix archived (slabbed) core can be found in D'Agostino and Houseknecht, (2002) and available on the U.S. Geological Survey Core Research Center website (https://my.usgs.gov/crcwc/core/report/14225). Illustrated specimens designated with AKGMC prefix catalog numbers are housed at the State of Alaska, Division of Natural Resources, Geologic Materials Center (Anchorage).

GEOLOGIC AND STRATIGRAPHIC SETTING

The Tenneco Phoenix #1 well (OCS-Y-0338 UWI: 55231000050000) is located in the Beaufort Sea approximately 65 km northwest of Prudhoe Bay, Alaska (Fig. 1) at 70°43'01"N, 150°25'40"W. The Phoenix #1 well, situated on a structural high north of the Barrow Arch, cored a nearly complete section through the Pebble Shale (Cretaceous), Sag River and Shublik Formations (Triassic-Jurassic), and the Eileen and Ivishak Formations (Permo-Triassic). The cored portion of the of the Shublik and Sag River Formations from the Phoenix #1 well have provided a wealth of sedimentological and geochemical data that has been the subject of several important papers (e.g., Robison et al., 1996; Yurchenko et al., 2018) and included in several theses (e.g., Hulm, 1999).

The Shublik Formation occurs in numerous test wells, both

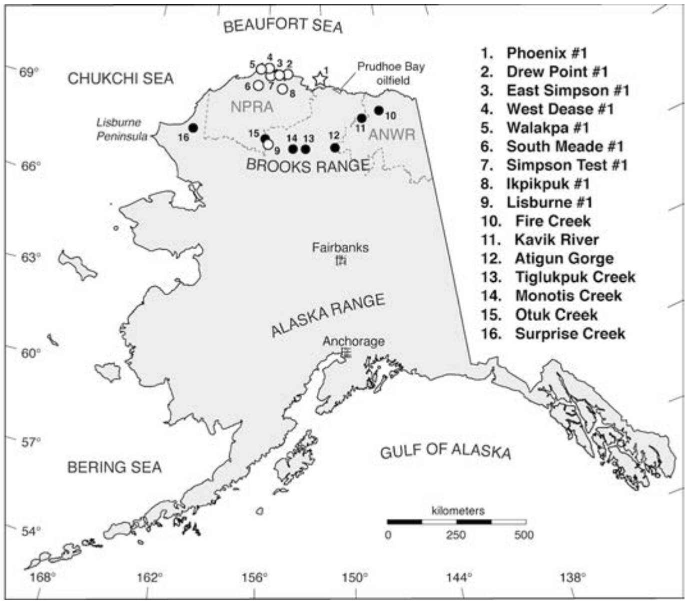

FIGURE 1. Locality map. Solid circles surface localities discussed in text, open circles, well cores discussed in text.

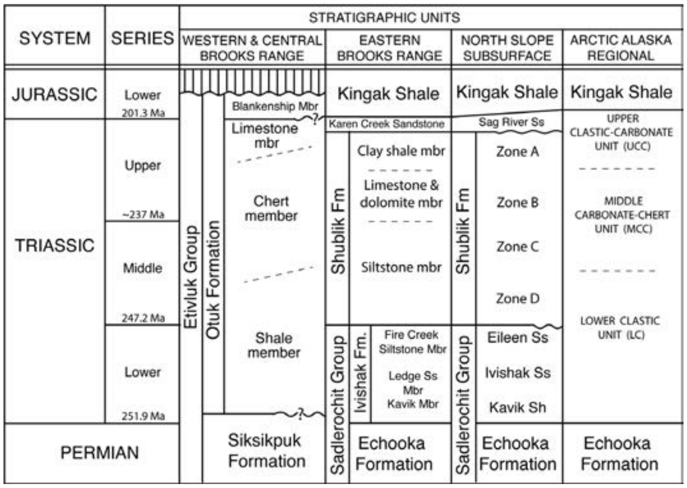

FIGURE 2. Generalized stratigraphy and facies relations of northern Alaska (from left to right adapted from Mull et al., 1982; Bodnar, 1984; Detterman et al., 1975; Jones and Spears, 1976; Kupecz, 1995; Whidden et al., 2018). Numerical age estimates after Ogg (2012).

offshore and onshore, more than 500 wells within the Prudhoe Bay oil field and in several relatively complete outcrop exposures including Fire Creek, Kavik River, and Last Creek in the Arctic National Wildlife Refuge (ANWR) of northeast Alaska (e.g., Detterman et al., 1975; Kupecz, 1995; Hulm, 1999, Parrish et al., 2001a, b; Kelly et al., 2007; Whidden et al., 2018). Both in the subsurface and where exposed, the Shublik Formation in northern Alaska is a heterogeneous assemblage of mudstone, siltstone, carbonate wackestone and packstone, phosphorite, sandstone and glauconitic sandstone. The formation ranges between 100—166 m thick in surface exposures (Detterman et al., 1975; Parrish et al., 2001b) and between 70—178 m thick as determined from subsurface well data (Bird, 1982; Parrish, 1987). From the Phoenix #1 well, the Shublik is 86.4 m (283.5 ft) thick (Robison et al., 1996). The Shublik thins northward in present-day coordinates due to depositional onlap and is, in the Prudhoe Bay area, truncated to the northeast by a Cretaceous erosional unconformity (Jones and Spears, 1976). Because the Shublik is organic-rich and contains phosphatic and glauconitic facies, it has been interpreted as representing a shallow shelf influenced by oceanic upwelling (Parrish, 1987; Kupezc, 1995; Parrish et al., 2001a, b; Kelly et al., 2007).

The complex spatial and temporal facies associations of the Shublik and equivalent units have led researchers to develop schemes to subdivide the formation into lithostratigraphic members and/or facies suites of genetic importance (Figs. 2, 3). From the subsurface in the Prudhoe Bay Field area, Jones and Speers (1976) subdivided the Shublik into four informal members (A-D), with a fifth member (E) now assigned to the Eileen Formation using present day nomenclature. A modification of that scheme was employed by Kupecz (1995) in her study of the Shublik in the Prudhoe field. Hulm (1999) extended that scheme to wells outside of the Prudhoe field area, including Phoenix and wells in the NPRA. This zonation is based on gamma-ray well logs and was established by participants in the Prudhoe Bay Unit and recorded in their PBU Common Database. Zone definitions have remained proprietary until the recent (authorized) release by Hosford Scheirer and Bird (2020). Gamma-ray profiles obtained in outcrop sections, particularly at Fire Creek, allowed extension of that scheme from subsurface to the surface (Kelly et al., 2007; Hutton, 2014; Whidden et al., 2018; Rouse, et al., 2020). The linkage of gamma-ray signatures to suites of sedimentary facies responding to relative sea-level changes have been used and refined in more recent sedimentologic and sequence stratigraphic studies of the Shublik and are used throughout this paper.

Based on data from the Phoenix #1 core, the Shublik Formation has been variably interpreted in light of sequence stratigraphic models (Fig. 3). Robison et al. (1996) considered the Shublik Formation to consist of a single depositional sequence with the transgressive system tract commencing within the Eileen Formation passing up through a condensed interval and maximum flooding surface at approximately 2408 m (7900 ft). In this model, strata above this maximum flooding surface were part of a highstand systems tract of the upper part of the formation and culminated in a sequence boundary at the Shublik-Sag River contact. A different sequence stratigraphic model was subsequently introduced by Hulm (1999) who considered the Shublik of the Phoenix #1 core to be composed of two discrete depositional sequences (Fig. 3). Hulm's (1999) model interprets the first sequence as consisting of a transgressive systems tract within the Eileen and lower Shublik (up through the top of Zone D), followed in turn by the highstand systems tract (Zone C) and a sequence boundary near the contact between Zones C and B, which corresponds closely with our determination of the Carnian-Norian boundary interval. The second sequence of Hulm (1999) consists of a transgressive systems tract (Zone B) and highstand systems tract (Zone A) and culminates in a sequence boundary at or just above the Shublik-Sag River contact. Applying a transgressive-regressive (as opposed to a depositional) sequence model (e.g., Embry, 1993), Whidden et al. (2018) recognize five transgressive-regressive sequences within the Shublik Formation of which the upper four are present in the Phoenix #1 well (Fig. 3). While the T-R sequence scheme employed by Whidden et al. (2018) may provide some explanatory power in interpreting the depositional response to sea level changes, it minimizes the significance of erosional unconformities at identified sequence boundaries. Likewise, Blodgett and Bird (2002) in an abstract earlier also recognized four T-R cycles in the Phoenix well based on biostratigraphy and lithologic features.

In the Phoenix #1 core, and cores from nearby wells, the Shublik Formation is sharply, and potentially unconformably, overlain by the Sag River Sandstone, which is largely composed of quartz-rich and glauconitic medium to fine-grained sand with minor amounts of siltstone and mud shale. Here, as elsewhere in

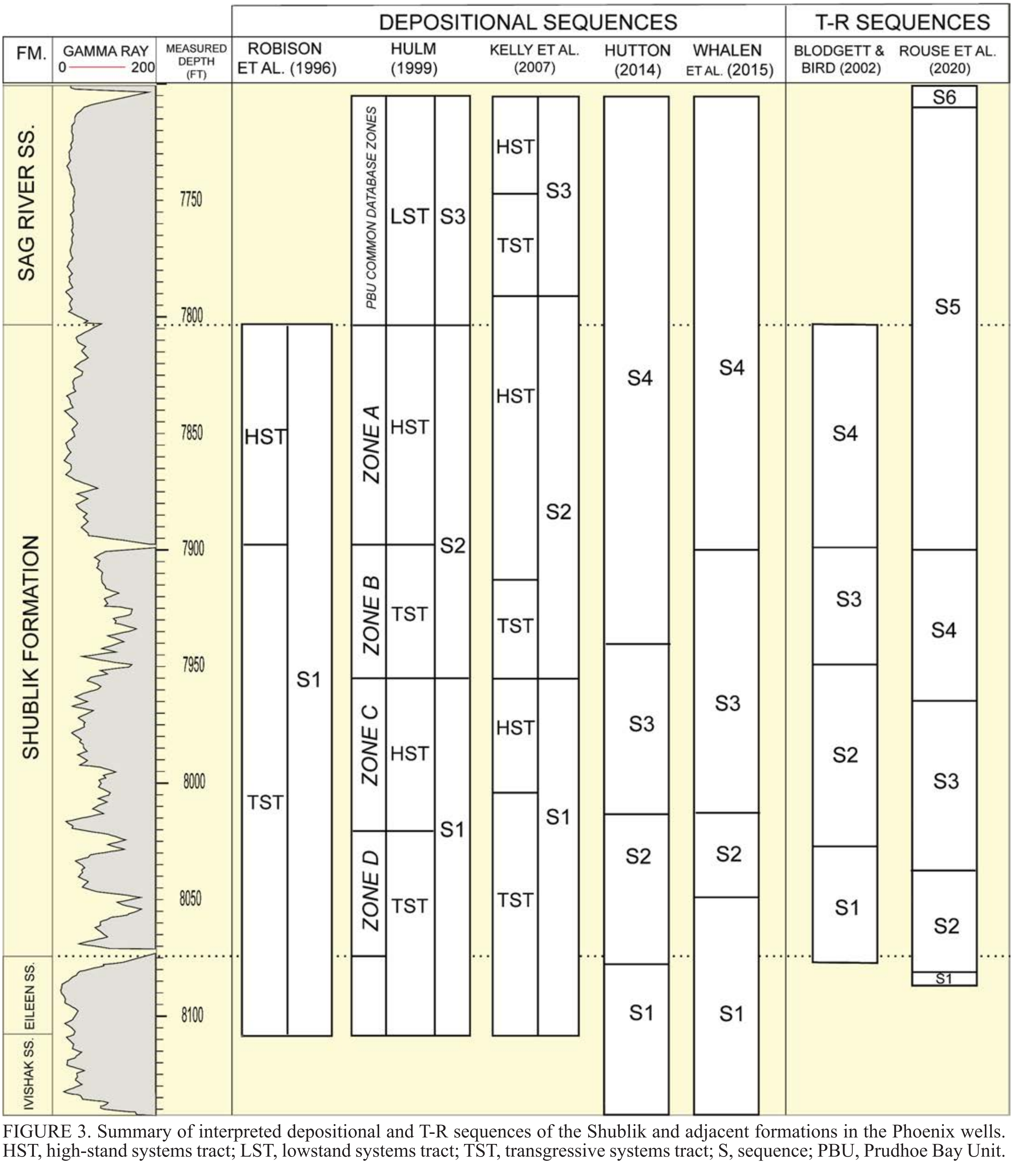

FIGURE 3. Summary of interpreted depositional and T-R sequences of the Shublik and adjacent formations in the Phoenix wells. HST, high-stand systems tract; LST, lowstand systems tract; TST, transgressive systems tract; S, sequence; PBU, Prudhoe Bay Unit.

the North Slope, the Sag River contains a distinctive molluscan fauna near its base and is often heavily bioturbated as we have observed in several localities. The Sag River Sandstone of the North Slope passes laterally eastward to similar quartz-rich bioturbated sandstone of the Karen Creek Formation.

The Triassic and Lower Jurassic strata of the North Slope pass laterally southwards and westwards into the Otuk Formation which is exposed in a zone extending from the central Brooks Range westwards to the Lisburne Peninsula, and recently (Blodgett, 2017) recognized it further to southwest on St. Lawrence Island in the northern Bering Sea (Fig. 2). The Otuk Formation is characterized by condensed, deep-water facies of organic-rich mudrocks and bedded chert and is rich in bivalves (e.g., *Daonella*, *Halobia*, and *Monotis*) and radiolarians (Mull et al., 1982; Blome et al., 1988).

BIOSTRATIGRAPHY

The primary basis for age determinations from the Phoenix # 1 core rest on species of the bivalve genera *Daonella*, *Halobia*, *Eomonotis* and *Monotis*. The Shublik and Sag River succession of the Phoenix #1 core contains eight halobiid and two monotid bivalve taxa from 50 unique depth levels and provides high-resolution age control of these units through the Middle-Upper Triassic (Fig. 4). Halobiid and monotid bivalves have widespread distributions and high species turnover rates, and their value as biostratigraphic indices has been discussed elsewhere (e.g., McRoberts, 2010). These fossils now provide a standard succession through which regional and global correlations of Triassic marine strata are possible (McRoberts, 2010). Their biostratigraphic utility is likely controlled, in part, by their unique paleoecology. Halobiid and monotid benthic paleocommunities are interpreted to have inhabited and dominated environments near a threshold oxygen minimum (dysoxic-anoxic) boundary which other shelly benthos found unsuitable (McRoberts, 2011). Population demographics inferred from shell accumulations together with functional morphologic analyses of shells and rare *in situ* occurrences strongly support a benthic habit for halobiid and monotid bivalves (Schatz, 2005; McRoberts, 2010, 2011).

The primary genus-group taxa used here are broadly construed (*sensu lato*) and include halobiid pteriid genera *Daonella*, *Halobia*, and the monotid pectinoid genera *Eomonotis* and *Monotis*. While a thorough assessment of individual species validity is beyond the scope of this paper due to relatively small sample sizes in our data set, an attempt has been made to include only species that have biochronologic value, are morphologically distinctive, are based on sufficient material, and are generally accepted by modern workers. Conventions of open nomenclature follow Bengston (1988) in which specific identifiers ‘cf.’ and ‘?’ for are provisional and uncertain species identifications respectively.

Given the absence of co-occurring ammonoid and conodont taxa from the Phoenix #1 core, age assignments resolved to the North American integrated ammonoid and conodont standard zones (e.g., Orchard and Tozer, 1997) rely on correlations with known ammonoid-bivalve faunal successions within other Shublik and Otuk localities within northern and offshore Alaska and elsewhere in the marine Triassic of the North American Cordillera. It should be noted however, that at the time of this writing only bases of the Ladinian and Carnian stages have been defined with a Global Boundary Stratotype Section and Point (GSSP) by the International Subcommission on Triassic Stratigraphy. Other stages of the Middle (base Anisian) and Upper Triassic (base Norian and base Rhaetian) have yet to be formally recognized. It should be further noted that two of these undefined boundaries, the base Norian and base Rhaetian, are relevant to the ages and timing of both biotic events and depositional sequences within northern Alaska.

The remaining parts of this section primarily focus on faunal equivalences and correlations of Phoenix #1 halobiid and monotid occurrences to occurrences known from other subsurface and outcrop localites of Triassic units across northern Alaska and especially within the NPRA and ANWR. Many of these bivalve successions have been reported on in Patton and Tailleur (1964); Silberling and Tozer (1968), Detterman et al. (1975), Mull et al. (1982), Blome et al. (1988), Dutro and Silberling (1988), Silberling et al. (1997), and Kelly et al. (2007) and also mentioned in unpublished industry reports and are further summarized in Whidden et al. (2018, table 1). Of particular importance is that in each of these studies, the halobiid and monotid occurrences occur in demonstrable succession and while some of the names used by the original authors have been modified herein, their co-occurrences and stratigraphic position provides valuable confirmation of the resilience of a standard bivalve biostratigraphic zonation. Most of the fossil collections described in these reports have been examined by two of us (CAM and RBB) and supplemented with additional collections made over the past 10 years (CAM, RBB, M. Whalen, and J. Dumoulin), from several key localities including Fire Creek and Kavik River (Fig. 1).

Although this report deals primarily with bivalve occurrences, there are additional mentions of biostratigraphically-important fossils from the Phoenix #1 and other correlative cores, that recovered Shublik macro and microfossils. Chief among these are ammonoids which are relatively rare in the Triassic rocks of northern Alaska. Dutro and Silberling (1988) reported ammonoids from the Drew Point #1 well, *Neohimavatites* cf. *N. canadensis* (McLearn) at depths of 2162.1—2165.0 m (7093.5—7103 ft.) indicating a late Middle Norian (*Mesohimavites columbianus* zone) age and *Ptychites* sp. indicative of a late Anisian–Ladinian age at 2299 m (7544 ft). At the Fire Creek section, Detterman et al. (1975, p. 16) note the occurrence of the ammonite *Leiophyllites*(?) suggesting a lower Anisian age for the part of the lower Siltstone Member of the Shublik Fm. From the Otuk Formation, ammonoids are also rare. At Monotis Creek, Patton and Tailleur (1964, p. 437) report the Anisian ammonoids *Proteusites*, *Leiophyllites*, and *Pseudaplococeras*. Also from the Otuk Fm., Bodnar (1984, p. 80, 81) reports the early Middle Triassic ammonoids *Amphipoanoceras* cf. *A. selwyni* (McLearn) and *Leiophyllites* sp. from the uppermost beds of the Shale Member from a locality on the Middle Fork of the Okpikruak River.

In addition, the Phoenix #1 core has yielded foraminifera which provide further data on (and in most cases confirmation of) biostratigraphic picks of the bivalves. These taxa and biostratigraphic picks from an unpublished report (see Hulm, 1999, Appendix 3) places the base of the Carnian at 2462.8 m (8080 ft), the base of the Norian at approximately 2429.3 m (7970 ft) with no data to reported from the Rhaetian. Given that the established ages and ranges of the foraminifers and radiolarians are rather broadly resolved is testament to the need for more detailed taxonomic study of these important groups. In correlative strata elsewhere, Tappan (1951) reported on moderately rare Carnian and Norian foraminifera from the Shublik Formation, both from the subsurface (especially the Simpson Test well #1) and several surface exposures. Although these foraminifera, primarily lageniidae, are unfortunately of little biostratigraphic value, they are noteworthy in being the first Triassic foraminifera discovered in the Western Hemisphere. Additional documentation of Shublik and/or Otuk foraminifera is provided in Bergquist (1960, 1966), Mickey et al. (2006), and Kelly (2004). Although ostracods of Ladinian through Norian are also common and relatively diverse in the Shublik Formation at the Fire Creek locality (Sohn, 1987), most species are, at least as presently known, endemic and provide little value in biostratigraphic correlation. Radiolarians are fairly common in the Triassic of but low diversity assemblages especially in

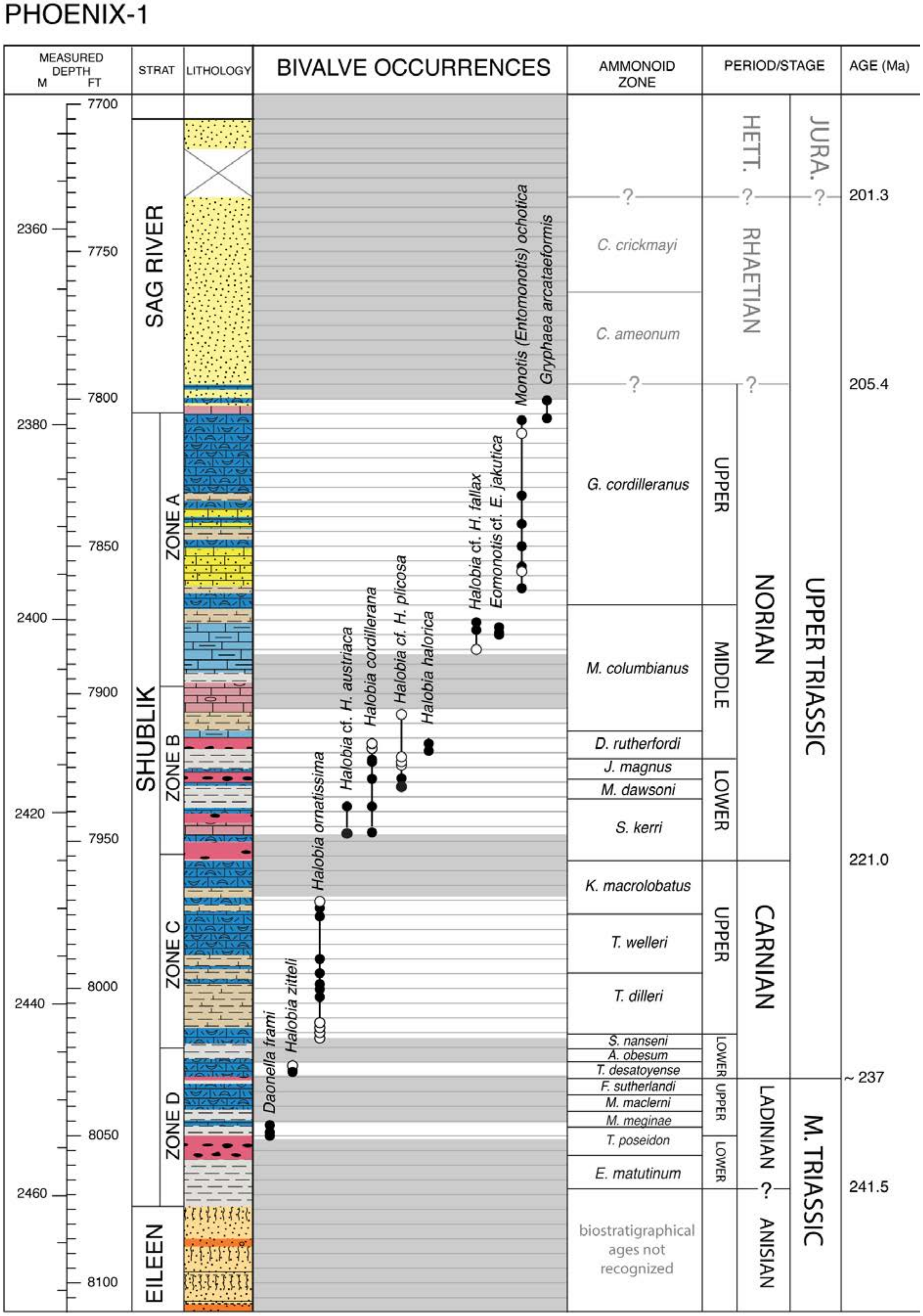

FIGURE 4. Occurrences and ranges of halobiid and monotid bivalves through the Phoenix #1 core. Solid circles are confident species identifications, open circles are questionable. Shaded regions represent strata between biostratigraphically recognized intervals. Lithology after Hulm (1999). Thicknesses of and boundaries between standard ammonoid zones (from Orchard and Tozer, 1997) are approximate and not all zones may be represented by strata. Numerical age estimates after Ogg (2012).

the Otuk Formation (Swain, 1981; Blome et al., 1988). Early and Middle Triassic conodonts, mostly species of *Neospathodus* and *Neogondolella* have also been recognized from the Shale and Chert members of the Otuk Formation at multiple localities (Mull et al., 1982; Bodnar, 1984).

Pre-Ladinian

The absence of macrofossils indicative of pre-Ladinian ages within the Phoenix #1 core may be due to unsuitable facies of the lowermost Shublik and underlying Eileen Formations. It is likely that the Eileen Formation represents strata of Olenekian age based on stratigraphic and fossil correlations with demonstrable Olenekian faunas from the Ivishak Formation to the east. Detterman et al. (1975, p. 43) reports the ammonoid *Euflemingites romunderi* (Tozer) from the both the Ledge Sandstone and overlying Fire Creek Siltstone Members of the Ivishak Formation at the Fire Creek locality and nearby outcrops which is likely Lower Olenekian (upper Smithian) in age. This *Euflemingites* occurs approximately 15 m below the aforementioned ammonite *Leiophyllites*(?) of likely lower Anisian age from the same locality (Detterman et al., 1975, p. 16). More recently, Hulm (1999) suggest that the upper Ivishak Formation (Fire Creek Siltstone Member) represents deeper-water facies and is largely age equivalent and correlative to the Eileen Sandstone in the North Slope. An additional correlative interval occurs in the Shale Member of the Otuk Formation which contains the Lower Olenekian (Smithian) pectinoid flat clam *Peribositra mimer* (e.g., Kelly et al., 2007) which is normally included within the Upper Ivishak Formation (e.g., Silberling and Patton, 1964; Detterman et al., 1975). It is probable that the lower part of Hulm's Shublik (Zone D) from the Phoenix #1 core represents strata of Anisian age strata at a depth between top Eileen Formation 2462.8 m (8080 ft) and the first Ladinian Daonellas identified at 2452.7 m (8047 ft) as discussed below. This is supported by correlating the late Anisian–Ladinian ammonoid *Ptychites* in the basal Shublik (Zone D) approximately 7 m above the top of the Eileen Sandstone in the Drew Point well (Hulm, 1999, pl. 5), some 130 km west of the Phoenix #1 well (Fig. 1).

Ladinian

The oldest recovered macrofossils from the Phoenix #1 core are Ladinian *Daonella frami* Kittl 1907 (Fig. 5 A–D). which occur at a depth interval of 2453.0—2053.6 m (8047.95—8049.7 ft). This species is distinctive among *Daonella* in that their shells are equant and rather large for the genus and their radial plicae are broader and typically fewer in number than in similar species. This occurrence of *D. frami* falls within Hulm's (1999) interpreted Shublik Zone D above the large phosphatic zone marking the transgressive phase of sequence 1. It is significant to point out that unspecified micropaleontological data reported in Hulm (1999) places the base of the Carnian stage at a depth of 2462 m (8080 ft), nearly 10 m below these demonstrably Ladinian macrofossils.

Daonella frami from the Phoenix #1 core can be correlated to several horizons elsewhere in the Shublik and Otuk formations of northern Alaska. Detterman et al. (1975) report *Daonella frami* together with several indeterminate limid and pectinoid bivalves and brachiopods from three stratigraphic levels near the top of the Siltstone Member and the lowermost part of the Limestone Member of the Shublik (Fig. 2) at the Fire Creek reference section (Fig. 1). The lowest of these occurrences is closely associated with the [likely] Ladinian ammonoid *Leiophyllites* sp.. Detterman et al. (1975) also reports scattered occurrences of *Daonella frami* from the Echooka River locality about 45 km west of the Kavik River locality and they are known (from unpublished collections of M.T. Whalen determined by CAM) at the Kavik River section (Fig. 1). Additionally, *Daonella frami* is well known from lower portions of the Chert Member of the Otuk Fm. at multiple localities in the central and western sectors of the Brooks Range. Here, *Daonella frami* has been reported from the Otuk Formation at both Monotis and Tiglukpuk Creeks (Fig. 1) (Mull et al., 1982; Kelly et al., 2007) and in these and other localities along the mountain front for at least 150 km Bodnar (1984, p. 108) describes a coquinoid *Daonella* biohorizon. Further west, *Daonella frami* is known from the Lisburne Peninsula (Fig. 1) and surrounding areas (Patton and Tailleur, 1964; Silberling report cited in Blome et al., 1988 and undescribed collections from Surprise Creek (Fig. 1) provided by Julie Dumoulin).

Daonella frami is a well-known species within boreal realm of the Middle Triassic and is largely restricted to an interval that begins in the upper Lower Ladinian *Tuchodiceras poseidon* ammonoid zone and extends into the Upper Ladinian *Maclernoceras maclerni* zone (McRoberts, 2010; Bakke, 2017). Earlier reports of this species were poorly constrained; it was often reported as Early Ladinain in northern Alaska (e.g., Silberling cited in Detterman et al., 1975) and in the Canadian Arctic (e.g., Tozer, 1961). This species has also been recorded with, and slightly above, beds containing *Daonella degeeri* from Svalbard (e.g., Korschinskaya, 1982; Bakke, 2017) and together with *D. subarctica* and *Narthorsites* ammonoids from Franz Joseph Land (Korschinskaya, 1985). It is interesting to note that *D. frami* provides a clear paleobiogeographic tie between Alaska, the Boreal regions of Arctic Canada and Spitsbergen suggesting, at least during the Middle Triassic, some oceanographic connection.

Lower Carnian

At a depth between 2446.8—2447.0 m (8027.6—8028.1 ft) are bivalves attributed either confidently or provisionally to *Halobia zitteli* Lindström, 1865 from the Lower Carnian (Fig. 5 E–G). These closely-spaced core samples of *H. zitteli* are situated within the transgressive system tract near the top of Shublik Zone D and immediately below the identified maximum flooding surface of Hulm (1999) and Kelly et al. (2007). *Halobia zitteli* is distinct from other Carnian halobiid species in its large size, obliquely ovate shape and radial ornamentation which possesses an angular deflection (so-called growth stop) somewhat later in ontogeny and exhibits a deepening of interplicae furrows on the anterior side of shells. Although *Halobia zitteli* (or *Halobia zitteli* group) has been reported from multiple Shublik and Otuk localities (e.g., Detterman et al., 1975; Dutro and Silberling, 1988), this species is often confused with similar species (e.g., *Halobia superba* Mojsisovics, 1874 and *H. ornatissima* Smith, 1927) which are of a younger, Upper Carnian, age. For example, at Echooka River (USGS loc. M6073), Detterman et al. (1975) list *Halobia zitteli* co-occurring with *H. ornatissima* and *Posidonia* approximately 3 m above a level with *Arctosirenites* cf. *A. canadensis*, *Juvavites* sp. and *Arcestes* sp. of likely Upper Carnian (*Tropites welleri* ammonoid Zone) age. The occurrence of *H. zitteli* from the Phoenix #1 core represents the first such confirmed occurrence of this age-diagnostic species from the Shublik Formation that we are aware of.

Elsewhere, *Halobia zitteli* is well known and temporally constrained in the Boreal regions of Canada, Svalbard, and Russia (e.g., Tozer 1961; Polubotko 1980, 1984; Campbell 1994; Bakke, 2017). In Svalbard, *H. zitteli* co-occurs with the ammonoid *Nathorsitites tenuis* which indicates of the Lower Carnian *Trachyceras desatoyense* ammonoid zone (Korschinskaya, 1982; Campbell, 1994). In northeast Siberia, *H. zitteli* is restricted to the lowermost Carnian (*Trachyceras desatoyense* Zone) as reported by Polubotko (1980, 1984).

Upper Carnian

Beginning at a depth of 2443.3 m (8016 ft) and continuing

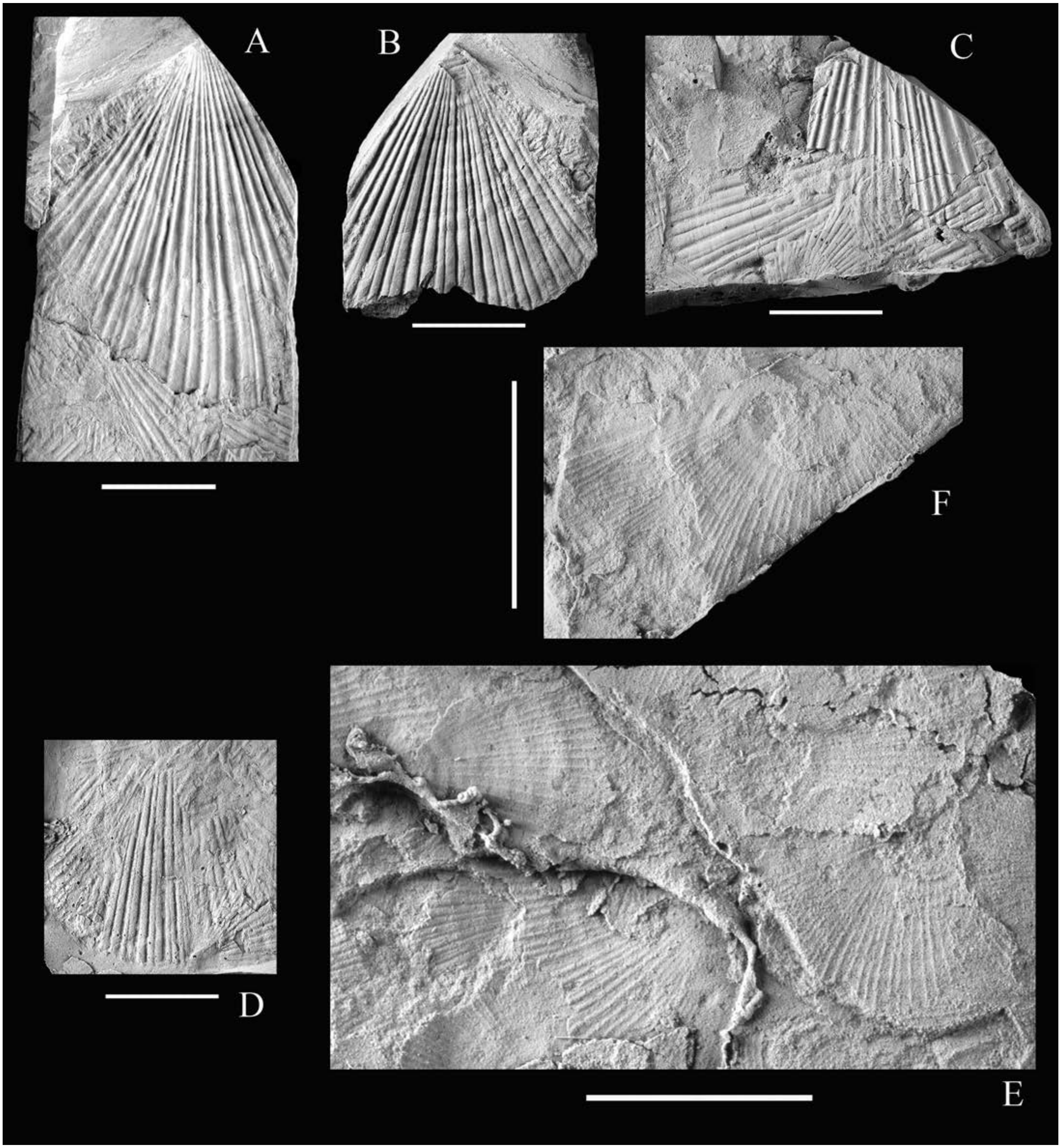

FIGURE 5. Ladinian and Lower Carnian *Daonella* and *Halobia*. **A**–**D**, *Daonella frami* Kittl, 1907, Ladinian *Meginoceras meginae-Progonceratites poseidon* Zones; **E**–**G**, *Halobia zitteli* Lindstöm 1863, Lower Carnian *Trachyceras desatoyense* Zone. **A**, AKGMC-12, left(?) valve, depth 2453.0 m (8048.0 ft). **B**, AKGMC-13, left(?) valve, depth 2453.0 m (8048.0 ft). **C**, AKGMC-14, fragments of valve interiors and exteriors, depth 2453.2 m (8048.55 ft). **D**, AKGMC-15, fragments of valve exteriors, depth 2453.5 m (8049.7 ft). **E**, AKGMC-16, latex mold of fragments of valve interiors, depth 2446.96 (8028.1 ft). **F**, AKGMC-17, latex mold left valve, depth 2446.96 (8028.1 ft). Scale bars are 1 cm.

through 2429.6 m (7971 ft) is a long succession of multiple horizons containing *Halobia ornatissima* Smith, 1927 of Upper Carnian age (Fig. 6). The lower occurrences remain somewhat questionable given that the specimens are of insufficient size to adequately determine the adult growth stages necessary for confident identification of the species. As discussed above, within Arctic Alaska it is likely that forms here attributed to *H. ornatissima* have been given a variety of other names (e.g., *H. zitteli*, *H. superba*, and even *H. cordillerana*) by previous workers. At the Fire Creek reference section, Detterman et al. (1975) reports *H. ornatissima* from multiple horizons co-occurring with the ammonoids *Arctosirenites* cf. *A. canadensis*, *Juvavites* sp. and *Arcestes* of likely Upper Carnian age. Unpublished collections at Kavik River section provided by M.T. Whalen examined by CAM document multiple horizons of *H. ornatissima* in approximately 10 m of strata below lowermost Norian *Halobia* species. Within the craton-bound mid latitudes of British Columbia, *Halobia ornatissima* is very abundant spanning a broad temporal range of the *T. welleri* through *K. macrolobatus* Zones with a few questionable occurrences within the Lower Norian *S. kerri* zone (McRoberts, 2010, 2011). In northeastern Russia, *Halobia ornatissima* is also largely Upper Carnian in age but may occur at slightly older levels into the uppermost Lower Carnian (Polubotko, 2005).

Lower and lower Middle Norian

The Lower to lower part of the Middle Norian is represented by four halobiid species: *Halobia* cf. *H. austriaca* Mojsisovics 1874, *Halobia* cf. *H. plicosa* Mojsisovics 1874, *H. cordillerana* Smith, 1927, and *H. halorica* Mojsisovics 1874 (Figs. 6, 7). The first occurrence of *H.* cf. *H. austriaca* at 2421.7 m (7945.2 ft) depth demonstrates the uppermost limit of a potential Carnian-Norian boundary which likely resides in the interval above the highest identified occurrence of *Halobia ornatissima* at 2421.7 m (7971.8 ft) depth. Hulm (1999) reported a micropaleontologically-identified base Norian at close to the 2429.3 m (7970 ft) depth which agrees with the macrofossil data reported herein and would be situated within the stratigraphic interval containing the sequence boundary between zones C and B of Kelly et al. (2007). It is worth noting that the Carnian-Norian boundary interval from the Phoenix #1 core is likely correlative to a 1 m-thick interval between the highest occurrence of *Halobia ornatissima*-group fossils and the lowest *H.* cf. *H. cordillerana* A correlative interval occurs in the Walakpa #1 well core between 1038 m (3404.3 ft) and 1039 m (3408 ft) approximately 170 km to the west (Fig. 1; Dutro and Silberling, 1988).

The Lower Norian of the Phoenix #1 core is represented by forms attributed to *Halobia* cf. *H. austriaca* (Fig. 7 A–C). *Halobia* cf. *H. austriaca* was identified from two depth levels, 2419.5 and 2421.7 m (7938.0 and 7945.2 ft), and represents the oldest Norian halobiids in the Phoenix #1 core above a presumed Carnian-Norian boundary interval. Like other halobiids, the sample size and condition of the Phoenix #1 specimens dictate only provisional assignment to *H austriaca*. Although *Halobia austriaca* has not been previously reported from Arctic Alaska, a lower Norian (*Stikinoceras kerri* ammonoid zone) age for these sampled horizons is suggested based on correlations to well sequenced localities in Cordilleran terranes of Southern Alaska, British Columbia, California and Oregon (e.g., Smith, 1927) and also in the craton-bound strata of northeastern British Columbia, Canada (McRoberts, 2011). It should be pointed out that in at least one locality (Huxley Island, Haida Gwaii, British Columbia, see Tozer, 1994; Orchard, 2014), a possible *Halobia austriaca* co-occurs with the ammonoid *Anatropites*, suggesting the possibility of a latest Carnian age for this halobiid across some of its broad geographic range.

Other Lower and lower Middle Norian halobiid occurrences in the core include specimens attributed to *H. cordillerana* (Fig. 7 D–G) and *Halobia* cf. *H. plicosa* (Fig. 8 A–E). Specimens attributed to *Halobia* cf. *H. plicosa* are identified from up to six levels beginning at 2414.9 m (7922.9 ft) through 2417.9 m (7932.7 ft) to as high as perhaps 2410.1 m (7907.2 feet). Even the best specimens (e.g., Fig. 8 C, E). at 2414.9 and 2416.7 m (7922.9 and 7928.8 ft) cannot be determined with confidence to the nominal species given the small sample size and fragmentary nature of the specimens at hand, yet they appear to exhibit the straight plication and nearly equant valve outlines seen in the Alpine European species *Halobia plicosa*. Forms similar to this have been reported from the Otuk Formation at Otuk Creek (Silberling report cited in Mull et al., 1982) situated between *Halobia halorica* and *Halobia* cf. *H. fallax* which would represent a potential correlation datum to the highest occurrence from the Phoenix #1 core at 7907.2 feet. Similar forms are known from around the Lower and Middle Norian boundary from multiple localities in northeastern and Arctic Russia (e.g., Bychkov et al., 1976).

Halobia cordillerana (Fig.7 D–G). is a rather long-ranging species within the Phoenix #1 core and likely spans a considerable amount of time from the early through middle Norian with lowest and highest occurrences at 2421.7 m (7945.2 ft) and 2413.4 m (7917.95 ft) respectively. *Halobia cordillerana* is one of the more common halobiids in Northern Alaska and has been reported from several Shublik test wells including the Ikpikpuk No. 1, Walakpa No 1, and Lisburne No. 1 wells (Dutro and Silberling, 1988, pl. 30.1, fig. 8). It also has been reported from several Otuk Formation (middle Chert member) localities in the Brooks Range including Otuk and Tiglukpuk Creeks (e.g., Silberling as cited in Mull et al., 1982, Kelly et al., 2007). A Lower through Middle Norian (*Stikineoceras kerri*–*Mesohimavitites columbianus* zone) range of this species has been discussed elsewhere (McRoberts, 2011).

Halobia halorica (Fig. 8 F–I), found at two closely-spaced intervals, 2413.4 m (7917.9 ft) and 2413.9 m (7919.5 ft), is assigned with high confidence to the Middle Norian *Deprenites rutherfordi* ammonoid Zone and provides one of the most robust age assignments in our study. This species is not well known in northern Alaska apart from a few named occurrences from the South Meade No. 1 well (Dutro and Silberling, 1988). Within the Otuk Formation outcrop belt, *Halobia halorica* is known from the Chert Member at Otuk Creek where it occurs above *H.* cf. *cordillerana* and below beds with *Halobia* cf. *H. fallax* and *Eomonotis* (Silberling cited in Mull et al., 1982; Blome et al., 1988; undescribed U.S. Geological Survey collections examined by CAM) consistent with a mid Norian age. Outside of the Arctic, this species is known from numerous occurrences in craton-bound strata in northeastern British Columbia and in several of the western Cordilleran terranes (e.g., Wrangell and Alexander terranes) and Nevada (Smith, 1927, Muffler, 1967; McRoberts, 2011).

Upper Middle Norian

Faunas of upper Middle Norian are well represented in the Phoenix #1 core with *Eomonotis* cf. *E. jakutica* (Fig. 9 D–F) and *Halobia* cf. *H. fallax* (Fig. 9 A–C) at depths between 2400.7 and 2401.5 m (7876.2 and 7878.8 ft). These samples are assigned with confidence to the *Mesohimavitites columbianus* ammonoid zone. This level is easily correlated with an equivalent level from the Drew Point #1 well in which Dutro and Silberling (1988) report *Halobia* cf. *H. fallax* Mojsisovics, and *Eomonotis* cf. *E. obtusicostata* (Westermann) and the ammonoid *Neohimavatites* cf. *N. canadensis* (McLearn) confirming an uppermost Middle Norian age (*Mesohimavitites columbianus* ammonoid zone). Additionally, within the Shublik Formation at Fire Creek, Silberling et al. (1997) illustrated specimens they attribute to *Eomonotis obtusicostata* Westermann and *Eomonotis* ?*jakutica*

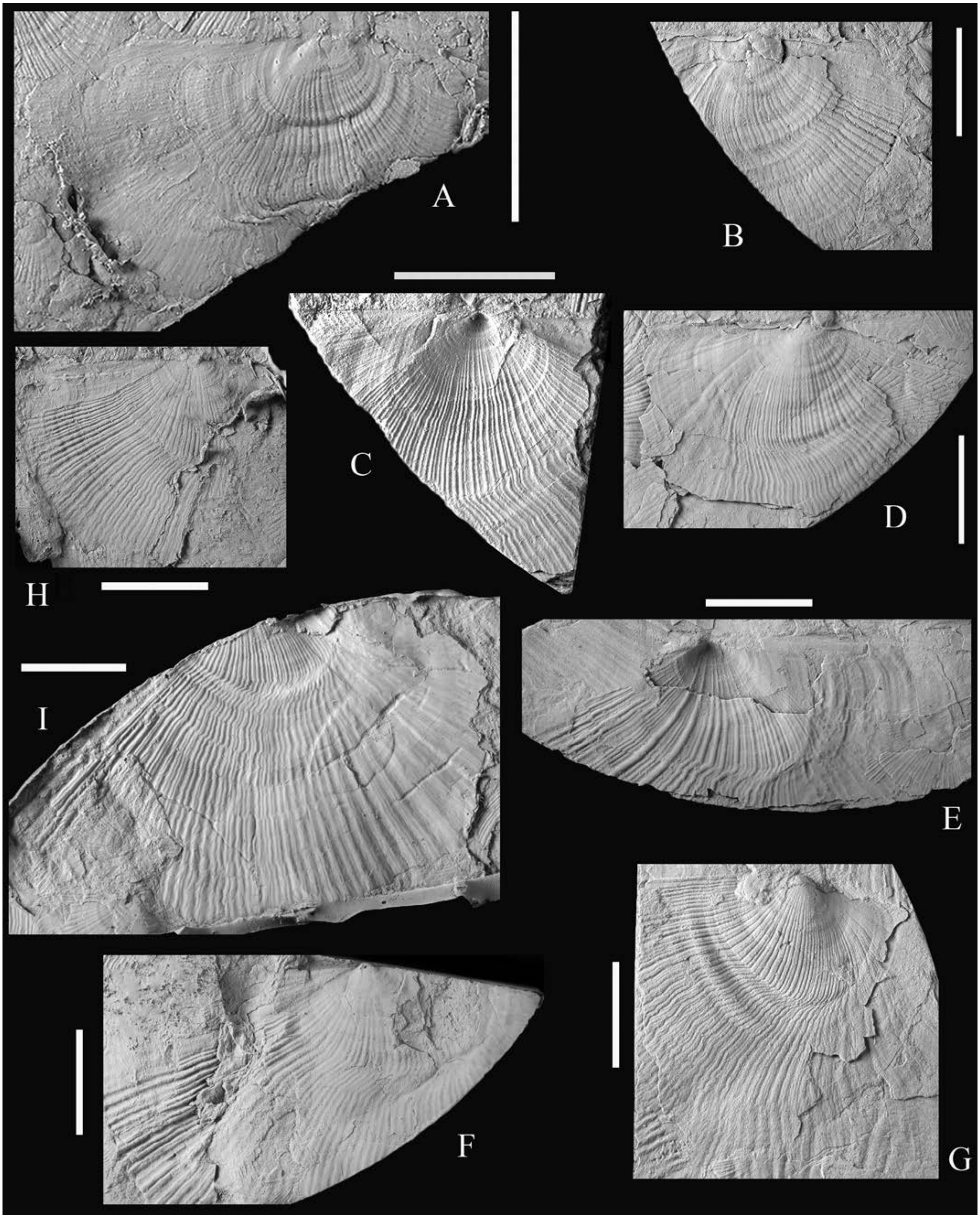

FIGURE 6. Upper Carnian *Halobia ornatissima* Smith, 1927. **A**, AKGMC-18, latex mold of right valve, depth 2443.1 m (8015.5 ft). **B**, AKGMC-19, right valve, depth 2442.1 m (8012.1ft). **C**, AKGMC-20 right valve, depth 2442.1 m (8012.1ft). **D**, AKGMC-21, right valve, depth 2439.6 m (8004.1 ft). **E**, AKGMC-22, latex mold of right valve, depth 2438.7 m (8000.9 ft). **F**, AKGMC-23, left valve, depth 2438.8 m (8001.3 ft). **G**, AKGMC-24, left valve, depth 2438.8 m (8001.3 ft). **H**, AKGMC-25, left valve, depth 2437.06 m (7995.6 ft). **I**, AKGMC-26, left valve, depth 2438.2 m (7999.6 ft). Scale bars are 1 cm.

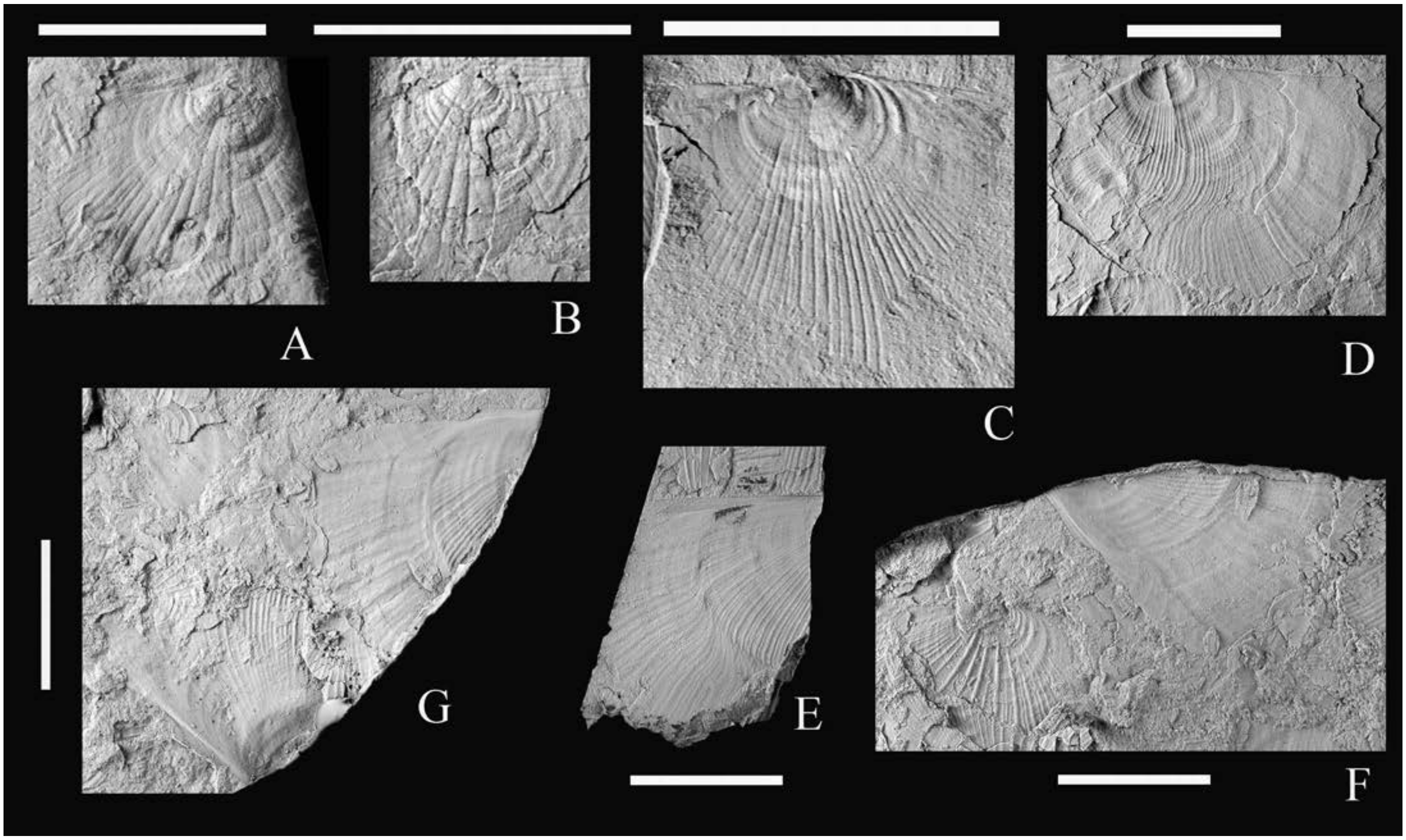

FIGURE 7. Lower and Middle Norian *Halobia*. **A**–**C**, *Halobia* cf. *H. austriaca* Mojsisovics, 1874, Lower Norian *Stikinoceras kerri* Zone; **D**-**G**. *Halobia cordillerana* Smith, 1927, Lower-Middle Norian. **A**, AKGMC-27, latex mold of right(?) valve, depth 2419.5 m (7938.0 ft). **B**, AKGMC-28, left valve, depth 2421.7 m (7945.2 ft). **C**, AKGMC-29, left valve, depth 2421.7 m (7945.2 ft). **D**, AKGMC-30, left valve, depth 2421.7 m (7945.2 ft). **E**, AKGMC-31, right valve, depth 2413.4 m (7917.95 ft). **F**, AKGMC-32, fragments of valve interiors, depth 2414.9 m (7922.9 ft). **G**, AKGMC-33, right valve, depth 2414.9 m (7922.9 ft). Scale bars are 1 cm.

and assign an Upper Norian (*Gnomohalorites cordilleranus* ammonoid Zone) age at approximately 6 m below the Shublik-Karen Creek contact. Within the Otuk Formation Mull et al. (1982) report both *Eomonotis* and *H*. cf. *H. fallax* near the transition between the Chert and overlying Limestone Members stratigraphically between Upper Norian *M. subcircularis* and above Middle Norian *Halobia halorica.* Outside of Alaska*,* species of *Eomonotis* are particularly common throughout the upper Middle Norian at numerous localities in the North American Cordillera (e.g., Westermann, 1962; McRoberts, 2011), and also throughout the boreal regions of Asia and the western Pacific especially northeastern Russia, Japan, and New Zealand (e.g., Kiparisova et al., 1966; Ando, 1987; Grant-Mackie, 1980).

Upper Norian

The upper Norian is well represented in the Phoenix #1 core with occurrences of *Monotis (Entomonotis) ochotica* (Keyserling, 1848) spanning approximately 17.5 m of core at depths ranging from 2396.9 m (7864 ft) through 2379.3 m (7806.0 ft) to the top of Shublik Zone A to just below the contact with the overlying Sag River Sandstone whose basal contact has been picked at 2378 m (7803 ft) depth (Hulm, 1999). The uppermost Shublik and lowermost Sag River Sandstone also contains several well-preserved specimens of *Gryphaea arcutaeformis* Kiparisova 1936. In the Phoenix #1 core, *M. (En.) ochotica* (Fig. 9 G–J) is not known from the lower Sag River Sandstone, yet, as discussed below, this is likely due to lack of sampling rather than a position above the last appearance datum of the species.

Monotis (Entomonotis) ochotica is known from several Upper Norian localities in Northern Alaska, mostly within the Sag River and Karen Creek sandstones. From the North Slope West Dease #1 Test well, Dutro and Silberling (1988, pl. 30.1, figs. 1–3) and Silberling et al. (1997, pl. 11, figs. 14–15) illustrated several *M. (En.) ochotica* from a depth of 1195 m (3919.1 ft) which is either in the uppermost Shubik Fm. (Haywood and Brockway, 1982) or lowermost Sag River Sandstone (as interpreted here based on lithology). This species has also been identified in core samples by one of us (RBB) from the basal Sag River Sandstone from approximately 100 ft above the base of East Simpson Test Well #1 and also from the South Barrow Test Well #3. *Monotis (En.) ochotica* is a common species from the Fire Creek locality where it occurs in the basal portions of the Karen Creek Sandstone (Silberling et al., 1997, pl. 11, figs. 1–12). Most authorities correlate the Sag River Sandstone to the Karen Creek Sandstone at surface outcrops such as at Fire Creek. This correlation was discussed by Detterman et al. (1975, p. 17) who suggested the contact between the Shublik Fm. and overlying Karen Creek Sandstone is conformable based primarily on its contained fauna of the two units. The lowermost part of the Karen Creek at the Fire Creek section is known to contain *Monotis ochotica* and *Gryphaea* (Silberling cited in Detterman et al., 1975, p. 17; Michael Whalen, personal communication) which agrees well with the base of the Sag River in the Phoenix #1 well contains *Gryphaea arcutaeformis*.

Within the central and western sectors of the Brooks Range front, *Monotis (En.) ochotica* can be found in a few localities, often associated with *Monotis (Pacimonotis) subcircularis*,

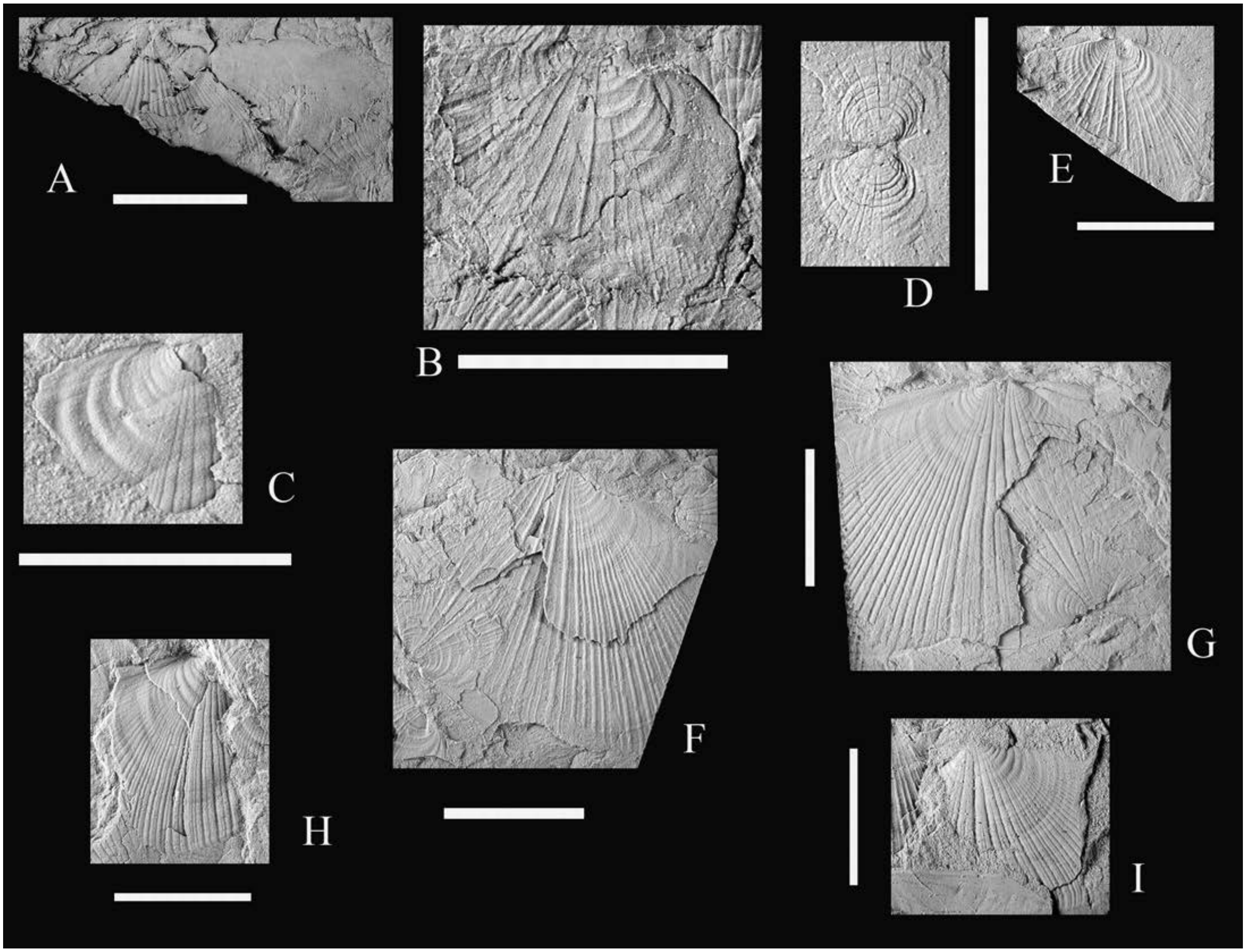

FIGURE 8. Early-Middle Norian *Halobia*. **A**–**E**, *Halobia* cf. *H. plicosa* Mojsisovics 1874, Lower Norian, **F**–**I**, *Halobia halorica* Mojsisovics 1874, Middle Norian (*Drepanites rutherfordi* Zone). **A**, AKGMC-34, left valve, depth 2415.1 m (7923.7 ft). **B**, AKGMC-35, right(?) valve, depth 2416.7 m (7928.8 ft). **C**, AKGMC-36 left(?) valve, depth 2417.9 m (7932.7 ft.). **D**, AKGMC-37, conjoined valves, depth 2410.1 m (7907.2 ft). **E**, AKGMC-38, left valve, depth 2410.1 m (7907.2 ft). **F**, AKGMC-39, right(?) valve, depth 2413.4 m (7917.95 ft). **G**, AKGMC-40, right valve, depth 2413.4 m (7917.95 ft). **H**, AKGMC-41, right valve, depth 2413.4 m (7917.95 ft). **I**, AKGMC-42, left valve, depth 2413.9 m (7919.75 ft).

within the upper Limestone Member of the Otuk Formation. One or both of these *Monotis* species are known from Tiglukpuk Creek and Otuk Creek (Silberling cited in Mull et al., 1982; Silberling et al., 1997, pl. 9, fig. 8; Kelly et al., 2007). Previous authors have differentiated the uppermost Norian into two monotid zones in certain mid to high-latitude settings; a lower zone consisting of *M. subcircularis* and an upper zone of *M. ochotica* and *M. alaskana* (e.g., Grant-Mackie & Silberling, 1990; Silberling et al., 1997). However, several more recent studies show that there appears to be significant, if not total, overlap in ranges of these species where they are known to co-occur from single horizons (McRoberts, 2010, 2011). Blodgett et al. (2014) noted the abundance of these two species, *M. (En.) ochotica* and *M. subcircularis* in early late Norian age strata of the Arctic Alaska and the British and Barn Mountains in northern Yukon Territory.

This Upper Norian interval in the Phoenix #1 core also contains several well-preserved specimens of *Gryphaea arcutaeformis* Kiparisova 1936 (Fig. 10). This species is likely the same as those reported by Silberling (in Detterman et al., 1975) from the Karen Creek Formation at Fire Creek under the name *Gryphaea keilhaui* Böhm, 1903. The Phoenix #1 *Gryphaea* from the uppermost Shublik and lowermost Sag River show a significantly narrower left valve breadth and less pronounced posterior flange than true *Gryphaea keilhaui.* Also from Fire Creek, Silberling (in Detterman et al., 1975) reported Carnian and Middle Norian examples of *Gryphaea* sp. from the limestone and dolomite member of the Shubik Formation which may belong to *G. keilhaui* (McRoberts, 1992). *Gryphaea arcutaeformis* is a rather long-ranging species well known from numerous Carnian–Norian localities in northeastern Russia, Arctic Canada, and throughout the North American Cordillera (Kiparisova et al., 1966; McRoberts, 1992).

IMPLICATIONS

A refined age control of the Shublik and Sag River units from the Phoenix # 1 core provides a test for sequence stratigraphic and depositional models. A preliminary assessment of this framework was conducted by Blodget and Bird (2002), who noted that each of their four recognized transgressive-regressive cycles was characterized by a distinctive suite of flat clams and also that sequence boundaries were marked by significant

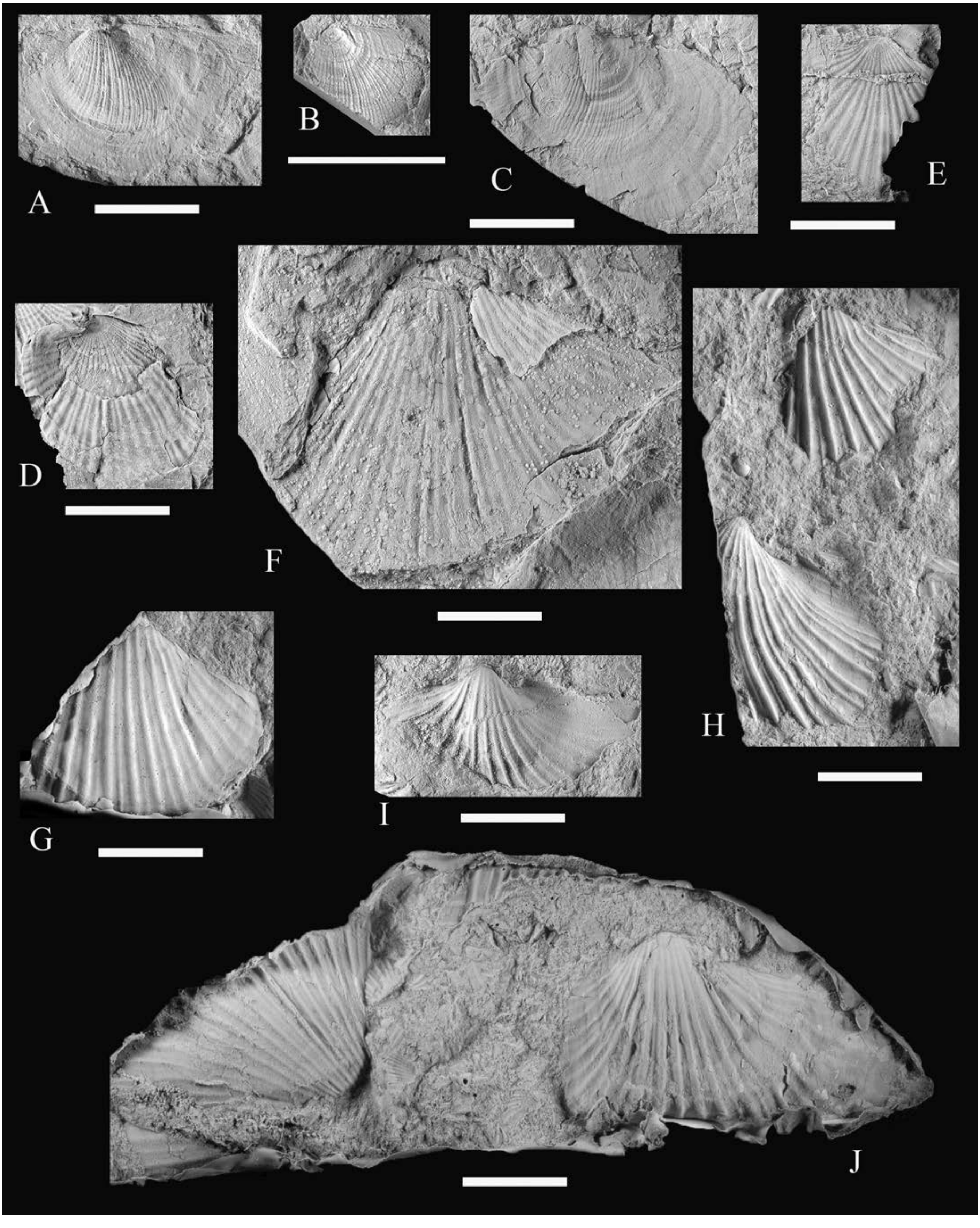
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FIGURE 9 (facing page). Middle and Upper Norian *Halobia*, *Eomonotis* and *Monotis*. **A**–**C**, *Halobia* cf. *H. fallax* Mojsisovics, 1874; **D**–**F**, *Eomonotis* cf. *E. jakutica* (Teller, 1896), Middle Norian *Mesohimavitites columbianus* Zone; **G**–**J**, *Monotis* (*Entomonotis*) *ochotica* (Keyserling, 1848), Upper Norian *Gnomohalorites cordilleranus* Zone. **A**, AKGMC-43, left valve, depth 2400.7 m (7876.3 ft). **B**, AKGMC-44, left valve, depth 2401.2 m (7878.0 ft). **C**, AKGMC-45, left valve, depth 2403.4 m (7885.2 ft). **D**, AKGMC-46, right valve, depth 2401.2 m (7878.0 ft). **E**, AKGMC-47, right valve, depth 2401.5 m (7878.8 ft). **F**, AKGMC-48, left valve, depth 2400.7 m (7876.3 ft). **G**, AKGMC-49, latex cast of left valve mold, depth 2394.6 m (7856.2 ft). **H**, AKGMC-50, left valve (lower) and right valve (upper). depth 2393.0 m (7850.9 ft). **I**, AKGMC-51, left valve, depth 2387.2 m (7831.9 ft). **J**, AKGMC-52, left valves, depth 2397.1 m (7864.6 ft). Scale bars are 1 cm.

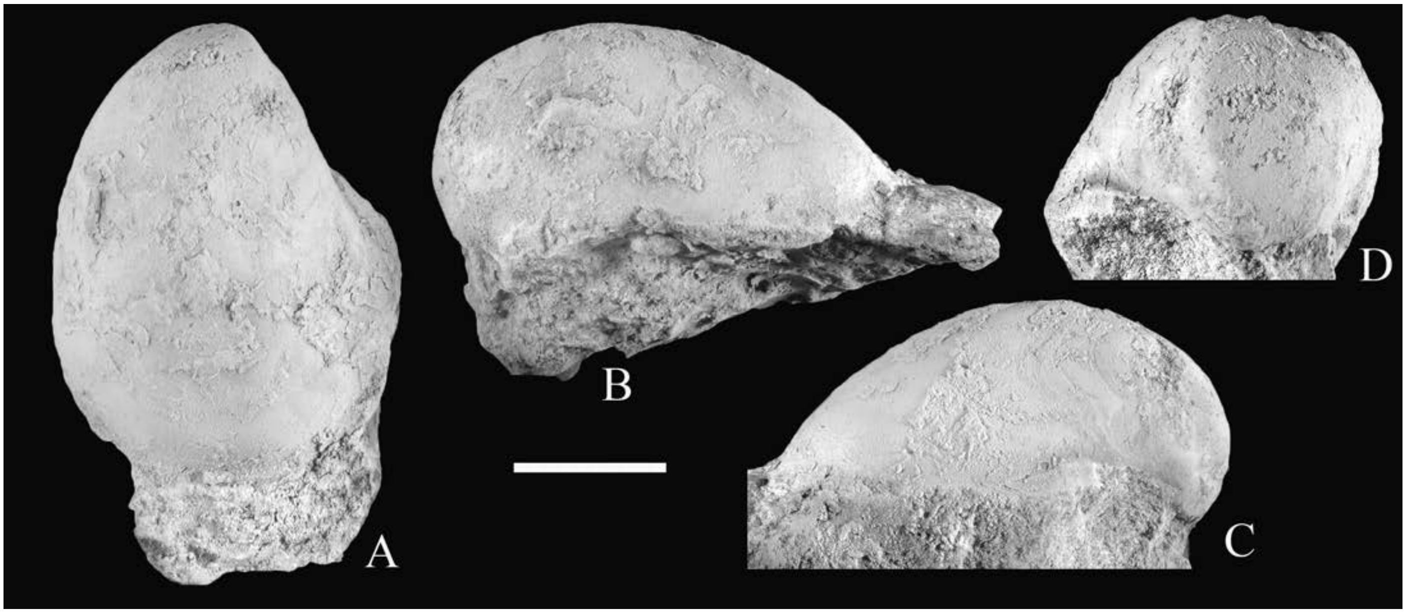

FIGURE 10. *Gyphaea arcutaeformis* Kiparisova, 1938, AKGMC-53, internal mold of left valve, depth 2379.3–2379.5 m (7806.0–7806.5 ft), Upper Norian *Gnomohalorites cordilleranus* Zone. **A**, left-lateral view, **B**, anterior view, **C**, posterior view, **D**, dorsal view. Scale bar = 1 cm.

biostratigraphic gaps and often characterized by superjacent oyster banks and phosphatic nodules. It should be noted that processes and drivers of faunal turnover of halobiid and monotid species is intrinsically evolutionary and, given the cosmopolitan distributions of most species, unrelated to regional influences on depositional systems and environments of north Alaska.

Our data show that the lower part of the Shublik in the Phoenix #1 core requires a reassessment of the hypothesized completeness of the formation within the core and inferred depositional environments recognized by previous workers (e.g., Whidden et al., 2018; Hulm, 1999). The marine claystone and phosphatic facies of the lower 15 m of the Shublik in the Phoenix #1 core were attributed by Hulm (1999) as representing Zone D. This was questioned by Whidden et al. (2018) who suggested that Zone D was not present in the Phoenix #1 core and was, given the proximal location of the well, likely removed by erosion. Whidden et al. (2018) drew comparisons between this part of the Phoenix #1 core and the Prudhoe Bay area where Kupecz (1995) recognized Zone D of the basal Shublik as missing from most of the well cores (only present in one well out of 11), and, when present, was mostly non-fossiliferous and non-calcareous phosphatic sandstone. More recently, Rouse et al. (2020) updated the correlations as presented in Whidden et al. (2018) and recognized a Zone D equivalent as being present in the lower Shublik in the Phoenix #1 core based on lithologic correlations. The lower, but not lowest, part of the Shublik in the Phoenix core contains *Daonella frami* and *Halobia zitteli* in organic rich dark grey mudstones closely associated with phosphorite, suggesting a more fully marine setting than the marginal marine environments suggested by Hulm (1999). As reported herein, this interval contains two biostratigraphic data points (Ladinian *Daonella frami* and Early Carnian *Halobia zitteli*) and can be directly correlated biostratigraphically to several outcrops (e.g., Fire Creek and Kavik River) and indirectly correlated (based on on gamma-ray log response and lithofacies) to several wells (e.g., East Simpson-1 and Drew Point-1) where Zone D is recognized by Hulm (1999, plates 1, 5, and 6) as comprising the lowest 8 m and 12 m, respectively, of the Shublik. We further suggest the possibility that the basal 7 m of Shublik Zone D below *Daonella* of the Phoenix #1 well may be Anisian in age if our inferred correlation to the *Ptychites* horizon in Drew Point well (Hulm, 1999) is correct. It is important to note that Rouse et al. (2020) also interpreted the basal Shublik in the Phoenix core as being mostly Anisian in age.

The sequence boundary interval delimiting Zones C and B (e.g., Hulm, 1999) cannot be fully assessed via biostratigraphic means. This identified sequence boundary lies within the 8.1 m thick interval (between 2421.7 m and 2429.8 m) that is devoid of identifiable macrofossils, but is positioned at the lithologic transition between bioclastic wackestones and packstones below and nodular/pebbly phosphorites above the inferred erosional surface and unconformity. Within the core, the unconformity itself may include the Carnian/Norian boundary, although it is unclear how much strata may actually missing; the established ranges of *Halobia ornatissima* and *Halobia* cf. *H. austriaca* are known from conformable successions elsewhere to occur within less than 1 m of succession and perhaps even overlap.

Of particular importance is the confirmation of the condensed interval in the transgressive phase through maximum flooding surface of Sequence 2 recognized in the top of Zone B by various authors (e.g., Robison et al., 1996; Hulm, 1999; Parrish et al., 2001b). This interval is well constrained within the lower *M. columbianus* ammonoid zone and is overlain by a relatively thick faunal succession of *Eomonotis* passing into *Monotis* in the highstand systems track of Hulm (1999). As discussed below, the upper part of Zone A, beginning at or slightly below the lowest occurrence of *Monotis (En.) ochotica* at 2397.1 m (7864.6 ft.) is quite expanded and relegated to a single ammonoid zone.

Several authors have postulated a significant sequence boundary at the transition between the top of zone A of the Shublik and the base of the Sag River Sandstone (e.g., Kupecz, 1995; Robison et al., 1996; Hulm, 1999). This sequence boundary has been interpreted as a correlative conformity (hard ground surface and depositional hiatus) or, in the more proximal position (e.g., Prudhoe Bay) as an erosional surface (Hulm, 1999). Other authors have suggested the contact to be conformable (e.g., Bird, 1985; Whidden et al., 2018). Kelly et al. (2007) places a sequence boundary approximately 2 m above the lithostratigraphic contact, approximately 2 m into the Sag River. While a postulated sequence boundary is demarked by a sharp lithologic change, fossil evidence suggests that the depositional contact between the Shublik and overlying Sag River does not likely represent a significant hiatus. In the Phoenix #1 core, *Monotis (En.) ochotica* has thus far only been found in the upper Shublik; whereas, as noted above, in other well cores and outcrops, this species is known only from the basal Sag River or Karen Creek Sandstones. We are confident in our identification of *M. (En.) ochotica* from the Shublik in the Phoenix #1 core which is consistent with stratigraphic occurrences above an upper Middle Norian fauna containing *Eomonotis* and *Halobia*. Reworking and re-deposition of *M. (En.) ochotica* in the basal Sag River and Karen Creek Sandstones is unlikely given the relatively completeness of the thin-shelled bivalves. Thus, we interpret the *Monotis (En.) ochotica* is exclusively relegated to the *G. cordilleranus* ammonoid zone (e.g., McRoberts, 2010, 2011) and numerical estimates of the duration of the upper Norian zone (taken from Ogg, 2012) range from 3 to 4.5 Ma.

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