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REVIEW OF THE DINOSAUR RECORD OF ALASKA WITH COMMENTS REGARDING KOREAN DINOSAURS AS COMPARABLE HIGH-LATITUDE FOSSIL FAUNAS

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Abstract: The record of dinosaurs from Alaska extends from the Late Jurassic through the Cretaceous. The record for the Late Jurassic is based on two photographed occurrences of dinosaurs, one a series of theropod tracks and the other a dinosaurian bone fragment. Both records occur in the southwestern part of the state. Similarly dinosaur records for the Early Cretaceous are represented but in very sparse numbers, consisting of a few footprint localities and a dinosaur skin impression locality that is also likely from this interval in time. Younger records of dinosaurs for Alaska also occur in the early Late Cretaceous (Cenomanian and Turonian). Such localities are growing in number and most are footprint localities. Generally these localities are confined to the northern part of the state. One exception to the footprint localities is that of a locality yielding a partial hadrosaur skeleton found in marine rocks in the south-central part of the state. By far the richest record of dinosaurs for the state is from the Campanian-Maastrichtian sequences of non-marine rocks. Whereas most of these localities are from northern Alaska, additional new localities have been found in the southwestern part of the state as well as in the central Alaska Range, near Mt. McKinley. This latest Cretaceous record consists of numerous fossil bone and footprint localities. The fossil vertebrate fauna recovered from Cretaceous rocks in Alaska include specimens of osteichthyan fishes, a chelonian, large and small theropods, birds, a hypsilophodontid, a pachycephalosaur, an ankylosaur, ceratopsians and hadrosaurians, as well as multituberculate, marsupial, and placental mammals. These specimens have been acquired through quarry and site excavations, and accumulated river bar and river bank float. The Cretaceous Gyeongsang Supergroup of Korea contains a comparably rich fossil vertebrate record. Whereas the Gyeongsang Supergroup is more prolific in the Early Cretaceous than the coeval Alaskan record it also contains fossil vertebrates that are correlative with the Campanian record of Alaska. Based on paleomagnetic reconstructions, both the Alaskan Cretaceous vertebrate fauna and the Korean vertebrate fauna represent ancient high-latitude faunas and should be examined in that light. In the modern Arctic, animals and plants demonstrate suites of unique features for life in extreme environments. Even though global climate in the Cretaceous in the high latitudes was milder than today some physical parameters, such as the quantity and angle of light, likely remained constant through time. Therefore, these Cretaceous vertebrate faunas hold valuable insights into adaptations for life in an ancient high-latitude environment.

Key words: Dinosaurs, Alaska, Korea, high-latitude, faunas

INTRODUCTION

The dinosaur record from Alaska spans the Late Jurassic (Kimmeridgian or Tithonian) to the Late Cretaceous (Maastrichtian). Increased efforts by workers from several institutions have produced a more thorough understanding of Alaskan dinosaurs and demonstrated that the state has great potential to contribute important insights into dinosaurian paleobiology. Further, this increased interest has yielded a regular flow of new discoveries in an area that comprises 20% of the entire United States, resulting in periodic summaries of the Alaskan dinosaur record in the literature (Rich *et al*., 1997; Gangloff, 1994, 1998a).

The Alaskan dinosaur record is robust and comprised of isolated bones and teeth, partial skeletons, footprints and rare skin impressions. Fossil vertebrates from the Cretaceous rocks in Alaska include specimens of osteichthyan fishes, a chelonian, large and small theropods, birds, a hypsilophodontid, a pachycephalosaur, an ankylosaur, ceratopsians and hadrosaurians, as well as multituberculate, marsupial, and placental mammals (Brouwers *et al.*, 1987; Clemens, 1994; Clemens and Nelms, 1993; Davies, 1987; Fiorillo, 2004; Fiorillo and Gangloff 2000, 2001; Fiorillo and Parrish, 2004; Gangloff 1994, 1998a; Gangloff *et al.* 2005; Nelms 1989; Parrish *et al.*, 1987; Rich *et al.* 1997). The resulting thousands of specimens from these studies have been acquired through quarry and site excavations, and accumulated river bar and river bank float.

Overwhelmingly, the richest geographic region of the state for dinosaur remains is the northern coastal plain of Alaska, often referred to as the North Slope, though other areas of the state are beginning to demonstrate their potential as dinosaurian fossil fields. By far, the richest part of the stratigraphic section for yielding dinosaur remains is contained within Campanian to Maastrichtian aged nonmarine rocks. A major revision of the stratigraphic nomenclature forthe North Slope (Mull *et al*., 2003) and new discoveries in new areas of the state form the basis of this review. In addition to providing a new review, this paper will also summarize the paleoecological significance of the Alaskan dinosaur record with respect to ancient high latitude terrestrial ecosystems and further suggest that the emerging Korean record of correlative dinosaur faunas may hold similar insights into high latitude ecosystems.

JURASSIC ALASKAN DINOSAURS

There have only been two Jurassic dinosaur localities in the state. Unfortunately, one locality, a track site, has only been documented by photographs in the popular literature (Conyers, 1978; Campbell, 1994) and the other, a highly fragmentary bone cobble, has been illustrated in the semi-technical literature (Fiorillo *et al.*, 2004). Both of these records are from the Upper Jurassic Naknek Formation in southwestern Alaska (Fig. 1).

This rock unit is the most widespread Mesozoic rock unit on the Alaska Peninsula (Detterman *et al.*, 1996; Wilson *et al.*, 1999), extending from the base of the Peninsula all the way southwestward to Black Hill. Spurr (1900) named the rock unit as a series during the first comprehensive geological survey of the region. Martin (1905) modified the term to Naknek Formation in his study of the strata of the upper Alaska Peninsula. Although the exact application of the term has undergone some alteration in subsequent years, most important to this report has been the subdivision of the Naknek Formation into thinner units or members. These members are from oldest to youngest, the Chisik Conglomerate Member, the Northeast Creek Sandstone Member, the Snug Harbor Siltstone Member, the Indecision Creek Sandstone Member, and the Katolinat Conglomerate Member. In general, these members represent a depositional change from a dominantly terrestrial fluvial system to a moderately deep to shallow marine environment. The maximum stratigraphic thickness of the Naknek Formation through the Alaska Peninsula is approximately 3200 meters, though the average thickness is between 1700 - 2000 meters.

Based on marine invertebrate fossils, the age of the Naknek is generally considered as Oxfordian to Tithonian. The date for the basal boundary of the Oxfordian is approximately 161 million years and the date for the upper boundary of the Tithonian is approximately 145 million years (Gradstein *et al.*, 2004).

In the Black Lake area of the western Alaska Peninsula a slab of rock has been photographed showing several tracks of a medium sized, three-toed, predatory dinosaur (Conyers, 1978; Campbell, 1994). Thorough documentation is unavailable due to the extreme logistical costs of extended operations (Gangloff, 1998a) but the slab is most likely in the Naknek Formation (Wilson, pers. comm.).

The second site is from within the boundaries of Katmai National Park (Fiorillo, *et al.*, 2004). Stratigraphically the site is within the Snug Harbor Siltstone Member of the Naknek Formation. Within this dominantly fine-grained member is a prograding delta complex that contained the bone cobble (Fig. 2).

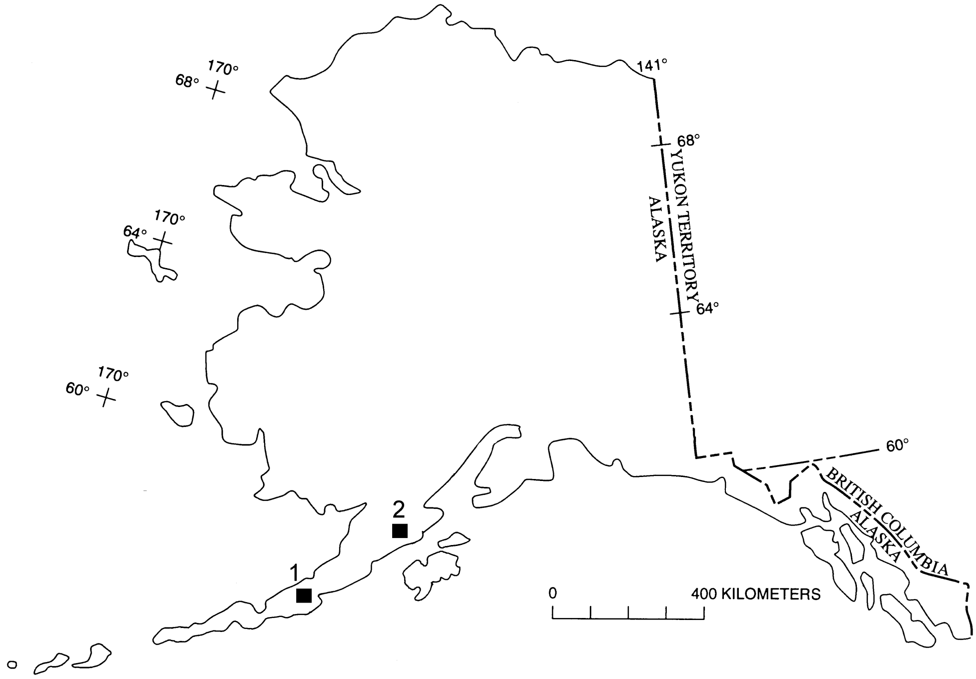

Fig. 1. Map of Alaska showing the known Late Jurassic dinosaur localities. Number 1 refers to the dinosaur tracks shown in photographs in Conyers (1978) and Campbell (1994), while number 2 refers to the presumed dinosaur bone fragment in Fiorillo *et al*. (2004).

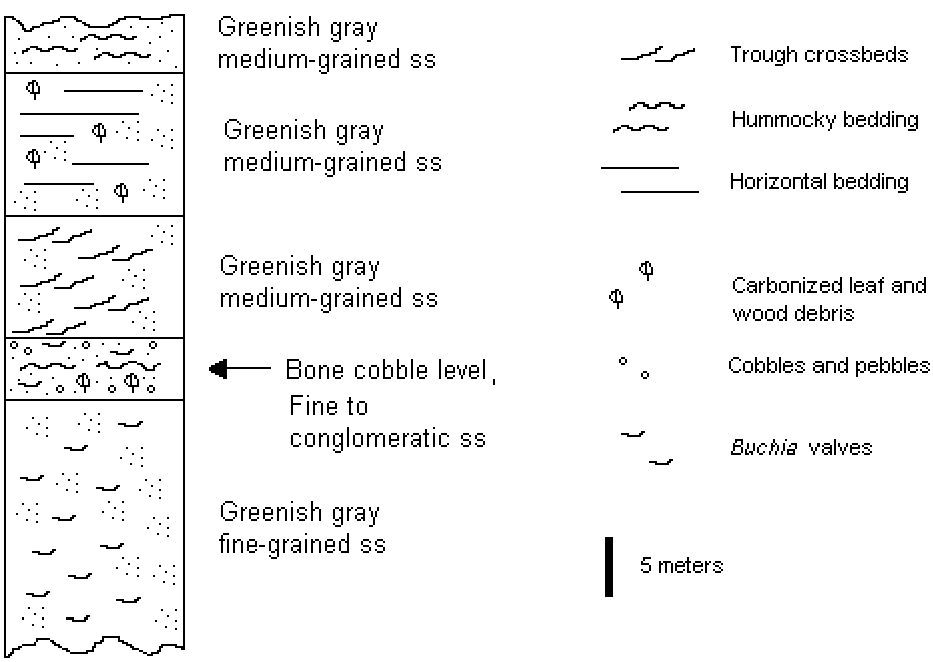

Fig. 2. Stratigraphic column for the deltaic deposit in Katmai National Park, Alaska that contains the dinosaur bone fragment shown in Fiorillo *et al.* (2004).

The specimen is a robust isolated bone cobble approximately 13 cm in length and 5 cm in width and is suggestive of a limb element. Given the robust nature of the specimen, combined with the age of the rocks, this specimen must have belonged to a large reptiliamorph. The specimen has a very thick cortical layer with a thick cancellous inner portion, a feature that precludes the cobble being attributed to a marine reptile. Therefore the specimen has tentatively been attributed to an indeterminate dinosaur.

PRE-CAMPANIAN CRETACEOUS ALASKAN DINOSAURS

Most records of this age occur in the northern part of the state. Figure 3 shows the general location of the more significant dinosaur localities that have been mentioned in the literature. Previous discussion of sites in northern Alaska has used stratigraphic terms such as the Corwin Formation (Roehler and Stricker, 1984) and the Chandler Formation (Gangloff, 1994, 1998b; Parrish *et al.*, 1987). The work in the Corwin Formation is of some historical significance because it is the first technical report of dinosaur remains from the state. Both the Corwin Formation and Chandler Formation designations have since been abandoned with a recent revision of stratigraphic nomenclature of Cretaceous and Tertiary rock units in northern Alaska (Mull *et al.*, 2003). These two units are now considered as within of the Nanushuk Formation (Mull *et al.*, 2003).

The pre-Campanian Cretaceous record of Alaska has been dominated by reports of footprints. The most notable exception to the footprint reports for this geologic interval of time is the partial skeleton of a

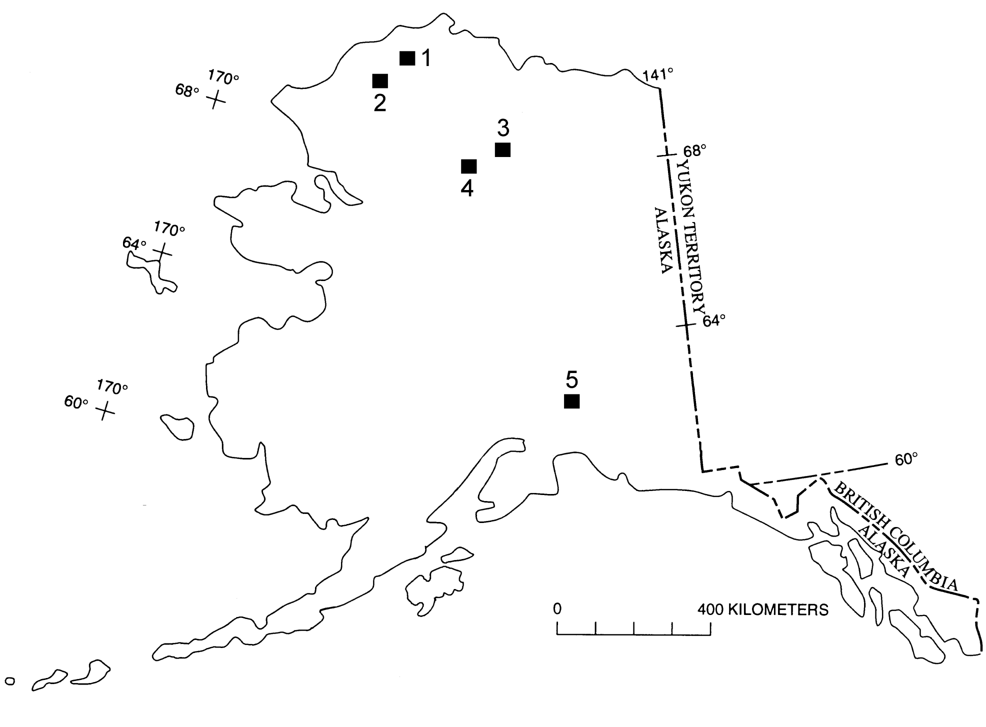

Fig. 3. Map of Alaska showing the major Cretaceous, pre-Campanian dinosaur localities. Number 1 refers to the combined dinosaur tracks and bones in Fiorillo *et al.* (2005). Number 2 refers to the dinosaur remains illustrated by Roehler and Stricker (1984). Numbers 3 and 4 refer to the general location of dinosaur footprints discussed by Gangloff (1998b). Number 5 refers to a locality that yielded a partial hadrosaur skeleton (Pasch and May, 1997; 2001).

probable hadrosaur from the marine Matanuska Formation in the Talkeetna Mountains of south central Alaska (Pasch and May, 1997, 2001). Reports of fragmentary dinosaur bones in northern Alaska from the Nanushuk Formation (Fig. 4; Fiorillo *et al*., 2005; Parrish *et al*., 1987) suggest that further study will increase the yield of dinosaur bones from this region and complement the growing number of reports of dinosaurian footprints.

CAMPANIAN-MAASTRICHIAN ALASKAN DINOSAURS

Similar to the pre-Campanian record, most of what is known about Campanian-Maastrichtian Alaskan dinosaurs is from the Prince Creek Formation which crops out in the northern part of the state most predominantly along the Colville River (Fig. 5). Further, the Prince Creek Formation contains the densest concentrations of dinosaur bones of any high latitude location in the northern or southern hemisphere (Rich *et al*., 1997; 2002). This rock unit represents a suite of fluvial environments that includes various types of river channels as well as various stages of floodplain maturation.

The Prince Creek Formation was originally divided by Gryc *et al*. (1951) into two members, the Tuluvak and Kogosukruk tongues. Initial reports of dinosaur remains from the Prince Creek Formation referred to the fossils as coming from the Kogosukruk Tongue of the Prince Creek Formation. However, Mull *et al*. (2003) have recently revised the Cretaceous and Tertiary stratigraphic nomenclature in the Colville Basin of the North Slope of Alaska. Following their nomenclature, all of the Cretaceous vertebrate fossil localities in northern Alaska are contained within the Prince Creek Formation.

Published palynological data (Fredriksen, 1990), as well as radiometric data (Conrad *et al*., 1990) provide a Campanian-Maastrichtian age for the most productive section for dinosaur remains within the

Fig. 4. Partial ornithopod ilium (University of Alaska Museum of the North AK-280-V-01a) from the Koalak River in northwestern Alaska (number 1 in figure 3). Though unprepared the ilium clearly has a blade-like appearance and shows the supraacetabular process or antitrochanter.

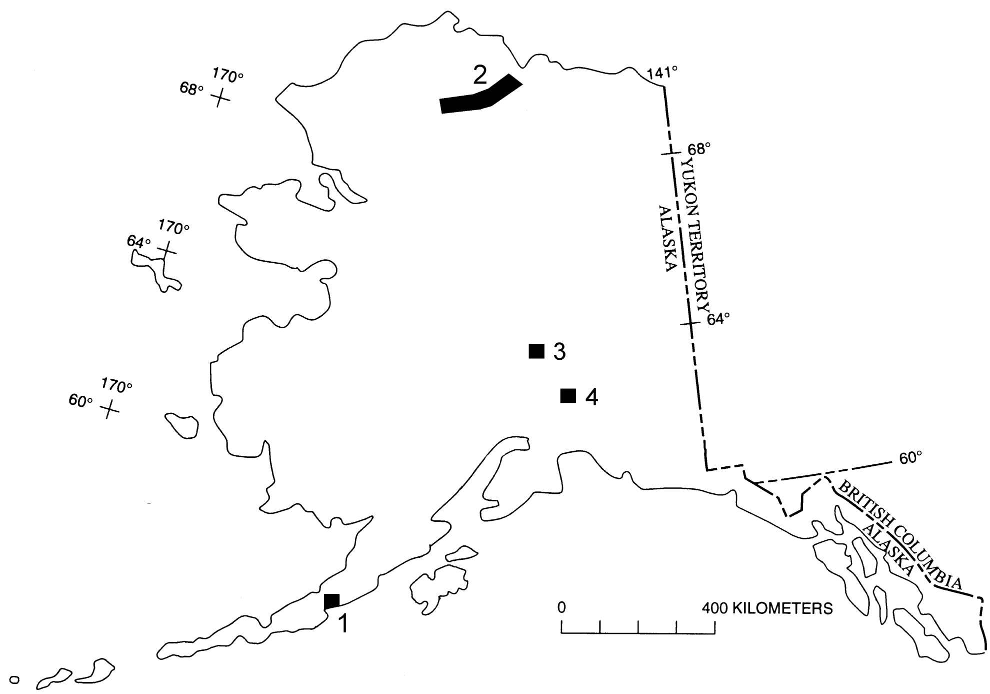

Fig. 5. Map of Alaska showing the major Campanian-Maastrichtian dinosaur localities. Number 1 refers to the dinosaur tracks found in Aniakchak National Monument (Fiorillo and Parrish, 2004). Number 2 refers to the numerous localities along the Colville River in northern Alaska (Brouwers *et al*., 1987; Clemens, 1994; Clemens and Nelms, 1993; Davies, 1987; Fiorillo, 2004; Fiorillo and Gangloff 2000, 2001; Gangloff 1994, 1998a; Gangloff *et al*. 2005; Nelms 1989; Parrish *et al*., 1987). Number 3 refers to new tracksites found in Denali National Park that are currently being studied. Number 4 refers to a locality that produced the skull of the ankylosaur *Edmontonia* (Gangloff, 1995).

Prince Creek Formation. Additional unpublished data from additional sites along the Colville River support this age determination.

Unlike the earlier Cretaceous records, what is known of dinosaurs of this age is based largely on bone specimens rather than footprints. These elements have been recovered from numerous quarry excavations (Fig. 6) or as float along river bars and the specimen yield is on the order of thousands of specimens (Brouwers *et al*., 1987; Clemens, 1994; Clemens and Nelms, 1993; Davies, 1987; Fiorillo, 2004; Fiorillo and Gangloff 2000, 2001; Gangloff 1994, 1998a; Gangloff *et al*. 2005; Nelms 1989; Parrish *et al*., 1987). Dinosaur bones are usually found as isolated elements or very fragmentary partial skeletons. Complete or articulated skeletons have not been recovered.

Other rock units that have comparable depositional environments but much smaller fossil yield thus far are the Chignik Formation of southwestern Alaska (number 1 in Fig. 5; Fiorillo and Parrish, 2004) and the Cantwell Formation of the Alaska Range (number 3in Fig. 5). The former rock unit crops out over much of the western portion of the Alaska Peninsula (e.g., Detterman *et al*., 1981; Wilson *et al*., 1999), while the latter rock unit is prevalent in the central Alaska Range (e.g., Csejtey *et al*., 1992). The best record for an ankylosaur from Alaska, consisting of an isolated skull, is known from a concretion within the marine Matanuska Formation of south-central Alaska (Gangloff, 1995).

Fig. 6. View to the north of the Kikak-Tegoseak Quarry along the Colville River in northern Alaska. Taxa from this locality include osteichthyan fishes, dromaeosaurs, troodontids, tyrannosaurids, ornithomimids, the ceratopsian *Pachyrhinosaurus* and hadrosaurs (Fiorillo and Gangloff, 2003).

THE SIGNIFICANCE OF HIGH-LATITUDE FOSSIL TERRESTRIAL FAUNAS AND KOREAN DINOSAURS

The Korean dinosaur record is experiencing a growth in recognition of importance similar to that of Alaska record (Lee *et al.*, 1997; Lee *et al.*, 2001; Lee and Huh, 2002; Lim *et al.*, 1994; Lockley *et al.*, 1992; Yang, 1982). In addition to the paleobiological importance, such reports have provided significant data for those reconstructing the tectonic and sedimentary evolution of the Korean Peninsula as a whole (e.g. Chough *et al.*, 2000). Therefore, does the emerging Korean Cretaceous record qualify as a high-latitude fauna and should these new studies be viewed for insights into the paleobiology of near polar terrestrial ecosystems?

The Alaskan record offers insights into the significance of ancient high-latitude terrestrial faunas. An abundance of paleomagnetic data establish that the geologic blocks comprising the geographic region of modern Alaska reached their modern configuration sometime in the Cretaceous (Churkin and Trexler, 1980; 1981; Hillhouse and Coe, 1994; Lawver and Scotese, 1990; Lawver *et al.*, 2002), likely around 100 Ma (Lawver *et al.*, 2002). Further, these workers have shown a likely land bridge connection during the Cretaceous between Asia and North America. The connection is almost certainly firm by the Turonian (Lawver *et al.*, 2002), a time of global high surface temperatures, and was a likely route for dispersal of dinosaurs from one continent to the other (Cifelli *et al.*, 1997; Russell, 1993; Sereno, 2000). From a geographical perspective, based on the tectonic history of the region, Alaskan dinosaurs were part of a high latitude terrestrial fauna.

Why are high-latitude paleofaunas significant? Since the discovery of dinosaurian remains in the high-latitudes of Spitzbergen, researchers have pondered the biological significance of such discoveries (e.g., Lapparent, 1962; Heintz, 1963; Hotton, 1980). Here I highlight some of the significant paleobiological aspects of the Alaskan dinosaur fauna.

The discovery of dinosaur remains at high latitudes has been problematic with respect to typical reptilian physiological models (Hotton, 1980; Brouwers *et al*., 1987; Parrish *et al*., 1987; Currie, 1989). To resolve these problems Hotton (1980), referring specifically to hadrosaur remains found in the Yukon Territory of Canada, invoked a long-distance migration model where these animals migrated thousands of kilometers on a journey tightly constrained by seasonality in forage, temperature, and light conditions. Subsequently, other workers used a modern analog, caribou (*Rangifer tarandus*), to support paleobiological conclusions regarding dinosaurian migrations (Parrish *et al*., 1987). Other workershave taken a critical look at this caribou analogy and have suggested based on biomechanical grounds that dinosaurs were year-round residents of the high-latitudes (e.g., Fiorillo and Gangloff, 2001).

If the prey did not migrate, then intuitively it seems logical that the predators similarly did not, and that they adapted to year-round existence in the high-latitudes. Given this consideration, one group of animals, the small theropods, have been examined more closely for an adaptive response to the physical constraints of high-latitude environments (Fiorillo and Gangloff, 2000). An adaptive response has been hypothesized for *Troodon formosus*, an animal known for its exceptionally large eyes compared to skull size (Fiorillo and Gangloff, 2000). This animal is known all the way south to west Texas but in the more southern occurrence of dinosaurs, *Troodon formosus* is very rare (e.g., 6% in Montana, Fiorillo and Currie, 1994). In Alaska *Troodon formosus* outnumbers all other theropods combined by a ratio of nearly 2:1 (Fiorillo and Gangloff, 2000).

In Alaska the preserved potential prey items include hadrosaurs, ceratopsians and pachycephalosaurs, animals also preserved in Montanan and Albertan dinosaur faunas. This theropod had similar food resources available all three areas. The basic jaw shape and estimated bite forces in Cretaceous small theropods are comparable suggesting these animals were likely in direct competition for food resources and developed some means to partition food resources. Given the large orbital diameter of *Troodon formosus*, the higher frequency in Alaska of this taxon probably indicates *Troodon formosus* was a preadapted form to the low light conditions of the Arctic where it thrived (Fiorillo and Gangloff, 2000).

To someone observing ecosystems from ground-level, the Arctic tends to be defined by earth-based parameters; the northernmost tree line, the geographic extent of highly adapted taxa such as *Ursus maritimus* (the polar bear), the average extent of sea ice, etc. For others, the Arctic is defined by that latitudinal line on the planet referred to as the Arctic Circle, that line above which the sun shines at midnight for at least one day out of the year.

In modern high-latitude ecosystems, three major factors constrain biological productivity: a short growing season, low temperatures, and restricted nutrient availability (Jefferies *et al*., 1992). In the Cretaceous, mean annual temperatures on the North Slope, ranged between 3°C and 13°C (Parrish and Spicer, 1988). For comparison, today's mean annual temperature for Portland, Oregon, and Calgary, Alberta, are 12°C and 4°C, respectively (Rich *et al*., 2002).

The proposed temperatures for the North Slope fall within tolerances of modern reptiles (Avery, 1982). Therefore, regardless of dinosaurs' endothermy or ectothermy, the proposed mean annual temperature for the Cretaceous high latitudes does not preclude the year-round existence of dinosaurs.

Higher temperatures typically relax constraints on nutrient availability (Jefferies *et al*., 1992), therefore the major remaining constraint on biological productivity in the Cretaceous Arctic must have been light. Anyone visiting the high latitudes cannot help but to be struck by the extended periods of light and dark.

In attempting to address the complexities of the north, Murie (1973) asked the simple question "Where is the Arctic"? Pielou (1994) and Officer and Page (2001), as examples, discussed in more detail the various perceptions of the biological verses the physical parameters that define the Arctic. Given the obvious differences between modern Arctic organisms and those of the Cretaceous, it is clear that projecting into back in time it is more meaningful to focus on the physical perspective, in other words the high-latitude component and the issue of subsequent radiant energy.

It has been shown that lower part of the Gyeongsang (=Kyeongsang) Supergroup, the Shindong Group was deposited at a paleolatitude of nearly 60^o north while the overlying Hayang Group was deposited at over 66^o north (Doh, *et al*., 1994). If paleolatitude is the defining criterion for identifying ancient high-latitude faunas, it seems that the Korean record qualifies as such. Further, if the Korean record of dinosaurs is accepted as representing a high-latitude terrestrial fauna several exciting paleobiological questions present themselves. For example, are these faunas year-round residents of the high-latitudes or were the various taxa migratory? Were there adaptations within these taxa that reflect upon life in physical constraints characteristic of the high latitudes? Also, given that there is a presumed land bridge connection between Asia and North America during the Cretaceous (Russell, 1993; Sereno, 2000) how does the structure of the ecosystem on each continent compare and contrast? Specifically for example, why is there evidence of higher latitude sauropods in Asia (Lee *et al*., 2001; Lee and Huh, 2002) yet none exists in North America at similar latitude? How did floral patterns compare or contrast? These are just a few questions but, like the Alaska record of dinosaurs, the Korean record seems ripe for insightful study into a fuller understanding of the paleobiology of dinosaurs.

CONCLUSIONS

The richest area in the world for the study of high-latitude dinosaurs is the Cretaceous of Alaska. The known record of dinosaurs from this region extends from the Late Jurassic through the Cretaceous. Though dinosaur remains are now known from various parts of the state, the most productive area of Alaska for dinosaur studies is the northern coastal plain.

Tectonic reconstructions for the Cretaceous place Alaska at its current latitude or higher, demonstrating that ancient Alaska contained a high-latitude terrestrial ecosystem capable of supporting large numbers of dinosaurs. In some taxa, adaptation to the physical constraints imposed by the high latitudes (i.e., abundance and intensity of light), has been shown. Given that the Cretaceous Korean record for dinosaurs is derived from rocks deposited at latitudes close to or above 60^o north latitude, it may be that the Korean record can offer comparable insights into the dynamicsof ancient high-latitude terrestrial ecosystems.

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고위도 화석군으로서 비교되는 한국 공룡에 대한 의미와 함께 알라스카의 공룡화석 기록에 대한 고찰

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요 약: 알래스카의 공룡화석은 후기 쥐라기에서 백악기까지 산출된다. 후기 쥐라기 공룡화석은 사진 기록으로 두건이 확인되는데 한 건은 일련의 수각류 공룡발자국이고 다른 것은 공룡뼈 조각이다. 이들은 모두 알래스카의 남서쪽에서 산출된다. 이와 유사하게 전기 백악기 공룡화석도 잘 알려져 있지 않은데 몇 개의 공룡발자국 산지와 공룡피부흔적이 발견된 곳이 있다. 알래스카에서 더 젊은 지층의 기록은 후기 백악기 전기인 Cenomanian과 Turonian 시기다. 많은 화석지가 발견되고 있으며 이들 화석지의 대부분은 공룡발자국 산지다. 일반적으로 이들 화석지는 알래스카의 북쪽 지역에 한정된다. 발자국 산지의 예외적인 한 곳은 알래스카 남중앙의 해성층에서 발견된 오리주둥이공룡의 뼈와 함께 산출된다. 현재까지 가장 풍부한 공룡화석은 Campanian-Maastrichtian 육성층에서 산출되고 있다. 대부분의 화석지가 북알래스카이지만 새로운 화석지가 남서부 지역과 McKinley산 근처의 중앙 알래스카 산맥에서도 발견되었다. 가장 최후기의 백악기 기록은 많은 뼈화석과 발자국 화석으로 채워진다. 알래스카 백악기에서 산출된 척추동물화석은 경골어류, 거북, 크고 작은 수각류, 조류, 힙실로포돈류, 파키케팔로사우루스류, 곡룡류, 각룡류, 오리주둥이공룡류 그리고 포유류인 multituberculate, 유대류, 태반류 등이다. 이러한 표본들은 강과 강 제방에 묻힌 것으로 발굴을 통해 수집되었다. 한국의 백악기 경상누층군은 다양한 척추화석 기록을 갖고 있다. 비록 경상누층군이 전기 백악기에 더 많은 화석 기록을 갖고 있지만 알래스카의 Campanian 시기에 대비되는 화석 기록도 갖고 있다. 고지자기 기록에 의하면 백악기의 알래스카와 한국의 척추동물화석은 고위도 지역의 화석군을 나타내며 이러한 점에서 논의해야 할 필요가 있다. 현재 북극권에는 동식물이 극한 환경에서 삶을 유지하기 위해 독특한 적응을 하고 있다. 백악기의 고위도 기후가 현재보다 더 온순했지만 빛의 강도와 각도 같은 물리적인 요소는 늘 일정했다. 그러므로 이러한 백악기 척추동물화석군은 옛날 고위도 환경에 적응한 생명체에 대한 가치 있는 통찰력을 제공한다.

주요어: 공룡, 알라스카, 한국, 고위도, 화석군

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