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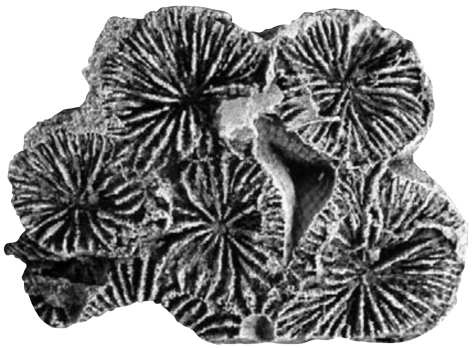
Detail of capsules of *Splachnum luteum*. The yellow parasol acts as a landing pad for insects and soon falls off.

Article on page 38.

Photograph by Gary A. Laursen



From Hot and Tropical to Cold and Arctic: The Triassic History of the Wrangell Mountains

By George D. Stanley, Jr., Andrew H. Caruthers and Robert B. Blodgett

Amidst the bold and unforgiving landscape of endless mountains, a thick and spectacularly exposed sequence of light-colored, sharp, craggy Upper Triassic carbonate rocks majestically rise-up and stand out against a background of short, dark-green, alpine grasses within the confines of the untamed Wrangell-St. Elias National Park and Preserve of southern Alaska, one of many mountainous areas making up Alaska *(Winkler 2000)*. In their present situation, it is difficult to imagine that this area once existed underwater, in a tropical marine setting. Buffeted by winds, covered by snow, eroded by the vicissitudes of ice and relentless glaciers, these massive outcroppings of limestone have been carved into the magnificent scenery now characterizing much of the park. However, some 220 million years ago during Late Triassic time they were deposits on top of thick volcanic flows in the middle of an ancient ocean called Panthalassa.

The vast Panthalassan Ocean covered one half of the world, and the present-day Pacific is all that remains of this once much greater ocean. Undersea volcanoes produced massive amounts of lava (11,500 feet/3,500 m thick) called the Nikolai Greenstone, which piled up and eventually broke the surface of the ocean, emerging as small clusters of volcanic islands. Massive amounts of carbonate rock called the Chitistone and Nizina Formations provide record of the geologic history. Now compressed and hardened into rock more than 3,500 feet (1067 m) thick, these rocks represent sediment on top of the volcanic islands. Sediment of this character often formed slopes, reefs with shallow lagoons, and tidal flats. Warm tropical waters were teaming with marine life, including many reef-dwelling organisms like sponges, corals and mollusks.

The complex task of deciphering the unique geological history of the Wrangell Mountains began as a collaborative effort by a team of U.S. Geological Survey (USGS) geologists—E. M. MacKevett Jr., A. K. Armstrong, N.J. Silberling, and many others—in the 1960s and early 1970s. Their effort was largely responsible for mapping and describing the rock units exposed in the Wrangell-St. Elias, and interpreting their deposition from Late Paleozoic to Mesozoic time *(MacKevett 1965, 1970, 1974, 1976; Armstrong et al. 1969; Armstrong and MacKevett 1982)*. Once mapping and field descriptions of the Wrangell-St. Elias was completed, the stage was set for more detailed comparative study of individual rock units and tectonic, sedimentary, paleontologic, and paleomagnetic analyses. As studies progressed it became evident that these rocks were formed in a setting bearing no resemblance to other fault-bound blocks. Furthermore, it also became apparent that these rocks were exotic to North America and had been displaced considerable distances since their formation.

Two studies in particular were instrumental in deciphering remnant magnetism to deduce just how far the Wrangell Mountains have traveled since being deposited. Hillhouse and Grommé *(1980)* and Yole and Irving *(1980)* analyzed the natural remnant magnetism using the orientations of magnetic minerals in basalt lavas that erupted during Triassic time. These data from volcanic rocks, compared with polar wandering and the present-day paleopoles, indicated formation between 15 and 18 degrees of the paleoequator—far from their present-day

Figure 1. (Left) View of the Kennicott River (foreground) from the McCarthy footbridge with the illuminated Mesozoic rock sequences (background) towering over the landscape. Rocks of this age make up much of the Wrangell-St. Elias National Park and Preserve.
Photograph by Andrew Caruthers

Figure 2. (Above) Silicified coral of genus *Margarosmilia*.

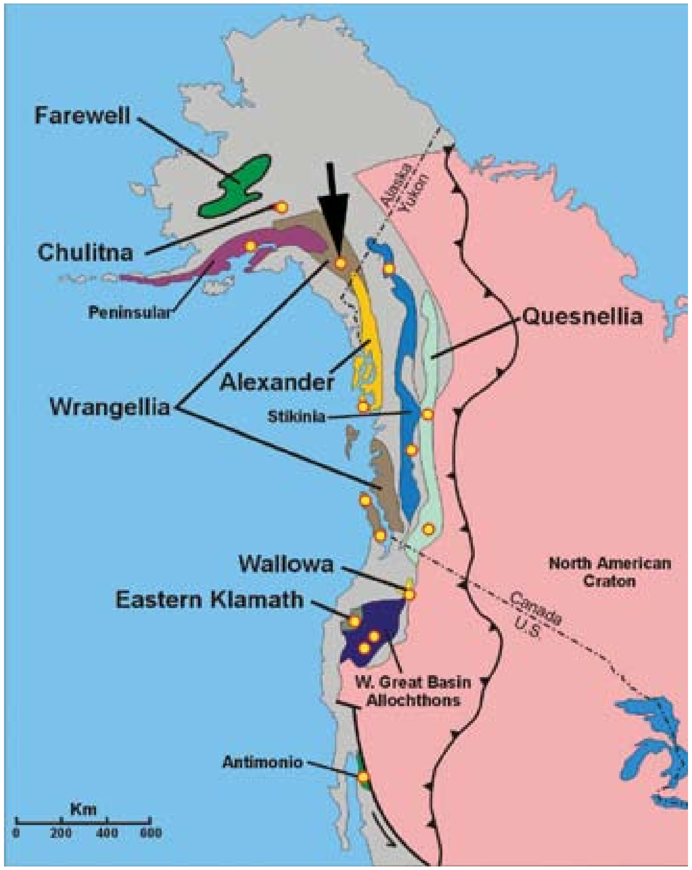


Figure 3. Generalized map of western North America showing approximate positions of various displaced terranes in their modern-day location. Arrow indicates study area for this paper; yellow circles are approximate locations of known Late Triassic fossiliferous marine localities. Figure adapted from Coney et al. (1980).

location. Fossils and carbonate rock units gave clear evidence of tropical to subtropical settings and lack of contamination by land-derived sediment suggested that the rocks were formed at some distance from the North American continent. Exact paleolongitude however were more difficult to decipher. Longitudinal positions in the ancient Pacific Ocean and exact distance from the ancient North American margin were suggested to have been far. Resolving a particular hemisphere in which the volcanic rocks formed is difficult and both a northern hemisphere and southern hemisphere were discussed. In the case of the latter, it would imply a remarkable change in latitude as the nearest comparable fossils and rock types reside in South America.

One of the spin-offs of plate tectonics was the realization that numerous bits and pieces of ancient real estate formed as volcanic islands in the ancient Pacific Ocean. Driven by the relentless forces of ocean sea-floor spreading, these fragments moved considerable distances, being subsequently transported along the North American seaboard via faults, eventually reaching very high latitudes. Some of these rocks contained fossils matching up closely with Asia and central Europe. These fragments or blocks were called "exotic" or "displaced" terranes and produced a crazy-quilt pattern when mapped geologically *(Figure 3)*. Many were oceanic in origin, existing as volcanic island arcs, similar to reef-fringed volcanic islands that dot the Pacific Ocean today. The concept of displaced terranes helped make sense of the crazy-quilted pattern of geology common throughout western North America *(Coney et al. 1980)*.

Geologists of the USGS made the exotic terranes of Alaska known in the 1970s, with basic concepts emanating from systematic field mapping in remote portions of Alaska, as well as in western conterminous United States *(Jones et al. 1977)*. Canadian geologists continued their studies of western interior Yukon Territory and British Columbia, Canada. Before advent of plate tectonics, workers such as J.P. Smith *(1912, 1927)* attempted to explain occurrences of Triassic fossil corals in southeastern Alaska by hypothesizing an expanded tropical belt extending from the equator to high latitudes near the poles in Triassic time, but that idea was put to rest after the emergence of plate tectonic theory. The concept of displaced terranes made better sense of anomalous, high-latitude occurrences of coral reefs.

After over 30 years of field investigations and mapping, geologists have come to interpret a diverse and tectonically active history for much of the North American Cordillera. This rather large and extensive area of western North America is now known to contain numerous tectonically displaced terranes preserved in mountain belts running from Sonora Mexico to Alaska, some of the more common terranes are shown in Figure 3. Some of these far-flung terranes are suggested to have traveled over thousands of miles across the ancient Panthalassan Ocean. Sequences of rock in the Wrangell Mountains of southcentral Alaska represent the northern part of one of the best known and most widespread of displaced terranes, designated " Wrangellia."

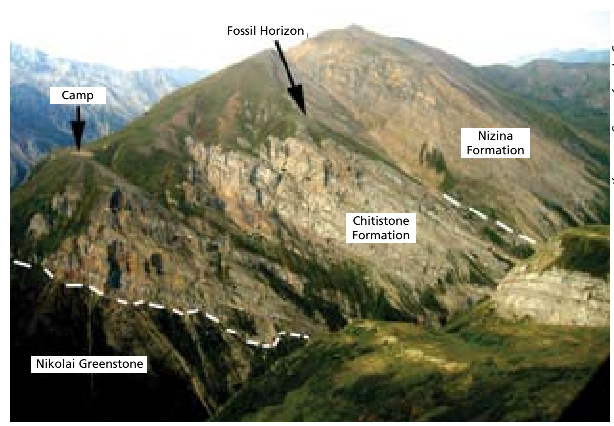


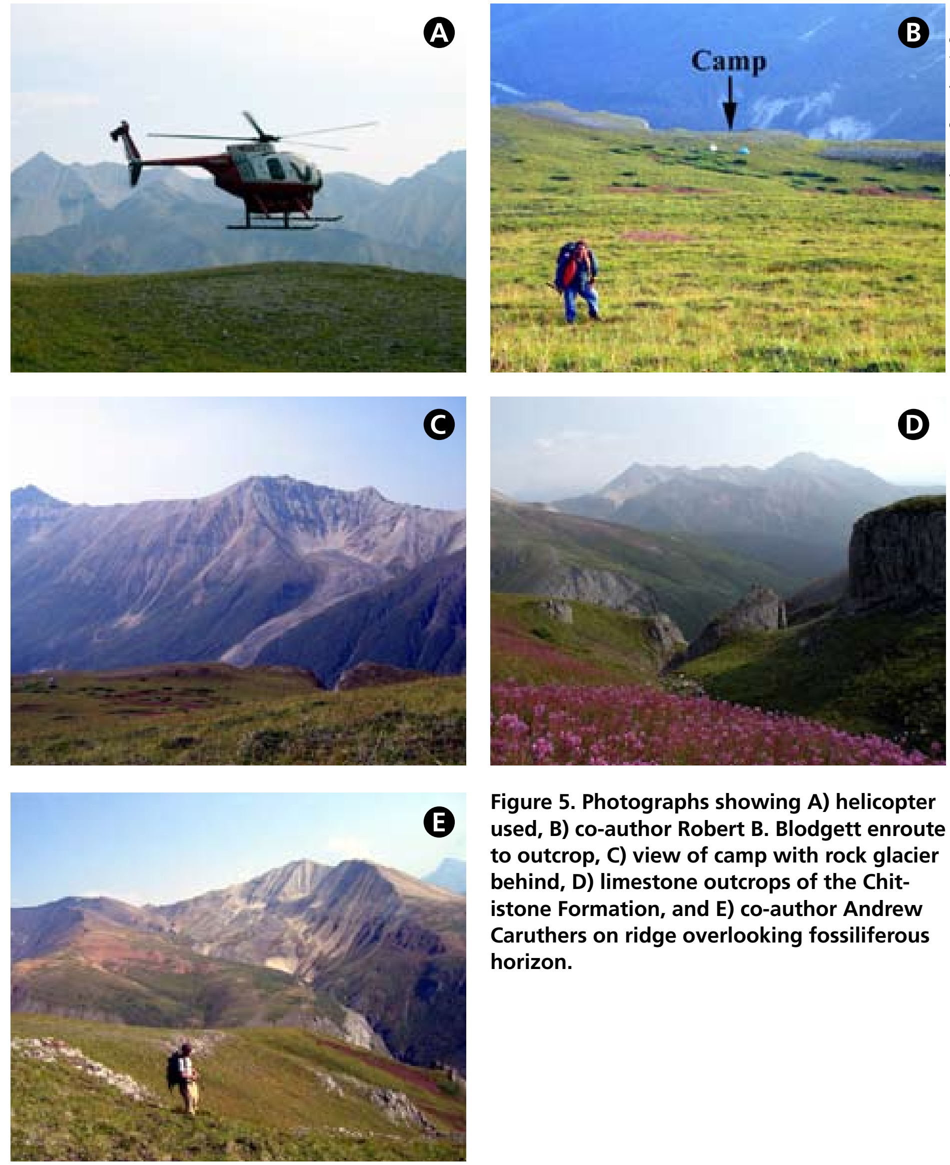
Figure 4. Photograph showing the east side of Green Butte in the Wrangell Mountains. Three distinct rock formations (Nikolai Greenstone, Chitistone Formation and Nizina Formation), making up the Triassic stratigraphy, are identified. Dashed line indicates formation boundary; arrows depict location of camp and fossil locality.

Following formation, Wrangellia broke apart and was propelled northward along lateral faults, eventually residing in present-day latitudes of Alaska and western Canada. Presently, bits and pieces of Wrangellia extend far to the south, comprising modern day Queen Charlotte Islands and Vancouver Island of western Canada, and even the Wallowa Mountains in eastern Oregon *(Jones et al. 1977)*.

During their northward journey, terranes of the North American Cordillera carried fossils as cargo in their stratigraphic successions. These fossils show paleobiogeographic alliances with distant regions such as the ancient Tethys—a now vanished tropical east-west seaway cradled in the arms of the one-world ancient continent called Pangea. During the Triassic the Tethys existed as a shallow to deep-water marine embayment containing a high-diversity of fauna including corals, mollusks, foraminifers and many other invertebrate groups that are remarkably similar to those found in stratigraphic successions of the North American terranes. Although somewhat rare, vertebrate remains also occur and include fish scales and teeth, the small tooth-like dentitions known as conodonts, as well as larger bones of swimming marine reptiles including fish-like ichthyosaurs and long-necked plesiosaurs. The mere presence of these ancient relics of a once tropical life has proven valuable to reconstructing ancient geography.

Unfortunately volcanic and tectonic forces, characterizing most terranes, result in destruction of valuable fossils. Without well-preserved fossils, paleontologists cannot accurately identify species and correlate coeval faunas. Nor can they solve the anomalies of paleogeography and ancient environment. Even without geologic pressure and heat, shallow-water fossils preserved in limestone are normally subjected to recrystallization, which destroys delicate microstructure rendering fossils difficult to identify. However, in certain key beds of island arc terranes, such as a fossiliferous horizon at Green Butte in the Wrangell Mountains, silica replacement of the original calcareous shells has preserved important details in these shelly fossils. Immersion in weak acid baths dissolve the enclosing carbonate matrix, leaving behind perfect three-dimensional fossils; many of which can be identified with accurate precision. Such beds are valuable as paleontological "gold mines" because they provide a wealth of information normally unavailable.

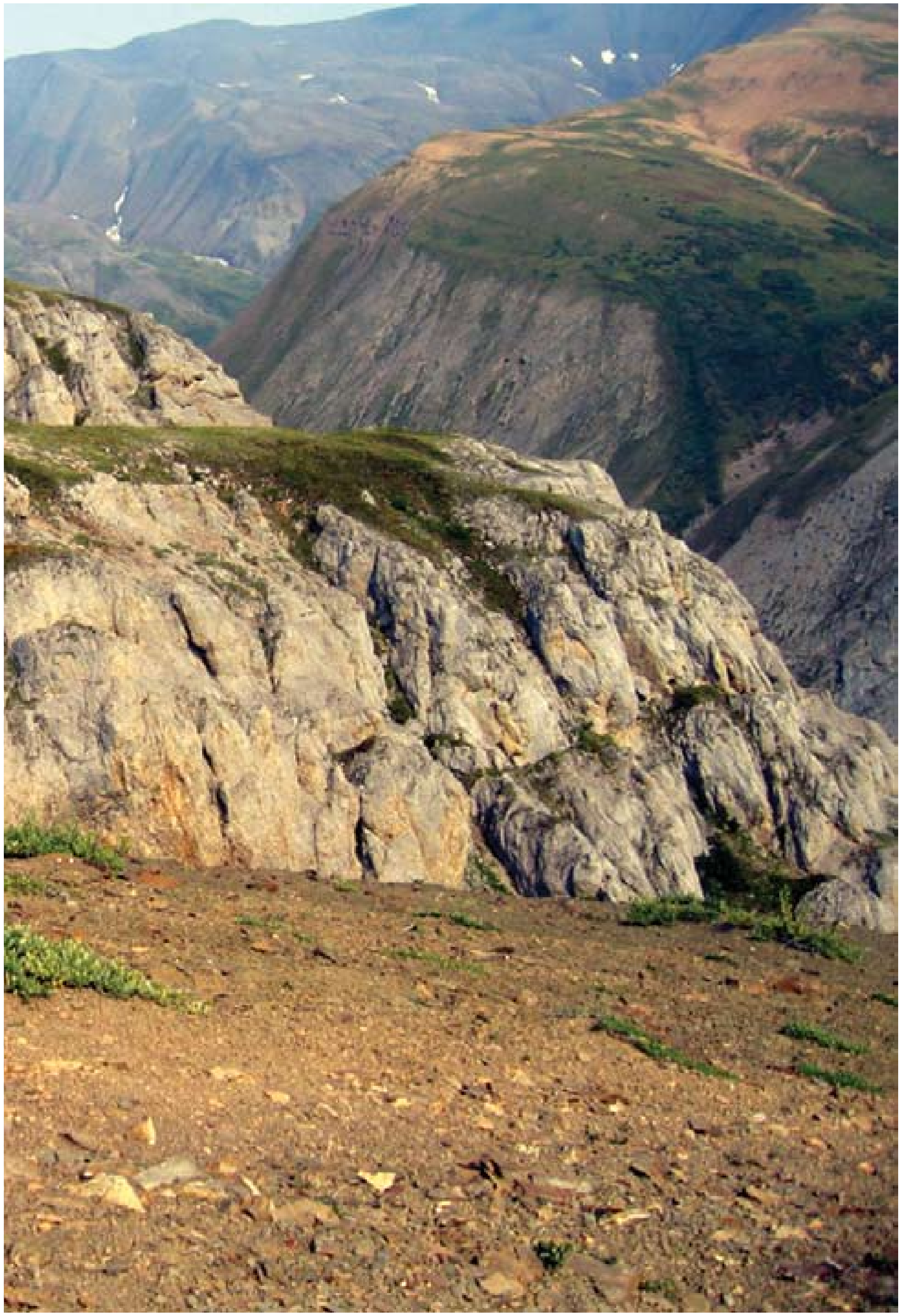
Original field mapping of Triassic rock at Green Butte, high above McCarthy, Alaska, revealed a distinctive horizon of silicified marine fossils sandwiched at the boundary (or contact) in between the Chitistone Formation and the Nizina Formation *(Figure 4)*. From previous USGS collections from this bed, Montanaro Gallitelli et al. *(1979)* described some of the silicified corals. In a separate study, Newton *(1983b)* described the bivalves. These studies found previously unrealized similarity between these corals and coral faunas from other displaced terranes as well as with similar aged counterparts of the former Tethys region. The studied bivalves revealed an especially strong connection with bivalve species in the Wallowa Mountains, Oregon. This correlation re-opened the door to the original claim by Jones et al. *(1977)* that large fragments of Wrangellia have been distributed over wide areas by plate tectonic processes. Careful study of the rock types and fossils allowed the rock sections to be correlated over such great distances.



Photographs by George Stanley, Jr.

Figure 5. Photographs showing A) helicopter used, B) co-author Robert B. Blodgett enroute to outcrop, C) view of camp with rock glacier behind, D) limestone outcrops of the Chitistone Formation, and E) co-author Andrew Caruthers on ridge overlooking fossiliferous horizon.

During the summer of 2004, a team of



Photographs by Andrew Caruthers

Figure 6. (Left) Fossiliferous horizon at the boundary between the Chitistone Formation and Nizina Formation at Green Butte, Wrangell Mountains. (Top) Lateral view with co-author George Stanley Jr. for scale. (Bottom) Down-slope view of outcrop with flagging tape for scale.

paleontologists, authors of this article, set out to reinvestigate the Triassic portion of Wrangellia at Green Butte. Our overall goal was to gather a sense for the faunal diversity, paleoecology and depositional environment and to interpret conditions of life in the ancient sea surrounding Wrangellia some 220 million years ago. With the aide of helicopter support *(Figure 5a)*, we collected large blocks of silicified limestone. By processing many large blocks of this fossiliferous limestone and studying the resulting material, we were able to gather new information on taxonomic diversity, significantly increasing our knowledge of fossils from this site.

After an exhilarating helicopter ride from the town of McCarthy, we reached the southeastern shoulder of Green Butte, set up camp, and started the search *(Figure 5)*. While traversing across the eastern face of the mountain, we used clues in the surrounding geology to locate this important bed of rock. Then, upon descending down a rather steep and unstable talus slope, a small knobby-looking outcrop (approximately 30 feet/ 9 m wide) emerged below. We immediately knew we had found it; this outcrop stood out from all others at Green Butte by the sheer abundance of silicified fossils jammed together in haphazard fashion, standing out in relief against the dull grey rock matrix *(Figure 6-7)*. Shallow-water marine organisms, immaculately well preserved in an eerie, almost ghostly state were so prevalent and congealed that deciphering between individual samples we wished to collect was difficult, as we wanted to keep them all.

While scampering across the face of this knobby-looking outcrop, we used our hammers and pry-bars to crack off limestone blocks for processing and began to pull various pieces of evidence together; slowly forming hypotheses surrounding this ancient relic of oceanic life. Clues revealing just how these fossils became trapped or "frozen" in time started to circulate through our minds as a new story of deposition emerged. The jumbled and inconsistent orientation of fossils *(Figure 7a-d)*, the evident scour at the base of the outcrop *(Figure 8)*, and the presence of large fine-grained areas of muddy carbonate almost completely devoid of fossils except for instances where lenses have been incorporated *(Figure 9)* all point to one conclusion. These fossils had been transported down-slope as a massive debris flow. The random, highly fragmented, orientation of fossils suggests downslope movement and the scour at the base suggests a sudden underwater avalanche-type of event. Deformed limy "blobs" with occasional fossil lenses indicate the incorporation of shells in soft carbonate mud lumps while rolling down a steep slope. All told, debris flows along the margin of this part of Wrangellia were responsible for transporting thousands of shallow-water organisms from their original living environment on the shelf into deeper-water *(Figure 10)*.

During much of the Mesozoic era tropical reef ecosystems of high diversity inhabited the now vanished seaway called the Tethys. Today remnants of this ancient seaway are especially well preserved in the Alps of central Europe. During Triassic time, vast reef complexes inhabited the Tethys; however, across the Panthalassan Ocean in distant Wrangellia, expansive reef complexes did not develop. This could have been caused by conditions of lowered nutrients, poor water circulation, or the influx of fine-grained volcanic sediment. Nevertheless, identical or very similar Tethyan species of corals *(Figure 11)*, gastropods, bivalves, ammonoids, echinoderms (sea urchins and crinoids), calcified sponges, spongiomorphs, and calcified algae occur at Green Butte *(Figure 12)*. Bone fragments (likely of reptilian origin), fish teeth and scales, as well as microscopic conodonts (small tooth-like structures) also are found and were part of the swimming open-water fauna that flourished in the tropical ecosystem of Wrangellia. Even though true reefs were absent, corals and sponges created small-scale buildups a couple of yards thick. Corals common in modern day tropical marine environments are sessile benthic creatures living attached on the ocean floor, killing their microscopic prey with stinging tentacles. Finding

Photographs by George Stanley Jr.

Figure 7. Close-up photographs of fossiliferous limestone, showing highly fractured, inconsistently oriented state of fossils. Photographs A and B represent the top of the deposit whereas C and D are taken in the middle section. All photos are uniform without any evidence of their being multiple depositional events.

Photograph by George Stanley Jr.

Figure 8. Photograph showing the non-uniform basal scour of the deposit, dashed line indicates scour. Note limestone below dashed line is relatively devoid of fossils, whereas limestone above is packed with broken up fossils, except for large fine-grained area containing muddy carbonate with a fossiliferous inclusion.

Photographs by George Stanley Jr.

Figure 9. (Top) Large, un-fossiliferous, fine-grained lenses of muddy carbonate, trapped in fossiliferous horizon. (Bottom) Lenses sporadically contain fossiliferous inclusions (arrows) indicating down-slope movement as an underwater debris flow.

corals and associated fossils in their original environment hold valuable clues such as water clarity, nutrient level, sunlight, water temperature, and depth—all vital for reconstructing paleoenvironment.

How the sea creatures disperse themselves also is important to reconstructing ancient geography. It is clear that as adults, many organisms like snails, spiny echinoids and other bottom-dwellers can move about on the ocean floor but cannot travel vast distances. As juveniles in their larval stages, however, most of these sea creatures existed as microscopic swimming or floating plankton that were capable of being transported immeasurable distances by water currents; not only between volcanic islands, but also across the expansive Panthalassan Ocean from the western Tethys. Our research utilizing modern faunas suggests that certain species of corals are "broadcasters" and produce offspring capable of wide dispersal while other corals are "brooders" whose larvae do not have the capability of wide dispersal. Furthermore, a certain group of snails called archaeogastropods do not have a free-swimming larval stage;

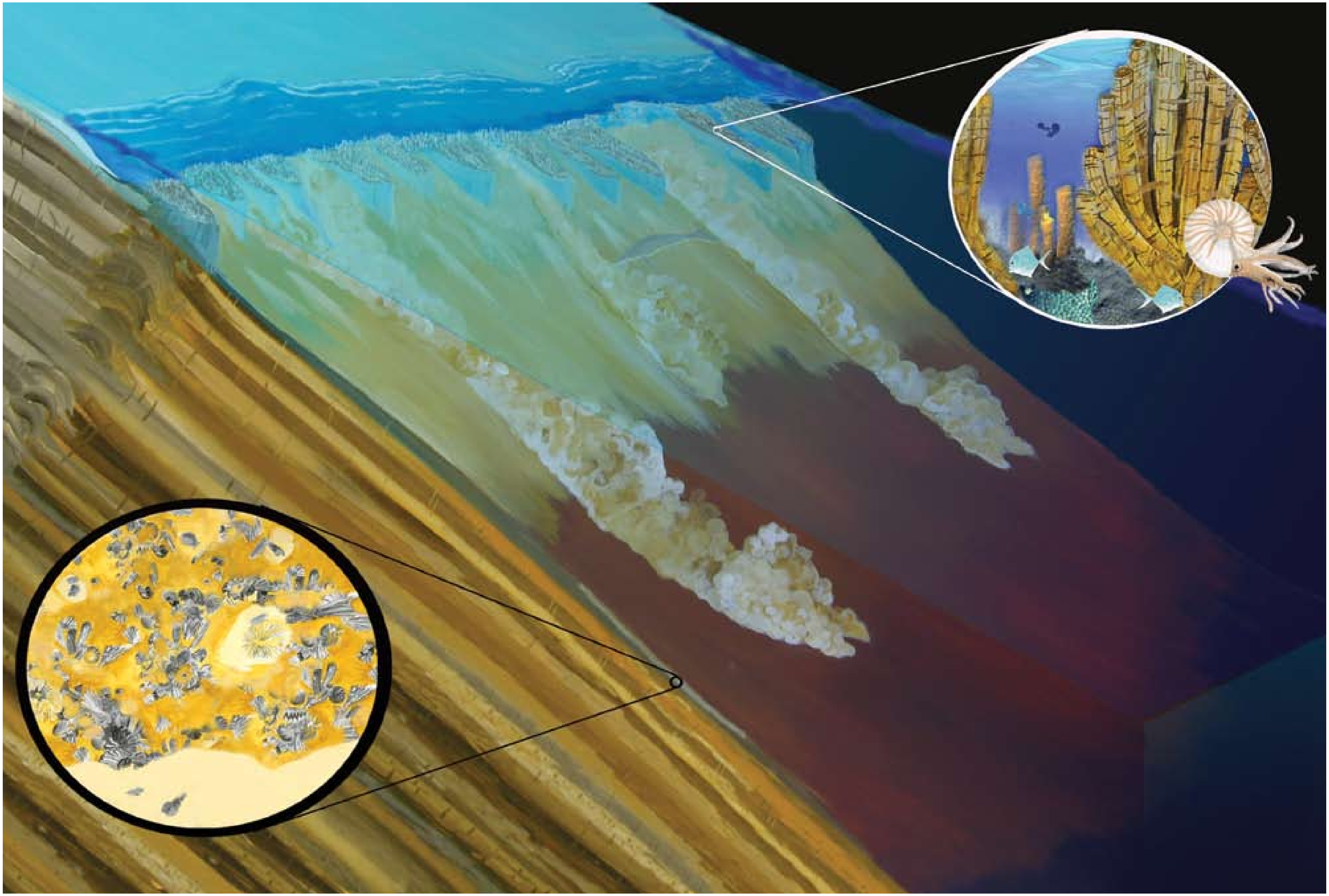


Figure 10. Illustration of Late Triassic Wrangellia depicting fossiliferous horizon before, during, and after debris flows, responsible for creating this valuable deposit. Rendition also shows the multitude of organisms recovered during acetic acid processing.

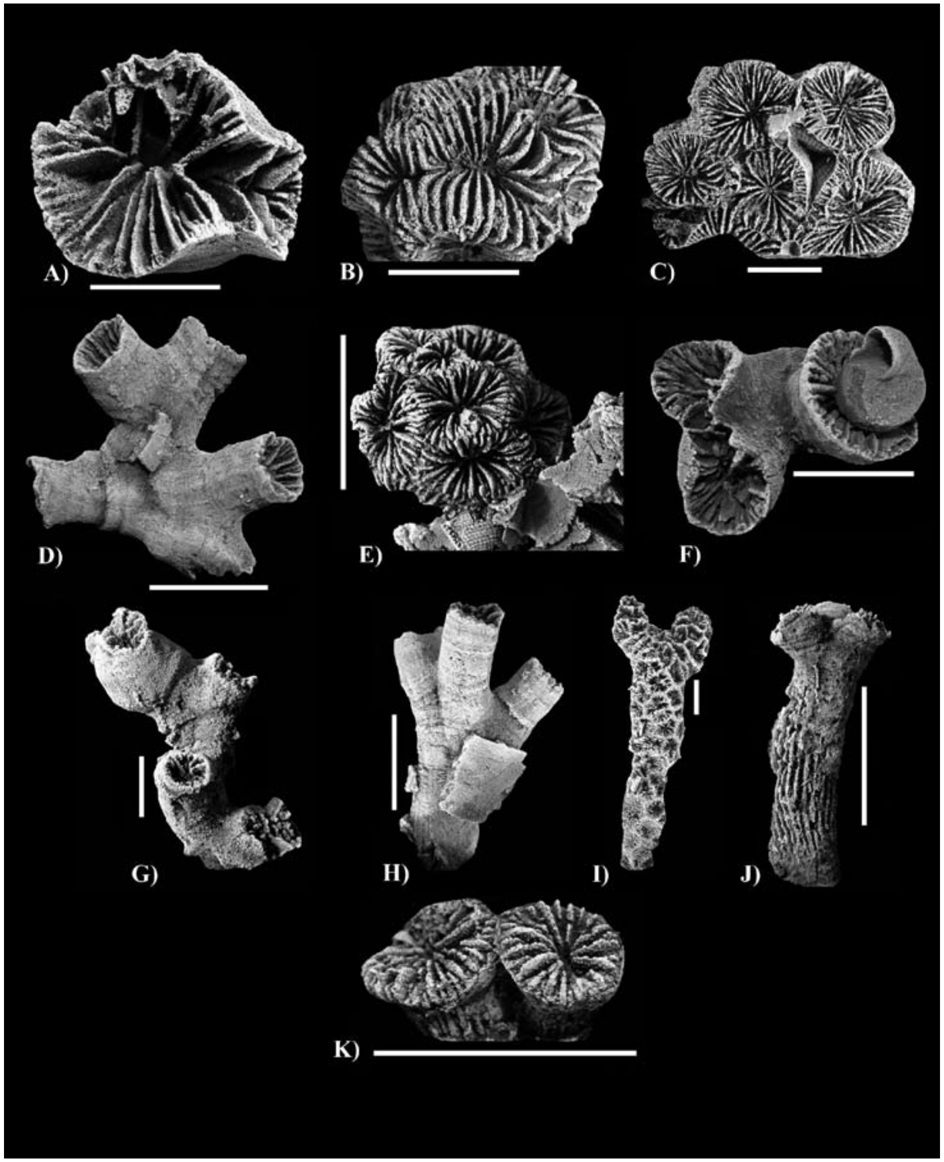


Figure 11. Composite photograph showing silicified corals obtained from the collected limestone blocks, from Green Butte. Corals identified from genera *Paracuifia* (A), *Pamiroseris* (B), *Margarosmilia* (C,K), *Retiophyllia* (D, F, G, H, J), and *Distichomeandra* (E, I). Scale bar is 0.39 inches (1 cm).

so do not take up life drifting about with the water currents. These types of sea creatures are extremely important in reconstructing ancient geography due to their "endemic" nature. Thus, recognizing endemic species is vital for deducing paleogeographic relationships between terranes.

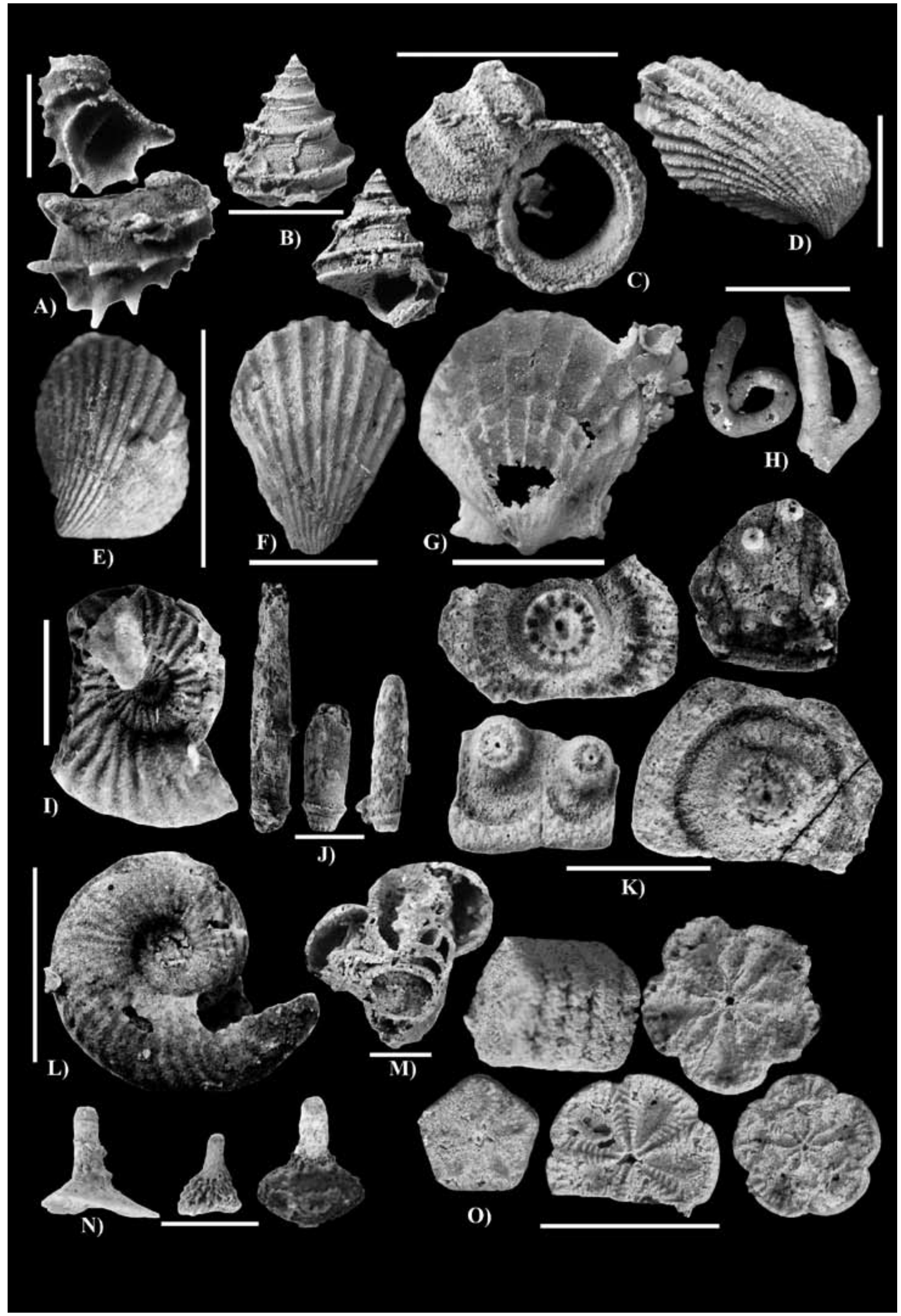
Armed with valuable data from the identified coral and gastropod species at Green Butte, we began our comparative analysis of similarity. For this we turned to the world of statistics, testing coral species found at Green Butte with coral fauna (of a similar age) from other displaced terranes of the North American Cordillera. We compared the Green Butte coral species with species from the Alexander terrane (another terrane comprising much of present day southeastern Alaska) as well as with fauna from the Peruvian Andes, which yielded low levels of similarity. Interestingly a similar statistical comparison of slightly younger corals from the southern Wrangellian counterpart (Vancouver Island), produced a surprising amount of similarity with Peruvian corals, implying that during the Late Triassic this portion of Wrangellia could have been located closer to South America than previously thought. We also noted an inordinate amount of overlap between Green Butte corals and species from the Wallowa terrane (Wallowa Mountains, Oregon). This connection was evident as well in the recovered snails. Paleontologically, this Wrangellia/Wallowa terrane connection was first noted by Newton *(1983a)*, who studied Triassic clams from Green Butte as part of her doctoral thesis and later mentioned by Stanley *(1987)*, concerning the associated reef-like ecosystem of the Blue Mountains of northeast Oregon.

Systematic study of the collected and processed fossils from the Wrangell Mountains reveals a complex and interesting story, allowing us to test ideas about paleogeography tectonic hypotheses and ancient environments. Most of the silicified fossils from Green Butte were reworked—mixed and transported down an ancient depositional slope, but they once existed in shallow-water setting of Wrangellia. These fossils provide a strikingly detailed snapshot of the diverse near-shore, shallow-water tropical marine ecosystem that inhabited the vanished volcanic islands of Wrangellia.

But where were these ancient volcanic islands situated? Research suggests that they existed in a remote setting, at a yet undetermined distance offshore the continent of North America. Paleomagnetic studies and a degree of similarity to fossils of distant Tethys Sea suggest a tropical position far to the south. Therefore, rocks of the Wrangell Mountains were moved thousands of miles northward out of the tropics to their present location in temperate southern Alaska. The established overlap in coral, snail, and bivalve species with the Wallowa terrane confirmed speculation by geologists more than 25 years ago that Wrangellia is composed of rocks spread along the western margin of North America as far south as northeastern Oregon *(Jones et al. 1977)*.

As briefly mentioned above, simi-

Figure 12. Composite photograph of diverse invertebrate fauna acquired from dissolved limestone blocks at Green Butte. Identified fossils include: (A) a young gastropod, genus *Spinidelphinulopsis*, known from the Wallowa, Wrangellia, and Alexander terranes; (B) the widespread gastropod, genus *Chartroniella*, known throughout the Western Hemisphere from Peru, the Wallowa terrane and northern Wrangellia; (C) the neritimorph gastropod, genus *Nuetzelopsis*, known from both Wrangellia and the Wallowa terranes; (D) strongly ribbed bivalve from genus *Septocardia*; (E) strongly ribbed bivalve, genus *Palaeocardita*; (F) Limid bivalve, possibly genera *Mysidoptera*; (G) left valve of a possible *Oxytomid* clam; (H) 2 annelid worm tubes belonging to a group called serpulids worms that secreted tubes on either hard substrate or shell debris; (I) coiled ammonite, extremely useful in providing constraints on relative age for the surrounding rock bed in which they are found; (J) 3 straight echinoderm sea urchin spines, functioned to provide protection against predators and were attached to the surface of the internal skeleton or shell; (K) 4 echinoderm sea urchin plates (or internal skeleton, shell) belonging to several different species; (L) coiled ammonite; (M) a chambered, calcified demosponge, such sponges are very rare in silicified beds due to their fragile skeletons; (N) 3 bulbous echinoderm sea urchin spines; (O) crinoid (sea lily) ossicles, another group of echinoderm whose calcite plates stacked together likes checkers to produce long flexible stems serving to attach the calyx or head, which has yet to be found in the deposit. Scale bar is 0.39 inches (1 cm). Bivalves E-G identified by Tom Waller.



Photographs A-C by Robert B. Blodgett and D-O by José Garcia

lar aged rocks and fossils from another Alaska terrane near Ketchikan (the Alexander terrane, *Figure 3*) were studied during our project. Alexander terrane fossils and associated rock sequences show lower similarity with those of Wrangellia *(Blodgett and Frýda 2001, Caruthers 2005, Caruthers and Stanley 2008)*, despite the fact that some geologists previously had postulated a geologically gigantic, contiguous Alexander/Wrangellia block called a superterrane. A super terrane theory is based strictly on geologic and tectonic evidence, suggesting Wrangellia was tectonically stitched to the Alexander terrane about 100 millions years earlier than the Triassic—in mid-Paleozoic time *(Gardner et al. 1988)*. Our findings call this hypothesis into question. Further testing of course will require more investigation into the respective geologic histories, extracting both paleontologic, stratigraphic, tectonic and geophysical data from both of these terranes.

Paleontology can produce exciting, stimulating and sometimes unexpected results. The silicified fossils we studied in the Wrangell Mountains had lain in their limestone tombs for over 200 million years before they were discovered and collected. Freed by acid etching and studied systematically, they provided details for geographic relationships of greater Wrangellia. Before becoming tectonically incorporated into the North American continent, Wrangellia had a long and complex history. Identification and similarity calculations using the fossil taxa, along with knowledge from living counterparts, has given us a better understanding of the ancient ecology and geography. It is testimony to the dynamic nature of our planet and the relentless forces of plate tectonics, especially those that formed the most famous displaced

Photograph by George Stanley, Jr.

Figure 13. Thick Upper Triassic limestone is spectacularly exposed resting above volcanic rocks in the Wrangell-St. Elias National Park and Preserve.

terrane making up the Wrangell-St. Elias National Park and Preserve.

Current hypotheses accounting for this terrane are many. They suggest several alternatives for Wrangellia and the Alexander terrane. These include: 1) Both terranes evolved separately as volcanic island arcs near the North American continent, 2) they evolved separately but existed far from North America and traveled unknown distances within the Panthalassan Ocean before they were incorporated into North America, and 3) Wrangellia was scraped off South America, fragmented and then moved thousands of miles northward to its present location along the North American margin. An even more exotic idea derives Wrangellia (and perhaps other terranes as well) from "source" rocks in Siberia and the Russian Far East. After having moved from the tropics of the eastern Tethys, these exotic rocks may have been translated along faults, similar to the San Andreas of California, to make a journey of many thousands of miles around the Pacific rim, eventually arriving at their present sites in Alaska and western North America.

From a hot and tropical ancient ecology to the cold and Arctic weather where their remains now are found, dead sea life has an interesting tale to tell. Paleontologists continue putting the dead to work to help reveal ancient geography. We expect that the fossils of Wrangellia will continue working for us, revealing more clues about how Alaska and the rest of western North America was made through complex movements of displaced terranes.

Acknowledgements

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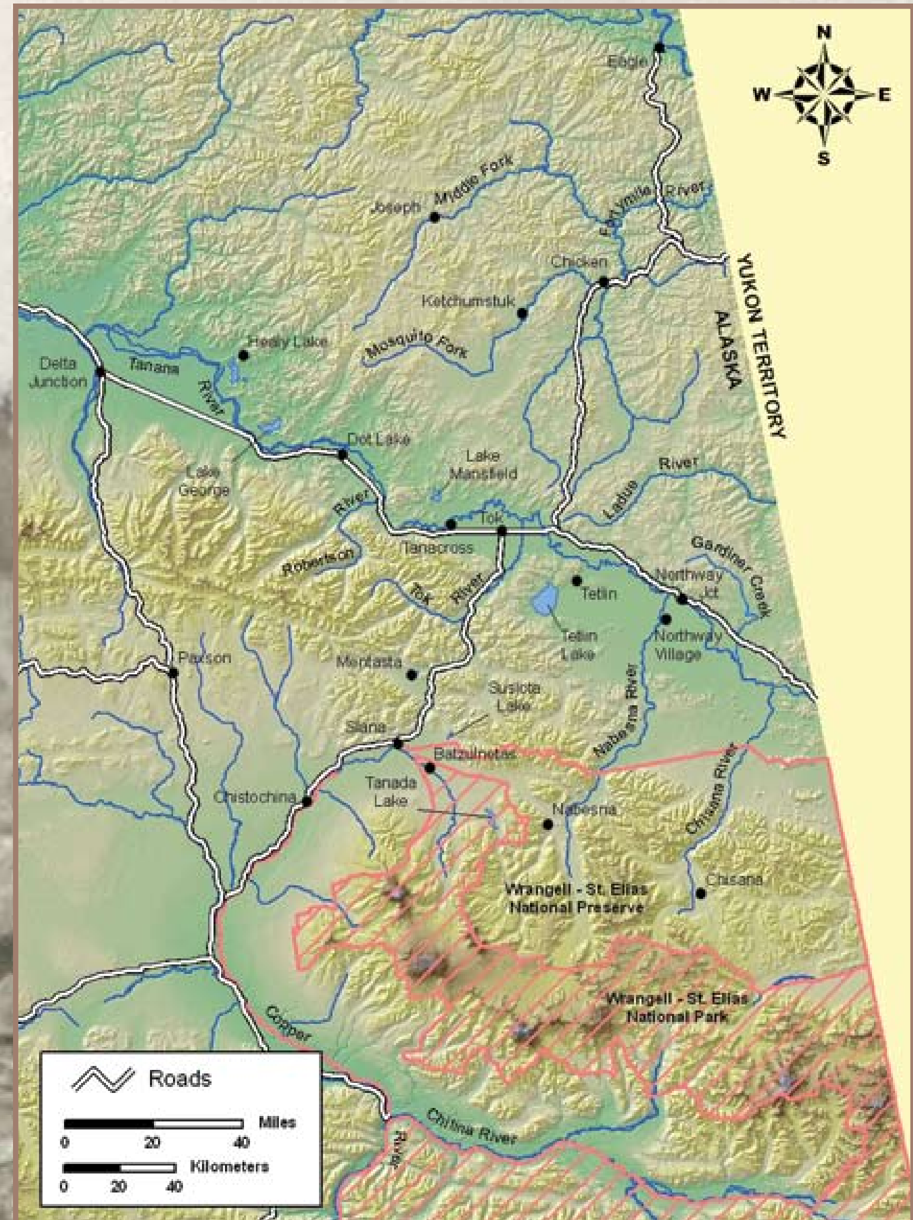
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Lake George
Lake Mansfield
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Tetlin
Tetlin Lake
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Gardiner Creek
Northway Village
Paxson
Mentasta
Suslota Lake
Slana
Batzulnetas
Nabesna River
Chisana River
Chistochina
Tanada Lake
Nabesna
Chisana
Wrangell - St. Elias National Preserve
Wrangell - St. Elias National Park
Copper River
Chitina River
Roads
Miles
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20
40
Kilometers
0
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Wrangell-St. Elias National Park and Preserve and the People of the Upper Tanana

Photograph by William E. Simeone

Figure 2. Martha and Oscar Isaac on Mansfield Creek. This creek is typical of many in interior Alaska. The creek flows out of Mansfield Lake, and at certain times of the year the creek is full of whitefish. On the right side of the photograph is a collapsed dip net platform that was part of an old fish weir used to harvest whitefish.

Figure 1. (Left) Map of upper Tanana and upper Copper River region. Photograph of woman packing dog, circa 1910.
Photograph courtesy of William E. Simeone

By Barbara A. Cellarius, Terry L. Haynes, and William E. Simeone

Visitors to the northern part of Wrangell-St. Elias National Park and Preserve may come away with memories of a spectacular mountain wilderness with glacial rivers, snow-covered peaks, elusive wildlife and brightly colored wildflowers. Underlying these spectacular vistas, however, is a landscape of indigenous human habitation. To the Native peoples of the upper Tanana region, this area is not wilderness but rather their historic home, an area crisscrossed by trails and travel routes where they and their ancestors lived, traveled, hunted, fished, trapped, and gathered.

In 2002, the upper Tanana communities of Healy Lake, Dot Lake, Tanacross, Tetlin, and Northway were added to the list of rural communities that have special access rights to hunt, fish and gather in Wrangell-St. Elias National Park, in recognition of their customary and traditional subsistence use of resources in the park. Wrangell-St. Elias recently commissioned an ethnographic overview and assessment for the upper Tanana area *(Haynes and Simeone 2007)*, focusing on these predominantly Alaska Native communities, in an effort to better understand their history and culture and their ties to the park. This report is based largely on existing ethnographic and historical literature along with archival materials, but the authors also drew on their personal fieldwork in the region. This article is derived from that larger report and focuses specifically on these ties between Wrangell-St. Elias and Alaska Natives living in the upper Tanana region.

For purposes of this article and the larger report, the upper Tanana region extends from the Wrangell Mountains north to Joseph Creek and from the Canadian border west to the confluence of the Goodpaster and Tanana rivers *(Figure 1)*. The region includes mountains, rolling hills and river valleys, numerous lakes and wetlands. With its subarctic climate, the region has long, cold winters and relatively warm summers with many hours of daylight and low precipitation. Two main northern Athabascan languages—Upper Tanana and Tanacross—are spoken by Native residents of the region, although the number of Native-language speakers is declining.

Settlement Patterns and Resource Use

The resource use and settlement patterns of Native people living in the upper Tanana region prior to sustained western contact were tailored to these sometimes difficult environmental conditions and the natural unpredictability of resource abundance. Aboriginal Upper Tanana Indians were semi-nomadic hunter-gatherers who moved seasonally throughout the year within a defined territory to harvest fish, wildlife, and other resources. The key subsistence resources included whitefish, caribou, moose, waterfowl and muskrats.

The basic unit of social organization was a small extended family-based group of between 10 and 30 people, referred to as a local band. These kinship-based bands would split up or join with another group in response to shifting resource availability. Each band was associated with a particular geographic area or territory and had a number of camps and semi-permanent villages. These camps and villages were often sited in proximity to important subsistence resources. Seven regional bands have been identified in the upper Tanana area *(Figure 3)*. The Upper Chisana/Upper Nabesna band territory fell largely within the northern portion of what is now Wrangell-St. Elias National Park and Preserve. In addition, the southern borders of several other bands overlapped with the territory included in the park.

Until the early twentieth century, leadership in Upper Tanana society rested with "'rich men,' who were charismatic, enterprising individuals who combined an in-

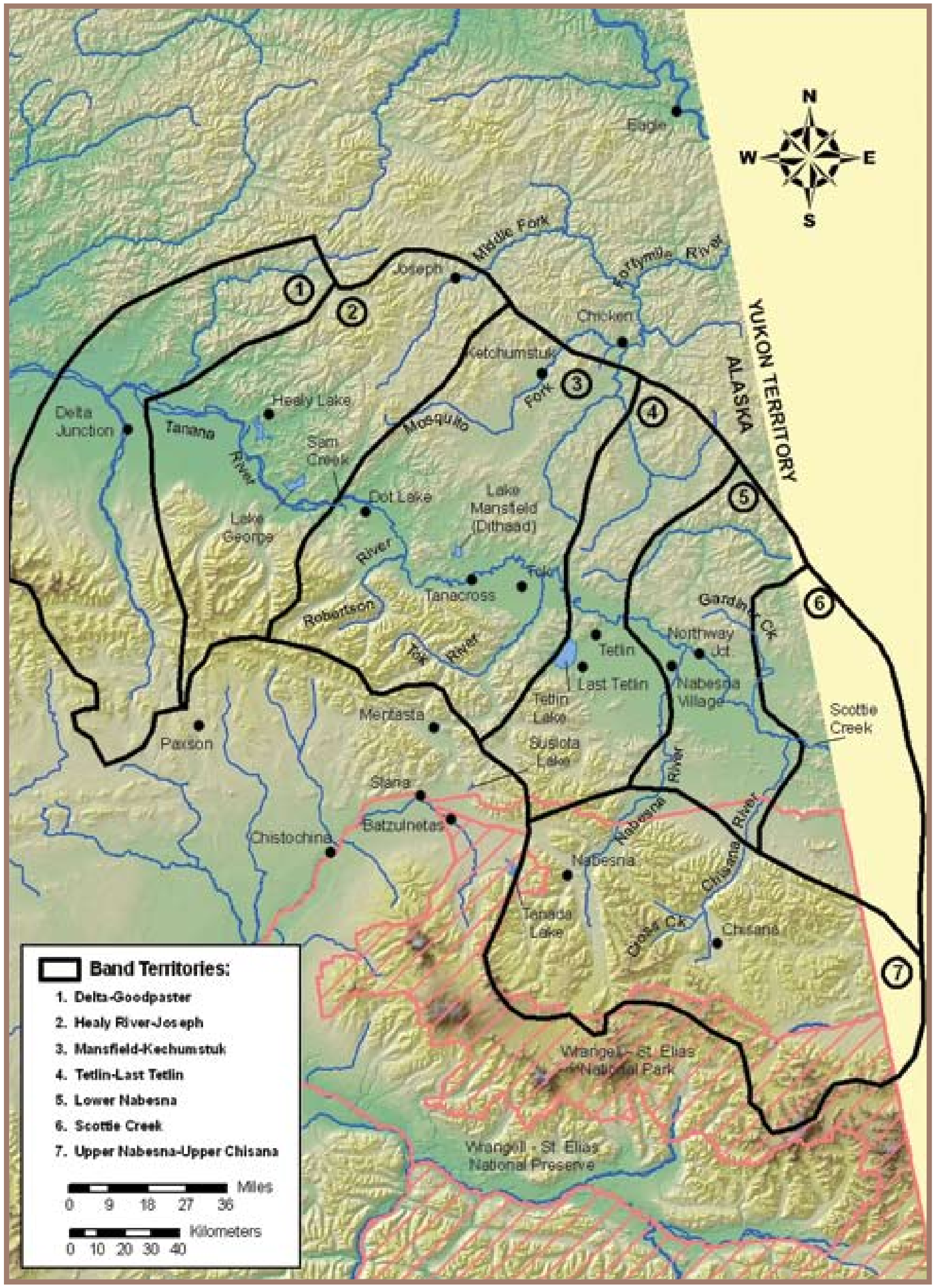

Figure 3. Band territories and villages, upper Tanana region

Photograph by William E. Simeone

Figure 4. Applying smoke to the skin is part of the tanning process and turns the skin a rich golden brown. Martha Isaac of Tanacross tans a moose skin.

Photograph by William E. Simeone

Figure 5. One of the first steps in tanning a skin is to scrape all of the residual fat and tissue from the inside of the hide using the foreleg of a moose or caribou that is sharpened at one end.

Photograph by William E. Simeone

Figure 6. In late May and early June one of the principal subsistence activities is hunting for muskrat. Oscar Isaac of Tanacross, at muskrat camp, is wearing a pair of canvas tennis shoes, the preferred footwear for hunting "rats". Note the aluminum canoe has replaced the traditional rat canoe, which was a one man boat with a birch frame covered in birch bark or canvas.

terest in others" with a degree of personal self-interest *(Haynes and Simeone 2007)*.

Sustained western contact in the upper Tanana region began in the early twentieth century. Residents initially acquired western goods through trade networks linked to the south starting in the mid-1800s, and then by traveling to trading posts outside the region. By the early twentieth century non-Native traders, trading posts and Episcopal missionaries had established a more lasting presence in the region. With World War II came construction of airfields and the Alaska Highway. Settlements began to develop at missions, trading posts, and along transportation links. By the 1930s a much more sedentary lifestyle and residence in villages developed, in part as a response to federal government demands for mandatory school attendance. The adoption of firearms hastened a decline in cooperative hunting efforts such as the use and maintenance of extensive caribou fences. Other agents of change affecting Upper Tanana people in the twentieth century included formal western education, diseases, market hunting associated with mining activities, opportunities for wage employment, and government regulation of hunting and fishing.

Today's Upper Tanana Native residents live in villages on or near the Alaska Highway or in the regional center of Tok. (Others have left the region and live in Fairbanks, Anchorage, or beyond.) Formal leadership in present-day villages takes the form of elected village or tribal councils, although elders continue to be respected for their traditional knowledge and wisdom. The

Figure 7. (Below) Muskrat hunting follows a certain routine. Rats are usually hunted in the evening and throughout the long summer night. In the morning the hunters eat and sleep. In the afternoon they skin the animals, as seen here, and stretch the skins. Some of the meat is roasted over an open fire while the rest is dried for later use. Burlap bags are an important piece of equipment used for a variety of purposes included storing skins and meat.

Photograph by William E. Simeone

Photograph by William E. Simeone

Photograph by William E. Simeone

Photograph by Terry L. Haynes

Figure 8. (Top) The potlatch is one of the most important events in the Athabascan culture of interior Alaska, and singing and dancing is an important component of every potlatch. People in this photograph are from Minto, Northway, Tanacross and Tetlin, all attending a potlatch in Tetlin.

Figure 9. (Middle) View of the upper Tanana River in August. The Chisana and Nabesna Rivers form to create the Tanana River which flows into the Yukon at Tanana.

Figure 10. (Left) Jessie David of Tetlin holding a fleshing tool used to remove flesh and fat from a moose skin. This tool has a steel blade attached to a moose tibia bone.

Photograph by William E. Simeone

Figure 11. The winter trail above Mansfield Creek. Snow machines are used for hunting moose and trapping in the winter.

Terry L. Haynes Collection, photo by Libby Halpin

Photograph by William E. Simeone

Figure 12. (Top) Women's "Dance with the Guns" at a potlatch ceremony in Tetlin, June 1984.

Figure 13. (Left) Julius Paul of Tanacross demonstrates how to hold a bow. Mr. Paul was an expert craftsman who made drums, bows and arrows. The bow and arrow stave are made of birch and the bow string of moose sinew.

councils are recognized by the federal government as tribal governments. Although many adults are employed and patterns of resource use have changed, subsistence hunting and fishing continue to contribute substantial amounts to their diet and to sustain profound cultural values of sharing, the appropriate treatment of animals, and respect and appreciation of elders.

Upper Tanana Ties to Wrangell-St. Elias

Residents of the upper Tanana villages continue to harvest resources in the northern part of Wrangell-St. Elias—for example, hunting moose along the Nabesna Road or sheep in the Mentasta and Wrangell mountains. In many cases this is done under the provisions of federal subsistence hunting regulations and a permit obtained from the park. Many of the descendents of the Upper Chisana/Upper Nabesna band now live in Northway, Chistochina, and Mentasta and continue to hunt in the areas used by their ancestors.

In addition to the location of the band territories and continued use of those territories for subsistence activities, another factor in these interregional ties is the close relationships between the Native residents of the upper Tanana and the neighboring Ahtna region, in the form of intermarriage, trade, potlatches, and other kinds of interregional cooperation. Potlatches, which are gatherings involving the ritual distribution of gifts to memorialize life transitions and mediate conflicts, play a key role in binding people from the two regions together. Additionally, people from Upper Tanana bands, with kinship ties to the Upper Ahtna, harvest resources in the Ahtna region, which also overlaps with the park. For example, salmon are not available in the upper Tanana River drainage, but through kinship ties to the Ahtna, residents of the upper Tanana villages harvest Copper River salmon. Ahtna people, in turn, sometimes hunted caribou near Kechumstuk. Further evidence of these ties can be seen in the extensive network of trails and travel routes that run between the two regions, with many of the trails crisscrossing what are now park lands.

Summary

This article is based on information presented in an ethnographic overview and assessment for the upper Tanana area that was prepared for the National Park Service

Terry L. Haynes Collection, photo by Libby Halpin

Figure 14. One method of harvesting whitefish in Tetlin was to use a dip net. A weir or "fence" made of spruce and willow branches and platform is used in combination with the large hand-made dip net.

(Haynes and Simeone 2007). The overview and assessment covers Athabascan culture in the upper Tanana region prior to sustained western contact at the beginning of the twentieth century and examines the traditional economy, sociopolitical organization, territory, language, ritual and religion, material culture, and trails. Additionally, it reviews changes that occurred during the twentieth century. An annotated bibliography for information on the history and culture in the upper Tanana region is also included. This larger report should be consulted for additional information about the topics discussed in this article (available at **http://www.subsistence.adfg.state.ak.us/geninfo/publctns/techpap.cfm** and **http://www.nps.gov/wrst/historyculture/upper-tanana-ethnographic-study.htm**).

Photograph by Terry L. Haynes

Photograph by Terry L. Haynes

Figure 15. (Top) Potlatch drummers (in foreground, left to right): Ahtna elder Huston Sanford, along with Upper Tanana elders Chief Andrew Isaac, Kenneth Thomas, Charlie James, and Abraham Luke.

Figure 16. (Left) Chief Andrew Isaac with Chief Walter Northway and Lily Northway dressed in chief's regalia.

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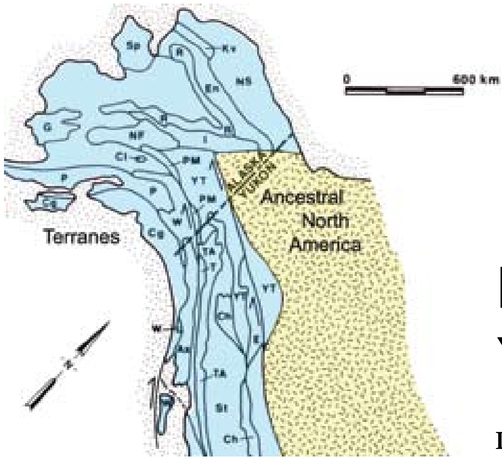


Figure 2. Generalized map of terranes of Alaska and Canada. Ancestral North America is shown in yellow, and the various accreted terranes are shown in blue. The Woodchopper Canyon terrane is too small to been seen at this scale and is part of the Yukon terrane (YT). Modified from Coney et al. (*1980*).

Figure 1. (Left) Outcrop and talus slope of Woodchopper limestone on the north side of the river opposite Woodchopper Roadhouse. The limestone is slightly recrystallized and contains abundant disarticulated crinoids and sparse brachiopods and corals.

Paleogeography of Woodchopper Volcanics, Yukon-Charley Rivers National Preserve, Alaska

David M. Rohr, Robert B. Blodgett, and Douglas Beckstead

In recent years, the concept that nearly all of Alaska, as well as much of the western Cordillera of North America, are composed of numerous discrete, accreted tectonostratigraphic terranes (*Figure 2*) has gained general acceptance. The only exception to this in Alaska is the triangular area of east-central Alaska, bounded on the northwest by the Porcupine River and on the southwest by the Yukon River.

The Yukon River meanders through the Yukon-Charley Rivers National Preserve for a distance of approximately 130 river miles in a roughly east-west transect across the Charley River 1:250,000-scale quadrangle. The river exposes a record of 800 million years of Earth history (Precambrian through Cenozoic) and contains an extensive fossil record. These rocks are separated into two disparate portions by an obliquely transecting basin of deep-water flyschoid rocks of Jura-Cretaceous age. Fossils from the eastern belt are relatively well known and are from autochthonous (non-accreted) strata belonging to the western edge of the Paleozoic North American continental margin. However, fossils and strata of the western belt of pre-Jurassic age rocks exposed along the Yukon River and the adjoining low hills to the north and south are more poorly understood.

Examination of the limited published reports as well as the more extensive unpublished fossil lists in the Alaska Paleontological Database (**www.alaskafossil.org**) show many anomalous taxa, particularly in the Devonian, Permian, and Triassic. These taxa, particularly brachiopods, are not known from cratonic North America, but have Asian affinities. The goal of the ongoing study is to resolve the question of whether or not this western belt represents an assemblage of accreted terranes, and what are their paleobiogeographic affinities and possible paleogeographic origin. Fossils have proven in the past two decades to have great utility in the study of Paleozoic biogeographic affinities and possible origins of accreted terranes along the western margin of North America (*Blodgett et al. 2002*).

This western belt has been suggested as being composed of several tectonostratigraphic terranes in previous tectonic reconstructions of this area (*Churkin et al. 1982, Jones et al. 1981, Nokleberg et al. 1994, Silberling et al. 1994*); however, the terrane units recognized show no consistency (and usually quite conflicting usage) between the various authors. Terrane names applied include: Woodchopper Canyon terrane (*Churkin et al. 1982, Jones et al. 1981, Silberling et al. 1994*), Slaven Dome terrane (*Churkin et al. 1982*), Circle terrane (*Churkin et al. 1982*), Takoma Bluff terrane (*Churkin et al. 1982*), Porcupine terrane (*Jones et al. 1981, Nokleberg et al. 1994, Silberling et al. 1994*), Tozitna terrane (*Jones et al. 1981, Silberling et al. 1994*) and Angayucham terrane (*Nokleberg et al. 1994*).

Mertie (*1930*) named the Woodchopper Volcanics for complexly folded and faulted basalt and pyroclastic rocks, interbedded limestone, shale, and chert cropping out along both banks of the Yukon River from the mouth of Coal Creek (*Figures 3 and 4*) and extending 15 miles downstream to the south bank of the Yukon beyond the mouth of Thanksgiving Creek (*Figure 3*). Edwin Kirk identified the fossils and regarded them as Middle Devonian (*Mertie 1930, 1937*). Mertie (*1930*) noted that the formation differed from other Middle Devonian units in Alaska in that it is mainly volcanic and that the fauna appeared to be diferent from the typical Middle Devonian fauna.

Mertie (*1937*) illustrated two masses of fossiliferous limestone, the type section later designated by Lane and Ormiston (*1976*), on the north side of the Yukon above Woodchopper Creek. Mertie (*1937*) described the limestones as being recrystallized to varying degrees, and the fossils as poorly preserved.

Brabb and Churkin (*1969*) mapped the Charley River Quadrangle and placed the Woodchopper Volcanics in fault contact with the Permian Step Conglomerate and Paleozoic argillite to the north and in fault contact to the south with the Permian Tahkandit limestone and Cretaceous Biederman argillite. Dover and Miyaoka (*1988*) reinterpreted the map placing the Woodchopper in fault contact to the north with the Devonian Nations River conglomerate and McCann Hill Chert. They also mapped a syncline in the Woodchopper in the Thanksgiving Creek area.

Lane and Ormison (*1976*) determined an Early Devonian (Emsian) age for the type section of the Woodchopper Volcanics (see geologic time terms in Figure 9). Conodonts found included *Polygnathus dehiscens*, *Pelekysgnathus furnishi*, *Pelekysgnathus* cf. *P. serratus*, and *Pandorinellina exigua*. Megafossils included the coral *Xystriphyllum* sp. They also evaluated the megafossil identifications made in Mertie.

Brabb and Hamachi (*1977*) provided chemical analyses of seven samples of volcanic rocks from the Woodchopper.

Churkin, Trexler and Carter (*1982*) reported Early Devonian (Pragian) graptolites (*Monograptus yukonensis*) from a volcanic rock section 5.5 km downstream of the mouth of Woodchopper Creek.

Churkin et al. (*1982*) named the fault-bounded Woodchopper Canyon Terrane to include the basaltic pillow lavas, pillow breccia, submarine tuffs, volcanic graywacke, and minor shale and limestone. They also observed turbidites and olistostromes in the Woodchopper, and concluded that the shelly fauna was transported into deeper-water deposits interbedded with the volcanics.

As part of the present study, field work was conducted in June 2006 by David Rohr, Robert B. Blodgett, and Doug Beckstead. Our objective was to access a number of previously known localities (from the Alaska Paleontological Database), and to gather a large, taxonomically diverse collection of Devonian fossils. During our visit, the Yukon River was high, many of the

Figure 3. The Woodchopper Volcanics are named for Woodchopper Roadhouse, across the Yukon River from the outcrops of the formation. Coal Creek and Woodchopper Creek were the site of gold placer mining. Squares are six miles on each side. From USGS Charley River 1:250,000 topographic map.


Photograph by David Rohr

Figure 4. View to the north across the Yukon River at Woodchopper Roadhouse. Cliffs are the Devonian-age Woodchopper Volcanics with an interbedded limestone layer at right.

Photograph by David Rohr

Figure 5. Pillow basalts of the Woodchopper Volcanics exposed in a cliff on the north side of the Yukon River.

Photograph by David Rohr

Figure 6. Pillow basalts in the Woodchopper Volcanics were first illustrated and described by J. B. Mertie in the 1930s as "ellipsoidal basalts". Pillow basalts are now generally accepted as evidence of subaqueous volcanic activity and formed by repeated oozing and quenching of the hot basalt.

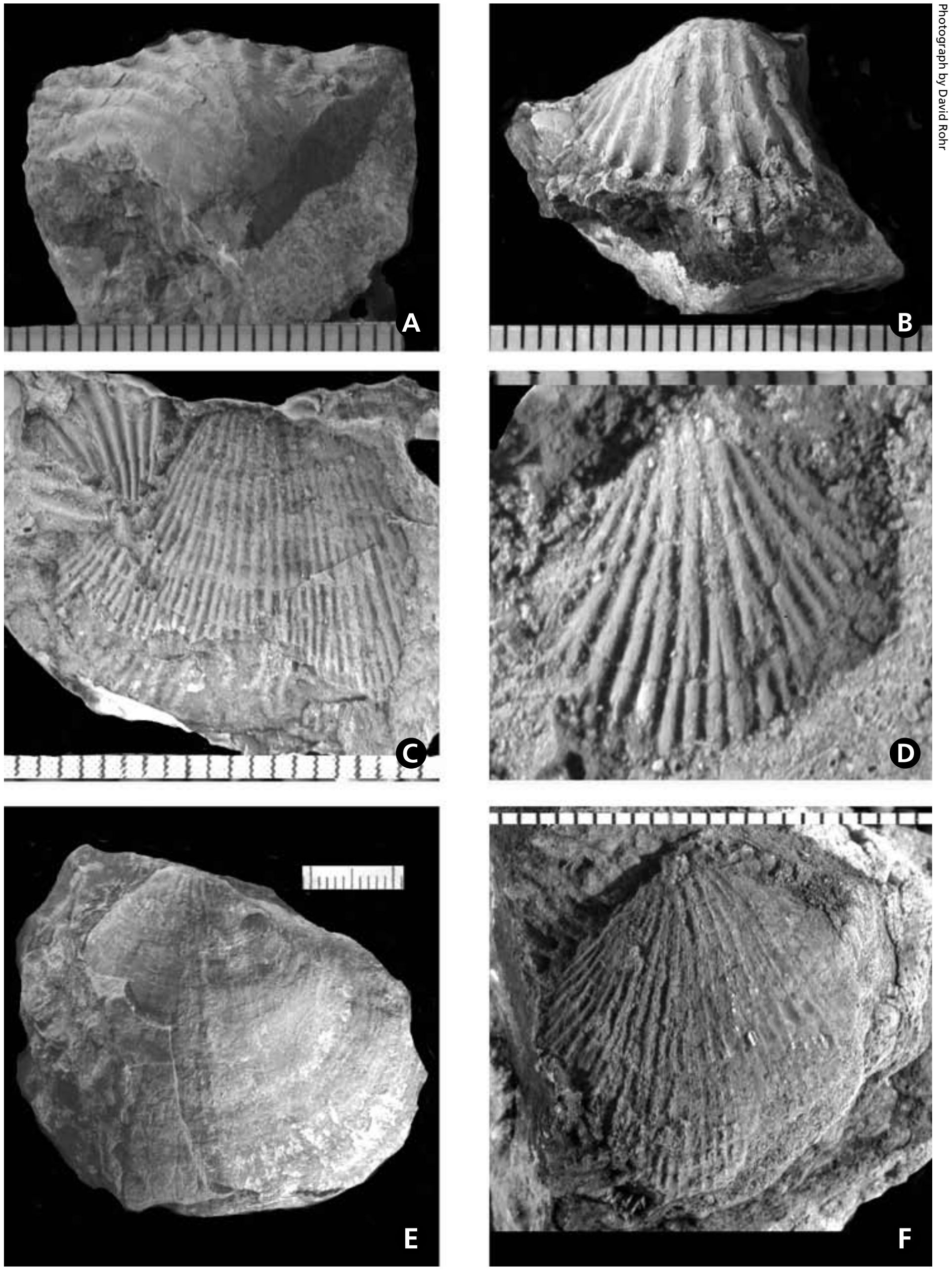


Figure 7. Devonian brachiopods from limestone bed within the Woodchopper Volcanics. (A) and (B) *Vagrania* sp., YUCH 2993; (C) *Schizophoria* sp., YUCH 2994; (D) indeterminate atrypid; (E) undetermined smooth brachiopod, YUCH 2995; (F) *Desquamatia*? sp., YUCH 2996. Scale is in millimeters.

intended collection sites were under water, and only two sites were accessible. One locality is a talus slope on the north side of the river adjacent to and below an outcrop of Woodchopper limestone (*Figure 4*). The limestone is a slightly recrystallized packstone to grainstone with abundant disarticulated crinoids and sparse brachiopods and corals. The second locality is talus below Woodchopper limestone outcrops on the south side of the river. The latter material is also recrystallized and contains slightly more abundant tabulate corals.

The limestone of the formation occurs interbedded with thick units of pillow basalts that are spectacularly exposed in cliffs along the river (*Figure 3, 5, and 6*). These volcanics were described by Mertie (*1930, 1937*) as ellipsoidal flows. Pillow basalts are now generally accepted as evidence of subaqueous volcanic activity and formed by repeated oozing and quenching of the hot basalt. The interbedded marine limestone indicates an origin on an oceanic plate or an island-arc setting.

Brachiopods from the Woodchopper are poorly preserved and include *Schizophoria* sp., *Ivdelinia* sp., indet. gypidulids, *Desquamatia*? sp., *Vagrania* sp., and indet atrypids (*Figure 7*). Solitary rugose corals belonging probably to the genus *Acanthophyllum* are relatively common.

Although most of the brachiopod elements are relatively cosmopolitan, the Eurasian aspect of the fauna is indicated by the typical Old World Realm gypidulinid *Ivdelinia* (*Figure 8*). The genus is widely reported from Early Devonian (Lochkovian-Emsian) and early Middle Devonian (Eifelian) age rocks of the Rhenish-Bohemian and Uralian Regions, but is almost unknown in the Cordilleran Region of the Old World Realm which, in the Emsian, included Arctic and western Canada and Nevada. Only two species have been described from Emsian-Eifelian strata of the Cordilleran Region: these are *Ivdelinia grinnellensis*, and *Ivdelinia* (*Ivdelinella*) *ellesmerensis*), both of which occur in the Canadian Arctic islands. The only other place in Alaska in which the Ivdelinia occurs is at Shellabarger Pass in rocks belonging to the Mystic subterrane of the Farewell terrane (*Blodgett et al. 2002*).

Based on our observations of the pillow basalts and limited collections from the

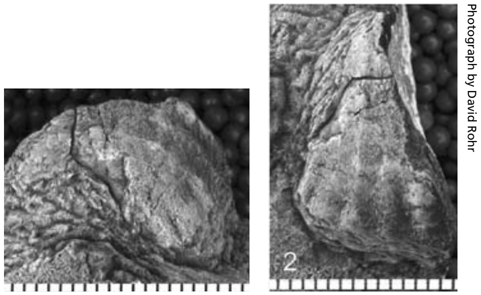
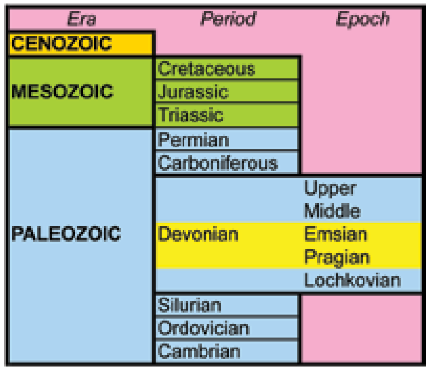


Figure 8. *Ivdelinia* sp., specimen YUCH 2997. The brachiopod genus *Ivdelinia* is widely reported from Early Devonian and early Middle Devonian age rocks of the Rhenish-Bohemian and Uralian Regions, but is almost wholly unknown in cordilleran North America. The presence of *Ivdelinia* indicates a link to Eurasia and the accreted Farewell terrane of southwest Alaska. Scale is in millimeters.

interbedded limestone we conclude that the Woodchopper Volcanics represent part of an accreted terrane not related to cratonic North America. It may have originated in an oceanic island-arc setting adjacent to the Urals and may be related to the Farewell and Alexander terranes of southern Alaska, which likewise have Emsian biotas of Uralian and/or Siberian aspect.

Fieldwork in Summer 2006 was supported by grant 7987-06 from the National Geographic Society to Rohr. Transportation and logistical support in the Yukon-Charley Rivers National Preserve was provided by the National Park Service. Specimen numbers are those of the Yukon-Charley Rivers National Preserve.

Figure 9. Generalized geologic times scale showing the divisions of the Devonian Period referred to in text.



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Photograph by M. Pepinelli

Photograph by M. Pepinelli

Figure 2. (Above Top) Myth buster: Although the name implies that all black flies are black, a small number of species are orange, including the large, pestiferous females of Alaska's *Prosimulium fulvum*.

Figure 3. (Above Bottom) Female mosquito of the genus *Aedes*, one of about 23 species of mosquitoes in Beringia that savage humans and other homeotherms.

Figure 1. (Left) The vast, open landscape of Beringia is dissected and pock marked by streams and pools, providing fertile breeding grounds for more than 80 species of black flies and mosquitoes.
Photograph by D.C. Currie

Barbarians at the Gate: Biting Flies of Beringia

By Peter H. Adler and Douglas C. Currie

For blood-sucking flies, the Far North is a paradise of food and breeding habitat, but for the animals and humans that reluctantly furnish the blood, the Far North is hell on Earth (*Figure 1*). The world's largest populations of black flies (*Figure 2*) and mosquitoes (*Figure 3*) are found in northern regions of the globe, where densities of larval black flies can exceed 600,000 larvae per square meter of streambed, and populations of even a single species of mosquito can reach unsettling densities of more than 30 million adults per hectare. Legendary for their blood-sucking habits and noxious behavior of ceaselessly swarming around their hosts (*Figure 4*), biting flies are responsible not only for enormous economic losses but also for the limited extent to which northern regions have been inhabited and developed (*Adler et al. 2004*). They can suppress tourism and gouge the economy of afflicted communities. They can be so vexatious to wildlife that the timing and extent of migrations of animals such as caribou are significantly altered. Biting flies also routinely transmit microorganisms that cause wildlife diseases such as avian malaria and leucocytozoonosis.

Although adult biting flies can have a negative effect on humans and wildlife, they also play an integral role in the environment as pollinators, food for predators such as songbirds, and regulators of wildlife populations (*Malmqvist et al. 2004*). There is also the controversial perspective that biting flies are some of the finest conservators of northern habitat, limiting settlement and development in environmentally sensitive areas. The immature stages of biting flies are innocuous, but important, components of the aquatic food web and are useful indicators of water quality, often providing the first signs that an aquatic habitat is polluted. Larval black flies (*Figures 5-6*) have been called "ecosystem engineers" because of their vital role in processing dissolved and particulate organic matter into larger fecal pellets used as food by other aquatic organisms (*Malmqvist et al. 2004*).

Despite the prominent role that biting flies play in the economies and ecosystems of northern regions, the individual species remain poorly known. This paradox can be explained by the logistical problems of conducting research in the vast expanse of the Far North, by independent efforts of scientists on either side of the Bering Strait, and by past technical limitations in distinguishing similar species. Alaska, for example, has 63 recorded species of black flies, but prior to our work, only 10 species were known west of Fairbanks, a significant underestimate of the area's true biodiversity (*Adler et al. 2004*). Thirty-two species of mosquitoes have been recorded from Alaska, with 18 known west of Fairbanks (*Darsie and Ward 2005*).

A major factor hampering an understanding of Beringian biting flies has been the largely independent efforts of North American and former Soviet researchers. Working in scientific isolation, researchers on different sides of the Bering Strait often gave the same species of fly different scientific names, obscuring faunal similarities and common experiences of the people and wildlife exposed to the pest species. The extent to which the species of biting flies are shared between Russia and North America remained unknown because the most critical areas, western Alaska (eastern Beringia) and Far East Russia (western Beringia)—physically connected as recently as 11,000 years ago and now separated by a mere 52 miles (84 km)—were poorly surveyed for biting flies.

Photograph by D.C. Currie

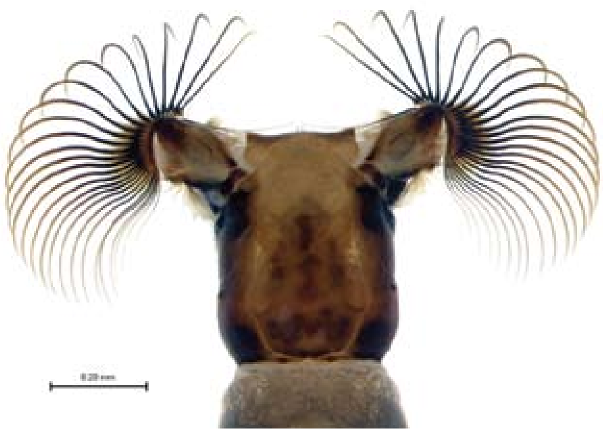
Figure 4. Bane of Beringia: mosquitoes.

Similarities in the biting fly fauna on the two sides of the Bering Strait would suggest that certain experiences, traditions, and cultural practices related to biting flies, such as the use of natural repellents and spiritual beliefs, also might be shared. Because biting flies can negatively impact reindeer (caribou) populations, they could affect the economy of some inhabitants of Beringia that rely on reindeer herding. Reindeer herding remains a viable industry and important part of the non-maritime Chukchi culture in Chukotka, where about a half million domesticated reindeer live; in fact, "Chukchi" means reindeer people.

Under the auspices of the Shared Beringian Heritage Program of the National Park Service, we began a multifaceted investigation of the biting flies of Beringia, focusing particularly on black flies, the more poorly known of the biting flies. To test the hypothesis that the Beringian black fly fauna includes a greater number of shared species than heretofore recognized, we sampled biting flies over a period of two years, concentrating in the heart of Beringia, roughly Alaska west of the road network and Far East Russia east of the Anadyr River. Beringia is a largely undeveloped land, difficult and expensive to access and traverse. Consequently, we used several less conventional modes of transportation including float planes, rafts, and track vehicles (*Figure 7*), and chose sampling areas that would provide the broadest range of topography and habitat. Our Alaska research took place in 2005 and 2006 on the Seward Peninsula, around Bethel, and along the 130-mile (210-km) Kisaralik River. Our research in Russia was carried out in July 2006 along the Andayr River from its confluence with the Belaya River to Anadyr, the capital city of Chukotka. Larval and pupal biting flies were sampled from seepages, streams, rivers, tundra pools, and lakes along these routes. Specimens were hand collected, using fine-tipped forceps, from all available substrates (e.g., rocks and vegetation) in the flowing waters (*Figure 8*) and by using aquatic dip-nets in standing waters.

Many species of biting flies are structurally similar to one another. To discover these look-alike species and test faunal similarities within and between eastern and western Beringia, we used a two-pronged approach involving cytogenetic and morphological techniques. Larvae and pupae were collected into Carnoy's solution (1:3 acetic acid: ethanol) for subsequent analysis of the banding patterns in the giant larval silk-gland chromosomes and in 95% ethanol for morphological study. Adult biting flies were collected with aerial nets and placed in 95% ethanol or pinned in the field. We linked the adult flies with their immature stages and associated breeding sites by rearing pupae to adults in small petri dishes lined with moist filter paper. Each species of black fly was categorized as a bird feeder or mammal feeder, based on the design of the female's claw, which has a thumblike lobe in bird feeders, but is a simple curved talon in mammal feeders. Our specimens were identified, cataloged, and deposited in the Clemson University Arthropod Collection in South Carolina and the Royal Ontario Museum in Toronto, Ontario, to serve as a permanent record of the Beringian biting fly fauna and a resource for future researchers.

We found 56 species of black flies in the heart of Beringia, 40 in eastern Beringia and 37 in western Beringia. At least 55% of the species are shared. Twenty-three species of mosquitoes occupy Beringia, with 18 eastern, 26 western, and 70% shared. Of the 56 species of black flies in Beringia's heartland, 23% acquire blood from birds and 45% from mammals, whereas 32% do not take blood, having mouthparts too weak to cut flesh. Those black flies that do not take blood must acquire their energy during the larval stage. The percentage of species without biting mouthparts is the highest for any area of the world, exceeding even that of Canada's Barrenlands (26%). Time not spent locating a host and acquiring a blood meal



Photographs by M. Pepinelli

Figure 5. (Left) The larval head of most black flies, such as *Prosimulium neomacropyga*, is fitted with a pair of labral fans for filtering particulate matter from the water current. When the fans have captured sufficient food, the larva folds them toward the mouth and scrapes off the adherent material.

Figure 6. (Right) Larvae of the Beringian endemic *Gymnopais dichopticus*, and seven other species of black flies, do not have fans for filter feeding, instead scraping their food from stones to which they adhere in flowing water.

Photograph by D.C. Currie

Figure 7. Sampling for biting flies in Beringia can require unconventional means of transportation, such as track vehicles in Chukotka, Russia, to reach a variety of habitats. Here the driving crew has set up lunch by a collecting station for the authors.

Photograph by P.H. Adler

Figure 8. A typical cold-water stream on the Nome-Taylor Road yields two species of black flies. The author (Currie) samples prime microhabitat—a stone in a riffle.

Photograph by D.C. Currie

Figure 9. Alaska streams and rivers emptying into the Bering Sea across the Strait from Russia produce prodigious numbers of black flies that could be transported to Chukotka on the wind. The author (Adler) samples larval black flies from stones in a small stream that produced eight species.

Figure 10. Barbarian at the gate: *Simulium vittatum*, a pest of humans and domestic animals, is common in eastern Beringia but has not yet crossed the Bering Strait.

Photograph by M. Pepinelli

is time devoted to reproductive effort in an extraordinarily harsh environment subject to the vagaries of weather. Two Beringian black flies have taken environmental independence a step further. Not only have they eliminated the need for blood, but also the need to mate; males of these species do not exist, and reproduction is by virgin birth (parthenogensis).

Beringia was a cradle of biodiversity in the Far North, with numerous species dispersing from Beringia as the ice sheets melted. We have consistently found that each species of black fly is more genetically differentiated as the distance east of Beringia increases. Approximately 58% of the species of black flies in western Alaska are shared with Russia, whereas about 70% of the species in Far East Russia are shared with Alaska. In other words, all but 11 of Far East Russia's 37 species also occur in North America, but only 23 of our 40 western Alaska species occur in Russia. Whereas most Beringian black flies are widely distributed in the northern hemisphere, seven species are endemic to Beringia, occurring nowhere else in the world. No mosquitoes, however, are Beringian endemics.

Although Beringia was the main source area for black flies that repopulated northern North America after deglaciation, it also received a substantial number of immigrant species from southern refugia. Among these immigrants are several major pest species of humans and domestic animals. These immigrant pests boil from the rivers and streams of eastern Beringia (*Figure 9*), yet none have managed to cross the Bering Sea into easternmost Russia.

But the barbarians are at the gate. Our previous work has shown that distances of less than 62 miles (100 km) are not a major obstacle to black fly dispersal (*Adler et al. 2005*). Species, including pests, from southern areas of North America have worked their way northward following the Wisconsinan glaciation, a process likely to continue with global warming. Insects, including biting flies, with their strong dispersal abilities and short generation times, track climate change far more quickly than most organisms. One of these species, *Simulium vittatum* (*Figure 10*), is among North America's most abundant and widespread black flies and is a significant pest of humans and large mammals. This species and others are poised to colonize the opposite side of the Bering Strait. We now have the baseline data to monitor ongoing changes in the Beringian biting-fly fauna as climate change continues.

Acknowledgements

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Volcanoes and Permafrost in Bering Land Bridge National Preserve, Arctic Alaska

By James E. Beget and Jeffrey S. Kargel

Introduction

A famous early twentieth century geologist named William Morris Davis proclaimed that "volcanoes are accidents of nature." Morris believed that volcanic eruptions were anomalous and random events that could not be scientifically classified. Today, scientists know that volcanic eruptions involve a bewildering range of behavior and eruptive styles, resulting in numerous very different landforms that are all called volcanoes. So many different kinds of volcanic eruptive processes and different varieties of volcanoes have now been described that the confusion and consternation that William Morris Davis evinced at the beginning of the twentieth century over the nature of volcanism seems entirely understandable.

That various volcanic features are produced by different kinds of eruptions is well known even to non-scientists. For instance, the mostly gentle slopes of Kileaua Volcano in Volcanoes National Park in Hawaii were formed by lava flows while the deep crater at Mt. St. Helens in the Mt. St. Helens National Monument was created when the side of the mountain collapsed into the valley below. To complicate things further, volcanic processes can be strongly influenced by non-volcanic factors in the local environment. For instance, lava will erupt quite differently depending on whether it has been erupted on land, or on the sea floor, or under a glacier.

My colleagues and I have been investigating the processes and landforms produced by prehistoric volcanic eruptions through permafrost in the Bering Land Bridge National Preserve (BELA). BELA was not originally set aside to preserve its unique volcanoes, and it is not well known as a "volcano" park. However, scientific interest is growing in the unusual volcanoes found there, as they provide evidence of a new variety of volcanic eruption.

Volcanic eruptions through permafrost

The first scientist to work on the volcanoes of BELA was David Hopkins of the U.S. Geological Survey, who made annual expeditions to the Seward Peninsula during the 1950s and 1960s. Hopkins had a broad and eclectic range of both personal and scientific interests and made important scientific discoveries in biology, paleoecology and archeology, as well as geology (*O'Neill 2004*).

Hopkins mapped the extensive lava flows and volcanic craters of the Seward

Figure 1. Imuruk Lake from Cinder Cone

Photograph by James Beget

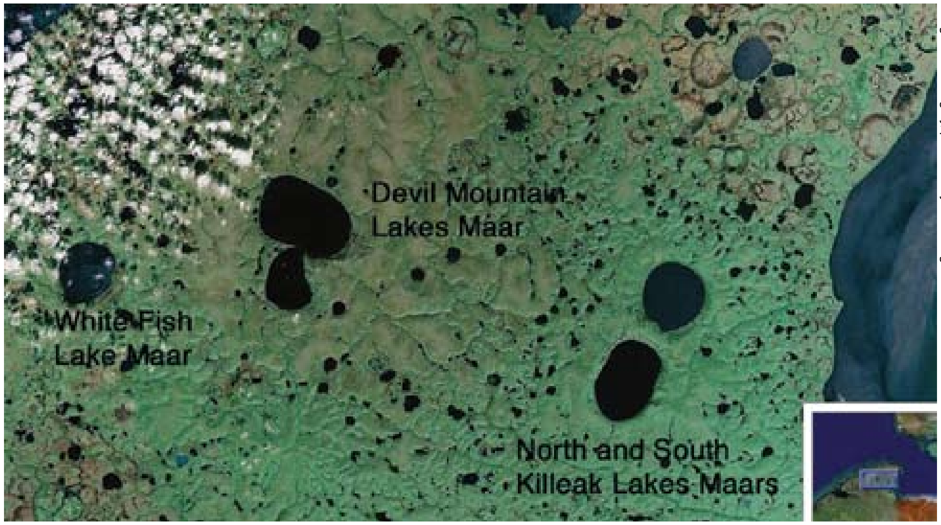

Figure 2. The Devil Mountain Lakes Maar, North and South Killeak Lakes Maars, and the White Fish Lake Maar are larger then any other maar on earth. The Killeak Lake Maars, for example, are about 5 km in diameter.

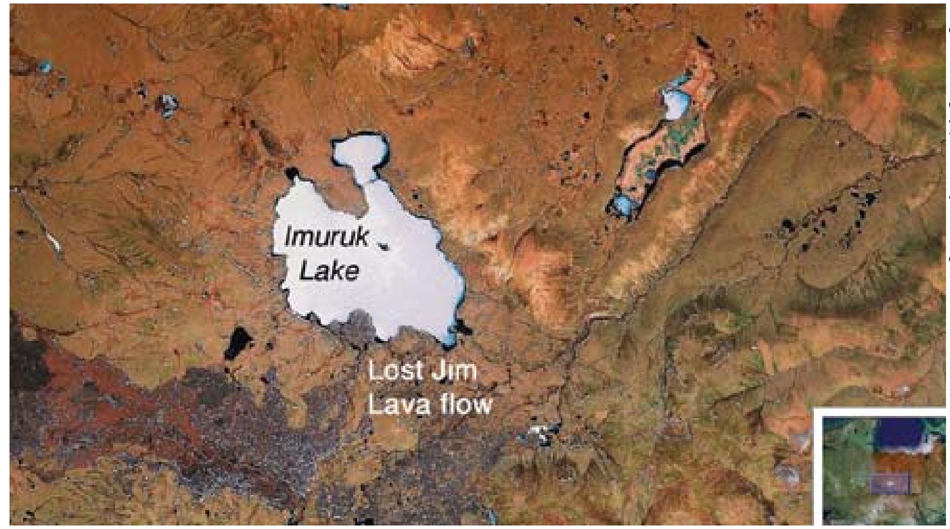

Figure 3. The Lost Jim lava flow is the youngest lava flow on the Seward Peninsula. It flowed northward over permafrost into Imuruk Lake and constructed a large delta on the south side of the lake.

Peninsula and recognized that some of the volcanic features were only a few thousand years old (*Hopkins 1959, 1967*). In the 1980s, David Hopkins took a position as a Professor at the University of Alaska Fairbanks, and the National Park Service sponsored a research program that allowed Hopkins to continue his research with a group of young faculty and graduate students. I was one of the young professors fortunate enough to accompany David Hopkins.

It soon became apparent that some of the volcanoes on the Seward Peninsula were quite unusual. Maar craters are common volcanic features created when volcanic explosions excavate a circular depression into the earth, which often fills with water. However, maars in the rest of the world are usually less than a thousand feet across, and rarely are more than 1.2 miles (2 km) in diameter. In contrast, each of the four maar craters on the Seward Peninsula was at least 3 miles (5 km) across, and the largest was more than 5 miles (8 km) across (*Figure 2*). The maar craters in BELA were the largest maars on earth…but why were they so large?

We looked at the lava chemistry and volume of the erupted material, but these weren't unusual in any way. We finally concluded that the BELA maars were formed by a previously unknown eruptive process—the interaction of magma and permafrost (*Beget et al. 1996*). At the Espenberg maars, the thermodynamic properties of ice played a key role in triggering large explosive steam eruptions. Radiocarbon dating indicated these eruptions occurred about 18,000 radiocarbon years ago. The explosive eruptions produced ash that fell many miles from the volcanoes and deeply buried the land surface around the volcanoes, preserving ice-age plants that were growing in this area when the eruptions occurred (*Höfle et al. 1999*). When magma at 1000-1100°C contacted permafrost, the result was large steam explosions. The frozen ground contained a large supply of water at the time of the eruptions, allowing numerous large steam explosions to occur and excavate the large craters

The Devil Mountain Lakes, Whitefish Lake and North and South Killeak Lakes on the northern Seward Peninsula were all recognized as giant volcanic maar craters created by eruptions through permafrost (*Figure 2*). Each crater was excavated by hundreds of steam explosions, and surrounding these craters were deposits of pyroclastic density currents and poorly sorted ejecta that had been blasted out of the frozen ground during the hundreds of phreato-magmatic explosions (*Beget et al. 1996*).

Martian environments, Martian volcanism and volcanoes in the Bering Land Bridge National Preserve

The discovery of the giant maar craters in BELA at first seemed to be merely a volcanologic curiosity without any wider signficance. There were apparently no other examples of these features anywhere on earth. Areas with active volcanism like Iceland or Kamchatka had little permafrost, and areas like Siberia and Tibet with signficant permafrost had little active volcanism. However, the possibility arose

Photograph by James Beget

Figure 4. We traversed the Lost Jim lava flow on foot. The surface of the flow showed beautiful pahoehoe texture, consistent with a tube-fed origin.

Photograph by James Beget

Figure 5. We used an air taxi to get to Imuruk Lake. All our field equipment, scientific instruments and supplies were tightly packed into the floatplane.

of looking for landforms similar to those in the Bering Land Bridge National Preserve in a surprising place…on the planet Mars.

NASA started sending satellite orbiters and landers to Mars with the Mariner missons in the 1960s and the Viking missions of the 1970s. The Soviet Union also sent missions to Mars in the early 1970s. After a 20-year-long hiatus, NASA returned to Mars with the Pathfinder Missions in the 1990s, and NASA, the Japanese Space Agency and the European Space Agency have all sent missions to Mars since then. From the time the earliest photographs from these Martian space probes were sent back, it was apparent that Mars combined volcanoes and permafrost. Mars was the perfect environment to search for the products of volcano-permafrost interactions similar to those found in Bering Land Bridge National Preserve.

Mars, with a mean average air temperature of -81°F (-63° C), has surface temperatures not that dissimilar to winter temperatures in Alaska, and the pictures sent from landers that successfully reached the Martian surface showed polygonal patterns and cracks that indicated the presence of permafrost and ice wedges, similar to ground ice features


Photograph by James Beget

Figure 6. There are numerous collapse features and pits within the Lost Jim lava flow. These features are interpreted as thermokarst produced when permafrost under the lava flow thawed due to the heat released by the active lava flow.

found in Alaska (*Mustard et al. 2001*). It is highly likely that Mars has been the site of magma-permafrost interactions.

New models of volcano-permafrost interactions on Earth and Mars

In 2003, NASA provided a research grant that allowed me to return to the Bering Land Bridge National Preserve in company with two new colleagues: Dr. Rick Wessels of the Alaska Volcano Observatory and Dr. Jeff Kargel, a longtime NASA researcher and expert on all things to do with Mars. Our goal was to discover new distinctive landforms and geologic deposits recording magma-permafrost interactions. There are many lava flows visible on Mars, and we began a study of lava flows in BELA that we knew had been erupted through permafrost.

David Hopkins had identified the "Lost Jim" lava flow in the Imuruk Lake area as the youngest and best preserved lava flow on the Seward Peninsula (*Hopkins 1959*). We studied satellite images of the Lost Jim lava flow from BELA and other lava flows, looking for differences between the Alaskan lava flows and Martian lava flows that we knew erupted through permafrost, and lava flows found in Hawaii and elsewhere on earth that didn't travel across permafrost. We then traveled to Imuruk Lake (*Figure 3-5*) from Kotzebue by float plane piloted by Buck Maxon. Buck had been our pilot when David Hopkins and I worked in BELA in the early 1990s. Buck flew us to a good campsite on the shoreline of Imuruk Lake only a couple of miles from the Lost Jim lava flow (*Figure 5*). After setting up camp, we took advantage of the midnight sun to hike across the tussocks and permafrost to start our study of the lava flow.

We quickly determined that the Lost Jim lava flow had been a "tube-fed" flow, constructed of multiple lobes and thin sheets of lava that traveled away from the source vent in small tunnels within the lava flow. The recognition that the Lost Jim flow was tube-fed raised concerns that hot lava traveling within the tubes might have been insulated from the underlying frozen ground.

We spent the next week walking for miles over the lava flows and the surrounding tussocks, surveying the lava's surface morphology and describing various characteristics of the flow (*Figure 4*). Eventually we collected enough data to determine that the Lost Jim lava flow did display a marked difference from a typical tube-fed flow. The surface of the flow is pockmarked with large collapse pits as much as 330 feet (100 m) across and tens of feet deep (*Figure 6*). Examination of the lava flow exposed at the edge of the collapse pits showed the presence of tunnels related to tube flow. The collapse pits apparently formed when the flow was active, rather then being a feature formed long after the flow had cooled.

We developed a hypothesis that the collapse pits are evidence of a sub-lava thermokarst field. Thermokarsts are forming in many areas of the Arctic today where permafrost is thawing due to global warming. Thermokarsts have also formed in the geologic past during unusually warm intervals (*Beget et al. 2008*). The discovery of thermokarst underneath the lava flow is consistent with the high temperatures (ca. 950-1100°C) associated with eruptions of lava like that of the Lost Jim flow. Even though the lava in the tube-fed Lost Jim flow never came into direct contact with permafrost, the heat of the lava was sufficient to thaw the underlying permafrost beneath the tube-fed lava flow.

The discovery of a second unusual geologic feature recording interactions of volcanism and permafrost is very exciting and scientifically important. These unique features, to our knowledge, have only been found on earth within BELA. We anticipate similar features will be seen in satellite imagery of Martian volcanoes. I am confident that new discoveries of this kind will continue to be made, as much remains to be learned about the history and processes of past volcano-permafrost interactions within the boundaries of the Bering Land Bridge National Preserve in Alaska's Arctic.

Acknowledgements

I would like to thank the staff of Bering Land Bridge National Preserve for their permission to conduct scientific research within the preserve boundaries, and for their assistance in selecting campsites and work schedules that allowed us to conduct our scientific research in harmony with the extraordinary environmental and ecological significance of the Imuruk Lake area. Buck Maxon, "bush pilot" extraordinaire, once again did a superb job in putting us in and getting us out of the field. Rick Wessels was a tremendous buddy in the field and played a key role in the development and progress of this project. Thanks are also due to NASA for their generous support of this project under the MFRP program.

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Beneath My Feet: Alaska's Miniature Forests

Photograph by Rodney D. Seppelt

Photograph by Rodney D. Seppelt

Figure 1. (Top) Black spruce boreal forest contains abundant bryophytes and lichens in the understory.

Figure 2. (Bottom) Some mosses are only found in wet fen margins.

Figure 3. (Left) *Sphagnum squarrosum*.

Photograph by Gary A. Laursen

By Rodney D. Seppelt and Gary A. Laursen

Abstract

Mosses are important components of low-lying vegetation of terrestrial ecosystems in most regions of the world, from the tropics to high altitude alpine and high latitude Arctic and Polar Regions. Throughout the boreal forest, alpine and Arctic tundra regions, both mosses and lichens may comprise a large part of the aboveground plant biomass. Extensive *Sphagnum* dominated peatlands in boreal regions are a well-known example of the potential, but the all too often unrecognized, dominance exhibited by mosses in various habitats. In Alaska there are at least 650 species of moss, 280 hepatics, but only one hornwort.

Introduction

Mosses, together with related groups, the liverworts and hornworts, collectively belong to a group of plants known as the Bryophytes. World wide there are a conservative 15,000 to perhaps an overestimate of 25,000 different species. They are typical green plants with chlorophyll a and b as their primary photosynthetic pigments, starch as an energy storage product, and may have been amongst the earliest of the land plants. They are known to date back as far as 300 million years in the fossil record. Bryophytes are generally small because they lack functional vascular tissues for internal water conduction and support. Water and nutrient absorption is primarily over their surfaces. The largest truly terrestrial moss, *Dawsonia superba* of Australia, New Zealand and nearby islands, reaches up to 30 inches (75 cm) in height. In the northern hemisphere, some *Fontinalis* species growing on rocks in streams may be longer, but the shoots are supported by the water. The smallest mosses are less than 0.04 inch (1 mm) tall with most in the 0.4-2.4 inch (1-6 cm) range.

Bryophytes are significant components of the biodiversity found in many habitats such as tundra, boreal forest tree line (*Figure 1*), peatlands and wetlands (*Figure 2*). They are able to colonize hard substrates such as rock (*Figure 4*) and bark surfaces (even old cars and buildings), and are primary colonists of recently uncovered or disturbed soil surfaces (*Figure 5*) such as those exposed by glacial recession, land slips, and fire denuded surfaces. They play a major role in the stabilization of substrates preparatory to colonization by vascular plants (*Figure 6*). Many bryophytes have a high tolerance for long periods of desiccation, high and low temperature and extreme daily temperature ranges of 120° F (50° C) or more. In Japan, the liverwort *Jamesoniella vulcanicola* lives in volcanic fumarole streams in highly acidic water with a pH range of 1.9-4.6 (*Yokouchi et al. 1984*). Apart from occupying a wide range of habitats, bryophytes provide specific substrates for many fungi (*Figures 7, 8, 9*), shelter for small mammals and a host of tiny invertebrate animals, a seed bed for higher plants, nest materials for birds and animals, and important ground cover insulation (*Figure 10*). They play a significant role in nutrient cycling, absorption of moisture, and in the carbon and nitrogen balance of high latitude ecosystems. Bryophytes and lichens are amongst the most sensitive indicators of atmospheric pollutants such as heavy metals, radioactive fallout, sulfur dioxide and nitrogen oxides as acid rain, and their effects on ecosystems of the world. They are also fascinating subjects of scientific study, aesthetically pleasing and beautiful (*Figures 11, 12*) but, sadly, all too often ignored.

In Alaska there are at least 650 species of moss, 280 hepatics and just one hornwort (*W.B. Schofield, unpublished lists*). In the genus *Sphagnum*, an important component of the moss flora of peatlands and wetlands, there are in Alaska 53 of the 97 species known from continental North America (*McQueen and Andrus 2007*).

The Life Cycle

Like vascular plants, the bryophyte life cycle (*Figure 13*) involves an alternation of two generations—a gametophyte (bearing the male and female reproductive structures) and a sporophyte, a specialized structure formed after fertilization and bearing the tiny spores in a capsule at its tip (*Figure 14*). Unlike vascular plants, however, the dominant generation in bryophytes is the gametophyte plant. In mosses the gametophyte is a leafy structure. In liverworts it may be either leafy or thallose (flattened and ribbon like). In hornworts the gametophyte is thallose.

All bryophytes need free standing water for growth and reproduction. Motile sperm from the male antheridium are released at maturity and swim in a film of water to a flask-shaped female archegonium, containing the egg cell. After fertilization the resulting zygote develops into a very different structure, the sporophyte, which has at its upper end a capsule that bears the spores. After being released, spores germinate usually via a filamentous or thread-like stage, on which will eventually develop new gametophyte plants. At the mouth of the capsule of many mosses are specialized and architecturally beautiful structures called the peristome teeth (*Figure 15*) which help to control spore liberation. The peristome teeth spread when dry and close over the capsule mouth when moist, thereby regulating spore liberation.

Duration of the life cycle varies considerably. It may be as short as two weeks to as long as several years. In the thallose liverwort *Riccia cavernosa* (*Figure 16*) found growing on silt shelves and sand banks along Arctic rivers such as the Kobuk, the life cycle is as short as two to three weeks. For the same species in temperate latitudes it is two to three months. Dung inhabiting mosses such as *Splachnum luteum* (*Figures 17*) and *Tetraplodon* (*Figure 18*), may take two to three years to produce mature sporophytes.

In addition to reproducing sexually, bryophytes produce a variety of specialized asexual reproductive structures called gemmae. These are particularly noticeable in the thalloid liverworts, such


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Figure 4. Near vertical rock face covered with mosses.

Figure 5. Moss colonizing barren ground.

Figure 6. Moss stabilizing a stream margin provides a seed bed for higher plant establishment.

Figure 7. Fungus: *Galerina paludosa* growing specifically in *Sphagnum*.

Figure 8. Fungus: *Spathularia flavida* growing in the moss *Hylocomium*.

Figure 9. Fungus: *Cystoderma amianthinum* growing in a dense carpet of the moss *Hylocomium*.

as *Marchantia latifolia* (*Figure 19*), where one can often see fertile plants with their conspicuous umbrella-like structures, which bear the tiny spores, as well as gemmae cups with their disc-shaped gemmae within (*Figure 20*). In leafy liverworts, such as *Lophozia*, the gemmae are usually tiny, often light green or brown, and borne on the leaf margins (*Figure 21*). Mosses may also have gemmae on their leaves (*Figure 22*) and stems. Bryophytes are also capable of producing new plants by fragmentation of the shoots or even from parts of a leaf.

Habitats

Bryophytes play major roles in all of the diverse habitats found in Alaska, from the extensive wetlands of the North Slope through open shrub heathlands, black spruce dominated forests and wetlands, into white spruce, birch and aspen dominated boreal forests and temperate wetlands, and in alpine zones. In boreal forests and sub-Arctic heaths, lichens are also abundant and provide an important winter source of food for larger browsing animals, particularly caribou and, to a lesser extent, moose and musk ox (*Figure 23*).

The **alpine tundra** zones throughout Alaska are home to a number of specialist mosses adapted to the extreme cold-dominated and variably changing climates. *Andreaea* (*Figure 24*), *Grimmia*, *Racomitrium* and *Hedwigia* (Figure 25) species are commonly seen on rocks, and *Encalypta*, *Syntrichia*, *Bryum* (*Figure 26*) and others, such as *Oncophorus* (*Figure 27*), on soil.

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Figure 10. Dense insulating moss layer in a black spruce forest.

Figure 11. *Ptilium crista-castrensis,* an upland forest understory moss.

Figure 12. *Plagiomnium cuspidatum*, a moist habitat moss.

In **sub-arctic heathlands** mosses often form thick carpets that, over time, may develop thick peat layers that act as huge carbon sinks. Increased global temperatures are likely to have a major impact on the decomposition rates of these peat deposits with the potential release of huge amounts of the greenhouse gas carbon dioxide. Many bryophytes and lichens are found in these heathlands.

Much of Alaska's surface topography is classified as **wetland**, a term often misunderstood, misinterpreted, and a never-ending source of argument and litigation for construction and development industries. Mosses are now being used to further delineate the classification of wetlands. *Sphagnum* species (*Figures 28, 29, 30, 31, 32*) are very important components of the wetland bryoflora. Because of their unique structure, the plants can absorb vast quantities of moisture, a feature that led to *Sphagnum* being used in wound dressings, early sanitary pads, diapers, and now extensively in horticulture and in oil spill remediation. Their physiology gives these plants a unique ion exchange capacity and the ability to acidify their habitat, which excludes many other plants.

In **black spruce forests** a wide range of bryophytes, particularly *Hylocomium* (*Figure 33*), *Pleurozium* (*Figure 34*), *Dicranum* (*Figure 35*) and *Aulacomnium*, and lichens, such as *Peltigera*, *Cladina*, and *Cladonia*, form the dominant ground cover and may, over time, develop a significant duff layer that provides shelter for small mammals, a host of small invertebrates, as well as forming a deep insulating blanket over the ground below. Duff, like that from a spruce, is very easily burnt, with severe fires burning through to the mineral soil below.

In **boreal forests**, leaf litter may limit the occurrence of bryophytes and lichens,

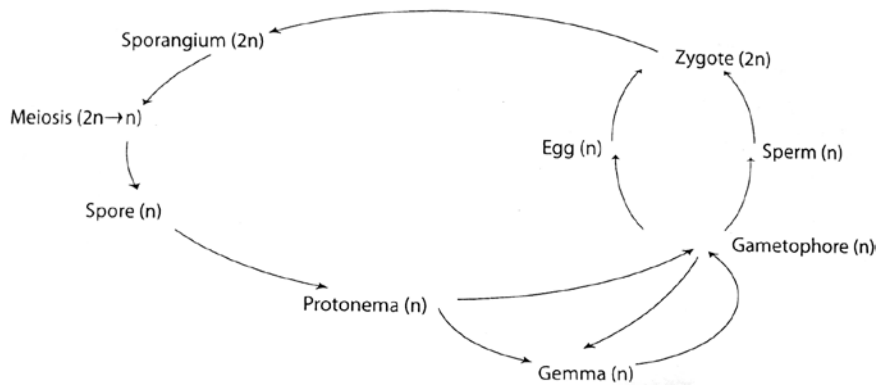

Figure 13. Diagrammatic life history of bryophytes.

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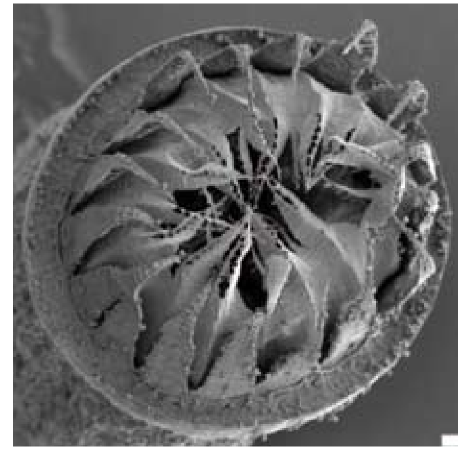

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Figure 14. *Polytrichum juniperinum* with capsules.

Figure 15. Scanning electron micrograph of double peristome of *Bryum*.

Figure 16. The liverwort *Riccia cavernosa*.

Figure 17. Moss: *Splachnum luteum* on old bear dung.

but extensive carpets of mosses such as *Hylocomium*, *Pleurozium*, *Dicranum*, and *Tomentypnum* (*Figure 36*), can be found along with a number of *Sphagnum* species.

Epiphytes. Mosses are not restricted to ground level substrates. Species such as *Orthotrichum* (*Figure 37*) occur on the trunks and smaller branches of many trees. *Pylaisiella* and some *Hypnum* species commonly form a skirt around the base of aspen trees (*Figure 38*). The liverwort *Ptilidium* (*Figure 39*) is often found closely adhering to the lower furrowed bark of aspen and on fallen logs. In moist temperate forests and in tropical regions, tree trunks and branches may be completely covered with a host of epiphyte species having a considerable influence on ecosystem water balance and nutrient cycling.

Bryophytes as Habitats for Other Organisms

Moisture is critical for survival and maintenance of bryophyte growth. Dense mats or clumps of mosses also retain considerable amounts of moisture and increase the humidity of the many microhabitats within the moss mats. This is important for the survival of small animals that inhabit both the moss and the forest duff layer. The physiological activity of the moss, tiny animals and microbes that live within the moss clumps can elevate the carbon dioxide levels in the clumps to around 2,200 parts per million (ppm)—currently atmospheric levels are at about 390 ppm. A thick moss insulating layer may also protect and allow subsurface permafrost to come very close to the ground surface, thereby limiting non-cold hardy plants.

Because of their high phenolic compound content, mosses are generally not eaten by other animals. However, compounds such as arachidonic acid, a polyunsaturated fatty acid, may be present in high amounts in some mosses that are eaten in large amounts by some animals, such as reindeer, Soay sheep, barnacle geese, and may impart greater protection against the cold (*Prins 1981*). Birds and slugs may consume, and some actively search for, the almost ripe capsules of mosses. Most birds, small mammals and even the larger browsing animals, generally avoid eating mosses. However, just prior to hibernation, bears may consume large amounts of moss, apparently to aid binding of their digestive system and blocking defecation during their winter sleep.

Birds and small mammals often use mosses as nest material. Small ground-dwelling mammals (voles, shrews, and mice) burrow into and through deep layers of moss to reach relative safety from predators and to gain insulation from cold winter temperatures.

Large suites of fungi live on or in intimate association with mosses. Most high latitude species of *Galerina*, *Cystoderma*, *Arrhenia*, many species of *Mycena*, *Cudonia*, *Spathularia*, and some species of *Dentinum*, *Geoglossum*, *Microglossum*, *Cantharellula* and, on rare occasions, even some *Cortinarius* species, utilize mosses as substrates (*Figures 40, 41, 42*).

Mosses as Miniature Forests

There are many useful and fascinating features of leaves, such as the number of rows (2, 3, 4, 5 or more), shape and size, cell shape and size and surface ornamentation, cross-sectional anatomy, where and how the plant grows (on tree bark, rocks, soil, in water or bogs; flat and creeping on the substrate, or erect and often in tufts or large patches) that help identify these plants. It is features of the mature sporophyte that are most often needed, however, to confirm their identity.

Because of the perceived difficulty in identifying bryophytes, along with the lichens and fungi, they are usually omitted from ecological surveys and, all too often, flora surveys. They are generally small in


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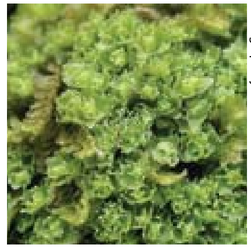
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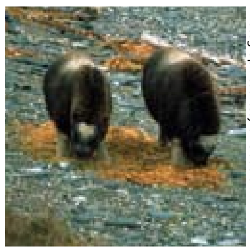
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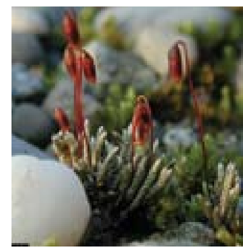
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Figure 18. The dung inhabiting mosses, *Tetraplodon angustatus* (foreground) and *Tetraplodon mnioides* (background).

Figure 19. *Marchantia latifolia* with umbrella-like sporangiophore. Capsules are borne under the finger-like rays.

Figure 20. *Marchantia gemma* cups with gemmae.

Figure 21. Leafy liverwort, *Lophozia incisa*, with light green gemmae on leaf margins.

Figure 22. Moss *Syntrichia papillosa*, clusters of gemmae on inner leaf surfaces.

Figure 23. Musk ox feeding on moss.

Figure 24. Moss: *Andreaea rupestris*, grows on rock.

Figure 25. Moss *Hedwigia ciliata*, grows over rock and soil.

Figure 26. Moss *Bryum argenteum*, early colonist of bare ground.

Figure 27. Moss: *Oncophorus wahlenbergii*, a colonist of bare ground and disturbed areas.

Figure 28. *Sphagnum russowii*.

Figure 29. *Sphagnum angustifolium*.

size, but often in the habitats where they live, are the equivalent of the forests of more temperate climates.

What we recognize as a forest contains trees, shrubs, ground cover plants, birds, herbivore and carnivore vertebrate animals, small mammals and other small animals, and below ground plant parts and a host of small or microscopic animals. So, too, a deep carpet or tuft of mosses can be viewed as a forest, although the scale of size is much smaller (*Figures 43, 44*). Small burrowing mammals and frogs, insects and their larvae, spiders and other

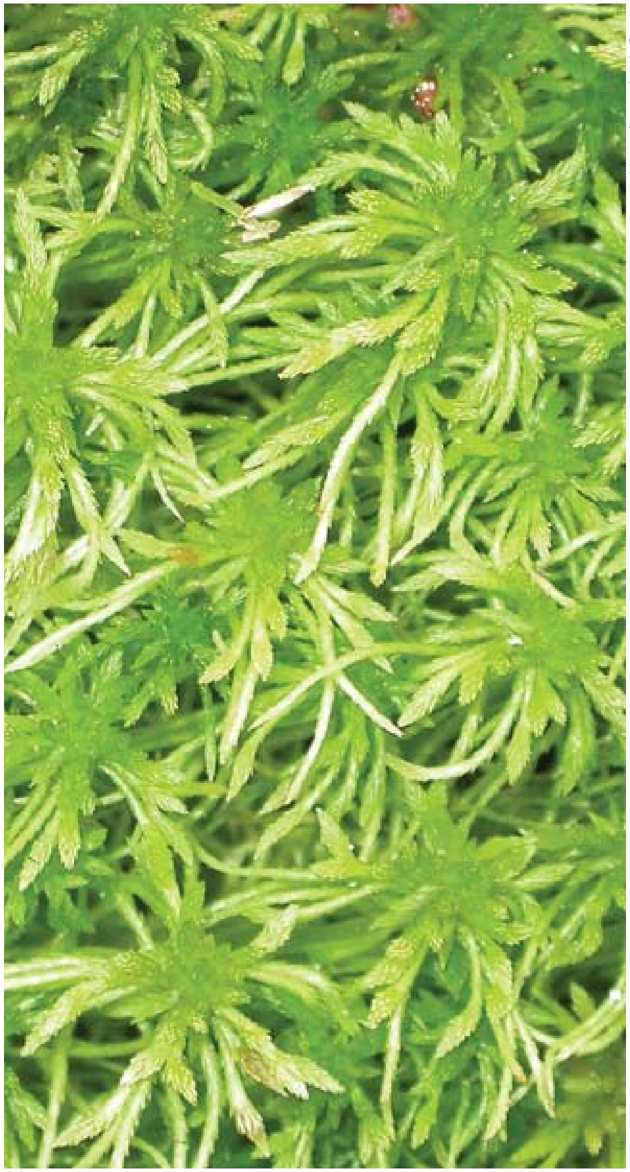
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Figure 30. *Sphagnum girgensohnii.*

Figure 31. *Sphagnum warnstorfii*.

Figure 32. *Sphagnum squarrosum* with capsules.

Figure 33. The stair-step feather moss: *Hylocomium splendens*, an abundant forest floor species.

Figure 34. Red-stemmed feather moss: *Pleurozium schreberi,* an abundant forest floor species.

Figure 35. The moss, *Dicranum polysetum*, with 2 or more mature sporophytes on each stem.

Figure 36. The yellow-brown shiny shoots of the moss, *Tomentypnum nitens*, common in moist heath, shrub and woodland are unmistakable.

Figure 37. *Orthotrichum speciosum*, a common moss on tree trunks, particularly aspen and cottonwood.

Figure 38. Skirt of the mosses *Pylaisiella polyantha* and *Hypnum* at the base of aspen.

invertebrates, microscopic organisms such as fungi and bacteria, abound in the moss layer. A moss tuft or a carpet of moss is indeed the equivalent of a tall tree forest—but in miniature beneath your feet.

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Figure 39. The liverwort *Ptilidium ciliare* is common on fallen decaying wood and loosely attached. The browner *Ptilidium pulcherrimum* is tightly attached to bark or old wood. Both have small overlapping leaves with hairy margins.

Figure 40. Fungus: *Cystoderma fallax* grows on moss.

Figure 41. Fungus: *Cantharellula umbonata* grows on moss.

Figure 42. Fungus: *Cudonia circinans* grows on moss.

Figure 43. Dense mats of *Brachythecium* species are found on the ground, fallen leaf litter and rotting wood.

Figure 44. Tuft of *Grimmia pulvinata* on rock. Leaves have long white hair points.

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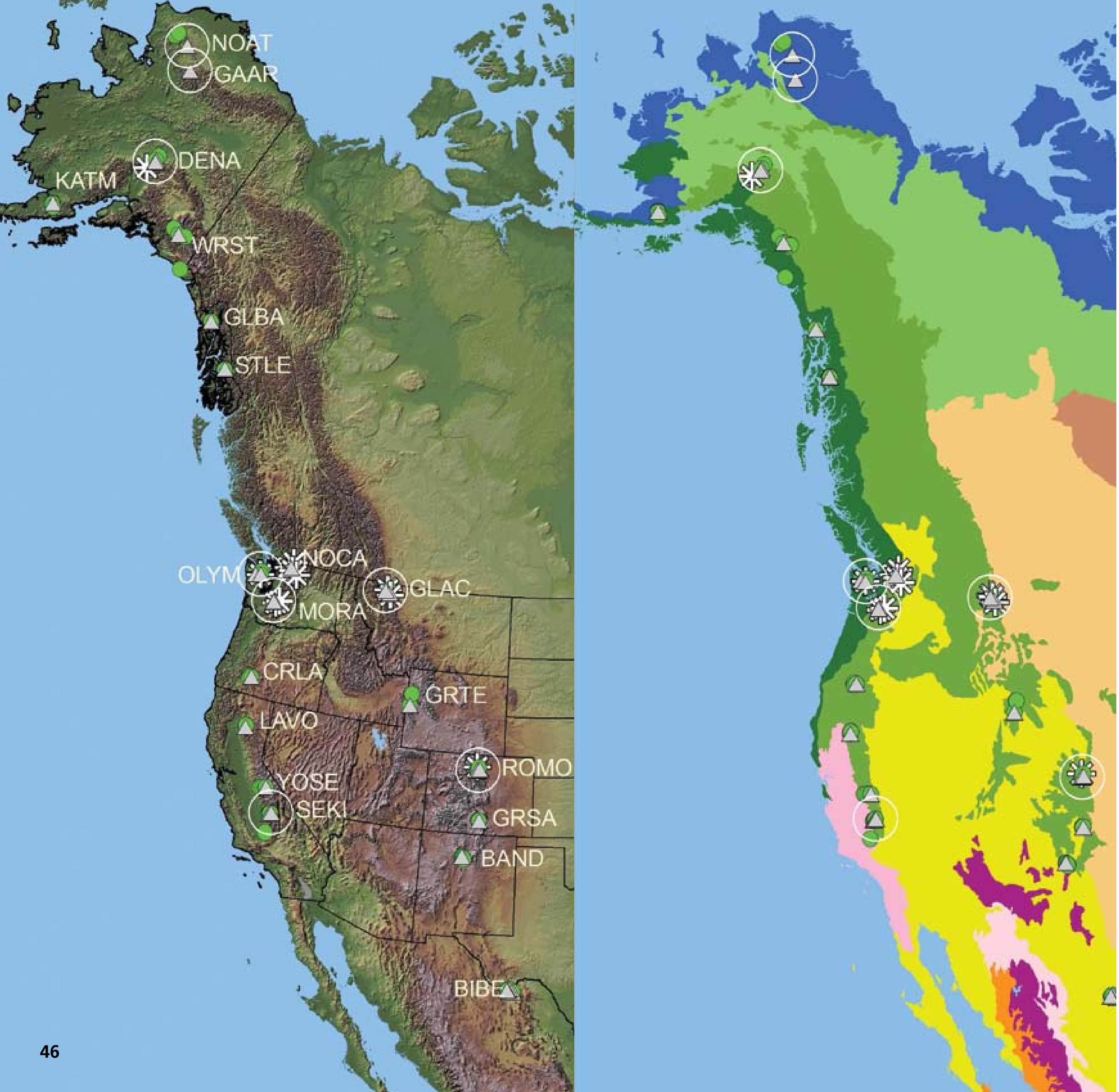

Figure 1. WACAP sites on a shaded relief map and EPA Level 1 ecoregions (biomes). Parks are designated by the four-letter NPS abbreviation. Vegetation-only sampling sites in core parks designate sites used in elevational transect, in addition to lake sites. Snow-only sampling sites in core parks designate alternate sampling locations, when lake sites could not be reached safely.

Evaluating Airborne Contaminants in Alaska National Parks: The Western Airborne Contaminants Assessment Project

By Dixon H. Landers, Tamara Blett, Marilyn M. Erway, and Linda Geiser

Background

Some of the world's most toxic persistent chemicals are carried in air masses, from sources as far away as Europe and Asia, and as close as local farmer's fields or a regional coal fired power plant. The objective of the Western Airborne Contaminants Assessment Project (WACAP) was to examine a broad suite of airborne contaminants in national park ecosystems using a network of eight "core" parks (Noatak, Gates of the Arctic, Denali, Glacier, Olympic, Mount Rainier, Rocky Mountain, and Sequoia) in the western U.S. In addition, 12 "secondary" parks were sampled for vegetation and air (*Figure 1*) to strengthen the spatial understanding of this issue. The National Park Service (NPS) is concerned about airborne contaminants because they can pose serious health threats to wildlife and humans, as some of these compounds tend to "biomagnify" in food webs. This means that some contaminants can be tens to thousands of times more concentrated in higher food web levels (i.e. fish) than in snow or water or the base of food webs (i.e algae, insects). Biological effects of airborne contaminants can include impacts on reproductive success, growth, behavior, disease, and survival of fish, wildlife, and humans, if these compounds accumulate to toxic levels.

The NPS initiated this project in 2002 because:

- Potential risk to park resources was identified from preliminary studies in the Arctic and other high elevation or high latitude areas, but little information about potential impacts of toxics on national park resources was known.
- There was concern about subsistence-based populations in Alaska who consume foods that could be bioaccumulating toxic compounds and elements.
- Parks contain relatively undisturbed and near pristine natural systems that can serve as early warning sites for the rest of the continent.
- NPS responsibilities and legal mandates are to protect ecosystems "unimpaired" for future generations (Organic Act).

This six-year WACAP project was designed to: 1) determine if contaminants are present in western national parks; 2) determine where contaminants are accumulating (geographically and by elevation); 3) determine which contaminants pose a potential ecological threat; 4) determine which indicators appear to be the most useful to address contamination; and 5) determine the sources for contaminants measured at the national park sites.

Scientific Partnerships

This project is likely unique for an NPS sponsored project because of its large scope, scale, duration, and number of cooperators. We held a series of workshops in 2001 that identified the need for more information about the risk of airborne toxics in parks. Following these workshops, Dr. Dixon Landers, an Environmental Protection Agency (U.S. EPA) scientist, was selected to identify and lead a transdisciplinary team of researchers to conduct a large scale integrated study on airborne contaminants in western national parks. Researchers from the U.S. Geological Survey, U.S. Forest Service, University of Washington, and Oregon State University worked with the NPS and U.S. EPA on various aspects of this project. Donald Campbell of the USGS coordinated the snow sampling and analyses. The Pacific Northwest Cooperative Ecosystem Studies Unit (CESU) has been instrumental in facilitating the participation of scientists in this project. At Oregon State University, Dr. Staci Simonich led the organic chemistry laboratory analysis and interpretation effort to determine the presence and concentrations of toxic contaminants in air, water, sediment, snow, vegetation, fish, and moose. Many of the analytical methods were customized for WACAP; Dr. Simonich and a large number of post-doctoral students, graduate students, undergraduates, and laboratory technicians pioneered and published new techniques to conduct the WACAP research. Adam Schwindt, Dr. Carl Schreck (leader of the Oregon Cooperative Fish and Wildlife Research Unit), and Dr. Michael Kent (director of the Center for Fish Disease Research at Oregon State University) have been key partners in looking at physiological,

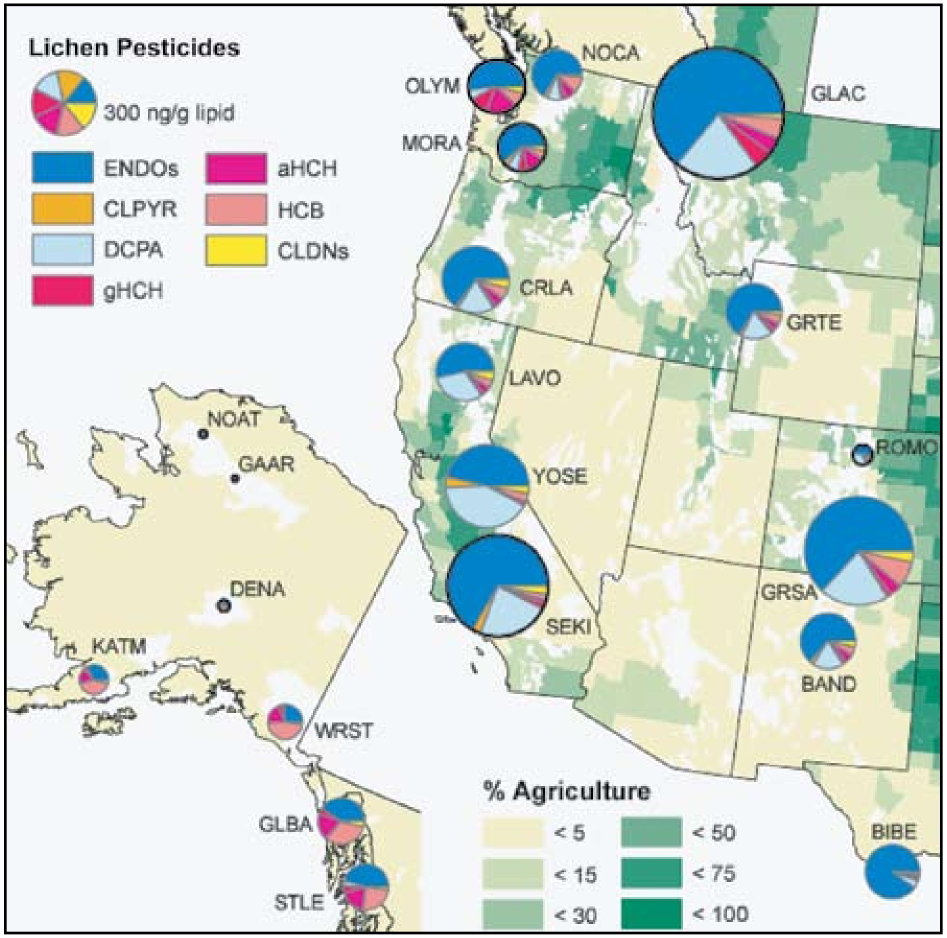

Figure 2. Pesticide concentrations (ng/g lipid) in lichens from core and secondary WACAP parks overlaid on a map of agricultural intensity (US Department of Agriculture, National Agriculture Statistics Service 2002). Circle area is proportional to total pesticide concentration. White shading indicates national forests or parks. Current-use pesticides endosulfan and dacthal dominate pesticide concentrations in parks in the conterminous United States, where most agriculture occurs. Historic use pesticides comprise a relatively larger fraction of total pesticide concentrations in Alaska. Sites outlined in black are core parks. Abbreviations for pesticide groups are endosulfans (ENDOs), chlorpyrifos (CLPYR), dacthal (DCPA), g-HCH and a-HCH (gHCH and aHCH), hexachlorobenzene (HCB), and chlordanes (CLDNs).

hormonal, and chemical characteristics of fish in the study lakes. Dr. Daniel Jaffe, Professor of Atmospheric and Environmental Chemistry at the University of Washington, analyzed complex atmospheric transport patterns that carry airborne contaminants into western national parks. These university scientists, along with other scientists from federal agencies, developed a unique integrative partnership through implementation of the project. For example, field data collection required approximately 2,000 pounds of scientific equipment and supplies to be transported by helicopter, floatplane, pack animals, and research staff into remote watersheds before the two week process of sample collection in each park could begin. Investigators also collaborated on development of data analysis, results, and publications; resulting in products where the whole is really more than a sum of the "parks".

Roadmap for Success

There are a few key elements that have made this project successful. 1.) Experienced and widely recognized scientists were selected to provide their expertise in designing and implementing the project. The CESU process provided an avenue to select those researchers with proven track records in publishing their work, and experience in working as part of an interdisciplinary team. 2.) A detailed, written research plan and quality assurance and quality control plan were developed with input from all scientists involved, and the research plan was peer-reviewed by an external, distinguished panel of subject matter experts. 3) Leadership and accountability was ensured by setting up a "Science Project Leader" and an "NPS Project Manager" to keep the project moving forward, facilitate integration among disciplines, receive feedback from NPS clients, and provide a mechanism for decision making. 4.) Avenues of communication such as a project web site, semi-annual investigators meetings, posters, and annual fact sheets helped keep everyone informed.

Results

Scientists involved with WACAP have now completed the collection, analysis and interpretation of all WACAP samples, and the WACAP Final Report is expected to be published on the Web in February, 2008. The final data base is scheduled to be published on the web by July 1, 2008. First, let's examine what we found out with respect to the objectives that drove all aspects of the study.

1.) **Are contaminants present in western national parks?** The answer to this question is an unqualified yes. We discovered scores of various semi-volatile organic compounds that we classified into historic use pesticides, current use pesticides, industrial/urban use compounds, and combustion by-products. Some of these have been banned for decades, while others are still in use in the United States or in Mexico and/or Canada. We also found selected metals such as mercury, lead and cadmium that were elevated over natural levels in some parks. Generally these contaminants were at concentrations below levels of concern raised by various government bodies (*Figure 1*).

2.) If present, determine where contaminants are accumulating (geographically and by elevation). We determined that some contaminants followed a pattern that suggests the chemical was easily transported, based on its physical and chemical properties, to high elevation and high altitude locations, which tend to be colder than most other places in a locality. We also found different rates of accumulation in the various environmental components we sampled, depending on the time over which the particular environmental component integrated and its own chemical characteristics. Snow and fish, for example had widely different contaminant concentrations and contaminant types. This difference is because snow represents only those contaminants deposited via several months of winter precipitation, whereas fish integrate contaminants over their lifetime and can live for decades (*Figure 2*).

3.) If present, determine which contaminants pose a potential ecological threat. Dieldrin, p,p'-DDE, and mercury were present in some fish at concentrations that exceeded established health thresholds for piscivorous fish and mammals, including humans. In Alaska, the average mercury concentration of the fish collected from Burial Lake in Noatak National Preserve, and some fish from Matcharak Lake in Gates of the Arctic National Park and Preserve, exceeded the U.S. Environmental Protection Agency (U.S. EPA) human contaminant health threshold (see *Figure 3*). All four lakes sampled in Alaska (Burial, Matcharak, and Wonder and McLeod lakes in Denali National Park and Preserve) had concentrations of dieldrin in some fish that exceeded the U.S. EPA human contaminant health threshold for subsistence fishing. Current use pesticides were generally undetected or very low in Alaska systems, but concentrations of historic use pesticides in Alaska parks were often similar to the concentrations in parks in the lower 48 states.

4.) Determine which indicators appear to be the most useful to address contamination. It appears that fish and sediments are the two indicators that, in combination, provide the most useful information regarding the numbers and types of contaminants, the long term history of exposure, the effects of bioaccumulation and the direct linkage to piscivorous components of the food webs.

5.) If present, determine the source of the air masses most likely to have transported contaminants to the national park sites. The source of most contaminants in the majority of sites in the lower 48 states appeared to be regional or local, with strong evidence of the importance of regional industrial and agricultural activities. In Alaska, given the greatly reduced occurrence of industrial and agricultural activities, the sources appear to be primarily long range transport and global background for contaminants like mercury and SOCs.

We found a long list of current and historic use contaminants in all parks

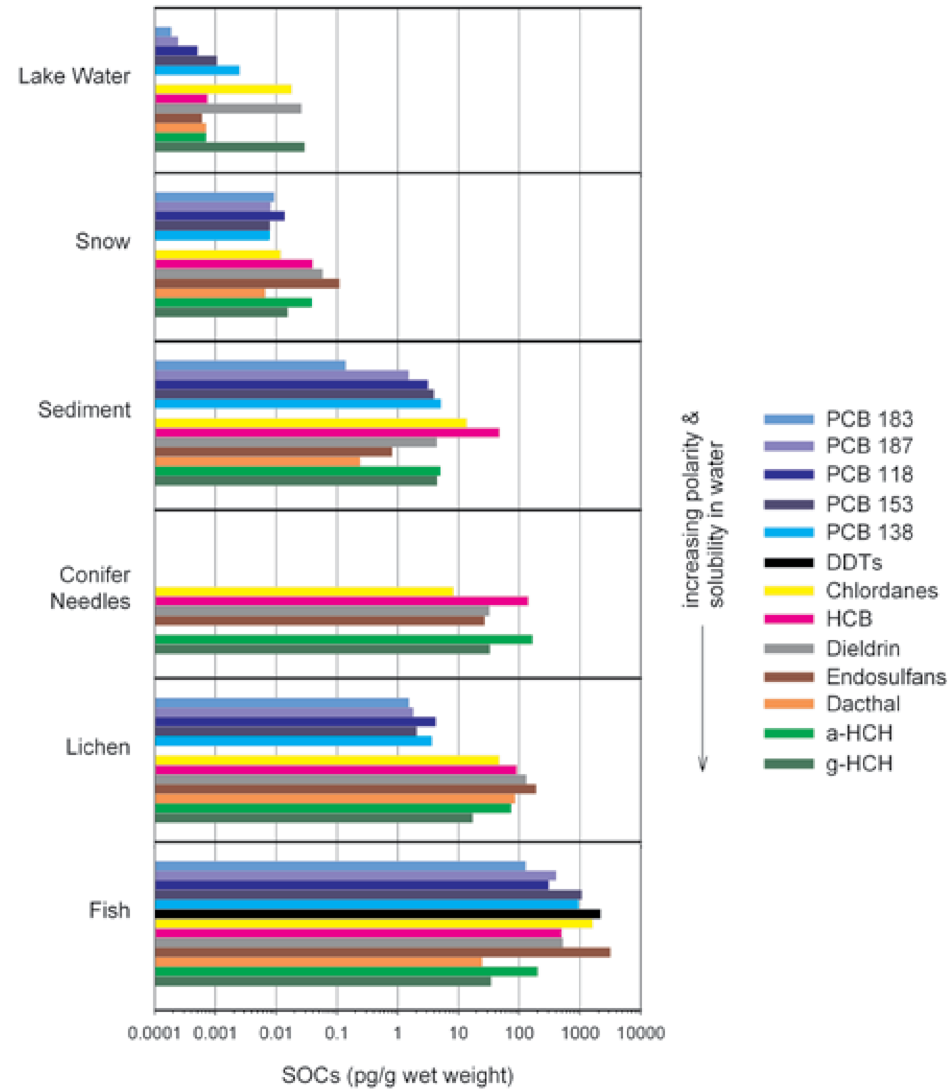

Figure 3. Comparison of patterns of semi-volatile organic compound (SOC) accumulation in lake water, snow, sediment, conifer needles, lichens, and fish from Wonder Lake in Denali National Park and Preserve. SOCs are listed in order of increasing polarity and solubility in water. The relative magnitude of the differences in concentrations is lake water, snow < sediment, conifer needles, lichens < fish. A 4 to 6 order higher accumulation of SOCs is observed in biota relative to snow and lake water. For compounds with measurable levels of SOCs in both fish and sediments, fish tissue concentrations were 2 to 3 orders of magnitude higher. Lake water, snow, and vegetation had higher affinities for more polar compounds, whereas sediments and fish accumulated the less polar compounds to a greater extent.

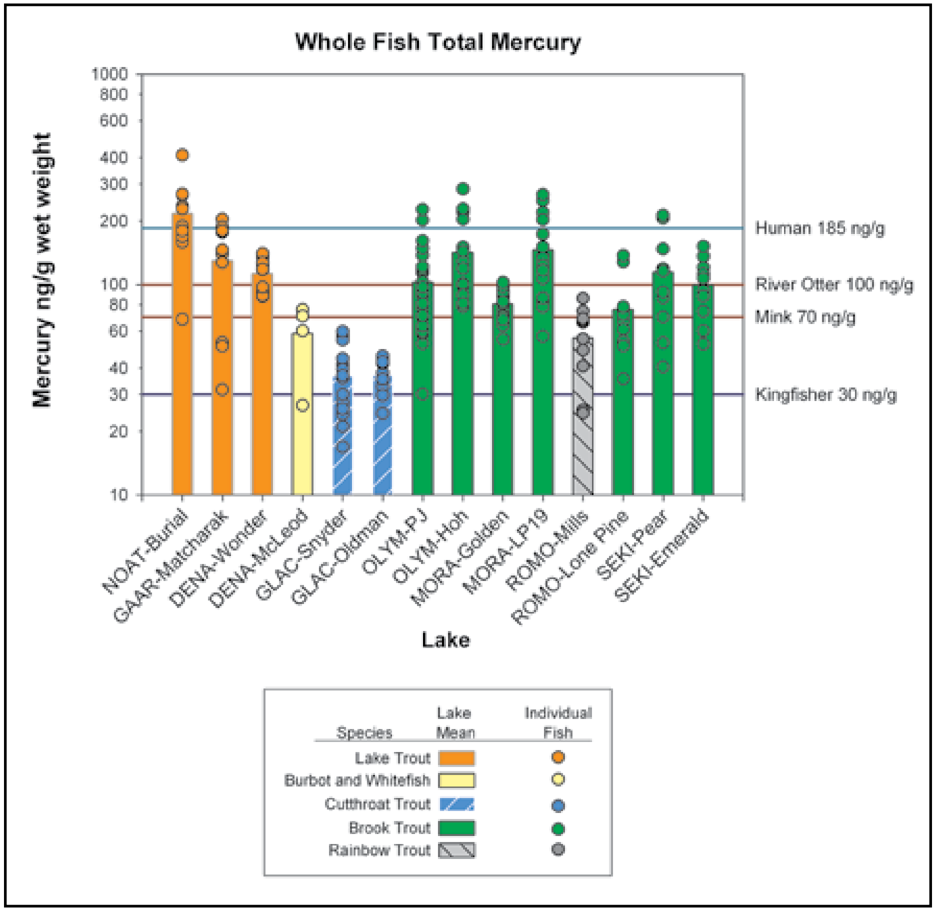

Figure 4. Total mercury for individual fish and means for lake sites, and contaminant health thresholds for various biota. The mean ng/g total mercury (Hg) in fish at NOAT exceeds the U.S. EPA human contaminant health threshold. The ng/g total mercury in some fish at GAAR (Matcharak), OLYM (PJ, Hoh), MORA (LP19), and SEKI (Pear) exceeds the U.S. EPA human contaminant health threshold. The mean ng/g Hg concentration in fish at all parks exceeds the kingfisher contaminant threshold, and the mean at seven lakes exceeds all wildlife thresholds—NOAT (Burial), GAAR (Matcharak), DENA (Wonder), OLYM (PJ, Hoh), MORA (LP19), and SEKI (Pear). 95-100% of mercury in fish is methyl-Hg (*Bloom 1992*) and 300 ng/g in the fillet is equivalent to 185 ng/g wet weight whole body methyl-Hg (*Peterson et al. 2007*). The human threshold is 300 ng/g wet weight (*USEPA 2001*), and is based on methyl-Hg in the fillet for a general population of adults with 154 pounds (70 kg) body weight and 0.0386 pounds (0.0175 kg) fish intake per day. Contaminant health thresholds in piscivorous animals (wildlife) are based on 100% fish in the diet for whole body total mercury, as determined by Lazorchak et al. (2003). Data are plotted on a log10 scale; the y-axis starts at 10 ng/g.

NPS photograph

Figure 5. McLeod Lake sunrise

but generally at concentrations below levels of concern raised by various government and scientific sources. Current use pesticides are the most abundant group of compounds we have found in three years of annual snow sampling, and these compounds appear to be strongly related to regional agricultural activities in proximity to the parks (*Hageman et al. 2006*). Historic use chemicals such as PCBs (banned in the U.S.) show similar, low concentrations in fish from all of the WACAP primary parks. However, there is evidence in some parks that fish are demonstrating a physiological response to chemical stressors. In most parks, accumulations of debris scavenging cells (macrophage aggregates), which can indicate exposure to degraded environments, are associated with mercury, fish age (*Schwindt et al. 2008*), and poor nutrition. In Rocky Mountain and Glacier National Parks, scientists observed feminization of some male trout possibly in response to man-made compounds that mimic the female sex hormone estrogen (*Schwindt et al. 2007*). Mercury flux to the watersheds in the western national parks is dominated by mercury derived from human activities such as coal burning and metal smelting, as well as global background concentrations for this element. The mercury flux to the Alaska parks is approximately one-fourth that for the parks in the lower 48, yet the mean fish concentrations in some Alaska lakes are significantly higher (*Figure 3*). This finding appears to be due to watershed, lake and food web characteristics in the Alaska systems that efficiently bioaccumulate mercury in the top aquatic predators—fish. The WACAP final report fully documents these and other findings to inform future management decisions relating to the protection of the natural resources in our national parks. Several WACAP related articles have already been published in peer-reviewed literature, and more are expected in 2008.

What Can Be Done About Toxics in National Parks?

The information gathered as a part of this multi-agency partnership project will be of great value to the NPS because of the diversity of sensitive ecosystems that we manage. Specific uses or management actions in response to the WACAP results will be formulated over the coming months.

One of the key accomplishments of WACAP is to inform the NPS and the public about the presence and potential effects of toxic compounds in national parks. To that end, the interest in the project by the national and local media has been keen, and numerous articles have already been published in online and print newspapers across the country. A "WACAP Final Report To Parks" session took place at the George Wright Society meeting in St. Paul, Minnesota in April 2007. The NPS believes that the problems with toxic compounds identified by the WACAP researchers in parks can be used to aid the development of solutions through collaboration with regulatory agencies and stakeholders (domestically) and/or in international diplomatic arenas.

Disclaimer

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Figure 6. Water sampling at Wonder Lake

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