

Geologic Resource Evaluation Scoping Summary

Arctic Network

Geologic Resources Division
National Park Service
US Department of the Interior



The Geologic Resource Evaluation (GRE) Program provides each of 270 identified natural area National Park Service units with a geologic scoping meeting, a digital geologic map, and a geologic resource evaluation report. Geologic scoping meetings generate an evaluation of the adequacy of existing geologic maps for resource management, provide an opportunity for discussion of park-specific geologic management issues and, if possible, include a site visit with local experts. The purpose of these meetings is to identify geologic mapping coverage and needs, distinctive geologic processes and features, resource management issues, and potential monitoring and research needs. Outcomes of this scoping process are a scoping summary (this report), a digital geologic map, and a geologic resource evaluation report.

The National Park Service held a GRE scoping meeting for the Arctic Network on May 8-10, 2007 at the National Park Service building in Fairbanks, Alaska. Tim Connors (NPS-GRD) facilitated the discussion of map coverage and Bruce Heise (NPS-GRD) led the discussion regarding geologic processes and features at the network parks. Participants at the meeting included NPS staff from the network and Geologic Resources Division, geologists from the Alaska Division of Geological and Geophysical Surveys and U.S. Geological Survey as well as cooperators from Colorado State University and other academics (see table 1). This scoping summary highlights the GRE scoping meeting for the Arctic Network parks (Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, and Noatak National Preserve) including the geologic setting, the plan for providing a digital geologic map, a list of geologic resource management issues, a description of significant geologic features and processes, lists of recommendations and action items, and a record of meeting participants.

Network and Geologic Setting

Collectively, the Arctic Network includes five park units: Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Gates of the Arctic National Park and Preserve (GAAR), Kobuk Valley National Park (KOVA), and Noatak National Preserve (NOAT). These units cover approximately 19.3 million acres, or nearly 25% of the total National Park Service land area in the United States. Much of the network land has wilderness designation and park lands are only accessible by boat, plane, or on foot. Set aside by presidential proclamation in 1978, redesignation of the lands in BELA, CAKR, and GAAR along with the creation of NOAT and KOVA occurred on December 2, 1980. BELA preserves a remnant of the once-exposed land bridge that connected Asia and North America more than 13,000 years ago. CAKR contains paleoshorelines and abundant archaeological resources. GAAR is the largest park in the network and encompasses a large portion of the central Brooks Range. KOVA protects the central valley of the Kobuk River. NOAT contains the largest virtually untouched mountain-ringed river basin in the nation. GAAR, KOVA, and NOAT are contiguous stretching from the central Brooks Range westward whereas CAKR and BELA contain shoreline along Kotzebue Sound, the Bering Strait, and the Chukchi Sea.

The geology of the Arctic Network is vast in terms of its size and scope, variety of features, and preserved span of time. This diversity and abundance combined with a relative lack of anthropogenic influence makes the network an incredible natural laboratory. However, relatively little is known about the local geology because of its isolation, short field season, and sheer scale. Dominant landforms include the Brooks Range, large regional rivers draining through broad lowlands, coastal lowlands, bluffs, shoreline areas, and rolling hills of the northern Seward Peninsula. The geologic bedrock units mapped in the parks range in age from the Precambrian to less than 1,000 years old. GAAR contains the oldest mapped rocks exposed on the southern flank of the Brooks Range, whereas early human inhabitants probably witnessed volcanic eruptions emitting lavas flows across the landscape in BELA. The creation of surficial geologic units is continuing at present in all five parks. Geologic processes including mountain building, volcanism, glaciation, aeolian/fluvial erosion and deposition, faulting, weathering, and karstification constantly change and influence the evolving landforms throughout the Arctic Network.

Geologic Mapping for Arctic Network Parks

During the scoping meeting Tim Connors (NPS-GRD) showed some of the main features of the GRE Programs digital geologic maps, which reproduce all aspects of paper maps, including notes, the legend, and cross sections, with the added benefit of GIS compatibility. The NPS GRE Geology-GIS Geodatabase Data Model incorporates the standards of digital map creation set for the GRE Program. Staff members digitize maps or convert digital data to the GRE digital geologic map model using ESRI ArcMap software. Final digital geologic map products include data in geodatabase, shapefile, and coverage format, layer files, FGDC-compliant metadata, and a Windows HelpFile that captures ancillary map data. Completed digital maps are available from the NPS Data Store at <http://science.nature.nps.gov/nrdata/>.

When possible, the GRE program provides large-scale digital geologic map coverage for each park's area of interest, usually composed of the 7.5-minute quadrangles that contain park lands. Due to the large land area of the Arctic Network parks, 1 x 3 degree sheets are more readily available and feasible for park resource management use. The process of selecting maps for management use begins with the identification of existing geologic maps and mapping needs in vicinity of the parks. Scoping session participants then select appropriate source maps for the digital geologic data to be derived by GRE staff. Table 2 (at the end of this document) lists the source maps chosen for the Arctic Network parks as well as any further action required to make these maps appropriate for inclusion in the final geologic map for each park.

The Arctic Network parks cover portions of 19 1 x 3 sheets at 1:250,000 scale (figure 1). Roughly from northeast to southwest these sheets are: Philip Smith Mountains, Chandler Lake, Killik River, Howard Pass, Misheguk Mountains, DeLong Mountains, Chandalar, Wiseman, Survey Pass, Ambler River, Baird Mountains, Noatak, Hughes, Shungnak, Selawik, Kotzebue, Shishmaref, Bendeleben, and Teller.

FY 2008 and FY 2009 are potential target start dates for the compilation of any ARCN digital geologic maps. At that time, GRE staff will once again conduct a thorough review of all available data (bedrock and surficial) and formats (paper, digital, published and unpublished) to determine the best plan for completing digital geologic maps for ARCN.

Currently, Tom Hamilton (USGS) has published **surficial** geologic maps for several of these sheets. At the time of scoping, published surficial map coverage was unknown for the DeLong, Noatak, Selawik, Shishmaref, and Teller 1x3 sheets.

Bedrock geologic map coverage exists for 17 of the 19 sheets in varying vintage and format (paper or digital). At the time of scoping, the Noatak and Shishmaref 1x3 sheets did not have published bedrock geologic map coverage. Consequently, BELA, CAKR, and KOVA are missing the most geologic map coverage of the five network parks. The GRE program plans to cooperate with the U.S. Geological Survey to complete digitization of all existing surficial and bedrock map coverage for the Arctic Network. This plan includes the addition of a GIS person based at the U.S. Geological Survey office in Anchorage devoted to digitizing maps. To this end, Nancy Norville was hired in early 2008, and is working on these projects.

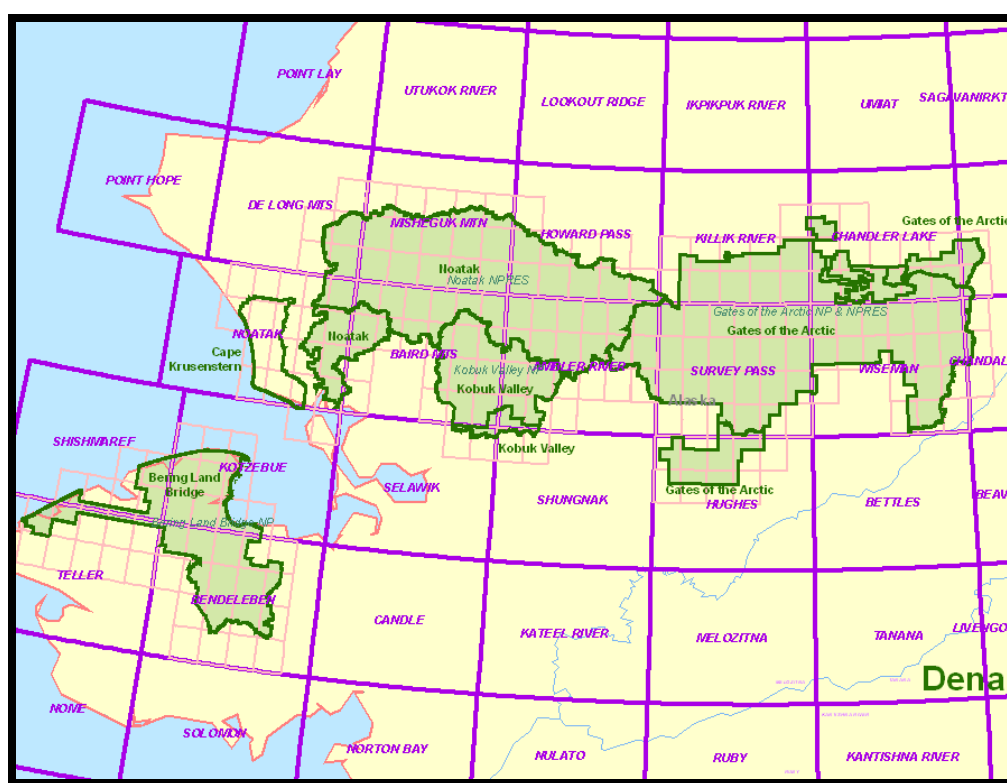


Figure 1. U.S. Geological Survey large-scale quadrangles of interest (pink outline), and smaller-scale (1:250,000) 1x3 degree (purple outline, purple font labels) sheets of interest for the Arctic Network.

At present, for each 1 x 3-degree sheet there is surficial and bedrock geologic map coverage per the references summarized in Table 2 at the end of the document.

A few more notable specifically mentioned items pertaining to ARCN geologic mapping are as follows:

- At CAKR and KOVA, there is a strong need for surficial geologic mapping at the present time; however, no definitive plans currently exist to accomplish this.

- For BELA, it was suggested to consult with Patricia Heiser (University of Alaska, Fairbanks) for some surficial geologic mapping she completed for them several years ago. GRE staff still need to follow up on this with Patricia. It is believed to exist in a digital GIS format.
- For NOAT, it is desirable to have inch-to-the-mile scale surficial geologic mapping along the Noatak River with an approximate 5-mile buffer. Intersecting quadrangles of interest included the Ambler River d3, d4, and d5; Howard Pass a5, and Misheguk Mountains a1 quadrangles.

Table 2 lists the source maps chosen for the Arctic Network parks and mapping needs in certain 1 x 3 sheets, in addition to a unique “GMAP ID” number assigned to each map by GRE staff for data management purposes, map scale, and action items.

Additional items of interest pertaining to geologic mapping from the scoping

The Arctic Network is also interested in derivative maps including detailed ecological subsection maps to layer with surficial and bedrock geologic map layers in a GIS. Vegetation pattern maps combined with geopositioned geochemical sampling points would be a useful data layer for the network. The Alaska Division of Geological and Geophysical Surveys is creating geologic hazard mapping using remote sensing, aerial surveys and field checking. Features include scarps, actively slumping areas, known active faults, and landslide potential based on geologic units layered on slopes. The significant coastal areas of CAKR and BELA require beach ridge mapping, erosion maps, coastal change index maps, and comprehensive coastline maps with subunits.

Geologic Resource Management Issues

The scoping session for the Arctic Network provided the opportunity to develop a list of geologic features and processes, which will be further explained in the final GRE reports. During the meeting, participants listed the most significant geologic issues as follows:

- (1) Mass wasting and thermokarst
- (2) Fluvial issues
- (3) Paleontological resources
- (4) Coastal erosion and shoreline evolution
- (5) Economic resources
- (6) Permafrost dynamics
- (7) Ecosystem connections
- (8) Seismicity
- (9) Disturbed lands

Mass Wasting and Thermokarst

The vast unconsolidated surficial deposits and steep slopes located throughout the Arctic Network are prone to mass wasting events. Large flows in GAAR resulted in the damming the Ikilik River. The upper John River area is also susceptible to major mass wasting events. Because of the undeveloped nature of the parks in the network, threats to park infrastructure are not a primary resource management concern, but should figure into future planning. However, despite the lack of impacts to infrastructure, erosion threatens to remove paleontological and archaeological resources before they are even inventoried. The network parks provide a unique opportunity to study erosion, solifluction, debris flow, landslide, and thermokarst processes without any anthropogenic influence. Erosion and solifluction occur along extremely unstable slopes along the south-central Brooks Range. Many of these large flows are associated with schistose geologic units. Landslides are massive in size and there is a need for future research to determine the nature of these features and identify areas especially susceptible to mass wasting.

Thermokarst processes are active on low slope areas throughout the network. Thermokarst refers to the irregular land surface containing cave-in lakes, bogs, caverns, depressions, and pits formed by the melting of ground ice (permafrost - described below). Approximately 5% of the total land area in Alaska is experiencing thermokarst. Some of the larger slumps may contain intact chunks of tundra (torevas?) and relict ice cores. Large-scale thermokarst subsidence occurred in GAAR during the late 1990s. The area around Feniak Lake seems susceptible to thermokarst enlargement that developed as large gullies. Knowledge of areas especially susceptible to thermokarst is of great interest to the network due to its widespread impacts on landforms, vegetation patterns, and implications for climate research. The potential exists for large-scale thermokarst features to develop rapidly with warming climate throughout the Arctic Network. Thermokarst features are not always large enough to appear on small-scale mapping, more detailed mapping is necessary in areas determined to be especially susceptible. Identification of thaw-related landform patterns is ongoing throughout the network.

Fluvial Issues

The surface water in streams, rivers, creeks and springs is a significant natural resource throughout the Arctic Network. The Continental Divide runs through NOAT and BELA. The parks of the

network contain several large watersheds. There are seven designated wild and scenic rivers in the network including the Noatak, Salmon, Kobuk, Alatna, John, Tinayguk, and Koyukuk Rivers. Because these rivers are all free of any anthropogenic engineering, they provide an excellent opportunity to study fluvial processes free of human influence. The network contains classic examples of nearly all known river types including braided rivers, meandering rivers, glacial streams, and spring streams. Careful, detailed mapping of the river corridors throughout the network parks would provide invaluable models of natural conditions for fluvial studies throughout the United States including remediation efforts of removing old dams and other engineering structures.

Rivers in the Arctic Network cut through thick glacial moraine and outwash deposits. Riverbanks and bluffs such as those along the Noatak River offer rare windows into the depositional history throughout the Pleistocene exposing cross sections of strata that is otherwise covered by thick glaciofluvial deposits. The network has interest in determining the evolution of the modern floodplain along the Kobuk River at KOVA. The development of the river channels throughout the Quaternary strongly influences vegetation patterns and modern landforms. Detailed studies of certain rivers could provide models for other rivers within the network.

During the extreme low temperatures of the long arctic winters in northern Alaska, most surface water freezes solid. Aufeis accumulates along river and stream corridors by upwelling of river water behind ice dams or by local groundwater discharge. In areas where discharge is blocked by ice, a local rise in the water table occurs along the stream bank atop the aufeis. Successive accumulations can reach several meters thick. Aufeis accumulations yield important information about the underlying hydrogeologic system. They may indicate the presence of springs as well as fault and karst conduits for groundwater through the subsurface. The presence of aufeis is sensitive to local climate and impacts of global warming on aufeis are correlative to those on glacial ice. Because aufeis forms during the winter months, access to study it is very difficult in remote areas of the network.

Along the northern flank of the Brooks Range in GAAR and NOAT, surface water drains northward. North of these units is the National Petroleum Reserve in Alaska. Exploration for petroleum and coal may impact the downstream areas of the major drainages within the park units. This could affect fish spawning and bird migration in addition to vegetation degradation in those areas.

Paleontological Resources

Fossils are present in abundance throughout the central Brooks Range and in all five Arctic Network parks. Most invertebrate fossils are not considered rare or especially valuable in the network area, but the threat of theft is possible. Theft is a significant concern for the variety of vertebrate fossils and Pleistocene macrofossil remains. Notable examples of fossils in the network include ichthyosaur remains in the Schublick Formation, Devonian brachiopods in the DeLong Mountains at GAAR, Ordovician fossils at Mulgrave Hills in CAKR, and many Pleistocene fossil localities along the coastal areas at BELA and CAKR including mastodon remains at Kotzebue Sound. Mammoth and other Pleistocene remains are preserved in glacial ice and periglacial deposits. The late Jurassic-early Cretaceous *Buchia* bivalve is the ubiquitous fossil of the network. Of the Arctic Network parks, GAAR contains the most fossil remains in vast layers of sedimentary rocks of the Brooks Range. NOAT and KOVA are also rich in fossil resources, but their

classification and distribution are not well understood. Conodont fossils are useful in dating specific units and they are present throughout the Brooks Range.

A cooperative effort is underway between the Alaska Division of Geology and Geophysical Surveys, the U.S. Geological Survey, and other agencies to produce a website pertaining to the fossils present in Alaska as part of the Minerals Data and Information Rescue in Alaska (MDIRA) project. Surficial records of fossil discoveries began in Alaska as early as 1898. Database developers are incorporating published and unpublished information including U.S. Geological Survey E&R reports, published literature, reports from state surveys and academics, well data (45,000 localities) and cores from industry, and field notes. Search parameters include quadrangle extent, fossil type, and author. To date, more than 12,000 fossil locality reports are in the Alaska Paleontological Database (www.alaskafossil.org). Approximately 80% of the information incorporated into the database was never previously released. As part of this project, a paleontological bibliography lists mapping and reports where faunal lists are included. To date, this project focuses on invertebrate fossil and microfossil data due in part to the sensitive nature of vertebrate fossil data. These data will be vital to network resource management. Paleontological data have implications for the reconstruction of the geologic history of all park lands. Legacy paleontological information is especially important for areas that researchers cannot revisit because they are too isolated or costly to access.

Coastal Erosion and Shoreline Evolution

BELA and CAKR contain significant coastal areas. There is more than 250 km of coastline at BELA and more than 120 km of coastline at CAKR. At present, there are 27 coastal monitoring stations along the coasts of both parks. Coastal features include barrier islands, dunes, bluffs, swail-constrained lakes, palsas (ice mounds), surge channels, beach ridges, enigmatic gravel beaches, marshes, driftwood lines, lagoons, sand flats devoid of vegetation, overwash areas, sand wedges, and eroded bluffs. Tides along these coasts fluctuate less than 1 m.

The geologic history of this area has strong ties to cultural resources since the Bering Land Bridge allowed prehistoric people access to North America from Asia. Today, the distance across the Bering Strait from Alaska to Siberia is only 88 km. Glacial fluctuations caused sea level to rise and fall locally several times throughout the Pleistocene. Seawater breached the land bridge approximately 15-14,000 years ago. Another transgression dates to approximately 11,000 years ago. Between 1,150 and 750 years before present (ybp), there was a time of a major regional erosional truncation. The last interglacial shoreline is mappable at both BELA and CAKR as overbluff dunes and stranded wave-cut benches located some 2 km inland. More research is needed in this area to determine the local sea level history. This type of research includes core sampling, sonar surveys, mapping ancient shoreline deposits, identifying and measuring paleoshorelines scars, dating buried peat deposits and detrital wood, and identifying marine remains in deposits. Cores at BELA show relatively little sea level rise over the past 5,000 years (~0.3 mm/yr average).

Understanding the impacts of major storms and rising sea level are important resource management needs at BELA and CAKR. Much research is focused on the coastal areas around Native Alaskan villages such as Shishmaref. These villages are susceptible to flooding and erosion as is much of the coastline within park boundaries. Attempts to anchor the coastline with seawalls near the village have led to localized erosion (1 m/yr at Shishmaref vs. 60 cm/yr nearby). The flood history of large

sand flat areas devoid of vegetation is a needed dataset. Data indicate that shoreline erosion at CAKR progressed further over the last 20 years than at BELA. This may be because hard bedrock underlies CAKR whereas the northern Seward Peninsula is mostly soft sediments. Coastal erosion and landform maps are crucial for resource management at BELA and CAKR. A GIS approach to erosion data would be useful for park resource management to correlate with other data layers. Determining erosion rates involves identifying the cause of erosion and forcing functions. Needed data sets include consistent reference points, ground truth comparisons, a record of storm climatology, as well as high spatial and temporal resolution maps, aerial photographs, and coastal monitoring.

Based on historic accounts and paleostorm layers in the exposed sediments at BELA and CAKR, major storms in the Chukchi Sea corresponded with cold spells, not warming periods. Large storms up to hurricane force were prevalent during the cooler climate of the mid to late 1800s. Thus, the presence or lack of major storms in the area is probably not an appropriate analog for global warming studies.

Much of the coast at BELA and CAKR has barrier island and lagoon systems. These barrier islands front tundra flats and coastal bluffs. This is a classic example of a sediment recycling system though questions remain as to the exact source of the sediments. As the bluff erodes, sediments build a spit at the end of the depositional system. Offshore bars, visible from aerial photographs also supply sediment to the coastal system. Coarser gravel deposits on local shores may anchor some areas while starving others for sediment. The effects of the shipping port for the Red Dog mine north of CAKR on the sediment supply are unknown. The barrier island coastal areas in BELA and CAKR are dynamic systems capable of rapid change and are sensitive to changes in sediment supply and type, sea level change, wind direction, and anthropogenic influences. A single storm can blow open inlets and close others. Early records indicate approximately 10 inlets were open in the barrier islands off the coast of BELA during the 1800s. Sea level transgressions force the barrier islands landward whereas regressions cause the barrier islands to migrate further from shore. Detailed mapping would help to determine the evolution of the barrier islands. Such mapping may reveal old, healed inlets, as well as buried lagoons and beach ridges, dune deposits, overwash fans, floodtide and ebb tide deltas, surge channels, and storm layers.

Ongoing mapping efforts by Owen Mason (see list of participants) in the BELA area have delineated 4 main ridge plain deposition units dated at 3,700-3,000 ybp, 3,000-2,000 ybp, 2,000-1,000 ybp, and less than 1,000 ybp. The paleorecord uncovered by the mapping of these coastal deposits now includes ~275 carbon dated peats, shells, and archaeological remains. This mapping also identified major erosional truncations, 11 beach ridge correlations, present eroding bluffs, and areas of aggradation and erosion. More mapping is needed for the lagoon side of the bluff, along the beach ridges and berms, and along the high tide line. The vegetated bluffs at Cape Espenberg contain a 4,000-year perspective of storm layers and erosional history. Mapping of the entire coast from the Wales area to Cape Espenberg as one system would increase understanding of longshore effects that could extend to CAKR as well. The coastal environments at BELA and CAKR are not independent of each other. The correlation of coastal features and deposits between the two parks and coastal change index maps would increase the regional understanding of shoreline development.

Economic Resources

Alaska with its natural resource abundance has been a target for petroleum and mineral exploration throughout its history. The National Petroleum Reserve in Alaska borders NOAT to the north and GAAR to the west. Human activity in this area is a resource management concern for all five Arctic Network parks. Drilling peaked during the 1940s and 1970s but exploration work is ongoing. The reserve lands also contain large coal seams (Lisburne coal beds) and barite. The Bureau of Land Management has interest in coal exploration in the area. The Arctic National Wildlife Refuge (ANWR), an area of ongoing political debate, sits just east of GAAR. Exploration studies stretch across the north slope of the Brooks Range north of GAAR amidst waterfowl nesting habitat and caribou calving grounds. However, interest in the state land lease sale there (initiated to divert attention away from ANWR) is waning as no drilling is revealing economically viable prospects. Most rocks within the Arctic Network parks are outside the oil maturation window, however, park exposures can serve as models for development elsewhere. The Castle Mountain outlier to GAAR sits within the north slope area. There is some interest to look for petroleum there, but law prohibits commercial operations within wilderness areas. The Alaska Division of Geological and Geophysical Surveys implemented a North Slope Program to understand the geologic evolution of northern Alaska. This study incorporates seismic data, field observations, structural models, and gravity surveys along the foothills of the north slope to create a working cross section.

With the global price of metals rising, mining operations may renew interest in older sites and less concentrated ore deposits. Mineral resources are present in many geologic units within the Arctic Network. The granitic rocks around Serpentine Hot Springs in BELA are tin bearing. Some claim posts exist in the park, are now overgrown, and were never staged. Tin and rare earth element deposits on the Seward Peninsula contain the nation's largest tin reserves. The potential for mining of these reserves depends on the global tin market. Also on the Seward Peninsula are polymetallic ore deposits rich in zinc and lead. There is active exploration northeast of BELA for zinc and lead. Gold, zinc, and lead mining continues south of BELA and the Anaconda Mining Company found tantalum in the area.

Within the schist belt along the south side of the Brooks Range in the Antler River area are volcanogenic sulfide deposits, approximately six of which are high grade. These deposits may continue laterally east or west outside of GAAR. Mining companies could attempt to establish access to these deposits. There are still some inholdings in GAAR for gold placer mining. Near the villages of Wiseman and Nolan, east of GAAR on the haul road, is a longstanding target for placer mining. Some quality quartz crystals, vein gold, and antimony are also associated with this area. Drilling and trenches at Nolan Creek and Little Squaw Creek revealed an 8-km gold bearing shear zone. The Ambler mining district located between GAAR and KOVA contains excellent polymetallic ore, but is mainly copper producer. Exploration for zinc is ongoing near the Squirrel River in the Baird Mountains quadrangle.

Energy costs for many of the rural areas surrounding the Arctic Network are very high. This high cost may also affect future plans for network park development. The Alaska Division of Geological and Geophysical Surveys has information regarding mines and mineral resources throughout Alaska and is compiling an energy inventory for the state including remote coal resources, coal bed methane, wind, natural gas, peat, and geothermal potential. The desired solution would be a clean, renewable energy resource for these remote areas.

Permafrost Dynamics

Permafrost refers to the layer of permanently frozen regolith (cryosphere) beneath the intermittent freeze-thaw zone known as the active layer. Maintaining permafrost requires sub-freezing mean annual temperatures (-6°C to -12°C locally). In the Arctic Network, relict glacial ice may be contributing to the permafrost layer, which is very thick (locally within 10 cm of the surface) and covered by a relatively thin active layer. Permafrost is relevant to geomorphology studies. In colder areas, aggradation of permafrost has an active uplift signature on the landscape. Degradation of permafrost occurs due to myriad factors including climate change, ground water movement, regolith texture, ice morphology, ice content, and landscape position. Degradation may appear as thermokarst, collapse (scars, fens, bogs, pits), water tracks and gullies, cryoturbation, tussocks, piping, mounds, hummocky topography, and polygonal patterned ground. Permafrost melting on hill slopes creates solifluction surfaces and large landslides. There are at least 100 thaw slumps in NOAT near Noatak Canyon. Glacial thermokarst is active on terminal moraines in the upper Noatak River valley. On the coastal plain areas, permafrost degradation affects 20-30% of the land surface. On the Seward Peninsula, more than 24 m of shoreline collapsed into a thaw lake feature. In a 3x5 km study area, there were more than 20,000 pits related to permafrost degradation. Permafrost degradation also locally lowers the land surface and causes water table fluctuations. As water floods into depressions, upland areas become drier, thus changes in permafrost can affect the entire landscape.

The dynamics of the interactions between the active layer and the underlying permafrost is important to understand for resource management in the Arctic Network. Active layer monitoring does not detect thaw from below. Thermokarst (described in an earlier section) studies throughout the network are ongoing and significant interest is towards developing remote sensing strategies and protocol for permafrost dynamics and thermokarst. High-resolution photography (0.3-0.6 m pixel size), LIDAR surveys, IFSAR and SAR, and ice mapping are needed data sets. Flights capture photoline surveys across vast tracts of land. Extensive ground checking is necessary to test the accuracy of aerial photographic mapping and surficial maps.

Permafrost is particularly sensitive to changes in climate. The network desires to understand the long-term effects of global climate change on the permafrost in the parks. Modern warming trends cause ice wedges to melt creating characteristic ground patterns. Where streams flow across ice wedge fields, they become “beaded” streams. A beaded stream is unique to Arctic settings. Permafrost is also prevalent in approximately 20 ice-cored mounds (pingos) in NOAT. Other pingos are in isolated areas of GAAR, KOVA, and the Seward Peninsula. These features can be tens of meters high and hundreds of meters across. Pingos last at least a year and form in response to hydrostatic pressure of water within or below the permafrost layer. Collapsed pingos are another unique geologic feature in the network.

Permafrost in buried organic regolith (so-called Yedoma soils) is an important carbon reservoir in the Arctic Network. Rising global temperatures may enhance decomposition of permafrost organic matter, releasing respired CO_2 . Yedoma is mineral rich and accumulated as wind blown loess deposits buried organic surface layers that were subsequently frozen in permafrost (Dutta et al., 2004). Permafrost ice may also contain chemical components that could threaten water and soil

quality in the Arctic Network. In the Kelly River, a western tributary to the Noatak River, ongoing soil and water studies are determining potential effects melting permafrost has on geochemistry.

Ecosystem Connections

Geology forms the foundation of any ecosystem and there are numerous examples of geologic factors strongly influencing flora and fauna distribution patterns throughout the Arctic Network. Geologic structures and formations often have unique characteristics that render them ideal habitat for birds and animals. For example, large granitic tors (isolated crags or pinnacles) surrounding Serpentine Hot Springs provide nesting habitat for raptors. Bedrock composition factors strongly into the overlying soil chemistry. Plants growing in soils derived from heavy metal deposits have high heavy metal tissue concentrations and this is creating teeth problems in moose populations feeding on these plants. On the Seward Peninsula, lichen species find refuge in large lava fields, and plants preferring iron and magnesium rich substrates (frequently derived from basaltic igneous rocks) thrive locally.

Glacial deposit distributions strongly control plant assemblages. For example, well drained glacial moraine crests support aspen groves whereas the poorly drained troughs between the crests host spruce forests. Some plant species are able to tolerate the movement associated with solifluction slopes developed on shale. Resource management wants to establish quantitative parameters for raster based predictive models of vegetation distribution. Geochemical data (including 40-element ICP analyses and As, Hg, and Se content) from widespread sampling is available through the U.S. Geological Survey and Alaska Division of Geological and Geophysical Surveys (much of this data is available for download). In general, there is a strong need for more derivative numerical products based on quantitative data from various factors including geology, soil, vegetation, geomorphology, water, climate, and topography.

Permafrost also has significant implications for ecosystem health. In transition areas between frozen and unfrozen ground, vegetation changes from spruce forests to aspen forests, respectively. Other permafrost-related features include patterned ground. At NOAT, wedges that support different vegetation separate some segments of the patterned ground and vegetation distribution influences animal migration patterns. Where permafrost is degrading, lowland areas flood, forest and shrub vegetation drowns, and upland areas become drier. Along thermokarst lakes, the margins degrade laterally as the shoreline slumps into the lake. This slumping releases bursts of sediment into the system. The effects of this increased sediment load on fish and aquatic habitats are unknown. Melting ice from permafrost degradation may release components that could also change local water and soil chemistry.

The Arctic Network is relatively free of anthropogenic influence; however, airborne contaminants are present in the surface water and regolith. The network is particularly concerned about the deposition of mercury into lakes and streams as well as the transformation of mercury naturally occurring in geologic units into bioavailable methyl mercury. The highest mercury concentrations in fish in the Arctic Network are in NOAT and GAAR. Other toxic metals such as arsenic, cadmium, lead, and zinc occur naturally in some surface water and springs. These areas tend to correlate with mineralized zones (magnetic highs). Understanding wind patterns, bedrock and soil geochemistry, the hydrogeologic system, and modern climate will help resource management create models to predict areas of the greatest potential impact.

Seismicity

Though active faults and seismic activity is focused further south and east in Alaska, the potential for earthquakes exists within Arctic Network parks. Most earthquakes in Alaska result from compressional and transtensional forces created by the collision of the Yakutat terrane on the southern coast. This collision is pushing a deformation wedge northward along a trend towards the Arctic National Wildlife Refuge east of GAAR. Patterns of past seismic activity appear to run from a roughly east-west zone across southern Alaska stretching in a Y-shaped north-south trend up into the Brooks Range, east of GAAR in the Mt. Chamberlain area. The Kobuk fault zone runs south of the Brooks Range. It may be outside of park boundaries, but seismic activity along this structure could impact a large area including park lands. Monitoring since 1973 reveals that not all earthquakes are centered along the Kobuk fault. There may be an accommodation zone under eastern GAAR. A massive zone of large-scale slumps in the Bettles area (south of GAAR) is evidence of an ancient earthquake rupture.

Shaking associated with the large (M 7.9) 2002 Denali earthquake was detectable in the Arctic Network. It is likely there are other active fault zones (predominantly normal faults) throughout the network parks. In general, faults within park boundaries are not well located on the surface. More detailed mapping, seismic monitoring and analysis could reveal active faults in the parks. There is limited information on this topic as well as any potential hazards to park resources in the event of a strong earthquake. The University of Alaska, Fairbanks maintains an earthquake-monitoring program as part of its geophysical center. At present, there is no data sharing arrangement with the National Park Service. The U.S. Geological Survey also maintains an excellent seismic website.

Offshore seismicity may trigger tsunami hazards, but there has been no indication of recent tsunamis along the coastal areas perhaps due to the relatively sheltered orientation of the landmass at BELA and CAKR. There is some seismic activity offshore in the Chukchi Sea. Some paleostorm deposits at BELA may actually be from tsunamis, but more data are needed to determine their cause.

Disturbed Lands

The size, isolation, and lack of infrastructure of the Arctic Network parks have lessened the potential for the development of disturbed lands. Nonetheless, anthropogenic impacts persist in the network. Resource management wants to map the human footprint at all five parks. All-terrain vehicles allow humans deeper access into natural areas and the vast borders of the parks are difficult to patrol. The haul road corridor for the Red Dog tin mine (located northwest of CAKR) crosses CAKR and is under a 99-year lease. There is heavy metal contamination along this access road and associated port facility. Road dust along the haul road pollutes local lichen and vegetation populations. Gravel mining operations also occur along this corridor. The Red Dog mine has satellite units that may attract future mining interest. The Arctic Network wants to collaborate with the U.S. Geological Survey to fly imagery of the impacted park areas.

There are proposals to spur the haul road to the village of Noatak for better access at CAKR. The BLM Kobuk-Seward plan aims to change the status of lands north and south of the Arctic Network. Understanding the baseline conditions is necessary prior to this plan's implementation. The network

wants information regarding remote sensing of negative impacts especially given the potential for mining operations to get larger in the coming years.

Abandoned mines of Mascot Creek are upstream of Glacier Creek, which flows in GAAR. The park is concerned about potential mine drainage issues from this abandoned mine. In BELA, the park is trying to acquire the Humboldt Creek mine in an old gold mining area. Associated with some mine features are old barrels containing mercury. Access trails to small-scale mines also cross the park.

Disturbed lands also include the Hickel Highway up the John River from Bettles to Anaktuvuk Pass and former military sites and landfills in GAAR and CAKR (“White Alice” site). Airstrips with the capacity to land C-130s built to access the north slope of the Brooks Range are also in GAAR and remain unreclaimed. A U.S. Geological Survey camp and airstrip are in the Feniak Lake area. Overuse of a popular camping area near the Arrigetch Peaks at Paco Creek degrades the lichen and plant communities there. The park is deciding whether to reclaim the area or try to limit the impact of the campground on the local ecosystem. The EPA website has record of a military camp and landfill at Desperation Lake in NOAT as a hazardous waste site. In approximately 5-10 years, a 6-mile right-of-way access to Native American gravel resources for the village of Shishmaref will cut across the panhandle of BELA. There are several lingering RS 2477 routes in park lands.

Imported European reindeer populations locally create grazing impacts. At BELA allotments are divided up for grazing areas. Overgrazing delicate tundra vegetation leads to significant degradation, increased erosion potential, and localized compaction.

Features and Processes

Aeolian

In northern Alaska, aeolian activity has abated somewhat compared to past levels. Aeolian features in the Arctic Network parks range from large, active dunes at KOVA to widespread loess deposits at GAAR. The active dunes at KOVA (Great Kobuk, Little Kobuk, and Hunt River dunes) are only a remnant of a much larger dune field that is primarily vegetated today. There are small dune fields along the Kilik River valley in GAAR and some limited dunes in NOAT. A terrestrial dune field may be submerged off the coast of BELA. More data are needed to determine its origin. Aeolian features such as dunes and loess deposits contain important information useful to reconstruct paleo wind direction, global deposition patterns, and regional paleoclimate. This information is vital to understanding modern climate change.

All parks in the Arctic Network contain deposits of fine-grained silt (loess) associated with aeolian processes during glacial periods. Loess particles form in part by glacial erosive scouring and thickness and distribution of these deposits locally influence landform expression, slope stability, and vegetation patterns. The presence or absence of a thick loess layer modifies the landscape. For example, thick loess deposits evenly covering a ridge will support ridge top forests and muted topographic expression whereas thin or non-existent loess atop ridges leaves barren rock rubble surfaces and exposed terraces on the flanking slopes. Because loess is a significant fine-grained surficial deposit and regolith component, the composition of the loess also influences plant assemblages. For instance, a calcareous loess composition supports specific flora assemblages versus non-calcareous loess. Vegetation patterns affect fauna distribution with broad implications.

For example, where vegetation supported caribou herds, prehistoric humans may have left archaeological resources. Loess also contributes to soil pH patterns. This influences acidic versus non-acidic vegetation communities. Surficial geologic maps do not often capture individual loess facies. Detailed mapping and geochemistry of these deposits is a resource management need at the Arctic Network.

The network is monitoring the current extent of active dunes. Increased knowledge of the orientation and distribution of aeolian features at the network would be helpful to establish detailed baseline conditions for future monitoring. The network also wants to delineate the source areas for paleo and active aeolian features. Climate changes may impact aeolian activity. Active aeolian areas include glacial outwash areas, which are closely linked to local climate patterns. The network wants to understand how warmer and drier climates may affect the dunes at KOVA and other aeolian processes and landforms throughout the network. The network needs more data to understand current patterns and create models to predict future responses to climate change.

Other aeolian features include blowout areas where wind has removed all fine mud and sand grains leaving only coarse gravels and pebbles. These serve as lag concentrate and anchor landforms. These are locations to target for cultural site investigations. Along the Kilik River in GAAR, lag concentrate contains clusters of flakes, chips, and other archaeological artifacts. Detailed mapping of blowout areas would be a useful data set for network management. Aerial photographic mapping would identify many aeolian features.

Glaciers and periglacial features

Most of the active glaciers (alpine glaciers) appear in GAAR nestled in north-facing cirques. The upper Noatak has a small ice cap. Today's glaciers seem underfit in the large U-shaped valleys carved millions of years ago by previous glaciers. Smaller ice fields persist throughout the network and are especially relevant for potential concentrations of cultural resources. Ice preserves organic artifacts such as bones, wood, arrows, feathers, etc. These artifacts are threatened as ice continues to melt, washing them away before they can be inventoried. In addition to glacial ice and snowfields, some glacial outwash plains contain active kettle lakes. Relict glacial ice beneath these active kettle lakes is still melting and causing the lakes to subside. The network has an interest in studying glacier dynamics and monitoring the overall condition of the glaciers. A photographic record spanning some 100 years exists for many of the network's active glaciers.

Classic periglacial and glacial features as well as subsequent landforms including moraine deposits, outwash deposits, perched drainages, erratic boulders, block fields, stone streams, eskers, drumlins, arêtes, spurs, horns, kame terraces, glacial lakes, cirques, hanging valleys, kettle lakes, and U-shaped valleys are abundant in the Arctic Network parks. The Arrigetch Peaks and Kilik areas are dramatic examples of glaciation in the Brooks Range at GAAR. The Arrigetch area has large blockfalls and talus cones. At Desperation Lake, iceberg wedges calving from glacial fronts once slammed against the shoreline leaving characteristic scars along the paleo-shorelines. At NOAT is a record of a series of glacial dammed lakes. Paleoshorelines of these lakes appear as wave cut notches with beach deposits at the base. Some glacial moraine deposits persisted as islands in these lakes and were reworked by wave action. As rising water breached glacial dams, torrential floods quickly reestablished the course of the Noatak River and preserved stranded paleolake shoreline features upstream such as iceberg scars. Bluff exposures along the river contain evidence of this

geologic history at the park over the last 130 Ka. Bluffs also contain a record of interglacial vegetation, which in turn will help in modeling future responses to climate change. In addition to detailed mapping, radiocarbon dating (for younger deposits), aerial photographs, and overprinting structures of the bluffs would be helpful to park resource management to understand the development of the larger river valleys.

Glaciers carved and sculpted much of the Brooks Range some 1 Ma. Later glacial events were smaller in scale and only partially overprinted the older events thus preserving a complex history of intermittent glaciations, interglacial periods, and periglacial conditions. The oldest features are beyond the scope of radiocarbon dating. For this reason, surficial geology studies, especially detailed mapping, are vital to determine the geomorphological history of the Brooks Range. Silts and organic material in interglacial bog deposits contain insect, plant, and pollen remains that could provide useful radiocarbon dates of more recent interglacial periods. The degree of landform modification, differential weathering patterns, loess distribution, volcanic ash layers, soil development, cyclic sedimentary deposits (glacial, lacustrine, fluvial, marsh, loess) and overprinting relationships are some of the features surficial geologists seek out to determine timing of glaciation in a given area.

Volcanism

Active plate tectonics responsible for the formation of Alaska including subduction and mountain building have led to widespread volcanic activity throughout the state. Many of the large volcanoes are associated with the subduction zone far to the south of the Arctic Network. However, volcanic flows and ash beds (tephra) on the Seward Peninsula attest to local activity. Ashfall completely buried the local tundra landscape at BELA at approximately 18-20 Ka. This setting may preserve entire paleontologic assemblages of plants and insects. Early Holocene eruptions at BELA lead to large pahoehoe lava flows to cover vast tracts of land from north to south. The youngest rocks at BELA are approximately 1,000 years old. The lava fields are largely unexplored. Morphologically young craters dot the landscape of the Seward Peninsula. The network has interest in determining the patterns of eruptions and predicting potential future volcanic activity in the area.

Caves and karst

In BELA on the Seward Peninsula, a series of caves called the Trail Creek Caves near Asses Ears in the southeastern section of the preserve serve as significant sites for paleontological and cultural resources. Other cave features at BELA may include lava tubes associated with the recent volcanism there.

Karst processes are active in many areas throughout the landscape of the Arctic Network. Karstification involves the processes of chemical erosion and weathering of limestone or dolomite (carbonate rocks) (Palmer, 1981). Dissolution occurs when acidic water reacts with carbonate rock surfaces along cracks and fractures. Karst features present may include caves, pinnacles (Asses Ears), and subsurface conduits. The Lisburne Limestone along the northern flank of the Brooks Range is associated with the formation of significant aufeis (described earlier) and “icing fields” possibly through the dissolution of limestone in the subsurface creating groundwater conduits. This may also be the case near Anaktuvuk in GAAR. Karstification is possible in many limestone bearing geologic units throughout the Arctic Network. More exploration is needed to determine the degree of dissolution and what influence the presence of karst has on the ecosystem.

Hot and warm springs

The pristine water quality of the hot and warm springs in the parks is unparalleled due to the relative lack of anthropogenic influences. The network would like to prepare a general inventory of all geothermal features in the parks. The Alaska Division of Geological & Geophysical Surveys has published maps of geothermal resources in Alaska that include hot springs and areas of strong geothermal energy potential. These in addition to detailed surveys and onsite research into the characteristics of the geothermal features would be valuable to network management. The warm springs (often only a few degrees higher than normal springs) of the network serve as vital habitat for unique extralimital flora and fauna. These springs do not freeze solid during winter months (maintain temperatures of approximately 4°C) protecting local fish, aquatic fauna, and distinct vegetation populations (cottonwood, poplar, gooseberry, and juniper). Warm springs are harder to locate, map, and characterize than hot springs. There are at least 20 known warm spring sites in GAAR alone. This is a significant research need for the network.

Several hot spring features exist on the Seward Peninsula including Pilgrim Hot Springs between BELA and Nome, Alaska and Serpentine Springs in BELA, some 75 km away. Pilgrim Springs is a potential target for development, but given the distance, it is unlikely park geothermal resources would be affected. In BELA, resource management has research needs for Serpentine Hot Springs in terms of the hot water source, hydrogeologic mechanics, and spring “plumbing”. Several of the lower springs have flooded out. Prehistoric people used these springs and they left archaeological remains, including housepits, spanning 10,000 years. The springs have healing and spiritual significance for indigenous people. This may have inspired early inhabitants to avoid damaging the landscape around the springs. Other named hot springs include Reed River Hot Springs in GAAR. Pilgrim and Reed River Hot Springs are located near young faults suggesting these structures may play a role in hot spring development. Geologists suggest Gates of the Arctic pass in GAAR (along young faults) may be another potential geothermal concentration site for detailed research focus.

Type sections and unique geologic features

Type sections refer to the originally or most complete described sequence of strata that constitute a geologic unit. It serves as an objective standard for comparison with spatially separated parts of that same unit. Preferably, a type section describes an exposure in an area of maximum unit thickness and completeness. In Alaska, unit definitions are less precise and highly variable spatially. Most “type sections” are informal descriptions of particularly well exposed areas and might be more appropriately termed reference sections. NOAT contains many type sections for lower Paleozoic and Cretaceous age units including the Noatak Sandstone of the Endicott Group. Unusually old ice age sections of sediments occur along the Noatak River. The northeastern Baird Mountains also contain classic exposures of widespread geologic units. In northeastern GAAR, geologists probably used the exceptional exposures to define geologic unit characteristics.

The Arctic Network contains spectacular geology and particularly unique and interesting features are too numerous to separate and list. However, some unique features are also important to the understanding of the regional geologic history. In the northeast corner of the Baird Mountain quadrangle, unusual blueschist forms part of an eyelid window surrounded by a pattern of faults with concurrent motion that splay off the central bulge. At BELA is another unique, flat-lying blueschist exposure covering a large area. The Nannelik area contains high-pressure metamorphic

rocks (kyanite bearing) that contain important clues regarding the collision event early in the history of the Brooks Range. Mt. Osborn, south of BELA in the Kigluaik Mountains has portions of a proposed mantle wedge (garnet peridotite) that was buried deeper than 36 km in the crust. This may be the only such exposure of garnet peridotite in the United States and more data are needed to determine its origin and extent. The Doonerak Mountain area in GAAR contains exposed faults that are critical to reconstructing regional fault motions of a late Tertiary duplex and understanding the buried area off the north slope. The oldest rocks known in northern Alaska (orthogneiss possibly of the original North American craton, ~970 Ma) are near Ernie Lake in central GAAR. This lake is only accessible via seaplane and some of the geologically significant areas are outside of GAAR. Geologists do not have a good working understanding of the geologic history of this area; understanding it would increase the knowledge of the earliest history of the entire Brooks Range.

The vast ice layers of permafrost throughout the Arctic Network preserve organic material. This material is an excellent target for carbon age dating. Other geochemical targets in the network include volcanic ash (tephra) beds. Dating volcanic deposits yields important information about specific short intervals of geologic time. Layers of ash form marker beds in sedimentary strata and when identified and dated, add greatly to the depositional history of an area. The Division of Geological and Geophysical Surveys maintains a website (www.AKgeology.info) that is in part a derivative of the U.S. Geological Survey's geochemical database and also delivers library collections of geologic information, updated digital geologic databases, a mining claim database, and geologic bibliography. These databases contain data for more than 300,000 separate samples throughout Alaska including many isotopic age dates on bedrock throughout the Southern Brooks Range. Geochemical data is important for resource managers to make correlations between geology and biology and for landscape evolution studies.

Lacustrine

There are many classic examples of unique lacustrine features throughout the Arctic network including large and deep freshwater lakes, alpine lakes, kettle ponds, thaw ponds, and maar lakes. Maar lakes form by volcanic eruptions through permafrost. Examples of these lakes include the Devil Mountain Lakes and Espenberg Lakes on the Seward Peninsula. The network contains the largest maar lakes in the world. Pingos locally degrade to form small ponds. The largest lakes are heavily used by fishermen and include Chandler, Takahula, Imuruk, Selby, Matcharak, and Fenaik Lakes. Walker Lake, a large basin in southwestern GAAR is a national natural landmark.

Most if not all known types of glacial lakes exist in the Arctic Network. Glacial lakes near the Arrigetch Peaks are dramatic. Moraine dammed lakes such as Feniak Lake are common throughout the Arctic Network. Many of these lakes are prone to thermokarst enlargement as underlying layers of ice are melting causing shoreline subsidence. Lakes are of particular interest to visitors and park management because they provide primary access points to remote areas by seaplane. Some of the more frequented lakes could be interpretation opportunities for the Arctic Network parks. Lakes also contain valuable climate records including pollen in lake sediments, bluff exposures, and lake patterns. Many lakes at BELA are aligned with wind direction and may serve as examples for paleowind determinations elsewhere.

Lakes are disappearing in the Arctic Network indicative of the fragile nature of the tundra environment. This is due to myriad processes including talik formation as well as warming and

drying climatic trends. Taliks form as a channel in the permafrost layer beneath a lake. When this channel forms, it acts as a drain for the lake and can cause an entire lake to disappear in a matter of hours. This has significant impacts on local bird and aquatic habitats. Warming and drying trends in modern climate are also causing lakes to shrink and disappear. Climate change is causing the evaporative demand to adjust and less water is being precipitated into the lacustrine basins throughout the network. Knowledge of factors such as surface water hydrology, current lake levels, shoreline morphology, proximity to permafrost, and climate trends will help resource management understand the changes in lacustrine environments.

Recommendations

- (1) Network should cooperate with the Geophysical Institute at University of Alaska, Fairbanks to monitor seismic activity throughout the area.
- (2) Obtain geothermal resources maps from the Alaska Division of Geological & Geophysical Surveys.
- (3) Contact Larry Gough at the U.S. Geological Survey in Reston, VA regarding biological-geological connections.
- (4) Contact Anita Harris regarding conodont age dates in the Brooks Range.
- (5) Contact Ilyla Bunnivitch at Woods Hole about coastal LIDAR surveys.
- (6) Perform detailed mapping of exposed bluffs along major network park rivers to determine Pleistocene geologic history and evolution of the current landscape. Tie specific glaciofluvial deposits with vegetation patterns.
- (7) Use preexisting geochemical sampling, surficial geologic maps, and known vegetation correlations to begin quantitative raster based modeling of plant community distribution.
- (8) Develop trail and aerial geologic guides for visitors to understand the geology of the Arctic Network parks while hiking, or exploring by plane.
- (9) Perform a comprehensive paleontological inventory of the network. Establish a plan to deal with potential illegal sampling and collecting.
- (10) Map current extent of lakes in the network focus on identifying specific lakes prone to disappear due to talik development as well as those experiencing thermokarst modification along shorelines.
- (11) Use the Alaska Paleontological Database at www.alaskafossil.org to determine the extent of paleontological resources in the network and target specific areas of interest for further study.
- (12) Monitor water table especially near known spring locations.
- (13) Reference the following website: www.akgeology.info from the Alaska Division of Geological and Geophysical Surveys geochemical, geologic hazard, mapping, mining claim, mineral resources, and other geologic information.
- (14) Perform landslide vulnerability index studies.
- (15) Identify areas susceptible to thermokarst development throughout the network. Focus detailed surficial mapping in these areas.
- (16) Focus on mapping river corridors to provide guidance for remediation efforts on engineered waterways elsewhere.
- (17) Examine cutbanks and bluffs along the Kobuk River to determine a history of floodplain development. Use this model for other rivers in the network.
- (18) Model impacts of north slope coal resource development on network natural resources.
- (19) Map all coastal areas of BELA and CAKR focusing on the entire system and coastal change index. Monitor changes in barrier island and lagoonal areas along these coasts.

- (20) Study erosion rates, sea level change, storm history, and deposition patterns along all coastal areas.
- (21) Model the effects of the Red Dog Mine port facility on sediment supply at CAKR.
- (22) Monitor surrounding economic resource development and potential for future development. Create models to predict future impacts on network resources.
- (23) Develop remote sensing strategy to determine nature and extent of permafrost degradation throughout the network. Perform ground checking of remote sensing surveys of permafrost degradation areas.
- (24) Encourage research to determine if melting permafrost is increasing CO₂ atmospheric input.
- (25) Research remediation strategies for ecosystem degradation along the haul road to Red Dog Mine through CAKR.
- (26) Develop remediation strategies for disturbed lands including access roads, airstrips and landfills across the network.
- (27) Encourage detailed mapping of loess facies.
- (28) Perform detailed mapping of blow out features as potential sites for cultural resources.
- (29) Encourage research into karst processes at carbonate rock exposures throughout the network.
- (30) Perform detailed mapping of lava fields at BELA to determine an eruption history and potential recurrence interval.
- (31) Encourage hydrogeologic study at Serpentine Hot Springs to understand the dynamics of the system and source of hot water.

Action Items

- (1) Contact Dean Tucker regarding the National Hydrographic Database for geothermal features in the Arctic Network.
- (2) GRE will produce digital geologic map coverage (surficial and bedrock) for each of the five Arctic Network parks.
- (3) GRE report writer will obtain the 1983 GAAR (Koyukuk mining district) BLM report on mines: *Environmental overview and analysis of mining effects Gates of the Arctic National Park and Preserve, Alaska*. Denver Service Center, National Park Service.
- (4) GRE report writer will obtain Professional Report 121 by Tom Hamilton.
- (5) GRD will contact Vince Santucci (NPS-GWMP) regarding a possible paleontological inventory for the network.
- (6) Contact Sara Wesser concerning the National Hydrographic database.
- (7) Contact Matt Nolin at the University of Alaska, Fairbanks regarding glacial monitoring and a time lapse photographic record of glacial change.
- (8) GRE report author will obtain Blodgett paleontological papers regarding Devonian fossils in the DeLong Mountains.
- (9) Partner with the U.S. Geological Survey to devote aerial surveys of impacted park lands.

References

www.akgeology.info (accessed May 24, 2007)

www.alaskafossil.org (accessed May 26, 2007)

www.nps.gov/gaar (accessed May 21, 2007)

www.nps.gov/noat (accessed May 21, 2007)

www.nps.gov/kova (accessed May 23, 2007)

www.nps.gov/bela (accessed May 22, 2007)

www.nps.gov/cakr (accessed May 21, 2007)

www.topozone.com (accessed May 23, 2007)

Sanzone, D.M, S.D. Miller, S.B. Young. 2006. *Monitoring Ecological Change in the Arctic Parklands: Vital Signs Monitoring Plan for the Arctic Network, Phase 2 Report*. Department of the Interior, National Park Service.

Palmer, A.N. 1981. *A geological guide to Mammoth Cave National Park*. Teaneck, NJ: Zephyrus Press.

Dutta, K., S.A. Zimov, E.A. Schuur. 2004. The Age and Amount of Carbon Released From Incubations of Permafrost Soil From Northeastern Siberia. *Eos Transactions, AGU* 85: 47, Fall Meeting Supplement, Abstract B13C-0240 1340h.

Table 1. Scoping Meeting Participants

Name	Affiliation	Position	Phone	E-Mail
Blodgett, Robert	USGS	Paleontologist	907-786-7416	rbodgett@usgs.gov
Booth, Mary	NPS, Arctic Network	Ecologist	907-455-0665	Mary_booth@nps.gov
Burkart, Greta	NPS, Arctic Network	Ecologist	907-455-0669	Greta_burkart@nps.gov
Chakuchin, Jobe	NPS, Arctic Network	Resource manager	907-455-0629	Jobe_chakuchin@nps.gov
Connors, Tim	Geologic Resources Division, NPS	Geologist	303-969-2093	Tim_Connors@nps.gov
Giffen, Bruce	NPS, Alaska Regional Office	Geologist	907-644-3572	bruce_giffen@nps.gov
Hamilton, Tom	USGS, emeritus	Geologist	907-786-7451	thamilton@usgs.gov
Heinlein, Tom	BELA	Superintendent	907-443-6101	Thomas_heinlein@nps.gov
Heise, Bruce	Geologic Resources Division, NPS	Geologist	303-969-2017	Bruce_Heise@nps.gov
Jorgenson, Torre				
Kucinski, Rus	NPS, Alaska Regional Office	Geologist	907-644-3571	Russ_kucinski@nps.gov
Lawler, Jim	NPS, Arctic Network	Coordinator	907-455-0624	Jim_lawler@nps.gov
Mason, Owen	Academic, INSTAAR	Geoarchaeologist	907-336-0092	geoarch@ptialarka.net
Miller, Scott	NPS, Arctic Network	Arctic Network Data Manager	907-455-0664	Scott_miller@nps.gov
Mills, David	NPS, GAAR-YUCH	Superintendent	907-457-5752	David_mills@nps.gov
Rattenburg, Kumi	NPS, Arctic Network	Biotechnician	907-455-0673	Kumi_rattenurg@nps.gov
Swenson, Robert	Alaska Geologic Survey	State geologist	907-457-5001	Robert_swenson@dnr.state.ak.us
Thornberry-Ehrlich, Trista	Colorado State University	Geologist, Research Associate	757-416-5928	tthorn@warnercnr.colostate.edu
Till, Alison	Alaska Science Center, USGS	Geologist	907-786-7444	atill@usgs.gov
Whitesell, Tara	NPS, Arctic Network	Biotechnician	907-455-0663	Tara_whitesell@nps.gov
Wilson, Ric	Alaska Science Center, USGS	Geologist	907-786-7448	fwilson@usgs.gov

Table 2. GRE Mapping Plan for Arctic Network

1x3 Sheet	BEDROCK CITATION	SURFICIAL CITATION
	ASSESSMENT	ASSESSMENT
Philip Smith Mountains	(2560) Brosge, W.P., Reiser, H.N., Dutro, J.T., and Detterman, R.L., 1979, Bedrock geologic map of the Philip Smith Mountains quadrangle, Alaska, , Miscellaneous Field Studies Map MF-879-B, 1:250000 scale <i>2008-0716: Only a-5 & b-5 intersect GAAR, so likely don't need full sheet. supercedes GMAP 2552; bedrock; Ric Wilson says USGS currently digitizing but GRE needs update to see where it's at; GRE will convert if its available digitally</i>	(2567) Hamilton, T.D., 1978, Surficial geologic map of the Philip Smith Mountains quadrangle, Alaska, , Miscellaneous Field Studies Map MF-879-A, 1:250000 scale <i>2008-0716: GRE has digital GIS version from AKSO that were produced by Greenhorn & O'Mara in Florida; not sure of quality; Ric Wilson says "suspect". Tom Hamilton says the digital versions have NOT been upgraded by USGS GIS group in Alaska and GRE doesn't have paper copy either. Likely needs redigitized to NPS standards</i>
Chandler Lake	(2568) Kelley, J.S., 1990, Generalized geologic map of the Chandler Lake quadrangle, north-central Alaska, , Miscellaneous Field Studies Map MF-2144-A, 1:250000 scale <i>2008-0716: Ric Wilson says USGS has this digitally; GRE will convert. should supercede GMAPs 2549 & 23007 as all by same author and extent; gives bedrock for Chandler Lake 1x3. GAAR needs a.1-a.5, b.1-b.5, c.4-c.5</i>	(2564) Hamilton, T.D., 1979, Surficial geologic map of the Chandler Lake quadrangle, Alaska, , Miscellaneous Field Studies Map MF-1121, 1:250000 scale <i>2008-0716: GRE has digital GIS version from AKSO that were produced by Greenhorn & O'Mara in Florida; not sure of quality; Ric Wilson says "suspect". Tom Hamilton says the digital versions have NOT been upgraded by USGS GIS group in Alaska and GRE doesn't have paper copy either. Likely needs redigitized to NPS standards</i>
Killik River	(2550) Mull, C.G., Moore, T.E., Harris, E.E., and Tailleir, I.L., 1994, Geologic map of the Killik River quadrangle, Brooks Range, Alaska, , Open-File Report OF-94-679, 1:125000 scale <i>2008-0716: Ric Wilson says USGS has digitally; GRE will convert but need data from USGS; awaiting status update. gives bedrock for Killik river 1x3. Mostly covers GAAR, but small sliver of NOAT too</i>	(2563) Hamilton, T.D., 1980, Surficial geologic map of the Killik River quadrangle, Alaska, , Miscellaneous Field Studies Map MF-1234, 1:250000 scale <i>2008-0716: GRE has digital GIS version from AKSO that were produced by Greenhorn & O'Mara in Florida; not sure of quality; Ric Wilson says "suspect". Tom Hamilton says the digital versions have been upgraded by USGS GIS group in Alaska, but GRE doesn't have these versions and don't have paper copy either. Likely needs redigitized to NPS standards</i>
Howard Pass	(67975) Dover, J.H., Tailleir, I.L., and Dumoulin, J.A., 2004, Geologic and fossil locality maps of the west-central part of the Howard Pass quadrangle and part of the adjacent Misheguk Mountain quadrangle, western Brooks Range, Alaska, , Miscellaneous Field Studies Map MF-2413, 1:100000 scale <i>2008-0716: covers 8 inch-to-mile quads for NOAT in Misheguk Mt (c1,b1) & Howard Pass (c3-c5; b3-b5) 1x3 sheets; appears to be mostly BEDROCK map; not sure if it supercedes surficial in GMAPs 2840 (Howard Pass; USGS mf-1677) or GMAP 7313 (Misheguk-Baird Mts.; USGS of-2003-367) ???s</i> <i>Ric Wilson says Howard Pass 1x3 needs more field work and digital cleanup as well; says there are unlabeled polygons in places, but has entire sheet digitally at the current time</i>	(2840) Hamilton, T.D., 1984, Surficial geologic map of the Howard Pass quadrangle, Alaska, , Miscellaneous Field Studies Map MF-1677, 1:250000 scale <i>2008-0717: surficial for Howard Pass; use for NOAT, not GAAR. have digitally from USGS cd-rom; have to reassess quality to make sure up to GRE standards</i>
Misheguk Mountains	(2828) Curtis, S.M., Ellersieck, Inyo, Mayfield, C.F., and Tailleir, I.L., 1984, Reconnaissance geologic map of southwestern Misheguk Mountain quadrangle, Alaska, , Miscellaneous Investigations Series Map I-1502, 1:63360 scale <i>2008-0717: should supercede GMAP 2830; covers Misheguk Mts. A.4, a.5, b.4, b.5, c.4, c.5 Ric Wilson says USGS has this digitally and can supply to NPS GRE, but its not available to general public</i>	(7313) Hamilton, T.D., 2003, Surficial geologic map of parts of the Misheguk Mountain and Baird Mountains quadrangles, Noatak National Preserve, Alaska, U.S. Geological Survey, Open-File Report OF-03-367, 1:250000 scale
	(2832) Ellersieck, Inyo, Curtis, S.M., Mayfield, C.F., and Tailleir, I.L., 1984, Reconnaissance geologic map of south-central Misheguk Mountain quadrangle, Alaska, , Miscellaneous Investigations Series Map I-1504, 1:63360 scale	

1x3 Sheet	BEDROCK CITATION		SURFICIAL CITATION	
	ASSESSMENT		ASSESSMENT	
	<i>2008-0717: should supercede GMAP 2834; covers Misheguk Mts a.2, a.3, a.4, b.2, b.3, b.4, c.2, c.3, c.4. Ric Wilson says USGS has this digitally and can supply to NPS GRE, but its not available to general public</i>			
	(2835) Mayfield, C.F., Curtis, S.M., Ellersieck, Inyo, and Tailleir, I.L., 1984, Reconnaissance geologic map of southeastern Misheguk Mountain quadrangle, Alaska, , Miscellaneous Investigations Series Map I-1503, 1:63360 scale			
	<i>2008-0717: should supercede GMAP 2836; covers Misheguk Mts a.1, a.2, b.1, b.2, c.1,c.2. Ric Wilson says USGS has this digitally and can supply to NPS GRE, but its not available to general public</i>		<i>2008-0717: recent USGS digital SURFICIAL pub covers southern 2/3 of Misheguk Mt and northern 1/3 of Baird Mts so gives much of NOAT but shows nothing for KOVA in Baird Mts. 1x3 sheet. Stops at NPS boundaries for NOAT</i>	
	(2827) Curtis, S.M., Ellersieck, Inyo, Mayfield, C.F., and Tailleir, I.L., 1990, Reconnaissance geologic map of the De Long Mountains A-1 and B-1 quadrangles and part of the C-1 quadrangle, Alaska, U.S. Geological Survey, I-1930, 1:63360 scale			
DeLong	<i>2008-0717: supercedes GMAP 2829 and gives larger-scale for NOAT in De Long 1x3. Ric Wilson says USGS has digitally to share with GRE but not available for public download</i>		NO DEDICATED PUBLICATION	
	(2831) Ellersieck, Inyo, Curtis, S.M., Mayfield, C.F., and Tailleir, I.L., 1990, Reconnaissance geologic map of the De Long Mountains A-2 and B-2 quadrangles and part of the C-2 quadrangle, Alaska, U.S. Geological Survey, I-1931, 1:63360 scale			
	<i>2008-0717: supercedes GMAP 2833 and gives larger-scale for NOAT in De Long 1x3. Ric Wilson says USGS has digitally to share with GRE but not available for public download</i>			
Chandalar	(74992) Till, A.B., Dumoulin, J.A., Harris, A.G., Moore, T.E., and Bleick, Heather, Siwec, Benjamin, 2008, Preliminary integrated geologic map databases for the United States: digital data for the geology of the southern Brooks Range, Alaska; Chandalar 1x3 sheet, , Open-File Report OF-2008-1149; Christian 1x3 sheet, 1:500000 scale		(2566) Hamilton, T.D., 1978, Surficial geologic map of the Chandalar quadrangle, Alaska, , Miscellaneous Field Studies Map MF-878-A, 1:250000 scale	
	<i>2008-0710: is full 1x3 for Chandalar; use for GAAR bedrock; likely only need to crop out a few inch to mile maps from this (Chandalar b,c,d-6 series). Should complement SURFICIAL of GMAPs 2283 and 2566. Should supercede GMAP 3045 (i-375)</i>		<i>2008-0717: GRE has digital GIS version from AKSO that were produced by Greenhorn & O'Mara in Florida; not sure of quality; Ric Wilson says "suspect". Tom Hamilton says the digital versions have NOT been upgraded by USGS GIS group in Alaska and GRE doesn't have paper copy either. Likely will need to be redone to NPS standards</i>	
	(74993) Till, A.B., Dumoulin, J.A., Harris, A.G., Moore, T.E., and Bleick, Heather, Siwec, Benjamin, 2008, Preliminary integrated geologic map databases for the United States: digital data for the geology of the southern Brooks Range, Alaska; Wiseman 1x3 sheet, , Open-File Report OF-2008-1149; Christian 1x3 sheet, 1:500000 scale		(2565) Hamilton, T.D., 1979, Surficial geologic map of the Wiseman quadrangle, Alaska, U.S. Geological Survey, MF-1122, 1:250000 scale	
Wiseman	<i>2008-0714: covers full Wiseman 1x3 for BEDROCK; supercedes GMAP 22930. GRE will convert</i>		<i>2008-0717: GRE has digital GIS version from AKSO that were produced by Greenhorn & O'Mara in Florida; not sure of quality; Ric Wilson says "suspect". Tom Hamilton says the digital versions have NOT been upgraded by USGS GIS group in Alaska and GRE doesn't have paper copy either. will likely need to be redone to NPS standards</i>	
Survey Pass	(74994) Till, A.B., Dumoulin, J.A., Harris, A.G., Moore, T.E., and Bleick, Heather, Siwec, Benjamin, 2008, Preliminary integrated geologic map databases for the United States: digital data for the geology of the southern Brooks Range, Alaska; Survey Pass 1x3 sheet, , Open-File Report OF-2008-1149; Survey Pass 1x3 sheet, 1:500000 scale		(2562) Hamilton, T.D., 1981, Surficial geologic map of the Survey Pass quadrangle, Alaska, U.S. Geological Survey, MF-1320, 1:250000 scale	

1x3 Sheet	BEDROCK CITATION		SURFICIAL CITATION	
	ASSESSMENT		ASSESSMENT	
Ambler River	2008-0717: use for NOAT; gives all of Survey Pass 1x3 BEDROCK; GRE will convert. Supersedes GMAP 3047		2008-0717: GRE has digital GIS version from AKSO that were produced by Greenhorn & O'Mara in Florida; not sure of quality; Ric Wilson says "suspect". Tom Hamilton says the digital versions have been upgraded by USGS GIS group in Alaska, but GRE doesn't have these versions and don't have paper copy either. Will likely need redone to NPS standards	
	(74995) Till, A.B., Dumoulin, J.A., Harris, A.G., Moore, T.E., and Bleick, Heather, Siwec, Benjamin, 2008, Preliminary integrated geologic map databases for the United States: digital data for the geology of the southern Brooks Range, Alaska; Ambler River 1x3 sheet, , Open-File Report OF-2008-1149; Ambler River 1x3 sheet, 1:500000 scale		(2561) Hamilton, T.D., 1984, Surficial geologic map of the Ambler River quadrangle, Alaska, U.S. Geological Survey, MF-1678, 1:250000 scale	
Baird Mountains	2007-0714: covers full Ambler River 1x3 for BEDROCK; use for KOVA, GAAR, NOAT; supercedes GMAP 3044 for BEDROCK		2008-0717: intersects GAAR, KOVA, NOAT. GRE has digital GIS version from AKSO that were produced by Greenhorn & O'Mara in Florida; not sure of quality; Ric Wilson says "suspect". Tom Hamilton says the digital versions have been upgraded by USGS GIS group in Alaska, but GRE doesn't have these versions and don't have paper copy either.. Will likely need to be redone to NPS standards	
	(74996) Till, A.B., Dumoulin, J.A., Harris, A.G., Moore, T.E., and Bleick, Heather, Siwec, Benjamin, 2008, Preliminary integrated geologic map databases for the United States: digital data for the geology of the southern Brooks Range, Alaska; Baird Mountains 1x3 sheet, , Open-File Report OF-2008-1149; Baird Mountains 1x3 sheet, 1:500000 scale		(7313) Hamilton, T.D., 2003, Surficial geologic map of parts of the Misheguk Mountain and Baird Mountains quadrangles, Noatak National Preserve, Alaska, U.S. Geological Survey, Open-File Report OF-03-367, 1:250000 scale	
Noatak	2008-0714: full Baird Mts 1x3 for BEDROCK; supercedes GMAP 2717. GRE will convert		2008-0717: recent USGS digital pub covers southern 2/3 of Misheguk Mt and northern 1/3 of Baird Mts so gives much of NOAT but shows nothing for KOVA in Baird Mts. 1x3 sheet. not sure why boundaries were picked on this one; needs further investigation. GRE will likely convert existing material though	
	NO DEDICATED PUBLICATION Ric Wilson is trying to have Gill Mull finish Noatak 1x3 BEDROCK; look for progress update in Fall 2008		NO DEDICATED PUBLICATION Owen Wilson mentioned as good candidate for Noatak 1x3 SURFICIAL; look for progress update in Fall 2008	
Hughes	(74506) Wilson, F.H., Labay, K.A., Shew, Nora, Mohadjer, Solmaz, and Patton, W.W., 2005, Preliminary integrated geologic map databases for the United States: digital data for the reconnaissance geologic map of the Yukon-Koyukuk Basin, Alaska; Hughes sheet, , Open-File Report OF-2005-1341, 1:500000 scale		(54627) Hamilton, T.D., 2002, Surficial geologic map of the Hughes quadrangle, Alaska, U.S. Geological Survey, Miscellaneous Field Studies Map MF-2408, 1:250000 scale	
	2008-0714: covers entire Hughes 1x3 for BEDROCK; useful for GAAR bedrock. May be partially superceded for d2-d6 by GMAP 74999 (OF-2008-1149)		2008-0717: use for GAAR; GRE has digital GIS files from USGS website that are latest and greatest MF maps; GRE will convert	
Shungnak	(74508) Wilson, F.H., Labay, K.A., Shew, Nora, Mohadjer, Solmaz, and Patton, W.W., 2005, Preliminary integrated geologic map databases for the United States: digital data for the reconnaissance geologic map of the Yukon-Koyukuk Basin, Alaska; Shungnak sheet, , Open-File Report OF-2005-1341, 1:500000 scale		(2847) Hamilton, Tom, 1999, Surficial Geologic Map of part of the Shungnak quadrangle, Alaska, , unpublished, 1:250000 scale	
	2008-0714: covers entire Shungnak 1x3; use for KOVA bedrock. Still has more coverage than newer GMAP 75000 (of-2008-1149) which only covers tiny sliver. Likely could crop down to just d5-d6 quads that are KOVA intersecting qoi's		2008-0717: only small portion of quad and is unpublished; part of cd-rom for GAAR surficial geology obtained from AKSO; have GIS data with it. Was likely developed only to complete GAAR compiled and give buffer for park, as none of park is in quad proper	

1x3 Sheet		BEDROCK CITATION	SURFICIAL CITATION
		ASSESSMENT	ASSESSMENT
Selawik		(74507) Wilson, F.H., Labay, K.A., Shew, Nora, Mohadjer, Solmaz, and Patton, W.W., 2005, Preliminary integrated geologic map databases for the United States: digital data for the reconnaissance geologic map of the Yukon-Koyukuk Basin, Alaska; Selawik sheet, , Open-File Report OF-2005-1341, 1:500000 scale <i>2008-0714: covers entire Selawik 1x3 sheet for bedrock; KOVA is in ne corner, so use it. GMAP 75001 (of-2008-1149) is only tiny sliver that likely has same information but is so small it isn't of much utility, so likely use this one for full Selawik 1x3 BEDROCK</i>	NO DEDICATED PUBLICATION
	Kotzebue	(3604) Till, A.B., Dumoulin, J.A., Gamble, B.M., Kaufman, D.S., and Carroll, P.I., 1986, Preliminary geologic map and fossil data, Solomon, Bendeleben, and southern Kotzebue quadrangles, Seward Peninsula, Alaska, U.S. Geological Survey, OFR-86-276, 1:250000 scale <i>2008-0717: looks like only "geologic" covering area so far. Ric Wilson says it is digital and GRE can acquire; not available on public websites though. May become superceded in near future by newer Seward Peninsula map</i>	(2415) Kaufman, D.S., 1986, Surficial geologic map of the Solomon, Bendeleben, and southern part of the Kotzebue quadrangles, western Alaska, U.S. Geological Survey, MF-1838-A, 1:250000 scale <i>2008-0717: looks to be of interest to BELA; not known to be digital. suggested to ask Patricia Heiser what she might have in addition to this for BELA</i>
Shishmaref		NO DEDICATED PUBLICATION <i>Ric Wilson says he has very simplified map of sheet for internal use though</i>	NO DEDICATED PUBLICATION
Bendeleben		(3604) Till, A.B., Dumoulin, J.A., Gamble, B.M., Kaufman, D.S., and Carroll, P.I., 1986, Preliminary geologic map and fossil data, Solomon, Bendeleben, and southern Kotzebue quadrangles, Seward Peninsula, Alaska, U.S. Geological Survey, OFR-86-276, 1:250000 scale <i>2008-0717: looks like only "geologic" covering area so far. Ric Wilson says it is digital and GRE can acquire; not available on public websites though. May become superceded in near future by newer Seward Peninsula map</i>	(2415) Kaufman, D.S., 1986, Surficial geologic map of the Solomon, Bendeleben, and southern part of the Kotzebue quadrangles, western Alaska, U.S. Geological Survey, MF-1838-A, 1:250000 scale <i>2008-0717: looks to be of interest to BELA; not known to be digital. suggested to ask Patricia Heiser what she might have in addition to this for BELA</i>
Teller		(2416) Sainsbury, C.L., 1972, Geologic map of the Teller quadrangle, western Seward Peninsula, Alaska (1972), U.S. Geological Survey, I-685, 1:250000 scale <i>2008-0717: covers portion of BELA; not known to be digital, but might be superceded in near future by USGS new Seward Peninsula map</i>	NO DEDICATED PUBLICATION

¹GMAP numbers are unique identification codes used in the GRE database.