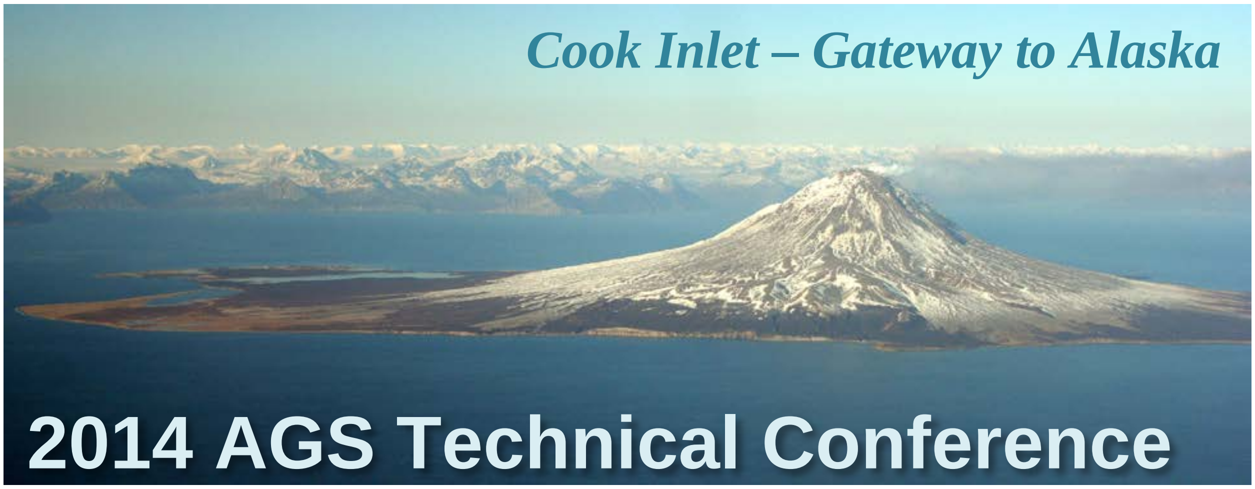


Abstracts with Program

University of Alaska Anchorage
ConocoPhillips Integrated Science Center

May 15, 8:30-4:30

Including,
Bird to Hatcher Pass Field Trip May 16
Led by Sue Karl and Chad Hults

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## Letter from the President

Dear participants of the 2014 AGS Technical Conference,

Welcome and thank you for attending this event. It's been an honor to be the Alaska Geological Society President for this past year and have the chance to see this conference come to fruition. My part in this has been small so all the credit goes to Chad Hults and his conference committee. They have put together quite a program of talks, posters and a sold out field trip in a relatively short amount of time. Having seen efforts in the past come to naught I know how difficult it can be to finally put an event like this together. This conference is the culmination of an impressive series of luncheon talks put on by the AGS and in conjunction with the Geophysical Society of Alaska and SPE Alaska. It is a fitting end to a fine year.

A title like Cook Inlet – Gateway to Alaska provides a focus but also promises a broader range of topics. I think you'll find the subjects in the speakers schedule to reflect this and I encourage you to follow up with the authors. There is always more behind what goes into a 20 minute talk than what can be adequately communicated in that time. The poster sessions and the field trip naturally provide this kind of opportunity, so don't avoid taking advantage of it. The field trip especially should provide a great opportunity to bring together everything you've just heard from the day before.

The 2014 AGS Technical conference is dedicated to Joe Kirchner, retired petroleum geophysicist at BP and senior consultant for Golder Associates, and retired DGGS geologist and endurance athlete Rocky Reifenstuhl. Both AGS members passed away recently and were well respected geologists and gentlemen of first degree.

I want to make sure to thank everyone involved in bringing this conference together. I also want to acknowledge our sponsors Canrig, ConcoPhillips, Hilcorp, PRA, and Schlumberger. Their help and support is fundamental to bringing these events to you now and in the future so make an effort to thank their representatives and let them know how much you appreciate it.

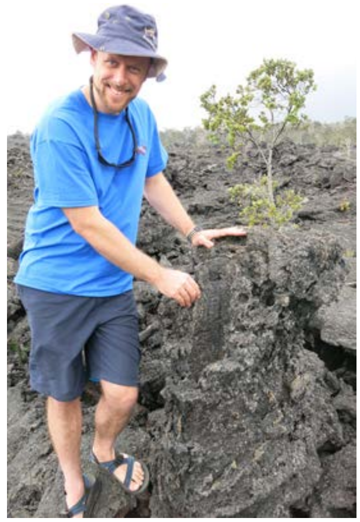
Please have a great time and take advantage of making or renewing friendships along with learning more about the geology of Cook Inlet and the rest of Alaska.

***~Matt***

Matt Frankforter

President, Alaska Geological Society

# Welcome from the Conference Chair



the conference theme *Cook Inlet – Gateway to Alaska* was inspired by the recent release of the AAPG Memoir 104 *"Oil and Gas Fields of the Cook Inlet Basin, Alaska,"* increased exploration, and the recent studies by the Alaska Division of Geological and Geophysical Surveys and the U. S. Geological Survey. The theme also has a deeper meaning, in that much of modern exploration of mainland Alaska started in the Cook Inlet area, and the first significant oil discoveries in Alaska were found in Cook Inlet. In order to provide a diverse range of topics, the AGS board decided to keep the Cook Inlet talks to about half the program, hence *Gateway to Alaska*.

In addition to the conference, we thought it would be good to provide a field trip, so that members would have a chance to spend time together outside on the outcrops in our backyard. There are some significant new studies that have reinvigorated our interest and reshaped our interpretations of these easily accessible rocks. Hopefully this field trip will spur thoughtful discussions and will be a good social occasion where members can form new connections, future collaboration, and, most importantly, friendships. Demand for the field trip was much greater than expected, so hopefully we can have a field trip as part of future annual AGS technical conferences.

A big thank you to the presenters that volunteered to talk or give posters. Thanks to all those that volunteered to help get the meeting logistics organized and the venue prepared. The annual AGS technical conference is a great venue for geologists to convene and discuss recent work on Alaskan geology. I look forward to the AGS technical conference every year and have enjoyed coordinating this year's conference.  We switch the venue from north of the Alaska range to south every year, so next year's conference will be held in Fairbanks. AGS is looking for a volunteer in Fairbanks to chair the next conference. Finally, the AGS board and the AGS members want to thank the sponsors that helped cover some of the conference expenses, so that the fee for the conference was kept reasonable.

Cheers – Chad Hults

## Program Schedule

| | | |
|---|---|---|
| 8:00 | | Doors Open |
| 8:30 | | Opening Remarks |
| 8:45 | | Rocky Reifenstuhl and Joe Kirchner Tribute |
| 9:00 | 30 | **Carl Tape** – Geological influences on the seismic wavefield in Alaska |
| 9:30 | 30 | **Patrick Druckenmiller** – Dinosaur tracks from the lower Yukon River; an extensive new record for Arctic dinosaurs in Alaska |
| 10:00 | 20 | Break, *with refreshments provided by PRA* |
| 10:20 | 20 | **Chad Hults** – Two flysch belts having distinctly different provenance suggest no stratigraphic link between the Wrangellia composite terrane and the paleo-Alaskan margin |
| 10:40 | 20 | **Richard Lease** – Arctic Alaska basin evolution: insights from detrital zircons |
| 11:00 | 30 | **Rick Saltus** – A tilted bed for the sleeping lady? **-** Gravity and magnetic evidence for a thrust-fault interpretation of the Mt Susitna/Beluga Mtn front |
| 11:30 | 30 | Buffet Lunch Served |
| 12:00 | 5 | Sue Karl - Scholarships |
| 12:05 | 55 | **Dave LePain** (Keynote) – Geologic framework of Cook Inlet basin, south-central Alaska: The depositional systems perspective |
| 1:00 | 10 | Break |
| 1:10 | 20 | **Bob Gillis** – Structural, stratigraphic, and thermochronologic evidence for Eocene transtension and exhumation along the arc-forearc margin, Cook Inlet |
| 1:30 | 20 | **Matt Frankforter** – Modeling concepts for reservoir geometries in the Trading Bay Field, Cook Inlet |
| 1:50 | 30 | **Michael Richter** – Petroleum geology of Alaska's interior rift basins |
| 2:20 | 20 | **Tim Ryherd** – Cook Inlet and non-North Slope production and revenue |
| 2:40 | 20 | **Marwan Wartes** – Predicting deep-water reservoirs in the Brookian Sequence: Underexplored plays on the North Slope, |
| 3:00 | | Poster Session |
| 3:30 | | Social Hour – *with refreshments sponsored by Schlumberger* |

# Presentation Abstracts

## Toward using the seismic wavefield to image subsurface geology in Alaska

**Carl H. Tape,** University of Alaska Fairbanks, carltape@gi.alaska.edu

Seismic waves from local earthquakes are strongly influenced by geological structures, such as topography, sedimentary basins, and variations of subsurface lithology. In active tectonic regions such as Alaska, the variations within the crust are strongly pronounced, and therefore so are the variations in the seismic wavefield. Seismic imaging seeks to use information within seismograms (basically lots of wiggles) to improve our initial description of the Earth's structure. Within a formal inverse problem, we minimize the difference between recorded seismograms and modeled seismograms, while iteratively improving our characterization of the subsurface Earth structure.

Seismic imaging in Alaska requires an initial 3D characterization of the crustal structure in terms of variations in density and elastic parameters (e.g. P wave speed and S wave speed). We use a 3D seismic model of Alaska that contains some of the major sedimentary basins, such as Cook Inlet basin and Nenana basin, embedded within a crustal model derived from previous seismological studies. Previous crustal imaging efforts in California suggest that we should be able to resolve subsurface variations with length scales of 4 km vertically and 12 km laterally. Resolving finer scale structures should be possible in regions with denser coverage of seismic stations or active source experiments. The long-term objectives for wavefield-based seismic imaging in Alaska are to provide the most accurate possible 3D seismic model in order (1) to produce accurate ground motion estimates for hazard assessment and (2) to help interpret the current and ancient tectonic setting of Alaska.

## Dinosaur tracks from the lower Yukon River; an extensive new record for Arctic dinosaurs in Alaska

**Patrick S. Druckenmiller[1], Kevin May[1], Paul McCarthy[2], Jørn Hurum[3], Katherine Anderson[4],** 1) University of Alaska Museum, 2) Department of Geology and Geophysics, University of Alaska Fairbanks, 3) University of Oslo Natural History Museum, 4) Department of Geology and Geophysics, University of Alaska Fairbanks, psdruckenmiller@alaska.edu

Globally, only a handful of localities are known to preserve a record of dinosaurs that lived at high paleo-latitudes. Two of the best-known high latitude sites occur in Alaska: the Prince Creek Formation on the North Slope and the Cantwell Formation in Denali National Park and Preserve. While both of these localities record valuable information on terrestrial Arctic ecosystems from the very latest Cretaceous (Maastrichtian), data from stratigraphically older sites has been sparse. In the summer of 2013, fieldwork conducted by the University of Alaska Museum resulted in the discovery of a prolific new dinosaur ichnofossil assemblage along the Yukon River in west-central Alaska. The fossils occur in an undifferentiated mid-Cretaceous sedimentary unit deposited at or above the paleo-Arctic Circle in the Yukon-Koyukuk Basin. Our initial investigations reveal a surprising abundance of tracks distributed throughout several thousand meters of section and exposed along at least a 200-kilometer corridor of river-cut exposures. Dinosaur tracks within the unit are primarily preserved as natural casts, some of which preserve impressions of integument. Skeletal remains are currently unknown in the unit. In many localities, the track-bearing units co-occur with a diverse paleobotanical assemblage. A preliminary analysis of the ichnofossil assemblage reveals the presence of several track morphotypes, the most abundant of which are ornithopods and secondarily, ankylosaurians. Small to medium-sized tridactyl theropods are also found, along with an unusual tetradactyl morphotype. Finally, we report the first documented occurrence of sauropod tracks in Alaska that likely represent the northernmost occurrence of the group in North America. Ongoing studies will focus on better constraining the age and depositional environments of the unit, and more thoroughly characterizing the taxonomic diversity of plants and dinosaurs found in the unit.

## Two flysch belts having distinctly different provenance suggest no stratigraphic link between the Wrangellia composite terrane and the paleo-Alaskan margin*

**Chad P. Hults[(1),2], Frederic H. Wilson[1], Raymond A. Donelick[3], and Paul B. O'Sullivan[3],** 1) U.S. Geological Survey, 2) National Park Service, 3) Apatite to Zircon, Inc., chadcph@gmail.com

The provenance of Jurassic to Cretaceous flysch along the northern boundary of the allochthonous Wrangellia composite terrane, exposed from the Lake Clark region of southwest Alaska to the Nutzotin Mountains in eastern Alaska, suggests that the flysch can be divided into two belts having different sources. On the north, the Kahiltna flysch and Kuskokwim Group overlie and were derived from the Farwell and Yukon-Tanana terranes, as well as smaller related terranes that were part of the paleo-Alaskan margin. Paleocurrent indicators for these two units suggest that they derived sediment from the north and west. Sandstones are predominantly lithic wacke that contain abundant quartz grains, lithic rock fragments, and detrital mica, which suggest that these rocks were derived from recycled orogen and arc sources. Conglomerates contain limestone clasts that have fossils matching terranes that made up the paleo-Alaskan margin. In contrast, flysch units on the south overlie and were derived from the Wrangellia composite terrane. Paleocurrent indicators for these units suggest that they derived sediment from the south. Sandstones are predominantly feldspathic wackes that contain abundant plagioclase grains and volcanic rock fragments, which suggest these rocks were derived from an arc. Clast compositions in conglomerate south of the boundary match rock types of the Wrangellia composite terrane.

The distributions of detrital zircon ages also differentiate the flysch units. Flysch units on the north average 54% Mesozoic, 14% Paleozoic, and 32% Precambrian detrital zircons, reflecting derivation from the older Yukon-Tanana, Farewell, and other terranes that made up the paleo-Alaskan margin. In comparison, flysch units on the south average 94% Mesozoic, 1% Paleozoic, and 5% Precambrian zircons, which are consistent with derivation from the Mesozoic oceanic magmatic arc rocks in the Wrangellia composite terrane. In particular, the flysch units on the south contain a large proportion of zircons ranging from 135 to 175 Ma, corresponding to the age of the Chitina magmatic arc in the Wrangellia terrane and the plutons of the Peninsular terrane, which are part of the Wrangellia composite terrane. Flysch units on the north do not contain significant numbers of zircons in this age range. The flysch overlying the Wrangellia composite terrane apparently does not contain detritus derived from rocks of the paleo-Alaska margin, and the flysch overlying the paleo-Alaskan margin apparently does not contain detritus derived from the Wrangellia composite terrane.

The provenance difference between the two belts helps to constrain the location of the northern boundary of the Wrangellia composite terrane. Geophysical models place a deep, through-going, crustal-scale suture zone in the area between the two fl ysch belts. The difference in the provenance of the two belts supports this interpretation. The youngest fl ysch is Late Cretaceous in age, and structural disruption of the fl ysch units is constrained to the Late Cretaceous, so it appears that the Wrangellia composite terrane was not near the paleo-Alaskan margin until the Late Cretaceous.

*Lithosphere, v. 5; no. 6; p. 575-594

## Arctic Alaska basin evolution: Insights from detrital zircons

**Richard O. Lease, David W. Houseknecht,** U.S. Geological Survey, rlease@usgs.gov

A precise chronostratigraphic and paleogeographic framework is needed across Arctic Alaska to help correlate on- and off-shelf depositional sequences, recognize hinterland tectonic influences on basin evolution, and quantify time-transgressive clastic progradation. The construction of this framework, however, has been limited by imprecise biostratigraphic and provenance data. We report new detrital zircon U/Pb geochronology that has the potential to illuminate these issues by providing absolute age constraints and provenance information. In this presentation we highlight initial insights from 30 detrital zircon samples collected from outcrops and wells (over 3000 individual zircon grains).

First, the age of the youngest population of detrital zircon grains within many Brookian sandstone samples agrees with the broad depositional age constraints available from biostratigraphy, suggesting that detrital zircons can refine Brookian chronostratigraphy with absolute ages. The young grains likely were derived from coeval volcanism in Russian Chukotka. We demonstrate the utility of this technique for Brookian chronostratigraphy with detrital zircon ages from the 110-78 Ma sequence (Nanushuk through Prince Creek Formations). This approach provides absolute ages for key horizons and sequence-bounding unconformities and we currently are working on correlating these surfaces off the shelf.

Second, dating a suite of samples collected from proximal to distal settings in a single sequence reveals the timing and rates of clastic progradation. New data from the voluminous Torok-Nanushuk sequence suggests that it prograded over 500 km from west to east between 116 and 106 Ma. The observation that rapid clinothem progradation of 50 km/m.y. was sustained for 10 m.y. suggests a supply-dominated system that filled relict Colville basin accommodation, which likely developed as a flexural response to Brooks Range tectonic loading.

Third, a major provenance change occurred following the terminal Torok-Nanushuk lowstand. Samples from Lower Cretaceous Torok-Nanushuk foreland strata are dominated by zircons derived from Triassic flysch (200-360 Ma), clearly of Chukotkan provenance to the west. In contrast, samples from Upper Cretaceous strata (Tuluvak, Schrader Bluff, and Prince Creek Formations) lack the Triassic signature and instead are dominated by 360-700 Ma zircons, suggesting derivation from Paleozoic units within the Brooks Range to the south. Overall, the change in provenance at ~95 Ma suggests a shift from longitudinal, east-flowing sediment dispersal to transverse, north-flowing dispersal. This shift is consistent with post-95 Ma erosional unloading of the Brooks Range.

Finally, work is in progress examining orogen-wide exhumation rates from detrital thermochronometers within the 135 Ma to modern basin fill. The goal is to determine lag times – the amount of time elapsed between rock cooling in source areas and deposition in the basin – for each clastic sequence. By examining lag-time trends throughout the Brookian sequence, we aim to identify phases of orogenic growth and decay and quantify hinterland exhumation.

## A tilted bed for the sleeping lady? Gravity and magnetic evidence for a thrust-fault interpretation of the Mt Susitna/Beluga Mtn front

**Rick Saltus, Rick Stanley, Krissy Lewis, Peter Haeussler,** U.S. Geological Survey, saltus@usgs.gov

Many geologists have contemplated the serene profile of the "Sleeping Lady" as they gaze, perhaps beer in hand, toward Mt Susitna from Anchorage. The steep slope along the northeastern flank of Mt Susitna descends to meet the adjacent Susitna Basin lowland. This slope, which continues to the northwest along the northeastern flank of Beluga Mtn, was previously interpreted as the surface expression of a down-to-the-northeast normal fault (e.g., Kirschner, 1988; Trop and others, 2007). We discuss the geophysical evidence for a thrust fault interpretation of this structure.

A 50-mGal gravity low culminating about 15 km northeast of the Mt Susitna mountain front corresponds to the >4-km-thick Cenozoic sedimentary section in the Susitna basin known from drilling, seismic, and previous gravity investigations. The gravity gradient from this low to the flanking bedrock high to the southwest spans a horizontal distance of about 40 km, centered roughly on the toe of the mountain front. The broad position of this gradient, straddling the mountain front, demonstrates that the lateral density contrast between the sedimentary basin strata and the igneous bedrock is also laterally distributed. The location and shape of the gravity gradient rules out the interpretation of the mountain front as a normal fault dipping into the basin. The gravity gradient is best explained by a southwest-dipping thrust fault with the leading edge projecting several km beneath the shallow basin cover northeast of the mountain front. To test and refine this initial interpretation, we collected several closely spaced, helicopter-supported gravity transects across the mountain front. The resulting high-resolution profiles confirm that the distributed gradient is not an artifact of regional data spacing and demonstrate that the lateral density transition occurs across a wide zone centered on the mountain front.

Igneous rocks exposed on Mt Susitna and Beluga Mtn produce significant aeromagnetic anomalies. Close examination of magnetic anomaly patterns on composite, high resolution aeromagnetic maps assembled from several generations of USGS airborne surveys corroborates the overthrust interpretation of the gravity data. Short-wavelength magnetic anomaly patterns trace the location and extent of the buried toe of the thrust front beneath the surface sediments.

Modeled cross-sections integrating the gravity and magnetic data produce a range of structural geometries that depend on physical property (primarily density) assumptions employed. Models using plausible densities as measured from outcrop samples suggest that underthrust sediments are up to 4 km thick and continue laterally beneath the Mt Susitna/Beluga Mtn block up to 20 km.

The interpretation of the Mt Susitna/Beluga Mtn fault as a contractional structure is consistent with a previously recognized need to account for discrepancies in lateral movement between the Denali and Castle Mtn fault systems. In particular, this newly recognized thrust fault might represent part of a tectonic transfer zone that, together with the previously proposed Broad Pass fault, connects the Castle Mtn and Denali faults.

## Geologic framework of Cook Inlet basin, south-central Alaska: The depositional systems perspective (Keynote)

**David L. LePain[1] Richard G. Stanley[2], Kenneth P. Helmold[3], Diane P. Shellenbaum[3],** 1) Alaska Division of Geological & Geophysical Surveys, 2) U.S. Geological Survey, 3) Alaska Div. of Oil and Gas, david.lepain@alaska.gov

The Cook Inlet basin is a northeast-trending collisional forearc basin that extends from Shelikof Strait to the Matanuska Valley. The basin is a prolific hydrocarbon province, with more than 1.33 billion barrels of oil and about 8 trillion cubic feet (TCF) of gas produced since 1958. The basin is located in the arc-trench gap between the Alaska-Aleutian Range batholith to the northwest and the modern Aleutian trench to the southeast. An enormous accretionary prism separates the basin from the modern trench. These tectonic elements are the products of subduction and associated magmatic and accretion processes that have operated for at least 200 million years. Crustal-scale faults have modified the basin margins over its history, including the Bruin Bay and Border Ranges fault systems, the Lake Clark-Castle Mountain fault, and the Capps Glacier fault.

The forearc basin has accommodated a cumulative thickness exceeding 10,600 m of Jurassic and Cretaceous dominantly marine strata and up to 7,600 m of Tertiary nonmarine strata. The Middle Jurassic and younger Mesozoic succession comprise several unconformity-bounded packages that record deposition in marginal-marine to deep-water settings. Compositional data from sandstones and conglomerates in the Mesozoic succession record the progressive uplift and exhumation of the arc edifice and deeper plutonic roots of the arc. Middle Jurassic organic-rich mudstones are thought to have sourced most of the oil discovered in Cook Inlet fields. Mesozoic sandstone compositions present challenges to conventional reservoir potential. The Mesozoic-Cenozoic contact is a pronounced angular unconformity of regional extent that records subduction of an oceanic spreading center during the Paleocene. The Tertiary succession ranges from Eocene to early Pliocene and records a complex suite of nonmarine depositional settings, including high-gradient alluvial fans along the basin margins that fed sediment to lower gradient axial-fluvial depositional systems. Relatively high accommodation during the Miocene and early Pliocene led to deposition of thick coal seams. Microbial gas from these coals sourced most of the gas in Cook Inlet fields. Reservoir quality in Tertiary sandstones ranges from fair to excellent.

Tertiary strata throughout the basin are deformed into a series of north-northeast-trending, discontinuous folds arranged in an en-echelon pattern. Most of these structures formed by right lateral transpressional deformation on oblique-slip faults whose origins are attributed to the ongoing collision between the Yakutat terrane and inboard terranes in Alaska. Most producing oil and gas fields are associated with fold structures. Gas in most fields resulted from desorption of microbial methane as thick coal-bearing successions were uplifted as these structures formed.

Cook Inlet Basin is underexplored for petroleum. A recent USGS assessment of undiscovered technically recoverable oil and gas resources in the onshore areas and state waters of the basin estimated mean undiscovered volumes of about 600 million barrels of oil and about 19 TCF of gas. A recent BOEM assessment of undiscovered technically recoverable resources in the OCS planning area of lower Cook Inlet estimated mean undiscovered volumes of about 1.01 billion barrels of oil and about 1.2 TCF of gas.

## Structural, stratigraphic, and thermochronologic evidence for Eocene transtension and exhumation along the arc-forearc margin, Cook Inlet, Alaska.

**Robert J Gillis[1], Marwan A. Wartes[1], David L. LePain[1], Paul L. Decker[2], Trystan M. Herriott[1], Paul B. O'Sullivan[3],** 1) Alaska Division of Geological & Geophysical Surveys, 3354 College Road, Fairbanks, Alaska, 99709, 2) Alaska Division of Oil and Gas, 550 W. 7th Avenue, Suite 1100, Anchorage, Alaska, 99501, 3) Apatite to Zircon, Inc., 1075 Matson Road, Viola, Idaho, 83872, robert.gillis@alaska.gov

Deformation along the arc-forearc margin of the Cook Inlet area is widely believed to have been driven mainly by transpressional tectonics since the forearc basin re-initiated as a terrestrial depocenter during Paleocene time. However, geologic relationships near the base of the Tordrillo and Neacola mountains indicate an unrecognized phase of early Cenozoic transtensional deformation. Major structures at the northwestern basin margin, including the Bruin Bay, Lake Clark, and Castle Mountain faults are traditionally considered to be chiefly dextral north-side-up reverse faults with several hundreds to thousands of meters of throw and several kilometers of right-lateral displacement. These faults commonly place exhumed Late Cretaceous and early Cenozoic plutonic rocks against Eocene and younger Cook Inlet strata, locally giving the basin margin a saw-toothed morphology. The footwall/hanging-wall relationship of the western-most and least-well studied of the faults in this region, the Capps Glacier fault (CGF), is particularly well-exposed and clearly demonstrates that some of the deformation at the periphery of the early Cenozoic basin was transtensional, rather than transpressional. Well-dated >45-41 Ma West Foreland Fm. strata are juxtaposed against a 59 Ma footwall granitoid along a SE-dipping fault plane and are syndepositionally deformed by numerous ESE-striking dextral-slip extensional faults in the proximal hanging-wall of the CGF. The transtensional faults and a pervasive fracture set in the footwall granite, some of which host thick mafic dikes dated at 55 Ma are oriented at a relatively low angle to the trace of the CGF, and are interpreted as synthetic Riedel shears in a dextral-slip system. A similar relationship is observed along the Lake Clark fault (LCF) near the McArthur River, which has been previously interpreted to be a NW-dipping reverse fault. Here, a well-exposed 200-300 m-wide SE-dipping brittle shear zone with dextral kinematics parallels the covered LCF, and a south-dipping fault projecting at a low angle into the LCF places Miocene-age Tyonek Fm. hanging-wall strata against Late Cretaceous granitic footwall rocks in clear normal-slip relationship. Extensional faulting and deposition into the proximal basin was coeval with denudation cooling of the sediment source areas from about 55-37 Ma based on results from 22 apatite fission-track (AFT) samples collected from bedrock surrounding the NW basin margin and 11 paired detrital AFT-zircon U-Pb samples collected from the entire Cenozoic stratigraphic succession (Eocene-Pliocene). AFT studies from elsewhere in the forearc region of south-central Alaska indicate that Paleocene-Eocene cooling is the dominant Cenozoic cooling event encompassing a broad area including the Susitna basin, parts of the western Alaska Range and Talkeetna Mountains. Likewise, Paleocene-Eocene extensional faulting, sometimes associated with remnants of exhumed sedimentary basins, has been recognized elsewhere in the forearc region to the SW and NE, but generally has been poorly studied and its occurrences considered in isolation. Results from this study may suggest that Paleocene-Eocene extension in the forearc was more common than previously envisioned, possibly occurring along a system of kinematically-linked dextral-slip structures between which slip was transferred across small pull-apart basins. Both the extensional basin development and regional cooling were coeval with, and closely followed subduction of the Kula-Farallon or Kula-Resurrection ridge system, and may be upper plate responses to oblique subduction of a spreading center and its associated slab window.

## Modeling Concepts for Reservoir Geometries in the Trading Bay Field, Cook Inlet, Alaska

**Matthew J. Frankforter,** Hilcorp Alaska, LLC, mfrankforter@hilcorp.com

The Trading Bay Field was discovered in June of 1965 with the testing of the Trading Bay State 1A well establishing oil production from the Hemlock formation. Before the end of the year two appraisal wells had been drilled that roughly defined the extent of the Hemlock accumulation and indicated potential in the Shallower Tyonek reservoirs. Development of the field resulted in a total of 60 drilled and re-drilled wellbores. The field is located on the west side of the northern Cook Inlet Basin in roughly 70 feet of water on trend with a series of en echelon transpressional faulted anticlines, a common feature of hydrocarbon accumulations in the basin. The petroleum system for the field is characterized by a Jurassic oil prone marine source rock charging a 3,000 foot stacked sequence of Tertiary Oligocene age Tyonek reservoirs that were caught up in a structure that formed during a late Miocene tectonic event.

Field production has totaled over 78 million barrels of oil coming from 57 producing sands in four separate fault blocks. This has presented a challenge both operationally and in the realm of subsurface evaluation. The reservoirs are interbedded with claystone and coal and consist of coarse grained sands deposited in a deep gravel-bed braided to gravel-sand meandering fluvial system. With so many sands being productive and in complicated structural relationships, understanding the extents and sequencing of the depositional environment is critical to understanding reservoir geometries, properties, and continuity both laterally and vertically. Observations from outcrops and the study of geometries and processes in modern fluvial environments locally, as in the Susitna and Matanuska valleys, have provided guidance in modeling the subsurface. These have not gone much beyond the conceptual stage but have provided insights for determining well to well correlation using all the elements of deposition, most notably the coals. Understanding the continuity and extent of the reservoir components has helped to make sense out of the results of past and present completion practices in the field. This will ultimately aid in the efforts to improve recovery efficiencies and target unswept or undeveloped portions of the field.

## Petroleum Geology of Alaska's Interior Rift Basins

**Michael A. Richter, Gerald K. Van Kooten,** Petrotechnical Resources Alaska, marichter@mac.com

Recent exploration activities by Doyon, Ltd. in the Nenana and Yukon Flats basins provide data that clearly demonstrate the presence of an active petroleum system in the rift basins of central Alaska. Recent drilling has confirmed the presence of excellent reservoir and source rocks in the Usibelli Group, and seismic data has shown that a number of trapping mechanisms exist in these basins.

New data in these basins include two deep wells drilled in the Nenana basin, 2D seismic data collected in the Nenana and Stevens Village basins, a 3D seismic survey in the Stevens Village basin, aeromagnetic data covering part of the Nenana basin 6000 sq km of airborne gravity data covering several of the Yukon Flats basins, as well as geochemical data collected at over 1400 surface locations in four basins.

Analysis of well cuttings collected from coal and shale in the Healy Creek Formation in Nunivak #1 and #2 indicate that both the shales and coals are hydrogen-rich and oil-prone. One shale in the Nunivak #2 well is 120 feet thick, has a TOC of 5.6%, and HI's of 300-435. Numerous coals have HI's ranging from 200 to 375 and have TOC's averaging 65%. Pyrolysis-GC traces of hydrocarbons generated from these cuttings have shown that these rocks produce medium to light gravity oil as well as wet gas in the lab. Fluorescent spectral analysis of samples collected in the surface geochemical survey have detected signatures associated with medium to light gravity oils.

Inversion of gravity data, coupled with seismic data, show that these basins have 20-25,000 feet of sedimentary fill. Temperature data from the Nunivak wells and vitrinite reflectance suggest that the onset of oil generation occurs at 8000-12000 feet in the Nenana basin. Expulsion models based on these results show the potential for the generation of billions of barrels of oil within these basins.

Excellent reservoir rocks were encountered in the Nunivak #2 well. A 550 foot thick sand in the Suntrana Formation has log porosities of about 28%. Sands at depths of 6500-8000 feet in the Lower Usibelli Group have thicknesses ranging from 10-120 feet and log porosities of 16-24%. These sands are described at the wellsite as being composed of 95-100% quartz.

Seismic data indicate that fault traps are the most common trapping style in these basins. Several intra-basin highs have also been identified. The lower Usibelli Group, particularly the Healy Creek Fm, have a desirable sand-shale ratio for facilitating sealing faults. The interbedded nature of the shales and sandstones in this interval provides many opportunities for effective reservoir/seal couplets.

Although these basins have been only lightly explored, the data that has been collected clearly demonstrate that all of the elements necessary for a new Alaska petroleum province exist in the rift basins of Interior Alaska.

## Cook Inlet and Non-North Slope Production and Revenue

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In the past few years we have perceived and increase in public interest in Cook Inlet oil and gas exploration, development and associated revenue. This increase in interest coincides with major changes in asset ownership and an increase in the number of companies participating in exploration and development activities in the area. Cook Inlet oil and gas production taxpayers have also experienced major changes in the tax and credit regime in Cook Inlet over a similar time period.

Following the production tax reforms beginning in 2006 DOR has provided data sets on primarily, a statewide or North Slope basis, with little detail provided on Cook Inlet and non-North Slope areas. With this report, we intend to enhance the understanding of Cook Inlet and non-North Slope oil and gas exploration, development and production-related revenue activities in Alaska. In recent years, the period covered in this report, Alaska has only experienced oil and gas production and revenue generating activity on the North Slope and in Cook Inlet, therefore users of this report can assume that "non-North Slope" as it is used here, equates to Cook Inlet-only regarding oil and gas production and gross revenue. However, if the data series in this report have implications in the realm of exploration, areas other than the North Slope and Cook Inlet may be included in the data.

In this presentation we focus on Cook Inlet and non-North Slope data for the years where annual data are mostly complete and compiled, 2009 through 2012. Data from tax returns for 2013 are not available and prior to 2009 annual tax data could not be compiled in a uniform manner due to the lack of a uniform tax return. Some data categories are compiled for years prior to 2009 and some of the data are reported here.

Important trends in the data collected for Cook Inlet and non-North Slope areas of Alaska include the following. Annual oil production declined from 2000 through 2009, but has increased steadily since from 2.7 million barrels of oil (MMBO) to 4.3 MMBO in 2013. Natural gas production in Cook Inlet declined steadily from 2005 through 2013. Property taxes associated with the Kenai Peninsula were relatively flat until 2011, but are up over 40 percent since then. No production tax for oil was collected and production tax collected for natural gas has declined steadily to $13.3 million. Royalty revenue collected in Cook Inlet for oil and gas has held relatively steady at about $70 million, far outstripping tax revenues. The number of credit recipients increased in 2011 and 2012 and the value of credits claimed increased simultaneously. Capital spending is up significantly in this same period while operating spending has been up and down.

## Regional Stratigraphy of the Brookian Sequence: A Summary of Underexplored Deep-water Plays on the North Slope, Alaska*

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The Brookian sequence of Alaska's North Slope remains lightly explored, despite a number of successful discoveries in the past 20 years. In order to encourage new exploration and improve our understanding of the Brookian depositional system, we've established a comprehensive sequence stratigraphic framework based on regional well log correlations, public-domain seismic data, and outcrop-based geologic mapping and stratigraphic studies. Our analysis suggests four deep-water stratigraphic intervals warrant further consideration as exploration targets:

CENOMANIAN—Cenomanian topsets of the upper Nanushuk Formation record a retrogradational stacking pattern culminating in a major transgressive flooding surface. Despite this evidence for relative sea-level rise, we have documented a significant amount of medium- to course-grained sand that was exported off the shelf. These amalgamated sediment gravity-flow deposits in the upper Torok Formation are locally oil-stained and represent a potential exploration target.

TURONIAN—The deep-water Turonian Seabee Formation locally has good reservoir quality and produces from the Bermuda interval (e.g., Tarn and Meltwater fields). These basin floor sands are encased between oil-prone tongues of the Hue Shale source rock. This vertical stratigraphic arrangement (source-reservoir-source) is widespread and the Seabee is routinely petroliferous in outcrop, indicating this play is prospective for both stratigraphic and structural traps.

MID-CAMPANIAN—The mid-Campanian is marked by a major unconformity that truncates underlying outer-shelf topsets. Incision and relief along this sequence boundary is readily apparent in seismic data and it is overlain by valley fills and shelf-margin deltas of the middle Schrader Bluff Formation (including the reservoir at the Tabasco field). This major episode of relative sea-level fall resulted in the reworking and bypass of material into bottomsets of the Canning Formation. These potential reservoirs are overlain by a major Campanian flooding surface that may seal a lowstand wedge or related deep-water facies.

PALEOCENE—The Paleocene shelf margin was incised and deeply eroded during a major base level fall, resulting in a regional downward stepping trajectory of toplap surfaces. Seismic data indicate significant submarine scouring occurred in deep-water settings and wells typically exhibit a sharp dislocation in log motif, indicating an abrupt influx of sandstone in slope and basinal facies of the Canning Formation. Several oil-charged slope-channel and slope-apron turbidite systems have been discovered in this lowstand systems tract (e.g., Badami and Flaxman A-1 pools).

Brookian stratigraphy is complex and reservoir-scale geometries are challenging to image in available seismic data. However, our work demonstrates that potential deep-water reservoirs do exist and our analysis permits generalized predictions of when significant volumes of sand were exported off the shelf.

* AAPG 3P Arctic Meeting, Oslo Norway, 3013

# Poster Abstracts

## Timing and distribution of upper crustal cooling in the parts of the western and central Alaska Range and adjacent Susitna basin, south-central Alaska from low-temperature bedrock and detrital thermochronology: Implications for exhumation above a flatly-subducting slab

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The Susitna basin (SB) is an actively subsiding coal-bearing basin that is bounded to the north and west by the Alaska Range, to the east by the Talkeetna Mountains, and is separated from the Cook Inlet forearc basin (CIFB) to the south by the Castle Mountain fault. Initiation of the SB as an interarc or forearc depocenter began by late Paleocene time and its development has been influenced by as many as two episodes of flat-slab subduction: 1) late Paleocene-early Eocene subduction of the Kula-Farallon or Kula-Resurrection ridge system, and 2) late Oligocene to present subduction of the Yakutat microplate. To better understand the history of exhumation and sedimentation in this region, we compare 23 apatite fission-track (AFT) and 18 apatite (U-Th)/He (AHe) bedrock ages from the SB and southern foothills of the western and central Alaska Range to 8 paired detrital AFT (DAFT) and detrital zircon (DZ) analyses from 6 measured stratigraphic sections of SB Cenozoic strata. Additionally, results from paired DAFT-DZ analyses of modern sands collected from 11 glacially-fed rivers draining the Alaska Range are assessed to understand patterns of strike-parallel exhumation across the western and northern basin margins.

Preliminary interpretation of the new bedrock cooling data from exhumed Late Cretaceous and Paleocene intrusive arc rocks and Cretaceous metasedimentary strata indicate that major early-late Eocene cooling was contemporaneous with clastic deposition in the SB, suggesting relative uplift and denudation of the basin margin during that period. AFT ages range from 75.1-24.7 Ma, but are concentrated between ~56 and 40 Ma. AHe ages range from 63.3-7.6 Ma, and most commonly between ~53 and 39 Ma. AFT and AHe ages tend to be older nearer the interior of the basin, younger at the SW margin, and become progressively younger toward the NW margin, suggesting that cooling is in part structurally controlled and that perhaps the basin margin migrated northwestward over time. Paired DAFT and DZ ages from poorly dated Oligocene/Miocene or younger strata record mostly late Paleocene-Eocene cooling with principal detrital age populations from ~57.9-37.5 Ma for all but the northwestern-most sample locations. DZ results from modern river sands are highly faithful to their respective source areas. DAFT results from the same samples indicate focused Miocene-Pliocene cooling (~11.3-4.2 Ma) restricted to what are likely structurally-controlled blocks in the Eastern Alaska Range.

These data reveal that a broad region of the forearc upper crust cooled mainly during latest Paleocene-middle Eocene time and was coeval with, and slightly lagged subduction of the spreading ridge system. Contemporaneous forearc subsidence and deposition suggests that cooling was due in part to denudation of its margin. Conversely, upper-crustal cooling since onset of Yakutat collision during latest Oligocene time has occurred only in restricted areas often marked by high relief. This suggests that the amount of crustal section denuded above much of the subducting Yakutat microplate inboard of the accretionary prism was relatively thin. Instead, exhumation appears to be focused near the periphery of the flat slab region, or along the boundaries of major pre-existing structures where deformation is concentrated. These results highlight unique upper-plate responses to two different modes of flat slab subduction.

## Preliminary Reservoir Characterization of Late Paleocene Coals in the Southern Nenana Basin, Interior Alaska: CO2 Sequestration and Enhanced Coal Bed Methane Recovery

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Naturally fractured, unmineable coal seam reservoirs are attractive targets for geological sequestration of $CO_2$ because of their high $CO_2$-adsorption capacities and possible cost offsets from enhanced coal bed methane production (ECBM). Recent seismic, drilling and outcrop studies suggest that the Nenana Basin has significant Tertiary mature coal deposits that contain large volumes of thermogenically-derived CBM, making it an attractive prospect for a geological $CO_2$ sequestration in Interior Alaska.

In this study, we have investigated $CO_2$ sequestration and ECBM recovery potential of Tertiary coal deposits of the southern Nenana Basin through initial geomechanical analysis, geostatistical reservoir characterization and fluid flow simulations. The target coal seams are subbituminous in rank and Late Paleocene in age. The depths of the coal seams lie mainly between 8110 ft and 11140 ft. A preliminary reservoir model is built using CMG Builder with a total of 15125 grid blocks (55-55-5, i-j-k configuration) and later simulated using a CMG GEM simulator for a mixture of water, $CH_4$ and $CO_2$. Sensitivity analyses have been conducted for a total simulation time of 5 years in base case scenario. We are particularly interested in investigating effects of the key reservoir parameters such as grid size, cleat permeability, cleat compressibility and adsorption isotherms which influence $CO_2$ sequestration and enhanced coal bed methane recovery processes in the southern Nenana Basin.

Our preliminary sensitivity analyses demonstrate that the total volumes of sequestered $CO_2$ and ECBM recovery are sensitive to the reservoir's geomechanical and flow properties. Simulation results $CH_4$ and $CO_2$ adsorption distribution at different time steps have been presented and discussed.

### Oil-stained sandstones of the Upper Jurassic Naknek Formation and Upper Cretaceous Kaguyak Formation, Kamishak Bay area, lower Cook Inlet, Alaska*

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The Cook Inlet basin of south-central Alaska hosts a prolific petroleum system that has been producing oil and gas for more than 55 years. The basin's producing reservoirs are nonmarine sandstone and conglomerate of Tertiary age, and oil is principally sourced from organic-rich shales in the Middle Jurassic Tuxedni Group. A persistent and as of yet unanswered question is whether the Upper Jurassic through Cretaceous stratigraphy of Cook Inlet hosts conventional oil reservoirs. Limited direct observations have been made in this regard and include fault- and fracture-controlled oil seeps in Jurassic rocks on the Iniskin Peninsula, oil shows in Upper Cretaceous strata of the Raven No. 1 and Anchor Point No. 1 wells, and oil stain in the Maastrichtian Saddle Mountain section.

During July–August 2012 fieldwork in the Kamishak Bay area of lower Cook Inlet, we studied an oil-stained outcrop in the Upper Jurassic Naknek Formation and discovered, in modern alluvium, oil-stained cobbles and boulders likely derived from nearby outcrops of the Upper Cretaceous Kaguyak Formation. We report our field observations and initial interpretations herein.

The hydrocarbon-bearing outcrop of Naknek Formation lies immediately north of the south shore of Kamishak Bay on a small, unnamed island near the mouth of Douglas River. The oil seep has previously been noted only briefly in published accounts. In this area, the Naknek Formation chiefly comprises cross-stratified and bioturbated sandstone, with locally abundant molluscan shells and plant debris. Sedimentary facies and an accompanying trace fossil assemblage suggest that these strata were deposited in a moderate to high-energy marine shoreface setting. Freshly-broken surfaces of the hydrocarbon-bearing sandstone have a strong—yet fleeting—kerosene-like odor. Hand-lens observations suggest that the oil-stained sandstone largely consists of quartz and potassium feldspar, with subordinate plagioclase and heavy minerals. Our observation of quartz-rich Naknek strata—and the likely relative abundance of potassium feldspar versus plagioclase—in the Douglas River area starkly contrasts with the quartz-poor and plagioclase-rich Naknek in the Iniskin–Tuxedni region. The occurrence of quartz-rich and plagioclase-poor Naknek sandstone is significant, because a more mature mineralogy is less susceptible to zeolite cementation and thus more likely to retain primary porosity upon moderate to deep burial. Hydrocarbon-stained sandstone at the Douglas River locality indicates that the Naknek Formation, at least locally, may serve as a conventional reservoir of petroleum. Numerous sandstone samples from the Naknek Formation in the Kamishak Bay area are currently being analyzed for reservoir quality, petrology, and organic geochemistry.

During a reconnaissance traverse along an unnamed, north flowing tributary of the Douglas River, we discovered abundant cobbles and small boulders of oil-stained sandstone in the modern stream gravel that were strongly petroliferous, particularly on freshly broken surfaces. The oil-stained rocks largely comprise very fine- to fine-grained sandstone and weather light gray to tan and light greenish-gray. Oil stain occurs as both matrix and fracture fill, with the latter commonly healed. One small boulder of porphyritic andesite was also strongly oil stained along a fracture plane and included visible hydrocarbons within a small vug. The hydrocarbon-bearing clasts in float are dissimilar to the nearby outcrops of Lower Cretaceous Herendeen Formation, and we infer that the clasts were sourced from outcrops of the overlying Kaguyak Formation that are exposed in small catchments immediately upstream to the east and south. We constrained the likely source of the oil-stained sandstone to a zone within the lower Kaguyak Formation that exhibits a similar weathering color and character, although we were unable to directly access the candidate outcrops due to extremely steep and inaccessible terrain. We collected several oil-stained samples from the alluvial cobbles and boulders to be analyzed for reservoir quality, petrology, and organic geochemistry; analytical results are pending.

The observations reported herein are consistent with the preliminary hypothesis that an active petroleum system is present in the southern Kamishak Bay area, and that this petroleum system may include oil-generating source rocks in the Middle Jurassic Tuxedni Group as well as potential oil-bearing reservoir rocks in the Upper Jurassic Naknek Formation and Upper Cretaceous Kaguyak Formation. Additionally, the occurrence of oil-stained and apparently more compositionally mature Naknek Formation sandstone in the Douglas River area of Kamishak Bay suggests that sufficient compositional variability exists within the Naknek for it to serve, at least locally, as a conventional reservoir in the Cook Inlet basin. Furthermore, hydrocarbon-bearing Upper Cretaceous sandstones have now been documented in both wells and outcrop in the lower Cook Inlet basin. Therefore, sandstones in the Upper Jurassic through Upper Cretaceous section of Cook Inlet may yet prove to be viable conventional oil exploration targets.

*A version of this abstract was presented at PSAAPG in April 2013.

## Analysis of P-T-t data to interpret genesis and emplacement of the Talkeetna Arc, southern Alaska

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The Talkeetna arc is believed to be one of only two almost-complete and minimally deformed exposed island arc sections currently known in the world. It comprises the majority of the Peninsular terrane, a large accreted terrane exposed in south-central Alaska. The Peninsular Terrane is believed to have amalgamated with two other oceanic fragments, the Wrangellia and Alexander Terranes, which were then accreted to North America during Mesozoic and Cenozoic time. Arc exposures include the ultramafic and mafic mantle and lower-crustal root, up through the uppermost volcanic and volcaniclastic sequences. It is generally accepted that the arc is a true intraoceanic arc, with the attendant geochemical and isotopic signatures. However, there is data that also supports a different interpretation, that the "Talkeetna arc" is instead composed of a series of separate accreted terrane slivers. This study addresses the debate on the origins of the Talkeetna arc by mapping P-T-t and geochemical data sets across the arc to see if they form a continuous and related series, and to further elucidate the geological history of arc emplacement and accretion.

Thus far, I have assembled a database of thermobarometric, geochronologic, major- and trace-element compositions, and isotopic data from published literature. I created contour maps of each data set, using ArcGIS interpolation methods, in order to visually assess the relationships of the segments of the Talkeetna arc. A single mapped database of sample locations allows me to target significant gaps in the data or segments of the arc that have not been sampled. Contour maps of individual data sets provide a ready tool to evaluate whether they overlap, or are related to each other as a series and fit the paradigm of intra-oceanic arc formation.

The entire mapped dataset provides a guide for summer sampling and further P-T analyses, which thus far appear to be necessary for the central, mid-crustal section of the arc. Furthermore, there are not enough P-T data to support the connection of the proposed southwestern extension of the Talkeetna arc (Red Mountain area; cf., Kusky et al., 2007) to the rest of the arc. Once these data gaps are filled, evaluation of whether all components of the arc form a contiguous sequence in P-T space will be possible. This will also enable me to further analyze the history of arc accretion. Finally, I will compare Talkeetna arc P-T-t and geochemical trends to those of the Kohistan arc in Pakistan and of type examples of modern intraoceanic arcs (Aleutian and Izu-Bonin-Mariana). Studying island arc genesis, which takes place at convergent margins, is vital to understanding the creation and evolution of continental crust.

## The Keeling Curve and Global CO2 Distribution

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The Keeling Curve is a remarkable series of atmospheric CO2 measurements taken at Mauna Loa, Hawaii, from 1960 to the present. The curve shows seasonal cycles and a steady rise in the concentration of CO2, beginning about 315 ppm and currently approaching 400 ppm. Long-term CO2 records are also available from a number of other observatories, located from the Arctic Ocean to the South Pole. Integration of the global dataset with carbon emissions data provides additional insights about the world's carbon cycle.
Atmospheric CO2 concentrations and CO2 carbon isotopes show seasonal and long term trends which vary by latitude. The seasonal cycle is strongest in the Northern Hemisphere, and the Northern Hemisphere leads the Southern Hemisphere in terms of rising CO2. People and plants in the Northern Hemisphere cause changes in atmospheric CO2, which propagate from the Northern Hemisphere to the Southern Hemisphere and can be seen as a progression through the global data. This progressive change is seen in bulk CO2, CO2 carbon isotopes, and the amplitude of the seasonal cycle. Long-term changes in global CO2 are consistent with known volumes of fossil fuel emissions. A simple model can be constructed that matches the observed seasonal and long-term trends in bulk CO2, based solely on emissions and estimates of agricultural biomass. The Energy Information Agency (EIA) predicts rising carbon emissions for the foreseeable future, from about 35 gigatonnes CO2 annually to nearly 50 gigatonnes CO2 by the year 2040, in the base-case forecast.

Carbon dioxide from fossil fuels and deforestation carries a distinctive isotopic signature, which marks the movement of man-made CO2 through the atmosphere and carbon reservoirs (soils, biomass, and oceans). This movement of carbon, as seen in both carbon isotope data and bulk CO2 data, reveals complexity in the carbon cycle. Discrepancies between the datasets imply the active exchange of carbon between the atmosphere and carbon reservoirs. More than 85% of anthropogenic CO2 emissions, as tagged by carbon isotopes, do not remain in the atmosphere, but are absorbed by carbon reservoirs. However, some of the anthropogenic carbon in the atmosphere is exchanged for natural carbon from carbon reservoirs, so that atmospheric CO2 concentration is maintained at a level equivalent to about 50% of cumulative annual CO2 emissions over the long term. The size of carbon reservoirs is estimated at more than 6 times the volume of carbon present in the atmosphere, based on a dilution calculation of anthropogenic carbon isotopes in the atmosphere. The role of the ocean in exchanging carbon with the atmosphere is illustrated by the correlation of atmospheric carbon isotope data with the Oceanic Niño Index (ONI), which is a measure of the El Niño/La Niña climate cycle based on sea-surface temperatures.

Understanding the patterns of atmospheric CO2 may provide a tool for recognizing and measuring changes in global climate. Additional monitoring of carbon reservoirs, particularly of the world's oceans, will be necessary to develop a comprehensive model of the earth's carbon cycle.

## Relative seal level change in western Alaska as constructed from repeat tide gauge and GPS measurements

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Western Alaska is a remote region with many small, isolated communities situated in low-lying coastal environments that are sensitive to variations in local relative sea level (RSL). Quantification of RSL variation requires measured vertical velocities for both tectonic motion (onshore component) and the ocean surface (offshore component). During the summer of 2013, a campaign GPS survey of geodetic benchmarks was undertaken to produce statistically significant velocity measurements of the tectonic component of sea level change for the region. Occupations of tidal benchmarks were also conducted to compare historic tidal records from the mid–1900s to more recent data. Preliminary results from the GPS survey suggest regional subsidence of approximately 1-2 mm/yr on the Seward Peninsula, which supports one of the current glacial isostatic adjustment (GIA) models available for western Alaska. We present a preliminary model of vertical crustal motion for the Yukon-Kuskokwim delta that incorporates an updated GIA in combination with local tidal datum shifts to project RSL trends. This velocity model will be used to aid local communities in the development of adaptation strategies for changing coastal environments.

## STYX RIVER MAP PROJECT: LIME HILLS C-1 QUADRANGLE WITH ACCOMPANYING GEOCHEMISTRY AND PETROLOGY

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The Alaska Division of Geological & Geophysical Surveys (DGGS) Mineral Resources Section conducted four weeks of fieldwork on the Styx River Project in the Lime Hills C-1 quadrangle during the summer of 2013 as part of the state-funded Airborne Geophysical/Geological Mineral Inventory (AGGMI) Program. This work included refining contacts, subdividing major units, and identifying new dikes and faults. The resulting 1:63,360-scale geologic map and supporting geochemical, petrologic, and geochronologic data will foster a better understanding of the geology and mineral potential of the area.

The study area lies in the Styx River and Farewell geophysical survey tracts, located about 100 miles northwest of Anchorage in the Lime Hills, Tyonek, Talkeetna Mountains, and McGrath quadrangles. Active ongoing mineral exploration for deposit types including porphyry copper ± molybdenum ± gold, reduced intrusion-related gold, and polymetallic veins in the geophysical survey tracts. Lead-zinc skarns, molybdenum-bearing quartz veins, sediment-hosted base-metal, platinum-group-element, and rare-earth-element deposit types are also present. The majority of these mineral occurrences are related to numerous Cretaceous and Tertiary age plutonic complexes, dike swarms, and volcanic fields. Previously unmapped mafic dikes trend generally northwest, while major fault sets trend northwest, north-south, and north-northeast. The study area was selected primarily because it was the part of the survey tracts with the largest number of plutons and volcanic rocks by previous regional geologic mapping.

The major plutons intruded into the Late Jurassic to Early Cretaceous Kahiltna flysch assemblage are the Tertiary Merrill Pass, Mount Estelle, and Crystal Creek plutons, as well as Tertiary McKinley sequence granites, and the Cretaceous South Fork gabbro. Most plutons northwest of the field area are reduced to oxidized, metaluminous, and calc-alkaline, however peraluminous and alkaline Windy Fork granite and Middle Fork plutonic complex rocks imply highly differentiated, shallow magma chambers. Tertiary volcanic rocks also cover a significant portion of the area.

A preliminary analysis of major oxide and trace element data helped differentiate distinct compositions of plutons and refine contacts on the new geologic map. The large, previously undifferentiated Merrill Pass pluton appears to have at least two separate phases, distinguished by their strongly contrasting magnetic susceptibilities. These were initially observed in airborne magnetic data and subsequently confirmed by field measurements. Subdivision of the Merrill Pass pluton may be possible through trace element data. The Tertiary volcanic unit appears to be both coeval and/or younger than the Merrill Pass pluton, based on field relationships and supporting major and trace element data. The previously unnamed TKiu unit (Tertiary-Cretaceous igneous undifferentiated) forms a chemically distinctive cluster, identical in trace element composition to the Cretaceous South Fork pluton.

Tertiary plutons in the mapping area with similarities to the copper-gold-bearing Tertiary Mount Estelle diorite highlight new areas of potential Cu-Au-Mo mineralization. We selected five samples for 40Ar/39Ar and ten samples for U/Pb dating to characterize and distinguish plutonic complexes and mineralization events, and to unravel the magmatic, structural, and metallogenic evolution of the area. Collaboration between the DGGS, USGS, and private industry allows for integration of a large dataset and enhanced interpretations.

## New geologic map, cross sections and structural data from the Iniskin Peninsula, Cook Inlet: revised mapping and new understanding of the of the Bruin Bay fault system

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An ongoing program by the Alaskan Division of Geological and Geophysical Surveys aims to understand the Mesozoic and Cenozoic geologic evolution of the northwestern margin of the Cook Inlet forearc basin. Prior to this campaign, understanding of the geology of the Iniskin Peninsula area and Cook Inlet Mesozoic stratigraphy was principally from studies by the U.S. Geological Survey from 1944 to 1958 that were published in a series of reports and maps and culminated in the seminal 1:63,360-scale compilation geologic map and accompanying report (Detterman and Hartsock, 1966). Our work on the peninsula and surrounding areas since 2009 has highlighted the need to: 1) document how stratigraphic units laterally wedge-out across the map area, 2) provide a revised Lower Jurassic volcanic arc stratigraphy, 3) establish new age assignments for several igneous units, 4) constrain the distribution and type of structures associated with the Bruin Bay fault system, and 5) record the distribution and density of cross-faults cutting the forearc strata. We present a new draft inch-to-mile geologic map of approximately 215 square miles on the Iniskin Peninsula that encompasses a complete, but structurally dissected crustal section from the Mesozoic Talkeetna arc complex upward through ~4,800 m of overlying Jurassic clastic forearc basin fill. Results include revisions to the map pattern and extent of unnamed Triassic metamorphic rocks and Jurassic volcanic rocks of the Talkeetna Formation; revised contact locations, stratigraphic pinch-outs, lateral facies transitions within the Jurassic Naknek and Chinitna Formations and two newly discovered oil-stained localities; and a locally revised interpretation of the Bruin Bay fault as part of a right-stepping transpressional fault system that transects the Iniskin Peninsula.

To better understand the kinematic history of the Bruin Bay fault system, accompanying the map we also present new fault kinematic data from 125 discrete minor faults on the Iniskin Peninsula. Results indicate that most of the faults (n=106, 86%) on the Iniskin Peninsula can be divided into two fault populations with statistically distinct kinematic axes. Faults from one set include northeast-striking reverse and left-lateral strike-slip faults and northwest-striking right-lateral faults that altogether record southeast-trending shortening (n=56). A second population of faults includes northeast- and northwest-striking right- and left-lateral strike-slip faults, respectively, that record east-trending shortening (n=52). Two small populations of oblique-slip (n=12) and normal faults (n=5) also occur but are too few to interpret their regional geologic significance. Analysis of fault slip data and spatial distribution of the two populations indicates that the data probably reflect two deformations and suggests that fault reactivation likely occurred along all of the major structures near the Iniskin Peninsula. Fault kinematic results indicate that the Bruin Bay fault system accommodated a heterogeneous slip history with at least two main phases of deformation that were characterized by both strike-slip and top-southeast contraction. This study and ongoing work in 2014 will comprise the first rigorous study of the kinematic history of the Bruin Bay fault system and attempt to understand it within the tectonic context of the Cook Inlet forearc basin.

## Preliminary top Mesozoic unconformity subcrop map, Cook Inlet Basin, Alaska

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This map shows the subcrop pattern of the rock units present at the top Mesozoic unconformity in the Cook Inlet basin, Alaska. The subcrop is projected onto the top Mesozoic unconformity depth surface of the Cook Inlet Basin, Alaska published in 2010. Since oil in the Cook Inlet basin is primarily sourced out of the Middle Jurassic Tuxedni Group (Magoon and Anders, 1992; Magoon, 1994), the subcrop trends of the Middle Jurassic oil source rock and other potential Mesozoic aged reservoirs are an important consideration in oil exploration in the inlet.

Multiple sources of publically available geologic and geophysical data were collected, interpreted, and integrated into the subcrop map. Formation picks at the top Mesozoic unconformity were determined for 109 wells. Mesozoic horizons from two regional marine 2D seismic data sets (~3300 miles) were interpreted. Eight map units were established for the top Mesozoic subcrop map: Matanuska-Kaguyak Formations Undivided, Naknek Formation, Chinitna Formation-Tuxedni Group Undivided, Talkeetna Formation, Talkeetna-BRUMC Undivided, Pogibshi-Port Graham Formations Undivided, Plutonic Rocks Undivided, and Metamorphic Rocks Undivided. Well formation picks, marine 2-D seismic interpretation, projection from outcrop, and interpreted aeromagnetic data had the greatest influence on the subcrop map unit boundaries.

Each Mesozoic sedimentary map unit regionally trends northeast-southwest, with perturbations in the map pattern often due to paleogeography and localized faulting and folding. The Mesozoic sedimentary rocks, in general, form a broad syncline with the Lower Jurassic Talkeetna bounded by plutonic rocks of the Alaska Range Batholith on the west, and the Lower Jurassic and Upper Triassic bounded by metasedimentary rocks of the McHugh Formation on the east (Fisher et al., 1978, Boss et al., 1976). The subcrop patterns of the Middle and Upper Jurassic map units parallel the Talkeetna on each side of the basin and the Upper Cretaceous Matanuska-Kaguyak map unit lays in the center of the subcrop map.

This map was prepared as part of a multiyear effort by the Alaska Department of Natural Resources to provide the public with the most accurate information possible on the geologic framework of this economically important area.

## Investigation of a Supraglacial Lake: Analysis of Hydrology and Variability

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A unique supraglacial lake exists on the surface of Matanuska Glacier. The lake is unique because, although the lake's volume may change yearly, it is found in approximately the same location. Geochemical analysis of major and trace elements from supraglacial and subglacial waters over a melt season allowed determination of the lake's water source. Supraglacial waters are low in dissolved ions because they are sourced from melting snow and ice. In contrast, subglacial waters are high in dissolved ions due to their interaction with bedrock and till beneath the glacier. The analysis clearly show the lake's water source is a mixture of subglacial and supraglacial waters.

The study initially examined the lake as a potential location where organic carbon could be produced and accumulate. Organic carbon produced on the Matanuska Glacier is released to the Matanuska River and Cook Inlet, affecting nutrient supply to microorganisms. This study indicates that the low concentration of organic carbon in the lake is likely a result of continual outflow and low residence time of the lake water. Higher concentrations of organic carbon correlate with low discharge of meltwater from the glacier.

The analysis of aerial photography from 1949 to 2012 determined that fluctuations in lake size and terminus position correlate with modern climate warming. The photography clearly shows formation of the lake by 1981 with increased melt ponds, stagnant ice, and changing crevasse patterns.