SUMMARY PROPOSAL FOR THE ALASKA DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS COOK INLET BASIN ANALYSIS PROGRAM:

Depositional Systems and Reservoir Quality: Recognition of Stratigraphic Traps in Tertiary Strata, Upper Cook Inlet Basin, Alaska

2008 Field Program

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EXECUTIVE SUMMARY

The Alaska Division of Geological & Geophysical Surveys (DGGS) and Division of Oil & Gas (DOG) propose an integrated program of research in Cook Inlet basin for 2008. The initial focus of this research is on the potential for stratigraphic traps and gas production from tight reservoirs in Tertiary strata in the upper Cook Inlet sub-basin. In subsequent years the focus will shift down-section to address Mesozoic strata. This proposal outlines eight topical projects, including: (1) reconstruct Tertiary depositional systems in the Homer–Kachemak Bay area and in the Capps Glacier–Beluga Lake area; (2) investigate depositional controls on sandstone reservoir quality; (3) evaluate temporal and spatial variations in sandstone composition across the basin and compositional controls on diagenetic history and reservoir quality; (4) develop a seismic stratigraphic framework for upper Cook Inlet basin that incorporates available core, wireline log, and outcrop data; (5) reconstruct the subsidence and uplift history of upper Cook Inlet basin; (6) construct a Mesozoic subcrop map for upper Cook Inlet basin; (7) evaluate the role of transpressional faulting along the western and northern margins of Cook Inlet; and (8) conduct a scoping study to address whether fluid inclusions are present in the zeolite mineral laumontite.

The following section is a brief summary of key findings from the 2007 field season and a description of the proposed topical projects listed above for 2008–09 (FY09). The cost of this program for 2008 (state FY09) is $288,561. We hope that your organization will support our program at the requested level of $35,000, and we welcome your input into the planning of the program. If your support cannot be at the $35,000 level, we will accept participation at a reduced level.

If funding is insufficient for the full program as proposed, we will scale back our plans and concentrate on fewer objectives. If sufficient funding is received we will run a day-long tour following our field work in July, highlighting stratigraphic relations along the northwest side of the basin in the Capps Glacier–Beluga River area. The decision to offer the proposed tour will be made by the end of May 2008 to allow sufficient time for travel arrangements.

INTRODUCTION

Rising commodity prices for oil and gas have contributed to increased interest in Cook Inlet basin. As a result of the discovery of oil in the giant Prudhoe Bay field, exploration activity in the basin declined precipitously in the late 1960s–early 1970s as the focus shifted to northern Alaska. Oil production continued from existing fields and exploration for new oil fields continued at a much-diminished pace. Most gas fields in the basin were discovered accidentally during this early exploration cycle and the lack of a market for Cook Inlet gas effectively discouraged exploration specifically for this commodity. Markets were created through local use of gas for power generation, home heating, and fertilizer manufacture, and an export market was created through construction of an LNG plant. Current estimates suggest the basin may hold between 30 and 3,480 bcf of gas and 60 and 2,850 million bbls of oil (**http://energy.usgs.gov/alaska/**; **http://www.mms.gov/alaska/re/reports/2006Asmt/**).

Much of this remaining resource is likely reservoired in stratigraphic traps and tight formations (low porosity and permeability).

Minor effort has been directed toward searching for oil or gas in stratigraphic traps in Tertiary nonmarine reservoirs in the basin. In a nonmarine basin like the Tertiary of Cook Inlet, stratigraphic traps should be common (figs. 1 and 2). Lateral discontinuity of channel sand bodies, channel belts, crevasse splay sand bodies, and alluvial fan sand bodies, and their encasement in fine-grained overbank lithologies capable of serving as reservoir seals are well documented in the literature from basins around the world. Lateral discontinuity and lithologic heterogeneity are inherent in most alluvial depositional systems—the rule rather than the exception.

Two questions arise when considering the exploration history of Cook Inlet basin.

- Why have stratigraphic traps not been pursued and documented?
- Why has gas production from tight formations not been pursued?

The answers to both questions includes the fact that structural traps involving porous and permeable reservoirs were relatively easy to find and produce—they represented the "low-hanging fruit" that was picked early in the basin's commercial history. Stratigraphic traps are far more subtle and difficult to recognize on exploration seismic data, and gas production from tight reservoirs is particularly challenging from a geological and engineering perspective. The search for stratigraphic traps and effectively producing gas from tight formations both require detailed knowledge of depositional systems in space and through time, knowledge of which depositional settings are more prone to low porosity and permeability sands at the time of deposition, and compositional and textural parameters influencing reservoir quality in the subsurface environment.

Other important questions should be considered when exploring for stratigraphic traps and trying to produce from tight formations, including:

- Are stratigraphic traps in Cook Inlet skewed toward low-volume reservoirs due to depositional architecture?
- What depositional systems present in the Cook Inlet Tertiary section are most likely to include stratigraphic traps and in which facies associations? and Can we recognize these depositional systems on available wireline logs and two-dimensional seismic data and, if we can, how?
- What depositional systems and facies associations are prone toward low porosity and permeability at the time of deposition and are these associations more prone to porosity and permeability destruction through compaction and diagenetic modifications?
- What clay minerals are present in fluvial sand bodies, what are their origins, and how do they affect reservoir performance?

Exploration specifically targeting Mesozoic reservoirs has been limited to a few wells in the OCS area south of Kalgin Island (figs. 1 and 2), yet all oil produced from Tertiary strata in upper Cook Inlet was derived from marine source rocks of Late Triassic and Middle Jurassic age. In addition to mature source rocks, the Mesozoic succession is endowed with many thick marine and marginal-marine sand bodies that, at the time of deposition, possessed textures characteristic of good reservoirs. Despite favorable depositional textures, limited well penetrations of Mesozoic rocks throughout the basin present a mixed picture. Penetrations of pre-Cretaceous strata encountered rocks with low porosity and permeability—the result of pervasive diagenetic modifications, whereas wells penetrating Cretaceous strata encountered rocks with significant preserved porosity and permeability.

These findings raise several questions regarding the prospectivity of Mesozoic rocks:

- Why are pre-Cretaceous Mesozoic sandstones with good reservoir potential so scarce?
- Are there areas, or stratigraphic intervals, in the basin where pre-Cretaceous Mesozoic sandstones have escaped extensive diagenetic modification and porosity destruction, or where diagenetic processes have resulted in creation of significant effective secondary porosity?
- Considering the tortuous migration pathways from Mesozoic source beds to Tertiary reservoirs, why have no traps been found in Mesozoic strata?
- Why does the reservoir potential of some Cretaceous units appear better than in Jurassic sandstones?
- What depositional systems are recorded in Cretaceous strata and what reservoir geometries can be expected?

These and other related questions will be addressed in the DNR Cook Inlet basin analysis program. This program is designed to provide relevant geologic data in the public domain to catalyze hydrocarbon exploration in the basin. DNR's Cook Inlet basin analysis consists of two phases. Phase I focuses on Tertiary strata of upper Cook Inlet sub-basin and is directed toward developing a better understanding of the potential for stratigraphic traps and geologic controls on formation of tight reservoirs. The first four to five years of the program will be devoted to phase I. Phase II focuses on the reservoir potential of Mesozoic strata throughout Cook Inlet. Detailed work on phase I began in May 2007 and included fieldwork along the lightly deformed eastern basin margin, located in the southern Kenai Peninsula, and along the highly deformed western basin margin, located in the Capps Glacier–Beluga River area. Limited preliminary work on phase II began in 2007, but the major push for Phase II will not begin until the 2009 or 2010 field season.

SUMMARY OF 2007 FIELD SEASON

Field studies conducted by DGGS and DOG during the 2007 season included ten days of detailed field work in the Homer–Kachemak Bay area in May and ten days of reconnaissance-level work in the Capps Glacier–Beluga River area in late August (figs. 1, 3a, and 3b). A brief summary of significant findings from each of these areas is presented below.

Homer–Kachemak Bay Area

Work in the Homer area during 2007 was a continuation of work begun in September 2006 and included measurement of 18 stratigraphic sections in the Beluga and Sterling Formations, collection of a detailed suite of samples for thin section microscopy, x-ray diffraction, SEM, porosity and permeability, mercury injection capillary pressure, geochronology, thermochronology, and palynology. In addition, a series of high-resolution digital photomosaics were constructed for selected bluff exposures to investigate sand body geometries. The goals of this work are to build a detailed depositional systems framework for the east side of the basin for use as a template for detailed studies of reservoir geometries and reservoir quality.

Tertiary strata in the Homer–Kachemak Bay area depositionally overlap the Border Ranges fault system and are only slightly deformed into long wavelength, north–northeast-trending folds (fig. 3a). Oligocene(?) and lower Miocene strata occupy paleovalleys eroded in Mesozoic rocks of the Peninsular and Chugach terranes (Wolfe and others, 1966; Bradley and others, 1999). These rocks include the type Seldovian flora of Wolfe and others (1966) and have been assigned by previous workers, largely on the basis of age, to the Tyonek Formation (fig. 2). Lithologically they have very little in common with the type Tyonek (Calderwood and Fackler, 1972). Near the base of paleovalleys and along their margins, facies include disorganized clast and cobble conglomerates with matrix- and clast-supported frameworks interstratified with poorly sorted green- and red-weathering lenticular lithic sandstones and mudstones. All lithologies are locally rooted, but roots appear more common in sandstones and mudstones. Dominant clasts and framework grains consist of volcanogenic material derived from the underlying Lower Peninsular terrane (Jurassic Talkeetna and Port Graham Formations). At one location green- and maroon-weathering matrix-supported conglomerate rests on top of a sloping surface formed on volcanogenic strata of the Talkeetna Formation at the paleovalley margin, and conglomerate interfingers toward the valley axis with poorly sorted clast-supported pebble conglomerate and pebbly sandstone. Chert and argillite clasts were probably derived from slightly more distant sources located up-paleodrainage in the Chugach terrane. Exposures at Coal Cove, Point Pogibshi, and Point Naskowhak (fig. 3a) typify the organization near the base of these paleovalleys. These facies record deposition from debris flows originating on valley walls and as hyperconcentrated stream flows away from valley margins in braided streams. Abundant plant roots suggest ephemeral flow and that the resulting land surface was colonized by vegetation between major flow events.

Facies at stratigraphically higher levels in the fill of these paleovalleys display characteristics of transport in more mature fluvial–alluvial depositional systems, including better sorting, greater lateral continuity of bedding, and more features attributable to traction transport in shallow, low-sinuosity gravelly streams. Lithologies include poorly sorted pebble conglomerate, pebbly sandstone, and poorly to moderately sorted sandstone, with relatively minor interbedded rooted mudstone. Pebbly sandstone, sandstone, and mudstone are present most commonly as lenticular bodies whereas, at the scale of typical outcrops, conglomeratic facies form more laterally continuous lithosomes. At Seldovia Point, valley-fill strata similar in composition and organization to Coal Cove, Point Pogibshi, and Point Naskowhak grade up-section toward the northeast to thicker-bedded, lighter brown- and buff-colored sandstones and interbedded mudstones (fig. 3a). This change in organization records a change in fluvial style from gravelly braided streams confined to paleovalleys to a more integrated alluvial drainage network that extended beyond the confines of paleovalleys and consisted, at least near the middle Miocene basin margin, of low-sinuosity, sandy streams. These rocks display a fluvial style similar to that recognized in the upper part of the Beluga Formation northeast of Homer, along the west shore of Kachemak Bay.

Exposures of late Miocene strata (Homerian floral stage of Wolfe and others, 1966) in the lower(?) Beluga Formation northwest of Homer (west of Diamond Gulch) and along the west shore of Kachemak Bay (near Fritz Creek) are distinctly different than older Tertiary strata filling paleovalleys between Seldovia and Coal Cove and younger strata in the upper Beluga and Sterling Formations (fig. 3a). Thick overbank successions in excess of 20 m thick consisting of siltstone, coal, and minor claystone encase lenticular sand bodies up to 7 m thick. These sand bodies record deposition in single-thread crevasse channels. Thicker, broadly lenticular sand bodies (7–10 m) are also present near Fritz Creek. These thicker sand bodies are the record of larger trunk channels that existed on a low-gradient alluvial plain. Crevasse channels were created during floods as flow in trunk channels breached levees at discrete locations. This organization contrasts with the organization in the upper Beluga and lower Sterling Formations near Falls Creek, on the west shore of Kachemak Bay, where sand bodies up to 15 m thick are overlain by mudstone, claystone, thin-bedded sandstone, and coal-forming overbank successions up to 15 m thick. In both areas, coal beds appear from the air to extend unbroken for many hundreds of meters, when in fact, on the ground many can be shown to be cut by faults. This is consistent with Dallege and Layer's (2004) findings near Diamond Gulch.

An exposure of the Sterling Formation in the upper reaches of Deep Creek, west of Kachemak Bay, includes a thick (>20 m?), compound sand body underlain by coal-bearing mudstones and overlain by Quaternary(?) deposits (fig. 3a). The sand body includes multiple through-going erosion surfaces that bound macroform elements up to 8 m thick. Intersecting near-vertical cuts bounding this exposure appear distinctly different. The face bounding the east half of the exposure reveals internally complex erosion and scour surfaces, whereas the face bounding the west half appears better organized, consisting of three near-planar through-going erosion surfaces that bound packages of planar–tabular and planar–tangential foresets. The east face is probably oriented perpendicular or oblique to paleoflow, whereas the west face is nearly parallel to paleoflow. Contrasting organization related to outcrop orientation relative to paleoflow is typical of sandy, low-sinuosity fluvial systems (Bristow, 1993; Adams and Bhattacharya, 2006).

Preliminary results from our work in the Homer–Kachemak Bay area through Fall 2007 will be released as a DGGS digital Preliminary Interpretive Report in early April 2008.

Capps Glacier–Beluga River Area

Ten days of reconnaissance fieldwork was completed in late August in the Capps Glacier–Beluga River area (figs. 1 and 3b). This work focused on preliminary stratigraphic studies of the West Foreland, Tyonek, and Beluga Formations exposed on the downthrown side of the Capps Glacier fault and along the banks of the Beluga, Chuitna, Lewis, and Theodore rivers, all in the Tyonek Quadrangle (figs. 2 and 3b). In addition, preliminary geologic mapping and structural studies were completed in the vicinity of the Capps Glacier fault and along a traverse extending south–southeast from a granitic body in the hangingwall (northwest side) of this structure to exposures of Tertiary strata in the lower reaches of the Beluga River (east side of the Bruin Bay fault).

Stratigraphic Studies

Approximately 400 m of pebble, cobble, and boulder conglomerate mapped as the West Foreland Formation are exposed in the footwall of the Capps Glacier fault, where they rest unconformably above Cretaceous–Jurassic metavolcanic rocks (unit KJu of Magoon and others, 1976; location 1, fig. 3b). The West Foreland in this area consists of poorly sorted, clast-supported, polymictic conglomerate and minor sandstone. Clasts and sandstone matrix are tightly packed and clast-on-clast contacts are commonly indented. Conglomerate is massive to horizontally stratified in beds that are typically poorly defined owing to limited grain size partitioning. Poorly sorted medium- to very-coarse-grained sandstone is generally present interbedded with conglomerate. Sandstone abundance varies along strike from locations where it is present only as rare discontinuous lenses up to 0.5 m thick to locations where sandstone is present in beds up to 1 m thick and composing up to 30 percent of the total stratigraphic thickness present in outcrop. Sandstone-poor exposures record deposition on the proximal part of an alluvial fan, relatively close to a feeder channel emanating from a bedrock valley, as gravelly sheetflood deposits (Blair and McPherson, 1994). Minor sandstone lenses at these locations record post-flood reworking of the fan surface. Sandstone-rich successions record deposition on the medial part of an alluvial fan. Significant post-depositional strain, either due to burial-related compaction or horizontal tectonic strain, is indicated by the common indented clast-to-clast contacts. Based on limited published descriptions, the lithological characteristics outlined here suggest this unit has more in common with the Hemlock Conglomerate than the West Foreland Formation. Whatever the correct lithostratigraphic assignment should be, it is clear that conglomerates near Capps Glacier and along the Theodore and Lewis rivers record fault-controlled deposition at the basin margin and 6-10 km basinward from the fault-bounded margin (latter two locations).

Nearby exposures to the west and southwest, in the headwaters of Straight Creek (location 2, fig. 3b), appear different than the conglomerates described above, at least in their appearance from the air. They include dark-colored beds resembling mudstones and thick, lighter-colored beds resembling tuffs. At least two domains are recognized, including one that dips gently toward the south and a second that dips more steeply toward the south. The gently dipping domain is cut by high-angle normal faults and appears to rest structurally(?) above more steeply dipping strata of the other domain. The stratigraphic affinity of these rocks are as yet unknown. Magoon and others (1976) included them in the West Foreland Formation. More structural observations from this area are presented below. Detailed examination of the stratigraphy and sedimentology of this unit is planned for the 2008 field season.

Exposures of conglomerate and sandstone mapped as West Foreland are present along the Theodore and Lewis rivers, southwest of Mount Susitna (locations 3a and 3b, fig. 3b). The West Foreland in this area contrasts with exposures of the unit near the Capps Glacier fault in that maximum clast size is significantly less (25 cm) and a greater variety of bedding styles are present, including massive beds, horizontally stratified beds, and cross-bedded conglomerate in sets up to 5 m thick. Clast-on-clast contacts are not indented. Sandstone is present in lenses and laterally continuous(?) beds up to few meters thick. These differences suggest a stream flow origin for the unit in this area, probably in large, low-sinuosity, gravelly streams. The large-scale cross-bedding noted above suggests that some streams were relatively deep (water depth at least equal to maximum preserved foreset height of 5 m). Assuming the successions exposed along the Theodore and Lewis rivers is correlative with conglomerates near Capps Glacier, which is reasonable given available coarse age control (Paleocene to Eocene; Magoon and others, 1976), they are interpreted as the deposits of coarse-grained, low-sinuosity axial fluvial systems.

Exposures of the Tyonek in the Capps Glacier–Beluga River region include thick overbank successions and well-developed fining-upward channel sand bodies. A thick succession of mudstone is exposed on the south side of Capps Glacier (location 4, fig. 3b). This succession appears similar to the lower Beluga near Fritz Creek, on the west shore of Kachemak Bay, in that it encases broadly lenticular sand bodies up to 4 m thick that record deposition in single thread channels. Also like the lower Beluga near Homer, the Tyonek here includes thicker sand bodies that display greater lateral continuity. Overbank mudstones a short distance to the south of this area include extremely thick coal seams, including the Capps coal seam, which is more than 15 m thick. These successions record deposition in long-lived flood basins that were traversed by single-thread streams that originated as crevasse channels. Again, like the lower Beluga on the east side of the basin, the thicker, more laterally continuous sand bodies record trunk fluvial channels.

Exposures of the Tyonek along the Beluga River (location 5, fig. 3b) include overbank mudstones punctuated by amalgamated channel-fill conglomerate and sandstone bodies. A measured section documents a complete fluvial channel-fill fining-upward cycle bounded by overbank mudstones. The relatively well-developed fining-upward grain size trend in the younger of these channel-fills suggests deposition in high-sinuosity, meandering streams (Bernard and Major, 1963).

Exposures of the Beluga Formation along the Beluga River (location 6, fig. 3b) include features common to both the lower and upper Beluga exposed along the west shore of Kachemak Bay. A measured section through part of the Beluga Formation documents a thick (>55 m) overbank mudstone succession. This mudstone succession includes tabular coarsening-upward successions of very-fine- to fine-grained sandstone and lenticular bodies of very-fine- to fine-grained sandstone up to 2 m thick. A short stratigraphic distance (10–20 m) above the top of this measured section the organization changes to a thick package of tabular sandstone bodies up to 10–15 m with intervening, thinner coal-bearing overbank mudstone successions. Two thick coal seams were completely cut out by erosion at the base of overlying tabular sand bodies. The stratigraphic position of these exposures within the Beluga is unclear.

Preliminary Mapping and Structural Studies

Field studies performed by DGGS on the northwest side of the basin in August 2007 included reconnaissance field mapping and structural studies in the Capps Glacier area, preliminary thermochronologic sampling across the Capps Glacier, Lake Clark, Castle Mountain, and Bruin Bay faults, and preliminary provenance studies of exposures of the Tertiary stratigraphic units in the area (fig. 3b).

Structural work focused on reconnaissance study of the Capps Glacier fault and possibly related structures deforming Tertiary-age basin fill deposits immediately southeast of the fault. Preliminary observations and limited structural data suggest that the Capps Glacier fault is a significant steeply northwest-dipping transpressional structure that may have accommodated several kilometers of dextral motion. The fault truncates gently to moderately deformed proximal Tertiary strata (conglomerates described above). Intrabasinal extensional faults in the Tertiary deposits truncate fold limbs at an oblique angle to their axes, implying extensional faulting was concurrent with, or more likely postdated transpressional folding. Near Capps Glacier, conglomeratic Tertiary strata unconformably overlie Cretaceous–Jurassic greenstone that is cut by the Capps Glacier fault.

Thirty samples were collected for 51 thermochronologic analyses from granitic, metasedimentary basement, and Tertiary basin-fill rocks in the Tyonek area. Sampling was conducted in the upthrown and downthrown blocks of the Castle Mountain, Bruin Bay, Lake Clark, and Capps Glacier faults to identify potential exhumation-induced differential cooling across regional structures. Sampling was concentrated primarily where exposures permitted along the Chuitna and Beluga river drainages and over vertical intervals at three locations near fault contacts to collect more comprehensive cooling information where accessible rock cropped out over moderate relief. These locations include granitic rocks from the upthrown and downthrown blocks of the Lake Clark fault near Blockade Glacier, the hangingwall of the Capps Glacier fault, and granitic rocks composing Mt. Susitna in the upthrown block of the Castle Mountain fault (Figure 3b). Due to funding constraints, six granitic samples have been high-graded for 14 analyses. Analyses will include $^{40}Ar/^{39}Ar$ of hornblende, biotite, and potassium feldspar; and apatite fission-track methods for their wide range of closure temperatures and collective ability to produce comprehensive cooling histories from emplacement temperatures to approximately 60°C.

Preliminary results from our reconnaissance work during August 2007 will be released as a DGGS digital Preliminary Interpretive Report in May 2008.

PROPOSED 2008–09 RESEARCH AND PRODUCTS

We propose an integrated program of field and subsurface studies designed to address questions raised in the introduction to this proposal. The topical projects outlined below are either ongoing projects that we are actively pursuing or projects that we plan to start in 2008. Each project description begins with a specific question that the research addresses and is followed by the methodology the basin analysis team intends to use in pursuing answers.

1. Do depositional systems in Tertiary strata in upper Cook Inlet vary in a predictable way with position in the forearc basin or relative to the basin margins? We hypothesize that depositional systems characterized by steep alluvial gradients and relatively coarse and immature textures characterize depositional systems near the basin margins, and lower gradient systems characterize the basin interior. To test this hypothesis we plan to carry out detailed facies analyses along the eastern and western basin margins and near the basin interior using all available outcrop and core, wireline log, and seismic data to

reconstruct depositional systems basin wide. An important part of this project is to evaluate sand body geometries and, where possible, to quantify apparent sand body dimensions in outcrop. An extensive suite of samples tied to facies through measured stratigraphic sections will be collected for reservoir quality (P&P, thin sections, XRD, and SEM), seal integrity (MICP), age control (palynology and geochronology), chemostratigraphy, and U-Pb dating of detrital zircons.

2. How does depositional environment affect sandstone reservoir quality? It is well established in many depositional systems in other basins around the world that original depositional texture (grain size, sorting, roundness, stratification, etc.) strongly influences the ultimate reservoir quality of many sandstones. Point-count and P&P data from samples tied to measured stratigraphic sections and core logs will be integrated with facies data to examine reservoir quality parameters and the influence of depositional processes on reservoir parameters.

3. Are there temporal and spatial variations in sandstone composition across the basin, and how do they affect diagenetic history and, ultimately, the reservoir quality of the sandstones? We hypothesize that there are temporal and spatial variations in sandstone composition within the basin and that these variations influence the diagenetic history of the sandstones. Previous work by industry geologists suggests that Tertiary sands derived from the accretionary prism contain elevated percentages of sedimentary rock fragments, that sediments derived from the volcanic arc are enriched in plutonic rock fragments and associated grains (Hayes and others, 1976), and that sands toward the basin axis have mixed provenance due to contributions from both sides of the basin. It is well established that the framework composition of sandstones can dictate the style and extent of diagenetic modification. For example, quartz arenites are commonly cemented by quartz overgrowths on detrital grains, plagioclase-rich arkoses are susceptible to laumontite replacement and cementation, and volcanogenic sandstones are readily cemented by chlorite, chlorite–smectite, and heulandite. To test this hypothesis we will obtain point-count data from a suite of sandstones from outcrops near the western and eastern basin margins and from wells located away from the basin margins. This suite of thin sections will then be studied to develop a paragenetic sequence of diagenetic events. Samples for detrital zircon dating will be collected from suitable outcrop around the basin margins.

Detrital zircon dates may be instrumental in differentiating relative contributions from different source terranes. A limited number of samples may be collected from the subsurface if sufficient extra material can be located that will not destroy the only record of a core.

Pending the outcome of a pilot project started in 2007 designed to test the applicability of chemostratigraphic techniques in differentiating lithostratigraphic units, we may collect a limited number of outcrop and subsurface samples for chemostratigraphic analysis. Chemostratigraphy presents a promising tool for use in subsurface correlation and provenance studies. The method utilizes major and trace elements to identify changes in sediment composition.

4. Can diagnostic stratal geometries be recognized on industry seismic data that reflect specific depositional systems recorded in Tertiary strata? We hypothesize that depositional systems can be recognized on high-quality industry seismic data. To test this hypothesis we will apply principles of seismic sequence stratigraphy to a licensed offshore two-dimensional seismic dataset and three-dimensional datasets that may be made available through a future license agreement with the Department of Natural Resources. Wireline log response will be calibrated to available core and tied to seismic data.

5. How does subsidence history in upper Cook Inlet basin vary in space and time, and what mechanism(s) controlled these variations? Our approach to answering these questions will incorporate traditional wireline log-based methods and licensed two-dimensional seismic data. Estimates of Tertiary uplift and erosion can be obtained from shale compaction curves derived from sonic and SP wireline logs. These curves are sonic transit time–depth (DT–depth) plots constructed specifically for clay-rich lithologies as determined from the SP log. Vertical offset (depth axis) between any two trend lines indicates the relative difference in uplift the two wells have experienced. If a well with little or no Tertiary uplift can be identified and used for comparison, estimates of absolute uplift can be determined. Otherwise, uplift estimates represent minimum values. If uplift estimates can be obtained from sufficient wells, a regional map of Tertiary uplift can be produced. DNR is in the process of purchasing a license to use a palynology database for

Cook Inlet. These data will be used in conjunction with licensed seismic data to map selected surfaces throughout the basin and, ultimately, to construct isopach maps of selected stratigraphic units/intervals. The resulting maps will provide information on subsidence and uplift in space and time and, in combination with wireline log-based analyses, will provide insights to basin evolution through time and its influence on source rock maturation and migration and timing of diagenetic processes affecting reservoir quality. The base Tertiary unconformity surface map and Mesozoic subcrop map (described below) will be utilized in this project.

6. What Mesozoic stratigraphic units subcrop the basal Tertiary unconformity surface in upper Cook Inlet basin? Constructing a Mesozoic subcrop map will provide a picture of source and reservoir rock juxtapositions across this unconformity. This map will also help in understanding the basin paleogeographic and structural configuration at the start of Tertiary deposition. This project involves creation of a subsurface geologic map using a structure contour map of the basal Tertiary unconformity as the base map. The first part of this project is to produce a depth map of the base Tertiary unconformity throughout the upper Cook Inlet basin. We will incorporate all available public well and outcrop data, as well as licensed 2D marine seismic data. Well synthetics and public velocity information will be used to establish seismic horizons and to convert time to depth. Where seismic data are not available, public formation tops and structural information for fields obtained from public record at the Alaska Oil & Gas Conservation Commission (AOGCC) will be used to estimate the shape of the basal Tertiary unconformity.

   The second part of this project is to map Mesozoic units that subcrop the basal Tertiary unconformity. Wireline log formation tops interpreted by DNR and other public sources (Petroleum Institute, Alaska Geological Society, U.S. Geological Survey) will be compiled with tops interpreted from seismic data by DNR and with AMSTRAT lithologic log tops. This detailed process will provide quality control of Cook Inlet top picks from the extensive AOGCC public well database. In addition a purchased palynology study will be incorporated as the license permits. Faults mapped at the surface will be extended to depth and included on the subcrop map only where other evidence supports such an interpretation. The attitudes of Mesozoic formations subcropping the unconformity will be inferred from seismic data where possible and, along with any public dipmeter data, incorporated into the subcrop trends. The map will eventually integrate new DNR interpretations of existing core at the Alaska Geologic Materials Center. The final product will include cross-sections across the basin showing the interpreted geometry of Mesozoic units at depth.

7. What role have major transpressional faults along the western and northern margins of the Cook Inlet basin played in sediment source area exhumation during Tertiary time? We hypothesize that up to several kilometers of throw along the Castle Mountain, Lake Clark, Bruin Bay, and perhaps the Capps Glacier faults has resulted in substantial denudation of upthrown blocks, and that motion has been partitioned between individual faults over time. To test this hypothesis, we intend to integrate new geologic mapping of regional structures in the Tyonek area with new thermochronologic analyses of samples collected across major faults to compare cooling histories of upthrown and downthrown fault blocks. Thermochronometry records the time since a sample cooled below a known temperature (closure temperature) and is a proven method for assessing tectonic controls on exhumation in a wide range of temperatures. When a suite of samples are collected and their cooling histories interpreted within the framework of the regional structural geology, a regional kinematic model of fault-controlled source area exhumation is achievable. We propose to map at 1:63,360 scale an approximately 4,300 km^2 area centered on Tertiary outcrops along the Beluga and Chuitna rivers in the Tyonek Quadrangle and collect a suite of samples from upthrown and downthrown blocks of mapped faults for apatite fission-track and selected $^{40}Ar/^{39}Ar$ and (U-Th)/He thermochronologic analyses to assess tectonic controls on exhumation in this region. This area encompasses surface exposures and/or subsurface projections of the Castle Mountain, Lake Clark and Bruin Bay faults. The proposed mapping will cover the area with the largest and best exposures of Tertiary basin-fill deposits along the entire northeastern Cook Inlet margin, with a clear relationship to the Capps Glacier fault, which reconnaissance work in 2007 suggests is a major structural element of possible regional significance. The structural style readily observed in these strata should provide an analog for Tertiary deposits deformed by the Castle Mountain, Lake Clark, and Bruin Bay faults that are poorly exposed in drainages to the southeast. New mapping and thermochronologic results will be integrated with results of our ongoing and proposed

stratigraphic and provenance studies in this area to produce a kinematic model of Tertiary-age exhumation along the northwestern margin of the Cook Inlet basin.

8. Are fluid inclusions present in laumontite? Addressing this question represents a modest start toward addressing the petroleum potential of Mesozoic strata in Cook Inlet. The ultimate question to be addressed here is ‘Does the generation of laumontite in the Mesozoic section precede hydrocarbon generation and migration, thereby condemning prospectivity?’ Work in several circum-Pacific basins shows that laumontite ($CaAl_2Si_4O_{12}{\cdot}4H_20$) is present as a direct replacement of plagioclase and a pervasive cement that typically occludes all residual porosity. Previous examinations of outcrop and subsurface samples from OCS wells in lower Cook Inlet by industry geologists show laumontite is regionally extensive in the Mesozoic section, particularly the Pomeroy Arkose Member of the Naknek Formation, where it is assumed to be economic basement. The timing of laumontite genesis relative to hydrocarbon migration is critical to evaluating the petroleum potential of the basin. If regional cementation postdates hydrocarbon migration, the potential exists for reservoirs in Mesozoic strata. It may be possible to estimate the temperature of laumontite formation through fluid inclusion analysis. The temperature of formation can then be related to the thermal history of the basin to estimate the time of cementation. Thermal history can also be used to estimate the timing of hydrocarbon migration. This work depends on the presence of fluid inclusions in laumontite, the assumption of no fluid leakage from them, and the ability to differentiate primary and secondary inclusions. No literature exists on fluid inclusions in zeolite minerals. This scoping study will involve examination of an existing suite of sandstone thin sections from Cook Inlet basin, the Yukon–Koyukuk flysch belt, the San Joaquin basin and Santa Ynez basin to answer two fundamental questions: ‘Are fluid inclusions present and, if present, can primary and secondary inclusions be differentiated?’

A preliminary interpretive report, or series of reports, summarizing our outcrop observations and associated data from the 2008 field season will be released in late winter–early spring 2009. Research results from other projects in this program will be published as more formal DGGS digital reports as results become available.

FIELD LOGISTICS, BUDGET, STAFF

Homer–Kachemak Bay

DGGS will resume field work on the southern Kenai Peninsula on May 5 and continue through May 16, 2008. The field party will spend approximately half of this period working from a base of operations in Soldotna on beach bluff exposures between Clam Gulch and Cape Starichkof, and half working from a base in Homer on bluff exposures between Homer and Anchor Point (figs. 1 and 3a). In an effort to maximize time spent on the outcrop, four-wheel ATVs will be used to access bluff exposures located long distances from beach access points.

Tyonek–Capps Glacier

DGGS will have a field party working in the Capps Glacier–Beluga River area from July 14 through July 26, 2008 (figs. 1 and 3b). The network of roads in this area is limited and helicopter support will be needed for this work. Field accommodations will be provided by a commercial camp located near the Beluga airstrip. Contingent on the level of funding, we are considering a one-day tour to be run immediately following field work in this area (July 27 or 28). The tour will require helicopter support to access field locations. DGGS will have limited space available in their chartered helicopter and interested parties will need to provide their own helicopter transportation. One possible way to handle helicopter arrangements would be for two or more companies to share helicopter logistics. DGGS will have helicopter fuel at the camp and, as long as we know ahead of time the number of helicopters to expect, we will make sure an adequate fuel supply is available on-site at cost. For our planning purposes, we will make a decision on whether to run this tour by the end of May and the decision will be posted on the DGGS website (**http://wwwdggs.dnr.state.ak.us/** look for the RSS News Feed link on the DGGS homepage).

Project Budget

A detailed budget for the proposed work is included as Table 1. The project, as proposed, will cost $288,561.

Project Staff

This program is managed by DGGS with research carried out by geoscientists at DGGS, DOG, University of Alaska Fairbanks, and Purdue University. Each geoscientist listed below is expected to contribute to, or lead, some aspect of the research covered in this proposal.

David LePain (DGGS)—Clastic sedimentology, sequence stratigraphy, and basin analysis

Paige Delaney (DGGS)—Wireline log analysis, subsurface correlations, and GIS applications

Marwan Wartes (DGGS)—Clastic sedimentology and basin analysis

Robert Gillis (DGGS)—Structural geology and thermochronology

Robert Swenson (DGGS)—Structural geology, petroleum geology, and program advisor

Paul McCarthy (UAF)—Nonmarine clastic sedimentology, sequence stratigraphy, and paleosols

Jacob Mongrain (UAF and DGGS) —Nonmarine clastic sedimentology and paleosols

Diane Shellenbaum (DOG)—Seismic data acquisition and licensing, seismic interpretation, and time–depth conversion

Laura Silliphant (DOG)—Wireline log analysis, subsurface correlations, and petroleum geology

Ken Helmold (DOG)—Reservoir quality and basin modeling

Shaun Peterson (DOG)—Wireline log analysis, subsurface correlations, and basin modeling

Meg Kremer (DOG)—Petroleum geology and program advisor

Emily Finzel (Purdue University)—Sedimentology and tectonics

Ken Ridgway (Purdue University)—Sedimentology and tectonics

In addition, we anticipate informal collaboration with Dr. Richard Stanley (USGS, Menlo Park, CA)

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Table 1: Proposed budget for DGGS 2008 field and subsurface studies in Cook Inlet. The State of Alaska will cover full-time permanent staff salaries, benefits, and overhead.

Budget Category	Unit Cost	Unit	No. Units	Outside Receipts
100 Salaries				
Student intern	28,000	year	1	$28,000
Subtotal				$28,000
200 Field Expenses				
Roundtrip airfare to Anchorage	250		5	$1,250
Charter from Anchorage to Tyonek/Beluga	1,700	one-way	4	$6,800
Lodging in Homer and Soldotna	115	day	75	$8,625
Per diem in Homer and Soldotna	60	day	75	$4,500
Food and lodging in Tyonek-Beluga area	250	day	126	$31,500
Bell 206B3 Helicopter (daily + 5 hrs/day) without mechanic	4,150	day	14	$58,100
Helicopter ferry to Tyonek/Beluga	1,873	one-way	2	$3,746
Jet A - Tyonek/Beluga	9	gallon	1080	$9,720
Subtotal				$124,241
300 Analytical Expenses and Contracts				
Thin sections	22	sample	50	$1,100
Thin sections - doubly polished	24	sample	10	$240
Total organic carbon	18	sample	40	$720
Rock-eval 6	28	sample	40	$1,120
Vitrinite reflectance/kerogen typing	210	sample	40	$8,400
Micropaleo	200	sample	100	$20,000
Megafossil ID	110	sample	20	$2,200
Porosity and permeability	240	sample	50	$12,000
MICP	300	sample	40	$12,000
Apatite fission track	750	sample	20	$15,000
Zircon U/Pb geochronology	1,200	analysis	10	$12,000
Ar/Ar geochronology	500	sample	20	$10,000
Point-count	200	thin section	30	$6,000
Fluid inclusion analysis	250	analysis	10	$2,500
Chemostratigraphy	156	sample	40	$6,240
Subtotal				$109,520
400 Miscellaneous Supplies and Travel				
Air photos and topo maps	3,000	one-time	1	$3,000
Miscellaneous field equipment	1,200	one-time	1	$1,200
Software licenses (Geographix)	4,000	renewal	1	$4,000
Report production, distribution, and computer support	5,000	one-time	1	$5,000
Travel to Anchorage for meetings and core work	800	trip	10	$8,000
Travel AAPG annual meeting	2,800	person	2	$5,600
Subtotal				$26,800
Total requested from non-state program sponsors				**$288,561**

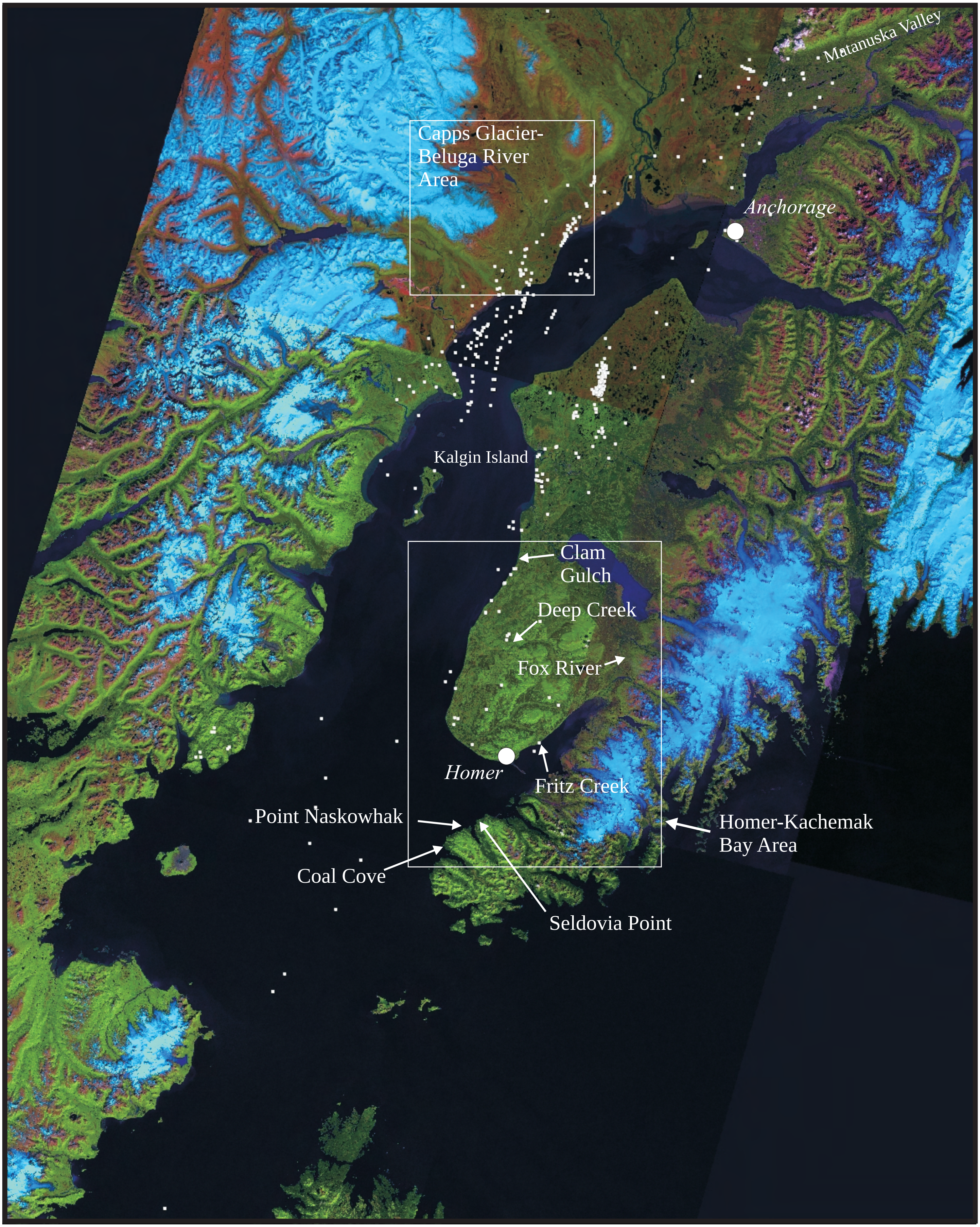

Fig. 1 - Landsat image showing oil and gas wells, selected 2006 and 2007 field locations, Homer-Kachemak Bay area and Capps Glacier-Beluga River area.

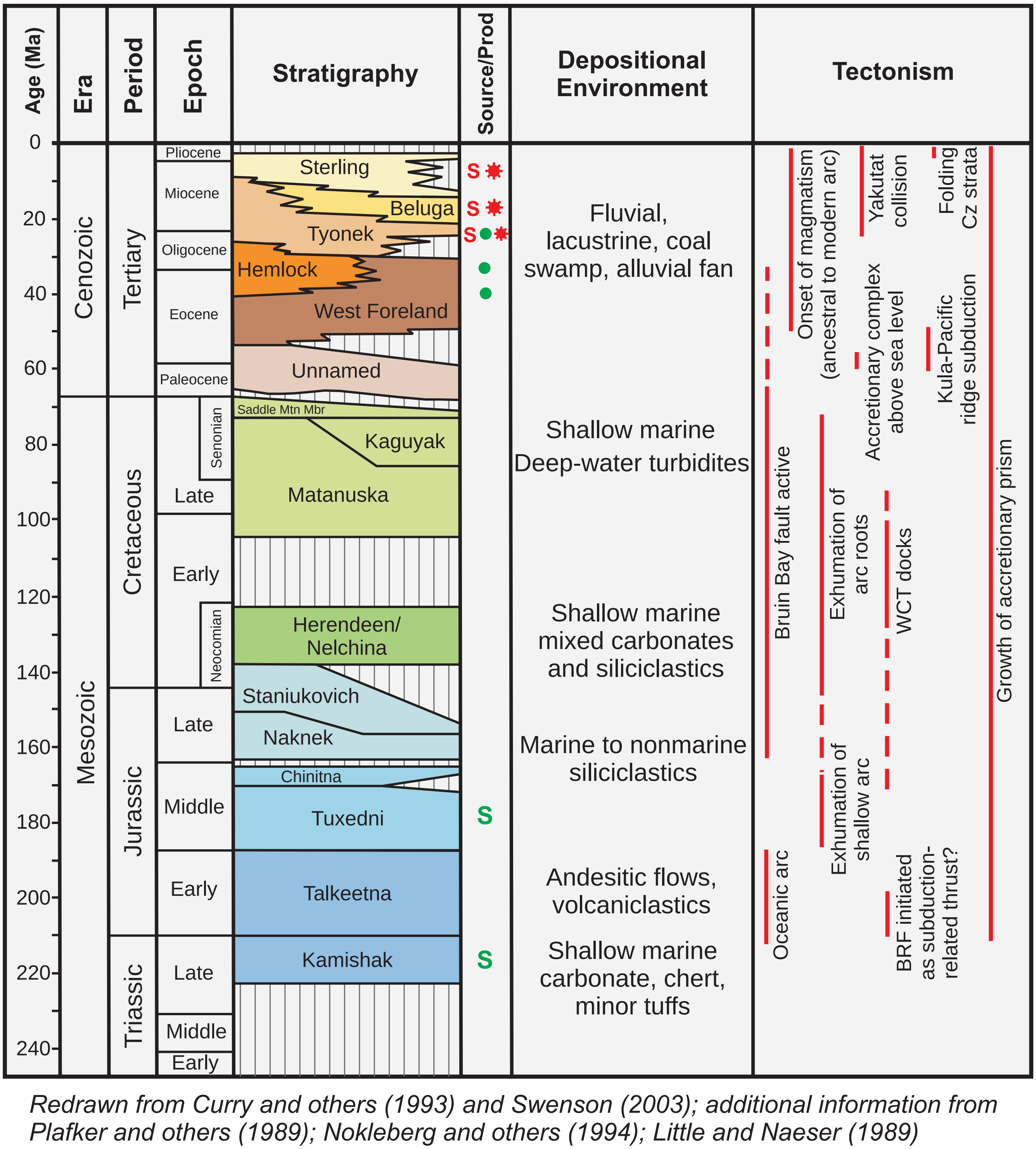

Fig. 2 - Generalized stratigraphic column for Cook Inlet basin, Alaska.

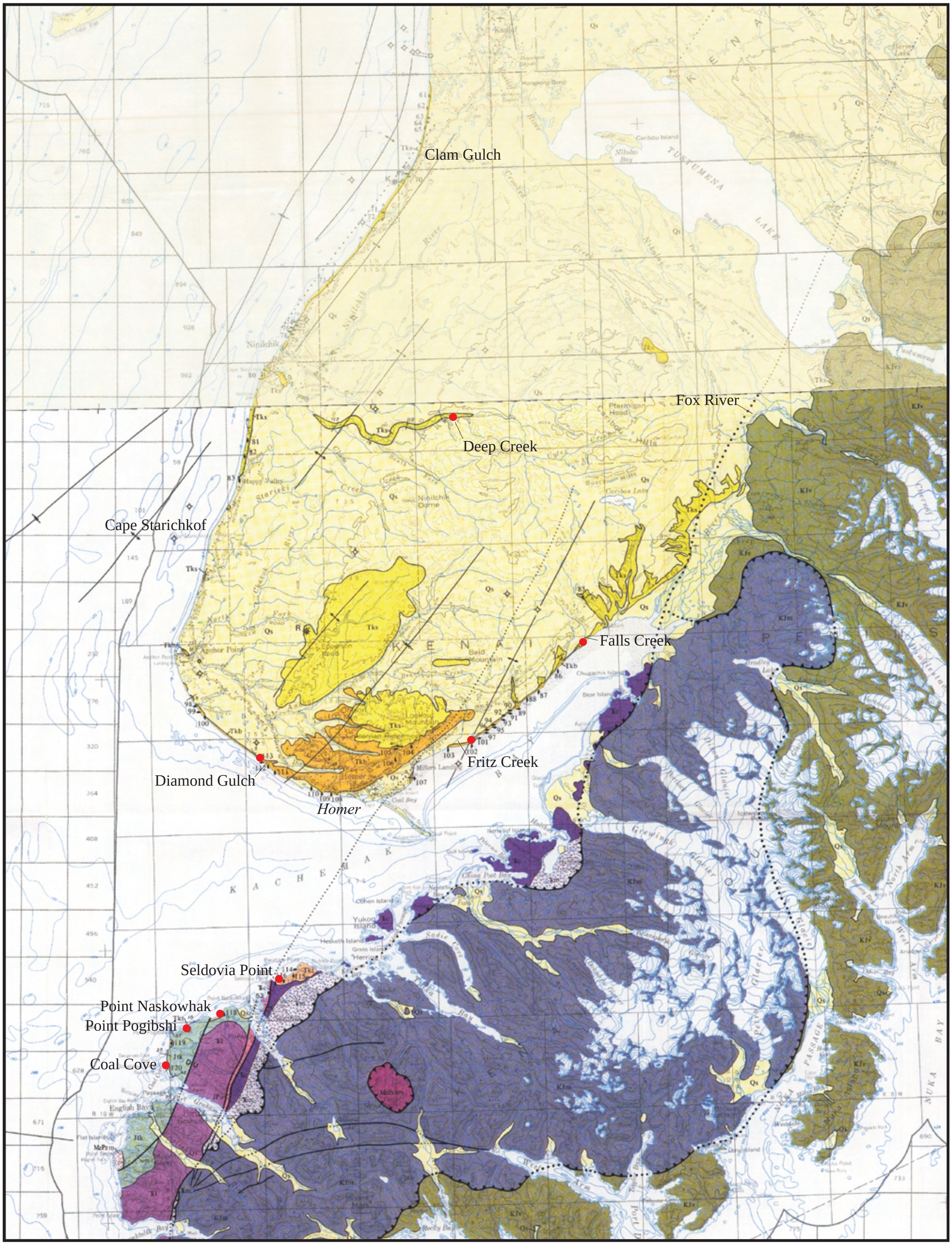

Figure 3a. Geologic map of the of the Homer-Kachemak Bay area. Modified from Magoon and others (1976).

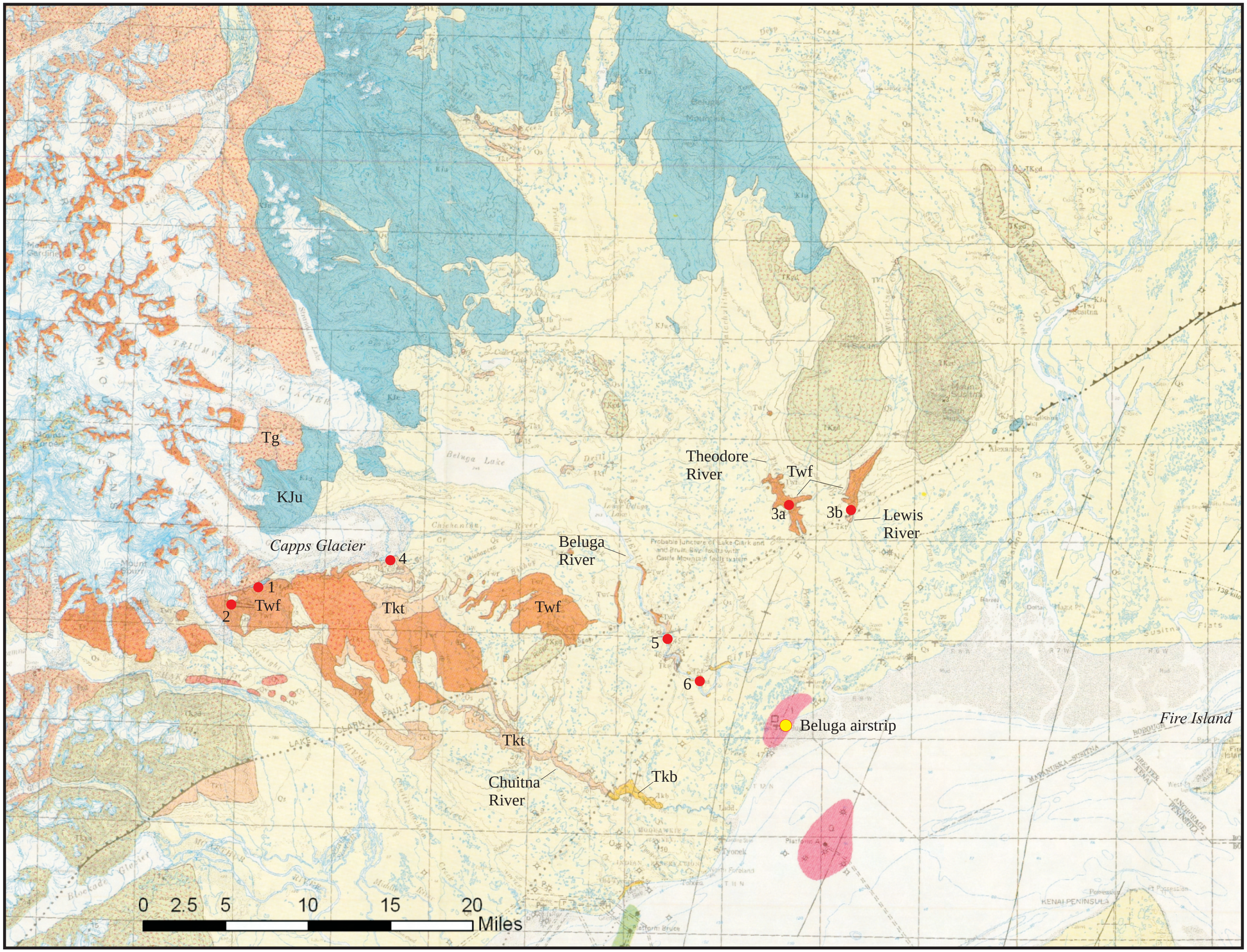

Figure 3b. Geologic map of part of the Tyonek Quadrangle west of Anchorage, Alaska. Modified from Magoon and others (1976). Numbered locations are discussed in the text. Tg = Tertiary granite; Twf = Tertiary West Foreland Formation; Tkt = Tertiary Tyonek Formation; Tkb = Tertiary Beluga Formation.