November 10, 1995 Price: $2.00

Division of Geological & Geophysical Surveys

PUBLIC-DATA FILE 95-36

GEOLOGIC HAZARDS IN AND NEAR PROPOSED STATE OF ALASKA OIL AND GAS LEASE SALE 85A (COOK INLET)

by

R.A. Combellick, R.D. Reger, and C.J. Nye

November 1995

THIS REPORT HAS NOT BEEN REVIEWED FOR TECHNICAL CONTENT (EXCEPT AS NOTED IN TEXT) OR FOR CONFORMITY TO THE EDITORIAL STANDARDS OF DGGS.

Released by

STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES
Division of Geological & Geophysical Surveys
794 University Avenue, Suite 200
Fairbanks, Alaska 99709-3645

GEOLOGIC HAZARDS IN AND NEAR PROPOSED STATE OF ALASKA OIL AND GAS LEASE SALE 85A (COOK INLET)

by
R.A. Combellick, R.D. Reger, and C.J. Nye

INTRODUCTION

The proposed State of Alaska Cook Inlet lease sale (85A) occupies onshore and state offshore areas in central and upper Cook Inlet between Turnagain Arm and Kachemak Bay (fig. 1). This area is located in one of the most seismically active regions in the world, is in close proximity to several active volcanoes, has some of the highest tides in the world with severe winter ice conditions, and includes several rivers that are subject to large-magnitude flooding. In spite of these environmental constraints, because of proper siting, design, and construction practices, petroleum-extraction and -processing facilities have functioned, both onshore and offshore, without significant environmental damage since the Swanson River field was discovered in 1957 (Magoon and others, 1976). This report provides a brief summary of available information related to the geologic hazards of this region.

EARTHQUAKES AND FAULTING

The Cook Inlet trough is a forearc basin between the Aleutian Arc to the west and the Kenai Mountains to the east (Kelley, 1985). Northwestward subduction of the Pacific crustal plate beneath the Kenai Mountains and Aleutian Arc (North American plate) accumulates crustal stresses that are periodically relieved by deep-focussed earthquakes. Sources of potentially damaging, shallow-focussed earthquakes include the active Castle Mountain fault and one possible extension, the Bruin Bay fault, which transect the northwestern margin of the Cook Inlet trough (Magoon and others, 1976; Hackett, 1977)(fig. 2). A magnitude-5.7 earthquake in 1984 with an epicenter near the town of Sutton in lower Matanuska Valley was attributed to subsurface movement along the Castle Mountain fault (Lahr and others, 1986). A possible southwest extension of the Castle Mountain fault has been mapped along the southeastern flank of Lone Ridge in the northwestern Tyonek A-4 Quadrangle (Schmoll and others, 1981, 1984; Schmoll and Yehle, 1987). The inferred trend of the Bruin Bay fault crosses several townships of the Lease Sale 85A area from the vicinity of Tyonek to near Harriet Point on the west side of Cook Inlet (Magoon and others, 1976). Several northeast-trending faults have been identified or inferred in the western Kenai Lowland. Several of these structural breaks are known to cut Tertiary-age rocks of the Kenai Group, but they are not known to offset younger deposits and their activities and subsurface extents remain speculative (Barnes and Cobb, 1959; Kirschner and Lyon, 1973; Tysdal, 1976).

Diffuse seismicity shallower than 35 km in the Cook Inlet area results from deformation that is still poorly understood. A 1933 magnitude 6.9 event (fig. 2), which caused intensity VII effects in Anchorage, may have been related to this shallow deformation. Some buried folds in the upper Cook Inlet area, such as at the Middle Ground Shoal oil field, are cored with blind reverse faults that may be capable of generating magnitude 6.3-6.9 earthquakes (Haeussler and Bruhn, 1995).

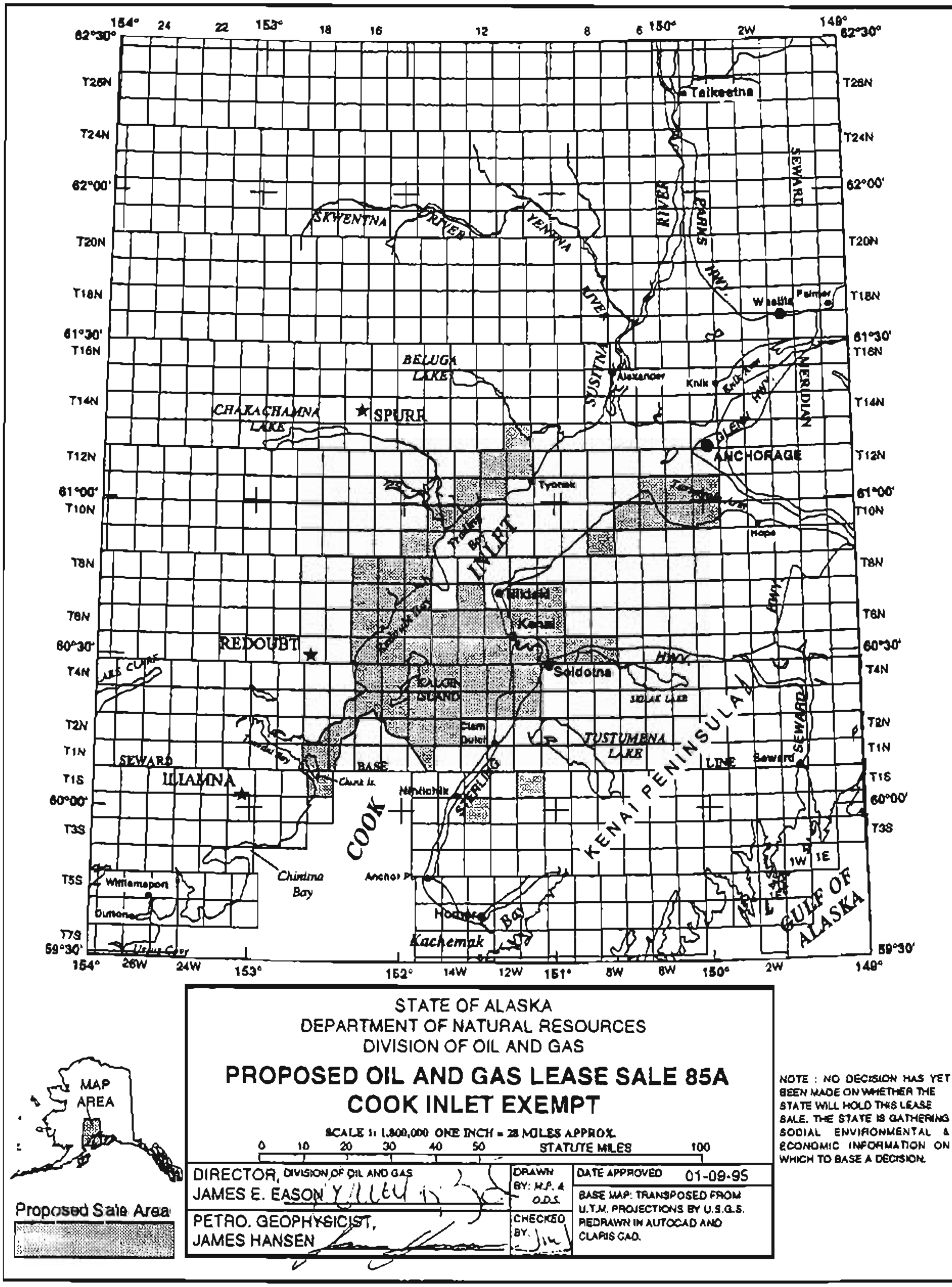

Figure 1. *Map of upper Cook Inlet showing area of proposed Lease Sale 85A. Stars indicate locations of active volcanoes.*

The epicenter of the great 1964 earthquake (moment magnitude 9.2) was just east of the map area in Prince William Sound. However, geologic effects related to that powerful seismic event were widespread in the lease sale area and included seismic shaking, ground breakage, landslides and other surface displacements, liquefaction, falling objects, and structural failures (Waller, 1966; Stanley, 1968; Foster and Karlstrom, 1967; Tysdal, 1976). Future strong earthquakes can be expected to produce similar effects. Studies of the geologic record indicate that very powerful 1964-style earthquakes have occurred with an average recurrence interval of 600-800 years during approximately the past 5,000 years (Combellick, 1994). Smaller great earthquakes in the magnitude 8 range probably have occurred more frequently. The most recent pre-1964 great subduction earthquake in the region was 700-900 years ago (Combellick, 1993).

According to Algermissen and others (1991), there is a 10 percent probability that peak horizontal ground acceleration during an earthquake in the lease sale area will exceed 0.58 g (gravitational

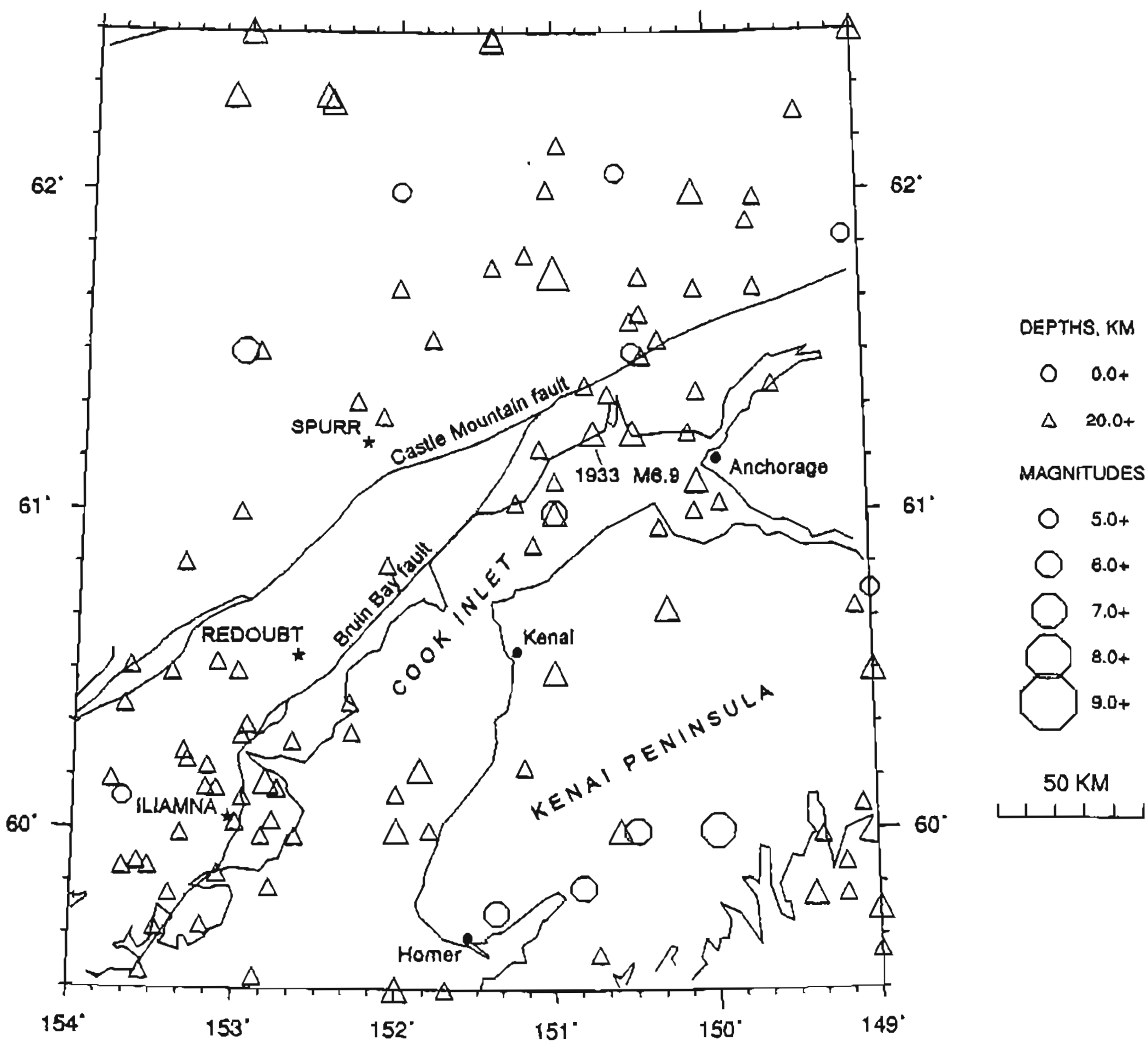

Figure 2. *Epicenters of earthquakes with magnitudes >5.0 in the upper Cook Inlet region. Stars indicate locations of active volcanoes (B. Hammond, Alaska Earthquake Information Center, 11/2/95).*

acceleration) during 50 years. By comparison, peak acceleration in Anchorage during the 1964 great earthquake was estimated at 0.15 to 0.20 g (Housner and Jennings, 1973). All structures should be designed and built to exceed the Uniform Building Code specifications for seismic zone 4 (highest earthquake hazard). Additionally, site-specific earthquake-hazards evaluations should be required for all major structures, such as offshore drilling and production platforms, to determine probable site effects. These potential effects include ground-motion amplification, soil liquefaction, and other earthquake-induced ground failures. Design, construction, and operation of these facilities must be performed in a manner to mitigate these effects with the goal of preventing loss of human life and significant environmental damage during earthquakes.

TSUNAMIS

Because marine portions of the Lease Sale 85A area are relatively shallow and protected from open ocean, the hazard from distant tsunamis is low. The hazard from local earthquake-generated tsunamis is also low because there are no known active surface faults in the inlet, no adjacent steep slopes to serve as sources of massive slides into the inlet, and no evidence of thick, unstable seafloor deposits that would fail in massive underwater slides. No tsunami affected this part of Cook Inlet during the 1964 great earthquake and there is no known geologic evidence of prehistoric tsunamis in this area. The possibility of volcanigenic tsunamis in Cook Inlet is discussed below.

VOLCANIC HAZARDS

Alaska is volcanically active, containing about 80% of all the active volcanoes in the United States and about 8% of the active volcanoes in the world. The western shore of Cook Inlet contains six volcanoes that have erupted in Holocene time. These are, from north to south, Hayes volcano, Mt. Spurr (Crater Peak), Redoubt Volcano, Iliamna Volcano, Augustine Volcano, and Mt. Douglas. Three of these (Crater Peak, Redoubt, and Augustine) have erupted more than once this century, and any of these three could well erupt again in the next few years or decades.

Study of volcanic-ash layers (tephras) in the Cook Inlet region indicates that eruptions have occurred every 1 to 200 years (Riehle, 1985). In the 20th century, these events have occurred every 10 to 35 years, and, for the last 500 years, tephras were deposited at least every 50 to 100 years, with Redoubt Volcano, Crater Peak, and Augustine Volcano being the most active (Stihler, 1991; Stihler and others, 1992; Begét and Nye, 1994; Begét and others, 1994). Augustine Volcano is one of the most active volcanoes in Alaska, with major eruptions in 1883, 1935, 1964, 1976, and 1986; it will be surprising if it does not erupt again in the next few to several years. Redoubt Volcano erupted in 1968 and 1989-90, and Crater Peak erupted in 1953 and 1992 (Wood and Kienle, 1990). No historic eruptions are known for Mt. Douglas, Iliamna Volcano, or Hayes volcano, although geologic evidence shows that each has erupted during the past 10,000 years.

During their periodic violent eruptions, the active glacier-clad stratovolcanoes produce abundant ash and voluminous mudflows that have threatened air traffic and onshore petroleum facilities (Riehle and others, 1981; Brantley, 1990). These are examples of the two major categories of volcanic hazards that will continue to threaten activities in the region. Proximal hazards are those close to volcanoes and consist of a wide variety of flow phenomena on the flanks of volcanoes or in drainages which head on the volcanoes. Distal hazards are those farther from volcanoes, such as ashfall and tsunamis. These two types of hazards are evaluated below.

PROXIMAL HAZARDS comprise a large variety of flow hazards on the flanks of volcanoes. Of particular concern to the area involved in Lease Sale 85A are watery to sediment-rich floods generated by the rapid emplacement of large volumes of hot volcanic ejecta onto snow and ice on the upper flanks of volcanoes. All the volcanoes in Cook Inlet except Augustine have permanent snow and ice stored in snowfields and glaciers on their upper flanks.

The largest volcanically generated flood this century was caused by the January 2, 1990, eruption of Redoubt Volcano. The peak discharge of this event was more than 100 times larger than that of the estimated 100-year meteorologically generated flood (Dorava and Meyer, 1994). The flood impacted the operation of the Drift River Oil Terminal, which is in the lower valley of the drainage down which the flood went; upgraded protective structures have since been constructed there (Brantley, 1990). Another, and probably much smaller, flood came down the Chakachatna River in response to the 1953 eruption of Crater Peak. Floods caused by eruptions can impact any drainage that heads on a volcano.

In the area of the proposed lease sale, drainages that could be impacted by volcanigenic floods are the Chakachatna River drainage (from Trading Bay to the McArthur River), the Drift River drainage (from Montana Bill Creek to Little Jack Slough), Redoubt Creek, and Crescent River. This is approximately half of the Lease Sale 85A lands on the western shore of Cook Inlet. These floods would not impact Lease Sale 85A lands on the eastern side of Cook Inlet. Drift River and Chakachatna River are the most likely to host floods. A very large debris avalanche came down Redoubt Creek and formed the land that now underlies Harriet Point in latest Pleistocene time, but that drainage does not appear to have hosted a large flow since that time (Begét and Nye, 1994). Large flows, some of which reached the present shoreline, came down Crescent River between about 3,600 and 1,800 years ago (Begét and Nye, 1994). These events illustrate the magnitude of potential flows. Larger events are less likely than smaller events. The most probable volcanically induced floods are small, water-rich floods, which depending on the local hydrographic conditions, could impact roads, pipelines, and other infrastructure.

Other proximal hazards typically associated with volcanoes similar to those on the western shore of Cook Inlet are lava flows, block-and-ash flows, pyroclastic flows and hot gas surges. The lands included in the proposed Lease Sale 85A area are far enough from the volcanoes that they are out of range of all but the very largest eruptions (eruptions on the scale of the 1980 Mount St. Helens or 1991 Mt. Pinatubo eruption). Eruptions this large are rare, although they are certainly possible and have happened at several of the Cook Inlet volcanoes.

DISTAL HAZARDS are those caused by volcanic eruptions but impact distant sites. The most common of these is ashfall, where volcanic ash (finely ground volcanic rock) is lofted into the atmosphere and stratosphere by explosive eruptions, drifts downwind, and falls to the ground. There have been dozens of such events from Cook Inlet volcanoes this century. In each case at distances of more than a few tens of kilometers from the vent of the volcano ashfalls have been a few millimeters or less in thickness. The primary hazard of such ashfalls is damage to mechanical and electronic equipment such as engines which ingest ash past the air filter, computers, and transformers, possibly causing electrical shorts. The hazard to large jet aircraft is high but not directly relevant to oil and gas development. Ashfalls of a few millimeters should be expected throughout the Cook Inlet basin with a long-term average frequency of a few every decade or two. Ashfalls thick enough to collapse buildings are possible but rare (the 1912 eruption of Novarupta on the Alaska Peninsula is a case in point).

Another distal hazard is posed by volcanigenic tsunamis. These are caused when volcanoes become gravitationally unstable either due to addition of lava to their summit regions or weakening by hydrothermally driven alteration. In either case they fail in large avalanches. If these avalanches hit water they can generate large waves that can travel quickly and for long distances. Augustine Island grows vertically by eruption of lava domes, which become unstable and fail in debris avalanches. At least 11 of these avalanches have reached beyond the present coastline in the past 1,800 to 2,000 years (Begét and Kienle, 1992). It is not known if any or all of these generated anomalous waves, although collapse of similar volumes of material from Japanese volcanoes have. There is some anecdotal evidence in historic records that the 1883 eruption of Augustine generated a wave that was several meters high when it impacted English Bay, on the east side of Cook Inlet (Begét and Kienle, 1992). There are also historical documents that discount the existence of this wave (Waythomas, 1995). In any event, geologic evidence of repeated anomalous waves has not been found (Waythomas, 1995). Other Cook Inlet volcanoes have also generated large debris avalanches, but only at Redoubt did one reach the present shoreline. The volcanigenic tsunami hazard in Cook Inlet is presently poorly understood, although the potential for the generation of large waves is real.

MARINE AND SEAFLOOR HAZARDS

Cook Inlet has a maximum tidal range of 4 to 11 m, depending on location, which produces rapid tidal flows and strong riptides (Evans and others, 1972; Hayes and others, 1976; National Oceanic and Atmospheric Administration, 1977). Winter ice conditions combined with tidal action may occasionally hinder offshore operations in the upper inlet from December through April (Sharma and Burrell, 1970). During the winter of 1970-71, inlet ice extended as far south as Anchor Point and Cape Douglas. Although blocks of floe ice generally reach thicknesses of 1.2 m in Cook Inlet, grounding of these blocks forms large piles of ice blocks (stamukhi) that exceed 12 m in thickness and, where floated, stamukhi have damaged ships in the inlet (Evans and others, 1972). Numerous large erratic blocks in shallow, nearshore waters are hazards to ship navigation. Frequent storms accompanied by strong winds and long fetches result in strong wave action that erodes shorelines composed of unconsolidated sediments and weakly cemented Tertiary sedimentary rocks (Hayes and Michel, 1982).

High tidal-current velocities in upper Cook Inlet prevent deposition of clay and silt-size sediments, which largely remain in suspension. Bottom sediments in the Lease Sale 85A area are mainly gravel and sandy gravel with gravel content of 50-100 percent (Sharma and Burrell, 1970). Similar deposits in lower Cook Inlet are thought to be reworked and redistributed coarse-grained glacial material (Rappeport, 1981). These deposits show no evidence of gravitationally unstable slopes or soft, unconsolidated sediment (Minerals Management Service, 1995). Liquefaction susceptibility of these coarse relict glacial deposits under earthquake loading is probably low, particularly if they remain overconsolidated due to ice loading. However, recent evidence of gravel liquefaction in the Portage area during the 1964 great earthquake indicates that gravel may be more susceptible to liquefaction than previously thought (Combellick, 1995). Site-specific testing of liquefaction susceptibility is advisable.

FLOOD HAZARDS

Besides volcanigenic flooding on the west side of Cook Inlet, flood hazards in the Lease Sale 85A area result from ice jams, glacial outburst (jökulhlaups), and high rainfall, in decreasing order of frequency. Ice-jam flooding is localized, but affects the greatest number of residents over time (J.M. Dorava, U.S. Geological Survey, personal communication, 1995).

Rivers subject to large-magnitude outburst floods as a result of the sudden drainage of large, glacier-dammed lakes directly affect the Lease Sale 85A area, particularly on the west side of Cook Inlet. There, major streams affected by outburst floods include Beluga River, Chakachatna River, Middle River, McArthur River, Big River, and Drift River (Post and Mayo, 1971). For example, Strandline Lake has drained catastrophically into Beluga River every 1 to 5 years since about 1954. In September, 1982, over 95 percent of Strandline Lake drained, releasing about 7×10^8 m^3 of water (Sturm and Benson, 1988). The most reliable precursor of outburst floods from Strandline Lake is the development of a calving embayment in the lobe of Triumvirate Glacier, which dams the lake.

In Kenai Lowland, high-water levels in Kenai River frequently occur due to the sudden drainage of glacier-impounded lakes at the head of the Snow River tributary east of Kenai Lake and lakes held in by Skilak Glacier. Several small lakes impounded by Tustumena Glacier are potential sources of unexpected floods in Kasilof River. In October, 1995, Skilak Glacier released an outburst flood that resulted in water levels cresting about 0.5 m below flood stage at Kenai Keys and Soldotna (unpublished data, National Weather Service, October 1995). This outburst flood had a total volume considerably less than previous events in 1985 and 1990; no damage was reported from the 1995 event. However, future outbursts from Skilak glacier dammed lake could result in extensive lowland flooding, as occurred in 1969 when severe damage resulted in Soldotna (Post and Mayo, 1971). Precursors to outburst releases are (1) high lake water levels, (2) abundant calving into the lake, and (3) water present on northern margins of the glacier, including small marginal lakes (unpublished data, National Weather Service, October 1995).

The least frequent cause of flooding in the Cook Inlet area is excessive rainfall, which results from unusual combinations of extreme meteorological conditions. Recent heavy flooding in September 1995 resulted from (1) interaction of tropical moisture and a deep low pressure center in the north Pacific Ocean, (2) blockage of the eastward movement of this low by a high-pressure ridge in eastern Alaska and western Canada, (3) saturated soil conditions, and (4) greater than normal glacial melt due to preceding storms. To exacerbate the severity of flooding, excess sediment deposition in channels due to rapid runoff decreased the carrying capacity of the streams. As a result, the lower Kenai River remained above flood stage for over 10 days. Crest water levels were 1.1 m above flood stage at Kenai Keys and 0.76 m above flood stage at Soldotna (unpublished data, National Weather Service, October 1995). Preliminary analysis of this flood indicates that it represents a 100-year event downstream from Skilak Lake (J.M. Dorava, U.S. Geological Survey, personal communication, 1995).

In addition to hazards caused by high water levels, the primary hazards to facilities from river flooding are bank erosion, deposition at the river mouth, high bedload transport, and channel modification.

CONCLUSIONS

Development in the proposed Lease Sale 85A area will be subject to potentially severe geologic hazards, including earthquake shaking, earthquake-induced ground failure, volcanigenic floods and ashfall, severe winter ice conditions, and nonvolcanigenic river floods. All structures should be built to exceed minimum requirements of the Uniform Building code for seismic zone 4. Additional precautions should be taken to identify and accomodate site-specific conditions such as unstable ground, flooding, and other localized hazards. Proper siting and engineering will minimize the detrimental effects of these natural processes.

ACKNOWLEDGMENTS

We thank Larry Rundquist of the National Weather Service River Forecast Center in Anchorage for providing meterological and river-stage data for the September 1995 Kenai River flood and October 1995 Skilak glacier dammed lake outburst. DeAnne Pinney kindly reviewed this report.

REFERENCES CITED

Algermissen, S.T., Perkins, D.M., Thenhaus, P.C., Hanson, S.L., and Bender, B.L., 1991, Probabilistic earthquake acceleration and velocity maps for the United States and Puerto Rico: U.S. Geological Survey Miscellaneous Field Studies Map 2120, scales 1:7,500,000 and 1:17,000,000, 2 sheets.

Barnes, F.F., and Cobb, E.H., 1959, Geology and coal resources of the Homer district, Kenai coalfield, Alaska: U.S. Geological Survey Bulletin 1058-F, p. 217-260, various scales, 12 sheets.

Begét, J.E., and Kienle, Juergen, 1992, Cyclic formation of debris avalanches at Mount St. Augustine volcano: Nature, v. 356, no. 6371, p. 701-704.

Begét, J.E., and Nye, C.J., 1994, Postglacial eruption history of Redoubt Volcano, Alaska: Journal of Volcanology and Geothermal Research, v. 62, no. 1-4, p. 31-54.

Begét, J.E., Stihler, S.D., and Stone, D.B., 1994, A 500-year-long record of tephra falls from Redoubt Volcano and other volcanoes in upper Cook Inlet, Alaska: Journal of Volcanology and Geothermal Research, v. 62, nos. 1-4, p. 56-67.

Brantley, S.R., 1990, The eruption of Redoubt Volcano, Alaska, December 4, 1989-August 31, 1990: U.S. Geological Survey Circular 1061, 33 p.

Combellick, 1993, The penultimate great earthquake in southcentral Alaska: Evidence from a buried forest near Girdwood, *in* Solie, D.N., and Tannian, Fran, eds., Short Notes on Alaskan Geology 1993: Alaska Division of Geological & Geophysical Surveys Professional Report 113, p. 7-15.

Combellick, 1994, Investigation of peat stratigraphy in tidal marshes along Cook Inlet, Alaska, to determine the frequency of 1964-style great earthquakes in the Anchorage region: Alaska Division of Geological & Geophysical Surveys Report of Investigations 94-7, 24 p.

Combellick, 1995, Coarse clastic dikes resulting from liquefaction at moderate epicentral distance during the 1964 great Alaska earthquake (abs.): Geological Society of America Abstracts with Programs, v. 27, no. 5, p. 11.

Dorava, J.M, and Meyer, D.F., 1994, Hydrologic hazards in the lower Drift River basin associated with the 1989-1990 eruptions of Redoubt Volcano, Alaska: Journal of Volcanology and Geothermal Research, v. 62, p. 387-407.

Evans, C.D., Buck, Eugene, Buffler, Richard, Fisk, Greg, Forbes, Robert, and Parker, Walter, 1972, The Cook Inlet environment, a background study of available knowledge: Anchorage, U.S. Army Corps of Engineers, 137 p.

Foster, H.L., and Karlstrom, T.N.V., 1967, Ground breakage and associated effects in the Cook Inlet area, Alaska, resulting from the March 27, 1964, earthquake: U.S. Geological Survey Professional Paper 543-F, 28 p., scales 1:24,850, 1:63,360, 1:250,000, and 1:1,000,000, 3 sheets.

Hackett, S.W., 1977, Gravity survey of Beluga Basin and adjacent area, Cook Inlet region, south-central Alaska: Alaska Division of Geological & Geophysical Surveys Geologic Report 49, 26 p., scale 1:375,000, 3 sheets.

Haeussler, P.J., and Bruhn, R.L., 1995, Is there significant earthquake hazard in the upper Cook Inlet basin, Alaska? (abs.): Geological Society of America Abstracts with Programs, v. 27, no. 5, p. 23.

Hayes, M.O., Brown, P.J., and Michel, Jacqueline, 1976, Coastal morphology and sedimentation, lower Cook Inlet, Alaska, with emphasis on potential oil spill impacts: Columbia, University of South Carolina Department of Geology Technical Report 12-CRD, 107 p.

Hayes, M.O., and Michel, Jacqueline, 1982, Shoreline sedimentation within a forearc embayment, lower Cook Inlet, Alaska: Journal of Sedimentary Petrology, v. 52, no. 1, p. 251-263.

Housner, G.W., and Jennings, P.C., 1973, Reconstituted earthquake ground motion at Anchorage in the great Alaska earthquake of 1964, *in* The Great Alaska Earthquake of 1964–Engineering: National Academy of Sciences Publication 1606.

Kelley, J.S., 1985, Geologic setting of the Kenai Peninsula and Cook Inlet Tertiary basin, south-central Alaska, *in* Sisson, Alexander, ed., Guide to the geology of the Kenai Peninsula, Alaska: Anchorage, Alaska Geological Society, p. 3-19.

Kirschner, C.E., and Lyon, C.A., 1973, Stratigraphic and tectonic development of the Cook Inlet petroleum province, *in* Pitcher, M.G., ed., Arctic geology: American Association of Petroleum Geologists Memoir 19, p. 396-407.

Lahr, J.C., Page, R.A., Stephens, C.D., and Fogleman, K.A., 1986, Sutton, Alaska, earthquake of 1984: Evidence for activity on the Talkeetna segment of the Castle Mountain fault system: Bulletin of the Seismological Society of America, v. 76, no. 4, p. 967-983.

Magoon, L.B., Adkison, W.L., and Egbert, R.M., 1976, Map showing geology, wildcat wells, Tertiary plant fossil localities, K-Ar dates, and petroleum operations, Cook Inlet area, Alaska: U.S. Geological Survey Miscellaneous Investigations Map I-1019, scale 1:250,000, 3 sheets.

Minerals Management Service, 1995, Cook Inlet planning area oil and gas lease sale 149–Draft environmental impact statement, volume 1: U.S. Department of the Interior report MMS 94-0066.

National Oceanic and Atmospheric Administration, 1977, United States coastal pilot 9: Pacific and Arctic Coasts, Alaska, Cape Spencer to Beaufort Sea: Washington, D.C., 8th edition, 349 p.

Post, Austin, and Mayo, L.R., 1971, Glacier dammed lakes and outburst floods in Alaska: U.S. Geological Survey Hydrologic Investigations Atlas HA-455, 10 p., scale 1:1,000,000, 3 sheets.

Rappeport, M.L., 1981, Studies of tidally dominated shallow marine bedforms, lower Cook trough, Cook Inlet, Alaska: Stanford University unpublished Ph.D. thesis.

Riehle, J.R., 1985, A reconnaissance of the major Holocene tephra deposits in the upper Cook Inlet region, Alaska: Journal of Volcanology and Geothermal Research, v. 26, p. 37-74.

Riehle, J.R., Kienle, Juergen, and Emmel, K.S., 1981, Lahars in Crescent River valley, lower Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Geologic Report 53, 10 p.

Schmoll, H.R., Chleborad, A.F., Yehle, L.A., and Gardner, C.A., 1981, Reconnaissance engineering geology of the Beluga coal resource area, southcentral Alaska, *in* Rao, P.D., and Wolff, E.N., eds., Focus on Alaska's coal '80: Fairbanks, University of Alaska Mineral Industries Research Laboratory Report 50, p. 92-110.

Schmoll, H.R., Yehle, L.A., Gardner, C.A., and Odum, J.K., 1984, Guide to surficial geology and glacial stratigraphy in the upper Cook Inlet basin: Anchorage, Alaska Geological Society guidebook, 89 p.

Schmoll, H.R., and Yehle, L.A., 1987, Surficial geologic map of the northwestern quarter of the Tyonek A-4 Quadrangle, south-central Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1934, scale 1:31,680, 1 sheet.

Sharma, G.D., and Burrell, D.C., 1970, Sedimentary environment and sediments of Cook Inlet, Alaska: American Association of Petroleum Geologists Bulletin, v. 54, no. 4, p. 647-654.

Stanley, K.W., 1968, Effects of the Alaska earthquake of March 27, 1964, on shore processes and beach morphology: U.S. Geological Survey Professional Paper 543-J, 21 p.

Stihler, S.D., 1991, Paleomagnetic investigation of seismic and volcanic activity recorded in the sediments of Skilak Lake: Fairbanks, University of Alaska unpublished MS thesis, 197 p.

Stihler, S.D., Stone, D.B., and Begét, J.E., 1992, "Varve" counting vs. tephrochronology and ^{137}Cs and ^{210}Pb dating: A comparative test at Skilak Lake, Alaska: Geology, v. 20, no. 11, p. 1019-1022.

Sturm, Matthew, and Benson, C.S., 1988, Jökulhlaups from Strandline Lake, Alaska, with special attention to the 1982 event: Alaska Division of Geological & Geophysical Surveys Report of Investigations 88-10, 19 p.

Tysdal, R.G., 1976, A preliminary evaluation of selected earthquake-related geologic hazards in the Kenai Lowland, Alaska: U.S. Geological Survey Open-File Report 76-270, 30 p.

Waller, R.M., 1966, Effects of the earthquake of March 27, 1964, in the Homer area, Alaska: U.S. Geological Survey Professional Paper 542-D, 28 p., scale 1:2,400, 1 sheet.

Waythomas, Chris, 1995. Search for volcanogenic tsunami deposits along the lower Cook Inlet coastline: Alaska Volcano Observatory Bimonthly Report, v. 7, no. 4, p. 15. *Quoted with permission of the Alaska Volcano Observatory Scientist-in-Charge.*

Wood, C.A., and Kienle, Jürgen, 1990, Volcanoes of North America: Cambridge, Cambridge University Press, 347 p.