STATE OF ALASKA

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

Tony Knowles, *Governor*

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GEOLOGIC HAZARDS IN THE YAKATAGA PLANNING AREA, SOUTHEASTERN ALASKA: AN OVERVIEW

By
R.A. Combellick and R.J. Motyka

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by
R.A. Combellick[1] and R.J. Motyka[1]

INTRODUCTION

The Yakataga planning area encompasses the uplands, tidelands, and submerged state lands between Cape Suckling and the northwestern boundary of Glacier Bay National Park (near Dry Bay) (fig. 1). Natural processes in this area will impose severe constraints on commercial and private development. Primary hazards within the planning area include high earthquake potential associated with the Yakataga seismic gap; active faulting; tsunamis; ground instability (both onshore and offshore) associated with high influx of glacially derived sediment; coastal erosion, glacier outburst and related flooding; snow avalanches near steep terrain; severe storms; and possible large icebergs.

This report provides a brief summary of available information related to these hazards and is a modification of Combellick (1993), which was prepared for proposed State of Alaska Oil and Gas Lease Sale 79 (Cape Yakataga). Geologic maps by Kachadoorian (1959), Plafker (1967), and Miller (1971) show the distribution of bedrock and surficial deposits and faults, but do not identify all active faults.

EARTHQUAKES

In the region surrounding the planning area over 100 earthquakes of magnitude >5.0 were recorded between 1899 and 1993 (fig. 2). These include two 1899 magnitude > 8.0 earthquakes near Icy Bay and Yakutat Bay, a magnitude 7.5 event near Mount St. Elias in 1979, and a magnitude 7.9 earthquake centered near Lituya Bay along the Fairweather Fault in 1958. Three additional earthquakes of magnitude 7.0 or greater occurred about 100 km offshore of the planning area and are associated with a transitional fault zone. The 1899 events resulted in as much as 15 m (50 ft) of uplift near Yakutat Bay and triggered large avalanches in the mountains between Icy Bay and Kayak Island (Tarr and Martin, 1912). No great earthquakes (magnitude 7.8 or greater) have occurred in this zone since 1899. Recent earthquake activity has centered around three zones: near the intersection of the Fairweather and Chugach-St. Elias faults, in an offshore area south of Cape Yakataga known as the Pamplona fracture zone (fig. 2), and in northern Glacier Bay (Horner, 1990). Most seismicity in the area is shallow (less than 30 km or 20 mi).

EARTHQUAKE PROBABILITY

The Yakataga planning area lies within the Yakataga seismic gap (YSG), which extends from Icy Bay to Kayak Island along the boundary between the Pacific and North American plates (McCann and others, 1980; Pérez and Jacob, 1980). The YSG is a complex transition zone between right-lateral strike-slip motion along the Queen Charlotte-Fairweather fault zone to the east and underthrust motion along the Alaska-Aleutian trench to the west (McCann and others, 1980). This zone is regarded as a seismic gap because of the length of time that has elapsed since it last ruptured in two great earthquakes in 1899. A magnitude 7.7 earthquake near Mount St. Elias in 1979 ruptured only a small part of the gap.

Plate motion in the region is accommodated not on a single crustal break but along three primary zones: (1) strike-slip faulting along the northwest-trending Fairweather fault, (2) thrust faulting along the east-west Chugach-St. Elias fault and related faults, which bisect the Chugach and Robinson Mountains, and (3) thrust faulting along the offshore Pamplona fracture zone south of Cape Yakataga.

Because of the tectonic complexity of this region, hazard estimates using the seismic-gap hypothesis may be less reliable than those for other zones along major plate boundaries (Nishenko and Jacob, 1990). Nevertheless, the YSG, along with two other segments of the Alaska-Aleutian seismic zone, has not ruptured in the last 50 yr; Lahr and others (1985) regard these seismic gaps as the most probable locations for the next great earthquake in Alaska. Nishenko and Jacob (1990) have estimated a probability of 67 percent during the next 15 yr for recurrence of the 1899 magnitude 8.2 event and 5 percent for recurrence of larger events within the YSG. Because of the recent (1958) magnitude 7.9 earthquake along the Fairweather fault to the east, the probability for recurrence of a magnitude 7.9 event along this fault in the next 15 yr is negligible. Although the reliability of these probability estimates may be poor—they are based on limited historical recurrence

[1]Alaska Division of Geological & Geophysical Surveys, 794 University Ave., Suite 200 Fairbanks, AK 99709-3645.

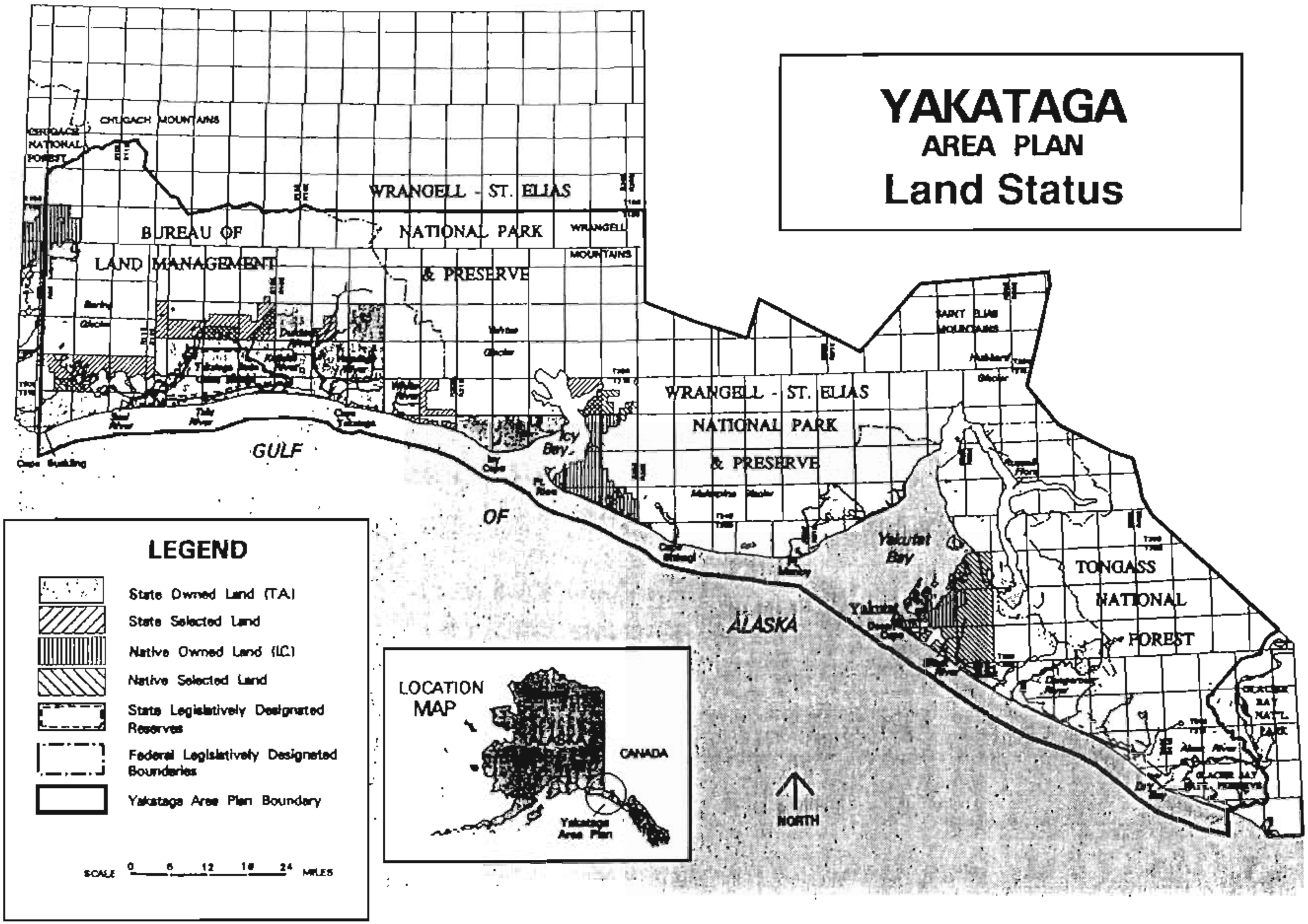

Figure 1. *Yakataga planning area.*

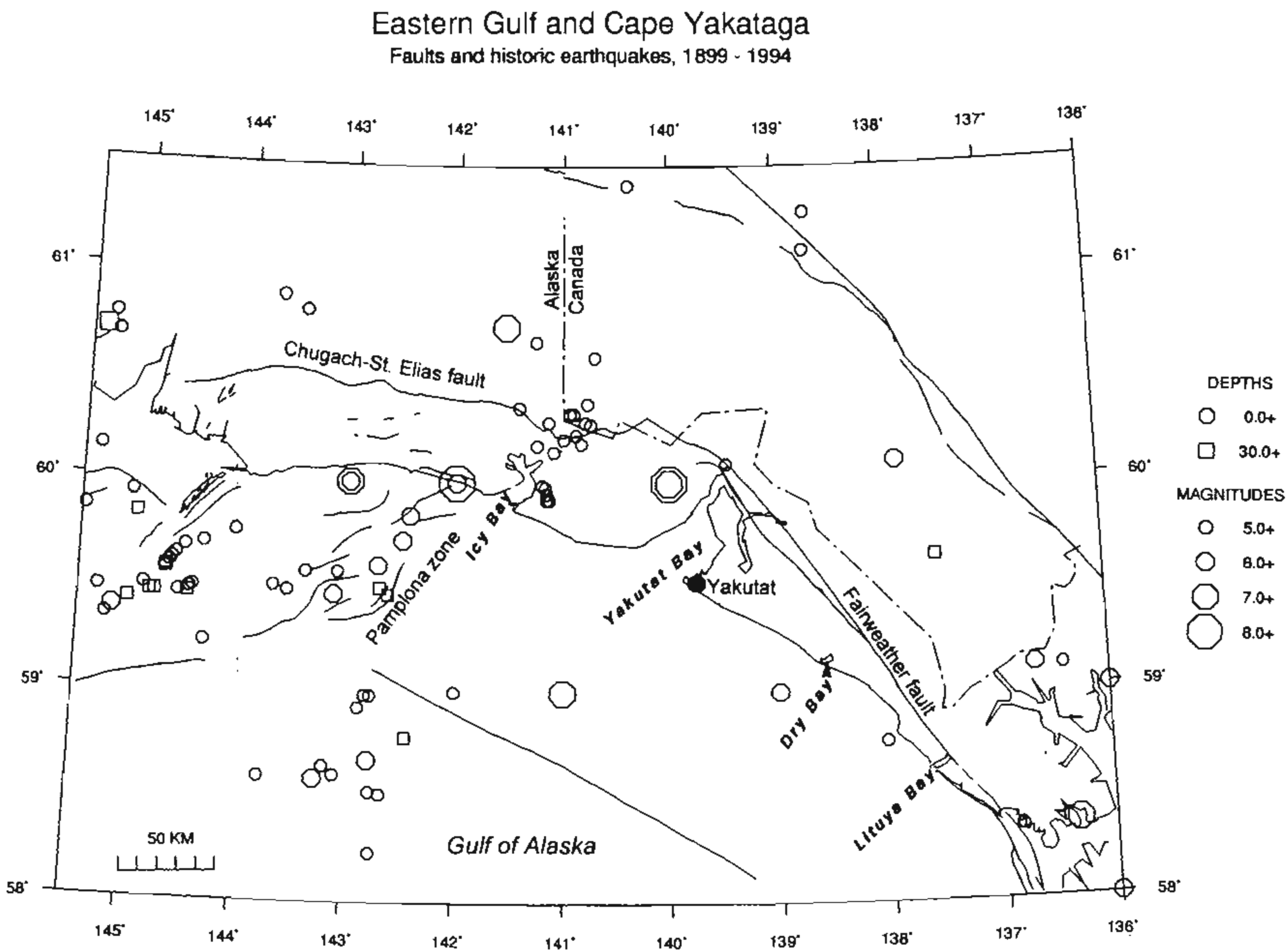

Figure 2. *Epicenters of earthquakes with magnitudes >5.0 in the area 58-61.5N, 136-145.5W, 1899-1993 (Alaska Earthquake Information Center, 4/26/94).*

data and, therefore, poorly constrained—these estimates give a rough idea of the likelihood of major earthquakes occurring near the Yakataga planning area in the near future.

Geologic study of elevated terraces in the YSG indicates a recurrence interval of 500-1,400 yr for major uplift events during the past 5,000 yr (Plafker, 1990). The events recorded by the terraces probably represent very large great earthquakes such as the 1964 magnitude 9.2 event near Prince William Sound. The recurrence interval for 'smaller' great earthquakes (magnitude 8-8.5) is probably much shorter. The recurrence interval for magnitude 7.9 or larger earthquakes on the plate boundary along the coast of southeast Alaska, based on historical data, is estimated to be about 120 yr (Horner, 1983; 1990). Earthquakes of magnitude 6 or greater would be expected about every 5 yr. For the Fairweather fault, Lisowski and others (1987) calculate a recurrence interval for a magnitude 7.9 earthquake of 67 to 85 yr from measured deformation rates and an average coseismic slip of 3.5 m (11.5 ft).

EARTHQUAKE EFFECTS

Thenhaus and others (1985) estimate a 10 percent probability of exceeding 0.63 g earthquake-generated horizontal acceleration in rock during a 50-yr period in this area. (For comparison, Woodward-Clyde Consultants (1987) estimated 0.15-0.20 g ground acceleration in Anchorage during the great 1964 earthquake.) Accelerations in areas underlain by soft sediments are likely to be higher than in bedrock areas because of amplification. Thenhaus and his colleagues point out that their estimate was a result of analyses completed in 1978, before the tectonic models of Pérez and Jacob (1980) and McCann and others (1980) were published.

Because of high sediment influx from glacial meltwater streams, most coastal and offshore areas are underlain by thick deposits of unconsolidated sediment (Miller, 1971; Carlson and others, 1975, 1977; Carlson and others, 1977; Carlson, 1978) (fig. 3). These loose deposits may amplify earthquake shaking and are susceptible to earthquake-induced failure (Seed and Idriss, 1982). West of Kayak Island, large volumes of sediment are also supplied to the continental shelf by the Copper River. Onshore, ground cracking and lateral spreading in glaciofluvial deposits, former beach ridges, and other unconsolidated deposits extended from Controller Bay to the Cape Yakataga area as a result of the 1964 magnitude 9.2 earthquake, centered nearly 330 km (200 mi) to the east (Plafker and others, 1969).

Maximum surface displacement caused by the 1958 Fairweather earthquake (magnitude 7.9) was measured near Lituya Bay south of the Yakataga planning area. The southwest side of the fault moved about 6.5 m (21.3 ft) laterally northwest and about 1 m (3.3 ft) vertically relative to the northeast side (Tocher, 1960). Fault displacement was observed from Palma Bay to Nunatak Fjord. The earthquake triggered an enormous rock avalanche into Lituya Bay and generated a wave that reached elevations of 530 m (1740 ft) on the opposite shore (Miller, 1960). The strongest ground shaking was on the coastal lowland, southeast of Yakutat, where part of an island subsided about 30 m (100 ft), resulting in three deaths (Davis and Sanders, 1960). Other effects included the damming of the Alsek River by accelerated ice calving from the Alsek Glacier and subsequent flooding a few hours later. Similar effects can be expected from future earthquakes.

Despite the tectonic complexity and uncertainty about earthquake probabilities and accelerations in the Cape Yakataga region, the area is generally recognized as having a higher likelihood for a great earthquake in the next few decades than most other areas along active plate boundaries. All future structures there should be designed to meet or exceed the Uniform Building Code requirements for seismic zone 4 (highest earthquake hazard). Builders should take special precautions to prevent damage from higher accelerations and earthquake-induced ground failure in areas underlain by thick, soft sediments.

SEAFLOOR HAZARDS

Detailed shipboard seismic profiling in the 1970s revealed numerous areas of unstable sediment on the continental shelf in northern Gulf of Alaska (Carlson and Molnia, 1977) (fig. 3). Large submarine slides south of Icy Bay and west of Kayak Island were probably triggered by earthquakes. Surface or near-surface faults were also identified in several areas, including the Pamplona fracture zone south of Cape Yakataga and a zone parallel to the southeastern shore of Kayak Island. The ongoing activity of these faults is demonstrated by recent seismicity (fig. 2).

In addition to the earthquake hazards described above, man-made structures on or near active surface faults may be subject to extreme ground accelerations, catastrophic ground failure, or direct displacement due to fault offset at the ground surface. Although these seafloor faults and slides were mapped largely in the federal Outer Continental Shelf (OCS) area, similar instability and active faulting probably extends shoreward into state-owned waters. The most effective means of reducing hazards to offshore structures due to seafloor instability or active faulting is by careful mapping and avoidance of these features.

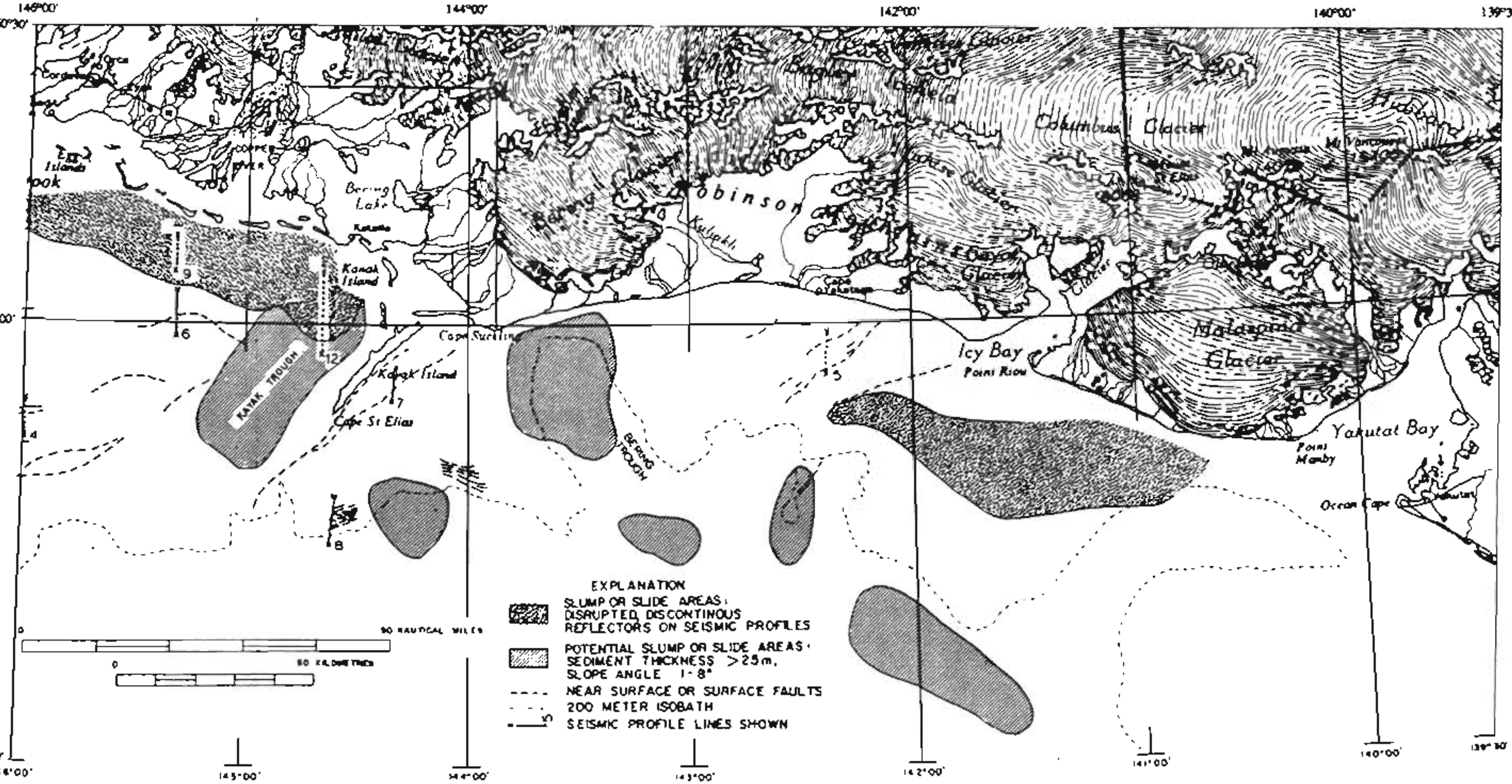

Figure 3. *Submarine slides and near-surface faults in the northern Gulf of Alaska (modified from Carlson and Molnia, 1977).*

TSUNAMIS

Because of the high likelihood of a local great earthquake and exposure of the northern Gulf of Alaska coast to nearly the entire Pacific Ocean, tsunami hazard in the Yakataga planning area is high. A tsunami, or seismic sea wave, generated by a local earthquake could be very severe and allow very little warning. Large and sudden offshore submarine landslides could also generate destructive tsunamis without warning. A tsunami generated by a distant source would allow public officials more time to warn inhabitants and evacuate coastal lowlands, but the physical effects could be equally severe. The primary hazards from tsunamis are personal injury and inundation of structures in coastal lowlands and shallow offshore areas, particularly if the tsunami occurs at high tide.

The Gulf of Alaska coast east of Prince William Sound was not seriously affected by a tsunami as a result of the 1964 great earthquake. Erratic tides, swift currents, and surges of 0.3-1 m (1-3 ft) were observed at Cape Yakataga and Yakutat, but none exceeded normal extreme high tide (Plafker and others, 1969). However, future large earthquakes involving offshore fault displacement or major tilting of the seafloor in the Gulf of Alaska could generate a tsunami that would be very destructive to coastal facilities.

VOLCANIC ERUPTIONS

Although the Yakataga planning area is more than 320 km (200 mi) east of the active Cook Inlet and Aleutian volcanoes and 160 km (100 mi) south of the Wrangell volcanic center, eruptions of these volcanoes can result in ash fallout in the area. A tephra plume from the August 18, 1992, eruption of Mt. Spurr, 120 km (75 mi) west of Anchorage, blew east over the Chugach Mountains, followed the northern Gulf of Alaska coast over the Cape Yakataga area, and caused significant ash fall at Yakutat (Alaska Volcano Observatory, 1993). An eruption about 1,500 yr ago in the Wrangell-St. Elias Mountains resulted in a widespread ash deposit (White River ash) covering an area of at least 300,000 sq km (125,000 sq mi) in southern Yukon Territory and eastern Alaska (Lerbekmo and Campbell, 1969). Such ash falls can be a serious hazard to aircraft, vehicles, and machinery.

GLACIER-RELATED HAZARDS

Small icebergs from Bering Glacier now pose a hazard to coastal small boat traffic in the Gulf of Alaska. Since a major surge ended in 1967, Bering Glacier has been retreating rapidly, releasing giant icebergs into Vitus Lake. The icebergs, some as long as 500 m (1,600 ft), are trapped in the lake by the shallow outlet at Seal River. If the narrow barrier beach holding in the icebergs erodes further or is breached by storm waves or a tsunami, Vitus Lake would become a fjord open to the sea, and the dammed-in icebergs would be released to the Pacific Ocean.

A major surge of Bering Glacier began in 1993 and resulted in a major but temporary advance of the terminus (Molnia, 1993, 1994). The surge did not extend far enough to affect coastal facilities, but renewed terminal retreat following the surge could be accompanied by a higher than usual rate of calving, which would increase the iceberg hazard if the Seal River outlet to the Gulf of Alaska is breached. Elsewhere, glacier surges can temporarily block streams and fjords causing outburst and related flooding (next section).

The Guyot, Yahtse, and Tyndall Glaciers all presently calve icebergs directly into Icy Bay. These icebergs pose a hazard to boat traffic within the bay, particularly near the calving termini; some occasionally stray into the Gulf of Alaska and present a hazard to coastal small boat traffic.

Hubbard Glacier is an advancing tidewater glacier that lies at the head of Disenchantment Bay. Icebergs from the calving front commonly choke the upper part of the bay, and present an extreme hazard to boat traffic, particularly near Osier Island and at the mouth of Russell Fjord, where tidal currents are exceptionally swift.

Areas that have been recently deglaciated are susceptible to ground subsidence due to melting of buried ice blocks. These areas include the forelands of Bering Glacier and glaciers in Icy Bay (Boothroyd and Cable, 1976). Glacial deltas should also be avoided because of the potential for delta-front slumping and slope failure.

OUTBURST AND RELATED FLOODING

Onshore facilities near streams that drain some glaciers in or near the planning area may be at risk from glacial-outburst flooding. Bering, Yakataga, and White River Glaciers all impound lakes with the potential of draining catastrophically if the physical character of the impounding glaciers changes (Post and Mayo, 1971). Berg Lake, which is impounded by the Stellar lobe of Bering Glacier, presents an extreme hazard on the Bering River lowland. Other streams with outburst potential are Campbell River, Seal River, White River, and all channels of Yakataga River. Outburst floods have not been documented on these streams, so their frequency and severity are unknown; these potential flood areas should be avoided where practical. Any structures placed along these rivers should be engineered to withstand stream erosion, deposition, and severe flooding. New Yahtse, Caetani, and Kettlehold deltas in Icy Bay are also subject to outburst flooding from the west margin of Malaspina Glacier and therefore unsuitable for shore facilities (Boothroyd and Cable, 1976).

Hubbard Glacier has advanced intermittently since mapped in 1895 and has dammed Russell Fjord as recently as 1986 (Trabant and others, 1990). Lake level in Russell Fjord reached 25 m (87 ft) above sea level before the ice dam failed catastrophically on October 7, 1986. The Hubbard Glacier has begun readvancing and the U.S. Geological Survey has forecasted that the glacier will probably again dam Russell Fjord within 10 yr (Trabant and others, 1990). If the blockage holds, Russell Fjord will be filled by fresh water until it reaches 40 m (130 ft) above sea level and overflows into the Situk River. Following this period of dams and failures, the glacier blockage of Russell Fjord is expected to be stable for centuries and increase the average flow of the Situk River tenfold (Trabant and others, 1990). Any future activities planned for the Situk drainage area should take this eventuality into account.

Three glaciers can potentially dam the Alsek River: Tweedsmuir, Lowell, and Konamoxt, all in British Columbia (Post and Mayo, 1971). Extremely hazardous Lake Alsek will re-form only if Lowell Glacier surges strongly. Hazardous lakes may form if Tweedsmuir Glacier surges moderately. The most recent lake is estimated to have formed around 1945. Outbursts from a large lake dammed by Konamoxt Glacier pose a moderate flood hazard on the Alsek River flood plain.

COASTAL MORPHOLOGY

The conclusions of Hayes and Ruby (1977) on the coastal morphology of the Northern Gulf of Alaska directly apply to shoreline development in the Yakataga planning area. The entire planning area is subject to severe storm-generated waves and surges wherever the shoreline faces the open gulf. The only protected areas are Icy Bay and Yakutat Bay. Therefore, any development of these exposed shorelines will necessitate reasonable setback distances with special attention to storm-surge flooding.

The spits in the planning area show dramatic historical changes, both erosional and depositional. Spit breaches by confined rivers behind them are common and unpredictable. Many of the spits are completely overwashed during storms and subject to storm surge flood or storm surge ebb breaching.

Erosion at the mouth of Icy Bay and downdrift (west) to Cape Yakataga is extreme (37 m/yr or 121 ft/yr maximum at Point Riou). Permanent structures in this area should be avoided. The shoreline immediately downdrift (west) of Cape Yakataga is relatively stable because of the protection and sheltering of the cape to southeast storm waves.

The inner eastern shoreline of Yakutat Bay has the most stable beaches in the planning area. These shorelines are well protected from storm waves approaching from directions other than southwest. They are generally composed of mature well-sorted gravels. The inner eastern shoreline of Icy Bay is also protected from storm waves from directions other than southwest. Its beaches are less mature with considerably more sand. The bay has a number of outwash streams depositing fan deltas, which modify the shoreline and fill in the bay. Sediment transported along Riou Spit also poses infilling problems for adjacent downdrift shorelines.

The Yakutat Foreland beaches are mildly erosional but, given adequate setback distances, may be a favorable location for development. However, this would also depend on suitability of adjacent surficial deposits, which should be determined before construction. Western shorelines of both Icy Bay and Yakutat Bay are subject to relatively high wave energies and should be avoided.

LANDSLIDES AND SNOW AVALANCHES

Steep terrain in the eastern part of the Yakataga planning area (east of Kaliakh River) presents potentially serious hazards because of slope instability, particularly debris slides, debris avalanches, and snow avalanches. High relief combined with heavy, wet snowfall, cold temperatures, and erratic strong winds in this area create conditions favorable for major snow-avalanche activity (Hackett and Santeford, 1980). Earthquakes can trigger large slope failures and snow avalanches, as they did in the mountains west of Icy Bay during the 1899 events (Tarr and Martin, 1912). However, these hazards are highly localized and can be avoided by careful evaluation and avoidance of susceptible slopes.

SEVERE STORMS

Low-pressure systems that develop in the northwestern Pacific Ocean typically track eastward into the Gulf of Alaska, causing strong southerly or southeasterly winds along the northern gulf coast. Streamflooding commonly occurs during periods of heavy precipitation associated with the storm systems. Pressure gradients are strengthened by the damming of air masses along the mountain barrier, resulting in even stronger inland winds. Venturi effects in mountain passes cause these winds to be erratic and locally intense near rough terrain. Average annual wind speed is 19 km/h (12 mph) at Middleton Island and 13 km/h (8 mph) at Yakutat, with maximums reaching 109 km/h (68 mph) and 120 km/h (75 mph), respectively, during the winter months (Searby, 1969). Sustained gusts up to 175 km/h (109 mph) have been recorded at Middleton Island, southwest of the proposed lease area (U.S. Dept. of Commerce, 1953). In addition to adverse loading effects of these strong winds, a secondary hazard to offshore or coastal installations is structural icing caused by water spray. These weather hazards are significant but can be mitigated with proper engineering.

CONCLUSIONS

Development in the Yakataga planning area will be subject to potentially severe geologic hazards, including earthquake shaking, earthquake-induced ground failure, tsunamis, seafloor instability and faulting, volcanic ash fall, possible large icebergs, glacier surges, outburst and related flooding, coastal erosion, slope instability, and severe storms. All structures should be built to minimum requirements of the Uniform Building Code for seismic zone 4. Additional precautions should be taken to identify and accommodate special conditions such as unstable ground, active faults, flooding, and other localized hazards. Proper siting and engineering will help minimize the detrimental effects of these natural processes.

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REFERENCES CITED

Alaska Volcano Observatory, 1993, Mt. Spurr's 1992 eruptions: EOS, Transactions, American Geophysical Union, v. 74, no. 19, p. 217 and 221-222.

Boothroyd, J.C, and Cable, M.S., 1976, Coastal morphology and sedimentation, gulf coast of Alaska, *in* Environmental assessment of the Alaskan continental shelf, annual reports of principal investigators, July 1, 1975 - April 1976: Boulder, National Ocean and Atmospheric Administration, p. 1-82.

Carlson, P.R., 1978, Holocene slump on continental shelf off Malaspina Glacier, Gulf of Alaska: American Association of Petroleum Geologists Bulletin, v. 62, no. 12, p. 2412-2426.

Carlson, P.R., Bruns, T.R., and Molnia, B.F., 1975, Submarine slides and near-surface faults, northern Gulf of Alaska: U.S. Geological Survey Open-File Report 75-504, scale 1:500,000.

Carlson, P.R., and Molnia, B.F., 1977, Submarine faults and slides on the continental shelf, northern Gulf of Alaska: Marine Geotechnology, v. 2, p. 275-290.

Carlson, P.R., Molnia, B.F., Kittelson, S.C., and Hampson, J.C., Jr., 1977, Map of distribution of bottom sediments on the continental shelf, northern Gulf of Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-876, 2 sheets, scale 1:500,000, 13 p.

Combellick, R.A., 1993, Geologic hazards in and near proposed State of Alaska oil and gas lease sale 79 (Cape Yakatage): Alaska Division of Geological & Geophysical Surveys Public-Data File 93-81, 10 p.

Davis, T.N., and Sanders, N.K., 1960, Alaska earthquake of July 10, 1958: Intensity distribution and field investigation of northern epicentral region: Bulletin of the Seismological Society of America, v. 50, p. 221-252.

Hackett, S.W., and Santeford, H.S., 1980, Avalanche zoning in Alaska, U.S.A: Journal of Glaciology, v. 26, no. 94, p. 377-392.

Hayes, H.O., and Ruby, C.H., 1977, Coastal morphology of the northern Gulf of Alaska, *in* Environmental Assessment of the Alaskan Continental Shelf, Quarterly Reports of Principal Investigators, April-June 1977, Volume II: Boulder, National Ocean and Atmospheric Administration, p. 329-405.

Horner, Robert, 1990, Seismicity in the Glacier Bay region of southeast Alaska and adjacent areas of British Columbia, *in* Milner, A.M. and Wood, J.D., Jr., eds., Proceedings of the Second Glacier Bay Science Symposium: Anchorage, U.S. National Park Service, p. 6-11.

__________1983, Seismicity in the St. Elias region of northwestern Canada and southeastern Alaska: Bulletin of the Seismological Society of America, v. 73, p. 1117-1137.

Kachadoorian, Reuben, 1959, Engineering geology bearing on harbor site selection along the Gulf of Alaska from Point Whitshed to Cape Yakataga, Alaska: U.S. Geological Survey Trace Elements Investigations Report 642, 32 p., 7 sheets, scale 1:63,360.

Lahr, J.C., Stephens, C.D., and Page, R.A., 1985, Regional seismic monitoring in southern Alaska: Application to earthquake hazards assessment, *in* Hays, W.W., and Gori, P.L., eds., A workshop on "Evaluation of Regional and Urban Earthquake Hazards and Risk in Alaska," Proceedings: U.S. Geological Survey Open-File Report 86-79, p. 64-75.

Lerbekmo, J.F., and Campbell, F.A., 1969, Distribution, composition and source of the White River Ash, Yukon Territory: Canadian Journal of Earth Sciences, v. 6, p. 109-116.

Lisowski, M., Savage, J.C., and Burford, R.O., 1987, Strain accumulation across the Fairweather and Totschunda faults, Alaska: Journal of Geophysical Research, v.92, p. 11552-11560.

McCann, W.R., Pérez, O.J., and Sykes, L.R., 1980, Yakataga Gap, Alaska: Seismic history and earthquake potential: Science, v. 207, p. 1309-1314.

Miller, D.J., 1960, The Alaska earthquake of July 10, 1958: Giant wave in Lituya Bay: Bulletin of the Seismological Society of America, v. 50, p. 253-266.

__________1971, Geologic map of the Yakataga district, Gulf of Alaska Tertiary province, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-610, 6 p., scale 1:125,000.

Molnia, B.F., 1993, Major surge of the Bering Glacier: EOS, Transactions, American Geophysical Union, v. 74, no. 29, p. 322.

__________1994, Modern surge of glacier comes to an end: EOS, Transaction, American Geophysical Union, v. 75, no. 47, p. 549.

Nishenko, S.P., and Jacob, K.H., 1990, Seismic potential of the Queen Charlotte-Alaska-Aleutian seismic zone: Journal of Geophysical Research, v. 95, no. B3, p. 2511-2532.

Pérez, O.J., and Jacob, K.H., 1980, Tectonic model and seismic potential of the eastern Gulf of Alaska and Yakataga seismic gap: Journal of Geophysical Research, v. 85, no. B12, p. 7132-7150.

Plafker, George, 1967, Geologic map of the Gulf of Alaska Tertiary Province, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-484, scale 1:500,000.

__________1990, Regional vertical tectonic displacement of shorelines in south-central Alaska during and between great earthquakes [abs.], *in* Environmental disasters: The nature of recovery, Symposium, March 21, 1990, Corvallis, Oregon, Proceedings: Northwest Scientific Association, .

Plafker, George, Kachadoorian, Reuben, Eckel, E.B., and Mayo, L.R., 1969, Effects of the earthquake of March 27, 1964 on various communities: U.S. Geological Survey Professional Paper 542-G, 50 p., 2 sheets, scales 1:2,500,000 and 1:250,000.

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

Searby, H.W., 1969, Coastal weather and marine data summary for the Gulf of Alaska, Cape Spencer westward to Kodiak Island: U.S. Environmental Sciences Services Administration Technical Memorandum 8, 30 p.

Seed, H.B., and Idriss, I.M., 1982, Ground motions and soil liquefaction during earthquakes: Berkeley, Earthquake Engineering Research Institute, 134 p.

Tarr, R.S., and Martin, Lawrence, 1912, The earthquakes at Yakutat Bay, Alaska, in September 1899: U.S. Geological Survey Professional Paper 69, 135 p.

Thenhaus, P.C., Ziony, J.I., Diment, W.H., Hopper, M.G., Perkins, D.M., Hanson, S.L., and Algermissen, S.T., 1985, Probabilistic estimates of maximum seismic horizontal ground acceleration on rock in Alaska and the adjacent continental shelf: Earthquake Spectra, v. 1, no. 2, p. 285-306.

Tocher, D., 1960, The Alaska earthquake of July 10, 1958: Movement on the Fairweather fault and field investigation of southern epicentral region: Bulletin of the Seismological Society of America, v. 50, p. 267-292.

Trabant, D.C., Krimmel, R.M., and Post, Austin, 1990, A preliminary forecast of the advance of Hubbard Glacier and its influence on Russell Fjord, Alaska: U.S. Geological Survey, Water-Resources Investigations Report 90-4172, 34 pp.

U.S. Department of Commerce, 1953, Summary of the climatological data of Alaska—Whittier: Washington, U.S. Weather Bureau.

Woodward-Clyde Consultants, 1987, Geotechnical investigation, Anchorage courthouse addition, Anchorage, Alaska–vol. II, Seismic considerations: Anchorage, Woodward-Clyde Consultants, table 2-1.