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EASTERN GULF OF ALASKA SEISMICITY: ANNUAL REPORT TO THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION FOR APRIL 1, 1979 THROUGH MARCH 31, 1980

By

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ANNUAL REPORT

Title: Earthquake Activity and Ground Shaking
in and along the Eastern Gulf of Alaska

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I. Summary of objectives, conclusions, and implications with respect to OCS oil and gas development.

The objective of this research is to analyze the earthquake activity in the Northeast Gulf of Alaska (NEGOA) and adjacent onshore areas in order to develop a better model for the current tectonic framework. This information is critical to the establishment of criteria for the safe development of oil and gas. A great earthquake ($M > 8$) associated with low-angle oblique underthrusting of the sea floor beneath the continental shelf could be accompanied by strong ground shaking throughout much of the eastern Gulf of Alaska, possibly from Cross Sound to Kayak Island (Page, 1975) and could trigger tsunamis, seiches, and submarine slumping, any of which could be hazardous to offshore and coastal structures (Meyers, 1976).

During the past year particular emphasis has been placed on developing a kinematic model to represent the regional tectonic framework applicable to the NEGOA. This has involved study of the seismic data collected during the past 5 years as well as review of the historic seismic record and geologic constraints. The tectonic model developed, although still tentative, reflects our current state of knowledge.

In the proposed model, the portion of the North American plate bordering the Gulf of Alaska is divided into two sub-blocks, which are partially coupled to the Pacific plate. Based on the model, future earthquakes will be most frequent along the north dipping thrust faults of the Pamplona zone, between Icy Bay and the Aleutian megathrust. Earthquakes should also be expected, although less frequently, on the thrust contact between the Pacific plate and the Yakutat block. This hypothesized thrust boundary underlies the offshore region south of Yakutat at shallow depth and dips gently to the north or northwest.

A rough estimate of the level of seismic activity and the largest expected event has been made for each of the four principal source regions effecting the NEGOA. For example, the return period for events greater than or equal 7.3 on the thrust zone underlying the Yakutat block is estimated to be 180 years. These estimates should be subjected to further review and compared with those derived by other methods before being used in further calculations. The final step in generating parameters useful to design engineers has not been taken. This would involve generating estimates of the probability of a given level of shaking as a function of exposure time and site location.

The level of seismic activity during the past tens of years has been lower than would be expected if the rate of seismicity were constant and given by the return periods calculated. This discrepancy could be interpreted as an indication that a large percentage of the regional plate convergence takes place aseismically. Given the temporal fluctuations in seismicity observed elsewhere in the world, the sequence of magnitude 8 events that occurred at the turn of the century, and the recent magnitude 7.3 (M_S) St. Elias earthquake, we conclude that the recent low level of activity is well below the average to be expected.

II. Introduction

A. General nature and scope of study.

The purpose of this research is to investigate the earthquake potential in the NEGOA and adjacent onshore areas. This will be accomplished by assessing the historical seismic record as well as by collecting new and more detailed information on both the distribution of current seismicity and the nature of strong ground motion resulting from large earthquakes.

B. Specific Objectives.

1. Record the locations and magnitudes of all significant earthquakes within the NEGOA area.
2. Prepare focal mechanism solutions to aid in interpreting the tectonic processes active in the region.
3. Identify both offshore and onshore faults that are capable of generating earthquakes.
4. Assess the nature of strong ground shaking associated with large earthquakes in the NEGOA.
5. Compile and evaluate frequency vs. magnitude relationships for seismic activity within and adjacent to the study areas.
6. Evaluate the observed seismicity in close cooperation with OCSEAP Research Units 16 and 251 towards development of an earthquake prediction capability in the NEGOA.

C. Relevance to problem of petroleum development.

It is crucial that the seismic potential in the NEGOA be carefully analyzed and that the results be incorporated into the plans for future petroleum development. This information should be considered in the selection of tracts for lease sales, in choosing the localities for land-based operations, and in setting minimum design specifications for both coastal and offshore structures.

III. Current state of knowledge

The eastern Gulf of Alaska and the adjacent onshore areas are undergoing compressional deformation caused by north-northwestward migration of the Pacific plate with respect to the North American plate (Figure 1). Direct evidence for continued convergent motion comes from studies of large earthquakes along portions of the Pacific-North American plate boundary adjacent to the eastern Gulf of Alaska.

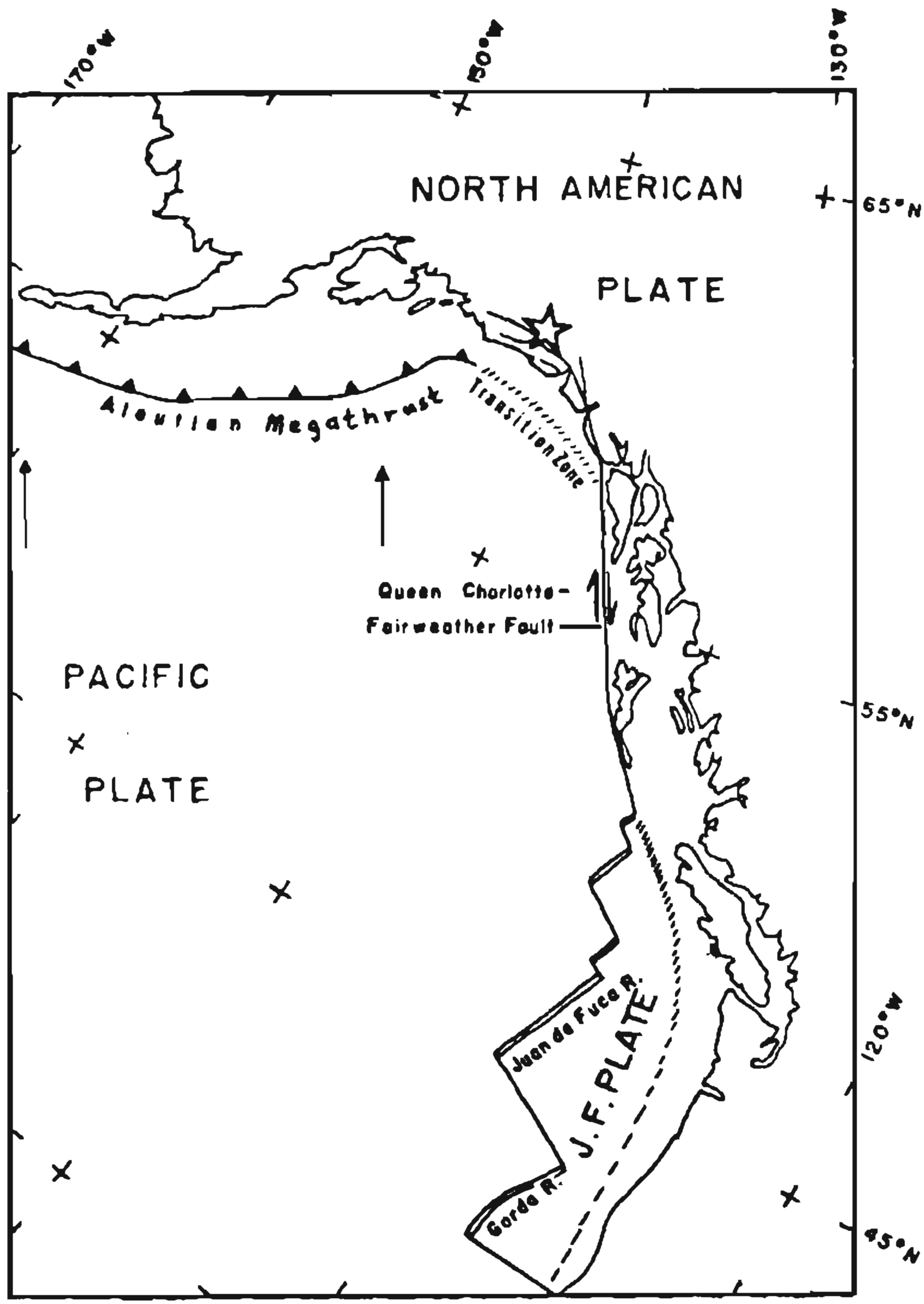

Figure 1. Current motion of Pacific plate with respect to North American plate. Juan de Fuca (J.F.) plate also shown. Star indicates epicenter of the earthquake of 28 February, 1979.

The 1958 earthquake on the Fairweather fault in southeast Alaska was accompanied by right lateral slip of as much as 6.5 m (Tocher, 1960). The 1964 Alaska earthquake resulted from dip slip motion of about 12 m (Hastie and Savage, 1970) on a fault plane dipping northwestward beneath the continent from the Aleutian Trench and extending from eastern Prince William Sound to southern Kodiak Island. In the intervening region between these earthquakes, from approximately Yakutat Bay to Kayak Island, the precise manner in which this convergent motion is accommodated is not known. The model which is presented here for accommodating the regional convergence is based on work in progress by Lahr and Plafker and has been reported on previously (Lahr et al., 1979A).

IV. Study Area.

This project is concerned with the seismicity within and adjacent to the eastern Gulf of Alaska continental shelf area. This is the southern coastal and adjacent continental shelf region of Alaska between Montague Island and Cross Sound.

V. Methods and rationale of data collection.

The short-period seismograph stations installed along the eastern Gulf of Alaska under the Outer Continental Shelf Environmental Assessment Program as well as the other stations operated by the USGS in southern Alaska are shown in Figure 1 of Chapter X. Single-component stations record the vertical component of the ground motion, while three-component stations have instruments to measure north-south and east-west motion as well. Data from these instruments are used to determine the parameters of earthquakes as small as magnitude 1. The parameters of interest are epicenter, depth, magnitude, and focal mechanism. These data are required to further our understanding of the regional tectonics and to identify active faults.

A network of strong motion instruments is also operated. These devices are designed to trigger during large earthquakes and give high-quality records of large ground motions which are necessary for engineering design purposes.

VI., VII. and VIII. Results, Discussion and Conclusions.

The next four sections on kinematic model, plate motions, comparison with observations, and implications for seismic hazards are excerpts from Lahr and Plafker (1980).

PROPOSED KINEMATIC MODEL FOR PACIFIC-NORTH AMERICAN INTERACTION

A working model has been developed for the Holocene Pacific-North American plate interaction along the Gulf of Alaska. In this model deformation within the North American plate is concentrated mainly on the boundaries of two blocks. First, these boundaries will be described, then the motions within the model will be given and finally the model will be compared with the available data on displacement rates. The tectonic setting and major boundaries are illustrated in Fig. 2. The Yakutat block (YB), which has been described by Plafker and others (1978), is bounded by the Transition zone (TZ), the Fairweather fault (F), and the Pamplona zone (PZ) which passes through Icy Bay (I). North and east of the Yakutat block is the Wrangell block (WB). The Wrangell block is bounded on the northeast by the Denali (D), Totschunda (T), Duke River (DR), Dalton (DA), and Chatham Strait (C) faults, and on the south by the Aleutian megathrust (AM), the Pamplona zone (PZ), and the Fairweather fault, including its offshore continuation (F). The northwestern boundary of the Wrangell block is speculative; it is tentatively assumed to diverge southward from the Denali fault, through Cook Inlet (CI), around Kodiak Island (KO) and back to the Aleutian megathrust.

The extent and configuration of the Pacific plate underlying Alaska can be inferred, at least partly, from the distribution of subcrustal earthquakes that make up the Benioff zone. These events occur within the underthrust

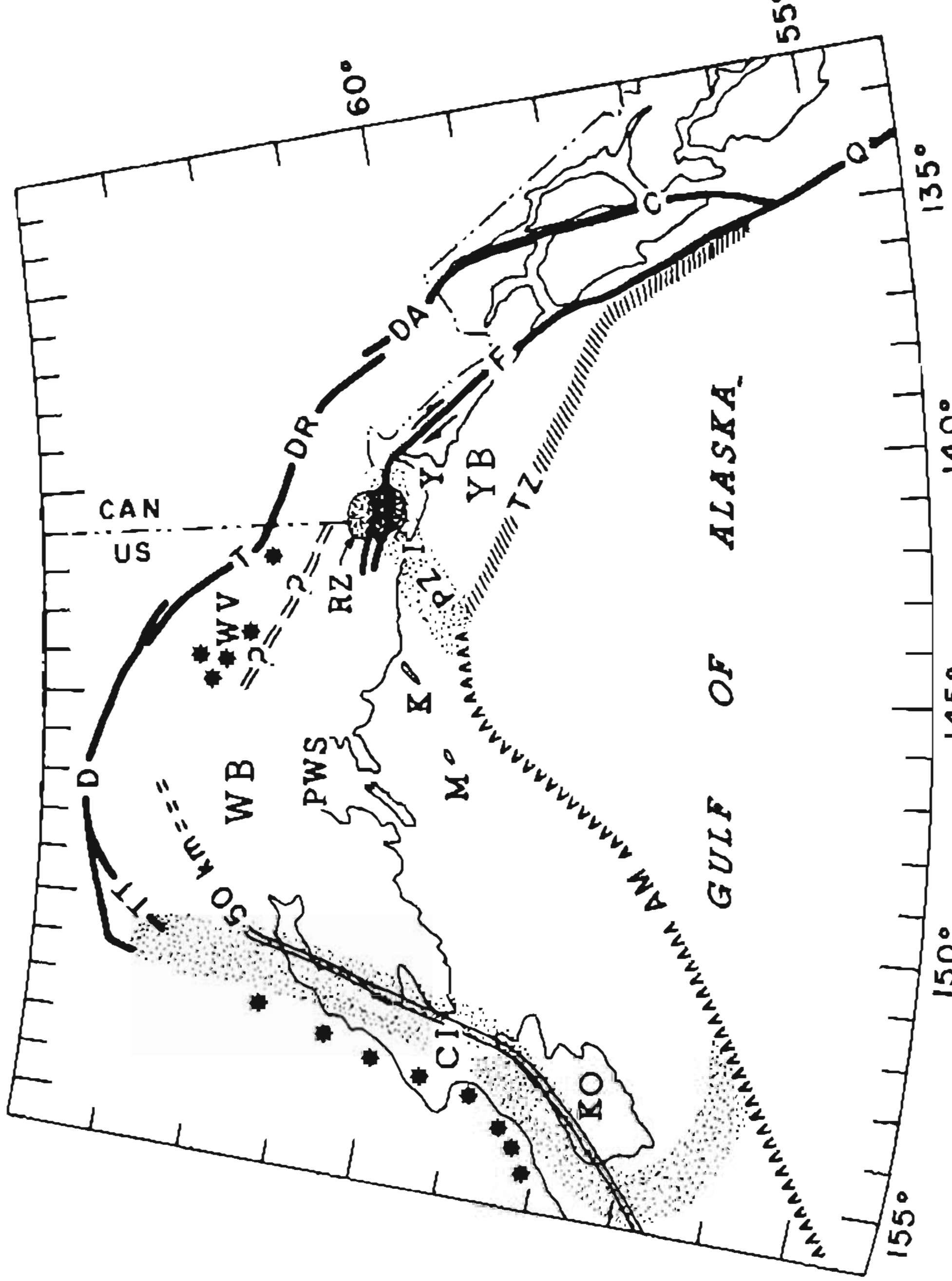

Fig. 2 Map of southern Alaska and western Canada emphasizing the principal regional tectonic features. Faults after (Clague, 1979; Beikman, 1978). KO, Kodiak Island; M, Middleton Island; K, Kayak Island; CI, Cook Inlet; PWS, Prince William Sound; I, Icy Bay; Y, Yakutat Bay; WV, Wrangell volcanics; RZ, rupture zone of 28 February 1979 earthquake; AM, Aleutian megathrust; TZ, Transition zone; Q, Queen Charlotte Islands fault; C, Chatham Strait fault; DA, Dalton fault; DR, Duke River fault; T, Totschunda fault; D, Denali fault; TT, Talkeetna fault; F, Fairweather fault; PZ, Pamplona zone; double line, 50 km isobath of Benioff zone, queried where inferred; WB, Wrangell block; YB, Yakutat Block.

oceanic plate near its upper surface. The 50-km isobath of earthquake foci shown in Fig. 2 northwest of the Aleutian megathrust (AM) represents an active Benioff zone (Lahr, 1975). Further east, however, northwest of the Transition zone (TZ), no earthquakes as deep as 50 km have been observed, and a Benioff zone is not defined here.

The continuity of the Pacific plate below the Gulf of Alaska and the hundreds of kilometers of convergence indicated by the Benioff zone northwest of Prince William Sound imply that a similar amount of convergence has taken place in the zone between Prince William Sound and the Queen Charlotte Islands fault. The queried 50-km isobath in Fig. 2 indicates a plausible position for the underthrust Pacific plate based on two assumptions: the first is that the andesitic Wrangell volcanic rocks (WV), (Deininger, 1972; MacKevett, 1978) are situated approximately above the 100-km isobath of the Benioff zone as is typical for andesitic volcanoes associated with an underthrust plate; the second is that the dip of the plate between 50 and 100 km depth is similar to that observed elsewhere along the Aleutian arc (Davies and House, 1979). The Wrangell volcanoes have not been highly eruptive for about 3 my, however, and may no longer be aligned above the Benioff zone. In any case it seems likely that the Pacific plate extends at shallow depths below much of the Yakutat and Wrangell blocks, a configuration that should be conducive to significant coupling between those blocks and the Pacific plate.

PLATE MOTIONS IN MODEL

Motions in the kinematic model presented in this paper are relative to the stable parts of the North American plate, in particular the interior of Alaska. First the velocities in the preferred model will be given and then they will be compared with the available data on relative rates of motion. The Pacific plate is rotating clockwise about a pole in eastern Canada, and is moving northwestward at 6.5 cm/yr along the Queen Charlotte Islands fault. The velocity increases to the southwest as distance from the pole of rotation increases. The Yakutat block is moving parallel to the Pacific plate but with a slightly lower relative velocity (~6 cm/yr). Motion of the Wrangell block is taken to be counterclockwise rotation about an axis near Kodiak Island, such that its northeastern edge moves in a right-lateral sense relative to the North American plate with a velocity of approximately 1 cm/yr. The relative rates of motion are indicated in Fig. 3.

COMPARISON OF MODEL WITH OBSERVATIONS

This kinematic model is in reasonable agreement with historical seismicity and known rates of relative plate movement, where data are available. Hisyorical large earthquakes along the Queen Charlotte Islands (Q) and the Fairweather (F) faults with dextral strike-slip motion support the viewpoint that these are principal plate boundaries (Tobin and Sykes, 1968; Gawthrop and others, 1973).

The rate of relative motion across the Fairweather fault has probably averaged roughly 5.8 cm/yr in a right-lateral sense for the past thousand years (Plafker and others, 1978), in reasonable agreement with the value of 5 cm/yr predicted by the model.

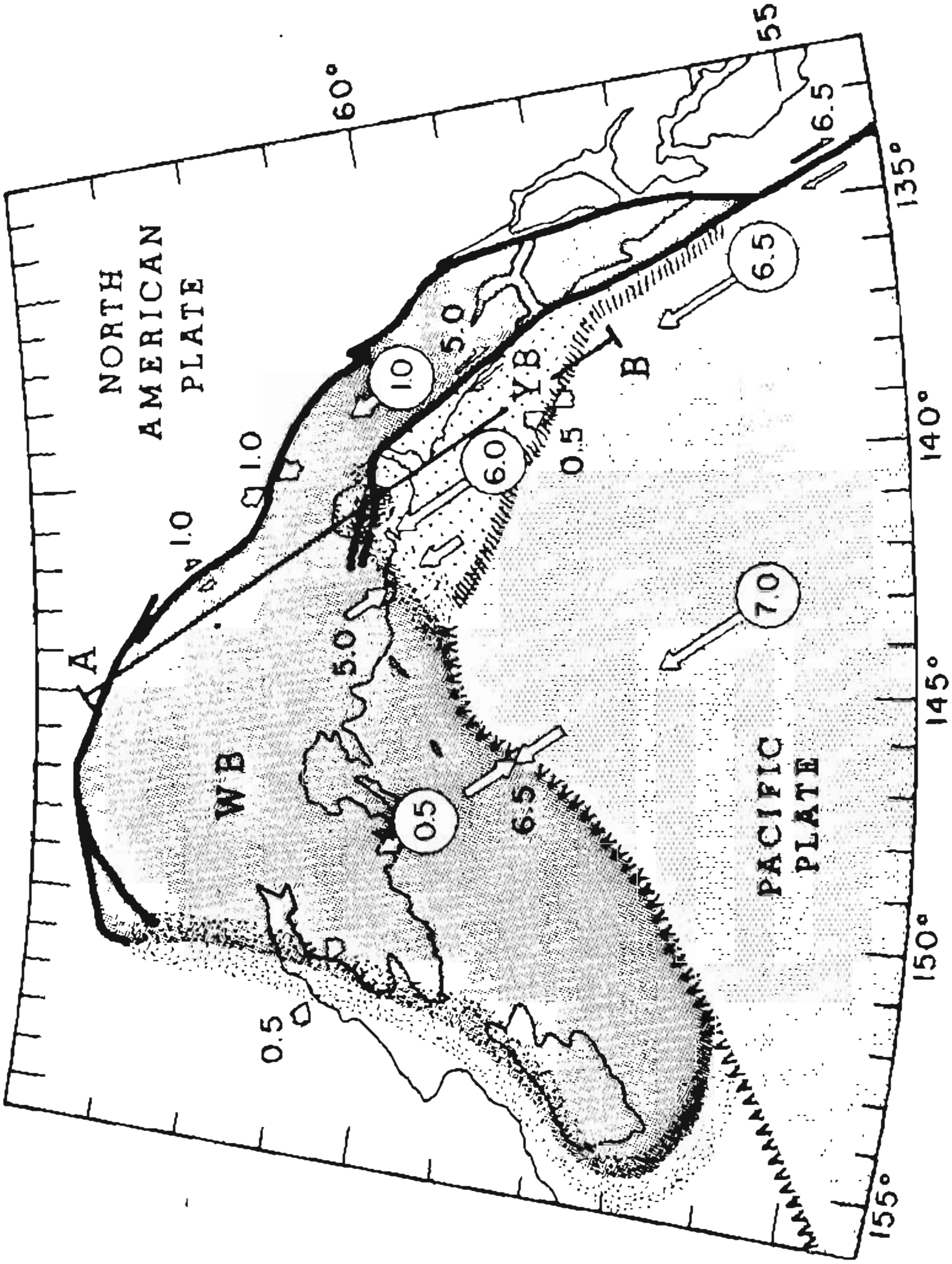

Fig. 3 Proposed model for present crustal deformation along the Pacific-North American plate boundary in southern and southeast Alaska. Circled numbers give rate of motion (cm/yr) of Pacific plate, Yakutat block and Wrangell block with respect to North American plate. Numbers next to paired vectors give rate of motion across indicated zone. Dotted bands enclose surface outcrops of major zones of deformation and faulting. A-B location of cross section of Fig. 3; WB, Wrangell block; YB, Yakutat block.

The Yakutat block may have a more northerly direction of motion than that given by the model. Convergence across the Fairweather fault is suggested by young uplift, folding and faulting along the coast in the Lituya Bay Area (Plafker and others, 1978) and uplift in the Yakutat Bay area that is best explained by movement on inferred northeast-to-north-dippling thrust faults (Thatcher and Plafker, 1977). Since the conclusions of this paper are not effected by the exact orientation of the Yakutat block motion, the simplet assumption of motion parallel to the Pacific plate motion has been used. The model rates for the Yakutat block and Pacific plate were set to give some convergence across the Transition zone (TZ), in agreement with data from the 6.7 (M_S) earthquake which occurred along the continental margin southwest of Cross Sound. The rupture zone of this earthquake, as delineated by aftershocks, was 60 km long by 15 km wide, and the focal mechanism is compatible with oblique thrust faulting (Gawthrop and others, 1973).

The Pamplona zone, which constitutes the northwestern boundary of the Yakutat block, is a broad zone of late Cenozoic onshore and offshore folds and thrust faults which dip to the northwest or north (Plafker and others, 1978; Thatcher and Plafker, 1977). Seismic activity has been recorded along both offshore and onshore portions of this zone (Page, 1975; Stephens and others, 1979).

The Denali (D) and Totschunda (T) faults of Fig. 1 have undergone 1 to 2 cm/yr average dextral displacement during the Holocene (Richter and Matson, 1971; Plafker and others, 1977; Stout and others, 1973) although some parts may not have moved during the past 1,500 to 2,000 years (Plafker and others, 1977). The Duke River (DR), Dalton (DA), and Chatham Strait (C) faults do not prove Holocene displacements, and in some places there is geomorphic evidence to support the viewpoint that they could not have moved more than one or two meters in the past few hundred years (Clague, 1979). However, because seismic activity has been noted in the vicinity of these faults (Clague, 1979), they are considered the most likely southern continuation of the Denali-Totschunda system. Dextral motion of more than a total of 0.5 km is precluded on a direct connection between the Totschunda and Denali faults by geologic data (Plafker and others, 1978). Thus, if the Fairweather fault has short circuited across the Saint Elias Mountains to connect with the Totschunda fault, this newly established break cannot be more than 25,000 to 50,000 years old.

Counterclockwise rotation of the Wrangell block (WB) would produce convergence on its northwestern edge which would be greatest towards the north, along the zone of unnamed faults (TT) that diverge from the Denali fault and trend southwestward parallel to the Alaska Range, between the Chulitna River and Tonzona/Tatina Rivers (Reed and Nelson, 1977). West of these faults, which are mostly thrust faults, there is no evidence that the Denali fault has been active in Quaternary time (Plafker and others, 1977). Rotation of the Wrangell block, as proposed here, is consistent with the change in strike between the Denali (D), Totschunda (T), and Chatham Strait (C) faults. The western boundary of the Wrangell block is hypothetical/ The convergent motion across this boundary may be accommodated by a broad zone of folding.

The Pacific-North American relative motion assumed in this model is roughly 10% higher than the average found for the past 3 my by global plate-motion reconstruction (Minster and Jordan, 1978). The higher rate allows a closer fit to the observed displacement rate on the Fairweather fault and is not an unreasonable deviation since only the Holocene epoch is of concern here.

IMPLICATIONS OF PROPOSED KINEMATIC MODEL FOR EASTERN GULF OF ALASKA SEISMIC HAZARDS

Lease sale 55 is located south of Yakutat Bay on the Yakutat block. This region will be subjected to ground shaking from five distinguishable seismic source regions.

1) Underthrusting of the Pacific plate below the Wrangell block northwest of the Aleutian megathrust. The 1964 Alaska earthquake (9.2 M_w, 8.4 Ms) was of this type and ruptured from about Kayak Island to southern Kodiak Island.

2) Underthrusting of the Yakutat block and the Pacific plate below the Wrangell block. This source region extends approximately 200 km northwest from the Pamplona zone. The February 1979 St. Elias earthquake (7.3 M_s) noted on Figs. 2 and 3 was of this type.

3) Faulting along the northeast boundary of the Yakutat block. Typical of this would be the 1958 earthquake (8.2 M , 7.9 M) which involved dextral strike-slip on the Fairweather fault. Also included would be the Yakutat Bay earthquake (8.4 M_s) of 10 September 1899 which involved complex thrust faulting with as much as 14 m of vertical displacement (Thatcher and Plafker, 1977).

4) Underthrusting of the Pacific plate below the Yakutat block. Although no historic great earthquake of this type is known to have occurred, it would not be prudent to exclude the possibility of one occurring in the future.

5) Earthquakes of smaller magnitude, up to perhaps 6.5 or 7.0, could probably occur with finite probability anywhere within the Yakutat and Wrangell blocks. Although the largest earthquakes would probably fall in categories 1 through 4 and account for nearly all of the convergent motion, smaller events that may occur very near the engineering structure in question must also be taken into account. Fig. 4 shows the known seismic activity in the region south of Yakutat between 1900 and 1979. The USGS seismic network

EVENTS SOUTH OF YAKUTAT BAY
1900 - JAN 1979

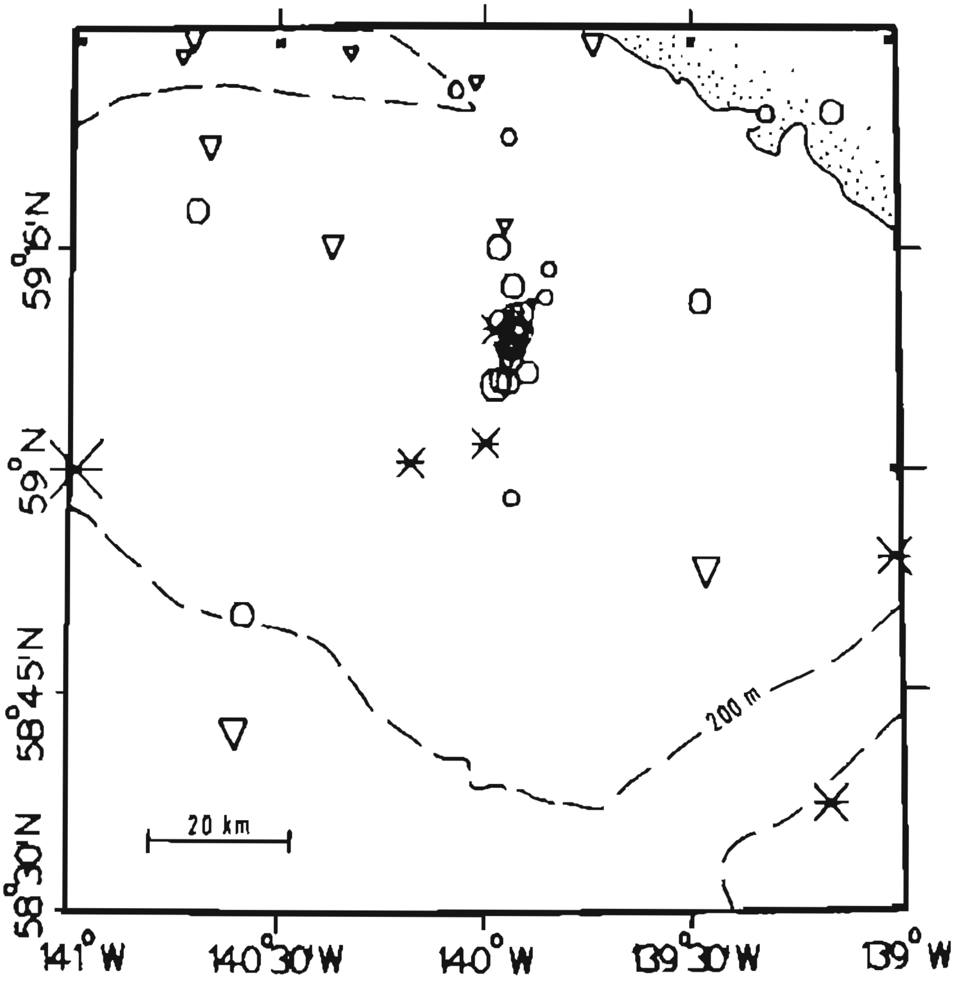

Figure 4. Map showing earthquake epicenters from NGSDC (X's) and USGS (circles - better control; triangles - poorer control) scaled by magnitude. Most of the events occurred in a cluster near the center of the figure. The apparent north-south trend of this cluster may be due to location error.

was installed to the north in the summer of 1974. The 46 events located by the USGS network since that time are indicated by circles (better epicentral control) and triangles (poorer control) on Fig. 4. The symbols are scaled by magnitude, which ranges from less than 1.0 to 3.8. Also shown, as X's, are the events from The National Geophysical and Solar Terrestrial Data Center (NGSDC) earthquake-data file for 1900 through July 1978. This file contains 15 events in the region. The earliest and largest being a magnitude 7 (M_s) in 1908 while the three most recent have magnitudes 4.1, 4.2 and 4.4 (Palmer magnitude) and occurred in early 1974. Due to lack of depth control for these events, it is not certain whether they occurred on secondary structures within the Yakutat block or on the interface between the Wrangell block and the Pacific plate (source region 4).

ESTIMATED RECURRENCE INTERVALS

We have thus far identified the plate boundaries in the southern Alaska region that are expected to be seismically active and estimated the rate of relative displacement across each. The next step is to estimate for each region the average number of earthquakes per unit time within each magnitude interval, up to the size of the largest expected earthquake in the region.

One approach to estimating the frequency versus magnitude distribution is to use the historic record of seismicity. This has several disadvantages. First, if the rate of occurrence of small earthquakes measured over a short interval of time is extrapolated to large events, the implicit assumption is that the rate for small events does not fluctuate greatly with time. Temporal fluctuations in seismicity are known to occur, however, and are documented in the Middle East (Ambraseys, 1975), eastern China (York, et al., 1976) and California (Eaton, in press). Therefore, the statistical parameters determined from a large number of small earthquakes cannot necessarily be extrapolated to small numbers of large earthquakes. Second, the historic record of large events ($M > 7$) in southern Alaska goes back only about 80 years, so the record is too short to be used as a reliable basis for the long term rate of occurrence of large events.

An alternate method of estimating recurrence time, based on the on slip rate and maximum seismic moment for a source region, has been suggested by Molnar (1979). This method equates the rate of relative motion across a fault zone with the long term average rate of slip from earthquakes. As a result of many uncertainties which enter into these calculations, Molnar (1979) estimates the derived recurrence intervals may be in error by as much as a factor of 3 to 5. We feel these errors are still smaller than those generated by using the historic seismic record alone.

Molnar applies this method to the composite Pacific and Indian ocean subduction zones and gets good agreement with the observed record of great earthquakes during the past 50 years. Following Molnar (1979), it will be assumed that the distribution of earthquake moments in each of four principal source regions identified above can be described by the relationship

$N(Mo) = \alpha Mo^{-\beta}$, where N(Mo) is the number of events per year with seismic moment greater than or equal to Mo, and α and β are constants. If Momx is the largest moment for a region, A is the fault area of the entire region, v is the long term slip rate, μ is the average shear modulus, and β is 2/3 then

$$N(Mo) = \frac{\mu A v}{3(Momx)^{1/3}} (Mo)^{-2/3} \qquad \text{(Molnar, 1979).}$$

β is defined to be b/c where b is the coefficient in the magnitude distribution equation ($\log(N) = a - bM$) and c is the coefficient in the magnitude-moment relationship ($M = (\log Mo)/c + d$). A β value of 2/3 is based on c = 1.5 and b = 1.0. The recurrence interval for events with moments greater than or equal Mo but not greater than Momx is $T(Mo) = N(Mo)^{-1}$

$$T(Mo) = \frac{3(Momx)^{1/3}}{\mu A v} (Mo)^{2/3} \quad \text{yr} \qquad (1)$$

Region 1. Underthrusting of the Pacific Plate below the Wrangell block between Kayak Island and southern Kodiak Island.

For this region the 1964 Alaska earthquake is taken as the largest event. From Kanamori and Anderson (1975):

$Mo = Momx = 8.2 \times 10^{29}$ dyne cm

$A = 1.3 \times 10^{15}$ cm^2

The values estimated for the remaining parameters are:

$\mu = 7 \times 10^{11}$ dyne cm^{-2}

$v = 6.5$ cm yr^{-1}

The recurrence relationship becomes:

$$T(Mo) = 4.7 \times 10^{-18}\ Mo^{2/3}\ \ yr$$

This gives the following recurrence times:

Region 1

Magnitude M_w	Mo (dyne cm)	Recurrence Interval (yr)
~ 9.2	$\sim 8.2 \times 10^{29}$	420
$\gtrsim 8.6$	$\gtrsim 10^{29}$	100
$\gtrsim 8.0$	$\gtrsim 10^{28}$	22
$\gtrsim 7.3$	$\gtrsim 10^{27}$	4.7

The magnitudes above are based on the following moment-magnitude relationship:

$M_w = (\log Mo)/1.5 - 10.7$ (Kanamori, 1977)

Observed number $\gtrsim 7.3$ during past 40 years: 1*

Expected number $\gtrsim 7.3$ during 40 year interval: 8.5

* The 1964 Alaska earthquake with $M_w = 9.2$.

Region 2. Underthrusting of the Yakutat block and the Pacific plate below the Wrangell block.

We will assume a source region of 250 x 200 km^2 and the kinematic model underthrust rate of 5.0 cm yr^{-1}. The maximum displacement is estimated from

$$u_{max} = \frac{3 \Delta \tau w}{4 \mu} \qquad \text{(Molnar, 1979)} \qquad (2)$$

Assuming the stress drop, $\Delta\tau$, is 30 bars (3×10^7 dyne cm^{-2}), typical of the largest events (Kanamori and Anderson, 1975); $\mu = 7 \times 10^{11}$ dyne cm^{-1}; and w, the down dip length, is 200 km, then

$u_{max} = 6.4$ m and

$$Momx = \mu A u_{max} = 2.3 \times 10^{29} \text{ dyne cm} \qquad (3)$$

The recurrence time relationship for this region is then:

$$T(Mo) = \frac{(3)(2.3 \times 10^{29})^{1/3}}{(7 \times 10^{11})(5 \times 10^{14})(5)} (Mo)^{2/3}$$

$$T(Mo) = 1.0 \times 10^{-17} (Mo)^{2/3} \quad yr$$

Using this equation, the following table is derived:

Region 2

Magnitude M_w	Mo (dyne cm)	Recurrence Interval (yr)
~ 8.9	~ 2.3×10^{29}	380
$\gtrsim$ 8.0	$\gtrsim 10^{28}$	46
$\gtrsim$ 7.3	$\gtrsim 10^{27}$	10

Observed number $\gtrsim$ 7.3 during past 40 years: 1*

Expected number $\gtrsim$ 7.3 during 40 year interval: 3.3

*The February 1979 St. Elias earthquake with $M_s = 7.3$.

Region 3. Faulting along the northeast boundary of the Yakutat block.

This faulting will be taken to be strike slip although, as mentioned previously, the northern end includes complex thrusting as well. The largest events in this region will be assumed to have an average of 4 m of strike slip motion on a 350 x 20 km portion of the Fairweather fault.

The estimated maximum moment is

$M_{omx} = \mu A u_{max} = (3.3 \times 10^{11})(7 \times 10^{13})(400) = 9.2 \times 10^{27}$ dyne cm

The recurrence interval equation, using the kinematic model's 5 cm yr slip rate, is then

$$T(Mo) \approx \frac{(3)(9.2 \times 10^{27})^{1/3}}{(3.3 \times 10^{11})(7 \times 10^{13})(5)} (Mo)^{2/3}$$

$$T(Mo) = 5.5 \times 10^{-17} (Mo)^{2/3} \text{ yr}$$

The following table gives recurrence intervals and rates of occurrence for events in a few size categories.

Region 3

Magnitude M_w	Mo (dyne cm)	Recurrence Interval (yr)
~ 7.9	$\sim 9.2 \times 10^{27}$	240
$\gtrsim 7.3$	$\gtrsim 10^{27}$	55
$\gtrsim 6.6$	$\gtrsim 10^{26}$	12

Observed number $\gtrsim 7.3$ during past 40 years: 1*

Expected number $\gtrsim 7.3$ during 40 year interval: 0.73.

* The 1958 Fairweather earthquake with $M_s = 7.9$.

Region 4. Underthrusting of the Pacific plate below the Yakutat block.

The maximum fault area for this zone is the triangular region with area approximately ½ (150 x 300) km . The maximum displacement can be estimated from

$$u_{max} = \frac{3\Delta\sigma w}{4\mu}.$$

If, as in the case of region 2, we assume an effective downdip length of 200 km, the maximum displacement would be approximately 6.4 m and

$$M_{omx} = \mu A u_{max} = 10^{27} \text{ dyne cm.}$$

Using the kinematic model underthrust rate of 0.5 cm yr , the recurrence relationship becomes:

$$T(Mo) = \frac{(3)(10^{29})^{1/3}}{(7\times10^{11})(2.25\times10^{14})(0.5)}(Mo)^{2/3}$$

$$T(Mo) = 1.8 \times 10^{-16} (Mo)^{2/3} \text{ yr}$$

This gives the following recurrence times:

Region 4

Magnitude M_w	Mo (dyne cm)	Recurrence Interval (yr)
~ 8.6	~ 10^{29}	3800
≥ 8.0	≥ 10^{28}	830
≥ 7.3	≥ 10^{27}	180
≥ 6.6	≥ 10^{26}	39

Observed number ≥ 6.6 during past 40 years: 1*

Expected number ≥ 6.6 during 40 year interval: 1.

* The Cross Sound earthquake of 1973 with $M_s = 6.7$.

The uncertainties in the calculated recurrence intervals should not be disregarded. One assumption inherent in the calculations was that all of the slip takes place seismically, as opposed to a slow creep process. If aseismic slip does take place, then the earthquake recurrence intervals would be proportionately greater.

SENSITIVITY OF CALCULATED RECURRENCE INTERVALS TO MODEL CHANGES

For Region 2, which involves underthrusting of the Yakutat block and the Pacific plate below the Wrangell block, the effects of changing the model parameters will be explored. The recurrence time interval, T (Mo), as estimated in equation 1, has the following dependence on fault length (L), downdip width (w), shear modulus (μ), and maximum moment (Momx):

$$T(Mo) \propto (Lwv\mu)^{-1} \, Momx^{1/3}$$

The upper limit of moment, Momx, when estimated from equations 2 and 3, has the following dependence on L, w and stress drop ($\Delta\sigma$):

$$M_{omx} \propto Lw^2 \Delta\sigma.$$

If, for example, the downdip width were actually 100 rather than 200 km, then Momx would be reduced by a factor of 4 to 5.6×10^{28}, or equivalently the largest events would be reduced from 8.9 M_w to 8.5 M_w. The recurrence intervals would be increased by $2x(\frac{1}{4})^{1/3} = 1.26$. Thus, the effect of reducing the width of the zone by a factor of two is to increase the recurrence intervals by only 25% while reducing the maximum event by 0.4 units of M_w. The summary table for this region would become:

Region 2

Magnitude M_w	Mo (dyne cm)	Recurrence Interval (yr)
~ 8.5	$\sim 5.6 \times 10^{28}$	190
$\gtrsim 8.0$	$\gtrsim 10^{28}$	60
$\gtrsim 7.3$	$\gtrsim 10^{27}$	13

PREVIOUS RECURRENCE ESTIMATES FOR THE OUTER CONTINENTAL SHELF OF THE EASTERN GULF OF ALASKA

Thenhaus and others (1979) have calculated recurrence rates for the Yakutat block (zone 13 in their report) which has almost the same boundaries as Region 4. Based on the past observed seismicity they obtain a b value of 0.6 and the following annual rates of occurrence:

Magnitude	Annual Rate (yr^{-1})
8.2-8.8	.00124
7.6-8.2	.00280
7.0-7.6	.00637
6.4-7.0	.0146
5.8-6.4	.0335
5.2-5.8	.0768
4.6-5.2	.176
4.0-4.6	.403

Their estimate for the magnitude of the earthquake is 8.8. These numbers reflect corrected values, and differ from those published in the draft EIS of BLM (1979) (Paul Thenhaus, personal communication, 1980).

The following table compares Thenhaus' results with those for Region 4 based on the recurrence equation calculated previously. This assumes their magnitudes are equivalent to M_W.

Magnitude M_w	M_o (dyne cm)	Recurrence Interval (yr) $1.8 \times 10^{-16} (M_o)^{2/3}$ Region 4	Thenhaus and others Zone 13
≥ 8.2	≥ 2.2×10^{28}	1430	806
≥ 7.6	≥ 2.8×10^{27}	360	248
≥ 7.0	≥ 3.5×10^{26}	90	96
≥ 6.4	≥ 4.5×10^{25}	23	40

In this study a b value of 1.0 is assumed while Thenhaus et al. uses 0.6. This accounts for the fact that the estimates agree for $M \geq 7$, while Thenhaus and others' recurrence times for the largest events are significantly shorter than ours. Considering the complications, errors and biases (Utsu, 1971) which can enter into calculated b values, we do not feel it is possible to regionalize them in a significant way on the basis of historic seismic data. In addition, Thenhaus and others (1979) remove aftershocks from consideration in their recurrence estimates. If this modification were made to Molnar's method the recurrence estimates would be increased. A model for aftershock occurrence would have to be developed to quantitatively remove their effect. Considering the differences in method and the erorrs inherent in both methods, the results are remarkably similar.

COMPARISON OF SEISMIC RECORD WITH RECURRENCE ESTIMATES

Utsu (1971) has pointed out many of the complexities of the Gutenberg-Richter log N(M) versus M linear relationship. Although the relation appears to be valid for large sets of data, its use in small regions and extrapolation above or below the observed data may be risky. There are many complications, such as: bias in the magnitude calculations which may change the slope of the distribution; aftershock sequences and the variation in their sizes and upper magnitude limits with region, depth, and size of the main shock; and variation in the upper bound magnitude with region and depth.

Keeping these problems in mind, the seismicity in the 140 x 140 km^2 area including the 1979 St. Elias earthquake and its aftershocks was reviewed as a sample portion of Region 2. During the 20 year interval from 1958 to 1978 6 events occurred with magnitudes greater than or equal 5.0. During the 5 year interval, 1974-1979 there were 7 events with magnitudes greater than or equal 4.0. These numbers would translate into recurrence intervals of 3.3 years for $M \geqslant 5$ and 0.71 year for $M \geqslant 4$. Assuming a b value of 1, the 3.3 yr recurrence time for magnitude 5 and above would give a .33 yr recurrence time for 4 and above. We will assume that the shorter recurrence interval determined from the 20 yr sample is closer to the true distribution. Extrapolating this recurrence time up to magnitude 7.3 and greater yields 658 years. Assuming this portion of Region 2 is typical of all of Region 2, the recurrence time for the entire Region 2 for magnitudes greater than or equal 7.3 is 258 yrs. This recurrence time is roughly a 20 times greater than that calculated previously for Region 2.

The Pacific-North American plate boundary between Yakutat Bay and Kayak Island has been identified as a seismic gap on the basis of its long period of relative quiescence for large events as compared with adjoining regions (Tobin and Sykes, 1968; Kelleher, 1970; Sykes, 1971). Although large events ($M \geq 7$) were used in identifing this region as a seismic gap, Sykes (1971) points out that the level of both moderate activity and microearthquakes may be low as well. Davies and House (1979) propose an episodic behavior for earthquake activity with four periods: (1) preseismic, (2) seismic, (3) postseismic, and (4) interseismic. The interseismic period of tens or hundreds of years would produce a "seismic gap" with relatively little seismic activity occurring.

Although it is possible that the recurrence intervals calculated by Molnar's (1979) method are an order of magnitude too short, it would be most prudent at this time to assume that Region 2, which is within the identified seismic gap, has been in a period of lower than average seismicity during the past tens of years and that this condition may not continue long into the future.

IX. Needs for further study

Toward the goal of developing improved seismic exposure maps for the NEGOA region, considerable additional research is needed. It would be beneficial to develop an integrated model for the adjoining Gulf of Alaska OCSEAP regions based upon data from all of the principal investigators involved. Various approaches should be explored in setting the level of seismicity and the size of the largest events expected for each region. Data from other regions in the world with a similar tectonic setting but longer historic record should be sought, as this data may help overcome the problem of Alaska's short historic record. Additional geologic work that might lead to a better estimate of the frequency of great earthquakes in Alaska is highly desirable. One example of this would be the study of marine terraces.

Once the source regions and moment distributions have been agreed upon, they may be used as the input to statistical programs that generate the return times for given levels of acceleration or velocity at a grid of points. These values may then be contoured and used in seismic hazard planning.

Careful thought should be given to the possibility of including the record of past events in the estimates of future ground motions. As the seismic gap hypothesis gains credence it becomes tempting to enhance the probability of strong ground shaking in regions of seismic gaps and reduce the probability elsewhere. In the light of the nonuniform temporal distributions observed, such as occasional clusters of large events, however, the gap hypothesis should not be given undue emphasis.

The fifth category of earthquakes, events on subsidiary structures, has not been addressed yet in terms of the moment-rate calculations.

X. Summary of October 1979-March 1980 Operations.

a. Field Work in Alaska

Alcan

The new USGS seismic station at Alcan was visited in November 1979. This site is recorded on a helicorder located at the U.S. Border Station on the Alaska Highway. Due to problems of high background seismic noise and poor WWV radio reception (needed for timing) the site was moved to a quieter location and a better antenna was installed.

Valdez

While Alascom was grading snow from the road at the Valdez Earth Station, the USGS data cable was cut. This resulted in an outage for seismic stations FID, GLC and VZW. In addition, carrier drift was occurring at the 3 component local site. Both of these problems were rectified during a December trip to Valdez. The signal was routed through a spare wire pair coming from the local seismic station. (It was not possible to locate the broken cable due to snow). To correct carrier drift problems, all three "202" VCO's were replaced with three new A1VCO's. To accommodate the new A1VCO electronics a new 34 inch diameter culvert replaced the smaller original culvert. The A1VCO's operate off of 3 sets of 3 air cell batteries. It is expected that they will run many years before the batteries need to be changed (as opposed to the "202" VCO 2-year battery change interval).

Finally, a new model filter bridge was installed inside the Earth Station at a more convenient location. This filter bridge will allow Alascom technicians to closely monitor seismic carrier activity.

Yakutat

Due to a severe lightning storm, all USGS equipment for receiving the 6 seismic station were destroyed. (The lighting also destroyed a NOAA weather radio transmitter and a Coast Guard Remote Radio installation). All the equipment was replaced during a December trip and all stations came back on the air except for YAH.

Cordova

During the December trip to Yakutat, a stop was made in Cordova to correct the problem with SGA and KYK (both were off the air). Currently an FAA technician is installing new USGS equipment at the Flight Service Center (the old USGS location is being torn down). The new location will have GE radios and a new model filter bridge. This should allow us to work closely with the FAA technician on future station problems, thus avoiding special trips to Cordova for routine problems.

b. Electronic Work in California

A1VCO

Work is proceeding on this years' production run of A1VCO's. Currently, the enclosures are being assembled and two circuit boards are going through initial screening.

The old version of the calibrator will be replaced in all new A1VCO's with the EPROM based version. This will allow programming of the calibration cycle plus field selection of one of four different cycles. This new board is presently being manufactured.

A1VCO Calibration Decoder

A new lighter weight calibration decoder with an LCD display has been designed and built. The unit will run several months from one 9-v transistor battery and be more compact. This should help reduce the weight of equipment carried on helicopters.

Seismic Chart Recorder

Work has started on the design of a new lightweight precision chart recorder. This unit will be taken on helicopters to record on-site calibrations.

Filter Bridge

A meter-speaker card for the new USGS filter bridge has been designed and built. This card allows technicians to monitor composite carrier output on a meter (calibrated in decibels) while listening to the carrier quality on a speaker. This will aid non-USGS technicians in tracing carrier noise problems and setting levels without special test instruments. Installation of the card in each filter bridge will take place by October 1, 1980.

c. Other Work

Open-File Report

The Open-File Report by Rogers and others (1980) on the A1VCO is complete. The report is 130 pages long and contains full documentation on all circuit boards, wiring and test procedures. The report is currently being distributed to interested individuals and organizations.

Calibrator Analysis

A Fortran program to analyze digitized calibrations has been written. It has been tested out on calibration data from HQN (located near Yakutat) with reasonable results. Further testing on other data is planned. When completed, the program will be documented in an open-file report.

VHF Radio Permits

The entire VHF radio network used to telemeter seismic data has been documented for use in applying for permanent radio operating permits from IRIG. IRIG is currently reviewing our request which involves 70 sites. We are presently operating under temporary permits, but due to increasing radio interference problems it was felt that permanent status would help avert problems as well as give us some legal standing for portions of the VHF spectrum.

XI. Auxiliary Material

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