Western Alaska: Large Earthquakes in *Terra Incognita*

Jeff Freymueller, Kaz Fujita, Mikhail Kogan, Kevin Mackey, Dave Scholl, and Wes Wallace

Equipment Required: 32 GPS (5 in Russia)

We propose a PBO instrument cluster for western Alaska (Figures 1, 2). This cluster will provide PBO with an opportunity to do something truly unique within the Pacific–North America plate boundary zone: fill in a huge empty space on the active tectonic map. Western Alaska is truly *terra incognita* as far as active tectonics are concerned. Areas of tectonic mystery remain in the Lower 48 states, but this unknown area is about 800,000 km^2, almost the size of the entire Basin and Range, has experienced several magnitude 6-7+ earthquakes within the last century, but we do not even have a first-order model to explain its active tectonics or interpret the pattern of seismicity there. The most prominent active tectonic features on geological maps of western Alaska are a set of roughly parallel, curved strike-slip faults that strike east-west to southwest-northeast, including the Denali and the Tintina fault systems (Figure 1). The pattern of magnitude 6+ earthquakes does not correspond with the general trend of faulting (Figure 2). None of the major earthquakes appear to have occurred on the geologically "obvious" structures!

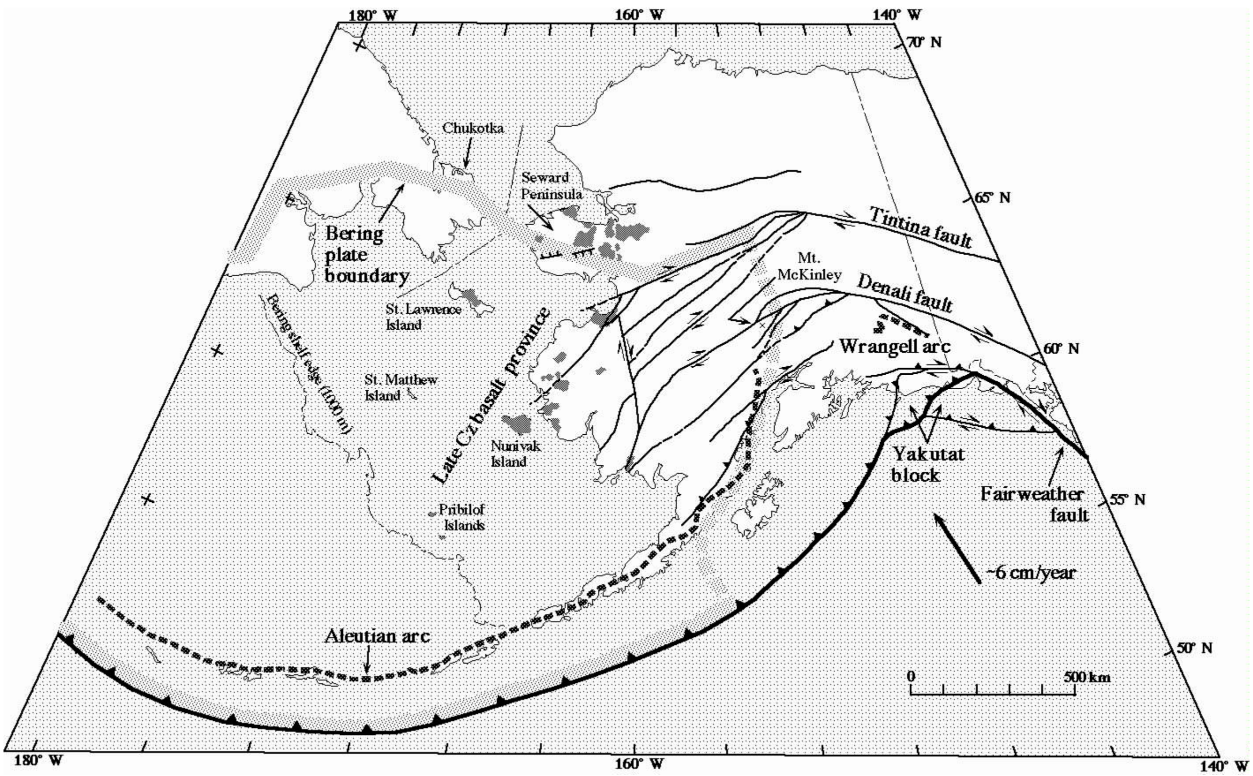

Figure 1: Tectonic sketch map of western Alaska and adjacent regions. The pattern of faults in western Alaska includes faults of known or suspected Late Cenozoic activity, as well as other major faults that could potentially be part of the network of active faults.

The pattern of faulting has been interpreted as a result of extrusion tectonics triggered by Pacific–North America plate coupling and the collision of the continental Yakutat block in southern Alaska, resulting either in slivering of the Bering Sea or the motion of the Bering Sea plate relative to North America. Existing data neither allow us to discriminate between these competing ideas nor to identify an alternative model. We know that several mm/year of relative motion occurs across this area, a rate about 2/3 of that across the Basin and Range, but we have no idea how it is accommodated. From survey-mode GPS work, we know that in its east-central part the

Denali fault slips at about 6 mm/year, and we know that at least part of its southern edge (the Alaska Peninsula and Aleutian arc) is moving 3-4 mm/year to the west-southwest relative to North America. We do not know where the slip on the southwest continuation of the Denali fault system is accommodated west of Mt. McKinley itself. We know from VLBI that Nome on the Seward Peninsula moves southward at a few mm/year relative to North America. We do not know what forces drive normal faulting in western Alaska and across the Beringian shelf. We do not know whether the active strike slip faults cut all the way through and into the Bering Sea or whether they terminate on the continental Beringian shelf. The location, age, and displacement of onshore faults are poorly known because of poor exposures and lack of detailed work. Reconnaissance work provides evidence for active faulting, including faults that have produced young scarp-like features and offset Quaternary features, but no geologist has done much beyond noting their existence. We are likely to find surprises.

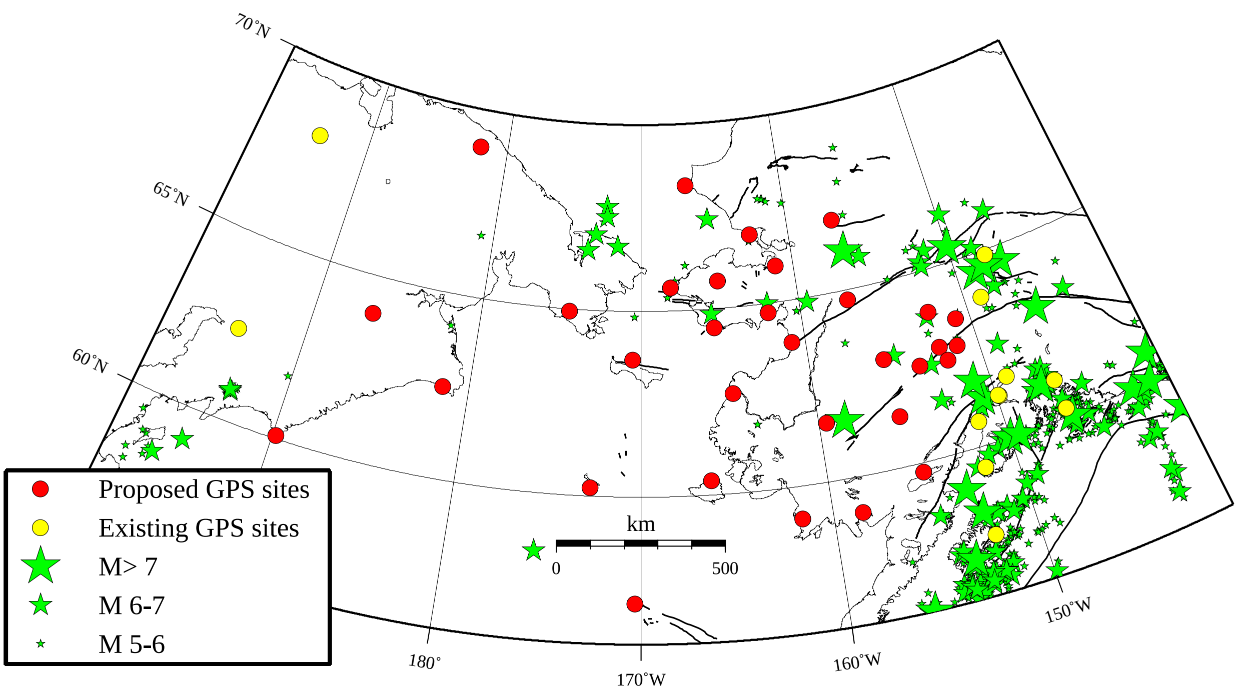

Figure 2: Earthquakes larger than magnitude 5, faults, and proposed network.

A combination of precise GPS data, geological mapping, and paleoseismic investigations will allow us to understand the tectonics of this region where several magnitude 6-7+ earthquakes have occurred this century. We are proposing only a modest investment from PBO, a deployment of similar density to the backbone network in the more populated and well-known parts of the plate boundary system, which will answer first-order tectonic questions. This vast region forms the central part of a narrow zone of continental crust that is bounded by three of the world's major plates, the Pacific, North American, and Eurasian plates. This region offers excellent opportunities to develop new insights into the tectonic processes that operate in broad zones of active continental deformation.

Background

In this proposal we use the term western Alaska to refer to the entire area west of the road system in Alaska; in essence, everything west of Fairbanks and Anchorage. Several magnitude 6-7+ earthquakes have occurred here this century, largely in a west-trending band extending from

Fairbanks to north of the Seward Peninsula and across into Chukotka; these earthquakes are not correlated with the major strike-slip fault systems to the south (Figure 2), although smaller earthquakes do occur along those faults. The Seward Peninsula is dominated by north-south extensional normal faulting. However, the remaining area displays earthquakes with thrust, strike-slip and normal-fault focal plane solutions. VLBI data suggest north-south extension on the Seward Peninsula, based on the southward velocity of Nome, located on the southern side of the Seward Peninsula, relative to Fairbanks. Another indication of tectonic activity of the region is an extensive belt of Late Cenozoic basalts (Figure 1), trending south-southwest from the northern Seward Peninsula to the Pribilof Islands near the Bering Sea shelf edge.

Only a few tectonic models have been proposed for the region. We can group proposed models into two rough classes. Either there is extrusion of sliver-shaped microplates in western Alaska toward the Bering sea, or of a single independent microplate incorporating most of the crustal material involved in the Bering sea region. Both classes of models call on tectonic extrusion of large parts of western Alaska and the offshore Bering Sea region southwestward toward the Aleutian arc as a response to the collision of the Yakutat block at the east end of the Alaska-Aleutian trench and the effects of Pacific-North America coupling. The main difference between the sliver-extrusion and independent microplate models is the extent to which the strike-slip faults of southwest Alaska extend offshore beneath the Bering Sea. The sliver-extrusion model predicts active faulting within the Bering Sea shelf and basin, while the independent microplate model predicts that active faulting terminates in basins within western Alaska and the Bering Sea shelf and that compression is taken up along the western side of the Bering Sea. None of the models make quantitative predictions, but all specify the style of expected deformation (directions of motion but not rates).

Whitney and Wallace proposed that this extrusion is a mirror-image analog of eastward extrusion of Asia toward the Pacific in response to northward collision of the Indian subcontinent. According to this analog, the strike-slip faults of western Alaska would correspond with those of China and southeast Asia, extension in Seward Peninsula would correspond with opening of the South China Sea, and the Aleutian arc would correspond with the Andaman-Sumatra-Java arc. Such extrusion would be expected to be accommodated by extensive strike-slip faulting and related counterclockwise rotation.

The extrusion model proposed by Scholl and others draws a parallel between the collisional effects of the Yakutat block with North America at the east end of the Aleutian Trench and the collisional extrusion of the Anatolian microplate westward into the Aegean sea and Hellenic subduction zone. In these models strike slip faults such as the Denali and Kaltag faults are analogues of the North and South Anatolian faults of Turkey. Counterclockwise rotation of western Alaska would also be expected. Western Alaska might be composed of several blocks or microplates, but broadly distributed deformation is the rule and the Bering Sea basin is unlikely to be a rigid block; instead the strike slip faults may carry across the Bering Sea to eventually link up with the Aleutian Trench or fault systems in Kamchatka.

The extrusion model suggested by Mackey and others suggests that the whole of the Bering Sea is comprised of a single large microplate bordered by complex boundaries. This model also draws the analogy to southeast Asia. The Bering Sea plate rotates about an Euler pole located in Chukotka, northeastern Russia, moving generally westward or southwestward relative to North America along its eastern edge. A complex pattern of strike-slip and extensional faulting in western Alaska and eastern Chukotka is associated with motion of the Bering plate. This pattern of motion is supported by focal mechanisms and geologic evidence that indicates extension on

Seward Peninsula and eastern Chukotka and thrusting in the southern Koryak Highlands of Russia. They propose that the oblique subduction along the Aleutian subduction zone plays a role in driving Bering Sea plate motion. In this model, the core of the Bering plate is generally rigid and not undergoing significant internal deformation.

While these models make some specific testable predictions, it is important to emphasize that other models probably can be proposed that are equally consistent with the sparse available data. Whichever model proves to fit the region best will undoubtedly have to be modified significantly to accommodate complexities that emerge as more is learned. The lack of knowledge of this active and tectonically significant region offers a prime opportunity to learn constrain plate boundary processes simply through developing the level of background knowledge that already exists for most of the rest of the western boundary of the North American plate. Permanent GPS stations now give us the chance to do what analysis of seismicity and structural geology can not do in so little time: to quantify confirm or reject the plate-boundary-driven sliver-extrusion model or the independent microplate model. Equally important, GPS data will determine if any of the above concepts explain the on-going deformation and seismicity of western interior Alaska.

Outstanding Questions

The fundamental question to be addressed by this study is how relative plate motions are accommodated in western Alaska and the Bering Sea shelf, which form the central part of the complexly deforming narrow continental region bounded by the Pacific, North American, and Eurasian plates. More specifically:

• What is the actual pattern of motions throughout western Alaska and the Bering Sea shelf, and how do those motions relate to the known or inferred faults of the region and to the distribution of seismicity?

• Do any of the proposed tectonic models reasonably explain the deformation patterns in western Alaska? If not, what is a better model?

• If the Bering Sea shelf and basin do move as a rigid block, what is its angular velocity?

• Is a coherent pattern of motion associated with the band of earthquakes across the northern part of the study region? At what rates do motions occur? Is the seismic moment release of the available record representative of the long-term rate expected from the inferred motion rates?

• How do motions change across the boundary between western Alaska, which is characterized by numerous northeast-striking faults, and eastern Alaska, which is characterized by only a few northwest-striking large-displacement strike-slip faults? Specifically, how are motions accommodated as the Denali fault system crosses this boundary along the north side of Mt. McKinley, the highest point in North America? Is the extreme uplift here related to differences in how motion is accommodated from east to west?

Proposed Network

We propose a GPS sparse network, average site spacing 200-250 km, densified to ~100 km in the region of greatest seismicity and denser near the Denali fault. This spacing is larger than the nominal backbone network spacing, but even so the number of sites equals or exceeds the number of backbone instruments allotted to all of Alaska in the PBO white paper (and this region is only about half of the deforming part of Alaska). A sparse GPS network is appropriate for solving the first-order tectonic questions we wish to solve; the precision of permanent GPS will allow us to resolve motion where rates are low and deformation may be broadly distributed. The proposed network extends from the Mt. McKinley massif to St. Matthew Island in the Bering

Sea, and from the southwestern tip of the Alaska mainland to the Brooks Range. The sparse network is nevertheless sufficient to place a few sites on each of the potential major blocks. A critical part of the network will be sites on most of the few islands on the Bering Sea shelf, which will provide the best control on motions in the heart of the proposed Bering plate.

The network includes a mini-cluster around Mt. McKinley, where the Denali fault changes strike, to test whether the slip rate of 6 mm/year continues to the west of Mt. McKinley or whether some of the slip on the fault is partitioned into thrust displacement that has built the tallest mountain in North America. We propose to include sites on the uplifted block to test whether the significant uplift of the recent geologic past (~8.5 km of rock uplift over the past ~5-6 My) continues today and if this is related to along-strike changes in slip on the Denali fault.

The proposed network extends across the Bering Strait into eastern Russia. Geologically and tectonically the Russian side of the Bering Sea is intimately linked with the Alaskan side, and a complete study of the problem area must cross the international boundary. Survey-mode GPS work has been carried out there and several permanent GPS sites are operated in eastern Russia by a collaboration between Lamont-Doherty Earth Observatory and the Russian Academy of Sciences. However, there are too few permanent sites to achieve of this study, so we request five additional permanent GPS sites to be installed in eastern Chukotka.

Logistics

Although the study area is essentially roadless, people live throughout the region and access by air is straightforward. Scheduled flights provide access to most of the towns and villages, and aircraft are easily chartered for flights to any of the scores of airstrips that dot the region. Power and communications are available at towns and villages, and also at government facilities like the many early warning radar sites. These sites have the advantage of generally being located on high points and usually on bedrock. Although some of these sites are now deactivated, airstrips or helipads still exist, along with possible shelters. With careful planning the extra cost of access need not be a significant part of the total site cost. It is not feasible to bring a drill rig to most of these locations, so we may need to try alternate forms of monumentation in some places. We may also be surprised: this year one of us (JF) met a person in a small Alaska town off the road system who had a drill rig like the one used to drill SCIGN sites. He charged only $300 to drill a vertical hole in bedrock, and then loaned us a concrete mixer!

The great majority of the locations we propose are places where power is available and we can connect the receiver directly to a phone line or the Internet, or perhaps will require a single radio modem link to connect to phone or Internet. A few remote, autonomous sites will be required, and satellite communications will be required unless we are willing to wait for data to be retrieved on yearly visits. St. Matthew Island in the Bering Sea is one example of a site in a critical location where no facilities exist at all. Even if data are recorded on-site for yearly retrieval, we could use satellite systems like ARGOS, used by some IRIS/PASSCAL instruments, to provide system status updates.

PBO will need to cultivate relationships with local communities. Placing sites at schools is one way to involve the local communities, and also can provide educational opportunities. PBO will have the opportunity to provide examples of practical science in action to children, including children from Alaska Native groups. The Alaska PEPP (Princeton Earth Physics Program) has already installed broadband seismometers at schools in western Alaska and PBO can complement and extend that program.