zero; the stress drop (similar to that shown in Fig. 1) was several kilobars. Bridgman (*12*) found that jerky motion accompanied the shearing of powdered compacts of brittle material even when normal pressure reached 50 kb.

Stick-slip appears to be common in geologic materials under laboratory conditions. We suggest that it might also be significant under shallow crustal conditions, and that it can be regarded as a possible source of earthquakes. An earthquake might represent one of the small stress drops associated with faulting or sliding.

The idea that the stress drop in faulting causes an earthquake is not new. There are, however, two features which we feel are new. The first is that, as in the experiments, the stress drop in an earthquake may represent release of only a small portion of the total stress supported by the rock. This could explain why the stress drop, even for fairly major earthquakes, is small relative to the strength of most rocks. The second new feature is that stick-slip provides a mechanism for sudden energy release in material which is already broken and fractured.

The amplitude of the stick-slip (several kilobars in the above experiments) is clearly greater than the 100 bars associated with earthquakes. In other experiments, particularly those carried out at high temperature and slow strain rate, sliding is smooth and stick-slip is absent. For example, Griggs *et al.* (*11*) found no jerky sliding with granite or dunite at 5 kb and 500°C. Riecker (*13*) observed that the violent snapping noted in a shearing experiment of the Bridgman type, conducted at room temperature, disappeared at 300°C and when shearing rates were slow.

It is quite possible that high temperature and slow strain rate suppress stick-slip in geologic materials. If this is true, the applicability of this phenomenon as an earthquake mechanism would be limited to very shallow depths. However, there is another factor to consider. It is known (*9*) that the amplitude of stick-slip in engineering materials does not depend solely on the material. In the laboratory, the amplitude of stick-slip can be altered drastically by changing the stiffness of the loading machine, the relative masses of sample and machine, and damping characteristics of the machine. It is conceivable that one might observe, for a given rock and given conditions, behavior, dependent on the characteristics of the loading system, ranging from faulting with complete loss of strength (through behavior similar to that shown in Fig. 1) to faulting followed by smooth sliding. At this time it is difficult to decide if the absence of stick-slip in a particular experiment means that it will not occur under these conditions in any mechanical system, or if it is simply being suppressed in that particular system. Until these effects have been sorted, comparison of stress drops from field and laboratory has little significance. However, it is clear that stick-slip with an amplitude comparable with natural earthquakes occurs under a certain range of conditions. Stick-slip deserves to be considered, in conjunction with the Reid mechanism, as one possible mechanism for shallow focus earthquakes.

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Exposure of Basement Rock on the Continental Slope of the Bering Sea

Abstract. *Profiles of repetitive seismic reflections reveal that the Bering continental slope, outer shelf, and rise overlay an acoustically reflective "basement" which extends at least 750 kilometers parallel to the trend of the slope. This acoustic basement is usually covered by several hundred meters of stratified sediments at the top and bottom of the slope; however, it is exposed in submarine canyons and flanking spurs along the main part of the slope for a distance of at least 550 kilometers northwest of the Pribilof Islands. The lithologic composition and the age of the rocks of the acoustic basement are not known. However, its probable seismic velocity of 3.1 to 3.7 kilometers per second suggests that it is composed of volcanic rocks or lithified sedimentary rocks or both. The regional geology suggests that the acoustic basement is the upper surface of folded late Mesozoic rocks which were locally intruded by granite and serpentine. The structure of the Bering slope, as deduced from the acoustic profiles, suggests that the surface of the basement has been monoclinically flexed and faulted between the shelf edge and the deep Aleutian Basin.*

Profiles of reflected seismic waves were made across approximately 3800 km of the outer shelf and the highly dissected continental slope of the Bering Sea (Fig. 1). The soundings were taken from the USNS *Charles H. Davis* (AGOR-5) by the U.S. Navy Electronics Laboratory and the U.S. Naval Ordnance Test Station during June and July 1965. The profiles were made by recording subbottom seismic reflections from subaqueous spark discharges having energies up to 38,000 joules; sparks were discharged at an average rate of 15 per minute. The basic profiling system consisted of multiple electrodes and ten hydrophones in linear arrangement. Reflected signals were processed with standard seismic amplifiers set to pass signals from 73 to 120 cy/sec.

Unlike most continental slopes, the Bering slope is not closely adjoined by a continental land mass; instead, it marks the southwestern boundary of one of the world's largest epicontinental seas and lies as much as 550 km from the nearest continental shore. An acoustic basement was detected along at least 750 km of the Bering slope and the adjoining continental shelf. The basement is exposed, probably continuously, in the steeper part of the slope for at least

550 km northwest of the Pribilof Islands (Fig. 1). Little or no acoustic energy was returned from depths greater than that of the top of this acoustic basement; in some areas, however, complicated but indistinct structures were discerned immediately beneath the main part of the basement echo. The term "basement" refers to this terminal reflecting horizon and not to a basement complex of crystalline rocks.

Beneath at least the outer 50 km of continental shelf the surface of the basement is irregular, although approximately horizontal, and is buried beneath 500 to 850 m of stratified sedimentary rocks (Figs. 2 and 3). South of the shelf edge, the basement surface slopes sharply downward toward the Aleutian Basin. Between the longitudes 168° and 175°W (a distance of approximately 550 km), the basement is exposed on the slope, both in canyon walls and on the flanking spurs (Fig. 1). Outcrops of the basement generally begin at a depth of about 1000 m and are continuous, or nearly so, to a depth of about 3000 m at the base of the slope. The slope of the basement surface flattens again beneath the continental rise and passes under undeformed or only slightly deformed sediments ranging in thickness from several hundred meters to several kilometers. Thus the surface of the basement has a sigmoid configuration from its high point beneath the outer shelf to its low point beneath the Aleutian Basin. The simple form of this surface has been modified by the formation of canyons and by one or more large northward-dipping faults in which the uplifted block lies south of the edge of the shelf (Figs. 2 and 3).

A series of seismic refraction profiles made by Shor (*1*, Fig. 1) in the Bering Sea provide information on the seismic velocities of the rock units encountered in our reflection profiles. According to Shor's data, a rock unit characterized by a seismic velocity of 3.1 to 3.7 km/sec underlies the outer part of the shelf about 80 km southeast of the Pribilof Islands. At the shelf edge, this rock unit underlies several hundred meters of sediment having a seismic velocity of only 1.7 km/sec. (In this same area a deeper rock unit with a seismic velocity of 5.5 km/sec was detected beneath the 3.1 to 3.7 km/sec layer.) Beyond the shelf edge, Shor's refraction profiles show that the unit having the seismic velocity of 3.1 to 3.7 km/sec bends downward, parallel to the continental slope (both east and west of the Pribilofs), and then passes beneath a sedimentary section, several kilometers thick, under the continental rise and the Aleutian Basin. The similarity in the geometries of Shor's refraction profiles and our reflection profiles is good reason to correlate tentatively our acoustic basement with the top of Shor's rock unit of 3.1 to 3.7 km/sec. Shor did not detect exposures of the 3.1 to 3.7 km/sec unit on the Bering continental slope, but his profile crosses the slope south-

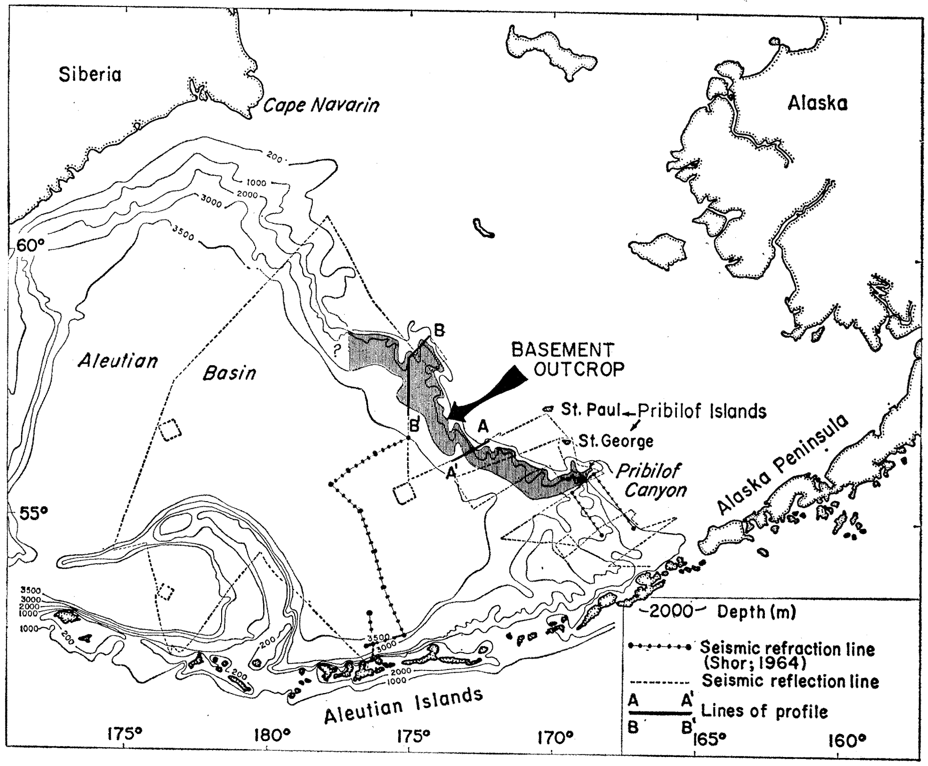

Fig. 1. Southern Bering Sea.

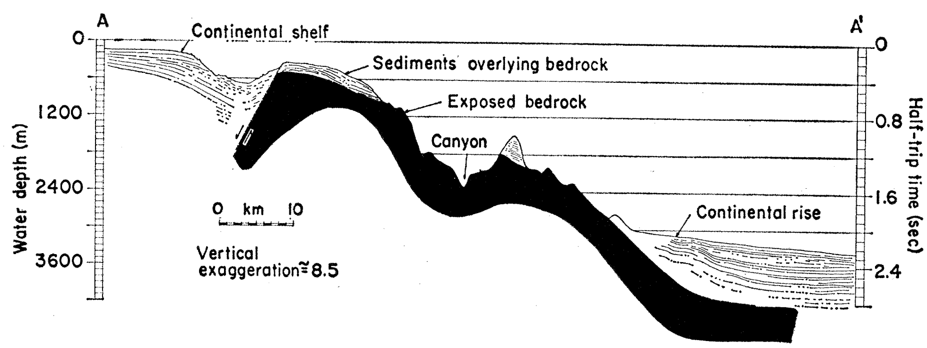

Fig. 2. Geologic interpretation of acoustic reflection profile across Bering slope along line *A-A'* (Fig. 1). Insufficient acoustic power prevented detection of basement beneath the outer edge of the self northeast of the fault. However, an adjacent crossing of the slope (Fig. 3), during which higher acoustic power was used, detected basement beneath 500 to 800 m of sediment near the outer edge of the shelf.

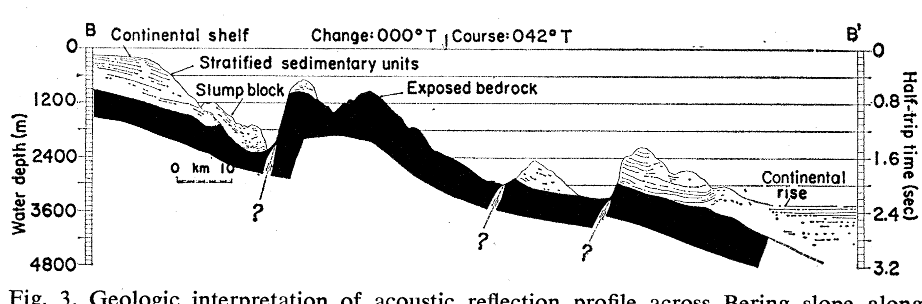

Fig. 3. Geologic interpretation of acoustic reflection profile across Bering slope along line *B-B'* (Fig. 1).

east of the Pribilof Canyon (Fig. 1) where our reflection records indicate that the surface of this seismic unit is buried beneath several hundred meters of younger sediments.

Rocks of the basement have not yet been sampled, although Russian investigators possibly obtained specimens in the course of their extensive dredging and coring in the Bering Sea (*2*). Data from studies of seismic velocities suggest that the rocks of the acoustic basement in the areas mapped by Shor consist of volcanic or indurated sedimentary rocks or both; the few highly reverberant reflections that we received from below the surface of the basement suggest that the rocks may be strongly folded.

The Pribilof Islands consist mostly of Quaternary basaltic lava flows (*3, 4*), but our reflection records and the submarine topography adjacent to the islands suggest that the Quaternary lavas do not extend far from the Pribilof Islands and that the basement rock which is exposed on the continental slope is not likely to be Quaternary volcanic rock.

Sialic as well as mafic crystalline rocks are also exposed on the Pribilofs. Pre-Quaternary crystalline rocks, consisting of serpentinized peridotite invaded by a large aplite dike, are exposed beneath the Quaternary lavas on eastern St. George Island (*3*). Inclusions of granitic rock and quartzite are abundant in some of the lava flows on St. George, and granitic inclusions are abundant in some of those on St. Paul. Granitic rocks and crystalline metasediments generally have seismic velocities that are considerably greater than the unit, 3.1 to 3.7 km/sec, detected by Shor on the slope. Therefore it seems unlikely that the acoustic basement encountered in our study is composed of crystalline rocks, except perhaps near the islands. Possibly Shor's deeper 5.5 km/sec section is actually exposed at the base of the Pribilofs, or possibly the crystalline rocks of the Pribilof Islands represent a local intrusive and contact metamorphic zone in the rocks of the 3.1 to 3.7 km/sec layer.

Although the lithologic composition and the age of the 3.1 to 3.7 km/sec basement rocks exposed or underlying the Bering continental slope at shallow depths remain uncertain, the geology of coastal Siberia (*5*) and Alaska (*6*) and the paleogeography of the Bering shelf (*7, 8*)suggest that the 3.1 to 3.7 km/sec unit consists of folded sedimentary and volcanic rocks of late Mesozoic age, which may have been locally intruded by granite and serpentinized peridotite. Thus we tentatively correlate our acoustic basement with a generally smooth surface cut across folded volcanic and sedimentary rocks of pre-Tertiary age. Hopkins has shown that large parts of the Bering shelf and of neighboring areas in Alaska were a subaerial landscape reduced to a surface of low relief during the Tertiary epoch (*7*). At the end of the Miocene epoch, tectonic movements submerged part of the shelf to provide a short-lived connection between the Bering Sea and the Arctic Ocean; the shelf was submerged more completely and permanently at the end of the Pliocene (*9*). The slightly deformed sediments with acoustic velocities of about 1.7 km/sec which cover the rocks of the acoustic basement (3.1 to 3.7 km/sec) on the outer shelf probably consist of Tertiary sediments deposited on the much narrower continental shelf of that time. Tertiary and Quaternary sediments are included in the low-velocity materials that mantle the basement rocks on the continental slope and rise and in the Aleutian Basin. The deeper 5.5 km/sec unit encountered beneath the shelf on Shor's seismic refraction profiles may consist of metamorphosed Paleozoic and pre-Paleozoic rocks such as are exposed in many areas in western Alaska and northeastern Siberia (*10*).

If the generally smooth surface of the basement is an erosional surface which has cut across folded sedimentary and volcanic rocks of Mesozoic age, then its configuration suggests faulting and flexuring of continental rocks between the shelf edge and the deep Aleutian Basin during Cenozoic time. Strengthening this supposition is the fact that the sedimentary section overlying bedrock is a progradational structure constructed by outbuilding and upbuilding of sedimentary units (Moore's and Curry's type "C" continental structure, *10*) on a basement surface. The sedimentary section, therefore, appears to have been deposited contemporaneously with, or subsequent to, downflexing of a basement surface. Further and later tilting and faulting of the sediment-draped basement surface in late Cenozoic times may have brought about instability of the slope and initial canyon formation by the slumping of sedimentary units. During the Pleistocene, at times of lowered sea level caused by continental glaciation, canyon cutting was probably greatly accentuated by the downslope movement toward the Aleutian Basin of river-deposited sediment on the steep Bering slope.

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Submarine Lithification of Carbonate Sediments

Abstract. *Recrystallized planktonic limestones from two guyots in the North Atlantic are in oxygen-isotopic equilibrium with their present ambient waters, suggesting submarine lithification and recrystallization. The early stages of submarine lithification of carbonates may involve precipitation of, and replacement by, magnesium-rich calcite; with time this may invert to magnesium-poor calcite. This type of lithification probably requires very low rates of sediment accumulation.*

It is commonly assumed that lithification of carbonates occurs only subaerially or in the intertidal zone (*1*), but increasing evidence suggests that subaqueous lithification can occur. Cemented clusters of particles ("grapestone"),